Niedersächsischer Landesbetrieb
für Wasserwirtschaft,
Küsten- und Naturschutz
Betriebsstelle Brake – Oldenburg

A comparative study of suspended litter in the Elbe, Weser and Ems Estuaries (southeastern North Sea).

Dr. Marcus Schulz

Celle am 7. Juni, 2015

Erstellt im Auftrag des Niedersächsischen Landesbetriebs für Wasserwirtschaft, Küsten- und Naturschutz

Dieser Bericht ist durch den Niedersächsischen Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz beauftragt worden. Die Verantwortung für den Inhalt liegt allein bei den Autoren. Der Bericht gibt die Auffassung der Autoren wieder und muss nicht mit der Meinung des NLWKN übereinstimmen. Der NLWKN übernimmt keine Gewähr für die Richtigkeit, die Genauigkeit und Vollständigkeit der Angaben sowie für die Beachtung der Rechte Dritter. Der Auftraggeber behält sich alle Rechte vor, insbesondere darf dieser Bericht nur mit seiner Zustimmung ganz oder teilweise vervielfältigt bzw. Dritten zugänglich gemacht werden.

Zitiervorschlag:

Schulz M., 2015. A comparative study of suspended litter in the Elbe, Weser and Ems Estuaries (southeastern North Sea). Bericht erstellt im Auftrag des NLWKN, 21 S.

Contents

Abstract

There is high demand for comparative analyses of macrolitter in estuarine and riverine waters. This study attempts to fill this need and analyzed three estuaries discharging into the southeastern North Sea, namely the estuaries of the Ems, Weser and Elbe Rivers, for suspended macrolitter. Consistent sampling was conducted using stow nets at three to five locations along each estuary in spring and autumn 2013 and 2014, respectively. Compositions of material categories and litter items were similar in all estuaries with portions of plastic/polystyrene of more than 94%. Abundances of total suspended litter (TSL) ranged from zero to 19.7 pieces of litter per 10^5 m^3. Mean TSL significantly differed between the Ems and Elbe Estuaries and amounted to 1.08±1.25, 1.98±1.66 and 2.49±3.75 pieces of litter per 10^5 m^3 in the Ems, Weser and Elbe Estuaries, respectively. This study provides considerably lower abundances of TSL in estuaries than previous studies und thus underpins the need for standardized monitoring procedures of estuarine and riverine litter.

Introduction

Within the last decade, a number of scientific studies investigated the amount and fate of litter in the marine environment (Browne et al., 2010; Howell et al., 2012; Ribic et al., 2010). Several authors dealt with spatial and temporal trends of marine litter (Dameron et al., 2007; do Sul and Costa, 2007; Ribic et al., 2010, 2012). Other authors focused on the ingestion of micro- and mesoplastics (Browne et al., 2008; van Franeker et al., 2011) or the entanglement of marine vertebrates in filamentous macrolitter (Gregory, 2009; Pichel et al., 2012; Votier et al., 2011), both representing potential environmental harms for marine ecosystems. Further potential risks arise from floating debris as a vector for invasive species (Barnes and Milner, 2005; Majer et al., 2012).

Increasing amounts of marine litter, mostly consisting of plastic, inspired further studies on its sources (Tudor et al., 2002; Williams et al., 2003). The sources of marine litter, such as fishing, shipping and tourism, are easily termed. However in the past, input of litter to the marine environment via rivers acquired little attention and only few studies examined riverine and estuarine abundances and loads of macrolitter (Lechner et al., 2014; Moore et al., 2011; Morritt et al., 2014). In addition, to fill the needs of the Marine Strategy Framework Directive 2008/56/EC (EU, 2008) it is necessary to increase knowledge on the occurrence of litter and the role of riverine input as a source for marine litter.

In some of the estuarine studies, shorelines were surveyed (Guneroglu, 2010; Rech et al., 2014), while other studies conducted tracer experiments to get information on the transport and retention of floating litter (Jang et al., in press). Further investigations employed trawl equipment to quantify litter transported downstream in suspension (Possatto et al., in press). Several authors described the composition of suspended riverine litter (Gasperi et al., 2014; Sadri and Thompson, 2014) and attempted to relate spatial and temporal trends to source locations (Morritt et al., 2014), rainfall events and thus to erosion events and the hydrological regime of fluvial waters (Moore et al., 2011; Possatto et al., in press).

However, most studies were restricted in space and time and not designed to detect systematic behavioral characteristics of suspended litter, or to compare litter abundances in different estuaries. Therefore, there is high demand for analyses of macrolitter in estuaries and investigations of factors influencing riverine transport patterns. This study intends to fill these needs. Three estuaries bordering on the southeastern North Sea, namely the estuaries of the Ems, Weser and Elbe Rivers, were investigated for suspended litter employing stow nets at three to five locations along each estuary and at four sampling dates each. Abundance and composition of collected litter were recorded and subsequently analyzed for spatial and seasonal differences. Thus, the design of this study allowed for comparisons of characteristics of suspended litter between the three estuaries.

