

Sampling of riverine litter with citizen scientists — findings and recommendations

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Abstract The quantity and composition of litter at riversides and in the surface waters, as well as the occurrence of illegal dumping sites, were studied along four rivers in Chile. Data generated by volunteers were compared to the results from a professional survey, using an identical protocol. Litter was found in considerable quantities at the riversides and in the surface waters at all the sites investigated. A generalized linear mixed model analysis showed that the recorded litter densities did not differ between volunteers and professionals, even after controlling for river, site, or distance between sampling locations, demonstrating that the volunteers successfully applied the sampling protocol. Differences occurred with respect to litter composition, which is most likely due to difficulties in the classification of litter items and particles and to the underestimation of litter present in surface water samples. Even though this study was only conducted at a small number of rivers and sites, a comparatively

consistent pattern of direct and intentional litter deposition at riversides was recorded, highlighting that river basins require more protection. The results also show that the citizen science approach can be a suitable means for more extensive litter surveys at riversides and in other natural environments.

Keywords Citizen science · Data validation · Litter abundance · Litter sources · Riverine litter · Floating microplastics

Introduction

The pollution of the marine environment by anthropogenic litter is increasingly recognized as a threat to global ecology and human well-being, and scientific research is expected to be able to find feasible solutions

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and generate policy changes (e.g., Thompson et al. 2009; Rochman et al. 2013; Lechner and Ramler 2015). The impacts of marine litter range from injuries and death (mainly due to ingestion and entanglement) of marine biota to the spreading of invasive species, and negative effects on coastal tourism, navigation, and human health (Moore 2008; Gregory 2009; Rochman et al. 2013). Some of the aforementioned impacts are also likely to occur in freshwater environments, which are heavily contaminated with litter (e.g., Free et al. 2014; Hoellein et al. 2014; Lechner et al. 2014). Indeed, the main share of marine pollution stems from land-based sources and reaches the sea via riverine transport (e.g., Galgani et al. 2000; Araújo and Costa 2007; Rech et al. 2014). While large amounts of litter items and particles have been reported in riverine and estuarine waters (e.g., Moore et al. 2011; Carson et al. 2013; Lechner et al. 2014; Lima et al. 2014; Morritt et al. 2014), and at riversides (e.g., Williams and Simmons 1997; Rech et al. 2014), studies quantifying the numbers and types of litter in rivers and at riversides are often very localized or from single rivers.

Current knowledge regarding sources and movement patterns of riverine litter is limited because comparatively few studies have been conducted in freshwater environments. A major litter source is direct dumping of litter at riversides or from boats (Williams and Simmons 1999). The frequency of illegal littering at riversides is suggested to depend largely on the area's land use and accessibility, especially to vehicles (Williams and Simmons 1999; Carson et al. 2013). For example, in a UK-based study, industrial sites were more affected than commercial (e.g., shopping centers) and residential areas or open spaces (Williams and Simmons 1999). In several studies, rather large shares of sanitary litter were found in and adjacent to rivers, especially in the vicinity of sewage treatment plants, pointing to their importance as litter sources (Williams and Simmons 1996, 1999; Araújo and Costa 2007; Morritt et al. 2014). The considerable amount of plastic preproduction material that was recently found in a large river (Lechner et al. 2014) indicates that the input of plastics by the industry might also be quite important (Lechner and Ramler 2015). Large quantities of litter also enter the river via stormwater runoff, especially after long dry periods, when accumulated litter is washed into rivers (Williams and Simmons 1999; Armitage 2007; Ryan et al. 2009; Moore et al. 2011; de Barros et al. 2014).

Once in the stream, riverine litter can not only be transported to the marine environment but also become buried in the sediment or stranded at riversides. Depositional patterns of litter in the river mainly depend on density of vegetation, watercourse obstructions, and climatic conditions (Williams and Simmons 1997; Balas et al. 2001; Armitage 2007). Storm events and high floods, for example, can shift litter between riversides, toward more vegetated shores, and deposit litter far away from the water's edge where it accumulates until being flushed away by a subsequent high flood (Williams and Simmons 1997). As the movement and depositional regimes along rivers are not yet fully understood, it is difficult to determine the primary source of litter found at riversides or in streams.

Previous studies on the litter situation in riverine locations provide initial indications of the underlying processes, but we are still far from a general understanding of the overall patterns of sources, transport, and distribution of such litter. The citizen science approach, in which volunteers collect scientific data, might be a suitable means for the investigation of this international problem on a large geographical and temporal scale.

Citizen scientists, ranging from schoolchildren to retirees (e.g., Cohn 2008; Donnelly et al. 2014; Eastman et al. 2014), have provided ecological field data for more than two centuries and are regarded as an "essential component of sustainability" by the United Nations Environmental Programme (Au et al. 2000). Their help is especially valuable when large datasets are needed to investigate large-scale phenomena (Cohn 2008; Dickinson et al. 2010; Kolok et al. 2011). Citizen science projects do not only provide scientific data but also have educational value, raise public awareness on environmental issues, and increase the social capital in participating groups (Cohn 2008; Conrad and Hilchey 2011). In addition, public monitoring is used by communities to investigate local environmental problems and enforce solutions (e.g., Au et al. 2000; Conrad and Hilchey 2011). Litter surveys and beach cleanings, including events organized by the Ocean Conservancy Inc. or Reef Check amongst others, often involve hundreds to several thousands of volunteers, thus disseminating knowledge about the problem with the potential to improve local policies (e.g., Rosevelt et al. 2013; Gura 2013). Still, a major challenge of citizen participation in scientific projects are concerns regarding the replicability, comparability, and completeness of the data contributed by volunteers,

which is why such data are often not considered in management decisions (Conrad and Hilchey 2011; Gillett et al. 2012). Although citizen science projects have to deal with challenges, including coordination, data collection, and ownership, the benefits can be substantial (Conrad and Hilchey 2011).

To gain precise data and prevent bias, citizen science protocols should be simple, volunteers should be trained, and the results obtained by volunteers have to be tested for reliability (Sharpe and Conrad 2006; Cohn 2008; Eastman et al. 2014). In previous studies, collection and sorting of litter samples on beaches were successfully conducted by citizens (e.g., Kusui and Noda 2003; Bravo et al. 2009; Hidalgo-Ruz and Thiel 2013). With respect to freshwater ecosystems, there exists a variety of community-based water monitoring programs (Conrad and Hilchey 2011) that have coordinated citizen scientists to successfully monitor various ecological factors, such as benthic macro-invertebrates (Nerbonne et al. 2008), bacterial contamination (Au et al. 2000), and invasive species (Boudreau and Yan 2004). Kolok et al. (2011) also argue for the employment of volunteers in screenings for contaminants in aquatic environments. In contrast to sandy beaches with relatively homogeneous surfaces, litter sampling along riversides is much more complex due to the very heterogeneous substrata, consisting of soil, sand, rocks, and vegetation, along irregular river courses. In order to determine whether citizen scientists, and in particular schoolchildren, are able to successfully conduct a litter survey at riversides, the reliability of data collected by citizen scientists was examined in the present study by comparing them to data from professional scientists.

