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Beach litter and woody-debris colonizers on the Atlantico department Caribbean coastline, Colombia

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ABSTRACT

Some marine invertebrates can inhabit floating substrates, and raft over long distances, becoming a significant environmental problem in terms of alien species and habitat disruption. On the Atlantico Department beaches (Colombia) woody debris and plastic litter dominate (86%) the types of refuse on the beaches with their densities ranging from 0.82–1.72 items m^{-1}. Such litter and woody debris generate the optimal conditions for floating colonizers. In this work, 26 beaches were surveyed, and 16 of them (62%) were found to have marine fauna using litter and woody debris as a substrate for potential rafting and dispersal. Serpulidae polychaete tubes, goose barnacles *Lepas* (*Anatifa*) *anserifera* Linnaeus, 1767, and the bryozoans *Arbopercula tenella* (Hincks, 1880), *Arbopercula angulata* (Levinsen, 1909), plus three unidentified species were found colonizing woody debris, seeds, plastic and glass bottles. These findings of woody debris and litter facilitating the arrival and dispersal of non-native species on this coast, demonstrate that preventive management of such refuse in coastal habitats goes beyond simply preserving coastal esthetics.

1. Introduction

Litter is one of the most critical problems currently facing marine environmental management. Massive amounts of refuse, especially plastics, arrive every day to the ocean and world beaches (Ryan et al., 2009; Kühn et al., 2015; Jambeck et al., 2015). Litter magnitudes are so high that worldwide estimates reveal that during 2010 at least 12.7 million metric tons of plastic litter came into the oceans, and that these values would be increased in coming years (Bergmann et al., 2015; Jambeck et al., 2015; Geyer et al., 2017).

The primary litter inputs are from land-based sources (e.g., rivers and storm-water runoff, McCormick and Hoellein, 2016; Rangel-Buitrago et al., 2016), as well as sea-based sources (e.g., ship waste disposal, Ryan et al., 2009; Reisser et al., 2013). Once in the oceans, litter can be fragmented and follow different pathways. Depending on size, composition, and other factors, litter can drift, sink, accumulate on the seafloor and coastline, or as nano-particles enter into the trophic webs (Cózar et al., 2014).

Woody debris includes all pieces of wood > 2 cm diameter that fall naturally or are introduced into river basins, lodging in the river channel for subsequent movement until its final deposition. The smaller material, including twigs, seeds, leaf litter, along with smaller branches and trunks are usually referred to as brushwood or Coarse Woody Debris (CWD). The term Large Woody Debris (LWD) is reserved for larger timber, including substantial branches and trunks, root boles, and whole trees. Other flora and fauna can attach to, or colonize surfaces of such debris.

Litter and woody debris has the ability drift vast distances across the world (Maximenko et al., 2012; Williams et al., 2017). Therefore, debris rafting can transport a great variety of species, facilitating the range expansion of non-native species and transporting fouling communities into new regions (Winston et al., 1997; Molnar et al., 2008; Gregory, 2009; Goldstein et al., 2014; NOOA, 2017). For this reason, litter is considered here in terms of its potential pathways for the introduction of invasive species by means of the rafting process (Molnar et al., 2008; NOOA, 2017).

It is well known that litter and woody debris can play an essential role in the non-native species colonization process into an area (Rech et al., 2016). Litter can move over long distances and favor first introductions into a new region, and over short distances contribute to secondary spreading within an already affected area. The rafting process is considered as an “other route of invasion”, and despite several examples of long and medium-distance transport of biota in different regions, the real contribution of litter to the introduction and spreading

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of non-native species is mostly unknown (Katsanevakis and Crocetta, 2014; Vegter et al., 2014; Kiessling et al., 2015).

Some rafted species can be a real hazard to biodiversity, human health and even have the ability to severely affect economic activities (e.g., fishing). Rafted species are sessile, and encrusters are adapted to live in the open ocean and under different environmental conditions. These species include, but are not limited to, arthropods such as barnacles of *Lepas* spp., membraniporid bryozoans, poriferans, chordates such as colonial ascidians, cnidarians such as hydroids and anemones, some sessile species of Foraminifera, Mollusca and Polychaeta, as well as, macroalgae, among others (Winston et al., 1997; Goldstein et al., 2014; Gündoğdu et al., 2017).

The potential harm of non-native species into other regions is definitive. Once non-native species are set out in a new habitat, they may outcompete the native fauna, causing severe imbalances in the ecosystem, and are almost impossible to control or eradicate (Thresher and Kuris, 2004; Molnar et al., 2008; Kühn et al., 2015).

The Atlantico Department coastline is a developing region divided into five municipalities with 1,278,822 inhabitants. This population represents 3% Colombia's total and is mainly concentrated at Barranquilla, the largest and most populated city on Colombia's Caribbean coast. This area is located next to the Magdalena River Delta, the most important tributary of the Caribbean Basin and the entire country. Preliminary studies developed by Rangel-Buitrago et al. (2013, 2016, and 2017) and Williams et al. (2016a), point out that the Atlantico Department coast has a critical environmental issue related to the high abundance of woody debris and litter. Under the conditions of this coastline, the transport and accumulation of litter are continuously converting the shoreline into a perfect setting for non-native species colonization by means of rafting.

