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A Study on the Threats of Shipping Activities to the Ecological Value of Marine Protected Areas and Control Strategies from the Perspective of International Law

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Abstract. Shipping is a backbone of global commerce, yet in and around marine protected areas it can generate a range of ecological pressures, including physical disturbance, chemical contamination, and chronic underwater noise. International law offers the principal tools for managing these risks. Under the United Nations Convention on the Law of the Sea (UNCLOS), states bear baseline duties to prevent, reduce, and control marine pollution. Building on this foundation, the International Maritime Organization (IMO) has developed operational instruments—most notably Particularly Sensitive Sea Areas (PSSAs) and Emission Control Areas (ECAs)—through which binding routing, discharge, and emissions measures can be adopted for vulnerable sites. Compliance is further supported by port-state control, regional regulatory arrangements, and emerging technological monitoring and mitigation methods. Given China's status as a leading maritime and shipping power, it should actively seek PSSA and/or ECA designations for ecologically critical protected areas, refine and enforce its domestic legal framework, and deepen cooperation within IMO and relevant regional regimes. These steps would help China meet its international environmental responsibilities while contributing to more effective global ocean governance and a workable balance between navigational use and biodiversity conservation.

Keywords: Marine protected areas, Shipping activities, Ecological risks, International legal regulation

1. Introduction

Over the past few years, concern about the deterioration of marine ecosystems has moved to the center of international environmental debates. At the 15th Conference of the Parties (COP15) to the Convention on Biological Diversity in 2022, governments adopted the Kunming–Montreal Global Biodiversity Framework, which calls for the effective protection of at least 30% of the world's oceans by 2030—the widely cited "30×30" target. This goal did not emerge in isolation. Rather, it reflects a convergence of several strands of conservation thinking and practice, including assessments of how well existing protected areas function, the "Half-Earth" vision, global biodiversity-hotspot mapping, ecoregion-based planning, and lessons drawn from implementing multiple biodiversity-related treaties. Taken together, these elements underpin an interim, but widely

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regarded, pathway for halting and then reversing biodiversity loss [1]. Within this policy setting, marine protected areas (MPAs) have become a primary vehicle for delivering the 30×30 ambition. Yet their ecological integrity and ability to sustain intended functions are increasingly tested by international shipping. Shipping is indispensable to global trade, but it also imposes substantial environmental costs on MPAs: air and water contamination from vessel emissions and discharges, physical disturbance and habitat degradation linked to navigation and anchoring, and long-term disruption of acoustic habitats and species behavior caused by underwater noise. These pressures sharpen a fundamental tension in the law of the sea—how to accommodate navigational freedoms while ensuring meaningful ecological protection in sensitive marine spaces. The International Maritime Organization (IMO), as the principal global rule-making forum for maritime activities, has built a regulatory architecture—anchored in instruments such as the International Convention for the Prevention of Pollution from Ships (MARPOL), UNCLOS, and the Particularly Sensitive Sea Area (PSSA) framework—that enables coastal states to pursue special protective measures for vulnerable waters. For China, deeper engagement in global ocean governance, including the policy vision of building a "Community of Shared Ocean Destiny," requires not only applying but also shaping these IMO-based mechanisms. Doing so makes it possible to identify, in a systematic way, the ecological and legal risks that shipping poses to MPAs and to develop a coherent control strategy rooted in international law. Such efforts respond to China's international environmental commitments and, at the same time, strengthen its capacity to contribute to—and influence—the ongoing evolution of global maritime rules.

