Environmental Pollution 214 (2016) 737–747

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Artificial breakwaters as garbage bins: Structural complexity enhances anthropogenic litter accumulation in marine intertidal habitats[☆]

Moisés A. Aguilera [a, b, *], Bernardo R. Broitman [b], Martin Thiel [a, b]

[a] Departamento de Biología Marina, Facultad de Ciencias del Mar, Universidad Católica del Norte, Larrondo, 1281, Coquimbo, Chile
[b] Centro de Estudios Avanzados en Zonas Áridas (CEAZA), Ossandón 877, Coquimbo, Chile

ARTICLE INFO

Article history:
Received 9 February 2016
Received in revised form
15 April 2016
Accepted 16 April 2016

Keywords:
Artificial reefs
Anthropogenic litter
Rocky intertidal
Structural complexity
Shoreline

ABSTRACT

Coastal urban infrastructures are proliferating across the world, but knowledge about their emergent impacts is still limited. Here, we provide evidence that urban artificial reefs have a high potential to accumulate the diverse forms of litter originating from anthropogenic activities around cities. We test the hypothesis that the structural complexity of urban breakwaters, when compared with adjacent natural rocky intertidal habitats, is a driver of anthropogenic litter accumulation. We determined litter abundances at seven sites (cities) and estimated the structural complexity in both urban breakwaters and adjacent natural habitats from northern to central Chile, spanning a latitudinal gradient of ~15° (18°S to 33°S). Anthropogenic litter density was significantly higher in coastal breakwaters when compared to natural habitats (~15.1 items m^{-2} on artificial reefs versus 7.4 items m^{-2} in natural habitats) at all study sites, a pattern that was temporally persistent. Different litter categories were more abundant on the artificial reefs than in natural habitats, with local human population density and breakwater extension contributing to increase the probabilities of litter occurrence by ~10%. In addition, structural complexity was about two-fold higher on artificial reefs, with anthropogenic litter density being highest at intermediate levels of structural complexity. Therefore, the spatial structure characteristic of artificial reefs seems to enhance anthropogenic litter accumulation, also leading to higher residence time and degradation potential. Our study highlights the interaction between coastal urban habitat modification by establishment of artificial reefs, and pollution. This emergent phenomenon is an important issue to be considered in future management plans and the engineering of coastal ecosystems.

1. Introduction

Urbanization is one of the most critical and increasing drivers of species loss and ecosystem degradation worldwide (e.g. Bulleri and Chapman, 2010; Pickett et al., 2014; Vitousek et al., 1997). The extent to which urban expansion can impact adjacent ecosystems has been related to different anthropogenic drivers like population density, city area, economic/industrial status and cultural profiles (Pickett et al., 2014; Thompson, 2015). An important impact of cities on their surrounding ecosystems is that they export substantial amounts of multiple pollutants (Pickett et al., 2014) and anthropogenic litter (Wright et al., 2013; Thompson, 2015).

In coastal ecosystems the rate of coastal zone modification by industrialization is increasing (Gittman et al., 2015; He et al., 2014). In economically growing countries, the presence of coastal artificial habitats will increase in future decades following demands of coastal reclamation for economic activities and tourism revenues (He et al., 2014; Hill, 2015; Perkins et al., 2015), and the construction of infrastructures like ports and residential buildings (Airoldi et al., 2015; Bulleri and Chapman, 2010; Gittman et al., 2015).

Intertidal and subtidal reefs that were constructed in association with urban areas (artificial reefs) harbour fewer species when compared with natural adjacent ones (e.g. Firth et al., 2013, 2014). Coastal artificial reefs built of granite boulders can provide shelter for some species assemblages (e.g. fishes Burt et al., 2011, 2012)) which seems to be related to its large-scale (dozens of cm to meters) structural complexity. However, these habitats are expected to have low spatial heterogeneity when compared to natural habitats given the lack of biogenic microhabitats (Aguilera et al., 2014; Firth et al., 2014, 2013).

☆ This paper has been recommended for acceptance by Maria Cristina Fossi.
* Corresponding author. Departamento de Biología Marina, Facultad de Ciencias del Mar, Universidad Católica del Norte, Larrondo, 1281, Coquimbo, Chile.
E-mail address: moises.aguilera@ceaza.cl (M.A. Aguilera).

