

Marine Pollution Prevention and Environmental Management Practices in Naval and Commercial Ports

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Abstract

Ports are indispensable nodes of global trade and national defence, but they are also concentrated sources of marine pollution. Commercial terminals and naval bases alike generate air emissions, wastewater, oily residues, solid waste, contaminated sediments, underwater noise and risks of biological invasion, all within sensitive coastal and estuarine waters. This article reviews the principal pathways of port-related marine pollution and the management practices used to prevent and control them. It examines emissions abatement and shore power, ballast and wastewater management, oil spill prevention and response, dredging and sediment management, hull antifouling and biosecurity, waste reduction, environmental management systems and monitoring indicators, and the governance arrangements that support implementation. The review shows that effective prevention rests on a combination of source control, infrastructure investment, systematic monitoring and cooperation among port authorities, operators, navies and regulators. It also identifies persistent gaps, including uneven enforcement, limited data from military facilities and the difficulty of managing cumulative effects. A risk-based, indicator-driven and transparent approach to port environmental management offers the most reliable route to protecting coastal ecosystems while sustaining maritime operations..

Keywords: marine pollution prevention, port environmental management, naval ports, shore power, sediment and ballast management

INTRODUCTION

Seaports sit at the boundary between land and sea, and their activities affect both. Vessels arrive carrying cargo, passengers and weapons systems, take on fuel and supplies, discharge wastes, undergo repair and depart again, while landside operations move goods through terminals, rail yards and industrial zones. Each of these processes can release

pollutants to air, water and sediment. Because ports are commonly located in estuaries, bays and harbours that are ecologically productive and heavily used by people, the consequences of pollution can be felt by fisheries, wildlife, recreation and public health. Shipping emissions illustrate the scale of the issue. Global assessments have linked emissions from ships to substantial premature mortality through fine particulate matter, with the greatest burden falling on populations living near coasts and busy trade routes (Corbett et al., 2007). Analyses of the climate and atmospheric effects of shipping likewise show that vessels contribute significantly to sulphur, nitrogen and particulate pollution as well as greenhouse gases (Eyring et al., 2010). Ports, where ships spend extended periods at berth, are therefore central to any strategy for reducing these impacts. This article provides a structured review of marine pollution prevention and environmental management practices in both naval and commercial ports. It begins with the main environmental pressures, then discusses specific control measures for emissions, water quality, oil spills, dredging, hull fouling and waste. It then considers management systems, monitoring indicators and governance. Naval ports share many problems with commercial ones, but they have distinct features, including specialised fuels and munitions handling, security restrictions and different regulatory arrangements, which are addressed throughout the discussion.

Environmental Pressures from Port and Naval Activities:

Port-related pressures can be grouped by the medium they affect and by the activity that generates them. Atmospheric pressures arise mainly from vessel engines and auxiliary boilers, cargo-handling equipment, trucks and locomotives. Aquatic pressures include discharges of ballast water, bilge water, sewage and graywater, leakage of oil and fuel, runoff from yards and storm drains, and the release of biocides from antifouling coatings. Benthic pressures result from dredging, construction and the accumulation of contaminated sediments, while terrestrial pressures involve land take, waste generation and the handling of hazardous materials. A key step in management is to identify which aspects are significant for a specific port. A procedure designed for sea ports proposes systematic identification of environmental aspects, evaluating them according to severity, frequency and sensitivity of the receiving environment so that priorities can be set rationally (Darbra et al., 2005). This avoids the common tendency to concentrate on the most visible problem, such as oil spills, while neglecting less obvious but chronic pressures such as air emissions or sediment contamination. Naval ports add several dimensions. Warships may carry large quantities of fuel, ordnance and hazardous materials, and their maintenance generates specialised wastes such as paint residues, solvents and heavy metals. Submarine bases and shipyards may handle radioactive materials under tightly controlled conditions. Operational security can limit the publication of environmental data, which complicates independent evaluation. Nevertheless, the physical processes of pollution are the same, and many navies now adopt environmental management practices modelled on civilian standards.