2. Case studies and analysis of shipping regulation in marine protected areas

2.1. Great Barrier Reef Marine Park, Australia: mandatory piloting and traffic separation schemes

To address challenges such as climate change, improve watershed and marine environments, and achieve integrated land–sea management, the Australian federal government, the Queensland government, the Great Barrier Reef Marine Park Authority, government partners, and various stakeholders have collaboratively developed legal policies and regulations for the protection and development of the Great Barrier Reef. These measures aim to assess and manage the cumulative impacts of natural climate variations, human activities, and other factors on the economic, ecological, social, and cultural aspects of the reef and its coastal zones [2]. Due to its proximity to busy international shipping routes, the reef faces significant risks, including vessel groundings, oil spills, and collisions with coral formations. To mitigate these risks, the Australian government has established a mandatory piloting system and a carefully planned network of shipping lanes. Within certain areas of the Torres Strait and the Great Barrier Reef, large vessels are required to employ qualified local pilots who use their expertise to navigate complex waterways safely. The system also includes one of the world's earliest and most sophisticated routeing schemes, featuring two-way lanes, deep-water channels, and avoidance zones that guide vessel traffic along the safest paths with minimal ecological impact. This system significantly reduces shipping accidents and exemplifies the prevention of physical threats through refined spatial management. Its success relies on the enforceability of legislation, technical expertise, and adequate financial support.

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2.2. Emission control areas in the Baltic Sea and North Sea: strengthening standards through regional management

Each summer, harmful algal blooms in the Baltic Sea severely affect local fisheries and tourism [3]. The Baltic is a semi-enclosed sea with limited water exchange and low self-purification capacity, making it particularly vulnerable to pollution from vessel emissions. In addition, its geography, the highly industrialized nature of its coastal states, and increasing population pressure lead to significant discharge of domestic, agricultural, and industrial wastewater, as well as waste and oil dumped from ships, making the Baltic one of the most polluted closed or semi-closed seas [4]. In response, the International Maritime Organization (IMO) has approved the designation of Sulphur Oxide (SOx) and Nitrogen Oxide (NOx) Emission Control Areas (ECAs) in the Baltic Sea and North Sea. Within these ECAs, the sulfur content of fuel used by vessels is strictly limited, far below global standards, and newly built ships must comply with the most stringent Tier III standards for nitrogen oxide emissions. Over time, these measures have helped mitigate eutrophication in the Baltic Sea. This represents a successful example of "regional management," whereby special areas enforce rules exceeding global standards to effectively address localized chemical pollution. It provides a legal and operational model under international law for implementing stricter environmental standards within MPAs.

2.3. Sanya coral reef national nature reserve, Hainan, China: refined management of tourist vessels

Coral reefs are highly specialized marine ecosystems with elevated primary productivity and biodiversity, often referred to as the "tropical rainforests of the ocean" and "oases in the blue desert." [5] The Sanya Coral Reef National Nature Reserve is renowned for its stunning reef ecosystems, yet intensive tourist vessel activity—including propeller damage, anchor damage, and oil discharges—poses direct threats. As China's awareness of marine protection grows, prospects for the conservation and cultivation of coral reefs are expanding. Marine study programs centered on the "human–sea relationship" aim to cultivate students' comprehensive awareness of ocean conservation, emphasizing that marine protection is a responsibility of all humanity, not just coastal communities [6]. In response, the local government of Hainan has enacted regulations establishing clearly defined tourist navigation channels, prohibiting vessels from entering core zones, and imposing speed limits to reduce wake and noise disturbance. Fixed buoys are installed at diving sites to prevent anchoring, fundamentally protecting coral formations from damage. Requirements are also imposed on vessel appearance and sewage treatment facilities, and fuel quality checks are strengthened. This represents a successful case of managing small, high-frequency tourist vessels in China, relying on precise spatial and behavioral control. The measures are concrete and operational, though regulatory authority over larger commercial vessels remains limited.

2.4. Yangtze Estuary Chinese sturgeon nature reserve: seasonal dynamic management

The Yangtze Estuary is a critical passageway for juvenile Chinese sturgeon migrating to the sea, yet it is also one of the world's busiest ports. Noise and underwater disturbances from shipping can disrupt the sturgeon's migratory behavior. In 2024, the General Office of the State Council issued the "Opinions on Persistently Advancing the Ten-Year Fishing Ban in the Yangtze River," calling for the continuous expansion of artificial breeding and release programs for rare and endangered species such as the Chinese sturgeon, aiming to rebuild wild populations [7]. The Chinese Sturgeon Nature

