Title: Guiding principles for the improved governance of port and shipping impacts in the Great Barrier Reef

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Abstract

The Great Barrier Reef (GBR) region of Queensland, Australia, encompasses a complex and diverse array of tropical marine ecosystems of global significance. The region is also a World Heritage Area and largely within one of the world's best managed marine protected areas. However, a recent World Heritage Committee report drew attention to serious governance problems associated with the management of ports and shipping. We review the impacts of ports and shipping on biodiversity in the GBR, and propose a series of guiding principles to improve the current governance arrangements. Implementing these principles will increase the capacity of decision makers to minimize the impacts of ports and shipping on biodiversity, and will provide certainty and clarity to port operators and developers. A 'business as usual' approach could lead to the GBR's inclusion on the List of World Heritage in Danger in 2014.

Keywords: Great Barrier Reef, World Heritage, ports, shipping, biodiversity, governance

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Introduction

International trade contributes to the functioning of the global economy and represents a significant share of gross domestic product for many countries. Around 8.4 billion tonnes of cargo are transported by sea each year, equating to 90% of international trade. This amount is predicted to triple globally by 2060 (UNTCAD 2011). Shipping and ports at the termini of shipping routes present a significant and increasing challenge to the conservation of coastal and marine biodiversity. Of the world's sources of air and water pollution, shipping is one of the most difficult to regulate (Brietling 2010). Shipping accidents can have devastating consequences for biodiversity, as demonstrated in 2011 when the *MV Rena* ran aground at Astrolabe Reef, New Zealand, killing as many as 2 000 seabirds (Perry 2012, May 25). Significant global progress has been made to reduce the impact of ports and shipping through regional environmental planning processes and the implementation of several international instruments (e.g. International Convention for the Prevention of Pollution from Ships 1972 [MARPOL]). However, the effects of this progress have, to some extent, been offset by large increases in shipping traffic and port developments since the 1970s (Brietling 2010) and the high costs associated with retro-fitting ports that are poorly located or have had serious adverse environmental impacts.

Ports and shipping in the Great Barrier Reef region

The global demand for coal and minerals is driving strong growth in Australia's mining sector, matched by increases in port and shipping activities. Coal, in particular, contributes to almost half of Australia's total exports by value, and significant coal reserves are found in the State of Queensland (Fig. 1). Port capacity in the Great Barrier Reef (GBR) region (Fig. 1) is expected to triple by 2020 to support the predicted growth in Queensland's annual coal production (BREE 2012). Major expansions are underway and proposed for the Ports of Hay Point (the world's largest coal export port), Abbot Point, Townsville and Gladstone (Fig. 1, 2 and 3). Gladstone is Queensland's busiest industrial port, with cement works, coal loaders, two alumina refineries, an aluminium smelter, power station, cyanide factory, and shale oil demonstration plant. Four liquefied natural gas plants and associated export facilities are either under construction or soon to start construction in Gladstone, together with the largest dredging operation in Queensland's history (Fig. 2). Two new coal export ports are proposed for Port Alma, near Gladstone, and a smaller coal-loading facility near Bathurst Bay in the remote north of the GBR (Fig. 1). The 12 ports located adjacent to the GBR are administered by four port authorities (Table 1). Port authorities are semi-government corporations, each controlled by boards appointed by the Queensland Government. Port governance activities address a combination of local, state, national and international requirements because ports cross jurisdictional boundaries (Fig. 3). Jurisdictions include local governments, State (Queensland) lands and waters, the Commonwealth (Australian) Great Barrier Reef Marine Park (GBR Marine Park), and the Great Barrier Reef World Heritage Area (GBR World Heritage Area).

Along with port developments, shipping movements are also increasing, particularly within the southern section of the GBR region (AMSA 2011). Currently, around 6,000 vessels transit the GBR and Torres Strait (between Papua New Guinea and Australia; Fig. 1) every year (GBRMPA 2009). The GBR Marine Park Authority, Australian Maritime Safety Authority, and Maritime Safety Queensland jointly manage shipping under domestic laws and regulations as well as international treaty law, such as the United Nations Convention of the Laws of the Sea and MARPOL. The GBR region is listed as a Particularly Sensitive Sea Area by the International Maritime Organization. All large vessels are monitored by a vessel traffic system (REEFVTS) and ships are only permitted to transit through Designated Shipping Areas (Fig. 1). Much of the region requires the compulsory pilotage of large vessels.

The state of the Great Barrier Reef region

The GBR is the world's most extensive coral reef ecosystem. Around 348 000 km^2 of the GBR region was inscribed on the World Heritage List in 1981 for its superlative natural beauty, ecological diversity, and relative intactness (GBRMPA 1981). The Commonwealth Government has international responsibilities under the World Heritage Convention to conserve the GBR region by ensuring that activities in *and adjacent to* the World Heritage Area do not affect its integrity. The GBR region is managed as a multiple-use area, with a long history of activities on its extensive coastline and in the region's catchments (Fig. 1), including ports and shipping, tourism, agriculture, urban and industrial development, and commercial and non-commercial fishing. The combined impacts of these activities are contributing to the ongoing decline of biodiversity within the region (Brodie and Waterhouse 2012). Since the mid-1980s, GBR reefs have lost almost 50% of coral cover (De'ath et al. 2012). Losses since the 1960s are estimated to be 75% (Hughes et al. 2011). The decline in coral cover is concentrated south of Cooktown (Fig. 1) with reefs in the remote and undeveloped north remaining relatively intact (De'ath et al. 2012). Since intensive European settlement, there have been significant reductions in populations of marine megafauna such as dugongs and loggerhead and hawksbill turtles (Limpus and Limpus 2003; Marsh et al. 2005). The GBR region's mangroves, saltmarshes and seagrasses have been relatively stable in extent, but recent climatic events, including a strong La Nina and several intense tropical cyclones, have caused massive loss of seagrass along much of the coast south of Cooktown (McKenzie et al. 2012). In particular, category-5 tropical cyclone Yasi (February 2011) caused substantial damage to one of Australia's largest mangrove forests.

The extent of ports and shipping in the GBR region is small in comparison to major industrial areas in Europe, North America and Asia. However, the presence of a large World Heritage property adjacent to significant coal, coal seam gas and mineral deposits makes ports and shipping in the region an issue of international importance. The failure to inform the World Heritage Committee of several proposed liquefied natural gas plants at the Port of Gladstone, together with reported declines in biodiversity, prompted a United Nations Educational, Scientific and Cultural Organization-International Union for Conservation of Nature (UNESCO-IUCN) reactive monitoring mission in 2012 (Brodie and Waterhouse 2012; McGrath 2012). The mission highlighted the possibility of adding the GBR to the List of World Heritage in Danger because the number and extent of port developments presents '*a significant risk to the conservation of the [Outstanding Universal Value] and integrity'* of the region (Douvere and Badman 2012). The Queensland and Commonwealth Governments, on the advice of the World Heritage Committee, are responding to the UNESCO-IUCN mission with a strategic assessment to identify, plan for, and manage existing and emerging risks from ports and shipping in the GBR region. The strategic assessment is potentially an important process (McGrath 2012). However, the assessment reports by the State and Commonwealth, due in mid-2013, will be limited by their restrictive terms of reference (GBRMPA 2012; Queensland Government 2012a) and the short time available for the assessment, consultation, and public and peer review (12 months). The recently released draft of the Queensland Government's Ports Strategy (Queensland Government 2012b) has also raised concerns about the future of port developments in the GBR region (McGrath 2012). The report to the 37th session of the World Heritage Committee echoed these concerns, and recommended that the Committee consider *'the [GBR] for inscription on the List of World Heritage in Danger at its 38th session in 2014 in the absence of a firm and demonstrable commitment on these priority issues'* (World Heritage Centre 2013).

The need for guiding principles

The GBR Marine Park is the best managed coral reef system in the world (Wilkinson 2008) but activities outside the Park are contributing substantially to its decline (Brodie and Waterhouse 2012). Focusing on some of these outside activities, the UNESCO-IUCN reactive monitoring mission found that the current '*scale and pace of [port] development proposals appear beyond the capacity for independent, quality and transparent decision making*' (Douvere and Badman 2012). Given the region's iconic status and World Heritage listing, the governance of ports and shipping in the GBR region should aspire to avoiding or minimizing impacts on biodiversity. In addition, decisions about new port developments and other activities should consider the long-term implications for the GBR region and Australia's obligation to maintain the GBR's Outstanding Universal Value. Our assertion is that policy makers, managers, and industry should increase their efforts to interpret the complex mix of imperatives, uncertainties, and weaknesses around the management of ports and shipping along the GBR's coast. In this paper, we review the impacts of ports and shipping on biodiversity in the GBR, and propose a series of guiding principles to improve the current governance arrangements. Our objective in developing these principles is to support Government, industry and the community by increasing the capacity of decision makers to take a strategic view of port management and adequately assess and manage the impacts of ports and shipping. We also consider that improved governance would provide greater investment certainty and clarity to port operators and developers.