Methods

Study sites

The study sites comprise the estuaries of the Ems, Weser and Elbe Rivers, all of which discharge into the southeastern North Sea (Figure 1). The morphometry of the estuaries was mainly formed by Holocene erosion events, as well as hydraulic construction and flood prevention works since medieval times (Schuchardt & Scholle, 2009). From a weir to their mouth in the German Bight, the estuaries of the Ems, Weser, and Elbe Rivers are tidal for about 48 km, 65 km, and 142 km, respectively. Due to the nival to pluvial hydrological regime, freshwater discharges from upstream waters regularly peak in winter and spring.

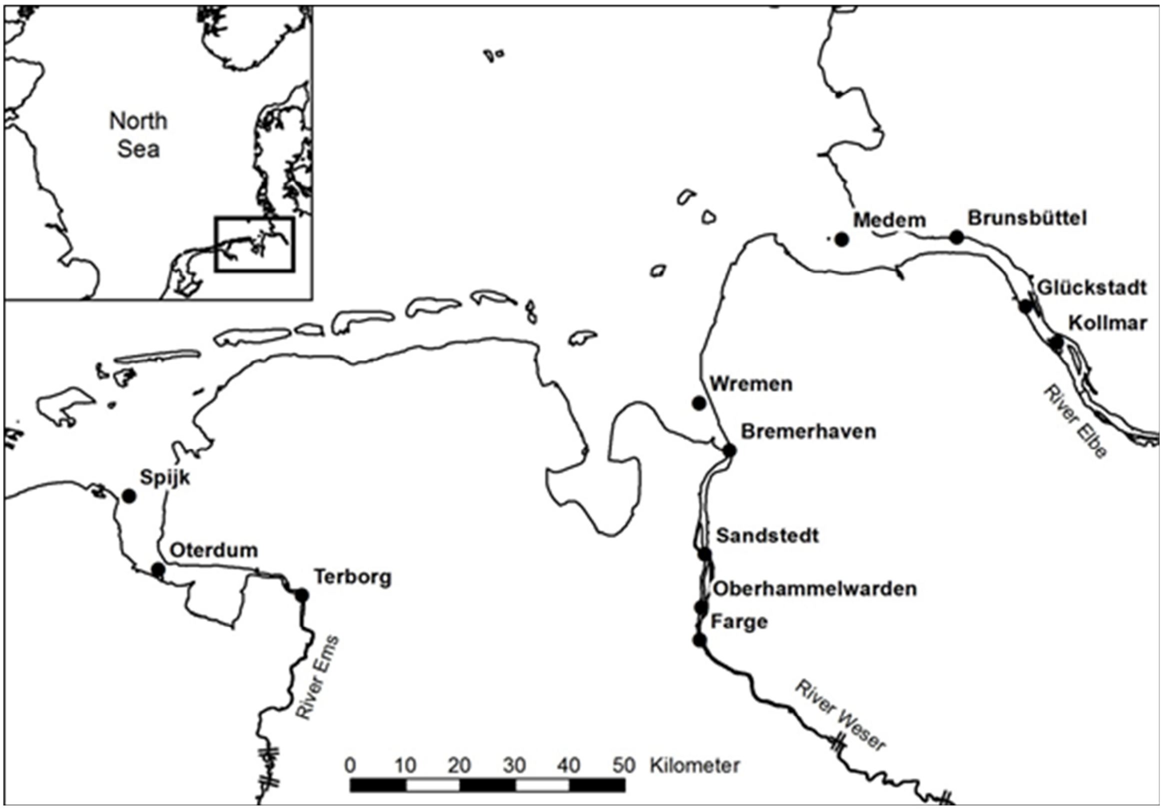

Figure 1: Location of study area and sampling sites at the southeastern coast of the North Sea including estuaries. Allocated names of the sites refer to towns/villages in the vicinity (source: A. Schröder, NLWKN).

Hamburg and Bremen are large harbor towns located upstream close to the weirs at the estuaries of the Elbe and Weser Rivers, respectively. Intense ship traffic within the three estuaries and recreational activities on their shores persist over the entire annual cycle, while riverine and estuarine fisheries have declined during the last decades.

Monitoring of suspended litter

Sampling of suspended litter took place at three (Ems Estuary) to four locations (Weser and Elbe Estuaries) along the freshwater to polyhaline zones (Figure 1). In each estuary, sampling was conducted in four campaigns in spring and autumn 2013 and 2014. Litter sampling was performed within a regular monitoring programme for fish in estuarine waters according to the Water Framework Directive of the European Union using commercial stow nets, deployed by a commercial fishing vessel. The method applied is described in detail in Scholle & Schuchardt (2012). Per sampling occasion, the flood and ebb period were sampled separately during about three hours per tidal phase.