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Reserve in the Yangtze Estuary has established a comprehensive seasonal dynamic management system. Based on scientific monitoring, ultrasonic receivers are installed on navigation markers to form a three-dimensional monitoring network that tracks sturgeon movements in real time. Shipping restrictions, including seasonal speed limits during peak migration periods, reduce noise and collision risks. Multi-agency joint enforcement ensures regular patrols and strict penalties for illegal fishing, implementing the ten-year fishing ban policy. For population restoration, large-scale artificial breeding and release programs continue, with over 600,000 sturgeon released in 2025, and social participation in scientific release programs is encouraged. Research institutions such as the Yangtze Fisheries Research Institute continue to deepen studies and share habitat protection experiences through international sturgeon conservation seminars. However, significant challenges remain: according to the Ministry of Agriculture and Rural Affairs (March 2025), natural reproduction of Chinese sturgeon has not been observed for consecutive years, and wild populations are still unable to sustain themselves. Given their 18-year maturation cycle, the effects of protection measures require long-term, sustained efforts. While a management system has been established, the species' survival status remains precarious, necessitating continued strengthening of protective measures.

3. Multidimensional threats of shipping activities to the ecological value of marine protected areas

3.1. Physical damage: vessel strikes and direct harm to marine life

The hulls and underwater propellers of large commercial vessels and high-speed ships pose lethal threats to slow-moving or air-breathing marine megafauna. Additionally, sewage discharge spreads pathogens and contributes to eutrophication, while plastic debris can be ingested or entangle marine organisms, causing physical injury or death [8]. These threats primarily target large marine mammals (such as whales, dolphins, and dugongs), marine reptiles (such as sea turtles), and large fish species (such as whale sharks and manta rays), many of which serve as flagship or keystone species within MPAs. Vessel strikes often cause internal bleeding, bone fractures, and immediate mortality. Individuals that survive collisions may suffer severe trauma, reduced reproductive capacity, or abnormal behavior, which over time undermines the resilience of entire populations. For critically endangered species such as the Chinese white dolphin and the North Atlantic right whale, each ship strike can push populations closer to extinction. Within the Exclusive Economic Zone (EEZ), Article 94 of the United Nations Convention on the Law of the Sea (UNCLOS) grants flag states near-exclusive jurisdiction over the administrative, technical, and social matters of their vessels. When a foreign vessel damages coral reefs within an MPA due to improper anchoring, the coastal state's enforcement authority is strictly limited. Flag states—particularly those of convenience—often lack the willingness or capacity to effectively regulate and hold accountable their globally distributed fleets. This results in an "enforcement vacuum," rendering rules against physical damage largely ineffective.

3.2. Chemical pollution: direct discharges and spills

Dissolved oxygen in seawater is closely linked to biological activity, and its variation serves as an important indicator of organismal health. Hypoxic conditions in marine environments can cause mass mortality of marine organisms, producing varying degrees of impact on marine ecosystems [9]. A significant cause of these conditions is the direct discharge or accidental leakage of toxic

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substances from vessels during operations, including oil-contaminated water, fuel spills, or ballast water. Oil films on the water surface can block oxygen, adhere to organisms, and cause suffocation, poisoning, or loss of thermal insulation and waterproofing. Polycyclic aromatic hydrocarbons (PAHs) present carcinogenic and teratogenic risks.

Antifouling paints applied to prevent organismal attachment to hulls continuously release copper, zinc, and organotin substitutes such as butyltin, which persist in the water and cause neurotoxic and reproductive toxicity to surrounding filter-feeding organisms (e.g., shellfish, corals), magnifying effects along the food chain. The establishment of an Emission Control Area (ECA) or special zone requires submission of a proposal to the IMO and approval by the Marine Environment Protection Committee. This process often faces political and economic resistance from major shipping nations and fuel producers, as stricter standards significantly increase shipping costs. Demonstrating that a vessel has used non-compliant fuel in international waters or within an ECA is technically challenging. Although remote sniffing technology can detect ship emissions, its status as legal enforcement evidence remains under development. Furthermore, enforcement gaps exist in international waters: port-state control cannot intervene, and flag-state enforcement may be weak, leaving high seas areas as relatively vulnerable regulatory zones.

