Continental Shelf Research 144 (2017) 112–119

Contents lists available at ScienceDirect

Continental Shelf Research

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

Benthic litter distribution on circalittoral and deep sea bottoms of the southern Bay of Biscay: Analysis of potential drivers

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ARTICLE INFO

Keywords:
Marine litter
Benthic litter
Distribution
Bay of Biscay
Continental shelf
Plastic
Fishing
MSFD

ABSTRACT

We analyze marine litter densities in soft bottoms of the southern Bay of Biscay using five years of demersal trawling data (2006–2010). Marine litter densities amounted to 43 ± 33 kg km^{-2} and 74 ± 28 items km^{-2}, with plastics and fisheries derived litter being the most widespread categories. Litter densities generally decreased along the water depth axis. To identify possible drivers for the observed litter distribution we performed a generalised additive model, which explained 14.8% of the variance and pointed to densely populated areas, number of fishing ports, geographical sector and fishing activity as the main explanatory factors. The most important driver for the benthic litter distribution was human population, as litter density linearly increased along this variable. Similarly, the number of ports in neighbouring areas had a positive effect on litter densities. Fishing effort had a negative and non-linear effect on benthic litter density which could be explained by litter delocalization during fishing operations. We hypothesise that litter might accumulate preferentially on the periphery of rocky bottoms, out of reach for our sampling methodology. Litter distribution differed among geographical sectors, pointing to other variables such as shipping traffic and oceanographic currents, which were not explicitly considered in the analysis. Our study sets a reference level for benthic macro-litter in the southern Bay of Biscay and identifies factors driving its distribution, which can be extrapolated to other continental shelf seas. Our findings lay the foundations to develop measures aiming to reduce macro-litter densities on the seafloor.

1. Introduction

Litter accumulation in the marine environment is a growing problem whose implications have not been comprehensively assessed to date. However, the concern on marine litter pollution has risen during the last decades, as indicated by the growing number of scientific publications on marine litter (Ryan, 2015) and its inclusion in the political agenda. Litter can be considered ubiquitous in the marine environment as it is present in the most diverse marine environments (Ramirez-Llodra et al., 2013; Pham et al., 2014; Galgani et al., 2015) either floating, stranded along the coast or deposited on the seabed (Galgani et al., 2015).

Regarding litter on the sea floor, existing studies are commonly based on bottom trawling (Galgani et al., 1995a, 1996, 2000; Stefatos et al., 1999; Moore and Allen, 2000; Lee et al., 2006; Koutsodendris et al., 2008; Keller et al., 2010; Sánchez, 2013; Strafella et al., 2015; Neves et al., 2015; Moriarty et al., 2016) although non-intrusive methodologies such as remote operating vessels (ROV) are gaining relevance (e.g. Mordecai et al., 2011 Schlining et al., 2013; Pham et al., 2014, Melli et al., 2017). These studies have described litter distribution along quite wide areas, elucidating, in some cases, the possible origin amongst ocean or land based sources. Regarding litter composition, plastic items constitute the majority of marine litter worldwide (reviewed in Derraik, 2002), although metallic objects, fishing gear and glass have also been commonly reported (Moore and Allen, 2000; Lee et al., 2006; Keller et al., 2010; Strafella et al., 2015). However, in spite of the scientific consensus considering marine litter as a major threat to ecosystems (Depledge et al., 2013; Pham et al., 2014), the main drivers determining the current litter distribution on shelf seas remain practically unknown.

The European Marine Strategy Framework Directive (2008/56/EC) identified marine litter as one of the necessary descriptors for describing environmental status within European marine waters, and its distribution and spatial-temporal trends on the sea floor is one of the criteria. Although the state of knowledge on the effects of marine litter on ecosystems is limited, a precautionary approach pleads for reducing the amount of marine litter in the environment. The most widely acknowledged effects of marine litter are due to the ghost fishing

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http://dx.doi.org/10.1016/j.csr.2017.07.003
Received 3 October 2016; Received in revised form 29 June 2017; Accepted 7 July 2017
Available online 08 July 2017
0278-4343/

activity of derelict fishing gear, which continue to fish once lost or abandoned and can entangle a wide range of animals from invertebrates to marine mammals (Baeta et al., 2009; Gregory, 2009; Gilardi et al., 2010), as well as gaining aggregation capacity for potential predators (Matsuoka et al., 2005). Ingestion of macro-litter by marine mammals, turtles and birds is also a recognized risk of marine litter pollution (e.g., reviewed by Laist, 1997; Gregory, 2009; Gall and Thompson, 2015). In addition to the mechanical risk (obstruction of the gut, etc.) and the potential harm due to translocation of degradation products from the plastic to the organisms fluids (Browne et al., 2008), organic pollutants adsorbed on the litter surface might get released when ingested (Teuten et al., 2007; Graham and Thompson, 2009; Rios et al., 2010; Rochman, 2015). The latter is one of the main concerns regarding micro-litter microliter, with unknown effects at the individual and population levels and the potential of recirculation of these substances through the foodweb (Lusher, 2015). However, direct ingestion of macro-litter by benthic and demersal species is not common (Anastasopoulou et al., 2013; Deudero and Alomar, 2015). In addition, the degradation process of macro- litter in benthic habitats on the continental shelf is thought to be slower when compared with pelagic or coastal environments due to the relatively low hydrodynamism and the absence of light (Hanke et al., 2013), and these bottoms are thus considered long-term sinks for marine litter (Nauendorf et al., 2016).