Table 1 gives an overview of sampling dates, locations and parameters. Different mesh sizes of stow nets were assumed to have no influence on measured abundances of litter, because only macrolitter (> 2.5 cm) was considered in this study. A flowmeter was attached to each net to measure the volume of filtered water and thus to standardize abundances of suspended litter.

The catches were sorted and classified on board at the item level applying the OSPAR 100m-beach litter categorization (OSPAR, 2010). Each piece of litter was assigned to one of 112 different items. Categorization was amended by the more precise and extended master list of items provided by the Technical Group Marine Litter of the European Union (MSFD GES TSG-ML, 2013). Items were assigned to different general categories according to the material they are made of (e.g. plastic/polystyrene, rubber, cloth/textile, paper/cardboard, wood, metal, glass, and ceramic/pottery) or their use (sanitary and medical waste).

Table 1: Overview of sampling locations and campaigns, including information on trawl equipment (stow nets).

Estuary	Location	Latitude	Longitude	Salinity	Sampling dates				Mesh size [mm]	Opening width [m x m]	Number of hauls [-]
Ems	Terborg	53°17.320	7°23.741	oligohaline	31.05.2013	05.09.2013	21.05.2014	12.09.2014	10	13.0 x 10.0	8
	Oterdum	53°19.527	7°00.087	mesohaline	29.05.2013	03.09.2013	19.05.2014	10.09.2014	10	13.0 x 10.0	8
	Spijk	53°28.109	6°54.775	polyhaline	30.05.2013	04.09.2013	20.05.2014	11.09.2014	10	13.0 x 10.0	8
Weser	Farge	53°13.452	8°29.126	limnetic	15.05.2013	24.09.2013	-	-	6	17.0 x 9.0	4
	Sandstedt	53°21.954	8°29.861	oligohaline	16.05.2013	25.09.2013	-	-	6	17.0 x 9.0	4
	Bremerhaven	53°32.254	8°33.861	mesohaline	21.05.2013	26.09.2013	-	-	6	17.0 x 9.0	4
	Wremen	53°36.886	8°28.752	polyhaline	17.05.2013	27.09.2013	-	-	6	17.0 x 9.0	4
	Oberhammelwarden			limnetic	-	-	10-13.06.2014	22-25.09.2014	10	13.0 x 10.0	16
Elbe	Kollmar	53°42.969	9°27.892	oligohaline	29.04.2013	23.09.2013	25.04.2014	11.10.2014	8	10.0 x 9.0	8
	Glückstadt/Krautsand	53°46.404	9°22.879	oligohaline	30.04.2013	24.09.2013	28.04.2014	10.10.2014	8	10.0 x 9.0	8
	Brunsbüttel	53°53.278	9°11.442	mesohaline	01.05.2013	25.09.2013	27.04.2014	12.10.2014	8	10.0 x 9.0	8
	Medem	53°52.321	8°53.160	polyhaline	02.05.2013	26.09.2013	26.04.2014	13.10.2014	8	10.0 x 9.0	8

Data analysis

Data were standardized to numbers of litter items per 10^5 m^3 filtered water volume. For each estuary, means and standard deviations of abundances of total suspended litter (TSL) were calculated. Calculations of litter compositions relied on the entity of hauls of each estuary. Abundance of TSL per haul were used as input data for statistical analyses.

According to the results of Kolmogorov-Smirnov-tests for normality, not all data were normally distributed. Therefore, non-parametric one-way analyses of variance (Kruskal-Wallis-tests) were used to test for significant differences in TSL between tidal states, seasons and locations. First for each estuary, data pooled from both years were analyzed for significant tidal differences. Subsequently for each estuary, ANOVAs were applied to data pooled from both tides, because there were no tidal differences and in order to increase the power of subsequent tests by increased number of replicates. Subsequently, ANOVAs were carried out for each estuary and factor, namely season and sampling location, separately. In order to identify significant differences between estuaries, one additional test based on all TSL data was calculated with estuaries as factor so that there were a total of ten ANOVAs. The ANOVA for significant differences between estuaries was amended by post-hoc tests (Least significant difference-tests). All statistical tests were calculated applying a statistical software (Systat 12.0, Systat Software, USA, http://www.systat.com/SystatProducts.aspx).

Results and Discussion

In the three investigated estuaries, compositions of suspended litter were very similar (Table 2). Plastic/polystyrene was the dominant general category with portions of TSL of more than 94%. Except for sanitary waste, all other general categories mostly showed percentages smaller than 1%. For the beaches bordering on the North Sea, OSPAR (2009) and Schulz et al. (2013) reported portions of plastic/polystyrene ranging between 50% and 70%. The discrepancy to the results of the present study is probably due to the low physical density of artificial polymers, which therefore are enriched in the suspended rather than in the sedimentary fraction.

