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Rivers as a source of marine litter – A study from the SE Pacific

S. Rech [a,b], V. Macaya-Caquilpán [a], J.F. Pantoja [a], M.M. Rivadeneira [c,a], D. Jofre Madariaga [a], M. Thiel [a,c,*]

[a] Facultad Ciencias del Mar, Universidad Católica del Norte, Larrondo 1281, Coquimbo, Chile
[b] Westfälische Wilhelmsuniversität Münster, Fachbereich Biologie, Schlossgarten 3, 48149 Münster, Germany
[c] Centro de Estudios Avanzados en Zonas Áridas (CEAZA), Av. Ossandón 877, CP. 1781681 Coquimbo, Chile

A R T I C L E I N F O

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A B S T R A C T

Composition and abundance of persistent buoyant litter (plastics, polystyrene and manufactured wood) were investigated at riversides and on adjacent coastal beaches of four rivers flowing into the SE Pacific Ocean. Persistent buoyant litter made up the main share of litter at riversides (36–82%) and on coastal beaches near the river mouths (67–86%). The characteristic litter composition of each river is attributable to human influences along its course. Riverine litter items were deposited to both sides of the river mouths on coastal beaches, and their abundance generally declined with distance from the river mouth. However, maximum litter accumulations were often found on beaches north of the river mouth, suggesting a long-term influence of the prevailing equatorward low-level jet along the Chilean coast. The results confirm that riverine transport has an important impact on litter abundances on coastal beaches.

1. Introduction

Marine pollution by anthropogenic litter is a world-wide issue, causing multiple ecological impacts (e.g. Gregory, 2009; Rochman et al., 2013). Anthropogenic litter enters the marine environment from sea-based sources, like vessel-traffic and fisheries, or from land-based sources, such as coastal tourism or river run-off (Derraik, 2002; Andrady, 2011). Potential origins of riverine litter include direct dumping at riversides, discharge from boats, urban and rural run-off and effluents from sewage plants (Williams and Simmons, 1997a, 1999).

Riverine litter can be transported to the sea, ending up on coastal beaches (Williams and Simmons, 1996, 1997b; Acha et al., 2003), or even on the seafloor (Galgani et al., 2000). In fact, globally an estimated 80% of solid beach litter originates from the nearest rivers (Araújo and Costa, 2007a). Consequently rivers are often identified as the main sources of litter on coastal beaches (Williams and Simmons, 1997b; Neto and da Fonseca, 2011). Studies based on litter samples in urban rivers confirm this pattern (Moore et al., 2011; Carson et al., 2013). Although several studies suggest the importance of rivers as a source of marine pollution by plastics and other litter (e.g. Williams and Simmons, 1997b; Galgani et al., 2000; Claessens et al., 2011; Cole et al., 2011), there are very few studies that provide quantitative data about the amounts and types of anthropogenic litter in rivers.

Plastics are the predominant litter items in rivers, at riversides and on coastal beaches, while other items are found in much lower abundances (for rivers: Williams and Simmons, 1997a, 1999; Moore et al., 2011; Carson et al., 2013; Lechner et al., 2014; for beaches: Williams and Simmons, 1997b; Acha et al., 2003; Neto and da Fonseca, 2011). The high abundance of plastic items is not only due to their ubiquitous utilisation, but also a result of their buoyancy and extreme persistence (Derraik, 2002; Moore, 2008). Wood is also a common litter type, which is transported by rivers and deposited on coastal beaches (Williams and Simmons, 1997b; Doong et al., 2011; Viehman et al., 2011). Some non-buoyant or non-persistent litter items, such as glass or cigarette buds, are frequently attributed to non-riverine sources, like direct litter dumping (Silva-Iñiguez and Fischer, 2003; Taffs and Cullen, 2005; Bravo et al., 2009).

Factors influencing riverine transport patterns are the river's flow rate, the presence of bottom currents and the occurrence of submarine river extensions, amongst others (Galgani et al., 2000). The non-tidal river Rhône, for example, was found to deposit the main share of the litter far offshore, which is due to its deep bed, while smaller rivers deposit litter closer to the coast (Galgani et al., 2000). High river run-off after storms and heavy rainfalls also cause the deposition of litter at greater distances from the river mouth (Moore et al., 2002; Lattin et al., 2004).

* Corresponding author at: Universidad Católica del Norte, Biología Marina, Larrondo 1281, Coquimbo, Chile. Tel.: +56 51 2209939.

E-mail addresses: s_rech01@uni-muenster.de (S. Rech), vmacaya.c@gmail.com (V. Macaya-Caquilpán), jpantoja@ucn.cl (J.F. Pantoja), marcelo.rivadeneira@ceaza.cl (M.M. Rivadeneira), djofremadariaga@gmail.com (D. Jofre Madariaga), thiel@ucn.cl (M. Thiel).

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The movement and deposition patterns of floating litter in coastal zones are determined by climatic and oceanic conditions, particularly wind, nearshore currents, wave motion and tidal dynamics (Browne et al., 2010; Doong et al., 2011; Carson et al., 2013), as well as the geomorphology of the shoreline (Araújo and Costa, 2007a,b). The abundance and composition of litter in rivers, at riversides and on beaches is furthermore determined by land use and social or economic activities in the coastal or stream area (Williams and Simmons, 1999; Shimizu et al., 2008; Carson et al., 2013; Lechner et al., 2014). It is therefore expected, that each river exhibits a characteristic profile of litter composition, based on the influencing factors in its course. Moreover, the abundance of persistent buoyant litter items on coastal beaches should decline with the distance from a river mouth, as has previously been shown for riverine driftwood by Doong et al. (2011). The patterns of abundance of these litter items on coastal beaches near the river mouth are expected to coincide with directions of coastal winds or water currents.

With a coastline of more than 4000 km, and river courses of only about 200–400 km in length from the headwaters to the mouth, Chile offers ideal conditions for the investigation of litter on coastal beaches and in the river courses. In previous studies, litter on Chilean beaches and in coastal waters has been suggested to come from local sources, including rivers (Bravo et al., 2009; Hinojosa et al., 2011; Thiel et al., 2013). To study the link between riverine transport and amounts of litter on coastal beaches, the composition and abundance of litter at riversides and beaches near the mouth of four rivers from central Chile were compared. Furthermore, the abundances of the persistent buoyant litter items, plastics, polystyrene and manufactured wood, were investigated at riversides and on coastal beaches at various distances from the mouths of the four rivers.