http://dx.doi.org/10.1016/j.envpol.2016.04.058
0269-7491/

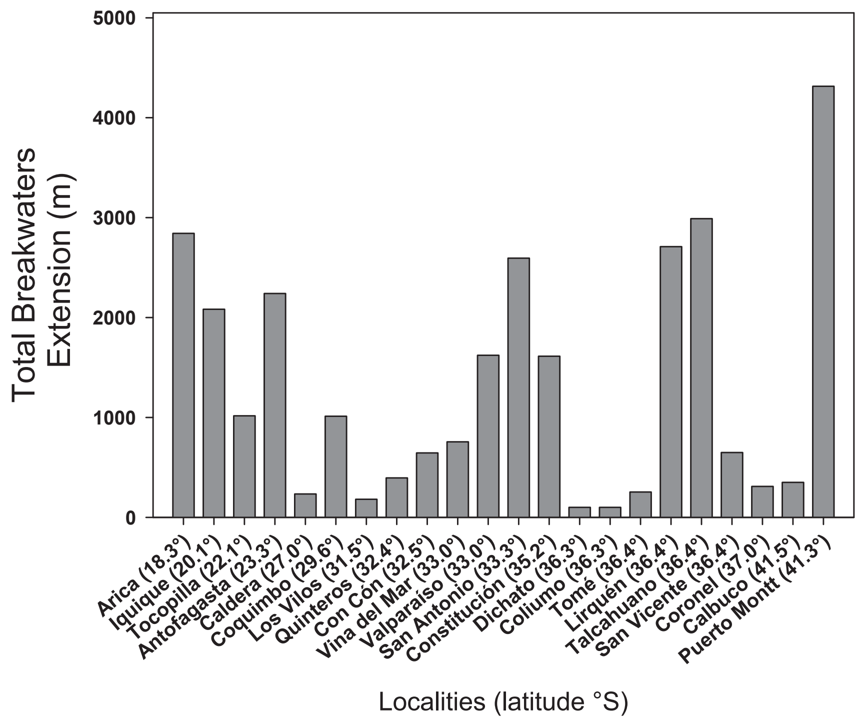

Fig. 1. Urban granite breakwaters linear length (meters) estimated at different localities across the Chilean coast (see Supporting information for details of the methodology). Latitude (°S) for each locality is shown in parenthesis.

Importantly, coastal habitat modification can 'open the door' to increased pollution by waste materials (e.g. plastic debris; Browne et al., 2015; Thompson, 2015). According to the specific spatial designs and anthropogenic uses of artificial reefs they may constitute hotspots for the accumulation of litter derived from human activities like recreational and commercial activities. Structural complexity of granite breakwaters created by spaces between boulders, or cavities among tetrapods, might enhance entrapment of anthropogenic litter (hereafter; AL), thereby favouring its accumulation. Commonly, anthropogenic litter accumulated on beaches cause a great risk to coastal biota (e.g. Browne et al., 2015; Thiel et al., 2011; Wright et al., 2013), with strong potential impacts on economy and human health (Sheavly and Register, 2007). However, the accumulation and residence time of AL in artificial intertidal reefs such as coastal breakwaters are unknown.

The South Eastern Pacific shores are polluted to varying degrees by anthropogenic litter (e.g. Bravo et al., 2009; Do Sul and da Costa, 2007). Studies of the composition of litter in coastal waters and on sandy beaches along the Chilean coast (see Bravo et al., 2009; Hinojosa and Thiel, 2009; Thiel et al., 2013) showed that most litter material had a local origin (Bravo et al., 2009; Hinojosa and Thiel, 2009; Thiel et al., 2013) when compared with other coasts where AL had more remote sources (e.g. Japan, Reimer et al., 2015). These studies have focused on AL accumulation along homogeneous natural shorelines, but little is known about the role of artificial infrastructures like breakwaters in AL accumulation. Economic and tourism development are the main drivers behind new coastal infrastructure (see for example; Bulleri and Chapman, 2010; Perkins et al., 2015), but protection against extreme natural events like storm surge and tsunamis are also important factors driving shoreline hardening (Gittman et al., 2015; Mimura et al., 2011). In this context, identifying the multiple impacts from urban infrastructures on coastal ecosystems can help managers and decision-makers to adopt more specific strategies for building and monitoring shoreline armouring (Scyphers et al., 2014).

As in other countries, shoreline hardening is expanding along the coast of Chile (Chilean Ministry of Public Work, MOP, and see Fig. 1). Most artificial structures are part of urban areas or incorporate public accesses that facilitate the use of shorelines for activities such as recreation or fishing. The purpose of this study was to examine if the abundance of AL is higher on urban coastal breakwaters than on adjacent, natural rocky platforms, and to determine if the structural complexity characteristics of both natural and artificial habitats influences AL distribution on them. We hypothesized that AL is more abundant on urban breakwaters compared with adjacent natural rocky platforms, following differences in patterns of structural complexity between habitats. Coastal human population density is commonly expected to contribute to an increase of AL accumulating in natural habitats nearby, with breakwater spatial extension potentially being directly related to the total accumulation of AL. Hence, we also examined the relationship between total AL density in breakwaters and local human population density and/or breakwater length.

2. Materials and methods

2.1. Details of the study region

The coast of Chile has an extension of about 6435 km, with more than 45% of the Chilean population living in the coastal zone (INE, 2012). Armouring of the coastal area, from 18°S to 41°S, is one of the most important management conflicts, and is proceeding either to expand human settlements, as disaster prevention/mitigation infrastructure or for the development of new activities related to tourism, deep-water harbours or leisure. Coastal cities in northern to central Chile (18°S to 33°S) develop economic activities related to tourism, and harbours are dedicated to fishing and shipping. Specifically, northern cities (18°–30°S) are located within the boundaries of the Atacama Desert characterized by low rain frequency