Table 2: Composition of suspended litter given in percentages [%] of standardized total suspended litter (TSL) [1/100,000 m^3]. The material categories used rely on the OSPAR categorization (OSPAR, 2010).

Material	Ems Estuary	Weser Estuary	Elbe Estuary
Cloth	0.7	0.2	0
Medical waste	0	1	0.2
Metal	0.4	0.4	0.3
Paper, Cardboard	1.1	0	0.4
Plastic/polystyrene	94.1	95.0	97.4
Other pollutant	0.4	0	0
Rubber	2.1	0.1	0.1
Sanitary waste	1	3.7	1.6
Wood (machined)	0.3	0	0

Compositions of litter items were also similar in all investigated estuaries. In the Ems Estuary, the most abundant items were plastic/Styrofoam pieces 2.5-50 cm, other plastic, plastic string, small plastic bags, crisp and sweet packages, plastic cups and fast food containers. In the Weser Estuary, suspended litter mostly consisted of plastic/Styrofoam pieces 2.5-50 cm, other plastic, plastic string, small plastic bags, crisp and sweet packages, plastic cups, fast food containers, sanitary towels and fishing line. In the Elbe Estuary, suspended litter was dominated by plastic/Styrofoam pieces 2.5-50 cm, other plastic, small plastic bags, crisp and sweet packages, plastic cups, fast food containers, sanitary towels, tangled nets, as well as caps and lids. Similar compositions of litter items hint at similar source compositions of macrolitter in the three estuaries investigated. However in addition to fishing-related items, such as tangled nets and fishing lines, only sanitary waste, such as sanitary towels, can be attributed to a given source with certainty, namely to insufficient waste water treatment (OSPAR, 2009).

TSL ranged from zero to 19.7 pieces of litter per 10^5 m^3. TSL significantly differed between the three estuaries (p = 0.027, n = 88) and amounted to 1.08±1.25, 1.98±1.66 and 2.49±3.75 pieces of litter per 10^5 m^3 in the Ems, Weser and Elbe Estuaries, respectively. Post-hoc tests gave one significant difference between the Ems and Elbe Estuaries (p = 0.047, n = 56). Differences in TSL are likely due to different discharges of litter input into the estuaries. However, identifications of sources are highly uncertain und therefore remain subject to speculation.

As in the Weser Estuary in the Ems Estuary, no significant seasonal pattern could be detected (Figure 2 and Table 3). In the Ems and Weser Estuaries, TSL tended to be higher in upstream regions than in downstream regions (Figures 3 and 4). These spatial differences were significant (Table 3).

Table 3: Results of non-parametric analyses of variance (Kruskal-Wallis-tests). n give the number of replicates, p-values give levels of significance. Significant p-values are marked with asterisks (*: p < 0.05, **: p < 0.01, ***: p < 0.001).

Grouping variable	Parameter	Ems Estuary	Weser Estuary	Elbe Estuary
Tide	n	24	32	32
	p-value	0.453	0.821	0.638
Location	n	24	32	32
	p-value	0.011*	< 0.001***	0.186
Season	n	24	32	32
	p-value	0.564	0.91	0.001**

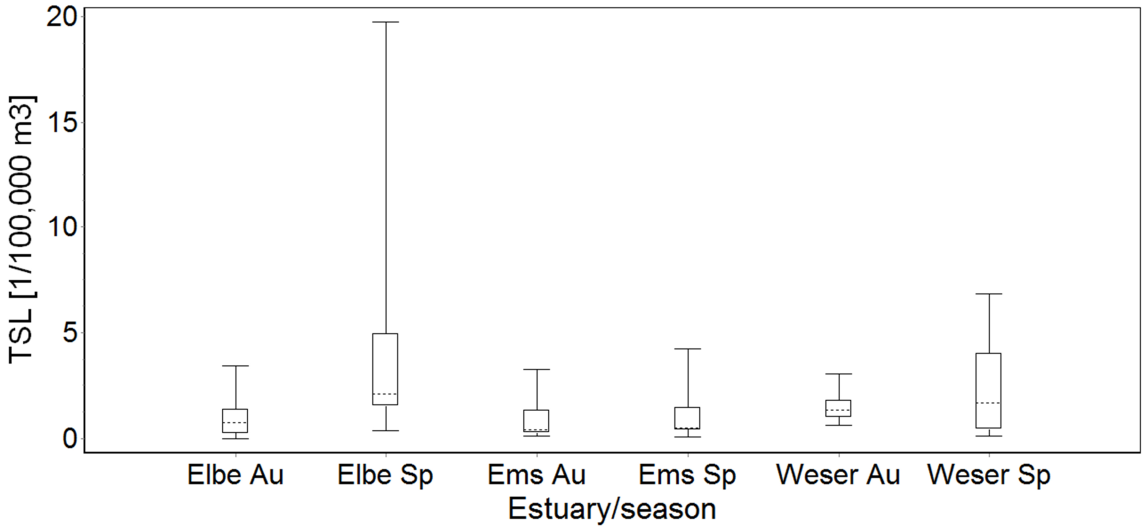

Figure 2: Boxplots of standardized total suspended litter (TSL) in the Ems, Weser and Elbe Estuaries for different seasons (Au = autumn, Sp = spring). Horizontal lines in the boxes give the three quartiles. Error bars give ranges.