Impacts of ports and shipping on biodiversity in the GBR

Ports and shipping exert a variety of pressures across multiple temporal and spatial scales with diverse impacts on biodiversity in the GBR region (Table 2; Appendix A). Port infrastructure, port-related boat traffic, and dredging are localised to designated port areas and disposal sites, within and adjacent to the GBR World Heritage Area (Fig. 1, 2 and 3). Shipping lanes extend along the entire length of the region (Fig. 1), exposing a wider area to shipping-related pressures. Pressures exerted by ports occur within the construction phase (e.g. reclamation) and during operation (e.g. introduction of contaminants from storage facilities and maintenance dredging of channels). Capital (initial) dredging during construction establishes shipping lanes, swing basins and berth pockets that require maintenance dredging during the operational life of the port. Capital and maintenance dredging exert similar pressures (although over different spatial and temporal scales), including the removal of benthic biota, smothering in spoil dumping areas, and elevated turbidity around dredging and dumping sites. Pressures from shipping and port-related boat traffic include noise, abrasion from grounding, scarring from anchoring and propeller turbulence, introduction of non-native (pest) species, and leaching of toxic anti-foulants into coastal waters. Pressures related to ports and shipping range from acute (e.g. ship grounding) to chronic (e.g. port illumination) (Foster et al. 2010).

Port-related effects on biodiversity in the GBR have recently received extensive media attention within Australia (Lloyd 2013, February 16) and globally (Taylor 2013, April 26). Dredging and other port activities in Gladstone have been blamed for declining water quality, dead and diseased fish, dead megafauna, human health issues and losses of shrimps and other crustaceans (Rollo 2012, June 28). Fishermen and conservationists are concerned about the recently approved expansion of Abbot Point Coal Terminal and its potential to affect local wetlands and dugong, turtle and commercial fish (ABC News 2011, October 11). The *MV Shen Neng 1*, which ran aground on a reef north-east of Gladstone in 2010, caused the largest ground scar recorded in the GBR (400 000 m^2) and deposited highly toxic anti-fouling paint onto the seabed, a common outcome of ship groundings (Marshall et al. 2002; Negri and Marshall 2009; Fig. 2). Over 600 shipping-related incidents (e.g. mechanical failures which have, or could have, resulted in ship groundings or pollution) have been recorded in the GBR region since 1987 (GBRMPA 2009), but many near-miss shipping incidents go unreported. A recent survey of pilots in the GBR found that '*the number of [shipping-related incidents] which they claimed to have experienced was about 10 times the number of reports of such events in records held by AMSA [Australian Maritime Safety Authority]*' (ATSB 2012).

Thirteen guiding principles for the improved governance of port and shipping impacts in the GBR

The current governance arrangements (e.g. regulatory, administrative and operational) are inhibiting the effective management of port and shipping impacts in the GBR. We present here 13 principles to describe a course of action to minimize the impacts of ports and shipping on biodiversity in the GBR region. Our intention in proposing guiding principles is not to replicate the Australian and Queensland strategic assessments or ports strategies. We acknowledge that the Commonwealth Government is showing leadership by transitioning from project-based to strategic environmental assessment (Commonwealth of Australia 2011). However, we believe that key issues around the transparency and rigour of the decision processes are not being addressed by the Australian or Queensland Governments. We identify major weaknesses in the current governance arrangements and provide solutions from the perspective of experts in biodiversity conservation who are primarily interested in high-quality rather than expeditious decision processes.

The principles are primarily focused on the ports governance sub-domain of coastal infrastructure planning and management (Dale et al. 2013). There are two main reasons for this focus. First, the assessment and approvals processes for new port developments suffer from the greatest weaknesses in relation to biodiversity conservation. Second, the impacts from shipping are well managed in the GBR region relative to ports. The principles derive from governance theory (*see* Dale et al. 2013) and our collective experience (> 200 years) working with the GBR management, industry and research sectors. The principles also reflect characteristics of the region, including its World Heritage status, governance arrangements, and the nature of the region's ports (bordering shallow water), shipping, and biodiversity features. The 13 principles are grouped into four broad themes: improvements to the governance system; planning, design and location of ports; assessment and decision processes for major projects; and valuing and paying for ecosystem services. The brief statement of each principle is followed by a rationale. A summary of the major weaknesses in the current governance arrangements, and solutions in the form of principles, is provided in Fig. 4.

Improvements to the governance system

<u>1. Transparent decision making ensures consistency in purpose and that development proposals are in the best interests of the wider community and the environment.</u>

There are more than 30 pieces of legislation at both the State (Queensland) and Commonwealth (Australia) levels that administer and regulate the assessment and decision processes of port developments in the GBR region. Management and environmental plans by Local Government and Port Authorities (Table 1) can also influence the approvals process. The spatial overlap between jurisdictions is complex (e.g. Fig. 3). For example, 10 of the 12 GBR ports are excluded from the GBR Marine Park but some of these remain within the World Heritage boundary, and all are within State (Queensland) waters.

This complexity of legal constraints is characterized by divergence of purpose and approach within the decision processes for major projects by State and Commonwealth Governments, especially in the administration of Environmental Impact Assessments (EIAs). EIAs for significant port developments in the GBR region are directed by the Queensland Coordinator General in the Department of State Development Infrastructure and Planning. This department is also broadly responsible for facilitating economic development and *'ensuring the management, delivery and facilitation of high priority commercial projects'*[1]*'*. The GBR Marine Park Authority's goal is the long-term protection and ecologically sustainable use of the GBR Marine Park, whilst the Commonwealth Government is focused on legal process and administering the *Environmental Protection and Biodiversity Conservation Act* 1999 (EPBC Act). These differences in expectations and needs create tension between managing authorities.

[1] http://www.dsdip.qld.gov.au/our-department/major-projects-office.html

Better alignment of purpose and approach of Governments would reduce tension between managing authorities, necessitating substantial changes to the current governance arrangements. Changing the current governance arrangements, however, would not necessarily lead to positive biodiversity outcomes if the alignment of purpose was pro-development. Instead, independent peer-review and greater stakeholder involvement within the ports governance sub-domain should be used to ensure greater impartiality and transparency in decision making processes. Greater stakeholder involvement enables consistency in decisions by ensuring consideration of the economic, social and biological consequences of development proposals in environmentally sensitive areas such as the GBR region. A transparent approach to decision making, with independent expert review, would also ensure best practice is applied if a development proceeds.

2. Active monitoring and adaptive management ensures the health of the ports and shipping governance system, with a particular emphasis on enhancing principled leadership.

A healthy governance system is vital to the effective management of the GBR region because it mediates the relationship between society's economic and social needs on one hand and biodiversity outcomes on the other. Dale et al. (2013) identified the "major project assessment" governance domain, including new ports, as at risk of failure within the overall system of GBR governance, both in terms of likelihood and potential adverse consequences. These authors also identified Queensland's current "coastal infrastructure planning" domain, again including ports, as representing a potential risk, primarily because of the lack of triggers for cumulative impact assessment. For these and other reasons, ports can be considered a risky area of governance in the GBR region. Current governance arrangements in relation to shipping in Queensland, on the other hand, are not considered at risk of failure because of effective national and international regulation (Dale et al. 2013).

Improving the effectiveness of two GBR governance domains - major project assessment and coastal infrastructure planning - could be achieved through monitoring and adaptive management. Two types of indicators used for measuring the effectiveness of governance are rule-based and outcome-based (Kaufmann and Kraay 2008). Rule-based indicators measure the appropriateness of policies, strategies and codified approaches, and outcome-based indicators measure whether the rules are being effectively implemented based on the experience of relevant stakeholders. There would be considerable value in society mobilising a cohesive, evidence-based approach, involving multiple stakeholders, to monitor the effectiveness of governance in the GBR region. Such an approach need not be expensive and could be linked to existing GBR management, research and reporting frameworks. With effective and shared leadership across multiple sectors (e.g. the State and Commonwealth Governments, Local Government, industry, ports corporations and the conservation sector), such an approach could provide the basis for continuous and reportable improvements in governance, resulting in measurable biodiversity gains.

Planning, design and location of ports

<u>3. A strategic and integrated approach to port planning maximizes biodiversity outcomes whilst maintaining efficient transport networks for industry.</u>

The location and extent of proposed port expansions at Hay Point, Townsville, Gladstone, Port Alma, Abbot Point and Bathurst Bay (Fig. 1) reflect the current demand for mining-related cargoes, as well as spatial characteristics of the region (e.g. distance to mine site). The locations also reflect the mining industry's transportation preferences and aspirations. Land-side transportation and other costs are reduced when goods are exported independently and from ports that are close to supply. However, industry-driven port planning can have poor biodiversity outcomes because many ports spread along an extensive coastline increase the spatial footprint of port and shipping related pressures (*see* Table 2 and Appendix A). Management resources in the GBR, including materials and equipment for disaster response, are dispersed and difficult to mobilise, particularly in the wet season when many roads can be impassable. Logistical difficulties and high costs also limit the ability of management and industry to respond quickly to disasters (e.g. ship grounding and spills), especially in the remote northern regions of the GBR.

Integrated planning of ports is a key part of a sustainable coastal development strategy for the entire GBR region. However, the Queensland Government's draft Ports Strategy (Queensland Government 2012b) is silent on this issue. Minimizing the impact on biodiversity via a strategic and integrated approach to port planning would require industry, port authorities, and State and Commonwealth Government agencies to work together toward transport networks that effectively manage for environmental and operational capacity (especially disaster-related), while also maintaining the efficient movement of goods to international markets. Given the present lack of coordination in planning ports, comprehensive and independent review of an integrated planning process, and reference to best practice in other countries, will be essential to ensure its adequacy.

