1. Introduction

It is common practice for ships to lie at anchor while waiting to access port facilities. Anchoring reduces fuel consumption and emissions as well as inhibiting drift of vessels toward land, submerged features or other vessels, thus minimising the risk of groundings and collisions. Nevertheless, vessels at anchor pose a risk to the seafloor and its biota. A ship’s anchor can shift, and its mooring chain swing across the seabed, causing abrasion of the seafloor and damage to benthic ecosystems; this phenomenon is known as anchor scour

These threats are ill-understood and little acknowledged, as is the challenge of identifying how anchor damage might be mitigated.

Anchoring occurs in offshore areas where there are multiple coincident and potentially conflicting activities and stakeholders, as well as jurisdictional complexities. Here, the multifaceted nature of the issue is outlined and multidisciplinary approaches that may afford solutions are considered. Our discussion is structured in four parts. First, the scale of anchoring is contextualised in terms of global trade patterns. Second, an Australian case study is used to highlight the scale of anchoring and the complex institutional-legal issues that influence its practice. Third, consideration is given to deep-water assemblages of marine organisms that exist in locations where anchoring takes place and which are likely to be impacted by anchor scour, although we acknowledge limitations to knowledge in this area. Finally, potential prevention or mitigation strategies are considered including the need to resolve conflict among stakeholders given that anchoring bears the hallmark of a collective action dilemma.

2. Anchor scour – a hidden cost of global trade

International shipping is a fundamental driver of global prosperity. Over 80% of global trade by volume is carried by sea, with a global fleet of more than 68,000 cargo-carrying vessels [49]. The scale of this multi-billion dollar global industry has escalated rapidly in recent decades in keeping with sharply increasing global trade. Indeed, ocean transport by volume has almost tripled since 1990 (Fig. 1). This trend appears set to continue with further significant growth predicted. Indeed, it has been estimated that sea borne trade will increase a further three fold by 2060 [44]. The dramatic growth in global trade is in part driven by the increasing size of modern vessels which enables shipping costs to remain low [50].
environment. Some environmental impacts associated with the shipping industry are well established. For example, vessels produced an estimated 2.2% of the world's CO₂ emissions in 2012 [19], and produce significant sulphur emissions [50]. Concerns have also been raised about international trade as a vector for marine invasive pests via ballast water or hull fouling [20] and a source of contamination from biofouling agents or spillovers [18,25]. Vessels may also contribute to light and noise pollution [23], particularly when at anchor in coastal waters awaiting an opportunity to dock.

Additionally, there is abundant evidence that the mooring chains of recreational or small (<50 m) commercial vessels can have dramatic impacts in shallow water environments, especially seagrass habitats. The production of circular mooring scars denuded of virtually all surface biota is well documented in these habitats [8,13] and recovery for some key habitat-forming species may be extremely slow [26]. It can be anticipated that large vessels at anchor also pose a threat to the marine environment, anchors on the largest vessels may weigh in excess of 25 t [16]. Anchors hold vessels fast in combination with the weight of the chain lying on the seabed [16]. Consequently, anchor chains for large vessels are often extremely heavy with individual links weighing between 60 and 200 kg [16], particularly for vessels anchoring on wave-exposed coasts with high dynamic loads on their anchoring systems [1]. The length or 'scope' of chain deployed is determined by the holding ground (bottom type), depth of water and the prevailing sea conditions [16]. The 'scope' is usually between three and seven times the water depth, with most ship masters preferring a scope greater than five [16].

In contrast to shallow water habitats, which have received scientific scrutiny, there is poor understanding of how large vessels at anchor interact with marine biota at depths beyond those easily sampled with SCUBA. This is a submerged and therefore largely hidden impact of shipping (Fig. 2). Sampling becomes logistically difficult and expensive beyond 30 m and usually requires remote sampling technologies [35]. Consequently, there is a general lack of awareness of the threats that anchoring may pose to the marine environment, arguably stemming from a limited understanding of the diversity and importance of the environments under threat (see below). This is illustrated by the fact that neither the International Maritime Organization – the UN agency charged with the global standard-setting for maritime safety, security and the environmental performance, nor the environmental code of practice developed by the International Chamber of Shipping makes mention of anchor scour [17,21].