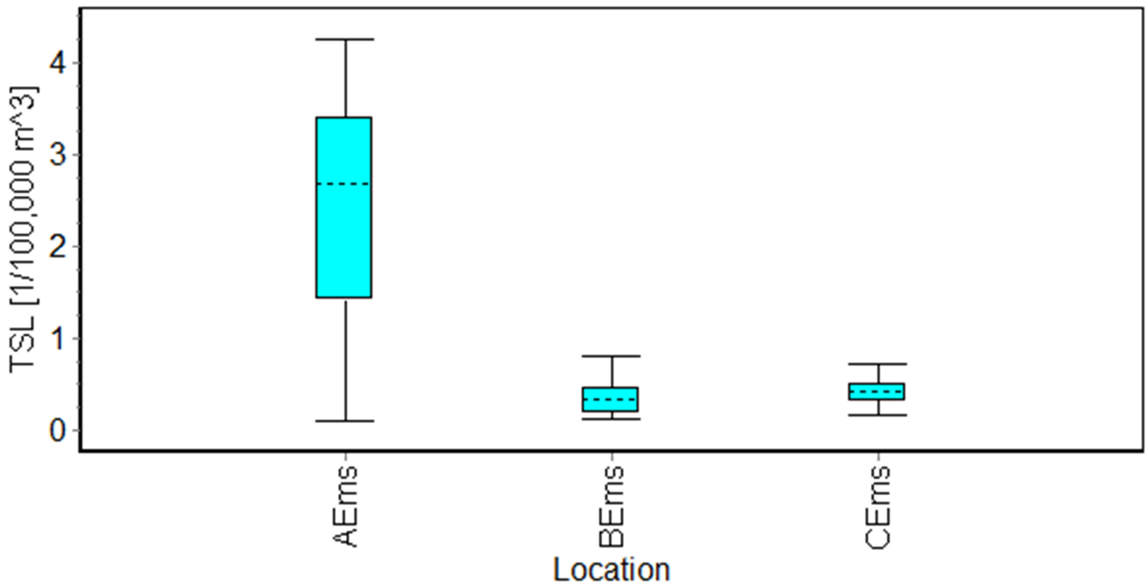

Figure 3: Boxplots of standardized total suspended litter (TSL) in the Ems Estuary for different sampling locations (AEms: Terborg, BEms: Oterdum, CEms: Spijk). Horizontal lines in the boxes give the three quartiles. Error bars give ranges.