3.3. Noise pollution: “smog in the ocean”

Underwater noise is often likened to “smog in the ocean.” The analogy is useful precisely because the harm is easy to miss: sound is intangible, yet for many marine species it structures daily life. Commercial vessels generate substantial low-frequency noise—roughly in the 10–1,000 Hz range—through engines and propellers. Because these frequencies travel efficiently, they can spread far beyond individual ships and gradually form a stable, human-made acoustic backdrop along busy routes. This matters for species whose communication is tuned to the same band. Humpback and bowhead whales, for example, depend on low-frequency calls to keep contact over long distances, sustain social ties, and find mates. Persistent shipping noise does not “silence” them so much as crowd them out: it narrows the usable acoustic channel, reduces effective calling range, and forces communication to become shorter or less reliable—much like trying to hold a conversation in a packed, loud restaurant.

The impacts are not confined to baleen whales. Toothed whales such as sperm whales hunt with echolocation; when vessel noise overlaps their sonar frequencies, it can obscure prey echoes or distort detection, increasing the risk of failed foraging and inadequate energy intake. Many fish and invertebrates also orient themselves using natural ambient cues (for instance, the sound of breaking waves). When shipping replaces these cues with a competing acoustic signal, navigation and habitat selection can be thrown off course.

Despite the growing scientific consensus on such effects, the legal response at the international level remains patchy. Existing rules tend to approach noise in a fragmented way, often targeting individual sources and leaving other contributors—including non-commercial activities—underregulated. Even where shipping noise is addressed, norms are typically framed at a high level of generality, with broad principles rather than concrete operational standards. Enforcement is correspondingly thin, and levels of protection differ markedly across regions. Together, these gaps constrain what international law can currently achieve in mitigating marine noise pollution [10].

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4. Constructing a regulatory strategy system for shipping activities in marine protected areas from the perspective of international law

4.1. Solutions for physical damage

Article 192 of the United Nations Convention on the Law of the Sea (UNCLOS) articulates a general duty for states to protect and preserve the marine environment. For the purpose of regulating shipping-related physical harm, this clause functions as the basic legal anchor. A practical regulatory pathway therefore begins with connecting observable injuries—such as anchor scarring on coral reefs or vessel strikes that kill endangered whales—to a breach of this overarching obligation. Once that link is established, the remaining task is to translate the duty into site-specific management measures.

In substantive terms, responses to physical damage are most effective when they reduce direct spatial overlap between vessels and vulnerable habitats. A first line of action is to create strict exclusion or restriction zones inside MPAs. In areas of exceptional ecological sensitivity—core reef patches, primary breeding grounds for marine mammals, or critical migration passages for species such as the Chinese sturgeon—navigation should be prohibited either year-round or seasonally, depending on ecological cycles. Where relevant, major migratory pathways can also be formally designated as "ecological corridors," with the highest level of control applied along these routes.

Second, outside core zones, MPAs can rely on marine spatial planning to steer traffic rather than halt it. This involves mapping "shipping-priority zones" or "green shipping lanes," then implementing mandatory routeing schemes that confine vessels to a small number of fixed corridors designed to avoid sensitive habitats. The advantage is twofold: shipping efficiency is largely maintained, while the likelihood of accidental entry into protected areas—or arbitrary anchoring—is sharply reduced. Concentrating traffic into predictable lanes also makes supervision easier for management agencies.

Third, MPAs should systematize data on local ecological vulnerability and recorded shipping threats, and use that evidentiary base to seek IMO designation as Particularly Sensitive Sea Areas (PSSAs). Once recognized, PSSAs allow coastal states to pursue complementary mandatory measures, including avoidance areas and anchoring prohibitions. At the operational level, establishing dedicated monitoring centers within MPAs—supported by AIS tracking, drones, and related tools—would strengthen detection of suspected violations, such as speeding or leaving designated green lanes, and improve the credibility of enforcement.