2. Materials and methods

2.1. Study area

Anthropogenic litter was studied at riversides of the Chilean rivers Elqui, Maipo, Maule and BioBio and on coastal beaches at different distances from the respective river mouths (Fig. 1). The study area reaches from northern-central (29°S) to southern-central Chile (37°S) and from the headwater regions (70°W) near the Andean cordillera to the river mouths on the Chilean coast (73°W) (Fig. 1). The annual precipitation and runoff increases from north to south, being almost two orders of magnitude higher in the BioBio than in the Elqui (Table S1). The river Elqui has highest runoff during austral summer as a result of Andean snow melt (Valle-Levinson et al., 2000), while maximum discharge of the rivers Maipo, Maule and BioBio typically occurs during the winter season after heavy rainfalls (Saldías et al., 2012). Human population density differs between the four rivers, with the maximum being associated to the Maipo nearby Santiago, the economic center of the country (Table S1).

2.2. Classification of litter

Litter was distinguished based on the type of material and its buoyancy. Plastics, polystyrene and manufactured wood are able to float over long distances without sinking or decomposing and were classified as "persistent buoyant" litter. Many of these persistent buoyant litter items have the potential to float from the headwaters to the mouth of the river, and into the ocean. Therefore they are used in the present study to infer riverine litter transport. Cigarette stubs, paper and carton, textile, rubber and "other" items made up the category of "short-time buoyant" items, as they initially float and get carried away by a stream, but will sink or decompose after a relatively short time, and many of these may not reach the ocean by riverine transport. Concrete, pottery, glass and metal were referred to as "non-buoyant" items, as they do not float and are too heavy to be transported over long distances by the river. It is very unlikely for these non-buoyant litter items to reach the ocean.

2.3. Riverside sampling

At each river, sampling sites were located in the headwaters, the central reaches and at the mouth of the river. Depending on the river morphology, at some rivers we sampled an additional site in the headwaters (Maipo) or in the central reaches (BioBio) (Fig. 1). Sampling sites were heterogeneous with respect to their accessibility (due to natural or logistic restrictions), and in their proximity to human communities, traffic or industry.

In order to sample the riversides representatively, sampling was conducted in three zones, based on their distance to the river bed: (1) river shore, at the edge of the river (maximally 3 m away), (2) mid bank covers the river bank up to the high watermark (the width of this zone varies between rivers), (3) upper bank, outside of the river bed, never reached by the river, even at record water stands. In each of the three zones, all litter items were counted in five sampling circles (three circles at the river mouths). Each sampling circle had a radius of 1.5 m, and circles were placed along a line parallel to the edge of the river, with a distance of 30 m between individual circles. All litter with a size of more than 1.5 cm was sampled. Litter categories were immediately classified in the field; if an item could not be clearly attributed to a category, it was stored and taken to the laboratory for subsequent identification.

2.4. Beach sampling

Samples were taken on coastal beaches to both sides (north and south) of the river mouths. Sampling sites were located immediately at the river mouth and then at distances of ~0.3 km, ~1 km, ~3 km, and 5–9 km from the river mouth. The distances to the river mouth depended on the geomorphology (location of sandy or cobble beaches) and accessibility of the seashore. In order to sample litter on the beach representatively, samples were taken from the most recognizable high tideline (which was usually the uppermost of several high tidelines) and from the historic tideline, which was defined as the uppermost tideline from very high floods in recent times (within the last 3 years). The historic tideline was usually at the very top of the beach, and characterized by accumulations of driftwood and other flotsam. Four quadrats of 3 m × 3 m were placed along each of the two tidelines, and all litter items were classified and counted as described above for the riverside samples.

2.5. Statistical analyses

Litter abundances at riversides and on coastal beaches are characterized by box-and-whisker-plots, showing median values and percentiles for each sampling site. Similarities and dissimilarities in litter composition within and between rivers (riversides and coastal beaches) were analyzed using SIMPER (Similarity percentages) and graphically visualized using nonmetric multidimensional scaling (nMDS), resulting from Bray–Curtis similarities. Analyses were carried out using the software PRIMER (Clarke and Gorley, 2006).

Litter accumulation patterns along the shoreline were analyzed by comparing the ability of three hypothetical models to approximate the recorded data. Based on the oceanographic conditions along the Chilean coast we suggest three models, which might well