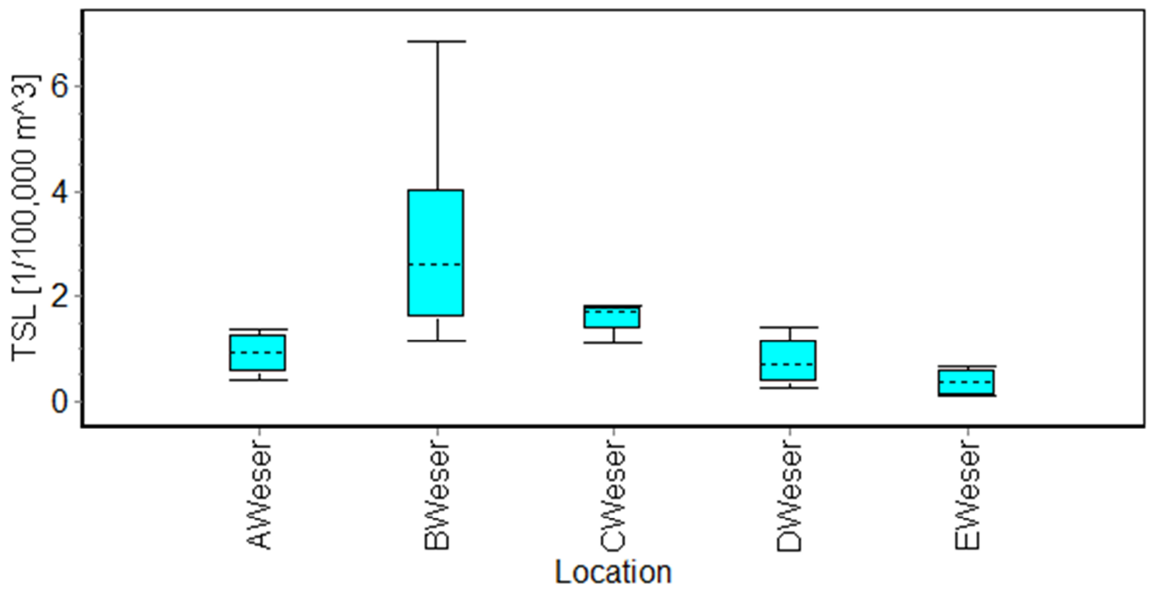

Figure 4: Boxplots of standardized total suspended litter (TSL) in the Weser Estuary for different sampling location (AWeser: Farge, BWeser: Oberhammelwarden, CWeser: Sandstedt, DWeser: Bremerhaven, EWeser: Wremen). Horizontal lines in the boxes give the three quartiles. Error bars give ranges.

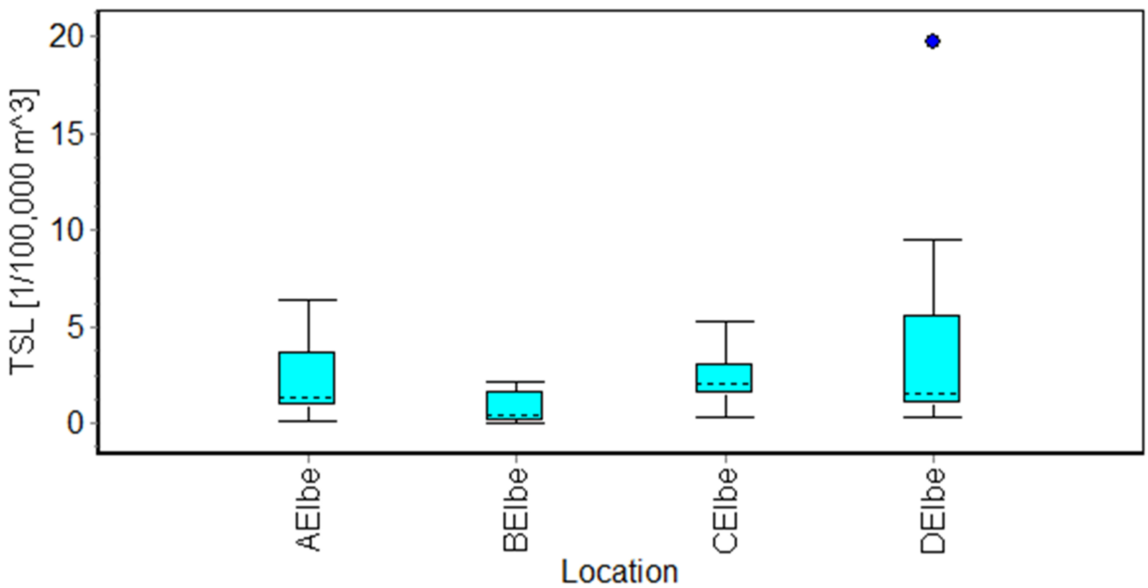

Figure 5: Boxplots of standardized total suspended litter (TSL) in the Elbe Estuary for different sampling location (AElbe: Kollmar, BElbe: Krautsand, CElbe: Brunsbüttel, DElbe: Medem). Horizontal lines in the boxes give the three quartiles. Error bars give ranges. A blue dot gives an outlying value.

In the Elbe Estuary, there was no definite spatial pattern (Figure 5), but TSL tended to be higher in spring than in autumn (Figure 2), and seasonal differences were significant (Table 3). This seasonal pattern in the Elbe Estuary coincides with the seasonal hydrological regime of the upstream freshwater system of the Elbe River, but this agreement was not confirmed for the Ems and Weser Estuaries. Positive correlations between temporal trends of TSL and the upstream hydrological regime would hint at freshwater inflow as a major determinant of temporal patterns of TSL. However generally, there was a lack of consistent temporal and spatial patterns in the three estuaries studied, which makes the identification of driving forces of temporal and spatial distributions of TSL difficult.

Previous studies on suspended litter in rivers and estuaries found values of TSL much higher than in this study (Gasperi et al., 2014; Lechner et al., 2014; Morritt et al., 2014). However, these studies deployed different sampling techniques and mostly focused on rivers rather than on estuarine waters. Similar to the present study, Morritt et al. (2014) measured consistent compositions of suspended litter employing stationary eel fyke nets, but in their study average portions of sanitary waste in the Thames River amounted to approximately 20%, a value much higher than in the German estuaries. Morritt et al. (2014) attributed spatial peaks of suspended sanitary waste to the proximity of sampling positions to waste water treatment plants.

