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Anthropogenic marine debris over beaches: Spectral characterization for remote sensing applications

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ABSTRACT

Anthropogenic Marine Debris (AMD) is one of the most important pollutants in the oceans. Millions of tons of debris across oceans have created a critical environmental problem. This study presents a novel method aimed to improve the identification of macroplastics through remote sensing over beaches, combining AMD hyperspectral laboratory characterization and digital supervised classification in high spatial resolution imagery. Several samples were collected from the Chiloé Island beaches, Chile. Spectral signature samples and physical properties were assessed through laboratory work. HyLogger3® (CSIRO), PS-300 Apogee and ASD Field Spec hyperspectral systems were used to characterize each sample. Using those measurements, a spectral library was generated by processing, filtering and sorting the spectral data gathered, determining distinctive spectral bands for digital classification. By using this spectral library, a digital classification method was implemented over World-View 3 imagery, covering the three beaches selected as test sites. Distinct classification methods and geospatial analyses were applied to determine land cover composition, aimed for the detection of Styrofoam and the rest of anthropogenic marine debris. Four field campaigns were carried out to validate the AMD classification and mass retrievals, performed on > 300 ground based points. The AMD hyperspectral library was successfully applied for an AMD digital classification in satellite imagery. Support Vector Machine method showed the best performance, resulting in an overall accuracy equivalent to 88% and over 50 tons of debris estimated on the pilot beaches. These results prove the feasibility of quantifying macro-AMD through the integration of hyperspectral laboratory measurements and remote sensing imagery, allowing to estimate anthropogenic influence on natural ecosystems and providing valuable information for further development of the methodology and sustainable AMD management.

1. Introduction

From the north to the south pole, anthropogenic marine debris (AMD) has accumulated on coastlines, in estuaries, marshes, ocean surfaces and even down into its depths (Thompson et al., 2009; Woodall et al., 2014). AMD represents a concern for many disciplines and communities (Bergmann et al., 2015; Nelms et al., 2017; UNEP, 2009). Studies on the composition of AMD in different regions of the world indicate that plastics represent between 50% and 90% of the total, which varies according to the proximity to the sources of pollution (Derraik, 2002; Galgani et al., 2010; Pham et al., 2014). Moreover, global plastic production soared from 5 million tons to 311 million tons between the years 1960 and 2014 (PlasticsEurope, 2012, 2015).

Some examples of how AMD impacts the environment and the fauna includes entanglement and ingestion, which can lead to the injury and/or death of turtles, cetaceans, seals, birds and fishes (Rochman and Browne, 2013; Gall and Thompson, 2015; Hardesty et al., 2015; Newman et al., 2015; Lavender, 2017; Nelms et al., 2017; Chubarenko and Stepanova, 2017; Unger et al., 2016). AMD can transport organic and non-organic pollutants across beaches and oceans (Barnes, 2002; Barnes and Milner, 2005; Nelms et al., 2017; Chubarenko and Stepanova, 2017; Romera-Castillo et al., 2018), on the seafloor it provides shelter for small animals and can reduce the gas exchange between the water column and the sediment, displacing multiple benthonic species (Watters et al., 2010; Lavender, 2017). It also impacts human communities with the loss of aesthetic value and the reduction

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of economic activities on beaches and other public locations (Cheshire et al., 2009). It is widely thought that AMD can be a major factor in the possible collapse of the ocean health, being a global stress together with others transformations, such as rising sea levels, warming waters, and changes in the ocean chemistry (Cheshire et al., 2009; ICC, 2009). However, the long-term impact of marine pollution on the deterioration of ecosystems and in the loss of biodiversity is still uncertain (Hyrenbach and Kennish, 2008; Mouat et al., 2009).

In Chile, numerous studies were carried out to identify, quantify and describe AMD on beaches and in coastal waters which have shown that anthropogenic marine debris is a problem along the entire coast (Bravo et al., 2009; Hidalgo-Ruz and Thiel, 2013; Hinojosa and Thiel, 2009; Hinojosa et al., 2011). Some of the studies highlight the abundance of plastics, either because they were found at all the points under study, or because they made up over 80% of the total observed AMD (Bourne and Clarke, 1984; Bravo et al., 2009; Hinojosa and Thiel, 2009; Ivar do Sul and Costa, 2007; Thiel et al., 2003). The abundance and composition of AMD found in southern Chile might be related to the aquaculture activity in the area (Hidalgo-Ruz and Thiel, 2013; Hinojosa and Thiel, 2009), which requires the use of plastics such as ropes, floats, and buoys. Eventually, part of the materials breaks off from the structures and can float away for long distances as floating marine debris (Astudillo et al., 2009; Jara and Jaramillo, 1979; Thiel et al., 2003). How far they travel depends on ocean currents and winds, as well as how long each object stays afloat, which is usually reduced by water saturation, biofouling, and stranding on beaches (Astudillo et al., 2009; Fujieda and Sasaki, 2005; Gregory and Andrady, 2003).