The presence and density of illegal dumping sites along the riversides, and of floating litter in the rivers were investigated at several sites along four Chilean rivers, covering a latitudinal distance of 900 km (from 29° S to 37° S). We compared litter data collected by professional scientists and by volunteers in order to estimate whether citizen scientists can help to expand the temporal and spatial coverage of litter studies along river shores.

Material and methods

Study area

Anthropogenic litter was studied along the courses of the Elqui, Maipo, Maule, and BioBio rivers from the

headwater regions (70° W) to the river mouths (73° W), spanning from northern-central (29° S) to southern-central Chile (37° S) (Fig. 1). The surveyed riversides were quite wide and could be divided into three areas. The *rivershore* is in permanent contact with the stream and stretches from the water's edge to a distance of no more than 3 m from the shore. The *mid bank* covers the area up to the river's high water mark and is in occasional contact with the stream, while the *upper bank* is situated outside of the river bed and is not in contact with the river, even at record water stands (see Supplementary Fig. S1).

The surveyed sites were chosen due to their proximity to participating schools along the four rivers studied. The sites are heterogeneous with regard to their substrata, vegetational profile, and river course characteristics; while this complicates intersite comparisons, it ensures that citizen-professional comparisons can be generalized across a wide range of site attributes. The substrata comprised mainly soil, often intermingled with pebbles and rocks (Fig. 2). At the river mouths, sandy riverine beaches also occurred. The vegetation mainly consisted of bushes, reed, and grass, which reached to the river's edge and occasionally into the river (Fig. 2).

The climate strongly differs between the study regions, with mean annual precipitation (MAP) and annual discharge (AD) augmenting the dissimilarities from the arid northern Elqui region (low MAP and AD), where the maximum discharges are due to Andean snowmelt during austral summer, to the more southerly river Maipo (moderate MAP and AD), and the southernmost rivers Maule and BioBio (rather high MAP and AD), where the maximum discharges are caused by strong rainfalls in austral winter (for details see Rech et al. 2014).

Citizen science approach

The investigation described herein was conducted in parallel by volunteers, the so-called citizen scientists, and professional scientists. The citizen scientists taking part in the activities were schoolchildren (ages 10–15) and their teachers from all over Chile, associated with the “Científicos de la Basura” program (“litter scientists”; see also www.cientificosdelabasura.cl). While part of the volunteers had participated in previous scientific activities of the “Científicos de la Basura,” others had no prior experience. Local marine scientists volunteered as supervisors for the surveys and sampling

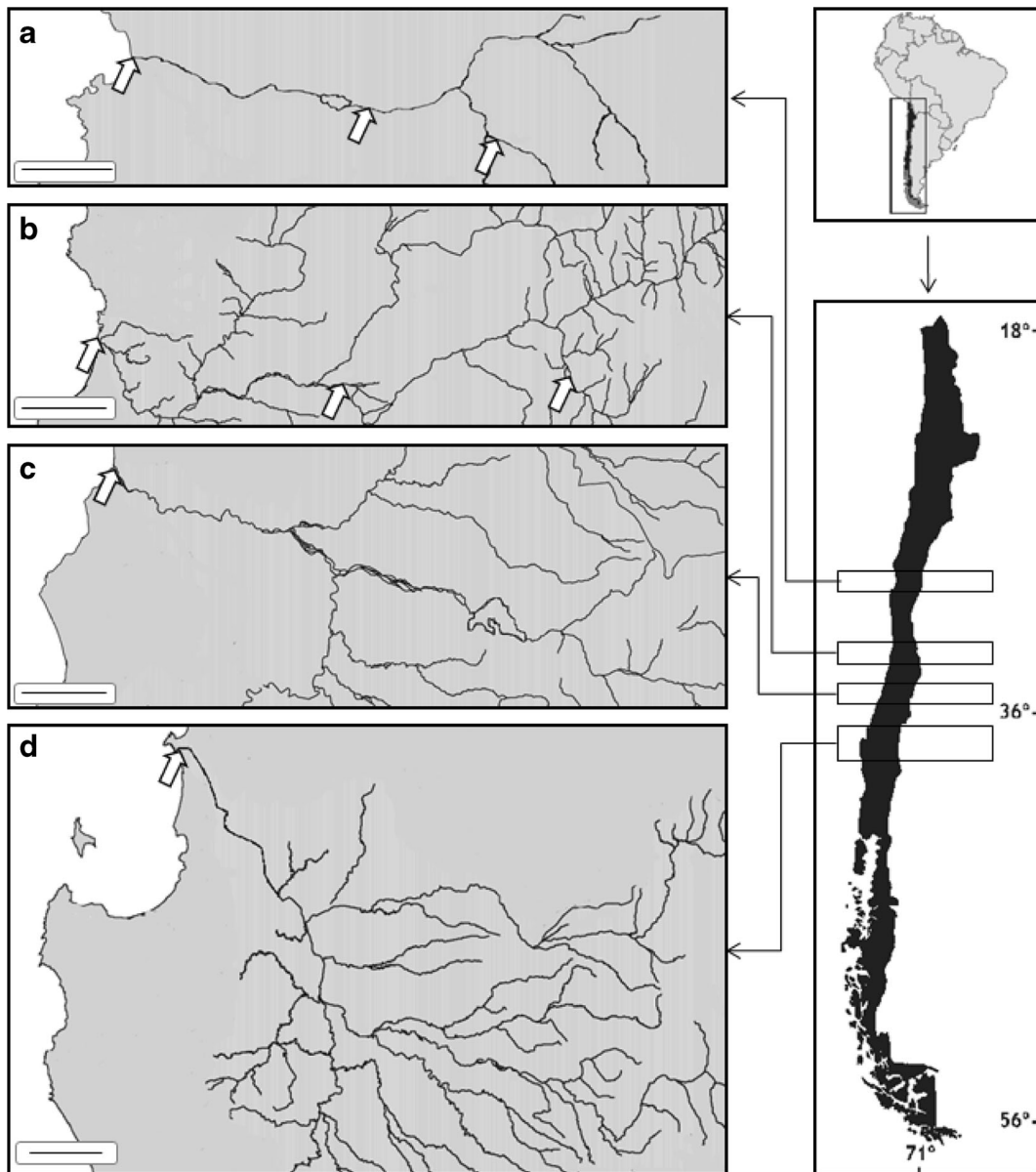


Fig. 1 Map of the sampling area. The sampling sites at riversides of **a** Elqui, **b** Maipo, **c** Maule, and **d** BioBio (from north to south) are marked with *white arrows*. The *black line* in the lower left corner represents 20 km. Published in a similar form in Rech et al. (2014)

activities at several sampling sites. To introduce the children and their professors to the scientific project and to prepare them for the surveys, everyone received an informative guide on litter sampling and scientific methods. Before the surveys were conducted, the volunteers also received a detailed sampling protocol, as well as all the necessary materials for the sampling, including a handmade neuston net. The professional coordinator of the volunteer survey was in close e-mail

and telephone contact with all participating schools before, during, and after the surveys.