Sadri and Thompson (2014) investigated tidal differences of floating litter in the Tamar Estuary employing manta trawls. Despite significant differences between spring and neap tides, these authors could not decide whether the Tamar Estuary was a net source or sink of floating litter to the marine environment. In contrary, Rech et al. (2014) identified estuaries as significant sources of beach litter in the south-eastern Pacific. The discrepancy between both above-mentioned studies might partly be due to different monitoring methods applied.

Overall, this is the first comparative study on suspended macrolitter in estuarine waters applying a standardized categorization of litter items and consistent sampling techniques. Significant differences in mean TSL between estuaries could potentially be attributed to different litter discharges into the estuaries, while the scarcity and inconsistency of significant temporal and spatial patterns does not allow for answering questions for the source, sink or filter functions of estuaries. Therefore, future studies should practice source and event-based (see Moore et al., 2011) monitoring of suspended litter, in order to identify the sources, as well as the driving forces of temporal and spatial trends of estuarine litter.

Furthermore, the present study underpins the need for standardized monitoring procedures of estuarine litter because the results presented here considerably differ from those of previous studies.

Acknowledgements

This work was financially supported by the Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN). I also kindly acknowledge the Council of Coordination of the Lower Elbe River, Martina Völkel (SUBV, Bremen), Gitta Bergen (NLWKN Stade, Lower Saxony), Eva-Christine Mosch (LAVES, Lower Saxony), Mervyn Roos (RWS, Lelystad) for supporting the collection of data on litter within the regular sampling scheme for fish in transitional waters of the Water Framework Directive. I owe thanks to Uwe Probst (SUBV, Bremen) for the allocation of data measured in the Weser Estuary in 2014 within the pilot study ‚Development of a methodology to monitor emissions of litter from estuaries into the North Sea exemplifying the lower River Weser'. I thank Peter C. Rathcke (Office of scientific investigations on fishing, Wedel) for collecting data on litter in the Elbe Estuary and BioConsult Schuchardt & Scholle for collecting data on litter in the Ems and Weser Estuaries as well as for comments on the manuscript. Special thanks are due to Kirsten Dau (NLWKN Oldenburg) for helpful comments.

References

Barnes, D. K. A., Milner, P., 2005. Drifting plastic and its consequences for sessile organism dispersal in the Atlantic Ocean. Marine Biology 146, 815–825.

Browne, M. A., Ayake, A., Galloway, T. S., Lowe, D. M., Thompson, R.C., 2008. Ingested Microscopic Plastic Translocates to the Circulatory System of the Mussel, Mytilus edulis (L.). Environmental Science & Technology 42, 5026–5031.

Browne, M. A., Galloway, T. S., Thompson, R. C., 2010. Spatial Patterns of Plastic Debris along Estuarine Shorelines. Environmental Science & Technology 44, 3404–3409.

Dameron, O. J., Parke, M., Albins, M. A., Brainard, R., 2007. Marine debris accumulation in the Northwestern Hawaiian Islands: An examination of rates and processes. Marine Pollution Bulletin 54, 423–433.

do Sul, J. A. I., Costa, M. F., 2007. Marine debris review for Latin America and the Wider Caribbean Region: From the 1970s until now, and where do we go from here? Marine Pollution Bulletin 54, 1087–1104.

EU, 2008. Marine Strategy Framework Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF (accessed 28.2.2013).

Gasperi J., Dris R., Bonin T., Rocher V., Tassin B., 2014. Assessment of floating plastic debris in surface water along the Seine River. Environmental Pollution 195, 163-166.

Gregory, M. R., 2009: Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions of the Royal Society B 364, 2013–2025.

Guneroglu A., 2010. Marine litter transportation and composition in the Coastal Southern Black Sea Region. Scientific Research and Essays 5(3), 296-303.

Howell, E. A., Bograd, S. J., Morishige, C., Seki, M. P., Polovina, J. J., 2012. On North Pacific circulation and associated marine debris concentration. Marine Pollution Bulletin 65, 16–22.

Jang S. W., Kim D. H., Seong K. T., Chung Y. H., Yoon H. J., 2015. Analysis of floating debris behaviour in the Nakdong River basin of the southern Korean peninsula using satellite location tracking buoys. Marine Pollution Bulletin, in press.

KÜFOG GmbH, 2013. Mülleintrag in die Nordsee über die Ästuare von Elbe, Weser und Ems und Müllvorkommen im Jadebusen im Jahr 2013 anhand von Hamenfängen. (Emissions of litter into the North Sea via the estuaries of the Elbe, Weser and Ems Rivers, as well as incidence of litter in the Jadebusen in 2013 measured by means of stow nets). Report commissioned by NLWKN, 33 pp.