4. The spread of contaminants is minimised by cargo-specific port and shipping infrastructure built to meet standards appropriate for a World Heritage property.

Serious problems arising from inadequate infrastructure for dangerous cargoes are evident at several ports in the GBR region. Coal dust, originating from uncovered coal trains and stockpiles, is a potential problem for human health and amenity in Gladstone (Moran 2011, January 28) and Mackay (Geiger 2013, March 1). Coal dust is also an issue for coral reefs, and it has been found far offshore from coal ports (Burns and Brinkman 2011). In Townsville, ‘black dust’ known to contain elevated lead concentrations has affected a section of the city and might originate from the port where lead, zinc, nickel and copper products are imported and exported (Johnston 2008, June 25). The dust also contaminates marine waters, contributing to higher than normal levels of metal in sediments near the port. The primary sources of contaminants in the Ports of Gladstone, Mackay and Townsville are large uncovered stockpiles which allow contamination of marine and estuarine waters via wind and runoff.

Port and shipping infrastructure that better manages cargoes according to toxicity, mobility and potential for accumulation would reduce the spread of contaminants in the GBR region. This necessitates a set of product-specific standards to minimise impacts from loss to marine and estuarine waters, in many cases requiring containment and enclosure to higher standards than currently apply. Publicly reported monitoring of contamination and rates of transfer and accumulation in marine and estuarine waters are essential to evaluate and adapt strategies for minimizing loss of transported material into GBR ecosystems.

5. Port developments that maximize biodiversity outcomes consider ecological implications early in the design process.

Ports change the local environment in multiple ways (Table 2; Appendix A). Care taken in the design of port developments determines whether they produce net negative, neutral or positive biodiversity outcomes. Port developments that maximise biodiversity outcomes: (1) minimize the exposure of species and ecosystems to potentially dangerous interactions with boats, equipment, pollution, and transported products (e.g. Kamrowski et al. 2012); and, (2) maintain ecosystems as close as possible to functioning natural environments by including innovative design elements. Such considerations have not always been part of previous port developments globally (Feary et al. 2011) or in the GBR region. Examples of innovative design elements that maximise biodiversity outcomes in ports are: intertidal pools, light mitigation, use of appropriate materials, and provision of surfaces with appropriate structural complexity, shape and orientation. Positive biodiversity outcomes can also be achieved by including purpose-built structures to mitigate altered ecosystem functions or species impacts (e.g. Paalvast et al. 2012). Such considerations need to be made early in the design process before the design of port developments in the GBR region become too advanced and decisions become irreversible.

Assessment and decision processes for major projects

6. Clarifying the legal basis for Commonwealth Government intervention provides certainty for investors and minimizes the overall risk to biodiversity.

The Commonwealth *Environmental Protection and Biodiversity Conservation Act* 1999 (EPBC Act) requires the Federal (Australian) Environment Minister's approval for any action that has, will have, or is likely to have a significant impact on a Matter of National Environmental Significance[2]. The *Significant Impact Guidelines* (Commonwealth of Australia 2009a) indicate that all port developments in the GBR region, including the expansion of an existing port, and dredging, are likely to have a significant impact on at least one MNES, including listed threatened species, migratory species listed under international conventions,

[2] http://www.environment.gov.au/epbc/protect/index.html

Ramsar listed wetlands, the GBR World Heritage Area, and the GBR Marine Park (Fig. 3). Although the *Significant Impact Guidelines* outline substantive criteria for MNES, they are silent on three important questions (Table 3): (1) how should the significance of actions that affect individual matters qualifying under more than one of the MNES criteria be considered?; (2) how should actions that have (a) significant or (b) less than significant impact on multiple MNES be considered?; and, (3) how should the cumulative impacts (Fig. 5) on MNES of multiple ports actions at multiple sites be considered, especially for mobile and migratory species that use different habitats at different life stages? We consider that the both the generic and species specific *Significant Impact Guidelines* should be revised to resolve such questions. Resolving these questions would provide an opportunity for Commonwealth Government intervention that enables the overall risk to biodiversity to be minimised. It would also provide clarity to port operators and developers on the legal basis for Commonwealth intervention.

<u>7. Independent quality control and peer review increases transparency and rigour in the development and interpretation of Environmental Impact Assessments (EIAs).</u>

EIAs integrate environmental management with planning for development proposals and are a key component of decision processes. EIAs are typically developed by environmental consultants on behalf of development proponents (e.g. Port Authorities). Environmental consultants are selected by proponents through a competitive process that often results in the letting of tenders to the lowest bidder deemed capable of meeting the legislative requirements of the EIA. Environmental consultants know that their chances of being awarded future work will be reduced if they are too conscientious in highlighting problems with a development that has support from a Port Authority and Government. In addition, Government regulators set the conditions for EIAs via Terms of Reference, and then judge the responses from consultants themselves. There is substantial expertise within all levels of Government and within the environment consulting companies in Australia, but no guarantee that this expertise will influence outcomes or be incorporated into decision making processes to minimize impacts of ports on biodiversity. Government and engaged environmental consultants are insiders in the decision making process and not impartial, so the EIA process involves considerable conflict of interest.

A mandatory, independent, peer-review process for EIAs and the development of Terms of Reference would provide Governments with unfiltered advice that is technically informed and would encourage transparency, separate EIAs from conflicts of interest, and increase public confidence. An independent peer-review process also enables the assessment of the technical adequacy of EIAs, including data quality, statistical design, consistency, and implications, and would ensure appropriate baselines and controls.

8. Data sharing enables the effective monitoring of biodiversity over the appropriate spatial and temporal scales.

EIAs require the collection of baseline data during or preceding the approval of port developments to support the design of monitoring programs for environmental compliance. However, baseline and monitoring data associated with EIAs are seldom required to be publicly available or independently peer-reviewed, with ownership of the data typically residing with the corporation that paid for their collection. Commercial and competitive forces further restrict the sharing of data. Limited data sharing can result in: (1) duplicative and redundant collection of data by proponents seeking to develop port facilities; and (2) the inability to capitalise on data and understanding from previous assessments, including repeating of mistakes and omissions. Limited data sharing and differing data collection methods across EIAs also result in data sets that are fragmented or incompatible and of limited wider or subsequent use.

Integrated research and monitoring programs that are not bound by the constraints of individual projects or agencies provide an avenue for the collection and sharing of data on biodiversity and impacts of wide relevance (e.g. Masini et al. 2011). Integrated monitoring programs could be established with support from, and in consultation with, scientific, Government and industry stakeholders, and independent peer-review. The aim would be to agree on key areas and/or species requiring collection of long-term, robust and consistent data relevant to planned and future port developments. Appropriate baseline data often take several years to collect. Sharing of information is therefore a cost-effective mechanism for proponents seeking approval under EIA. In line with the current requirements for independent scientists undertaking research at Government institutions, baseline and monitoring data associated with EIAs should be viewed as public property rather than the property of proponents, thus enabling the sharing of information across ports and other stakeholders.

9. Independent and enforceable policies that detail best-practice approaches to baseline data collection and monitoring increase both the capacity of proponents and Government and scientific rigour.

Baseline data and powerfully designed and executed monitoring programs are integral for avoiding and/or mitigating impacts during the construction and operation of ports. However, there are very few Commonwealth guidelines related to significant impacts or referrals that provide advice to proponents and Government on the appropriate collection of baseline and monitoring data of nationally listed species within the GBR region[3]. Other policies and guidelines for the monitoring of features (e.g. species, habitats) and impacts (e.g. Commonwealth of Australia 2009b) exist, but are, by their very nature, guidelines that encompass a high degree of flexibility in application. Moreover, there is little or no penalty if, for example, EIAs are later shown to be wrong. The lack of guidelines and enforceable policy can result in data collection that: (1) has inadequate baselines and insufficient statistical power; (2) fails to identify relevant data or wastes effort collecting data of little relevance to management or assessment of impacts; and, (3) has inconsistent design, reporting and interpretation of results.

Increasing the number of policies and guidelines, especially for MNES and port-related impacts, could be achieved via the independent development of documentation that describes the best-practice collection of baseline and monitoring data. Experts across a range of disciplines could provide input into the development of such guidelines, in collaboration with the relevant Government agencies, industries and stakeholders. Independent guidelines would serve two important purposes. First, they would assist proponents in the design of effective baseline and monitoring programmes for both biodiversity features and impacts. Second, they would increase the capacity of Government regulators to judge the adequacy of data collection programmes.

[3] http://www.environment.gov.au/epbc/guidelines-policies.html

Enforcing the guidelines via the development of conditions, sanctions or penalties would also increase the likelihood that baseline and monitoring programmes are of a high standard.

10. Making uncertainties explicit enables their effective consideration in the assessment and decision processes and in adaptive management.