For all surveys, both professional and citizen scientists followed the same sampling protocol (for instructions to the participants, original data sheet, and photos, see Kroeger et al. 2013 and <http://www.cientificosdelabasura.cl>). The survey was divided into two activities, which were generally conducted at the same site (for exact locations, see Table 1).



Fig. 2 Examples of surveyed riversides with varying vegetational profile and substratum

During the first activity, the schoolchildren explored the chosen sampling site and recorded accumulations of litter and illegal litter dumping sites (as defined in the “Litter survey along riversides” section). For the second activity, the schoolchildren counted litter quantities at the riversides and sampled floating litter from the water surface with a neuston net; these samples were then analyzed in class. Professional scientists conducted the surveys some days before or after the schoolchildren (the exact dates of professional and volunteer samplings are shown in Tables 4 and 5). Some of the data from professional scientists were recorded for a prior litter survey on coastal beaches and riversides along the central Chilean coast (Rech et al. 2014). Thus, the professional and volunteer surveys did not always occur at the exact same locations. For comparison, we only chose data in which the professional and volunteer sites were similar with respect to riverside characteristics, access, and land use. The exact location of and distance between compared sampling sites are listed in Table 1.

Litter survey along riversides

Litter at riversides

Litter was sampled representatively in three zones along the riversides (rivershore, mid bank, and upper bank). In each of the three zones, all litter items were counted by the professional scientists in five sampling circles (three circles at the river mouths) with a radius of 1.5 m, and a distance of 30 m between individual circles (see Supplementary Fig. S1). As time was a limiting factor in the volunteers’ surveys, the same area was sampled as the professional scientists, but in only three circles with a radius of 2 m each. On uneven riverside ground, with rocks and vegetation, it is often difficult to mark the sampling area on the ground with standard quadrats. Therefore, we chose to sample in circles, which were defined by fixing a line with the length of the radius in the center of each circle, and marking the outer edge of the circle along the tightened rope. In this part of the study, we were interested in macrolitter; since cigarette stubs are small (~15 mm in length) and common litter

Table 1 Overview of sampling sites and participating schools

River	Site	Coordinates	School	Sampling	Linear distance (km)
Elqui	Mouth	29° 53' 41.20" S, 71° 15' 26.23" W	Our data	a, b, c	–
		29° 53' 41.20" S, 71° 15' 26.23" W	Los Carrera (LC)	a, b, c	0
		29° 53' 40.39" S, 71° 15' 34.45" W	Claudio Arrau (CA)	a, b, c	0.23
		29° 53' 37.75" S, 71° 16' 24.74" W	Eusebillo Lillo (EL)	a, b, c	1.53
	Central reaches	30° 01' 27.08" S, 70° 46' 43.18" W	Our data	a, b, c	–
		30° 02' 09.56" S, 70° 44' 09.37" W	Lucila Godoy (LG)	a, b, c	4.39
	Headwaters	30° 06' 02.41" S, 70° 29' 27.10" W	Our data	a, b, c	–
		30° 06' 02.41" S, 70° 29' 27.10" W	Gabriela Mistral (GM)	a, c	0
Maipo	Mouth	33° 36' 50.83" S, 71° 37' 42.87" W	Our data	b, c	–
		33° 37' 06.52" S, 71° 37' 30.91" W	Espiritu Santo (ES)	a, b, c	0.57
	Central reaches	33° 42' 55.69" S, 71° 12' 40.72" W	Our data	a, b, c	–
		33° 42' 55.69" S, 71° 12' 40.72" W	San Agustín (SA)	a, b, c	0
	Headwaters	33° 42' 23.85" S, 70° 20' 06.51" W	Our data	a, b, c	–
		33° 42' 23.85" S, 70° 20' 06.51" W	El Melocotón (MC)	a, c	0
Maule	Mouth	35° 19' 12.36" S, 72° 24' 02.95" W	Our data	a, b, c	–
		35° 19' 00.18" S, 72° 24' 53.14" W	Martín Abejón (MA)	a	1.35
		35° 20' 24.10" S, 72° 23' 49.63" W	Nueva Bilbao (NB)	a	2.27
		35° 19' 28.64" S, 72° 24' 26.59" W	Martin Abejón & Nueva Bilbao	b, c	0.78
BioBio	Mouth	36° 48' 24.37" S, 73° 10' 14.24" W	Our data	a, b, c	–
		36° 48' 21.21" S, 73° 10' 08.47" W	Vila Centinela (VC)	a, b, c	0.15
		36° 48' 36.96" S, 73° 10' 24.84" W	Rosita Renard (RR)	a, b, c	0.45

a = litter accumulations, b = litter numbers at riversides, c = litter in the surface water. Bold = data generated by authors. The column "linear distance (km)" shows the distance (air line) of each volunteer sampling site to our (the authors') respective sampling site

items (Hoellein et al. 2015; Lee and Lee 2015), this size was taken as the lower size limit of macrolitter. All litter with a size of more than 15 mm was sampled and placed outside the circle, where it then was classified as plastic, paper, cigarette stubs, glass, metal, or "others," and subsequently counted. The category "others" comprised all items that could not be clearly assigned to any of the previously listed categories, including TetraPak® packages, disposable sanitary napkins, textiles, synthetic and natural rubber products, construction material, and manufactured wood items. Despite different sampling strategies, the total area sampled by professional scientists and volunteers were very similar (35.3 and 37.7 m², respectively). Indeed, the correlation between the density of items and total area sampled was not significant (total litter quantity, $r=0.05$; paper, $r=-0.09$; cigarette stubs, $r=0.04$; plastics, $r=0.12$; metal, $r=-0.03$; glass, $r=0.01$; others, $r=0.16$; $p>0.35$ in all cases, after Bonferroni correction). Thus, variations in sampling strategy

between professional scientists and volunteers should not introduce a severe bias in further analyses.

Litter accumulations and illegal dumping sites

Litter accumulations and illegal dumping sites were counted on one or both sides of the river (for location of the surveyed sites, see Table 1). The size of the surveyed area was estimated by the volunteers' supervisors, while global positioning system (GPS) was used in the professional surveys. Three categories of litter accumulations were defined and distinguished. A *litter patch* contains at least three litter items in a maximum area of 1 m². These small accumulations can be due to intentional litter dumping but may also result from litter being accumulated by wind, rain, or flood events. Dumping sites, in contrast, are accumulations of intentionally and directly dumped litter (Fig. 3). A *small illegal dumping site* has an area of more than 1 m² but does not exceed 10 m². A *large illegal dumping site* exceeds 10 m² in size (Fig. 3).