Lechner A., Keckeis H., Lumesberger-Loisl F., Zens B., Krusch R., Tritthart M., Glas M., Schludermann E., 2014. The Danube so colourful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river. Environmental Pollution 188, 177-181.

Majer, A.P., Vedolin, M.C., Turra, A., 2012. Plastic pellets as oviposition site and means of dispersal for the ocean-skater insect Halobates. Marine Pollution Bulletin 64, 1143–1147.

Moore C. J., Lattin G. L., Zellers A. F., 2011. Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. Journal of Integrated Coastal Zone Management 11, 65-73.

Morritt D., Stefanoudis P. V., Pearce D., Crimmen O. A., Clark P. F., 2014. Plastic in the Thames: A river runs through it. Marine Pollution Bulletin 78, 196–200.

MSFD GES TSG-ML, 2013. Report: Galgani F., Hanke G., Werner S., Oosterbaan L., Nilsson P., Fleet D., Kinsey S., Thomson R., Van Franeker J., Vlachogianni T., Scoullos M., Veiga J., Palatius A., Maes T., Korpinen S., Budziak A., Leslie H., Gago J., Liebezeit G., Guidance on Monitoring of Marine Litter in European Seas. EUR 26113 EN. Luxenbourg (Luxembourg): Publications Office of the European Union; 2013. JRC 83385.

OSPAR, 2009. Marine litter in the North-East Atlantic Region: Assessment and priorities for response. London, United Kingdom, 127 pp.

OSPAR, 2010. Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area. OSPAR Commission, ISBN 90-3631-973.

Pichel, W. G., Veenstra, T. S., Churnside, J. H., Arabini, E., Friedman, K. S., Foley, D. G., Brainard, R. E., Kiefer, D., Ogle, S., Clemente-Colón, P., Li, X., 2012. GhostNet marine debris survey in the Gulf of Alaska – Satellite guidance and aircraft observations. Marine Pollution Bulletin 65, 28–41.

Possatto F. E., Spach H. L., Cattani A. P., Lamour M. R., Santos L. O., Cordeiro N. M. A., Broadhurst M. K., 2015. Marine debris in a World Heritage Listed Brazilian estuary. Marine Pollution Bulletin, in press.

Rech S., Macaya-Caquilpán V., Pantoja J. F., Rivadeneira M. M., Jofre Madariaga D., Thiel M., 2014. Rivers as a source of marine litter – A study from the SE Pacific. Marine Pollution Bulletin 82, 66–75.

Ribic, C. A., Sheavly, S. B., Rugg, D. J., Erdmann, E. S., 2010. Trends and drivers of marine debris on the Atlantic coast of the United States 1997–2007.Marine Pollution Bulletin 60, 1231–1242.

Ribic, C. A., Sheavly, S. B., Rugg, D. J., Erdmann, E. S., 2012. Trends in marine debris along the U.S. Pacific Coast and Hawai'i 1998–2007. Marine Pollution Bulletin 64, 994–1004.

Sadri S. S., Thompson R. C., 2014. On the quantity and composition of floating plastic debris entering and leaving the Tamar Estuary, Southwest England. Marine Pollution Bulletin 81, 55–60.

Scholle J., Schuchardt B., 2012. A fish-based index of biotic integrity – FAT-TW an assessment tool for transitional waters of the northern German tidal estuaries. Coastline Reports 18: 1-71.

Schuchardt B., Scholle J, 2009. Estuaries. Thematic Report No. 16. In: Marencic, H. & Vlas, J. de (Eds.), 2009. Quality Status Report 2009. Wadden Sea Ecosystem No. 25. Common Wadden Sea Secretariat, Trilateral Monitoring and Assessment Group, Wilhelmshaven, Germany.

Schulz M., Neumann D., Fleet D. M., Matthies M., 2013. A multi-criteria evaluation system for marine litter pollution based on statistical analyses of OSPAR beach litter monitoring time series. Marine Environmental Research 92, 61-70.

Tudor, D. T., Williams, A. T., Randerson, P., Ergin, A., Earll, R. E., 2002. The use of multivariate statistical techniques to establish beach debris pollution sources. Journal of Coastal Research SI 36, 716-725.

van Franeker, J. A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., Hansen, P.-L., Heubeck, M., Jensen, J.-K., Le Guillou, G., Olsen, B., Olsen, K.-O., Pedersen, J., Stienen, E. W.M., Turner, D. M., 2011. Monitoring plastic ingestion by the northern fulmar Fulmarus glacialis in the North Sea. Environmental Pollution 159, 2609-2615.

Votier, S. C., Archibald, K., Morgan, G., Morgan, L., 2011. The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. Marine Pollution Bulletin 62, 168–172.

Williams, A. T., Tudor, D. T., Randerson, P., 2003. Beach litter sourcing in the Bristol Channel and Wales, U. K. Water, Air, and Soil Pollution 143, 387–408.