There are many uncertainties associated with the impacts of ports on biodiversity in the GBR. Even in this well studied region, there is limited spatio-temporal information on the distribution, status and trends of species, ecosystems, and ecological processes. Few empirical studies have quantified the effects of ports on these matters. Interactions between multiple pressures and the resultant cumulative impacts on species, habitats and ecological processes are largely unknown (Grech et al. 2011). Because of these uncertainties, stakeholders, industries and regulators are limited in their ability to make informed planning decisions. For example, uncertainties around the impacts of ports on ecological processes make it difficult to determine the relative effects on biodiversity of a few large versus many small ports, and the appropriate spatial locations of port developments. For two reasons, these uncertainties are unlikely to be resolved in the short- to medium-terms: (1) lack of attention by regulatory agencies to cumulative impacts of ports (Dale et al. 2013); and, (2) unprecedented growth in Queensland's industrial and mining sector creating demand for rapid expansions of ports in the GBR region. The extent to which pressures from ports threaten the integrity of the GBR therefore largely depends on how these uncertainties are managed by Government, industry and stakeholders.

Requiring EIAs to be explicit about uncertainties would enable their effective consideration in the assessment and approvals process. Governments could then define a level at which uncertainty about the potential extent of adverse impacts prevents port developments occurring in their proposed form. Managing for uncertainties cannot be done adequately at one point in time such as prior to approval, but should continue throughout the construction phase and operational life of a port development, involving active adaptive management to find and interpret new or better information on environmental impacts.

11. Cumulative impact assessments are effective for understanding the combined effects of port developments when they address the impacts of past, present and future actions at appropriate spatial and temporal scales.

The impacts of individual ports and related shipping activities on biodiversity features, even for individual pressures (Table 2 and Appendix A), are often poorly assessed. The situation is compounded for the assessment of cumulative impacts, where one or more actions generate multiple, interacting pressures (Fig. 5). For example, a voluntary cumulative impact assessment conducted by several proponents at the Port of Abbot Point[4] was the first of its kind in the GBR region. While the voluntary nature of the assessment is commendable, its scope was inadequate to assess the cumulative impact of the port development. The assessment did not quantify the relative magnitude of pressures or the potential interactions between multiple pressures. The assessment also failed to consider the cumulative effects of the proposed developments in combination with other past, present, and future port actions in the GBR region and non-port pressures, such as fishing, marine rubbish and agriculture. In Fig. 5, we locate the Port of Abbot Point exercise conceptually relative to what could be achieved in a cumulative impact assessment. Fig. 5 also illustrates the scope of assessments that are currently required for individual port developments. The fact that cumulative impact assessments are not required as standard practice and that clear guidelines do not exist for such assessments indicate regulatory inadequacy at multiple levels of Government. Comprehensive cumulative impact assessments across the entire GBR region are the only mechanisms available to understand the actual effects on biodiversity of each new port development.

Valuing and paying for ecosystem services

12. Offset programmes to counter the effect of port developments require high-level strategic design by Government and peer-review.

The primary objective of the assessment and decision processes are to ensure that significant effects on biodiversity features are avoided by proposed actions (e.g. Commonwealth

[4] http://www.nqbp.com.au/abbot-point/

of Australia 2009b). Where impacts cannot be avoided, proponents must demonstrate that significant effects are minimised by impact mitigation measures. However, most port developments produce residual impacts after avoidance and mitigation steps have been taken, necessitating environmental offsets under offsets policies in Queensland[5] (State; currently under review) and the Commonwealth (Commonwealth of Australia 2012). The Commonwealth Government is providing leadership by requiring offsets to result in net conservation gains and be at least 90% direct. Direct offsets are intended to improve conservation outcomes for the impacted species, habitat and/or ecosystem. Direct offsets are, however, generally land-based and counterbalance biodiversity loss by offsite restoration and rehabilitation measures, with potential problems related to, among other issues, temporal gaps in available habitat for species (Bekessy et al. 2010). For the marine environment, uncertainty remains in the Commonwealth Government policy on the meaning of net conservation gain and what constitutes a direct offset. Coastal ecosystems are complex, creating uncertainty around the conservation actions that lead to an effective outcome from offsets and how that outcome should be measured.

Overcoming some of the uncertainties associated with the current offsets policies could be achieved through: (1) clarification of the terms “net conservation gain” and “direct offset” in the marine domain; and, (2) an offsets programme that is measurable and monitored transparently by Government with peer-review and public disclosure. Government should be responsible for the high-level strategic design of when, where, and how offset funds are used. However, funds need to be managed externally and implemented by independent specialists following peer-review to increase transparency and objectivity, and minimize the risk of Government becoming reliant on offset funds and thus influencing regulatory decisions. For example, the Commonwealth Government has proposed that the Great Barrier Reef Marine Park Authority would receive $2-4 million in direct payments for environmental offsets from coastal developments, potentially creating a serious conflict of interest for the Authority. Both independence of regulators and outcomes for biodiversity would benefit from the establishment of a strategic offset fund whereby major offset projects that promise large benefits can be accommodated by combining multiple offsets from different projects (e.g. multiple liquefied natural gas plants in Gladstone). An effective offsets programme would also allow for the

[5] http://www.ehp.qld.gov.au/management/environmental-offsets/environmental-offsets.html

implementation of: (1) conservation actions in areas where realistic biodiversity outcomes can be achieved, regardless of whether the area is within or adjacent to a port site; and, (2) indirect offsets that include support for appropriate research, but with realistic expectations of enhancing and protecting the biodiversity asset that is lost.

13. Transparent financial liabilities that are the responsibility of industry provide security in the face of unplanned impacts on biodiversity.

Offsets, at least in principle, are used for impacts that cannot be avoided or mitigated, but ports can adversely affect biodiversity features in unplanned ways, such as the spread of dredge plumes to a greater area then predicted by modelling. There is no requirement for industry to assess the mitigation costs of unplanned impacts. This can lead to financial burden on both industry and Government (and therefore the public) when unplanned impacts occur. A potential mechanism to cover the cost of unplanned impacts would be for the relevant Government to require a financial bond from the port industry. The bond concept has many precedents in Australia, including the shipping industry. The Protection of the Sea Levy, administered by the Australian Maritime Safety Authority, requires vessels greater than 24 metres in length to pay a fee based on the amount of oil carried as fuel or cargo. The levy funds the National Plan for Maritime Environmental Emergencies and is also used to pay for clean-up costs which cannot be attributed to a known source. An example of the bond concept applicable to the port industry is the Queensland mining permit, which requires a company to invest in a Government fund for use if the company fails to conduct adequate rehabilitation.

Conclusions

The decline of biodiversity within the GBR region can be attributed to a long-history of human activities, to which recent port developments have been added. Serious weaknesses in the current governance arrangements, especially the assessment process, are inhibiting the effective management of biodiversity impacts. The current pace of growth in port developments and shipping activity are unprecedented, resulting in insufficient attention being paid to their incremental and cumulative impacts. The guiding principles we present describe governance improvements that focus attention on minimizing the biodiversity impacts of ports and shipping. The principles are primarily concerned with ensuring a transparent, open and scientifically robust decision-making process that adequately addresses uncertainties. Implementing the principles would require independent peer-review to oversee the assessment and decision processes for port developments, and ensure high standards of data for EIAs and monitoring programmes.

We acknowledge that a limitation of our paper is that we have not conducted a systematic evaluation of the costs and benefits of implementing these guiding principles. Implementing the principles would come at a cost, but the previous approach of minimizing costs to industry and regulators has led to accumulated damage to GBR species and ecosystems that could soon undermine the region's World Heritage status. The cost of implementing our proposed principles will have large benefits for the GBR. Our principles can also result in substantial savings in the long term because mimimizing initial impacts is much cheaper than repair, which often comes with the additional financial burden of compensation for damage. Strategies for mimimizing the impacts of ports on the GBR would also place the financial responsibility for port developments appropriately on proponents, whereas the costs of repair have tended to fall to governments and therefore the public. The principles should not require substantial change to the current regulatory framework or a consequent increase in 'green-tape'(Powell 2012, May 29). Rather, the principles would streamline and improve the decision-making process by, for example, using independent peer review to identify the critical components that require attention.

We suggest that an evaluation of the biodiversity outcomes arising from application of our guiding principles (e.g. *Principle 3*) compared with a 'business as usual' approach could be achieved using scenario analysis and ecological forecasting. Scenario analysis is a process informed by expert opinion to elicit and explore alternative possible futures (e.g. Bohensky et al. 2011). Scenario exercises improve our understanding of the potential state of GBR region in the future by investigating the range of uncertainty in biodiversity outcomes of multiple management decisions. Ecological forecasting combines scenario analysis with field observations and statistical models to quantify the state of biodiversity, with fully specified uncertainties (Clark et al. 2001). The time scale and spatial extent of ecological forecasting required to evaluate the impacts of ports and shipping in the GBR would need to extend up to 25 years and range from individual ports to the entire GBR to effectively inform management decisions. Robust ecological forecasts would require Government and research institutions to prioritise the support of: (1) integrated programs for collection of data across multiple temporal and spatial scales; and, (2) experimental research to identify critical thresholds and the effects of individual and cumulative pressures on biodiversity features and processes. Scenario analysis and ecological forecasting provide the information required to solve important management questions, such as the biodiversity benefits of fewer, larger ports versus many small ports.

