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Review

Application of management tools to integrate ecological principles with the design of marine infrastructure

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ABSTRACT

Globally the coastal zone is suffering the collateral damage from continuing urban development and construction, expanding resource sectors, increasing population, regulation to river flow, and on-going land change and degradation. While protection of natural coastal habitat is recommended, balancing conservation with human services is now the challenge for managers. Marine infrastructure such as seawalls, marinas and offshore platforms is increasingly used to support and provide services, but has primarily been designed for engineering purposes without consideration of the ecological consequences. Increasingly developments are seeking alternatives to hard engineering and a range of ecological solutions has begun to replace or be incorporated into marine and coastal infrastructure. But too often, hard engineering remains the primary strategy because the tools for managers to implement ecological solutions are either lacking or not supported by policy and stakeholders. Here we outline critical research needs for marine urban development and emerging strategies that seek to mitigate the impacts of marine infrastructure. We present case studies to highlight the strategic direction necessary to support management decisions internationally.

1. Introduction

Continuing human population growth and corresponding expansion of coastal cities has contributed to a modern day multi-use seascape including natural and engineered habitat features (e.g. Lee et al., 2006; Waltham and Connolly, 2011). Along with essential ecological services for fisheries production (Nagelkerken et al., 2013), the modern day seascape is also expected to provide services essential for humans, such as residential living, recreation, commercial, navigation, wastewater disposal and tourism activities (Dennison, 2008). Costanza et al. (1997) estimated these marine and coastal services to be worth in the order of US$31.5 trillion yr^{-1}. The challenge for coastal managers is to now balance ecological biodiversity and habitat protection at the same time as approving expansion of coastal centres and development.

To move forward in the management of marine developments, we require a clear definition of what constitutes “marine infrastructure”. We propose that the term includes basic recreational infrastructure (e.g. marinas, pilings, pontoons, boat ramps, swimming enclosures), coastal and foreshore defence infrastructure (e.g. seawalls, groynes, breakwaters), offshore energy installations (e.g. gas and oil extraction, wind farms), fisheries infrastructure (artificial reefs, offshore aquaculture facilities) and residential infrastructure (canal estates, bridge crossings). Currently these “marine infrastructure” are differentially managed, and lack comprehensive or consistent guidelines and regulations for their planning, construction and restoration.

Clear objectives for the management of marine developments will be essential in the future as the construction of infrastructure is forecast to increase considerably with the increasing urbanization of space and predicted climatic changes (Asif and Muneer, 2007; Dugan et al., 2011; Pérez-Alberti et al., 2013; Troell et al., 2009). For example, a significant amount of urban shorelines are occupied by marinas and recreational infrastructure (Table 1). In Australia, Sydney Harbour alone comprises almost 40 marinas

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Table 1
The extent of current marine infrastructure.

