Marine Environmental Research 106 (2015) 61–67

Contents lists available at ScienceDirect

Marine Environmental Research

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

Comparative analysis of time series of marine litter surveyed on beaches and the seafloor in the southeastern North Sea

Marcus Schulz [a, *], Roland Krone [b, 1], Gabriele Dederer [c], Kai Wätjen [b], Michael Matthies [d]

[a] AquaEcology GmbH & Co. KG, Marie-Curie-Strasse 1, 26129 Oldenburg, Germany
[b] Alfred-Wegener-Institute Helmholtz Centre for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany
[c] Datadiving GmbH & Co. KG, Övelgönner Str. 25, 20257 Hamburg, Germany
[d] Institute of Environmental Systems Research (USF), University of Osnabrueck, Barbarastrasse 12, 49076 Osnabrueck, Germany

ARTICLE INFO

Article history:
Received 19 January 2015
Received in revised form
2 March 2015
Accepted 8 March 2015
Available online 10 March 2015

Keywords:
Beach litter
Seafloor litter
Kriging
Time series
Correlation analysis
Transport process

ABSTRACT

The comparative analysis of marine litter in different marine compartments has rarely been attempted. In this study, long-term time series of marine litter abundance on the seafloor and on the coast, both from the southeastern North Sea, were analyzed for temporal trends and correlations. On four beach sections of 100 m length, mean abundances of total beach litter collected four times a year from 2002 to 2008 varied between 105 and 435 items. Mean densities of total inorganic litter on the seafloor amounted to 10.6 ± 9.7 kg km^{-2} in the offshore region (2001–2010) and 13.7 ± 12.6 kg km^{-2} in the Wadden Sea (1998–2007), respectively. In the offshore region, there was no significant long-term trend, while in the Wadden Sea, densities of marine litter declined significantly. Correlations between time series were weak, indicating different sources and transport processes responsible for compositions of beach litter and litter on the seafloor. Decreases in inputs from fisheries and substantial export due to resuspension are discussed as reasons for the decrease in litter on the seafloor in the Wadden Sea.

1. Introduction

Previous studies on marine litter have highlighted its potential risk to the marine environment through the introduction of alien species (Barnes and Fraser, 2003; Barnes and Milner, 2005; Majer et al., 2012) and the ingestion of plastic particles by marine biota (Browne et al., 2008; van Franeker et al., 2011), as well as by entanglement in lines, ribbons, ropes and nets (Gregory, 2009; Rodríguez et al., 2013; Votier et al., 2011). Other investigations focused on the quantification of marine litter in different marine compartments, such as beaches (Kako et al., 2012; Tudor et al., 2002; Velander and Mocogni, 1998), the seafloor (Galgani et al., 2000; Katsavenakis and Katsarou, 2004; Watters et al., 2010) and marine surface waters (Hinojosa et al., 2011; Lebreton et al., 2012; Lecke-Mitchell and Mullin, 1992; Williams et al., 2005). However, except for three studies by Ribic et al. (2010, 2012) and Williams et al. (1993), linkages of marine litter to its sources and to source regions has been qualitative rather than quantitative (Kako et al., 2011; Law et al., 2010; Lebreton et al., 2012).

Moreover, linkage of litter pollution levels between different marine compartments has rarely been attempted (Van Cauwenberghe et al., 2013; Zhou et al., 2011). The former authors assessed abundance, weight, and composition of marine debris, including microplastics, by performing several beach, sea surface, and seafloor monitoring campaigns. In their study, 34% of total marine litter surveyed was found on beaches, 37% was found floating on the sea surface, and 29% could be found on the sea floor. However, similar to the comprehensive monitoring study of Zhou et al. (2011), the results of Van Cauwenberghe et al. (2013) remained descriptive rather than analytic in terms of identifying relationships between different marine compartments.

Thiel et al. (2013) investigated floating marine litter in coastal waters in comparison with beach litter on adjacent local beaches. These authors found that composition differed slightly between the two environments. The results of Thiel et al. (2013) suggest that floating litter near the coast tends to get deposited on the coast.

Overall, there is a considerable lack of comparative studies on litter in different marine compartments, and there are few studies

* Corresponding author.
E-mail addresses: mschulz@uos.de (M. Schulz), r.krone@datadiving.de (R. Krone), g.dederer@datadiving.de (G. Dederer), Kai.Waetjen@awi.de (K. Wätjen), mmatthie@uos.de (M. Matthies).
[1] Present address: Datadiving GmbH & Co. KG, Övelgönner Str. 25, 20257 Hamburg, Germany.

http://dx.doi.org/10.1016/j.marenvres.2015.03.005
0141-1136/

on marine litter on the seafloor. The present study was designed to bridge these gaps. The major targets of the study were to

- identify potential temporal trends of marine litter on the seafloor in tidal and subtidal regions,
- detect potential correlations with beach litter data,
- and thus enable conclusions concerning sources and transport of marine litter.