In Los Lagos region of Chile, rapid growth in aquaculture since the 1980s has had undesired side effects, such as beaches polluted with AMD, especially on the Island of Chiloé (Kiessling et al., 2017). According to DIRECTEMAR reports (2016), 141.8 linear km of coastline on Chiloé's channels and fjords are affected by AMD, mainly in the form of polystyrene buoys (i.e. Styrofoam), plastic ropes, and remnants of nets or meshes used in aquaculture. The region is currently home to 39% of Chile's salmon production (*Salmo salar*, a foreign species to the marine ecosystem of Chiloé) and 99.9% of its mussel production (*Mytilus chilensis*), making it the region with the highest intensity and density of salmon and mussel farming in Chile (Hinojosa and Thiel, 2009; SERNAPESCA, 2015). This relates directly to the large quantities of AMD found in Chiloé, which vary between 10 and 50 Items/km^2 in the sea, and exceed the 200 Items/km^2 in areas such as the Desertores Islands (Hidalgo-Ruz and Thiel, 2013; Hinojosa and Thiel, 2009; Ivar do Sul and Costa, 2007).

Furthermore, due to the remoteness of the areas where AMD can potentially accumulate, such as uninhabited and geographically isolated islands, refined and widely applicable estimation methods must be developed (Convey et al., 2002; Morishige and McElwee, 2012). The methods for estimating AMD quantities and distribution can be grouped into the following categories: surveying on beaches, surveying from vessels, trawl sampling, surveying from diving, and surveying via satellite or aerial remote sensing (Brainard et al., 2000). To apply these, considerable logistics and economic resources are required, with remote sensing as the less constricted in spatial coverage and temporal resolution (Brainard et al., 2000; Driedger et al., 2015; McElwee et al., 2012; Pichel et al., 2012). However, remote sensing it is not widely developed for the detection of AMD in the marine environment (Driedger et al., 2015), and their identification through classification algorithm is still a challenge due to their variety and disposal in different site conditions and backgrounds (Morishige and McElwee, 2012).

Flow models may also be included in the previous categories, as a method that predicts distribution and quantities of AMD, considering the influence of oceanic flows in the trajectory and accumulation through simulation algorithms (Derraik, 2002; Sepulveda et al., 2011).

In remote sensing one of the primary detection methods are supervised classifications, which has multiple applications including the determination of environmental damage, monitoring land use, urban planning, and tree species distribution (Michez et al., 2016; Zhong and Zhang, 2012). It has also been used for the detection of hydrocarbons as plastics (Driedger et al., 2013; Hasituya et al., 2016; Hörig et al., 2010; Kühn et al., 2004; Novelli and Tarantino, 2015; Pichel et al., 2012; Slonecker et al., 2010), but not for AMD in the natural environment with high spatial resolution satellite imagery. It should be noted that to support the proper identification of each cover, supervised classifications require training data with valuable spectral information (Egorov et al., 2015).

Considering plastics as the usual AMD type, and its different size classes: microplastics (1 to < 5 mm), mesoplastics (5 to < 25 mm), and macroplastics (> 25 mm) (Barnes, 2002; Lee et al., 2013), the main objective of this work is to estimate the amount of macroplastics AMD on beaches through the use of very high spatial resolution imagery, and the hyperspectral characterization of AMD in the laboratory. Here we present an application to determine the amounts of AMD in a large scale over the Island of Chiloé, generating coastal maps of AMD, information that may be used for debris management strategy in the coordination of beach cleaning and decision making regarding the current status of AMD in Chiloé.

2. Study area and data

The Chiloé Archipelago is located in the northwestern area of Chilean Patagonia as an extension of the coastal mountain range located between 41° 48′–43°22′ S and 74° 14′–73° 20′ W, approximately. The Isla Grande of Chiloé is separated from the mainland by the Gulf of Ancud to the east, by the Corcovado Gulf to the south, and is surrounded by the Pacific Ocean to the west. Tourism and fishing, especially aquaculture, have become prevalent on the island of Chiloé as a result of the local economic growth, which has led to a major shift in human settlements and to the expansion of the population limits, with insufficient land planning that might provide adequate accessibility and connectivity (Andrade et al., 2000).

The climate in the area is temperate and humid, with increased rainfall and maritime influence towards the southern and western parts of the island. The annual precipitation for Isla Grande is 2073 mm, spread out over the year with maximums in the winter months. The meteorological station in the provincial capital Castro records an accumulate average of 1891 mm per year (74–289 mm in February and June respectively) and an average temperature of 10.5 °C (14–6.8 °C in the months of January and July) (Pesce and Moreno, 2014).

For this work, we selected the inner sea of Chiloé which includes Detif, Punta Apabón, and Punta Mallil-Cuem beaches located in the communes of Puqueldón and Quinchao, respectively, both in the Los Lagos Region (Fig. 1). The sector has been recognized by the Aquatic Environment group of the Dirección General del Territorio Marítimo y de Marina Mercante ("General Directorate of Maritime Territory and Merchant Marine") (DIRECTEMAR), as a site of coastal debris accumulation (DIRECTEMAR, 2014, 2016).

3. Method

3.1. Sample collection

Between January and February 2017, fieldwork was carried out on the beaches in the study area by collecting various AMD macroplastics, such as Styrofoam, plastic buoys, ropes, general plastics (e.g. bottles, containers, fragmented plastics) and any other type of object with a coverage > 0.5 m^2. These AMD selection criteria were estimated in campaigns through frequency, abundance and superficial area, from the intertidal zone until the presence of dense vegetation (ending of a stone-sand substrate). In addition, samples of natural elements such as algae, sands, stones and shells were acquired to characterize the natural substrate on the beaches. Over 144 samples were collected on the beaches of Punta Mallil-Cuem, Detif and Punta Apabón, as shown in