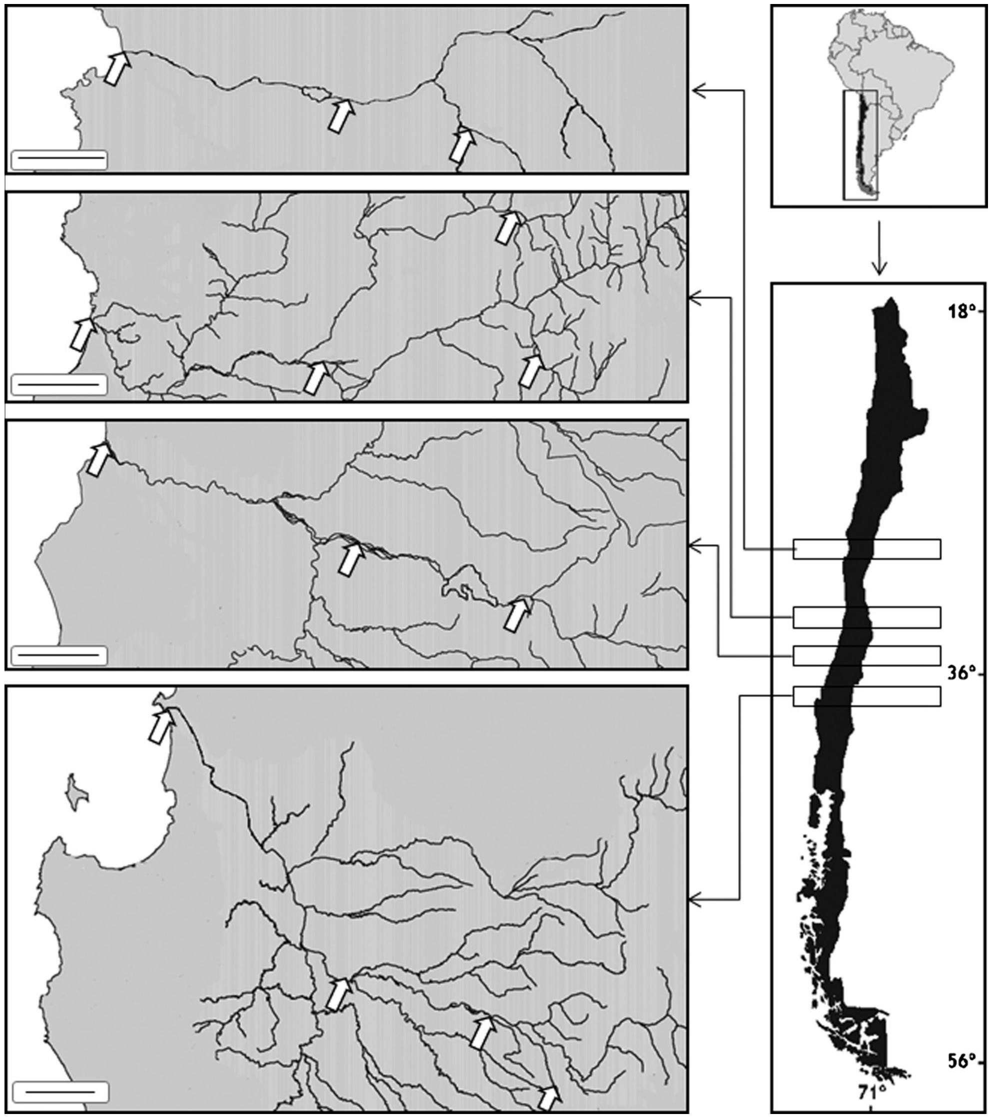

Fig. 1. Map of the study area. Sampling sites at beaches and riversides of Elqui, Maipo, Maule and BioBio (from north to south) are marked with white arrows. Black line in the lower left corner represents 20 km.

approximate litter maximum abundances, if the main share of the litter sampled really originates from rivers. (1) Main litter accumulation on northern beaches with a decline from the river mouth to southern beaches would occur if the prevailing equatorward winds are the main driver of litter deposition and a smaller share of riverine litter is carried to southern beaches due to seasonal or intertidal variations in nearshore currents (Northern accumulation model). In contrast, (2) seasonal poleward winds and currents might cause main accumulations of riverine litter on southern beaches, with declining abundances toward northern beaches, especially in the southern rivers, which have a high discharge in the rainy season and might therefore transport and deposit more litter in austral fall, when these poleward currents occur (Southern accumulation model). (3) If neither of these seasonal winds and water currents has a dominant effect, riverine litter might be dispersed in all directions, including the open ocean, and its abundance would peak at the river mouth and quite rapidly decline toward northern and southern beaches (Mouth accumulation model). The data for each sampling site were standardized to the most contaminated sample (=100%) of each combination of litter type and river. To minimize the effect of ocean-based litter, all replicates of a sampling site were reset to the least contaminated replicate. Because models are expected to mimic the maximum (and not the mean) litter abundance vs. the distance from the river mouth, the traditional OLS regression approach is not suitable for statistical testing. Instead, a quantile regression was carried out between the observed values of standardized litter abundance and the predictions of each model, using the 90th quantile. P-values were obtained through bootstrapping (100,000 runs). The performance of each model was compared using the Akaike weights (AIC_w). The AIC_w value represents the probability for a model to be the best-fitting among the chosen candidate models (Mazerolle, 2004), where values close to 1 indicate higher support. Analyses were carried out using the libraries *quantreg* and *MuMin* in R (Team, 2013).

3. Results

3.1. Composition of litter at riversides and on beaches

The main proportion of litter found at the riversides and the coastal beaches was persistent buoyant litter, followed by short-term buoyant litter and non-buoyant litter (Table 1). Plastics were the prevailing litter items at most sampling sites, and were

Table 1
Composition of litter found at riversides of Elqui (n = 3 river sites), Maipo (n = 4), Maule (n = 3) and BioBio (n = 4), and on beaches in the area of the river mouths of Elqui (n = 11 beach sites), Maipo (n = 8), Maule (n = 8) and BioBio (n = 9). Numbers in parentheses show the total number of litter items.

	Elqui		Maipo		Maule		BioBio	
	River (649)	Beach (817)	River (328)	Beach (2250)	River (144)	Beach (671)	River (645)	Beach (409)
Persistent buoyant								
Plastics	24.2	60.0	42.9	52.0	40.3	51.0	13.3	55.0
Polystyrene	2.3	4.0	30.4	33.1	25.0	9.7	2.0	12.2
Man. wood	9.9	2.7	2.1	0.7	10.4	24.1	66.2	18.1
∑	**36.4**	**66.7**	**75.4**	**85.8**	**75.7**	**84.8**	**81.5**	**85.3**
Short-term buoyant								
Cigarette stubs	5.4	19.1	5.2	10.4	11.8	3.3	6.5	5.1
Paper/carton	14.3	5.4	9.7	1.1	7.6	4.0	5.3	3.4
Textile	1.8	1.3	2.7	0.5	0.7	1.3	0.6	0.5
Rubber	0.8	1.2	0.6	1.3	0.0	0.4	0.2	0.0
Other	1.2	1.0	0.6	0.0	2.1	3.9	1.9	2.4
∑	**23.5**	**28.0**	**18.8**	**13.3**	**22.2**	**12.9**	**14.5**	**11.4**
Non-buoyant								
Concrete/pottery	34.2	1.2	0.0	0.0	0.0	0.0	0.5	1.5
Metal	3.1	2.4	2.1	0.3	1.4	1.0	2.3	0.7
Glass	2.8	1.6	3.6	0.6	0.7	1.2	1.2	1.0
∑	**40.1**	**5.2**	**5.7**	**0.9**	**2.1**	**2.2**	**4.0**	**3.2**

Table 2
Similarities (Bray–Curtis index, expressed in %) in litter composition within a river group (=riversides and coastal beaches) and dissimilarities between river groups, shown as results of SIMPER (similarity percentages) analysis.

Within rivers	Average similarity (%)	Between rivers	Average dissimilarity (%)
Elqui	74.35	Elqui and Maipo	28.60
Maule	80.44	Elqui and Maule	27.87
Maipo	82.51	Elqui and BioBio	28.34
BioBio	75.53	Maipo and Maule	24.73
		Maipo and BioBio	30.20
		Maule and BioBio	19.63

more frequently found on beaches than at riversides, suggesting that some of the litter arrived at the beaches via the sea, probably originally coming from the rivers. Polystyrene was most frequent at sampling sites on the river Maipo, where its share of total litter was similar at riversides and beaches, indicating a possible polystyrene flux from this river to the adjacent seashore beaches. Manufactured wood was the predominant litter type at riversides of the BioBio, which can be attributed to its exceptionally high occurrence at one sampling site. Manufactured wood also had a high share of total litter on beaches near the mouths of the two southern rivers, BioBio and Maule. In contrast to persistent buoyant litter items, short-term buoyant litter was more frequent at riversides than on beaches (Table 1), being most abundant at riversides and beaches of the river Elqui and least at those of the BioBio. The proportion of non-buoyant litter items was generally low at the investigated riversides and beaches, mainly found at riversides of the Maipo and Elqui, where there was an exceptionally high share of concrete and pottery items at two out of three sampling sites, and on beaches near the mouth of the Elqui.