Beam trawl data of high spatial and temporal resolutions collected in a spatial cluster in an offshore region of the southeastern North Sea and within the Wadden Sea were analyzed for significant long-term trends in densities of marine litter on the seafloor. In addition, the long-term time series of beach litter on shores bordering the southeastern North Sea, collected within the framework of the OSPAR Beach litter Monitoring Programme (OSPAR, 1992, 2010), were used for statistical comparison with the beam trawl data. Parallel trends in marine litter could provide evidence for common sources, source regions, or transport behavior. On the other hand, missing correlations between time series of both marine compartments would support the hypothesis of different sources and sorting processes during transport and deposition, which might lead to different compositions of marine litter observed in deposition areas. Finally, the potential linkage between both investigated marine compartments would allow for adequate strategies to combat emissions of marine litter, as required by the Marine Strategy Framework Directive of the European Union (MSFD, 2008).

2. Materials and methods

2.1. Study site

The study site is situated in the North Sea, a semi-enclosed shelf sea adjacent to the Northern Atlantic Ocean (Fig. 1). The North Sea is connected to the Atlantic via a) the English Channel between England and France/Belgium and b) the Norwegian Sea located between Scotland and Norway. Westerly winds and the counterclockwise residual tidal currents mainly transport floating and submerged objects from the Channel along the southern coast eastward to the German Bight (Vauk and Schrey, 1987).

Four survey sites of 100 m length, located on beaches on the southeastern coast of the North Sea (Fig. 1), were selected from the OSPAR beach litter monitoring database, namely Sylt (OSPAR beach ID DE1), Scharhörn (OSPAR beach ID DE2), Minsener Oog (OSPAR beach ID DE3) and Juist (OSPAR beach ID DE5). Two areas of seafloor in the German Bight covering several hundred square kilometers were investigated for long-term trends in densities of marine litter. One area is located offshore of the border islands and one in the Wadden Sea (Fig. 1). Besides others, the implementation process of the Marine Strategy Framework Directive (MSFD, 2008) requires monitoring and evaluation of litter in benthic offshore regions. For comparative analysis in this study, the area in the Wadden Sea was additionally investigated.

Marine litter in the German Bight originates from several sources, such as fishing, shipping, and tourism. Plastic debris account for between 50% and 70% of the items recorded (OSPAR, 2009).

2.2. Monitoring of beach litter pollution

Since 2002, regular surveys of beach litter pollution have been carried out within the framework of the OSPAR convention on 100 m standard sections of beach on the North Sea coast (OSPAR, 2010). Beaches included in the monitoring program were selected according to the following criteria:

- composed of sand or gravel and exposed to the open sea,
- accessible to surveyors all year round,
- accessible for ease of marine litter removal,
- a minimum length of 100 m and if possible over 1 km in length,
- free of 'buildings' all year round,
- ideally not subject to any other litter collection activities.

Ideally surveys were carried out at intervals of about three months in winter (mid-December–mid-January), spring (April), summer (mid-June–mid-July), and autumn (mid-September–mid-October) according to the Guidelines for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area (OSPAR, 2010).

Data on the abundance of litter collected on a given section of coastline were recorded at the item level. Items are identifiable pieces of litter such as plastic bottles, Tetra-Pak type containers, metal drinks cans, rubber gloves, etc. Each piece of litter was assigned to one of 112 different items defined by OSPAR (2010). Only intact objects and fragments >2.5 cm in the longest dimension were used for this analysis, although fragments smaller than 2.5 cm

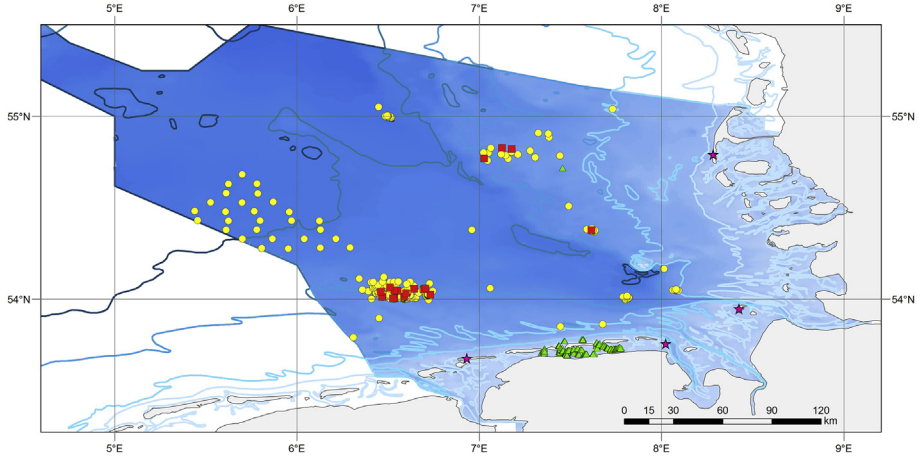

Fig. 1. Map of the study site and sample stations in the southeastern German Bight (pink stars = OSPAR 100 m beach litter surveys, yellow circles = beam trawls in the offshore region (AWI fishery protocol), red squares = beam trawls (100 m OSPAR beach litter monitoring protocol), green triangles = beam trawls in the Wadden Sea (AWI fishery protocol)). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)