Air Emissions, Cold Ironing and Cleaner Fuels:

Vessels at berth typically run auxiliary engines to power lighting, refrigeration, pumps and onboard systems, producing exhaust that settles directly on port cities. Studies of coastal air quality in Europe show that shipping emissions can make a measurable contribution to concentrations of sulphur dioxide, nitrogen oxides and particulate matter in harbour cities, with the effect depending on distance, meteorology and traffic intensity (Viana et al., 2014). Emission models developed for individual ports demonstrate that cruise and ferry operations, with long hotel loads at berth, can be especially significant sources (Tichavska and Tovar, 2015). Shore power, often called cold ironing, allows ships to connect to the electrical grid and shut down auxiliary engines while moored. The measure can eliminate local exhaust almost entirely, and when the grid is supplied by low-carbon sources it also reduces climate impacts. Implementation requires investment in high-voltage connections, compatible vessel equipment and agreements on tariffs and standards. Naval vessels, which spend long periods alongside in home ports, are well suited to shore power, although differences in electrical systems and operational readiness requirements must be addressed. Other options complement shore power. These include low-sulphur and alternative fuels, exhaust gas cleaning systems, speed reduction zones, electrification of cargo-handling equipment, cleaner trucks and incentives such as differentiated port dues for cleaner ships. Emission inventories, regularly updated, allow ports to track progress and to target the most important sources. Because emissions drift between jurisdictions, regional agreements on emission control areas help ensure that cleaner operations in one port are not undermined by weaker rules in neighbouring ones.

Water Quality, Ballast and Wastewater Management:

Water pollution in ports arises from both routine discharges and accidents. Ships generate sewage, graywater, bilge water containing oil, and cooling water, and international rules restrict discharges in many areas and require reception facilities ashore. Port authorities are responsible for ensuring that adequate facilities exist, that they are accessible and affordable, and that their use is monitored. Inadequate facilities encourage illegal discharge, so investment in collection and treatment is a core component of pollution prevention. Landside sources are equally important. Stormwater washing across yards, fuelling areas and workshops carries oils, metals and nutrients into the harbour. Good practice includes paved and bunded work areas, oil-water separators, sediment traps, regular sweeping and training of personnel. Treatment of process water from shipyards and repair facilities prevents the release of abrasive blasting residues, paint

particles and solvents. In naval dockyards, strict controls on the handling of fuel, lubricants and hazardous compounds reduce the risk of chronic leakage. Ballast water management bridges water quality and biosecurity. Ballast discharges can carry plankton, pathogens and larvae of non-native species, and the rapid growth of global shipping has increased the potential for such introductions. Treatment systems, ballast exchange procedures, port-based sampling and risk assessments for high-risk voyages help reduce transfers. Port authorities can support compliance through inspection, record checks and cooperation with neighbouring ports to harmonise requirements and share data on detected species.

Oil Spill Prevention and Emergency Response:

Oil and chemical spills are among the most visible forms of marine pollution, and ports are high-risk locations because of dense traffic, bunkering operations and cargo transfers. Most spills in port areas are small, caused by overfilling, hose failures or human error during fuel transfer, but they occur frequently and their cumulative effects on sediments and shoreline habitats can be significant. Prevention therefore focuses on procedures, equipment maintenance and personnel training during bunkering and cargo handling. Preparedness is built through contingency planning, equipment and exercises. A port oil spill response plan identifies potential spill sources, sensitive resources such as marshes, shellfish beds and protected areas, and the roles and responsibilities of port authorities, operators, naval units and government agencies. Containment booms, skimmers, dispersant policies, storage for recovered oil and communications arrangements need to be in place and regularly tested. Mutual aid agreements allow neighbouring ports and navies to share resources during large incidents. Naval ports often possess significant response capabilities, including trained crews, specialised vessels and logistical support, and cooperation with civil authorities can strengthen regional readiness. Response should be followed by assessment of ecological damage and restoration. Lessons from incidents, together with near-miss reporting, feed back into procedures and design. Increasing attention is being given to non-oil hazardous and noxious substances and to the risks associated with new fuels such as liquefied natural gas, ammonia and methanol, which require tailored safety and response arrangements.