Fig. 3 Examples of **a** litter patches, **b** small illegal dumping sites (small DS), and **c** large illegal dumping sites (large DS), as found and recorded during the present survey

Water surface sampling

Sampling of litter from the rivers’ surface water was conducted using a neuston net with a mesh size of 1 mm and an opening area of 27 * 10.5 cm². The net was hung from a bridge or fixed at the riverside for approximately

1 h. A recycled plastic bottle at each side of the net opening kept it afloat, so that only half of the opening area was submerged in the water. The deployment time and flow velocity near the neuston net were recorded. Flow velocity (in m s⁻¹) was determined as the time it takes for an orange to float a distance of 10 m. In the professional survey, flow

velocity was additionally measured with a flowmeter (TS-Flowmeter, Patentnr: 411740.441828, Tsurumi-Seiki Co, Japan) when the stream current did not allow for the orange to pass the net's deployment site (which was the case at two sites). In order to determine the relationship between the data obtained from the aforementioned two methods, both methods were employed at nine sites and the correlation between the data was determined (Pearson's product moment correlation coefficient, $r=0.615$, $p=0.078$) to calculate comparable flow velocities for all sites.

The content of the neuston net was dried and litter items were then separated from natural items and counted in class by the schoolchildren and the supervising teachers. Litter was categorized as plastic, polystyrene (expanded polystyrene, EPS), cigarette stubs, metal, glass, and others. Items in the category "others" included cotton fibers, paper and paperboard, synthetic and natural rubber products, remains of construction material (e.g., concrete and ceramics), and any item which could not be clearly placed into any of the above mentioned litter categories. In this part of the study, we expected to mainly observe persistent buoyant litter (as defined in Rech et al. 2014). As polystyrene is a common component of this group (e.g., Viehman et al. 2011; Rech et al. 2014), it was maintained as a separate category. Due to its limited persistence in water, "paper" was not considered as an individual category for the surface water sampling but pooled with the "others" items.

After the schoolchildren had separated and counted the litter items, each sample was carefully stored in labeled plastic bags and sent to the coordinating laboratory at Universidad Católica del Norte to be recounted and reanalyzed by a professional scientist. The litter load at the water surface was calculated according to the following formula, from Moore et al. (2011):

$$\text{Particle load [m}^{-3}] = \frac{\text{particles in net}}{(\text{fv [m s}^{-1}] * \text{noa [m}^2] * \text{dt [s]})}$$

where fv is flow velocity, noa is net opening area, and dt is the deployment time of the net.

Data validation and comparison

The data obtained by the citizen scientists on litter quantities and litter accumulation sites at riversides were compared with the data collected by professional scientists at the same or nearby sampling sites. The water surface samples, including the items previously classified

as litter by the citizen scientists, were reexamined and litter items were reclassified and recounted by a professional scientist using a dissecting microscope. The classification and quantity of litter items present in each sample as recorded by the citizen scientists were compared with the professional recount. These data were additionally compared to data obtained by professional scientists at the same or nearby sampling sites.

Statistical analyses

We tested the effect of the investigator and distance between the sampling sites on the estimates of litter quantities at riversides using generalized linear mixed models (GLMMs). Data normality and homoscedasticity were ensured after square root transformation and using a Gamma structure of errors. A total of four models were tested, including the additive effects of investigator and distance (between the volunteer and professional survey sites) as fixed factors, and river and sampling site as random nested factors. The probability of each model to most accurately describe litter quantities at riversides was indicated by Akaike weights (AIC_w) (Mazerolle 2004). Analyses were carried out using the packages *lme4* and *MuMin* in R (R Core Team 2013).

We tested differences in litter composition at riversides measured between researchers (professionals and volunteers) and distances (between the volunteer and professional survey sites) using a permutational analysis of variance (PERMANOVA). This non-parametric multivariate analysis of variance, based on Bray-Curtis similarities, is preferable for ecological data, as its assumptions are not as stringent as those of traditional multivariate analyses (Anderson 2001). Data were square-root-transformed and samples with no litter were not considered in the analysis. Values of p were calculated using 10,000 bootstrapped values. The similarity matrix was used to calculate the mean similarity in litter composition between professionals and volunteers. A similarity percentage (SIMPER) analysis was conducted in order to identify items contributing most to the overall differences in composition; analyses were carried out using the package *vegan* in R (R Core Team 2013).

The differences between the litter load in the surface water samples as counted by volunteers and the recount by professional scientists were determined via the paired Student's t test. To determine the direction of differences, the correlation between the initial count by the volunteers and the professional recount was calculated. Furthermore,

the determination coefficient was calculated to identify how well the values fit the linear regression.

The effect size between investigators across different analyses was estimated using Cohen’s *d*, based on log-transformed values and corrected standard deviations of litter quantity. If the investigator bias is small, then values of Cohen’s *d* should be close to zero; analyses were carried out using the package *lsr* in R (R Core Team 2013).

Results

Litter quantities at riversides

The litter quantities at riversides of the four investigated rivers ranged from a median of 0.14 items per square meter (central Elqui reaches and Maipo mouth region) to 3.42 items per square meter (BioBio mouth region), with large variations within the sampling sites (Fig. 4).

The visualization of the results as box-and-whisker plots indicates that there are no major differences between professionals and volunteers at most sampling sites (in terms of quartile overlap; Fig. 4). There are two exceptions: the litter quantities counted by volunteers are substantially higher than those counted by the professional scientists at the sampling site in the Maipo mouth region, and, relating to one of two volunteer groups, at the sampling site of the BioBio mouth region.

When the four hypothetical models (on the influence of the investigator and distance between the volunteer and professional sampling sites) were compared, the most fitting model included only the fixed effect of investigator and the random nested effect of rivers/sampling sites ($AIC_w=0.59$); neither the effect of distance nor investigator was significant in any of the tested models ($p>0.05$; Table 2). The effect size was relatively moderate (Cohen’s $d=0.36$).

Litter composition showed discrepancies between investigators (PERMANOVA, $R^2=0.024$; $p=0.015$),