The composition of litter was similar between riversides and coastal beaches of each river, with similarities ranging from 74% for the Elqui sampling sites to 83% for the Maipo sampling sites (Table 2). The litter composition also did not differ strongly between the four rivers, especially not between the southern rivers Maule and BioBio (average dissimilarity: 20% between Maule and BioBio; Table 2). Consequently, riversides and coastal beaches of the rivers Elqui and Maipo form a river-specific group, while the Maule and BioBio form a combined group (Fig. 2).

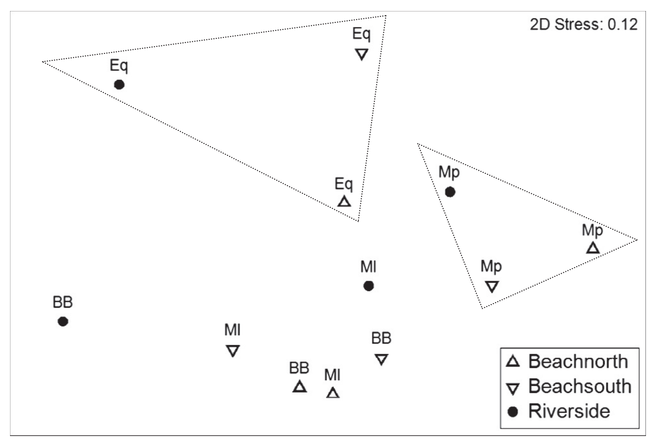

Fig. 2. Similarities in litter composition of riversides and coastal beaches to the north and to the south of the river mouths of Elqui (Eq), Maipo (Mp), Maule (Ml) and BioBio (BB), shown as nonmetric multidimensional scaling (nMDS) plot, based on Bray–Curtis similarities. Data were transformed to square roots for analysis. R global = 0.386.

3.2. Litter abundances

Litter abundances at riversides and on beaches varied strongly between rivers and sampling sites, as well as within sampling sites (Figs. 3–6), which can be due to direct anthropogenic influence on the sampling sites, such as illegal dumping, or recreational activities and beach cleanings.

Plastics, which were found at almost all river sampling sites, were the most abundant litter items at riversides followed by polystyrene and manufactured wood (Fig. 3). Their highest abundances were at riversides of the Elqui and Maipo. Polystyrene was also found at almost all sampling sites, but in contrast to plastics, often occurred in high densities in single replicates. Manufactured wood occurred sparsely at riversides of the Elqui and Maipo, with single

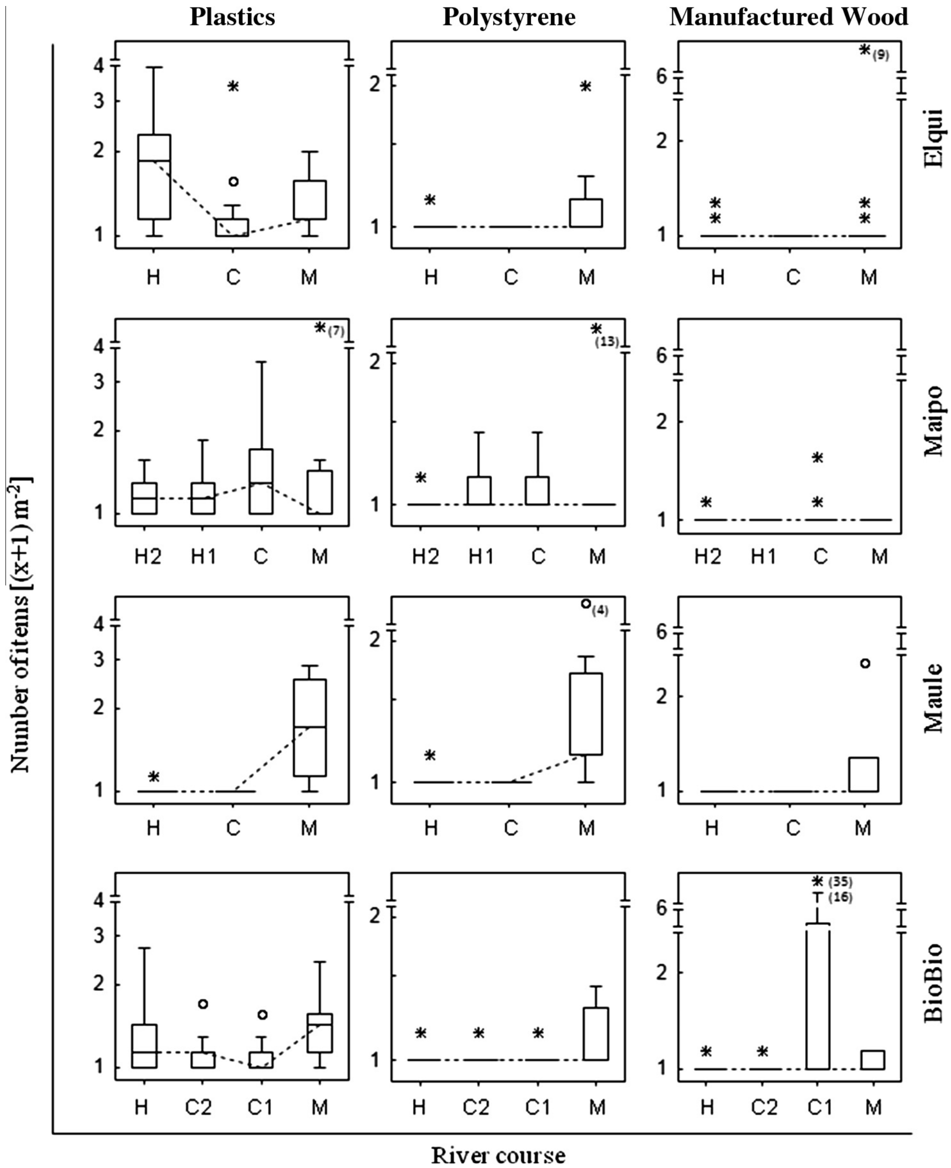

Fig. 3. Abundance of plastics, polystyrene and manufactured wood at riversides along the rivers Elqui ($n = 3$ sampling sites), Maipo ($n = 4$), Maule ($n = 3$) and BioBio ($n = 4$). Sampling sites were distributed along the main course of the different rivers: H – Headwaters, C – Central reaches, M – River mouth. Numbers in parentheses show outliers.

locations of high abundance, but was found in comparatively high abundances at some riversides of the BioBio and Maule.

