Global Ecology and Conservation 12 (2017) 80–95

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: http://www.elsevier.com/locate/gecco

Original Research Article

Land reclamation and artificial islands: Walking the tightrope between development and conservation

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ARTICLE INFO

Article history:
Received 31 July 2017
Accepted 13 August 2017

Keywords:
Coastal management
Ecological engineering
Erosion
Mangrove
Ocean sprawl
Sustainable coastal development
Urbanisation

ABSTRACT

Coastal developments worldwide have put entire shoreline ecosystems at risk. Recently, land reclamation has been extended to the construction of whole new islands; a phenomenon that is particularly common in Asia and the Middle East and is recognised as a global conservation issue. Using Penang Island, Malaysia as a case study, we illustrate the relationship between rapid population growth and the simultaneous increase in urbanisation, land reclamation and extent of artificial shorelines; and decrease in the quality and extent of natural coastal habitats. Our goal was to provide an up-to-date assessment of the state of coastal habitats around Penang, identify knowledge gaps and identify locations that may be potentially suitable for eco-engineering. Comparisons of historical and current topographic maps revealed that land formerly consisting of coastal swamp and forest, mangrove forests, sandy beaches, and rubber and oil plantations have been lost to large-scale land reclamation and urbanisation. Between 1960 and 2015, there were increases in urbanised area, reclaimed land, and artificial shoreline extent. The total extent of mangrove forests has remained relatively stable but this balance is characterised by significant losses on the east coast coupled with increases on the west coast. Coastal development on the island is still on-going with plans for the construction of five artificial islands and another two coastal reclamation projects are either underway or scheduled for the near future. If the plans for future land reclamations are fully realized, 32.3 km^2 of the 321.8 km^2 island (10%) will be reclaimed land and the associated negative effects on the island's natural coastal habitats will be inevitable. This study highlights sections of the coast of Penang Island in need of effective monitoring, conservation and management and explores the possibility of incorporating ecological engineering into development projects, either prospectively or retrospectively, to create more environmentally-friendly urban environments and to promote educational, amenity and economic activities. With coastal development taking place on a global scale, opportunities to balance development needs with conservation strategies abound and should be integrated into present and subsequent projects to protect these coastal ecosystems for future generations.

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http://dx.doi.org/10.1016/j.gecco.2017.08.005

1. Introduction

1.1. Burgeoning coastal populations

Throughout history, people have settled and built cities in coastal zones due to the prevalence of natural resources, easy access to transport and trade and better defence opportunities (Small and Nicholls, 2003; Neumann et al., 2015). Consequently, coastal ecosystems support disproportionally higher densities of people, many of whom are urban dwellers (McGranahan et al., 2005). In relation to rapid population growth and high proportions of urban populations living in coastal areas (McGranahan et al., 2005; UNEP, 2016), Asia has shown some of the greatest intensification of coastal development (Jongman et al., 2012), with 20 of the top 30 (67%) most populated coastal cities located there (UNEP DESAP, 2014; Firth et al., 2016a).

To accommodate the rise in human population, coastal areas are becoming progressively saturated with high-rise buildings, and while this serves as a temporary solution in some cases, available land for development becomes scarcer in others. In the latter, land reclamation (the gain of land from the sea, wetlands, or other water bodies) is often one of the few solutions to provide space and counteract erosion (Charlier et al., 2005; Lai et al., 2015). Land reclamation can be extended to the construction of whole new islands; a phenomenon that is particularly common in Asia and the Middle East (e.g. the Palms, Dubai, Burt et al., 2010). The construction of artificial islands to support infrastructure and people is not a new concept but there is increasing concern about the environmental and political implications of these developments (Larson, 2015). For example, in a recent horizon scanning review paper, Sutherland et al. (2016) identified the construction of oceanic islands as a "global conservation issue".