While the short and medium term effects of benthic macro-litter in the ecosystem are surrounded by high uncertainty, following a precautionary approach, measures aiming at reducing the amount of marine litter in these environments should be undertaken. To do so, determining the origins and drivers of benthic macro-litter distributions is of the upmost importance. Using the northern Spanish continental shelf as a case study, the aims of this study were (i) to determine the abundance distribution of macro-litter on the continental shelf and (ii) to identify factors driving this specific distribution.

2. Methods

2.1. Study area

The study area is located on the North Atlantic coast of Spain, spanning the continental shelf of the southern Bay of Biscay from the border with France on the east to the border with Portugal on the southwest (Fig. 1). The continental shelf in this area is characterised by its narrowness (min ≈ 30 km) and by being the frontier between Atlantic boreal, Atlantic macaronesian and Mediterranean fauna.

The main oceanographic patterns in the area are seasonal and of variable intensity, including the poleward current on the shelf-break predominant in winter months and upwelling events during the summer, which preferentially occur on the western edge of the study area. Spring and autumn are considered transitional seasons dominated by mesoscale circulation structures such as eddies (Gil, 2008). The rivers discharging in the area have generally low flows and do not make a major contribution to the regional oceanography (Gil, 2008).

2.2. Data used in the analysis

2.2.1. Marine litter data

Marine macro-litter on the sea bottom (hereafter "marine litter") was recorded during five bottom trawl oceanographic surveys (DEMERSALES surveys- under ICES IBTSWG standardisation, ICES, 2010) carried out every autumn between 2006 and 2010 in the Southern Bay of Biscay. The survey follows a randomly stratified sampling design in five geographical sectors and three depth ranges: 70–120 m (shallow circalittoral), 120–200 m (deep circalittoral) and 200–500 m (bathyal) with some additional tows outside these depth ranges (for a complete description of the survey design see Sánchez and Serrano, 2003). Between 2006 and 2010, 136 hauls on average were carried out on the shelf using a BAKA otter trawl with 20 mm meshsize at the cod end. Each haul consisted of 30 min trawling at 3 knots covering an area of approximately 0.051 km^2. After each haul individual items of marine litter were classified, cleaned of epibionts and weighed on board (wet weight to 0.1 gr. precision). Haul data were subsequently standardised as density per square km (both using number of litter items and weight) and averaged for a 5 × 5 nautical miles grid covering soft bottoms of the continental shelf (Fig. 1). In order to reduce the number of categories, and following technical group classification (Cheshire et al., 2009; ICES, 2010), litter items were binned into six groups based on their material composition, degradability and original activity, namely: Plastics, Solid hydrocarbons, Textile, Metal, Fisheries derived items and Other Materials (Table 2). The latter included wood, ceramics and glass with medium to large degradation times but low polluting potential, while fisheries derived items consisted on pieces of rope, nets, lobsterpots, etc.

2.2.2. Potential drivers

Several variables were considered as potentially influencing the amount of marine litter on the continental shelf bottom, including variables describing land-based and sea-based mechanisms for marine litter production. We considered thus, human population, industrial parks, river flow, ports/ harbours and their activities, and fishing activity. In addition we considered five geographical sectors over which the sampling design is based. These sectors were constructed by projecting the main capes towards the sea perpendicularly to the coast (see Fig. 1). Average river flow ($m\ s^{-1}$) was obtained from regional monitoring programs including the Cantabrian Hydrographic Confederation, the Hydrographic Confederation of Miño- Sil, and Aguas de Galicia, the organism managing continental waters from the Galician Regional Government (Xunta de Galicia, Spain). The index to compute the influence of neighbouring rivers (Gonzalez-Irusta et al., 2014) was calculated as follows:

$$River\ index = Distance\ to\ closest\ river\ mouth\ (km)/River\ flow(m^3 \cdot s^{-1})$$

This index integrates thus the decreasing effect that the river might exert when getting further from the river mouth, with the strength of the river for transporting litter items given by the river flow. The updated census record of population from 2011, and the geographical location of each coastal municipality were obtained from the Spanish National Centre of Geographic Information (Nomenclator Geográfico de Municipios y Entidades de Población; www.cnig.es). From the centre of each 5 × 5 nm grid, the radius necessary for encircling a population of 50000 inhabitants was calculated in kilometres. These radii were thus used as a proxy for population stress on each grid within the study. The location of industrial parks in the neighbouring regions was obtained from the National Geographic Institute (www.ign.es), using the BCN25/BTN25 database on land use. We computed the area occupied by industrial activities within a 30 km radius from each marine grid centre, considering it as a proxy for industrial activity in the area. Port activity was evaluated using two different approaches. Firstly, we considered the number of ports within a 30 km radius from each grid centre, including leisure, fishing and commercial harbours. Additionally, we calculated the number of artisanal fishing vessels registered in harbours within a 30 km radius (approx. 17 nm). Artisanal vessels (< 12 m length) activity is not registered with a vessel monitoring system. These vessels do not normally operate far from their base, due to their limited facilities on board and their need to maximise cost-effectiveness, therefore they have a higher polluting potential than the commercial fleet in the vicinity of their base harbour. The activity of the fishing fleet (> 12 m vessel length) in the study area was obtained through the vessel monitoring system (VMS) data. Fishing activity in each grid was estimated as the elapsed time between successive signals, without discrimination between navigation time and fishing operations. Additionally, we also