Although there is no overall pattern of litter abundances along the river course, there are some tendencies for the individual rivers. At riversides of the Elqui, abundances of all three litter types were highest at river banks of the headwaters and river mouth. At riversides of the Maipo, abundances of the different litter types varied between sampling sites in the headwaters and central reaches, reaching the lowest abundances at the river mouth. In contrast, the Maule riversides showed highest abundances of plastics, polystyrene and manufactured wood at the mouth and only isolated spots with high densities of plastics and polystyrene at the headwaters. There was no litter at the sampling site in the central reaches of this river. In the case of the BioBio, litter also occurred mainly at the river mouth, with the exception of manufactured wood, for which one sampling site in the central reaches had the highest abundance. Overall, the BioBio is the only river where manufactured wood was found in higher abundance than polystyrene (Fig. 3).

On the coastal beaches, plastics were also the most abundant litter items, followed by polystyrene and manufactured wood. Plastics and polystyrene items were most abundant on the beaches corresponding to the river Maipo, especially to the north of the river mouth, where median values of up to 3.4 (plastics; Fig. 4) and up to 2.1 items m^{-2} (polystyrene; Fig. 5) were observed. Plastic items were found on all sampled beaches with a rather broad distribution (median > 0 on 34 out of 36 sampled beaches), while polystyrene was absent or only found in single replicates (median = 0) on some beaches (Figs. 4 and 5). Interestingly, the river Elqui, which after the Maipo had the most plastic contamination, is much less contaminated in terms of polystyrene, with several sampling sites not having any (Fig. 5). Manufactured wood was mostly found on beaches of the southerly rivers Maule and BioBio, with the highest abundance on the northern beach nearest to the Maule mouth (median = 1.00; Fig. 6). Remarkably, manufactured wood items were only found on three of the eight sampled beaches of the Maipo.

Generally the abundance of plastic litter increased from the southernmost beaches toward the river mouths and highest accumulations were often found on northern beaches (Fig. 7, Table 3, Table S2). In contrast to the distribution of plastics, the main accumulation sites of polystyrene were the river mouths, and abundances declined toward northern and southern beaches (Fig. 7). This pattern is statistically significant for the overall distribution

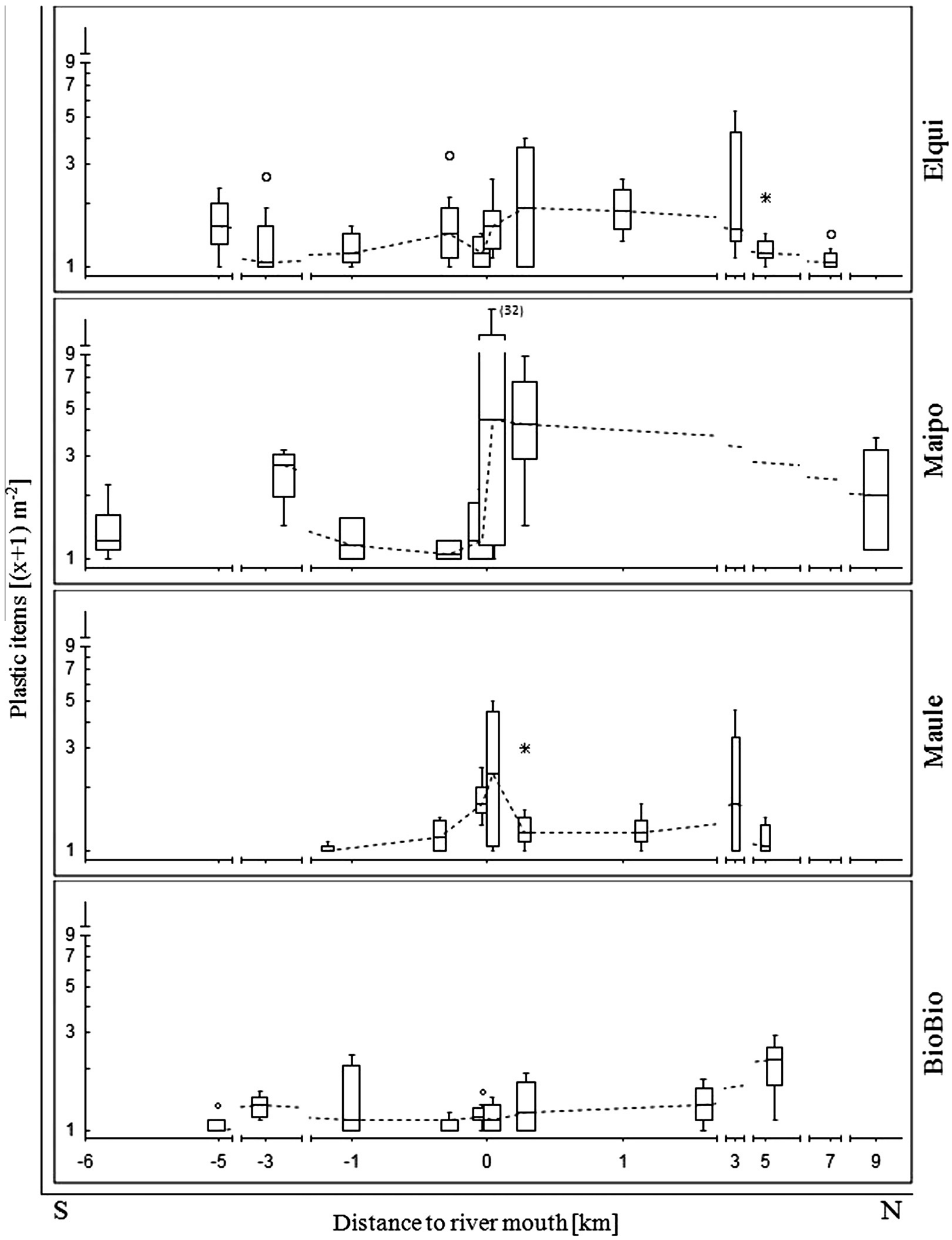

Fig. 4. Abundance of plastics on coastal beaches corresponding to the rivers Elqui ($n = 11$ sampling sites), Maipo ($n = 8$), Maule ($n = 8$) and BioBio ($n = 9$). Numbers in parentheses show outliers.

of polystyrene (independently of the river), as well as for its distribution on coastal beaches of the Elqui (Table 3). For manufactured wood, no general distribution pattern was found, but on the coastal beaches of the Elqui and Maipo the "mouth accumulation model" is the most fitting (Table 3). The most fitting model for the distribution of the sum of all persistent buoyant litter is the accumulation north model (Fig. 7, Table 3).