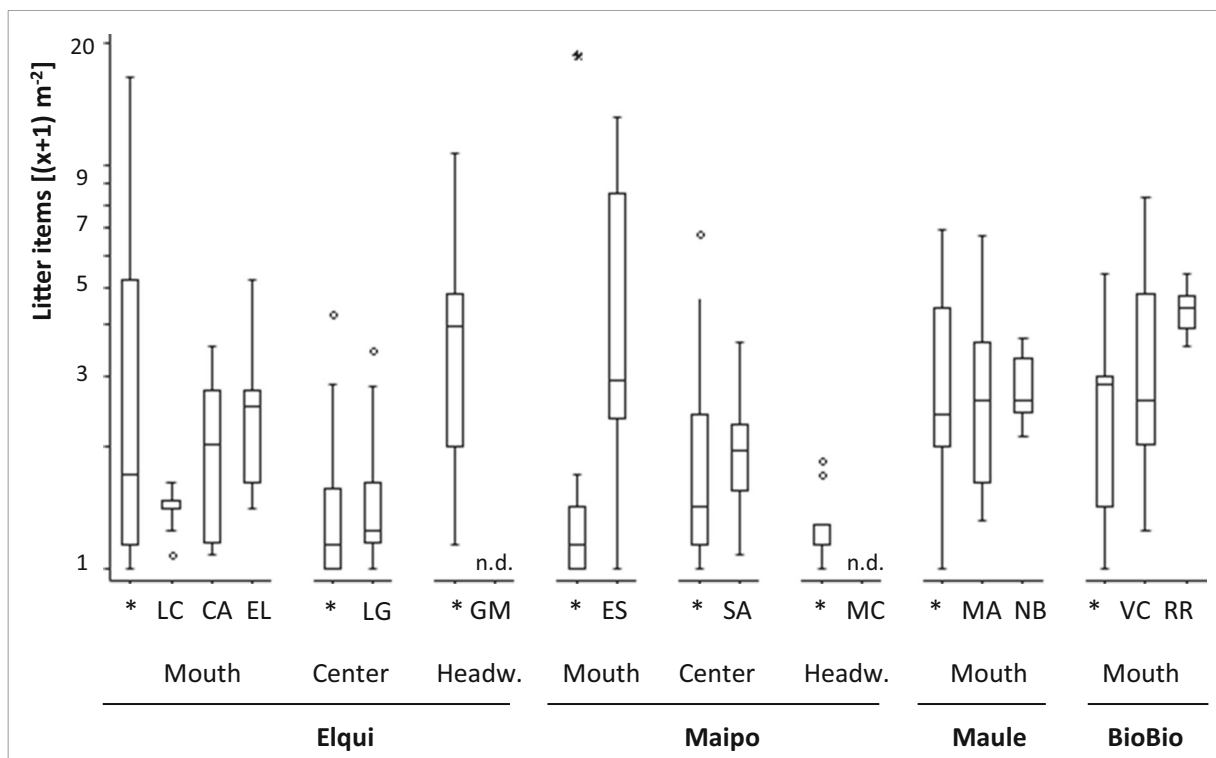


Fig. 4 Number of litter items at riversides in the rivers’ mouth regions (all rivers), central reaches, and headwaters (only Elqui and Maipo). Comparison of data generated by several groups of citizen scientists (schools) and professional scientists. Data are visualized by box-and-whisker plots, showing median values (-),

quartiles (\square), non-outlier range ($|$), outliers (\circ), and extreme values (*) for each sampling point. x-axis: asterisk = our samplings. For the complete names of participating schools, see Table 1. n.d. no data available

Table 2 Performance of four hypothetical models (GLMM), describing the influence of the investigator and distance between volunteer and professional sampling sites in each sampling area, considering the random nested effects of river and site

Model	AIC _w	p value	
		Investigator	Distance
Litter~Investigator+(1 River)	0.12	0.10	–
Litter~Investigator+(1 River/Site)	0.59	0.21	–
Litter~Investigator+Distance+(1 River)	0.06	0.06	0.45
Litter~Investigator+Distance+(1 River/Site)	0.23	0.35	0.72

Akaike weights (AIC_w) indicate the probability of being the most fitting of the four models. The statistical significance is indicated by the *p* value. Bold = highest AIC_w (best model)

but not among sampling distances (PERMANOVA, $R^2=0.004$; $p=0.85$). Consistently, the degree of similarity in litter composition between investigators was relatively low (mean Bray-Curtis index=0.41). The SIMPER analysis showed that differences in composition detected between investigators were mainly due to litter items in the category “others,” which were counted more frequently by volunteers than by the professionals, and items in the categories “plastics” and “paper,” which were counted more frequently by the professionals than by the volunteers. Items from the categories “cigarette stubs,” “glass,” and “metal,” which had a minor contribution to the overall differences, were also more frequent in the volunteer counts (Table 3).

Litter accumulations and illegal dumping sites

Litter accumulations were reported at all investigated sites by the professional scientists and schoolchildren.

Table 3 Differences in litter composition between samples taken by volunteers and professional scientists and contribution of each litter category

Item	Contribution	Standard deviation (SD)	Ratio contribution: SD	Average volunteers (items m ⁻²)	Average professionals (items m ⁻²)	Cumulative sum
Other	0.13479	0.11059	1.2189	5.2934	3.7045	0.2633
Plastics	0.11782	0.10133	1.1628	5.2297	5.4879	0.4934
Paper	0.10020	0.09432	1.0623	2.6093	2.7141	0.6891
Cig. stubs	0.06419	0.06698	0.9583	1.7218	1.2272	0.8145
Glass	0.05499	0.07572	0.7262	1.2786	0.9576	0.9218
Metal	0.04001	0.06336	0.6316	0.9216	0.6809	1

Results from similarity percentages (SIMPER) analysis, based on Bray-Curtis similarities. Bold = highest values

Accumulations of illegally dumped litter (small dumping sites, large dumping sites) were found in all surveyed regions (headwaters, central reaches, and river mouths) along the rivers' courses, with exception of the Maipo mouth region, where only litter patches were recorded (Fig. 5 and Table 4). Visual inspection of the results from each sampling site demonstrated that the results differ not only between professional scientists and volunteers but also between different groups of school volunteers at sampling sites in the mouth regions of the Elqui, Maule, and BioBio, respectively. As the survey area was not standardized, we cannot conclude from the results whether the discrepancies are due to investigator bias or reflect real differences in the number and distribution of litter accumulations in the respective sampled areas. Interestingly, differences between the data collected by professionals and volunteers are less pronounced when considering the absolute numbers per estimated survey area. If the data are normalized to an area of 1000 m², the results from the volunteer surveys are substantially higher than those from the professional surveys (Table 4). This indicates that the estimation of the sampling area, as conducted by the volunteers and their supervisors, may not be reliable. Cohen's *d* values were high in all cases ($d>0.70$) suggesting rather large differences between investigators.

Litter loads in surface waters

Anthropogenic litter contamination of the riverine water was detected at all investigated sites, independently of the region (river mouth, central reaches, or headwaters). The main items at most sites were plastics; in the surface waters of the Maipo, where the highest litter loads were measured, polystyrene was found in the central reaches and the mouth region.

