Marine Pollution Bulletin 126 (2018) 516–524

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Spatio-temporal variation of anthropogenic marine debris on Chilean beaches

Valeria Hidalgo-Ruz[a,b], Daniela Honorato-Zimmer[a], Magdalena Gatta-Rosemary[a], Paloma Nuñez[c], Iván A. Hinojosa[a,d,e], Martin Thiel[a,c,d,*]

[a] Facultad de Ciencias del Mar, Universidad Católica del Norte, Larrondo 1281, Coquimbo, Chile
[b] Colegio San Adrián de Quilicura, Lo Ovalle 275, Quilicura, Santiago, Chile
[c] Centro de Estudios Avanzados en Zonas Áridas (CEAZA), Larrondo 1281, Coquimbo, Chile
[d] Millennium Nucleus Ecology and Sustainable Management of Oceanic Island (ESMOI), Coquimbo, Chile
[e] Facultad de Ciencias, Departamento de Ecología, Universidad Católica de la Santísima Concepción, Alonso de Ribera 2850, Concepción, Chile

A R T I C L E I N F O

Keywords:
Anthropogenic marine debris
Beaches
Citizen science
Temporal trends
Antofagasta
Economic development

A B S T R A C T

We examined the hypothesis that in an emerging economy such as Chile the abundances of Anthropogenic Marine Debris (AMD) on beaches are increasing over time. The citizen science program *Científicos de la Basura* ("Litter Scientists") conducted three national surveys (2008, 2012 and 2016) to determine AMD composition, abundance, spatial patterns and temporal trends. AMD was found on all beaches along the entire Chilean coast. Highest percentages of AMD in all surveys were plastics and cigarette butts, which can be attributed to local sources (i.e. beach users). The Antofagasta region in northern Chile had the highest abundance of AMD compared with all other zones. Higher abundances of AMD were found at the upper stations from almost all zones. No significant tendency of increasing or decreasing AMD densities was observed during the 8 years covered by our study, which suggests that economic development alone cannot explain temporal trends in AMD densities.

1. Introduction

Anthropogenic marine debris (AMD), mostly composed of plastics, has been characterized as a global and persistent environmental problem that has considerably increased over the last decades (Galgani et al., 2015). The accumulation of AMD has multiple impacts that can be categorized into three types: biological, ecosystemical, and socio-economical (Kuo and Huang, 2014). Biologically, marine organisms can be affected by AMD through ingestion and entanglement (Gregory, 2009; Kühn et al., 2015), which can lead to physical and chemical damage and even death (Rochman et al., 2013; Vegter et al., 2014). In terms of ecosystems and biogeography, AMD may serve as dispersal vehicle for invasive species, which can modify local ecosystems (Amaral-Zettler et al., 2015; Kiessling et al., 2015; Thiel and Gutow, 2005). With respect to socio-economic factors, since coastal AMD is aesthetically detrimental, it can affect the perception of beach-users and eventually coastal tourism, requiring high beach cleaning costs and causing losses in revenue (Jang et al., 2014; Newman et al., 2015; Santos et al., 2005).

Marine debris can be classified according to two main source categories: ocean- and land-based debris, depending on where AMD entered the marine environment (Galgani et al., 2015). Ocean-based AMD sources include waste from shipping, fishing, oil platforms, and aquaculture (Astudillo et al., 2009; Edyvane et al., 2004; Hinojosa and Thiel, 2009; Hong et al., 2014; Sheavly and Register, 2007; Watters et al., 2010). Land-based AMD might enter the marine environment by rivers, outflow from industries, harbors, unmanaged landfills, sewage waters, extreme events (tsunamis, hurricanes), or through direct littering by beach visitors (Aguilera et al., 2016; Goto and Shibata, 2015; Green et al., 2015; Khordagui and Abu-Hilal, 1994; Rech et al., 2014). It has been estimated that > 8.4 million tons of plastic waste enter the oceans annually from land-based sources (Jambeck et al., 2015).