3. Anchoring in south eastern Australia: a case study

As an island nation Australia is heavily reliant on shipping with 99% of trade by volume being carried by sea [4]. Australia's ports receive more than 26,000 ship visits annually supporting a $200 billion industry [39]. The economic reliance on commodities is reflected in the percentage of global trade shipped from its ports. Coal exports from Australia account for 29% of the world's coal transported by ship [6] 56% of the world's iron ore [42] and 9% of global grain exports [6]. Australia's eastern seaboard is a focal point for Australia's resource rich industries. Ports in the Sydney region (the Ports of Newcastle, Sydney, Botany Bay and Wollongong) distribute a large portion of Australia's commodities. The most recent figures available for Sydney Ports (2011–2012 financial year for Sydney Harbour and Port Botany combined) document 2141 ships visiting trading 30.7 million tonnes. Reports for Wollongong's Port Kembla (2012–2013) document 946 ship visits for a total trade volume of almost 29 million tonnes [29]. While the Port of Newcastle, the world's largest coal port registered almost 160 million tonnes of trade in 2014 and 2170 ship visits in this period [30].

New South Wales (NSW) offers an attractive area in which to focus a case study. In addition to busy ports, there are challenging jurisdictional issues surrounding Port limits as well as complex issues of jurisdiction and responsibility shared between State and Federal authorities. Fortunately, deep-water assemblages near Sydney have received attention by biologists; this research highlights significant knowledge gaps for key habitat-forming organisms on deep reefs and their recovery following disturbance. These challenges are explored below.

3.1. Anchoring practices in New South Wales

Many of the vessels entering NSW ports lay at anchor while awaiting their turn to dock. Environmental conditions experienced on the NSW coastline include highly changeable winds, a strong south-flowing western boundary current (the East Australian Current) and large swell associated with storm systems originating in the southern ocean. These conditions cause vessels to swing on their anchor chains. Such changes in vessel position appear as anchoring arcs, visualised with AIS (Automatic Identification System) vessel tracking data made available by the Australian Maritime Safety Authority (AMSA) (Fig. 3). These data also confirm that vessels often remain at anchor for several days. The average is more than four days in waters adjacent to Port Kembla and nearly three days at the Port of Newcastle (Table 1), although some vessels remain at anchor for as long as almost 32 days. Two substantive points can be discerned from the AIS data. First, the scale of the anchoring arcs identified is substantial; some exceed 500 m in diameter. Here it can be noted that only part of the anchor chain will come into contact with the seafloor, something that is dependent on the depth of water and load placed on the anchoring system [3]. Second, there is evidence that some areas of sea bottom have experienced repeated scouring over the three years of data examined. It should be noted that many anchorages, including Port Kembla and Newcastle, have been receiving vessels for decades.

3.2. Complex jurisdictional challenges in NSW

Australia claims a territorial sea extending seawards to 12 nautical miles (M) from baselines along the coast, consistent with the United Nations Law of the Sea Convention [48]. Australia's constituent states and territories such as NSW have principal...
legislative authority within the first 3 M offshore (‘coastal waters’) [12]. Anchoring occurs within the territorial sea, and often (although not exclusively) within that part of the territorial sea that constitutes coastal waters.

Article 18(2) of UNCLOS provides that foreign ships have the right to anchor within other States’ territorial seas. This arises from the longstanding ‘right of innocent passage’ for foreign vessels, permitting them to stop and anchor if this is ‘incidental to ordinary navigation’ or rendered necessary by an emergency. This means that foreign vessels entering the territorial sea en route to a port in the coastal State have the right to anchor within the territorial sea as a normal activity ahead of their entry into an available berth. UNCLOS does not provide any restrictions on where anchoring can take place. It is common practice in NSW to recommend to the masters of vessels to anchor seaward of the 3 M limit of coastal waters and beyond harbour limits [45]. The advice to anchor beyond three M is not a regulation; it is simply a strongly worded recommendation:

‘Anchoring is at the discretion of the Master, however it is highly recommended that vessels remain at least 3 nautical miles from the coastline and outside port limits’. Sydney Ports Corporation [45]

In practice and as demonstrated by the AIS data, anchoring straddles the three M limit, occurring in coastal waters and that part of the territorial sea seawards of three M from baselines along the coast.