We focus on the impacts of ports and shipping activities on biodiversity in the GBR region. However, the decisions made about new port developments in Queensland potentially have an impact on biodiversity around the world. The increase in shipping to Queensland's ports exerts pressure on sensitive reef areas in neighbouring counties, particularly in the complex shipping routes around Papua New Guinea. The National Maritime Safety Authority of Papua New Guinea has instigated a threat and risk assessment program for these shipping lanes due to concerns over the increase in shipping in their waters. These shipping routes currently have far fewer controls on transiting ships than the Torres Strait and GBR (Fig. 1), with no compulsory pilotage or declaration of a Particularly Sensitive Sea Area. The Australian Maritime Safety Authority is working with the Papua New Guinea Government to address these issues in their waters. The carbon emissions from ports, port-associated industry and shipping within the GBR region are contributing to global climate change, a significant current and future threat to coral reefs globally (Hoegh-Guldberg et al. 2007). Australia has one of the highest per capita emissions of carbon dioxide because there is no requirement for carbon capture and storage of greenhouse gas emissions derived from Australian coal exports. However, falling coal prices, higher production costs and the decline in coal demand globally (Parker 2012, December 5) could result in a reduction in greenhouse gas emissions and reduce the rate of port development in the GBR region (e.g. the deferred expansion of Abbot Point; Fraser 2012, May 19).

The Queensland and Commonwealth Governments have international responsibilities under the World Heritage Convention to conserve the GBR by ensuring ports and shipping do not affect the integrity of the World Heritage property. The guiding principles in this paper are our attempt to assist Queensland and Australia in meeting their responsibilities by overcoming weaknesses in the current process of decision making. Implementing the principles would increase the capacity of decision makers to adequately assess the impacts of ports and shipping at the current rapid pace of expansion (Douvere and Badman 2012), and provide certainty and clarity to port operators, developers, and affected stakeholders. A ‘business as usual’ approach that does not directly address the concerns of the World Heritage Committee and others, could eventually lead to the GBR’s inclusion on the List of World Heritage in Danger in 2014 (World Heritage Centre 2013). Ultimately, the future of the GBR will be determined by whether or not there is a political will to make decisions that prioritise the protection of biodiversity and World Heritage responsibilities over economic development. Considering that Australia is one of the world's most wealthy and politically stable countries, the Australian response to the concerns of the World Heritage Committee could signal the likelihood that globally significant biodiversity will be a priority for other countries.

Appendix A: Categorization of pressures from ports and shipping in the Great Barrier Reef region.

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Figure 1 (Colour Web and in print): Locations of minor, medium and major ports and designated shipping areas and channels within and adjacent to the Great Barrier Reef (GBR) region. The rail transport network and mineral and coal provinces of Queensland are also shown. The GBR region encompasses the entire World Heritage Area, GBR Marine Park and coastal waters adjacent to the Queensland coast. The ports of Weipa, Bundaberg and Brisbane lie outside the GBR region, but are shown for context.

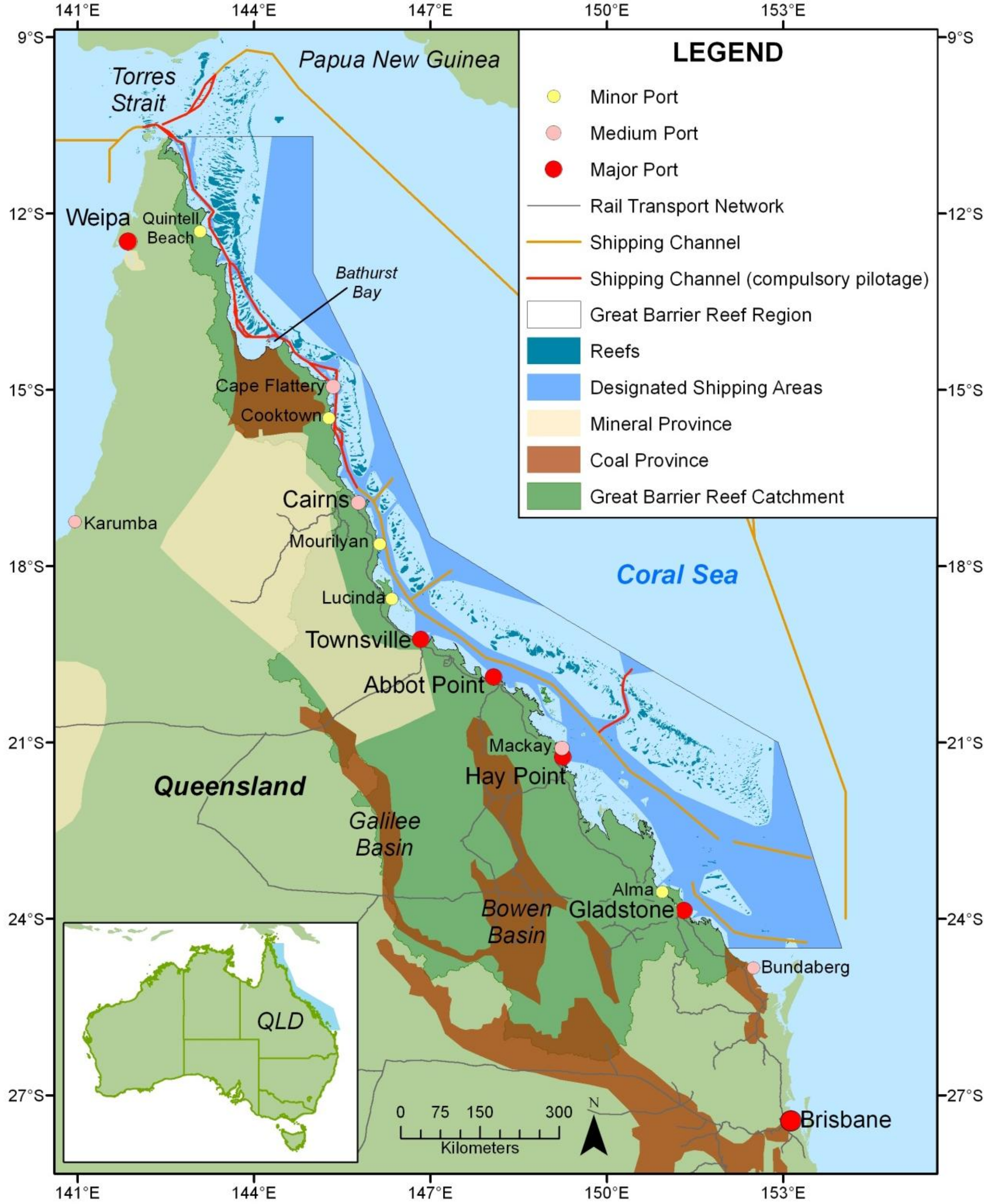


Figure 2 (Colour Web and in print): Images of ports and shipping on the Great Barrier Reef coast. **(**A) Dredging operations at Port of Gladstone. (B) Coal loading and storage facilities at the Port of Hay Point, near Mackay. (C) Propeller and vessel movement causing turbulence, suspended sediments, and loss of light. (D) Proposed site of port expansion in the Fitzroy Basin (Port Alma) inundated during a king tide, January 2013. (E) The *MV Sheng Neng 1* which ran aground on a coral reef east of Rockhampton, while en route from Gladstone, April 2010. (F) Seagrass habitats and dugong feeding trails adjacent to coal loading facility at the Port of Gladstone.

Figure 3 (Colour Web and black-and-white in print): An example of the complex spatial overlap between local, State and Commonwealth (Australian Government) jurisdictions that administer and regulate port developments in the Great Barrier Reef (GBR) region. The map is centred on the Port of Townsville and associated shipping lanes. The Queensland (State) Coordinator General's Department is currently overseeing the Environmental Impact Assessment (EIA) process of the Townsville Port expansion. The expansion will potentially have significant impacts on many Matters of National Environmental Significance (including the GBR World Heritage Area), and therefore requires approval from the Federal (Australian) Environment Minister. The Port of Townsville falls outside the boundary of the GBR Marine Park, and the dredge spoil grounds do not require a permit from the GBR Marine Park Authority (a Commonwealth Statutory Authority). The disposal of dredge material outside the port limits and within the GBR Marine Park, however, would require a permit. The Townsville City Council and Queensland Government regulate commercial waste derived from port facilities.