As a result of land reclamation, natural habitats (e.g. mangrove forests, seagrass beds, saltmarshes and mudflats) are rapidly being replaced by artificial "habitats" such as seawalls, rock armour, breakwaters and marinas (Airoldi et al., 2009; Bulleri and Chapman, 2015; Dafforn et al., 2015a; Ng et al., 2015), with the loss of valuable ecosystem services and disruption to natural connectivity among terrestrial and marine systems (Airoldi et al., 2005, 2015; Bulleri and Chapman, 2010; Bishop et al., 2017). It is estimated that by the year 2030, up to 12.5 million km^2 of natural habitat will potentially have been replaced by artificial habitats (Seto et al., 2011; Browne and Chapman, 2014) and there is a pressing need to find ways to mitigate this loss.

1.2. Ecological engineering

Environmentalists have traditionally disfavoured city growth and urbanisation. Interestingly, in recent years, there has been a turnaround in environmental thinking (Martine, 2008) based on the recognition of urban biodiversity and the potential for landscapes to support valuable ecosystem services (Bolund and Hunhammar, 1999). Through appropriate planning and management, cities can be designed to have reduced ecological footprints and even promote urban biodiversity and conservation (McKinney, 2002).

Ecological engineering (eco-engineering) is an emerging field which integrates engineering criteria and ecological knowledge to create more environmentally-friendly urban environments (Schulze, 1996; Bergen et al., 2001; Chapman and Underwood, 2011). A recent surge of literature is calling for a shift in the way artificial environments (often referred to as "grey" spaces) are perceived and designed to become "green" and "blue" spaces (Goddard et al., 2010; Kong et al., 2010; Sutton-Grier et al., 2015; Firth et al., 2016a; Mayer-Pinto et al., 2017). A range of different eco-engineering trials have now been trialled in coastal regions globally, with the vast majority being implemented in a few key hotspots (e.g. Europe, USA, Australia, Toft et al., 2013; Strain et al., 2017; Perkol-Finkel et al., 2017). As a result, there is now an increasing number of "proof-of-concept" methods emerging for a range of different types of coastal infrastructure (e.g. see Dyson and Yocom, 2015; Firth et al., 2016a for comprehensive reviews).

In the past "hard" (i.e. physical manipulation of artificial structures, Chapman and Blockley, 2009; Martins et al., 2010; Loke et al., 2014; Evans et al., 2016; Firth et al., 2016b; McManus et al., 2017) and "soft" (i.e. the incorporation of natural habitats for coastal defence Hanley et al., 2014; Ondiviela et al., 2014; Willemsen et al., 2016) approaches were typically applied on a local scale and treated as two separate approaches to eco-engineering of coastal habitats. More recently, the combination of hard and soft approaches has been trialled and has been referred to a "hybrid stabilisation" (Hashim et al., 2010; Bilkovic and Mitchell, 2013), "ecosystem-based flood defence" (Temmerman et al., 2013) or "hybrid-infrastructure" (Sutton-Grier et al., 2015).

It is important to note that all management strategies will be context-dependent and what works in one location may not work (or indeed be desirable) in another location (Chapman and Underwood, 2011; Lai et al., 2015); and consideration of the environmental setting and management goals is advocated (Firth et al., 2014). The ecosystem approach may be feasible in locations where sufficient space between urban areas and the coastline is available (Sutton-Grier et al., 2015) to accommodate the creation of natural ecosystems (e.g. shellfish and coral reefs, seagrass beds, saltmarshes, mangroves), that have the natural capacity to attenuate waves (Gedan et al., 2011; Shepard et al., 2011; Zhang et al., 2012), and can keep up with sea level rise by natural accretion of mineral and biogenic sediments.

1.3. The case of Malaysia and Penang Island

Malaysia has the highest urban population and is one of the fastest growing countries within Southeast Asia (World Bank, 2016a,b). Urbanisation in Malaysia began during the British administration in the Straits Settlements of Penang and Malacca