Jurisdictional issues surround ports in south eastern Australia are further complicated by reliance on several legal instruments protecting biodiversity in these waters. Generally, the extent of the State’s jurisdiction extends to three M off the coast while Federal legislation generally provides protection to marine biodiversity from 3 M to the 12 M limit under the Environment Protection and Biodiversity Conservation Act 1999. The integration of management for transboundary issues between local and Federal agencies has long been a bedevilling challenge [14]. Nevertheless, managers

<table>
<thead>
<tr>
<th>Variable</th>
<th>Port Kembla</th>
<th>Port of Newcastle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of anchoring events</td>
<td>1393</td>
<td>3066</td>
</tr>
<tr>
<td>Average number of vessels anchored per month</td>
<td>37.5</td>
<td>89.4</td>
</tr>
<tr>
<td>Average number of anchoring events per month</td>
<td>41.0</td>
<td>90.2</td>
</tr>
<tr>
<td>Average time spent at anchor (days)</td>
<td>4.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Maximum length of anchoring event (days)</td>
<td>32.0</td>
<td>23.2</td>
</tr>
</tbody>
</table>

Fig. 2. Hidden cost of global trade (a) a commercial vessel lies at anchor awaiting it’s turn to berth in south eastern Australia, (b) Vessels lie at anchor off Singapore illustrating the global nature of the issue and the potential scale of impacts.

Fig. 3. Anchor arcs based on AIS (Automatic Identification System) vessel tracking data near the Port of Newcastle acquired from the Australian Maritime Safety Authority (AMSA). Vessels moving faster than 1 knot were removed from the data set. Dashed line is the extent of state waters. Different shades denote individual vessels. Note the spatial scale.

Table 1
Summary of key variables relating to anchoring of vessels > 50 m in length at two NSW Ports (Port of Newcastle and Wollongong’s Port Kembla) based on 32 months of AIS data (September 2012 to June 2015) provided by the Australian Maritime Safety Authority (AMSA).
continue to articulate the importance of an integrated approach for the planning, regulation and management between Federal, State and local governments of their natural environments\cite{14,40}. The Marine Estate Management Act 2014 (NSW) is a significant recent legal instrument directed at protecting marine biodiversity in coastal waters. It adopts a risk-based approach to assess threats to coastal marine resources and has prompted examination of the threat posed to natural systems by large vessels using ports in the region, including risks to deep reef habitat.

Another area of complexity is the jurisdiction of port authorities and their focus on commercial operations to facilitate efficient access to ports. There are no safe recommended anchorages near ports along the NSW coastline. There are four anchorages within Sydney Harbour. However, these need to be booked in advance and they cannot accommodate the number of ships entering NSW ports. The combined effect of the three M anchoring directive by Harbour Masters and the preference of the Masters of vessels to anchor in water shallower than 60 m depth means that anchor roadsteads are linear features predominantly sandwiched between the three M line and the 60 m depth contour. As a result, the extent of the coastline and offshore areas impacted by anchoring may extend over considerable distances; the anchoring arcs south of the Port of Newcastle extend over more than 15 M of coastline (Fig. 4).

### 3.3. Biological knowledge gaps

The depth range over which vessels lie at anchor in south eastern Australia is rarely shallower than 30 m or deeper than 60 m. It is a costly and significant logistic challenge to conduct detailed biological assessments at these depths, thus explaining the knowledge gaps surrounding the fauna and flora over this depth range. Further complicating matters, some taxa are particularly difficult to identify to the species level and constitute gaps in scientific understanding of what biota exist in these habitats. Biological assessment requires samples to be collected to confirm identification and highly developed taxonomic skills to access this biodiversity. As an example, sponges are a key habitat-forming species over the depth range of interest and are particularly challenging to identify. They are diverse and dominate the sea floor on rocky reefs in deep water\cite{33} but are often also abundant on soft sediment\cite{41}. Research in south eastern Australia at depths in excess of 30 m suggests that around 60% of sponges are undescribed to science. This poses significant challenges in assessing biodiversity and any changes to the status of that diversity\cite{7,33}.