Dredging and Sediment Management:

Maintenance and capital dredging are essential for navigation but carry well-known environmental risks. Dredging resuspends sediment, increases turbidity, can release buried contaminants and removes benthic habitat, while disposal of the dredged material may smother organisms at the placement site. Because harbour sediments often contain legacy pollutants from industry, shipping and antifouling paints, the management of contaminated material is a central problem for many ports. A habitat-based approach to the disposal of maintenance dredged material has been advocated to minimise ecological impacts, matching placement options to the physical and biological characteristics of potential sites and considering opportunities for beneficial use (Bolam and Rees, 2003). Beneficial use includes using clean sediment for beach nourishment, wetland creation, land reclamation or construction fill, which converts a waste stream into a resource and can enhance coastal resilience. Careful timing of dredging to avoid spawning and migration seasons further reduces harm. Sediment management should begin with characterisation. Sampling and chemical and biological testing determine contaminant levels and guide decisions on treatment, confined disposal or open-water placement. Techniques such as environmental buckets, silt curtains and controlled overflow limit dispersion during operations, and monitoring during and after dredging verifies that predicted effects are not exceeded. Reducing the need for dredging through source control, upstream sediment management and efficient channel design offers a long-term strategy.

Hull Antifouling, Biofouling and Invasive Species Control:

Marine organisms attach to ship hulls, increasing drag and fuel consumption and serving as a vector for invasive species. Antifouling coatings reduce this growth, but many conventional products rely on biocides, notably copper compounds, which leach into harbour water and accumulate in sediments. Studies of copper emissions from antifouling paint on vessels in enclosed marinas demonstrate that high vessel density and restricted flushing can raise concentrations to levels of environmental concern (Schiff et al., 2004). Invasive species represent a parallel threat. Marine invasive alien species have been recognised as a major threat to global biodiversity, affecting ecosystems, fisheries, aquaculture and human health (Bax et al., 2003). Forecasts of shipping growth suggest that opportunities for species introductions will continue to increase unless management improves (Sardain et al., 2019). Hull fouling is particularly difficult to control for vessels that remain idle for long periods, a circumstance common to naval ships in reserve or maintenance. Management measures include the use of effective and less toxic coatings, scheduled hull cleaning and inspection, in-water cleaning with capture and treatment of debris, and biofouling management plans. Port authorities can regulate hull cleaning in harbour waters, provide capture facilities and monitor port areas for new arrivals. Rapid response plans for detected species increase the chance of eradication before establishment. Cooperation among ports and navies in sharing biofouling data helps prevent species from being spread along trade and deployment routes.

Waste Management and Circular Practices at Ports:

Ports handle large quantities of waste from ships, terminals, shipyards and associated industries. Ship-generated waste includes food waste, plastics, packaging, oily residues, cargo residues and, on larger vessels, hazardous wastes such as

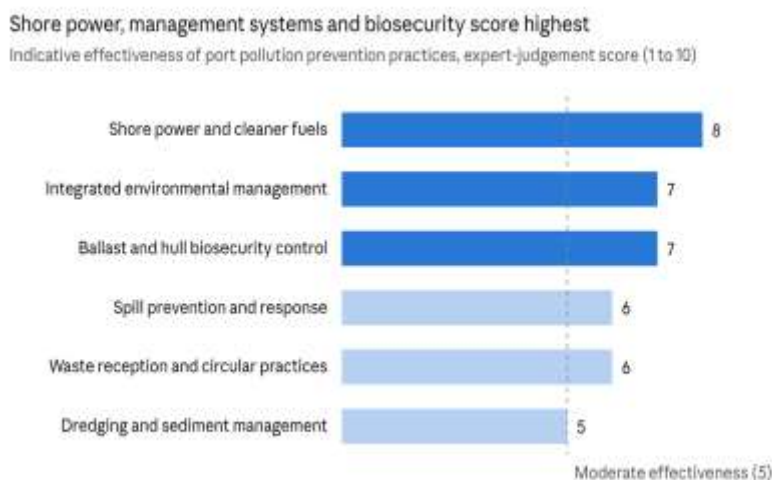
batteries and chemicals. International regulations prohibit disposal of most of these wastes at sea, so reception facilities and clear procedures for segregation, collection, treatment and recording are essential. Plastic debris is a particular concern because it persists and can be transported far from its source. A waste hierarchy that emphasises prevention, reuse, recycling and recovery before disposal provides a useful framework. Ports can reduce waste through procurement policies, reusable packaging, deposit systems and cooperation with shipping lines. Recovery of oily waste for energy, recycling of metals from ship repair and composting of organic waste create secondary value. Industrial symbiosis, in which by-products from one activity serve as inputs to another within the port area, supports circular economy goals. Naval ports have additional waste streams, including expired munitions components, contaminated personal equipment, and decommissioned ship parts. Safe handling and traceability are required, and disposal may be subject to special regulation. Ship recycling and decommissioning should follow environmentally sound procedures that prevent release of hazardous materials, including asbestos, polychlorinated biphenyls and heavy metals. Transparent reporting on waste quantities and treatment improves accountability and enables continuous improvement.