4. Discussion

4.1. Litter composition

Persistent buoyant items, particularly plastics, are the most abundant litter items along Chilean riversides and on beaches, which is in agreement with the findings of previous studies on rivers, riversides and beaches from several parts of the world (Williams and Simmons, 1999; Derraik, 2002; Carson et al., 2013; Thiel et al., 2013). High percentages of plastics and wood were also found on beaches around the northern South China Sea, where more than 95% of litter was attributed to land-based sources (Zhou et al., 2011). A study on sandy beaches of northern-central Chile corroborates our results: Plastics, polystyrene and manufactured wood were the main litter items, making up 83%, 3%, and 8%, respectively (Thiel et al., 2013). Herein, the proportions of short-term and non-buoyant riverine litter was generally lower on coastal beaches than at riversides which most likely is due to the fact that some of this litter has already sunk or degraded in the river or shortly after entering the sea.

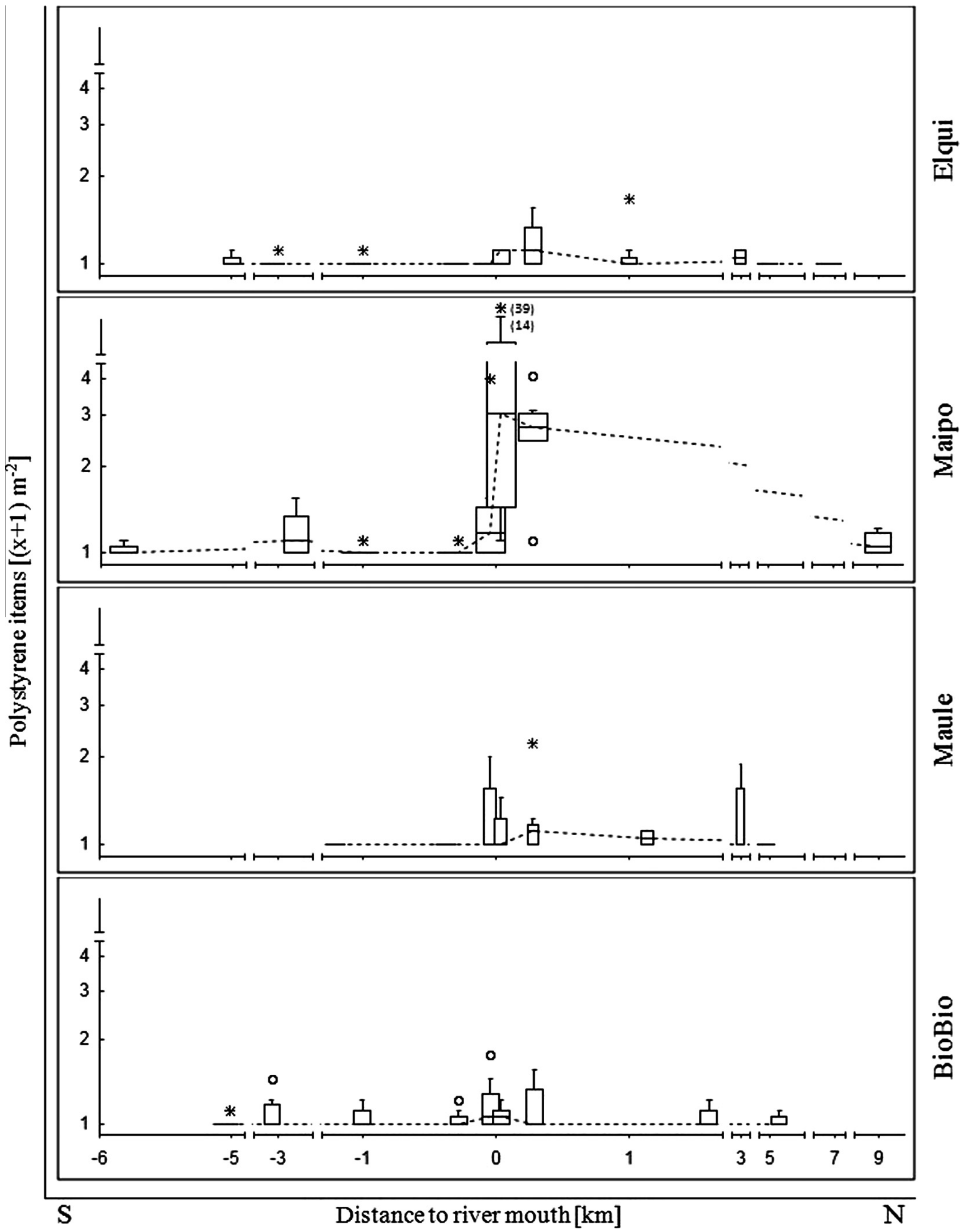

Fig. 5. Abundance of polystyrene on coastal beaches corresponding to the rivers Elqui (n = 11 sampling sites), Maipo (n = 8), Maule (n = 8) and BioBio (n = 9). Numbers in parentheses show outliers.

The composition of riverside litter is attributable to activities within the drainage area of the respective river. The relatively high shares of the short-term buoyant litter items paper and cigarette stubs at riversides of the Elqui and on its corresponding beaches are suspected to be the result of direct littering by tourists, campers and beach-goers. In contrast, the concordance of high proportions of plastics and polystyrene at riversides and on coastal beaches of the river Maipo indicate their riverine origin. This finding is not surprising, considering that the Mapocho, a tributary river of the Maipo, directly flows through Chile's capital, Santiago. Part of the litter generated by the local industry and other human activities is discharged into this river without major treatment (Lehn et al., 2012). The high shares of manufactured wood at riversides and on beaches of the Maule and BioBio can be attributed to the wood industry and related pulp mills, which are concentrated in the area of these two rivers (Videla and Diez, 1997).

