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# A proposed interdisciplinary framework for the environmental management of water and air-borne emissions in maritime logistics

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ABSTRACT

This paper develops and tests a conceptual environmental risk assessment and management framework to guide businesses and other stakeholders, including government, in defining and addressing potential environmental problems in ocean shipping and port operations. The framework aims to protect the natural environment and its ecosystem services while at the same time allowing society to obtain goods and benefits from the seas. As such it integrates three elements: firstly, the criteria required to achieve sustainable management that, secondly, underpin a problem structuring method which, thirdly, can be assessed using an ISO Bow-tie industry standard analysis tool. Ocean pollution from water and air-borne discharges are used to illustrate this framework; this uses an input from an exploratory research study with maritime practitioners which investigated the framework veracity and potential for use, highlighting its potential and shortcomings.

## 1. Introduction

All industry and other users of the natural environment have to demonstrate that their activities are environmentally sustainable and that they fulfil all relevant national and international legislation protecting the environment (Boyes and Elliott, 2014). It is axiomatic under the precautionary principle that an industry has to prove that it is not harming the environment whereas an environmental regulatory body does not have to prove that an industry is harming the environment. In defining and tackling environmental problems and potential problems, industry has to undertake a proper risk assessment and risk management approach that may go beyond normal environmental impact assessment requirements (Lonsdale et al., 2017). This requires a robust and legally defensible approach irrespective of whether the activity is building a new power plant or operating a vessel in coastal and international waters. Once an activity has been determined as actually or potentially causing an adverse environmental effect then there is the need to implement a management approach involving problem-alleviation measures. This requires a sound conceptual framework based on good science and fit-for-purpose approaches.

Against an increasing background and knowledge of marine effects and management, we introduce a conceptual framework to provide guidance for businesses and their stakeholders, including government, to address these issues. We use ballast water and aerial discharge pollution and other environmental effects in the logistics of ocean lane shipping and transport to illustrate the use of this framework.

We first illustrate the marine environmental effects stemming from ocean lane shipping and transport and ships resident in port developments, focusing on the Baltic Sea as a busy trading and shipping context. Building on previous work, we then define, describe and discuss three inter-linked elements underlying the framework: the 10-tenets of sustainable management and stakeholder consultation criteria (Elliott, 2013; Barnard and Elliott, 2015), the DAPSI(W)R(M) (**D**rivers-**A**ctivities-**P**ressures-**S**tate changes-**I**mpacts (on human **W**elfare)-**R**esponses (as **M**easures)) problem structuring method (Elliott et al., 2017), and the Bow-Tie risk assessment and management analysis approach that integrates the other two elements (Cormier et al., 2013). We then discuss our integrated, conceptual framework with implementation observations for ballast water and aerial emissions that incorporate our exploratory research study with maritime practitioners, e.g. shippers and port operators, to solicit their views on its veracity and potential usability. Finally, given that the application of the framework may be included in the rapidly developing field of Translational Ecology which aims to determine the science repercussions for policy and vice-versa (Enquist et al., 2017), we suggest future research and application.

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## 2. Theoretical and conceptual background

### 2.1. Effects of increased logistics on the marine environment – the size of the problem

There are many marine activities potentially causing environmental problems; Halpern et al. (2008) illustrated the degree of activities on the oceans and many studies have identified the large number of sea-area users (e.g. Boyes et al., 2007; Smith et al., 2016). Of these, shipping and its associated activities are a major concern. Tournadre (2014) analysed global ship density using altimeter data and found a large-scale quadrupling of traffic between the early 1990s and 2014. The only region where there was a decline of traffic is near Somalia and is related to piracy starting in 2006–2007. The distribution of growth over different ocean basins reflects the redistribution of the international trade with the largest growth in the Indian Ocean and the Western Pacific Seas.

Ocean transport combined with short-sea shipping is necessary for the intercontinental shipment of bulk cargo, bulky goods, containers and dangerous materials such as oil and gas over large distances. Its strengths include being very economic and environmentally-friendly as regards $CO_2$ emissions per tonne of cargo despite bunker fuel being a particularly 'dirty' fuel, handling very large transport volumes, and operating independent of weather conditions (Grant, 2012). As a result of globalization, container trade has increased on average 5% per year over the last two decades and is currently around 350 million twenty-foot equivalent (TEU) container movements a year. Container traffic is around 42 million TEU between Asia and Europe and 31 million TEU between Asia and North America. It is of note that the 45 million TEU in Intra-Asia reflects trade between Asian countries related to sub-contracting manufacturing and providing logistics services such as consolidation for other marketplaces (Grant, 2012).

By comparison, the cruise line sector is smaller than the cargo sector although an estimated 23 million passengers cruised globally in 2015. At an average of 3000 passengers per cruise ship that means there are about 7700 annual cruise ship movements. Annual growth in the sector over the last thirty years has been just over 7.2%. As a result, many new, large cruise ships have entered the market and it was forecast that 33 new cruise ships with over 100,000 berths and an investment of US $25 billion are planned for delivery during the period 2015–2020 (F-CCA, 2016).