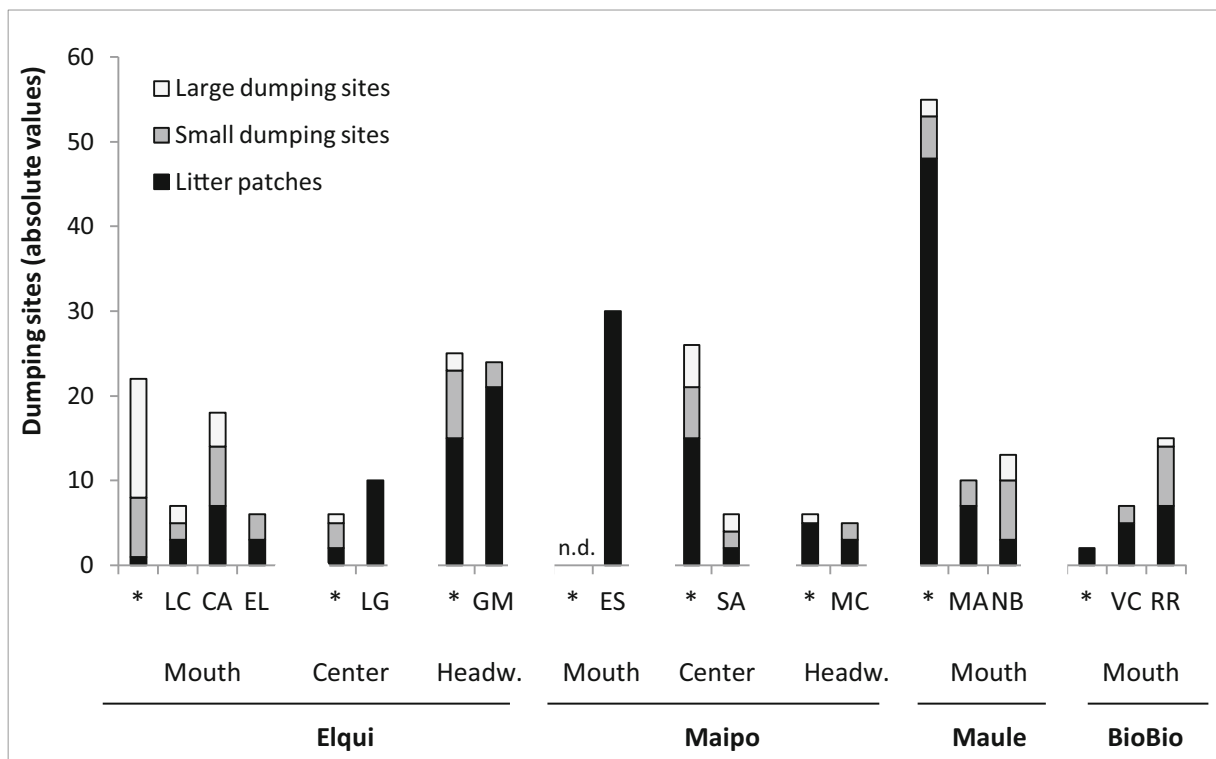


Fig. 5 Number and classification of illegal dumping sites at the riversides in the rivers’ mouth regions (all rivers), central reaches, and headwaters (only Elqui and Maipo). Comparison of data

generated by several groups of citizen scientists (schools) and professional scientists. *Asterisk* = our samplings. For the complete names of participating schools, see Table 1. *n.d.* no data available

The results obtained by volunteers and professional scientists were comparable at a few sites (e.g., in the mouth region of the Maipo) but strongly differed at other sites (e.g., in the central reaches of the Maipo; Table 5 and Fig. 6). The results from the Elqui river mouth are especially interesting, as the data are similar for all three participating schools, but the professional scientists, who had sampled the site 1 week before the volunteers (Table 5), did not find any litter in the surface waters. In contrast, considerable litter loads were detected by the professional scientists in the Maipo central reaches and headwater region, whereas no litter was found by the volunteers 1 month later. Due to such differences in sampling time and, moreover, site of net employment, the results are not statistically comparable. It can, however, be stated that most of the schools were able to follow the sampling protocol and employ the neuston net in such a way that water could pass and floating items could enter.

Plastics (including polystyrene at certain sampling sites) made up the largest share of litter found in the surface waters, in both the samples taken by the volunteers and by the professionals. However, the professional

recount of the surface samples taken by the volunteers showed that the total litter amount, and especially the amount of plastics in the volunteer’s samples, was underestimated by the volunteers. This investigator effect is statistically significant (as indicated by the Student’s *t* test) and appears to be rather strong (see high values of Cohen’s *d*; Table 6). For example, small litter particles (down to 1 mm² size) that are difficult to find were often recovered in dense plant detritus that entered the neuston net. Furthermore, litter particles can easily be mistaken, which is the case for items particularly in the “metal” and “others” categories that were recorded in the volunteers’ count but were not located when the samples were recounted by professionals (Table 6).

Discussion

Citizen science approach

This investigation demonstrated that the volunteering schoolchildren successfully applied the sampling

Table 4 Litter accumulations and illegal dumping sites (DS) — comparison of our data with data obtained by the citizen scientists

River	Site	School	Date	Area (m ⁻²)	Patches (1000 m ⁻²)	Small DS (1000 m ⁻²)	Large DS (1000 m ⁻²)	Sum (1000 m ⁻²)
Elqui	Mouth	Our data	28 May	1250	0.8 (1)	5.6 (7)	11.2 (14)	17.6 (22)
		LC	30 April	~250	12.0 (3)	8.0 (2)	8.0 (2)	28.0 (7)
		CA	02 May	~1000	7.0 (7)	7.0 (7)	4.0 (4)	18.0 (18)
		EL	02 May	~400	7.5 (3)	7.5 (3)	0.0 (0)	15.0 (6)
	Central reaches	Our data	27 May	900	2.2 (2)	3.3 (3)	1.1 (1)	6.7 (6)
	LG	03 May	~150	66.7 (10)	0.0 (0)	0.0 (0)	66.7 (10)	
	Headwaters	Our data	27 May	3000	5.0 (15)	2.7 (8)	0.7 (2)	8.3 (25)
	GM	29 April	~300	70.0 (21)	10.0 (3)	0.0 (0)	80.0 (24)	
Maipo	Mouth	Our data	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
		ES	17 May	6000	5.0 (30)	0.0 (0)	0.0 (0)	5.0 (30)
	Central reaches	Our data	15 May	3900	3.8 (15)	1.5 (6)	1.3 (5)	6.7 (26)
		SA	14 May	~3000	0.7 (2)	0.7 (2)	0.7 (2)	2.0 (6)
	Headwaters	Our data	14 May	400	12.5 (5)	0.0 (0)	2.5 (1)	15.0 (6)
	MC	09 May	~300	10.0 (3)	6.7 (2)	0.0 (0)	16.7 (5)	
Maule	Mouth	Our data	13 May	2800	17.1 (48)	1.8 (5)	0.7 (2)	19.6 (55)
		MA	02 May	~100	70.0 (7)	30.0 (3)	0.0 (0)	100.0 (10)
		NB	08 May	~100	30.0 (3)	70.0 (7)	30.0 (3)	130.0 (13)
BioBio	Mouth	Our data	11 May	4800	0.4 (2)	0.0 (0)	0.0 (0)	0.4 (2)
		VC	08 May	~150	33.3 (5)	13.3 (2)	0.0 (0)	46.7 (7)
		RR	23 May	~1000	7.0 (7)	7.0 (7)	1.0 (1)	15.0 (15)

Value inside parentheses is the absolute amount. Bold = data taken by authors. For full names of the participating schools, see Table 1
n.d. no data available

protocol and reliably estimated the litter quantities at riversides. The higher values obtained by the volunteers in comparison to the professionals in the mouth regions of Maipo and BioBio can be explained by the climatic conditions during the sampling period. The professional samplings were conducted during the first half of May (i.e., shortly before the annual rainy season), whereas the majority of volunteers sampled in mid-June at the Maipo site and at the beginning of July at the BioBio site, when strong rainfalls had already occurred and led to an augmentation in water levels and stream velocity in the river. It can be assumed that the rainfalls flushed litter into the rivers and also moved upstream litter toward the river mouths, thereby causing the observed litter accumulations at the riversides of the Maipo and BioBio mouth regions. The increase in rainfall may also be the reason for the slightly higher quantities recorded by volunteers in comparison to professionals at several other sampling sites. These findings corroborate the importance of hydrological regimes on the number and distribution of riverine litter (hydrological data from <http://dgasatel.mop.cl/>). It can also be inferred that

citizen science studies in central and southern Chile should be carried out during the summer, when precipitation is much lower, reducing bias due to the timing of sampling.