4.2. Abundances of riverine litter

Litter abundances at riversides differ between the four rivers, as well as between the sampling sites of each river. As the sampling sites chosen for this study were heterogeneous with regard to the land use of the surrounding area, proximity to human settlements and industry, and accessibility, these factors might

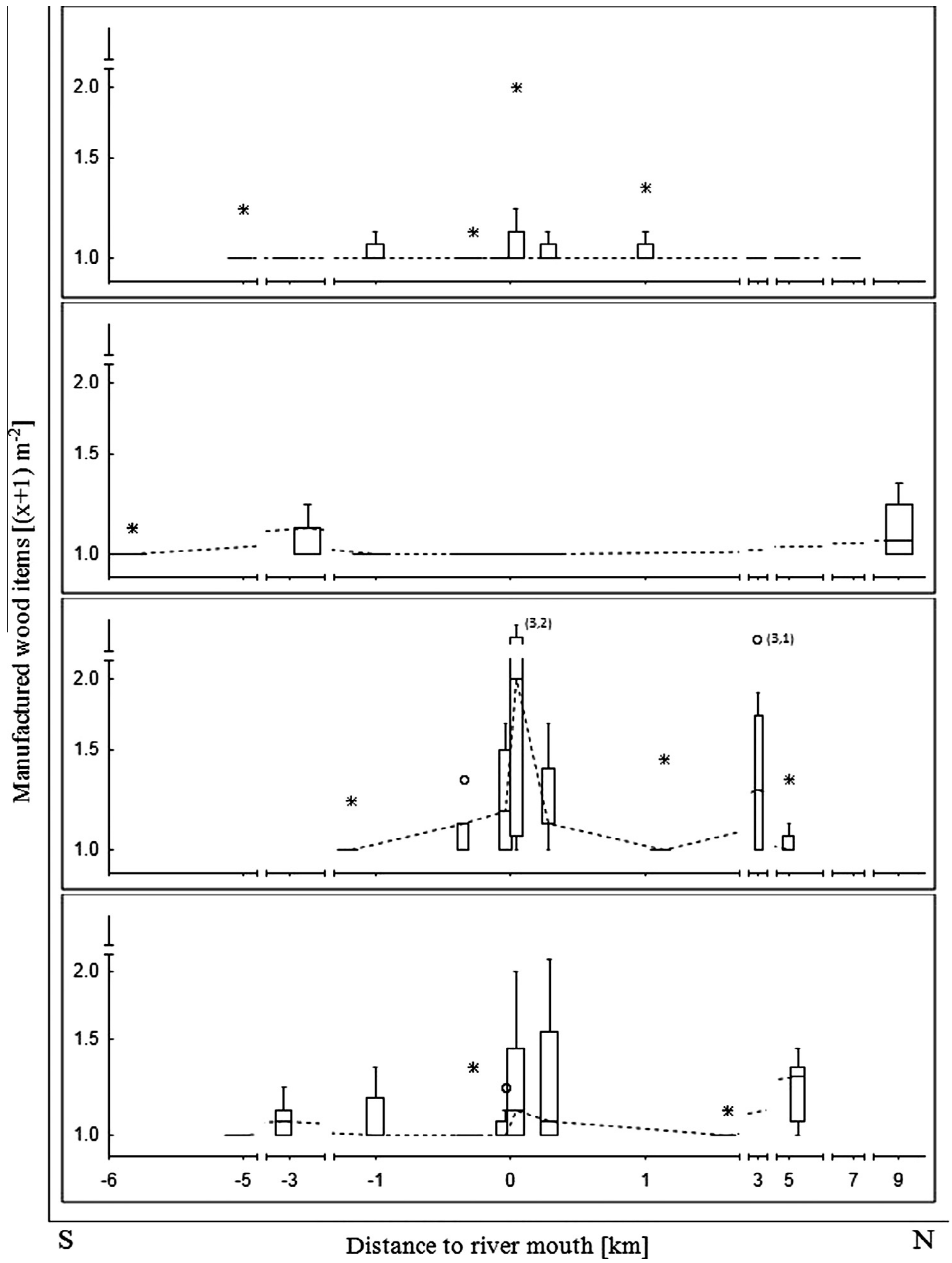

Fig. 6. Abundance of manufactured wood on coastal beaches corresponding to the rivers Elqui ($n = 11$ sampling sites), Maipo ($n = 8$), Maule ($n = 8$) and BioBio ($n = 9$). Numbers in parentheses show outliers.

contribute to the observed differences in litter abundances at riversides (Williams and Simmons, 1997a). The type of land use influences both the amount of litter generated in the area, and the frequency of illegal litter dumping at a sampling site (Williams and Simmons, 1999; Carson et al., 2013). The accessibility of the river shore, especially for vehicles, also influences the degree of illegal litter dumping (Williams and Simmons, 1999).

Runoff varies strongly between the four rivers (mean annual discharge: from $10\,m^3\,s^{-1}$ in the Elqui to values of almost $1000\,m^3\,s^{-1}$ in the BioBio; see Table S1) and is very likely to influence the observed litter abundances. Since the present study was carried out during austral fall, after the highest discharge of the Elqui and before the highest discharges of Maipo, Maule and BioBio, different hydrographic regimes may be responsible for differences and patterns of litter abundances at riversides within and between rivers. When runoff of the southerly rivers increases in the rainy season (austral winter), litter will most likely be transported from the riversides to the coastal beaches or even further offshore (e.g. Galgani et al., 2000; Moore et al., 2002; Lattin et al., 2004). Within the river course there might be a shift of litter from sparsely vegetated river banks to river sections with denser vegetation that traps floating litter (Williams and Simmons, 1997a,b). Heavy local rainfalls and flash floods may also wash litter away from riversides (Williams and Simmons, 1997a), possibly causing the complete lack of litter in the central reaches of the river Maule.

The studied rivers are relatively small compared to other rivers that transport large volumes of water and litter such as the Rio de la Plata (Argentina) and the Rhône (France) (Galgani et al., 2000; Acha et al., 2003). There are no major estuaries in any of the studied rivers, the river plumes are comparatively small and the river fronts are on the seaward side, close to the river mouth (e.g. Piñones et al., 2005; Saldías et al., 2012). These river plumes and