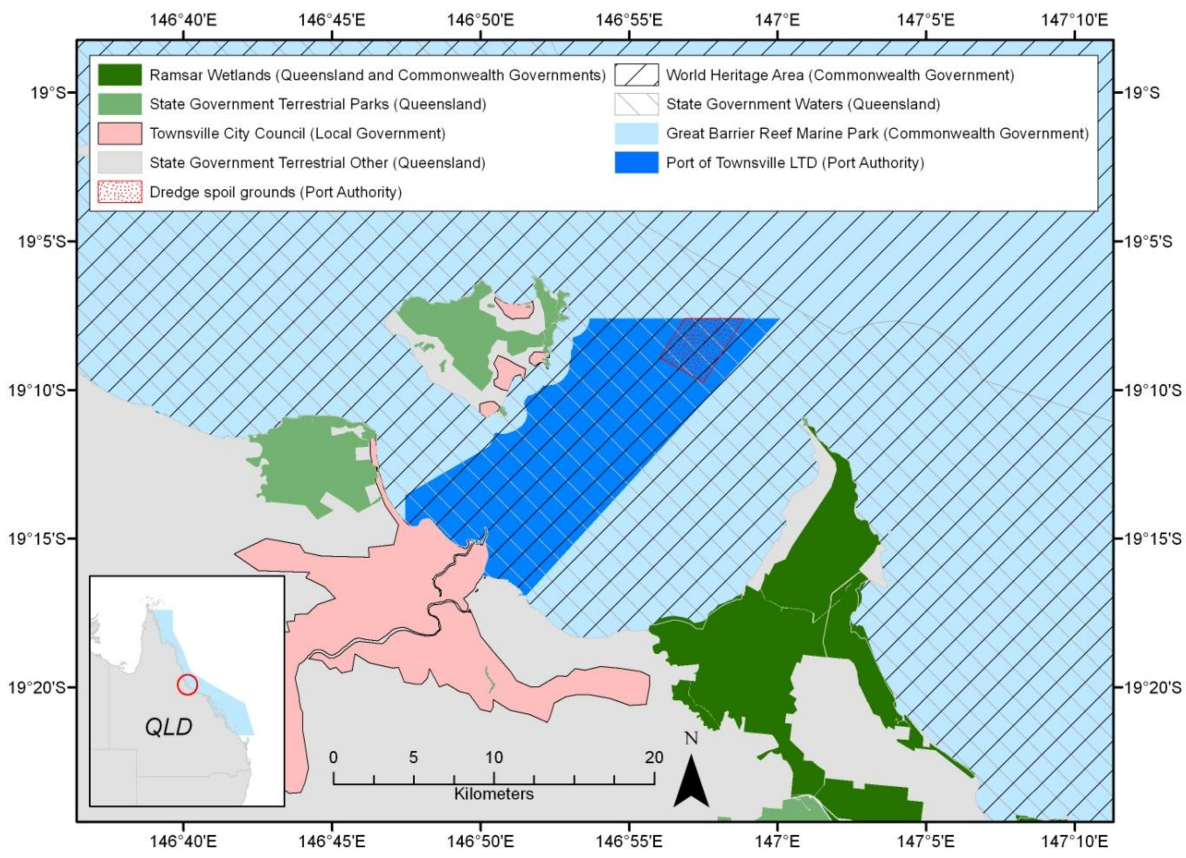


Figure 4 (Black-and-white Web and print): Summary of the major weaknesses in the current governance arrangements of ports and shipping in the Great Barrier Reef (GBR) region, and the associated guiding principles identified in this paper. The weaknesses and principles are separated into three groups: strategic issues, existing operations (or day-to-day management) and new port actions (development proposals). EIA indicates Environmental Impact Assessment and CIA indicates cumulative impact assessment.

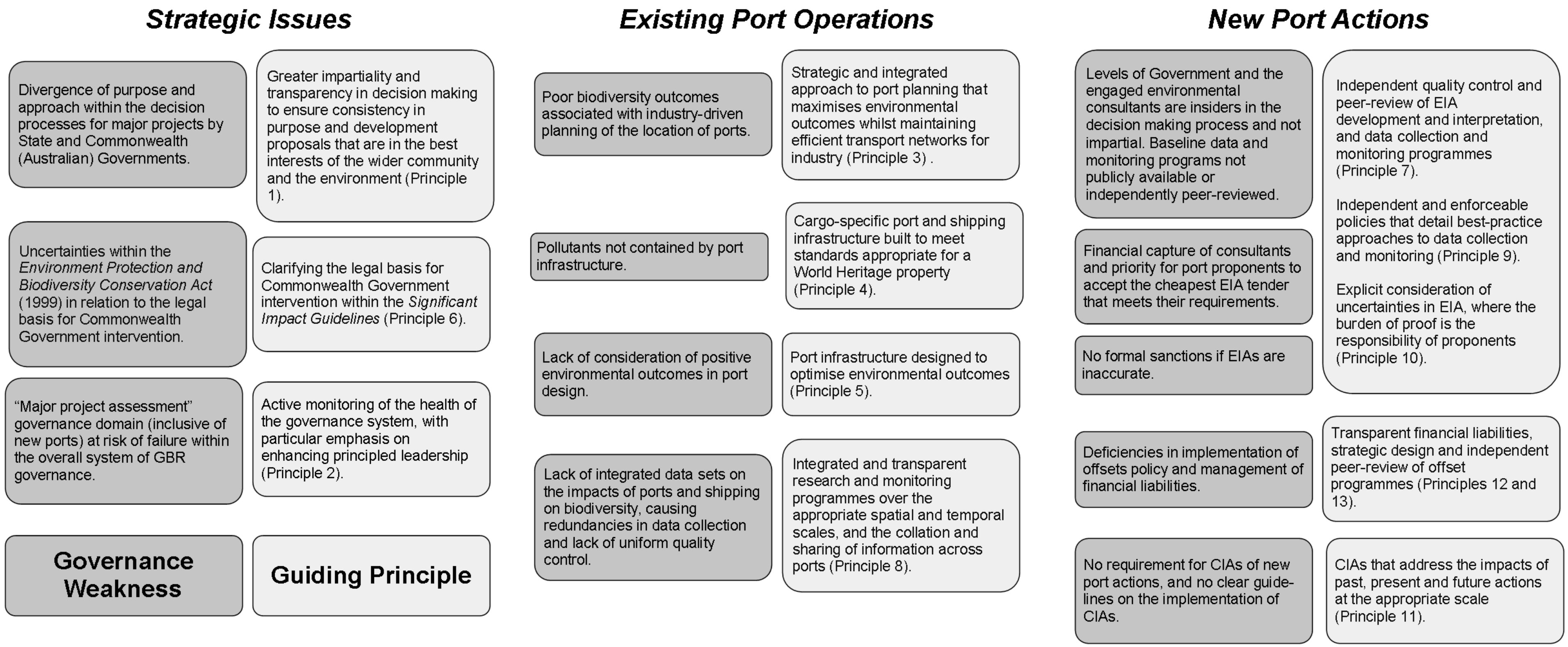
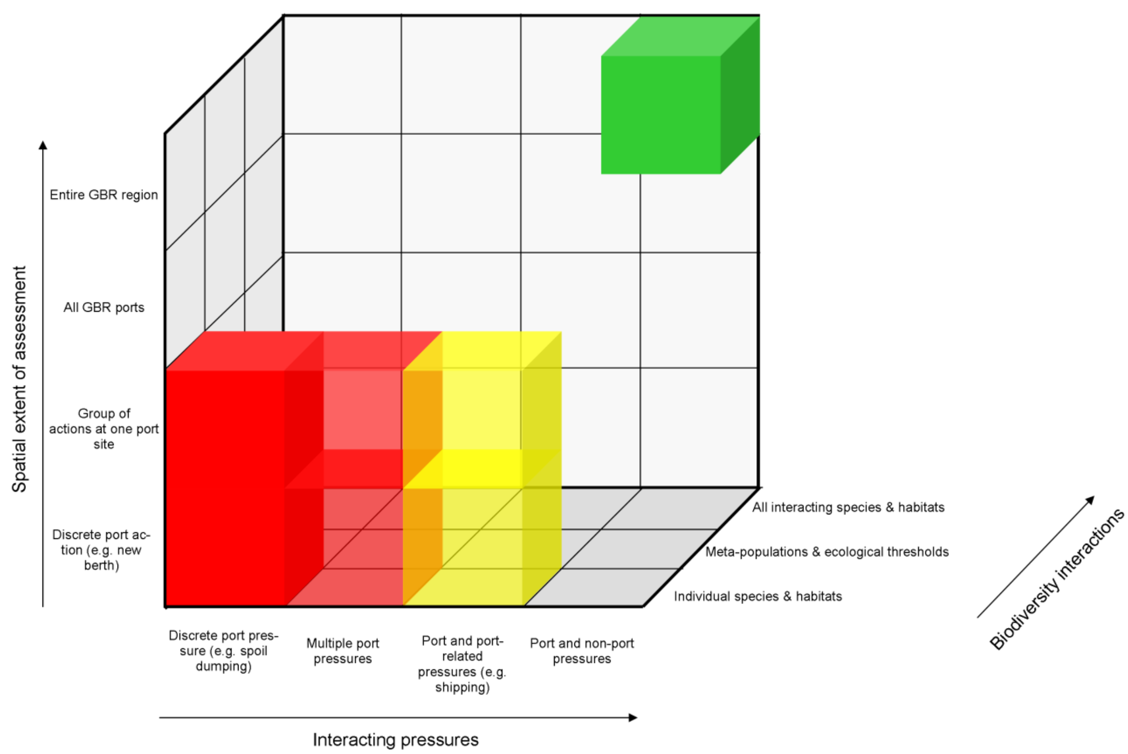


Figure 5 (Colour Web and in print): Conceptual representation of cumulative impact assessments. Queensland and Commonwealth (Australian) Environmental Impact Assessments (EIAs), shown in red, focus on impacts on individual habitats or populations of individual species that are caused by discrete port actions (e.g. new berth or maintenance dredging) or a group of actions at one port site. Although multiple pressures are included in EIAs, the interactions between these pressures have not been considered (and hence are shown as transparent in the figure). The voluntary cumulative impact assessment conducted by several proponents at the Port of Abbot Point (yellow) included a discussion on potential interactions between port and port-related pressures. However, this assessment did not quantify the relative magnitude of pressures or the additive, synergistic or antagonistic interactions between them (and hence is shown as transparent in the figure). A comprehensive cumulative impact assessment (green) would consider the entire GBR region (vertical axis) and the interacting pressures of proposed port actions in relation to past, present and future actions, both related and unrelated to ports (horizontal axis). The three levels of biodiversity interactions refer to: (1) species-by-species or ecosystem-by-ecosystem assessments; (2) meta-populations of directly affected species and ecological thresholds related to progressive attrition of directly affected ecosystems; and (3) physical and ecological interactions between species and ecosystems that are directly and indirectly affected. A comprehensive cumulative impact assessment would also consider this third level of interaction.



