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Monograph

Effects of ocean sprawl on ecological connectivity: impacts and solutions

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ABSTRACT

The growing number of artificial structures in estuarine, coastal and marine environments is causing "ocean sprawl". Artificial structures do not only modify marine and coastal ecosystems at the sites of their placement, but may also produce larger-scale impacts through their alteration of ecological connectivity - the movement of organisms, materials and energy between habitat units within seascapes. Despite the growing awareness of the capacity of ocean sprawl to influence ecological connectivity, we lack a comprehensive understanding of how artificial structures modify ecological connectivity in near- and off-shore environments, and when and where their effects on connectivity are greatest. We review the mechanisms by which ocean sprawl may modify ecological connectivity, including trophic connectivity associated with the flow of nutrients and resources. We also review demonstrated, inferred and likely ecological impacts of such changes to connectivity, at scales from genes to ecosystems, and potential strategies of management for mitigating these effects. Ocean sprawl may alter connectivity by: (1) creating barriers to the movement of some organisms and resources - by adding physical barriers or by modifying and fragmenting habitats; (2) introducing new structural material that acts as a conduit for the movement of other organisms or resources across the landscape; and (3) altering trophic connectivity. Changes to connectivity may, in turn, influence the genetic structure and size of populations, the distribution of species, and community structure and ecological functioning. Two main approaches to the assessment of ecological connectivity have been taken: (1) measurement of structural connectivity - the configuration of the landscape and habitat patches and their dynamics; and (2) measurement of functional connectivity - the response of organisms or particles to the landscape. Our review reveals the paucity of studies directly addressing the effects of artificial structures on ecological connectivity in the marine environment, particularly at large spatial and temporal scales. With the ongoing development of estuarine and marine environments, there is a pressing need for additional studies that quantify the effects of ocean sprawl on ecological connectivity. Understanding the mechanisms by which structures modify connectivity is essential if marine spatial planning and eco-engineering are to be effectively utilised to minimise impacts.

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Contents

1. Introduction

Continued human population growth and associated development of coasts and offshore waters have led to marine and coastal environments that are increasingly dominated by artificial (engineered) structures, termed “ocean sprawl” (Duarte et al., 2012; Firth et al., 2016a). More than 40% of the world's population and 60% of the world's largest cities are within 100 km of the coast (Tibbetts, 2002) and the proportion of the world's population living in the coastal zone is projected to further increase (Nicholls et al., 2007). This population growth has led to construction of residential and commercial developments (e.g. waterfront housing, canal estates, bridges and crossings), coastal roads, railways and transport infrastructure for shipping (e.g. berths, moorings, dolphins, shipping canals), tourism and recreational infrastructure (e.g. marinas, pilings, pontoons, mooring buoys, boat ramps and swimming enclosures), as well as structures for offshore resource extraction (wind farms, oil and gas platforms) and for intensive fisheries and aquaculture industries (see Dafforn et al., 2015a,b). Many of these developments involve land reclamation and often have to be defended (e.g. by seawalls, groynes and breakwaters) against rising and stormier seas (Titus et al., 1991; Nicholls and Cazenave, 2010; Hinkel et al., 2014).

In estuarine and coastal environments, the desire for a waterfront lifestyle has led to the construction of over 4000 linear km of residential canal estates globally, covering 270 km^2 of intertidal wetland habitats (Waltham and Connolly, 2011). The construction of marinas, boat ramps, wharves and docks to support recreational boating and commercial passenger services has also extensively modified urban foreshores and coastal habitats (see Dafforn et al., 2015a). International shipping accounts for >90% of global trade (IOC-UNESCO et al., 2011) and an extensive network of global port infrastructure has been developed to support these movements. Port facilities and other commercial and residential assets are protected by armouring, such as seawalls, which in some parts of Asia, America and Europe now account for >50% of shoreline (Bacchiocchi and Airoldi, 2003; Bulleri and Chapman, 2010; Dugan et al., 2011; Lee and Li, 2013).

This extensive, human-mediated, habitat modification is not just limited to coastal waters, with sprawl of infrastructure into offshore environments also recognised as an increasingly important source of environmental and ecological change (Duarte et al., 2012). As the world's coastal population has grown, so too has demand for food and energy production. Fisheries and aquaculture assure the livelihoods of 10–12% of the world's population (FAO, 2014). While offshore mariculture remains in its infancy, the potential for large areas of the oceans to be utilised for this purpose is increasingly considered (Kapetsky et al., 2013). In 2009, offshore oil fields accounted for 32% of worldwide crude oil production with expectations that this will increase to 34% by 2025 (IOC-UNESCO et al., 2011). Infrastructure associated with offshore renewable sources of energy, such as marine tides, waves, currents and temperature and salinity gradients, are gaining momentum and construction is expected to increase around the globe (IOC-UNESCO et al., 2011; Firth et al., 2016a). Overall, the construction of artificial structures in coastal areas is growing at rates ranging from 3.7% $year^{-1}$ to support merchant shipping requiring harbor space, up to 28.3% $year^{-1}$ for the development of offshore wind energy installations (Duarte, 2014).

Urban, coastal and offshore infrastructure has a myriad of impacts on biodiversity and ecosystem functioning (e.g. Airoldi and Beck, 2007; Bulleri and Chapman, 2010; Dugan et al., 2011; Dafforn et al., 2015b). Early studies on the effects of artificial structures focused on the extent to which they modify ecological communities at the site of construction (Bacchiocchi and Airoldi, 2003; Martin et al., 2005; Moschella et al., 2005), and the extent to which they can act as surrogates for the microhabitats provided by natural rocky shores and reefs (Moschella et al., 2005; Bulleri and Chapman, 2010). Artificial structures differ physically from natural habitats with respect to substratum composition, complexity, surface area, age, orientation, movement and disturbance regimes (Bulleri and Chapman, 2010; Airoldi and Bulleri, 2011; Chapman and Underwood, 2011). Increasingly, the novel habitat they provide is shown to support very different ecological communities to natural habitats (Connell and Glasby, 1999; Connell, 2001; Firth et al., 2013a), often characterised by greater abundances of opportunistic and non-native species (Glasby et al., 2007; Dafforn et al., 2009; Firth et al., 2011, 2015; Bracewell et al., 2013; Airoldi et al., 2015). Additionally, they may modify the communities of adjacent habitats by affecting light availability, flow, wave energy, sediment and resource transport, by leaching chemicals, modifying predator-prey interactions and/or by