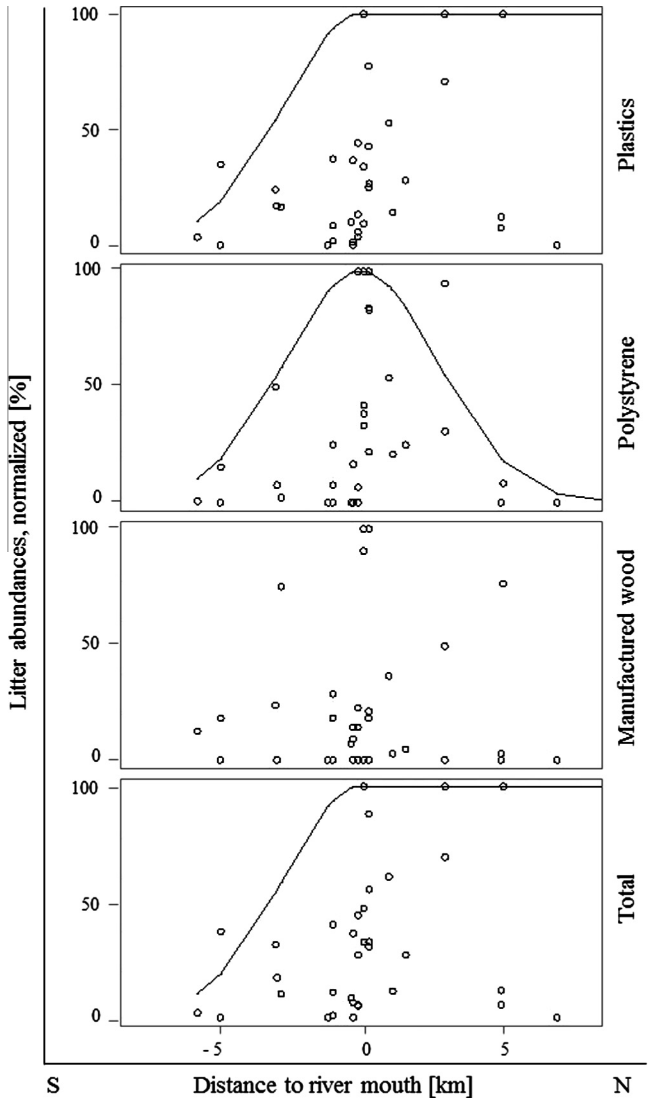

Fig. 7. Normalized abundances of plastics, polystyrene and manufactured wood on coastal beaches corresponding to the rivers Elqui, Maipo, Maule and BioBio. For each river: Highest value = 100%. Lines show the best fitting model (see Table 3).

Table 3
Summary of the performance of three hypothetical models explaining the relationship between standardized litter abundance (plastics, polystyrene, manufactured wood and the sum of items of these three litter types) and distance to river mouth. Probability to be the best of three chosen models is indicated by Akaike weights (AIC_w). Bold = statistically significant ($P < 0.05$) highest AIC_w values. acc. mouth = Mouth accumulation model, acc.north = Northern accumulation model, acc. south = Southern accumulation model. See text for details.

Item	Model	AIC_w	*p*
Plastics	Acc.mouth	0.006	1.000
	Acc.north	**0.966**	**0.012**
	Acc.south	0.028	0.637
Polystyrene	**Acc.mouth**	**0.921**	**0.005**
	Acc.north	0.078	0.175
	Acc.south	0.001	0.036
Man.wood	Acc.mouth	0.027	1.000
	Acc.north	0.944	0.470
	Acc.south	0.029	0.833
All items	Acc.mouth	0.006	1.000
	Acc.north	**0.980**	**0.018**
	Acc.south	0.014	0.776

their direction will thus influence the depositional pattern of riverine litter after entering the sea.

4.3. Litter abundances on beaches

On beaches, some distinct patterns of litter abundances can be recognized and assigned to wind and water currents. A broad equatorward low-level jet is predominant along the central Chilean coast in austral summer, with localized speed maxima (coastal jets) in the regions near the Elqui and BioBio mouths (Aguirre et al., 2012; Rahn and Garreaud, 2013). Equatorward winds are likely to cause the overall pattern of main litter accumulations on beaches north of the river mouths, which was detected in this study. This assumption is corroborated by a study of Browne et al. (2010), who found that plastic litter predominantly accumulates on downwind beaches of the Tamar estuary, UK. The decline in abundances of persistent buoyant litter items from the river mouths towards southern beaches (plastic items) or beaches in both directions (polystyrene and manufactured wood items), which was detected in the present study, has also been reported for driftwood along the Taiwanese coast (Doong et al., 2011) and clearly indicates the riverine origin of the respective litter.

While large-scale oceanography seems to drive the large-scale patterns, the nearshore oceanography of the coastal areas adjacent to the river mouths is more complex and needs to be considered with regard to the observed distributional patterns. In northern-central Chile, the climate and equatorward currents are generally stable throughout the year (Aguirre et al., 2012; Rahn and Garreaud, 2013), but there is variable tidal and sub-tidal circulation in the bay of Coquimbo, with currents toward the north on northern beaches, as well as to the south on beaches south of the Elqui river mouth (Valle-Levinson et al., 2000), depositing riverine litter on coastal beaches to both sides of the river mouth. In the coastal region off central and southern-central Chile, oceanic and climatic conditions are seasonally variable (Piñones et al., 2005; Saldías et al., 2012), which influences the shape and extent of river plumes. The Maipo river plume is a surface-advected plume and has a highly variable spatial structure. During austral fall, the river plume extends mainly offshore and southward. Northward excursions of the plume occur on a diurnal scale, due to wind forcing, in summer and as a result of high runoff, after rain pulses in winter (Piñones et al., 2005). Following the river plume, riverine litter can reach the coastal zone to the north as well as to the south of the Maipo mouth. Off southern-central Chile, high river runoff, strong southward winds and earth rotation cause southward-oriented plumes of the Maule and BioBio in austral winter. During austral summer, however, river plumes are small and directed northwards (Saldías et al., 2012). The comparatively large river plumes and the seasonally shifting current directions might spread riverine litter over a larger area in the southern rivers, thereby impeding the detection of clear depositional patterns. For submarine litter, Galgani et al. (2000) also observed a distinct spatial pattern near the mouth of a small river, but the distribution of litter was less clear under the plume of a large river. The heterogeneity in accessibility and therefore human influence of sampled beaches can additionally contribute to differences in litter abundances and also disrupt hydrodynamic patterns of litter deposition (Viehman et al., 2011).

The abundances of litter on Chilean beaches found in this study are similar to those found in a nation-wide survey in 2008 (Bravo et al., 2009), but higher than those found on less urbanized beaches in northern-central Chile (Thiel et al., 2013). Abundances of plastic litter were also in the same range as those on estuarine beaches in the UK (Williams and Simmons, 1997). But the pollution of the investigated Chilean beaches is high in comparison to several other parts of the world (Bravo et al., 2009).

5. Conclusions and outlook

Based on the results of the present study it can be concluded that rivers transport large amounts of anthropogenic litter from inland sources to the ocean and coastal beaches of the SE Pacific. This is underlined by the findings of (i) similar composition of persistent buoyant litter on riversides and on adjacent, coastal beaches, and (ii) litter accumulations at the river mouths, or on beaches at the principal downwind side (north), with abundances declining from the river mouths towards southern beaches (plastics) or southern and northern beaches (polystyrene). Results presented here are based on a single sampling during austral fall. It is assumed that patterns will be more pronounced after the main raining season, when large quantities of anthropogenic litter may have been washed into the rivers and from the rivers into the ocean. Furthermore, herein few sites were sampled within each river, and it is suggested that the distribution patterns of riverside litter will become clearer when more sites are sampled along each river course. Sampling beaches repeatedly would also help to identify seasonal patterns in litter accumulation on coastal beaches that are influenced by riverine input.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.marpolbul.2014.03.019.

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