It is apparent that understanding of the biota living on the sea floor (epibiosis) and in the sediment (infauna) at the 30–60 m depth range is fragmentary and it remains unclear how vulnerable such biota are to anchor scour. It can be expected, based on impacts associated with towed nets or dredges, that biota coming into direct contact with an anchor or chain would be swept from the sea floor or crushed\cite{46,51}. There might also be obliteration or damage to reefs on which biota attach\cite{9}. There are also indirect impacts that would be anticipated over broader spatial scales. These include sediment plumes stirred from the bottom. These plumes will reduce light levels, resuspend contaminants into the water column and have the potential to clog the feeding apparatus of suspension-feeding organisms, such as bivalves, sponges and sea squirts\cite{5,15,34}. Assemblages would also be expected to shift to groups dominated by scavengers attracted to crushed and damaged organisms\cite{24}. A further scientific shortcoming is that the rates of recovery following damage are also largely unknown.

The potential for negative impacts in the south eastern Australia offshore area is alarming, especially because the habitat is already considered to be in ‘poor’ condition (see definition). The status of the marine environment is assessed regularly through Federal ‘State of the Environment’ reporting. For the eastern area of Australia, the seafloor environments (which include ports within the broader Sydney area), are considered ‘poor’. A more detailed breakdown of categories for the inner shelf (0–50 m) in the most recent environmental report card\cite{40} is concerning (Table 2). It may be premature to judge the status of these habitats given that 80% of these assessments are based on ‘limited evidence or limited consensus’. What is evident from these reports is that with the destruction of complex benthic systems containing high biodiversity, oversimplified systems are being created with the attendant loss of critical marine habitat and ecosystem services. Some scientists have argued for enhanced regulation and responsibility for these habitats\cite{36}. The destruction and degradation of these habitats may have important implications for fishing and the loss of fishery resources\cite{47}.

### 4. Potential mitigation strategies

There are several approaches that may mitigate the impacts of the anchoring practice of large ocean-going vessels. The first is simply not to anchor. There are, however, clear shortcomings with this approach. Risks of collisions will increase if vessels are not at anchor and fuel costs will escalate, suggesting that, such an approach is not a viable solution. However, the use of a Vessel Arrival...
Adequate high-quality evidence and high level of consensus

Very good:
- Persistent, substantial effects on many populations of dependent species
- Sea Areas (PSSAs) to help protect fragile environments from the risks posed by shipping, although there are only 14 of these worldwide [22]. Arguably, such an approach could also be applied to protect sensitive marine environments near ports by the development of anchoring regulations.

There may be tangible benefits to the shipping industry in moving to the use of designated anchorages. The selection of anchoring areas where the ‘holding ground’ is known to be good should result in a reduced chance of anchor drag. This would also minimise the risk of accidents and the costs associated with them while also enhancing safety of life at sea. From an environmental standpoint, an advantage of this approach is that it would restrict the anchoring footprint, thereby reducing the scale of any environmental impacts. Designated anchorages would result in a relatively small area being repeatedly disturbed. Environmental best practice rests on the assumption that the seabed biota has been assessed prior to anchorage designation to ensure that vulnerable species do not occur within these areas. There are currently no documented examples of this practice for Australian Ports.

The protection of areas of high conservation value is another valuable approach. As an example, unique reefal systems described as an ‘international treasure’ have been afforded protection in British Columbia, Canada [10]. Marine Protected Areas that prohibit bottom trawling in Hecate Strait and Queen Charlotte Sound were introduced to protect deep-water glass sponge (Hexactinellid) reefs [2]. Similarly, the incorporation of habitat of high conservation value into anchor exclusion zones would be a cost effective approach. If areas of high conservation value can be assessed remotely with side scan or multibeam sonar (for example, see [32]) the excision of areas from anchoring roadsteads would be an attractive solution while minimising disruption to industry. Though such an approach requires the adoption of simplified assumptions with the use of habitat mapping as a proxy for biodiversity, it would speed the response of the shipping industry until biological knowledge gaps (as raised in Section 3.3 above) can be addressed.

A fundamental mechanism or tool that has emerged in the enduring and ongoing quest for less sector-specific and more integrated oceans management is marine spatial planning (MSP). MSP does not replace well established sector-oriented management approaches. Rather, it offers more strategic planning with a more rational and harmonised uses of marine space. This type of approach is not new. Indeed, it can be argued that the sophisticated zoning and management plans established for the multiple-use Great Barrier Reef Marine Park and particularly the extensive rezoning of the park that occurred in the mid-1990s, is an early example of MSP in practice involving an extensive and frequently intense process of engagement with users, scientists, environmentalists and the general public [11,37].