4.2. Solutions for chemical pollution

Article 211 of UNCLOS specifically regulates pollution from vessels and establishes a tripartite governance structure involving the flag state, port state, and coastal state, while emphasizing that rules should be developed through the competent international organization, namely the IMO. First, relevant authorities should address pollutant discharges from aquaculture operations by improving effluent treatment, optimizing feed-based aquaculture practices, and increasing the proportion of filter-feeding species (e.g., shellfish and algae) that remove nitrogen and phosphorus [11]. Second, for high-value MPAs facing severe threats from vessel emissions—such as key estuarine and bay MPAs in China—scientific assessments should support proactive proposals to the IMO for establishing Emission Control Areas (ECAs). Collaboration with port authorities and shipping associations can establish a "green vessel" rating system. Ships employing low-noise propellers, clean energy sources (LNG, methanol), ballast water treatment systems, and other environmentally

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friendly technologies can be incentivized through reduced port fees or priority berthing. This represents the most effective international law pathway to reduce chemical damage at its source. Third, the use of drones and unmanned vessels for atmospheric sniffing and monitoring can be promoted, with results serving as clear legal grounds for port-state inspections, thereby establishing a new "airborne monitoring–port verification" enforcement model. The international legal framework for regulating chemical damage demonstrates a relatively comprehensive system, spanning global framework conventions (UNCLOS), specialized technical regulations (MARPOL), and regional strengthening mechanisms (ECA/Port State Control).

4.3. Solutions for noise pollution

Currently, the IMO has not established a globally uniform, mandatory limit for underwater radiated noise from ships. Challenges include the complexity of noise measurement procedures, ensuring fairness across different ship types, and establishing baseline data. Consequently, noise pollution regulation remains a long-term goal. To address current marine protection and noise management issues, "soft law" has predominantly been used, resulting in weak international constraints, avoidance of responsibility, and conflicts of interest. Reducing and controlling ocean noise requires introducing mandatory implementation mechanisms. Broad participation in conventions can signal the urgency and necessity of regulating marine noise, while mandatory consequences ensure compliance with ocean protection obligations [12]. First, member states—particularly port states—can incentivize compliance by incorporating adherence to relevant guidelines into conditions for vessel entry or operation in their territorial waters, or through economic incentives such as port fee discounts. Second, MPAs can deploy underwater acoustic sensors and online water-quality monitors, combined with satellite remote sensing and drone patrols, to create a real-time monitoring network. Alternatively, flag states can include underwater noise management requirements in the issuance of the International Air Pollution Prevention Certificate or a newly established "Ship Noise Compliance Certificate," making compliance part of vessel seaworthiness criteria. From the perspective of international law, there is no single "magic clause" to resolve shipping noise pollution. Instead, it is a strategic, gradual legal construction process. Third, based on the binding obligations of UNCLOS and leveraging the IMO's PSSA mechanism, regionally mandatory noise control measures—such as dynamic speed limits and optimized routing—can be first implemented in MPAs with the highest ecological value and greatest threat levels, while globally promoting the transition from voluntary guidelines to binding standards.

5. Conclusion

With the increase in maritime activities, traditional marine management theories no longer fully meet the practical demands of governance. The emergence of global governance theory provides a foundation for transforming marine management into a governance-oriented approach [13]. This study systematically analyzed the multidimensional threats posed by shipping activities to the ecological value of marine protected areas (MPAs) and explored solutions from the perspective of international law. The research reveals that physical damage, chemical pollution, and noise pollution are not isolated threats but interact cumulatively, exerting systemic negative impacts on biodiversity, habitat integrity, and ecological functions within MPAs. This stark reality underscores the urgency and complexity of coordinating marine environmental protection with freedom of navigation under the concept of a "community of shared ocean destiny." International law is not powerless in addressing these challenges. Anchored by the United Nations Convention on the Law of the Sea

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(UNCLOS) and centered on the International Maritime Organization (IMO) as the primary platform, the legal framework provides crucial tools and pathways for evolution. Protecting MPAs from the adverse impacts of shipping activities is a comprehensive governance undertaking that involves law, technology, economics, and politics. Looking ahead, states—particularly maritime and shipping powers like China—should strategically utilize international legal instruments, actively promote the upgrading of key MPAs to internationally recognized Particularly Sensitive Sea Areas (PSSAs) or Emission Control Areas (ECAs), and continuously strengthen regional enforcement cooperation. This approach is not only essential for fulfilling international environmental obligations and safeguarding global marine heritage but also serves as a strategic initiative to participate in shaping future marine governance rules and leading sustainable blue development globally. Only through resolute international legal action combined with pragmatic multilateral collaboration can humanity find a sustainable path of harmonious coexistence between shipping arteries and the cradle of marine life.

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