Environmental Management Systems and Monitoring Indicators:

An environmental management system provides the organisational framework for turning policy into practice. It typically includes a stated environmental policy, identification of significant aspects, objectives and targets, assigned responsibilities, operational controls, training, monitoring, audits and management review. Studies of port environmental management show that implementation of policy through scientific monitoring is essential for demonstrating that controls are effective rather than merely planned (Wooldridge et al., 1999). Indicators allow performance to be measured and communicated. A review of environmental performance indicators for port management identified and prioritised measures such as air emission inventories, water and sediment quality, waste volumes, energy consumption, noise levels and the proportion of ships using shore power, providing a basis for comparison among ports (Puig et al., 2014). A comparison of management tools used by leading ports in Asia and Europe shows that leading ports combine environmental indices, monitoring programmes, incentive schemes and certification to drive improvement (Lam and Notteboom, 2014).

Governance, Regulation and Stakeholder Collaboration:

Port environmental performance depends on a layered system of international conventions, regional agreements, national laws and local permits. International instruments set standards for discharges from ships, ballast water, air emissions and ship recycling, but their effectiveness depends on enforcement by flag states, port states and port authorities. Port state control inspections, reception facility requirements and penalties for violations form the regulatory backbone, and consistency among neighbouring jurisdictions prevents operators from seeking the least demanding location. Naval ports occupy a distinctive position because warships often enjoy sovereign immunity from some regulations. Many navies nevertheless adopt voluntary policies that match or exceed civilian standards, and internal environmental inspectorates, compliance programmes and reporting systems have become more common. Public summaries of environmental performance, independent audits and partnership with research institutions can build trust without compromising security. Joint planning of environmental protection in shared harbours encourages consistency between military and commercial operations. Collaboration with stakeholders strengthens implementation. Port authorities, terminal operators, shipping lines, shipyards, local governments, environmental organisations and communities all have roles to play. Green port programmes, environmental incentive schemes and voluntary certification encourage operators to exceed minimum requirements. Capacity building, technology transfer and financing support are especially important for ports in developing regions, where resources are limited but trade volumes are growing rapidly. Long-term success depends on integrating environmental objectives into port strategy rather than treating them as a compliance burden.



Summary

Ports, whether commercial or naval, concentrate pollution pressures that affect air, water, sediment and marine life. Significant aspects include vessel emissions, discharges and leaks, contaminated sediments, hull biocides, invasive species and waste. Identifying which of these pressures matter most in a given location is the first step toward effective control. The practices reviewed here are mutually reinforcing. Shore power and cleaner fuels address air quality, adequate reception facilities and treatment systems protect water quality, careful dredging and sediment management prevent contamination, biofouling and ballast controls limit invasions, and circular waste practices reduce material losses. Environmental management systems, measurable indicators and credible monitoring ensure that these measures work and improve over time. Strong governance, cooperation between civil and military authorities and open reporting make progress durable. Ports that adopt such an integrated and transparent approach protect coastal ecosystems while securing their own long-term operational and social licence.

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