The significant deviation in litter composition between professional and volunteer samples may imply that the litter was not correctly characterized by the participating schoolchildren. Therefore, in future citizen science studies, sampling protocols must be more precise, with specific explanations of litter categories. Also, a more thorough presurvey training with the participating volunteers, as is routine for volunteers classifying plant or animal species, could help to overcome difficulties in identification (e.g., Osborn et al. 2005; Mellors et al. 2008; Gillett et al. 2012). Regardless, it should be kept in mind that, even if the distance between the compared sampling sites was excluded as an influencing factor, the different groups of investigators never did sample the exact same area (in terms of sampling circles). As the distribution of the overall litter and specific litter items varies strongly,

Table 5 Particle loads (amount of floating litter) captured with a neuston net in the surface waters of the studied rivers

River	Site	School	Date	Flow velocity (m/s)	Deployment time (s)	Particle load (m ⁻³)		Particle load (m ⁻³) RECOUNT	
Elqui	Mouth	Our data	27 May	0.34	3600	0.00	(0)	0.00	(0)
		LC	04 June	0.80	3600	0.18	(15)	0.15	(12)
		CA	05 June	0.38	3600	0.08	(3)	0.21	(8)
		EL	06 June	0.58	3600	0.17	(10)	0.24	(14)
	Central Reaches	Our data	27 May	2.04	3600	0.13	(28)	0.13	(28)
		LG	07 June	1.12	3600	0.02	(2)	0.03	(4)
	Headwaters	Our data	27 May	0.44	3600	n.d.		n.d.	
GM		14 June	1.18	1800	0.07	(4)	0.12	(7)	
Maipo	Mouth	Our data	07 May	1.09*	4800	1.05	(156)	1.05	(156)
		ES	14 June	0.30	3600	0.10	(3)	0.39	(12)
	Central Reaches	Our data	15 May	1.67	3300	5.03	(784)	5.03	(784)
		SA	11 June	0.52	3600	0.00	(0)	n.d.	
	Headwaters	Our data	14 May	0.66	3600	0.01	(1)	0.01	(1)
		MC	13 June	0.90	1800	0.00	(0)	0.00	(0)
Maule	Mouth	Our data	13 May	0.26*	3900	0.74	(21)	0.74	(21)
		MA	29 May	0.50	6000	n.d.		n.d.	
		NB	29 May	0.00	3000	n.d.		n.d.	
BioBio	Mouth	Our data	11 May	0.17	3720	0.00	(0)	0.00	(0)
		VC	01 July	1.10	3600	0.00	(0)	0.00	(0)
		RR	25 June	1.50	4200	0.12	(22)	0.17	(30)

Comparison of samples taken and counted by citizen scientists, with the same samples recounted by the authors (SR) and with our data from the same or a nearby sampling site. Flow velocity based on the time required by an orange to drift 10 m, except at sites where only the flowmeter was used, which are marked with asterisk (for details, see the “Material and methods” section). Value inside parentheses is the absolute amount of particles found. Bold = data taken by authors. For the complete names of the participating schools, see Table 1

n.d. no data available

even within one sampling area (Rech et al. 2014), this may additionally contribute to the observed differences.

With regard to the litter accumulation counts, it can be stated that the volunteers were able to recognize and distinguish the three categories (litter patch, small illegal dumping site, and large illegal dumping site). It is interesting, however, that the results obtained by the two groups of investigators (volunteers and professionals) differ more strongly when comparing standardized values, rather than absolute values. This indicates that the volunteers generally found many individual litter accumulations in a small area. Therefore, it may be assumed that the area estimations reported by the supervisors, which are based on subjective distance estimations rather than on rigorous landmark estimations or GPS data, have been underestimated. As human perception of walked distances is influenced by factors

including age, gender, familiarity with the area and its environment (e.g., city or countryside), and ground profile (Okabe et al. 1986; Crompton 2006; Crompton and Brown 2006; Stone and McBeath 2010), the determination of the sampling area should be standardized (ideally using GPS) with the exact sampling site documented and if possible determined in advance, in future studies. It is also possible that the volunteers concentrated on heavily polluted areas. Such concentration on subjectively more “interesting” areas was also discussed in a citizen science study by Gillett et al. (2012).

With respect to the litter sampling in riverine waters, it can be stated that most of the schools were able to correctly use the neuston net in the rivers in such a way that water could pass through and floating items could enter the net. There are many factors that most likely influenced the results obtained. First of all, the small neuston net used in