A major part of AMD studies have been conducted in coastal areas, because of their proximity to sources, facility of access, and due to potential aesthetic impacts (Galgani et al., 2015). These studies provide insights about dominant types of AMD, their abundance, potential origins and accumulation rates. Nevertheless, these characteristics might be highly variable, e.g. due to the influence of urban cities, coastal use, river flushing, and the geomorphology, hydrodynamics and oceanography of each coastal area (Galgani et al., 2015; Moriarty et al., 2016). Consequently, studies with standardized methods that extend over a certain region and time are needed to evaluate the spatio-

* Corresponding author at: Universidad Católica del Norte, Biología Marina, Larrondo 1281, Coquimbo, Chile.
E-mail address: thiel@ucn.cl (M. Thiel).

https://doi.org/10.1016/j.marpolbul.2017.11.014
Received 24 July 2017; Received in revised form 10 November 2017; Accepted 10 November 2017

temporal variability of AMD abundances and composition (Browne et al., 2015; Hong et al., 2014; Moreira et al., 2015; Thornton and Jackson, 1998).

Temporal changes of AMD have been studied over different spatial scales, but most of them have been done on a small scale, such as single beaches, bays or islands (e.g. Agustin et al., 2015; Tourinho and Fillmann, 2011), or during shorter periods of time (e.g. Madzena and Lasiak, 1997; Storrier et al., 2007). Only few studies extend over a large temporal and spatial scale (for examples see Gago et al., 2014; Nelms et al., 2016; Ribic et al., 2010, 2011; Schulz et al., 2015a, 2015b). The generated results are contrasting: in some cases trends of AMD densities can be identified, either increasing in Indonesia (Willoughby et al., 1997), decreasing in Australia (Edyvane et al., 2004), or being consistent over time in Canada and Scotland (Lucas, 1992; Storrier et al., 2007). But in other cases, the results are highly variable and no temporal tendencies are observed (Cheung et al., 2016; Eriksson et al., 2013; Nelms et al., 2016). Consequently, no consistent global long-term trend has been identified for AMD densities on beaches (Browne et al., 2015).

Changes of AMD abundance over time might be related to the socio-economic and educational conditions of a country; pro-environmental behavior (e.g. adequate waste disposal) is generally higher in developed countries (Morren and Grinstein, 2016). Developed economies might have educational programs to increase environmental awareness in the population, such as environmental campaigns, frequent clean-up campaigns (e.g. NOAA, Ocean Conservancy), and well-established recycling infrastructure (Borja et al., 2011; Veiga et al., 2016). On the other hand, developing countries might focus on economic growth, often at the expense of environmental care. Environmental degradation might increase as the economy grows, up to a point where economic development leads to higher environmental awareness, and amounts of AMD are likely to be lower on beaches of developed countries, with a tendency to decrease over time. For an emerging economy such as Chile we should thus expect that the amounts of AMD of beaches are high, with a tendency to increase over time.

The Chilean citizen science program *Científicos de la Basura* ("litter scientists") has been studying the problem of AMD in the SE Pacific for approximately 10 years, conducting the first national survey of AMD on beaches in 2008 (for further details of the program, see Eastman et al., 2014). The mean density of AMD was by that time 1.8 items m^{-2} (which included wood and "others") and the most common AMD types were plastics, cigarette butts and glass (Bravo et al., 2009). Nevertheless, these results represented only a first snapshot of the general situation, and there was no information on the spatio-temporal dynamics of beach litter in the SE Pacific. Therefore, the national AMD survey was repeated during the years 2008, 2012 and 2016 along the entire Chilean coast, in order to (1) determine composition, (2) estimate abundance and spatial patterns, and (3) explore temporal trends of AMD densities on beaches from the SE Pacific.