			Throughput (tonnes)			Proportion (%) of total throughput by commodity										
Port Authority	**Port**	**Total Vessels**	*Export*	*Import*	*Total*	*Coal*	*Bauxite*	*Nickel ore*	*Alumina*	*Lead and zinc concentrates*	*Ammonium nitrate*	*Oil and petroleum*	*Sugar*	*General cargo*	*Silica sand*	*Other*
Gladstone Ports Corporation LTD	Gladstone	1316	594 340	169 707	764 047	70	18	-	5	-	-	1	-	-	-	7
	Alma	78	1 415	1 820	3 235	-	-	-	-	-	53	21	-	-	-	26
North Queensland Bulk Ports Corporation LTD	Hay Point	892	878 052	0	878 052	100	-	-	-	-	-	-	-	-	-	-
	Mackay	175	13 949	11 571	25 520	-	-	-	-	-	-	41	35	-	-	24
	Abbot Point	190	150 639	0	150 639	100	-	-	-	-	-	-	-	-	-	-
Port of Townsville LTD	Townsville	732	47 251	58 761	106 011	-	-	35	-	14	-	9	9	3	-	31
	Lucinda	12	4 165	41	4 206	-	-	-	-	-	-	-	96	4	-	
Far North Queensland Ports Corporation LTD	Mourilyan	25	5 071	0	5 071	-	-	-	-	-	-	-	86		-	14
	Cairns	712	3 973	6 279	10 253	-	-	-	-	-	-	52	19	20	-	9
	Cooktown	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-
	Cape Flattery	39	20 261	0	20 261	-	-	-	-	-	-	-	-		100	-
	Quintell Beach	15	0	14	14	-	-	-	-	-	-	-	-	100	-	-

Table 1: Vessel and trade statistics for the 12 ports of the Great Barrier Reef (GBR) region (Fig. 1) in the 2010/11 financial year, including export, import and total throughput (tonnes) and the proportion (%) of total throughput by commodity (Queensland Transport and Main Roads 2012). The primary export commodity of the three largest ports (Gladstone, Hay Point, and Abbot Point) was coal. The Ports of Weipa, Brisbane and Bundaberg are not included in the table because they lie outside the GBR region.

Pressure category	**Pressure type**
Physical loss	Removal of sediment and associated benthic organisms during dredging operations
	Smothering caused by deposition of dredged material on spoil dumping areas
	Coastal erosion due to changes in hydrodynamics caused by port infrastructure (e.g. groynes)
	Direct loss of habitat caused by port infrastructure development (e.g. reclamation)
Physical damage	Damage to habitats caused by the eroding, scouring and smothering by marine rubbish
	Physical damage caused by the impacts of vessels and anchors with bottom/benthic habitats
	Propeller and ship movements causing turbulence, resulting in abrasion and scars on bottom/benthic habitats
Toxic contamination	Bottom disturbance causing remobilization of synthetic contaminants (e.g. antifoulants), hydrocarbons and heavy metals from bottom sediments
	Contamination caused by the release of synthetic contaminants, hydrocarbons, coal dust and heavy metals from storage facilities on both land and on ships and during transfer
	Contamination caused by the release of synthetic compounds associated with vessels (e.g. antifoulants) and their cargoes
	Discharge of oil from ships, boats and dredging equipment during both normal operations and shipping accidents
Non-toxic contamination	Dredging operations, propeller and ship movement causing turbulence, suspended sediments and loss of light
Biological disturbance	Bycatch of non-benthic species during dredging operations
	Introduction of non-native species via dredge equipment, construction equipment, marine rubbish, ballast water, cargoes, fouling, marine rubbish and cooling systems
	Entanglement and ingestion of marine rubbish by species
	Injury and/or death of biota from collisions with vessels
Non-physical disturbance	Above-water noise pollution generated by equipment during dredging operations, port construction and operation, and vessels
	Underwater noise pollution generated by equipment during dredging operations, port construction and operation, and vessels
	Light pollution caused by artificial lighting associated with dredging equipment, port infrastructure, and vessels
Climate-change disturbance	Carbon dioxide emissions causing increases in greenhouse gases

Table 2: Summary of pressures on biodiversity arising from ports and shipping. Appendix A defines each pressure type and indicates its frequency, spatial extent, and impacts on biodiversity in the Great Barrier Reef region.

	Problem	Unresolved matter
1	Some actions damage features of the Great Barrier Reef region that qualifies as MNES under several criteria e.g. reclaiming a marine turtle nesting beach in the Great Barrier Reef World Heritage Area would adversely impact, an endangered species, a migratory species, and an explicit World Heritage Value.	How should the significance of an action that affects a matter that qualifies as a MNES under more than one criterion be considered?
2	Port developments can simultaneously effect several MNES (e.g. reduce the population of one or more listed threatened and/or migratory species, modify the area of a Ramsar listed wetland, damage one or more World Heritage Values by reducing the diversity or modifying the composition of plant or animal species).	How should developments that have (a) significant or (b) less than significant impact on multiple MNES be considered?
3	There is uncertainty about the spatial scale at which cumulative impacts of ports on one or more MNES should be considered.	How should the cumulative impact of multiple ports on MNES be considered, especially for mobile and migratory species that may use different habitats at different life stages?

Table 3: Under the Commonwealth (Australian) *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act), an action will require approval from the Federal minister of environment if it will have or is likely to have an effect on a Matter of National Environmental Significance (MNES). Port developments in the Great Barrier Reef region inevitably affect several MNES. However, policy is silent on the matters outlined in this Table, leaving key issues unresolved and potentially leading to decisions that are not in the best interests of biodiversity conservation.

Appendix A

Categorization of pressures from ports and shipping in the Great Barrier Reef region

A best-practice approach to classifying effects of human activities is to translate activities into their ecosystem-specific pressure types (e.g. Eastwood et al. 2008). Grouping activities into generic pressures recognizes that biodiversity features respond to the effects of individual activities through the pressures they exert (e.g. abrasion, smothering, extraction; Foden et al. 2011). The tables below apply this classification system to three broad kinds of activities associated with ports and shipping in the Great Barrier Reef (GBR) region: dredging and spoil dumping; port infrastructure; and, shipping and port-related boat traffic.

Dredging and spoil dumping: Dredging activities include the direct removal of bottom sediments and material placement (spoil dumping). Dredging occurs within port limits and in adjacent shipping lanes. Spoil dumping occurs within port limits and adjacent to ports and shipping lanes. Dredged material can be used for land reclamation or other purposes. Capital dredging occurs during the construction phase of ports, and maintenance dredging during port operation.

Port infrastructure: Port infrastructure includes the constructions required for the storing and transfer of cargo, e.g. wharves, general cargo and bulk berths, cargo transfer facilities (e.g. gantry crane), storage facilities (e.g. silos), pipelines and groynes to protect structures and loading areas.

Shipping and port-related boat traffic: Shipping and port-related boat traffic includes the processes of transporting cargo by sea with container vessels and associated small vessels (e.g. tug and patrol boats) that aid in the movement of container vessels and cargo.

Table key

Pressure category: Broad categories of pressure types exerted by dredging and spoil dumping, port infrastructure and shipping and port-related boat traffic.

Pressure type: Ecosystem-specific pressure type exerted by dredging and spoil dumping, port infrastructure and shipping and port-related boat traffic.

Definition: Detailed explanation of the pressure type.

Frequency: The rate of recurrence of the pressure event (frequently / occasionally / rare / never).

Spatial extent: The average area over which a pressure event occurs. Pressure events that are very small equate to a spatial extent of impact < 1 km^2; small 1 - 10 km^2; medium 10 - 100 km^2; large 100 – 10,000 km^2; very large > 10,000 km^2; and, global.

Biodiversity features affected: The broad category(ies) of species and/or habitats that are primarily affected by the pressure type, and specific examples.

References: Examples from the literature demonstrating causal relationships between pressure type and biodiversity impact. References from the GBR region are identified with *.