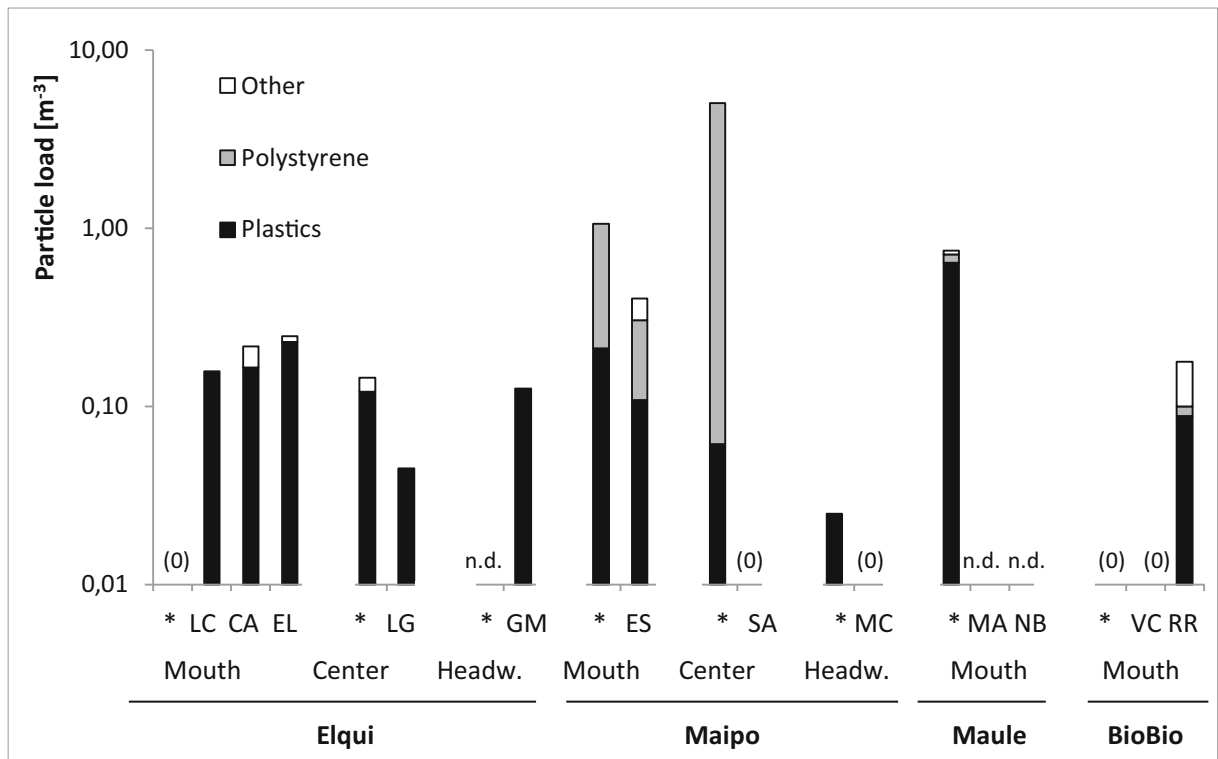


Fig. 6 Particle load of litter, determined by using a neuston net, in the riverine water of the mouth regions (all rivers), central reaches, and headwaters (only Elqui and Maipo). Comparison of data

generated by several groups of citizen scientists (schools) and professional scientists. *Asterisk* = our samplings. For the complete names of participating schools, see Table 1. *n.d.* no data available

this study limited the section of the river that could be sampled. Furthermore, the amount of captured litter does depend not only on the exact location of net deployment but also on the sampling time and

the respective hydrological regimes (see also Moore et al. 2011). It is also suspected that the rise of the litter load observed in the Elqui mouth region within 1 week is linked to such a rain event in the

Table 6 Comparison of the litter amounts in the surface water samples taken by the volunteers, counted by them, and recounted by a professional scientist

Item	Volunteers' count [items]	Professionals' recount [items]	Correlation	R ²	t	p-value	Cohen's d
Plastics	29	59	0.92	0.8500	-3.85	0.0049	1.28
Polystyrene	4	8	0.21	0.0422	-0.61	0.5588	0.20
Cigarette stubs	2	3					
Glass	0	1					
Metal	3	0					
Other	21	16	0.04	0.0021	0.38	0.7124	0.12
Total	59	87	0.91	0.8268	-2.40	0.0431	0.80

Absolute values are shown for all litter items. The correlation and the determination coefficient (R^2) of the linear regression, as well as the result of Student's t test, the statistical significance (p value) and the effect size (Cohen's d) are shown for plastics, polystyrene, other items and the total amount of litter. For cigarette stubs, glass, and metal, no statistical analyses were conducted due to low number of observed items. Bold = statistically significant values

drainage area, but to draw reliable conclusions, the complex patterns of riverine litter movement should be investigated over time at certain sites with more standardized sampling protocols. Moreover, the sampling date should be standardized in future litter surveys.

The volunteers were also able to distinguish different litter types, but certain items were also misidentified. Nevertheless, their estimation of the share of plastics, which was the main component of the litter samples, was highly correlated with the validated values. The quantities of litter items were significantly underestimated by the volunteers. Identification problems can be overcome by thorough volunteer training. In the case of challenging tasks, such as identifying microlitter categories, it might also be advisable to select volunteers with prior experience or a higher educational level, as these factors are suggested to influence the accuracy of data collected by volunteers (Delaney et al. 2008; Jiguet 2009). There exist criteria to identify microplastic particles larger than 1 mm, including the absence of cellular or organic surface structures, clear and homogenous colors, or, in the case of fibers, an equal thickness throughout its entire length (Hidalgo-Ruz et al. 2012). In future studies, volunteers should be trained especially with regard to the characterization of microplastics.

A professional recount of volunteer-collected samples is absolutely necessary when dealing with such small litter fragments, especially when the fragments are mingled with vegetational debris. The need for a professional validation of the data from citizen scientists is also emphasized by other authors (e.g., Foster-Smith and Evans 2003; Cohn 2008).

Anthropogenic litter in the riverine environment

Apart from the validation of the citizen science approach, the volunteer surveys brought insight into the complex subject of riverine litter. The contamination of riverine water with litter items and particles typically is higher when rivers flow through areas with strong anthropogenic influence (Moore et al. 2011; Carson et al. 2013). Notably, in this citizen science project, contamination was recorded at all sampling sites, regardless of whether rivers are flowing through comparatively scarcely populated areas (Elqui, Maule, BioBio) or through the country's densely populated metropolitan region (Maipo). Moreover, floating litter was even

detected in the rivers' headwater regions with little human influence upstream. This finding is especially interesting, as studies that found litter in rivers or on coastal beaches have mostly related it to urban population and industrial centers (Araújo and Costa 2007; Neto and da Fonseca 2011; Moore et al. 2011; Carson et al. 2013). The extent of riverine pollution is worrisome and should be further investigated. Future studies of riverine litter should therefore focus on the entire extension of the river course.

The almost ubiquitous occurrence of illegal dumping sites in areas that vary in several aspects indicates that land use may not be as important as suggested in previous litter studies (e.g., Carson et al. 2013). This is also in contrast to the situation reported from a UK-based riverside survey, in which only 50 % of all studied riversides were affected by illegal litter dumping, which was related to the area's land use and the accessibility of the riversides (Williams and Simmons 1999).

Although there are several possible sources of litter along rivers, for example, from boats or sewage and stormwater runoff (Williams and Simmons 1999; Armitage 2007), illegal dumping appears to be a major source for litter at the riversides investigated. After litter is deposited at the riverside, it can be spread or washed into the river by storms and flood events (Williams and Simmons 1999; Armitage 2007).

Small plastic fragments result from the breakdown of larger items (Barnes et al. 2009). Therefore, a considerable amount of the small particles found in the rivers' surface waters might originate from deposition of plastic items at the riversides. Although plastics made up the main share of litter, samples from the surface water taken in the present study also contained particles of other litter categories, including paper (data not shown), mingled with vegetational debris. This is consistent with the results of Carson et al. (2013) who captured a variety of riverine litter, the main share being plastics. The relation of illegal litter deposition along rivers and the number and composition of litter fragments in the river water should be addressed in future studies.

Conclusions and outlook

This study demonstrates that litter is a serious problem along the Chilean rivers investigated, both at the riversides and in river waters. Illegal dumping and subsequent transport of litter appear to be responsible for the

contamination not only of riverine water but also of coastal waters and seashores. To reliably investigate this relationship, future surveys should be conducted over a large geographical scale. In order to examine the relationship between rainfall and litter transport, consecutive surveys at specific sites are needed. The citizen science approach is suitable for such surveys, as it was shown that volunteering schoolchildren are able to quantify litter amounts and detect accumulations of illegally dumped litter even at riversides with a complex geomorphologic and vegetational structure. Based on the volunteer-professional comparison, it is suggested that the sampling protocol should be formulated more precisely and the participating volunteers and their supervisors should be trained more thoroughly before conducting the survey, especially with regard to the distinction of litter types. Volunteer support may not only improve the spatio-temporal coverage of surveys but might also help to raise awareness of the fragile state of rivers with respect to litter contamination.

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