Infrastructure	Extent	Refs.
Recreational infrastructure	Australia: 356 marinas and approx. 800,000 registered recreational boats	(MIAA, 2010)
	United Kingdom: 545 marinas/yacht harbours, 541,560 recreational boats	(Laaksonen, 2012)
	Europe: 2700 Germany, >1500 Sweden, 1135 Netherlands, 1293 Poland, 1770 Finland, 421 Italy, 358 Spain, 250 Denmark, 156 Croatia, 22 Greece, 22 Ireland, 15 Czech Rep marinas/yacht harbours; 881,000 Sweden, 737,000 Finland, 617,638 Italy, 523,000 Netherlands, 506,000 France, 503,795 Germany, 219,998 Spain, 151,331 Greece, 58,585 Poland, 55,000 Denmark, 27,000 Ireland, 16,283 Czech Rep recreational boats	(Laaksonen, 2012)
	United States: ~11,000 marinas/yacht harbours, ~16.6 million recreational boats	(Laaksonen, 2012)
	Asia: 570 marinas/yacht harbours, ~224,000 recreational boats in Japan	(Laaksonen, 2012)
Coastal and foreshore defence infrastructure	Australia: 32–49% of foreshore modified with seawalls in some Sydney estuaries	(Creese et al., 2009)
	United Kingdom: 44% of coastline in England and Wales defended with hard engineering	(Society, 2001)
	Europe: 22,000 km^2 of coastal zone armoured	(Airoldi and Beck, 2007)
	United States: >50% of some estuaries and bays modified and ca. 5–30% coastlines armoured	(Dugan et al., 2011)
	Asia: ca. 27% of 34,500 km of Japan's coastline hardened with coastal defence structures	(Koike, 1996)
Offshore energy resources	Australia:	
	Wind: no current proposals	(Amin, 2014)
	Oil & Gas: >17 oil & gas fields, largest in Bass Strait comprises 23 platforms	(COA, 2012)
	United Kingdom:	
	Wind: 18 wind farms, >700 individual turbines	(Amin, 2014)
	Oil & Gas: 170 operational oil fields, 132 operational gas fields	(DECC, 2013)
	Europe:	
	Wind: 73 wind farms, 2304 individual turbines	(EWEA, 2014)
	Oil & Gas: 181 Netherlands, 6 Ireland, 123 Italy, 4 Spain, 2 Greece, 7 Romania, 1 Bulgaria, 3 Poland	(EC, 2010)
	United States:	
	Wind: 5 active projects	(OffshoreWind.net, 2012)
	Oil & Gas: 2634 Gulf of Mexico, 23 Pacific installations	(BSEE, 2013)
	Asia:	
	Wind: 5 wind farms, 70 individual turbines (China); 1 wind farm, 1 individual turbine (South Korea), 3 wind farms, 17 individual turbines (Japan)	(Amin, 2014)
	Oil & Gas: China >20 oil fields, 257,292 km^2 exploration areas, China >5 gas fields, Japan 1 oil & gas field	(CNOOC, 2013; JAPEX, 2015)
	South America:	
	Oil & Gas: Brazil > 20 oil fields	www.petrobras.com.br
Artificial reefs	Australia: 2 Western Australia, 19 South Australia, 6 Queensland, 1 New South Wales	
	United Kingdom: 6 reefs	(Fabi et al., 2011)
	Europe: 103 Spain, 70 Italy, 30 France (total 246)	(Fabi et al., 2011)
	United States: 83 reefs from 120 decommissioned oil and gas platforms Louisiana, >35 reefs from 70 decommissioned oil and gas platforms Texas, 448 artificial reef sites covering ~664 nm^2 (~300 active) concrete materials dominate (38%) followed by concrete modules (30%), steel vessels and barges (11%), bridge materials (9%), military equipment- mainly armored combat tanks (4%), steel materials (4%), limestone (3%) and miscellaneous materials (0.8%) Florida, Delaware - 14 reefs; Maryland - 20 artificial reef sites of Chesapeake Bay and 10 permitted reef sites on the oceanside/coastal bays; 8 fishing reefs in the ocean; one research reef in the ocean and one small reef in the bay behind Ocean City.	(Kaiser, 2006a), EPA, USA (website, accessed 19-01-2015) (Kaiser, 2006b)
	Asia: 44 throughout Asia	(Baine, 2001)
	South America: Brazil: At least 2 sets of 16 artificial reefs made by concrete and tire on the North coast of Rio de Janeiro	Zalmon et al., 2002
Artificial residential waterways	Australia & New Zealand: 93 canals and lakes, 381 km long, 35 km^2	(Waltham and Connolly, 2011)
	Europe: 27 canals and lakes, 279 km long, 9 km^2	(Waltham and Connolly, 2011)
	North America: 150 canals and lakes, 2960 km long, 171 km^2	(Waltham and Connolly, 2011)
	Asia: 29 canals and lakes, 300 km long, 43 km^2	(Waltham and Connolly, 2011)

that support around 35,000 vessels (Widmer et al., 2002). Furthermore, up to 70% of coastlines have been modified to protect coastal cities globally (reviewed by Dafforn et al., 2015; Dugan et al., 2011) (Table 1) and the footprint of marine developments is spreading seaward with an increasing number of offshore energy platforms. Globally, there are around 10,000 operational fixed platforms and 395 operational floating platforms (Ferentinos, 2013), and Australia's largest offshore oil and gas field in the Bass Strait supports 23 operational platforms (Table 1). This proliferation of human-made structures in the marine environment is ecologically significant because of the increasing range of impacts associated with their construction, operation and decommissioning (Dafforn et al., 2015; Dugan et al., 2011).

Important marine habitats have suffered from the collateral damage of coastal development (Browne and Chapman, 2011). For example, the desire for residential real estate with waterfrontage