Finally, there are many scheduled short- and long-haul ferry services worldwide. Holthof (2014) estimated the number of ferries globally as 1085 large displacement ferries plus 111 freight-only, roll-on-roll-off (Ro-Ro) with a capacity exceeding 12 passengers, 222 pure freight Ro-Ro ferries with a capacity of up to 12 passengers, 1877 lightweight fast craft - 180 with car capacity and 1697 passenger-only fast craft. He further estimated that the global ferry market carried 2.2 billion passengers, 258 million cars and 39 million Ro-Ro trailers in 2013. Ferry traffic volumes in the Baltic region in 2013 were 238 million passengers, 92 million cars and 12 million Ro-Ro trailers. Needless to say, there are various environmental effects that this increased movement of ships has on marine areas, i.e. ocean or short-sea shipping lanes and port developments.

### 2.2. Environmental effects of increased logistics – water and air-borne issues

The generally accepted major pollutants and other environmental effects from ocean and short-sea shipping include $CO_2$ and sulphur dioxide ($SO_2$) emissions in ports and at sea, fuel consumption of a non-renewable resources, pollutants from ballast water, sewage and garbage discharges, space occupation that may inhibit natural ecosystem development, acidification of ocean and sea pH levels from $CO_2$ and $SO_2$ emissions (OSPAR Commission, 2009). We discuss these effects in more detail with reference to the specific examples of aerial discharges and ballast water discharge (BWD) in a conceptual model (a 'horrendogram' in Fig. 2). This model has been developed from a wide knowledge of the port and navigation activities and their repercussions (e.g. McLusky and Elliott, 2004). The main consequences from navigation emanate from two sources – the ocean traffic and the port development. The former intermittently occupies sea space and discharges various materials, all of which can lead to changes to the ecosystem. The port activities again have these impacts but continuously occupy more space, remove or change habitats, and create obstructions. These activities can introduce and provide settlement surfaces for non-indigenous species.

Arguably the largest environmental consequences of shipping are from aerial $CO_2$ emissions. Rigot-Muller et al. (2013) found that the maritime leg represents the major contributor to $CO_2$ emissions in an end-to-end global supply chain that includes distant overseas destinations. Their analysis showed that such $CO_2$ emissions could be reduced by 16–21% through direct delivery to a UK port as opposed to transshipment via a continental European port, i.e. cargo feeder systems that suggest more efficient operations. Further, McKinnon (2014) argued that by packing more products into containers, shippers could reduce the number of container movements and related $CO_2$ emissions. The pressure to minimise shipping costs would also give these companies a strong incentive to maximise fill. He surveyed 34 large UK shippers and found that inbound flows into the UK were of predominantly low density products bound for retail stores that 'cubed-out' before they 'weighed-out; ' in that they reached the volume limit of the container before reaching the weight limit. For illustration, 46% of respondents importing containerised freight claimed that 90–100% of containers received were 'cubed-out'. McKinnon (2014) also found that only approximately 40% of shippers have so far measured the 'carbon footprint' of their deep-sea container supply chains with just 6% implementing carbon-reducing initiatives. The companies surveyed also assigned a relatively low weighting to environmental criteria in ocean carrier selection. Therefore, while many shippers have the means to influence the carbon footprint of their maritime supply chains, the survey suggested that they are not currently using them explicitly to cut $CO_2$ emissions.

There are many operational modifications that UK shippers and their ocean carriers are implementing to improve economic efficiency, most notably slow-steaming, to help to achieve carbon mitigation efforts. Slow-steaming involves reducing the speed of a ship while at sea to reduce engine load and emissions. Slow-steaming was mooted by the Maersk Line as a response to the 2008 economic recession as the spot-market price Maersk Line received in late 2008 for shipping containers from Asia to Europe or North America was approximately US $500 below their operating costs. The relationship between ship speed and fuel consumption is non-linear and Maersk Line calculated that by redesigning their shipping schedules, using nine ships instead of eight to ensure customer volumes were handled and slowing the vessel sailing speeds from 22 knots to 20 knots, they could reduce annual fuel consumption from 9500 to 8000 and thus also reduce carbon emissions 17% from 30,000 to 25,000 t metric tonnes of $CO_2$ (Grant et al., 2015).

As with most countries, only a few UK ports measure and report their carbon emissions. Gibbs et al. (2014) estimated that emissions generated by ships during their voyages between ports are much larger than those generated by port activities. However, 70% of shipping emissions occur within 400 km of land; thus ships contribute significant pollution in coastal regions thus affecting communities. Shipping-related particulate matter (PM) emissions have been estimated to cause 60,000 cardiopulmonary and lung cancer deaths annually with most deaths occurring near coastlines in Europe, East Asia and South Asia (Corbett et al., 2007; Winebrake et al., 2009).

It is now well-accepted that increasing atmospheric $CO_2$ results in a slow acidification of the surface ocean (Pörtner and Karl, 2014). Anthropogenic emissions of sulphur and nitrogen oxides ($SO_x$, $NO_x$) create acidification and can also contribute to eutrophication of coastal, land and freshwater ecosystems (De Jonge and Elliott, 2002). There are atmospheric aerosol effects on regional and global climate, but deposition