Dredging and spoil dumping

Pressure Category	*Pressure Type*	*Definition*	*Frequency*	*Spatial extent*	*Biodiversity features affected*	*References*
Physical loss	Extraction	Removal of sediment and associated benthic organisms during dredging operation.	Capital - Occasionally Maintenance - Frequently	Very small - Small	Benthic communities and processes e.g. sponge gardens, coral reefs and seagrass habitats.	Andrews et al. (2006)* Ellison (1999) Erftemeijer et al. (2006) Esslemont et al. (2004)* Foster et al. (2010) Pringle (1989)* Rasheed and Balchand (2001) Rogers (1990) Smith et al. (2006) Smith et al. (2007)*
	Smothering	Smothering of bottom caused by deposition of dredged material on spoil dumping areas.		Very small - Small		
Physical damage	Siltation	Increased concentration of suspended sediment and accumulation of fine sediments as a result of the dredging plume.		Medium - Large		
Non-toxic contamination	Turbidity	Dredging operations causing turbulence, suspended sediments and loss of light.		Medium	Photodependent and filter feeding organisms, habitats and processes e.g. seagrass habitats and coral reefs.	
Toxic contamination	Introduction of synthetic compounds	Bottom disturbance causing remobilisation of synthetic contaminants (e.g. antifoulants).	Occasionally - Frequently	Small - Medium	Benthic and nektonic communities and processes e.g. invertebrates and fish.	Esslemont et al. (2004)* Greenpeace (2012)* Rasheed and Balchand (2001) Roberts (2012) Smith et al. (2006) Smith et al. (2007)*
	Introduction of non-synthetic compounds	Discharge of oil from dredging equipment; bottom disturbance causing remobilisation of hydrocarbons and heavy metals.	Rare - Frequently	Medium	Biota sensitive to oil contamination and heavy metals e.g. seabirds	
Biological disturbance	Bycatch	Bycatch of non-benthic species during dredging operations.	Rare	Very small - Small	Nektonic species e.g. marine turtles.	Guinea (2007)
	Introduction of non-native species	Introduction of non-native species via dredge equipment.	Rare	Small - Large	Benthic and nektonic communities and processes e.g. native molluscs.	Hayes et al. (2005)
Non-physical disturbance	Above-and sub-surface water noise	Noise pollution generated by equipment during dredging operations.	Capital - Occasionally Maintenance - Frequently	Medium - Large	Species sensitive to noise and reliant on underwater vocalisation e.g. coastal dolphins and seabirds.	Ellison et al. (2012) McKenna et al. (2012)
	Illumination	Light pollution caused by artificial lighting associated with dredging equipment.		Medium - Large	Light sensitive biota e.g. marine turtles.	Kamrowski et al. (2012)* Salmon (2003)
Climate-change disturbance	Various	Carbon dioxide emissions from dredging equipment causing increases in greenhouse gases.		Global	All aspects of ecosystem can be affected ultimately.	GBRMPA (2009)* Johnson and Marshall (2007)* OECD (2011)

Port infrastructure

Pressure Category	*Pressure Type*	*Definition*	*Frequency*	*Spatial extent*	*Biodiversity features affected*	*References*
Physical loss	Coastal erosion	Coastal erosion due to changes in hydrodynamics caused by port infrastructure (e.g. groynes) and the removal of coastal habitats (e.g. mangroves).	Frequently	Very small - Large	Shoreline communities and processes e.g. sandy beaches.	Ellison (1999) UNESCAP (1992) MacKinnon et al. (2012) Mazda et al. (2002)
	Smothering	Direct loss of habitat caused by port infrastructure development (e.g. reclamation).	Rarely	Very small - Small	Benthic and nektonic communities and processes e.g. seagrass habitats and mangroves.	
Physical damage	Eroding, scouring and smothering	Damage to habitats caused by eroding, scouring and smothering by marine rubbish.	Frequently	Large	Benthic and nektonic communities and processes e.g. mangroves.	Derraik (2002)
Toxic contamination	Introduction of synthetic compounds	Contamination caused by the release of synthetic contaminants from storage facilities and during transfer.	Frequently	Very small - Medium	Benthic and nektonic communities and processes e.g. coral reefs.	GBRMPA (2009)* Burns and Brinkman (2011)*
	Introduction of non-synthetic compounds	Contamination caused by the release of hydrocarbons, coal dust and heavy metals from storage facilities and during transfer.	Frequently	Very small - Medium		
Biological disturbance	Introduction of non-native species	Introduction of non-native species via construction equipment and marine rubbish.	Rarely	Small - Large	Benthic and nektonic communities and processes e.g. native molluscs.	Hayes et al. (2005) Barnes (2002)
	Entanglement and ingestion	Entanglement and ingestion of marine rubbish by species.	Frequently	Small - Large	Benthic and nektonic communities e.g. marine turtle, sharks and rays.	Limpus (2007)* Dobbs et al. (2004)*
	Loss of connectivity	Direct loss or modification of habitat causing changes to drainage patterns and loss of connectivity between coastal ecosystems.	Frequently	Small - Large	Benthic and nektonic communities and processes e.g. seagrass habitats and mangroves.	GBRMPA (2009)*
Non-physical disturbance	Illumination	Light pollution caused by artifical lighting associated with port infrastructure.	Frequently	Medium - Large	Light sensitive biota e.g. marine turtles.	Kamrowski et al. (2012)* Salmon (2003)
	Above-and sub-surface water noise	Noise pollution generated during port construction phase and operation.	Frequently	Medium - Large	Species sensitive to noise and reliant on underwater vocalisation e.g. coastal dolphins and seabirds.	Ellison et al. (2012) McKenna et al. (2012)
Climate-change disturbance	Various	Carbon dioxide emissions from port machinery causing increases in greenhouse gases.	Frequently	Global	All aspects of ecosystem can be affected ultimately.	GBRMPA (2009)* Johnson and Marshall (2007)* OECD (2011)

Shipping and port-related boat traffic

Pressure Category	*Pressure Type*	*Definition*	*Frequency*	*Spatial extent*	*Biodiversity features affected*	*References*
Physical damage	Abrasion - grounding	Physical damage caused by the impact of vessels.	Rarely	Very small	Benthic communities and processes e.g. seagrass habitats and coral reefs.	Dinsdale and Harriot (2004) GBRMPA (2009)* GBRMPA (2011)* Negri et al. (2002)* Uhrin and Holmquist (2003)
	Abrasion - anchoring	Physical damage caused by vessel anchors.	Occasionally			
	Abrasion - scarring	Propeller and ship movement causing turbulence, resulting in abrasion and scars.	Frequently			
	Siltation	Increased concentration of suspended sediment and accumulation of fine sediments as a result of propeller and ship movement.	Frequently	Small - Medium		
	Eroding, scouring and smothering	Damage to habitats caused by eroding, scouring and smothering by marine rubbish.	Frequently	Large		Derraik (2002)
Toxic contamination	Introduction of synthetic compounds	Contamination caused by the release of synthetic compounds associated with vessels (e.g. antifoulants) and their cargoes; propeller and ship movement causing remobilisation of synthetic compounds from bottom sediment.	Occasionally - Frequently	Small - Medium	Benthic and nektonic communities and processes e.g. coral reefs.	GBRMPA (2009)* GBRMPA (2011)* Hayes and Loong (2002)* Heubeck et al. (2003) Marshall (2010)* Negri and Heyward (2001) Negri and Marshall (2009)* Negri et al. (2002)* Raaymakers (1994)* Roberts (2012) Tolhurst et al. (2007)
	Introduction of non-synthetic compounds	Discharge of oil from ships during both normal operations and shipping accidents; contamination caused by the release of hydrocarbons and heavy metals associated with vessels and their cargo; propeller and ship movement causing remobilisation of hydrocarbons and heavy metals from bottom sediment.	Rarely - Frequently	Small - Large	Biota sensitive to oil contamination and heavy metals e.g. seabirds.	
Biological disturbance	Introduction of non-native species	Introduction of non-native species via ballast water (e.g. Asian green mussels), cargo, fouling, marine rubbish, and cooling systems.	Rarely	Small - Large	Benthic and nektonic communities and processes e.g. native molluscs.	Hayes et al. (2005) Hutchings et al. (2002)* Neil et al. (2005)* Barnes (2002)
	Strike	Injury and/or death of biota from collisions with vessels.	Occasionally	Large	Megafauna e.g. dugongs and whales.	Dobbs et al. (2004)* Hazel et al. (2007) Meager and Limpus (2012)*
	Entanglement and ingestion	Entanglement and ingestion of marine rubbish by species.	Frequently	Large	Benthic and nektonic communities e.g. marine turtle, sharks and rays.	Limpus (2007)* Dobbs et al. (2004)*

Pressure Category	*Pressure Type*	*Definition*	*Frequency*	*Spatial extent*	*Biodiversity features affected*	*References*
Non-physical disturbance	Above-and sub-surface water noise	Noise pollution generated by vessel movement.	Frequently	Large	Species sensitive to noise and reliant on underwater vocalisation e.g. whales.	Ellison et al. (2012) McKenna et al. (2012)
	Illumination	Light pollution caused by artificial lighting on vessels.	Frequently	Large	Light sensitive biota e.g. marine turtles.	Salmon (2003)
Climate-change disturbance	Various	Carbon dioxide emissions from ships and boats causing increases in greenhouse gases.	Frequently	Global	All aspects of ecosystem can be affected ultimately.	GBRMPA (2009)* Johnson and Marshall (2007)* OECD (2011)

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