2. Materials and methods

2.1. Study area

The Chilean coast covers most of the South East Pacific, extending over ~4500 km from 18°S up to the southern tip of the continent at 56°S. The coast is composed mainly of rocky shores and sandy beaches between 18° and 42°S, and extensive channels and archipelagos in the Patagonian region south of ~42°S (Miloslavich et al., 2011). In order to guarantee a representative sampling of the Chilean coast, we invited participants from specific locations that are more or less evenly distributed along the coast. During each AMD survey between 29 and 40 beaches were sampled, with a total of 69 different beaches for the three surveys (Fig. 1a). Locations from the oceanic islands, Rapa Nui and Juan Fernandez, were only included during the AMD survey of 2016. At each selected location, beaches were chosen depending on the importance of the beach for the community, ease of access, and proximity to the participating schools. The selected beaches ranged from urban to semi-urban beaches with sandy sediments.

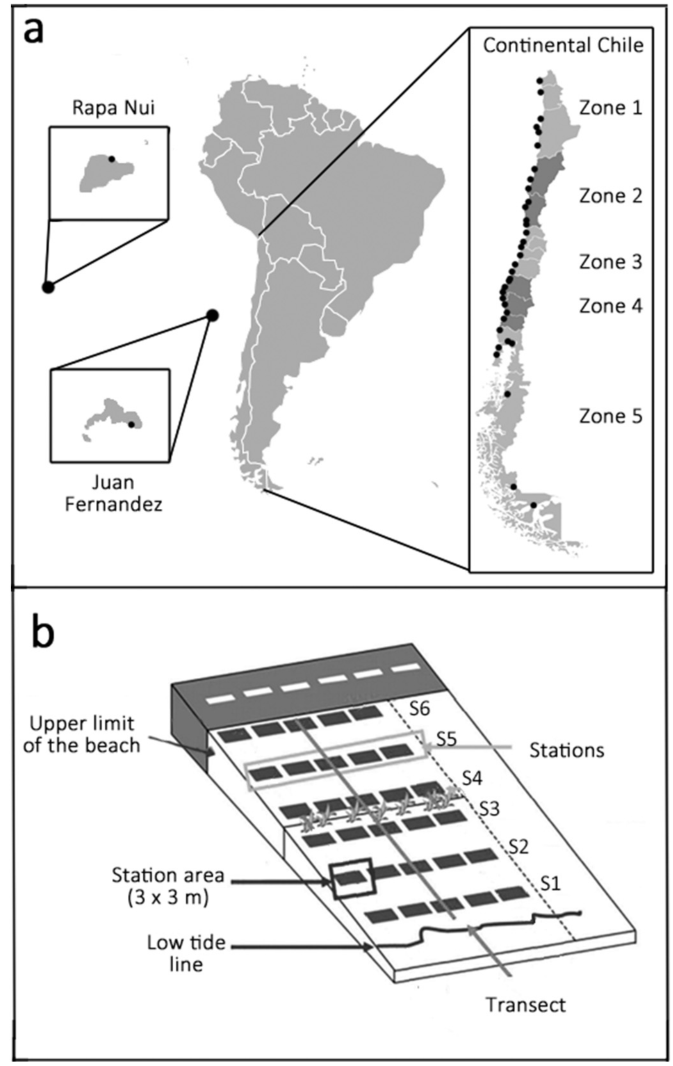

Fig. 1. (a) Beaches sampled during the three AMD surveys along the Chilean continental coast (within their five zones) and islands. (b) Schematic overview of beach survey design. S1 to S6 indicate the number of station per transect, in which station 1 (S1) represents the station closer to the low tide line, and station 6 (S6) corresponds to the station closer to the highest site of the beach.

2.2. Citizen science participation

2.2.1. Recruitment

The general coordinator of the program contacted and invited prospective schools from selected locations with potential interest in the project. Once each institution agreed to participate, one specific person acted as the responsible local person (teacher or school director) who was in charge of keeping contact with the general coordinator of the Program. Whenever possible, the schools were supported by local city governments, corporations, and local environmental organizations, in terms of transportation and materials for the activity. A total of 3551 students and 84 teachers from 99 schools participated in the three surveys, with the support of 46 regional advisors (some of which participated in two or all three survey years) (Table 1). Surveys were conducted during August–September of 2008, April–May of 2012, and June–July of 2016, i.e. during austral fall or winter.