This paper presents a study of 26 beaches of the Atlantico Department, Caribbean coast, with the goal of defining a first approximation to the character of rafted marine fauna in beach refuse. Results presented in this work allow a better understanding of the susceptibility of this coast to invasive species by means of the analysis of existing interactions between litter, woody debris and colonizers. The results should be beneficial to local or national coastal managers and planners, who need to improve the baseline information for monitoring and controling the arrival pathways of non-native and invasive species in the Southern Caribbean region.

2. Study area

This work sampled 26 beaches distributed along a 72 km coastal strip of the Atlantico Department; Caribbean coast of Colombia (Table 1 and Fig. 1). Coastline orientation is NE–SW with sporadic sectors oriented E-W that have generated alternate stretches of medium-long linear segments with Z-curved bays.

Quaternary interactions among tropical climate, oceanographic processes, and tectonic activity gave rise to a great diversity of unstable, littoral geomorphologic features characterized by terrigenous sandy beaches, sand spits, Tertiary rocky coasts, coastal plains and coastal lagoons, dunes and mangrove swamps. The recent coastline evolution is strongly influenced and linked to the Magdalena River Delta natural and anthropogenic modifications (Anfuso et al., 2015; Rangel-Buitrago et al., 2016).

Average wind velocity usually has values lower than 12 m/s. Lower wind values are observed in the September–November period related to winds blowing from E, while higher velocity values are associated with winds blowing from the NE during the dry period (Rangel-Buitrago et al., 2017).

Along the study area, average significant wave height is 1.6 m and peak period average is 7 s. From November to July, the wave system along the study area is dominated by NE swells; for the remainder of the time waves from NW, WSW, and even SW occur. This seasonal variation of wave direction corresponds with a decrease in significant wave heights, with the lowest values occurring between August and October (≤ 1.5 m); whereas the highest energy conditions occur from November to July when wave heights can exceed 2 m (Rangel-Buitrago et al., 2015). Extreme wave events, mainly Hurricanes, occur from June to November affecting the study area with heavy rains and high winds. During January–March period, cold fronts cause strong swell waves whose impact may be increased by trade winds blowing from ENE.

Table 1
Location and general types of the investigated beaches.

ID	Name	Location	Type
A1	Punta Roca	Puerto Colombia	Rural
A2	Salgar	Puerto Colombia	Village
A3	Pradomar - Resort	Puerto Colombia	Resort
A4	Pradomar - Urban	Puerto Colombia	Urban
A5	Puerto Colombia - Nort	Puerto Colombia	Urban
A6	Puerto Colombia - Urban	Puerto Colombia	Urban
A7	Puerto Velero - Exposed	Tubara	Remote
A8	Puerto Velero - Resort	Tubara	Resort
A9	Puerto Velero - Punta Velero	Tubara	Village
A10	Puerto Velero - Mirador	Tubara	Village
A11	Caño Dulce	Tubara	Village
A12	Puerto Caiman	Tubara	Remote
A13	Playa Mendoza	Tubara	Resort
A14	Turipana	Tubara	Resort
A15	Tubara	Tubara	Rural
A16	Palmarito	Tubara	Village
A17	Playa Linda	Tubara	Remote
A18	Santa Veronica - Cajacopi	Juan De Acosta	Resort
A19	Santa Veronica	Juan De Acosta	Urban
A20	Salinas del Rey	Juan De Acosta	Village
A21	Loma de Piedra	Juan De Acosta	Remote
A22	Aguamarina	Juan De Acosta	Resort
A23	Bocatocinos	Juan De Acosta	Rural
A24	Punta Astilleros	Juan De Acosta	Rural
A25	Salinas de Galerazamba	Piojo	Remote
A26	Galerazamba	Piojo	Village

Longshore sand drift and sediment transport have a dominant southwestward component. Some minor reversals (to the northeast) can occur during rainy periods when southerly winds prevail in some areas and set up short, high-frequency waves able to generate significant erosion along cliffed and sandy beaches. Tides are mixed semi-diurnal, with maximum amplitudes of 65 cm (Andrade, 2008).

All beaches surveyed are located SE of the Magdalena River Delta which is the most extensive river system located in Colombia with 1612 km in length. Its drainage basin covers 257,430 km^2 (25% of the Colombian territory) and occupies 65% of total Colombian area. This is one of the most critical fluvial systems of the world thanks to its 230 km^3 of annual water yield. This basin is the primary source of water for the country and one of the most biologically diverse areas in the world (ELOHA, 2016).

3. Methodology

Twenty-six beaches belonging to the Atlantico Department coastline were surveyed following the UNEP (2009) method (Fig. 1; Table 1). For each beach a study site was selected with an area of 100 m length × 50 m width located in the central part of the beach, and between the low tide mark and the backshore, the latter coinciding with vegetation line, dune foot, or anthropogenic features such as fences, seawalls, etc.

Due to the great amount and variety of observed refuse items, beach litter (that includes woody debris) was sampled along a line named "sampling unit." Within each sampling unit, all litter was collected, counted and categorized. Litter items were collected and separated based on the type of material and its buoyancy properties according to the Rech et al. (2014) classification. All elements were counted to measure and compare the total amount of litter available in each beach. Results were presented as a number of litter items and associated