It can be envisaged that the definition of designated anchoring and non-anchoring or protected areas of the seabed could form part of a comprehensive MSP zoning exercise. Unfortunately, in the Australian context at least, no single organisation or office manages MSP efforts. This means that spatial planning efforts tend to be fragmented and piecemeal and often driven by sectoral interests such as fisheries, the oil and gas industry or shipping.

5. Resolving conflict

The marine areas where anchoring occurs can be considered multiple-use common pool resources (CPRs), with the interests of multiple resource users at stake [43]. CPRs are characterised by the problem of getting a resource user to refrain from self-interested behaviour when there is no guarantee that other similar users will...
do likewise [38]. A case in point is ensuring ships masters and owners cooperate by considering the effects of anchoring on the benthic environment, and thus to take into account the interests of other (non-shipping) users and the wider public. In the absence of a guarantee that all shipowners with vessels that anchor in a particular area will change their anchoring practices, any particular shipowner is unlikely to revise their practice. This dilemma is brought into sharp focus when it is a foreign flagged vessel impacting on another State’s resources for non-extractive purposes. Regulatory solutions need to be considered when cooperation is unlikely to occur spontaneously in order to resolve a collective action dilemma in a marine common.

Anchoring occurs in offshore areas where there are multiple coincident and potentially conflicting activities and stakeholders as well as jurisdictional complexities and uncertainties. In order to address the complex, multifaceted issue of anchoring and resolve what bears all the hallmarks of a collective action dilemma in a marine common, important knowledge gaps need to be identified and legal-regulatory solutions considered. This is far from straightforward in the marine milieu, where stakeholders hold differing points of view, institutional complexities exist and ‘overlapping jurisdictions... make stewardship difficult’ [28]. Lack of information is a common challenge of environmental stewardship where managers are expected to make assessments based on limited information [27]. As managers face significant uncertainties, a precautionary approach seems prudent and this should include the collection of quantitative data on anchoring and its impacts.

There are several potential ways to resolve conflict surrounding anchoring activities near ports. Given that the ocean floor is a common pool resource it is important that there is early engagement with stakeholders. The shipping industry needs to be engaged in the process and demonstrate its performance as a good corporate citizen. There is a compelling argument for the shipping industry to adopt environmental best practice in relation to anchoring activities within existing environmental management frameworks. In management terms best practice is defined as techniques that are ethical as well as effective [27]. Using this definition of ‘best practice’ and in seeking resolution of potential conflicts between multiple-users of a common pool resource, environmental ethics need to be given a high priority in addition to social and economic considerations. The international shipping industry must accept its corporate environmental responsibilities while other stakeholders must remain mindful that industry should experience minimal disruption.

6. Conclusions and future directions

The global economy cannot do without ships or their anchors. Consequently, anchors are not readily sent ‘away’ as alluded to in the title to this article. That said, it has become clear that anchor scour poses a significant and increasing threat to vulnerable yet valuable marine environments about which our knowledge is incomplete. This paper has identified important knowledge gaps, jurisdictional complications, and uncertainties associated with addressing this threat. While these matters have been illustrated through a south eastern Australian case study, to the extent that shipping is a global industry, the issues raised are of global relevance to marine environments.

This paper has outlined several potential pathways to address this growing concern. Among these, designated anchoring areas, embedded in a comprehensive MSP approach is considered the ideal option – serving to protect vulnerable, high-value areas while at the same time delivering safety and efficiency benefits to the shipping industry. Such an approach might also be employed in conjunction with initiatives such as vessel management systems. In combination, these approaches might limit anchor scour to specific areas and reduce the number of ships at anchor awaiting entry into port and the duration of their anchoring. Further, the designation of anchoring areas of good holding ground will reduce the chances of shipping accidents caused, for example, by anchor drag.

There are many facets to environmental problems. To ensure science is implemented for tangible conservation outcomes, the longer and more difficult path to action through an integrated and multidisciplinary approach is worthwhile if it promises to deliver a more powerful and long-lasting solution [27]. In the absence of a single solution to environmental problems caused by anchoring, a multifaceted approach may offer an alternate path [31].

Acknowledgements

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