



## Distribution and abundance of small plastic debris on beaches in the SE Pacific (Chile): A study supported by a citizen science project



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### ABSTRACT

The accumulation of large and small plastic debris is a problem throughout the world's oceans and coastlines. Abundances and types of small plastic debris have only been reported for some isolated beaches in the SE Pacific, but these data are insufficient to evaluate the situation in this region. The citizen science project "National Sampling of Small Plastic Debris" was supported by schoolchildren from all over Chile who documented the distribution and abundance of small plastic debris on Chilean beaches. Thirty-nine schools and nearly 1000 students from continental Chile and Easter Island participated in the activity. To validate the data obtained by the students, all samples were recounted in the laboratory. The results of the present study showed that the students were able to follow the instructions and generate reliable data. The average abundance obtained was 27 small plastic pieces per m<sup>2</sup> for the continental coast of Chile, but the samples from Easter Island had extraordinarily higher abundances (>800 items per m<sup>2</sup>). The abundance of small plastic debris on the continental coast could be associated with coastal urban centers and their economic activities. The high abundance found on Easter Island can be explained mainly by the transport of plastic debris via the surface currents in the South Pacific Subtropical Gyre, resulting in the accumulation of small plastic debris on the beaches of the island. This first report of the widespread distribution and abundance of small plastic debris on Chilean beaches underscores the need to extend plastic debris research to ecological aspects of the problem and to improve waste management.

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### 1. Introduction

Anthropogenic debris is accumulating in marine ecosystems throughout the world. It is found at the sea surface (e.g. Pichel et al., 2007), on sandy beaches (e.g. Santos et al., 2009), and in the deep sea (e.g. Lee et al., 2006). Between 60 and 80% of marine anthropogenic debris is composed of plastic items (Derraik, 2002). The small size fraction of plastic debris is generated by gradual fragmentation of larger objects, mainly by the action of intense solar radiation (Andrady, 2011). There is also a considerable contribution of small plastic debris from primary sources, such as industrial pellets (Takada, 2006) and tiny plastic pieces used in cosmetics (Fendall and Sewell, 2009). Small plastic debris can be ingested by invertebrates, such as worms, barnacles and mussels (e.g. Thompson et al., 2004; Browne et al., 2008; Ward and Kach, 2009;

Von Moos et al., 2012), as well as large vertebrates, such as fishes, birds and mammals (e.g. Jacobsen et al., 2010; Provencher et al., 2010; Davison and Asch, 2011). Plastic debris also represents known sources of persistent organic pollutants (POPs) (Mato et al., 2001) that can be potentially transported and bioaccumulated in marine organisms (Teuten et al., 2009; Engler, 2012). Also, plastic fragments on sandy beaches cause changes in the permeability and heat transfer between sediment grains, which could affect beach organisms (Carson et al., 2011).

Plastic debris can be transported over long distances from the sites of origin and it accumulates via ocean currents in oceanic gyres (Moore et al., 2001; Maximenko et al., 2012; Eriksen et al., 2013). According to modeling exercises, accumulation of debris in the South Pacific Ocean occurs in the eastern-central region (Lebreton et al., 2012), close to Easter Island. Recent reports of microplastics on the Chilean coast are from the cities of Viña del Mar and Punta Arenas (Browne et al., 2011), but there is no information on the large-scale distribution and abundance of small plastic debris along the extensive Chilean continental and insular coast (Easter Island), comprising approximately 4500 km coastline between 18°S and 56°S.

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In order to adequately describe the abundance and distribution of small plastic debris along a long coastline, such as the SE Pacific (Chile), many different sampling points are necessary. When extensive collection of data is required to achieve an appropriate geographic coverage and funding is limited, a useful approach is for scientists and the public to work together in an alliance called “citizen science” (Cohn, 2008; Silvertown, 2009; Bonney and Dickinson, 2012). Citizen science projects involve volunteer participants from schoolchildren to adults, who participate in data collection, data processing or even design of project protocols (Bonney and Dickinson, 2012). They support a variety of biological and ecological studies (see Cooper et al., 2012), gather data on topics such as biodiversity (e.g. Devictor et al., 2010), evolutionary traits (e.g. Worthington et al., 2012), and ecological risks (e.g. Delaney et al., 2008). Particularly in marine debris studies, volunteer participation has been instrumental for the generation of extensive sets of data in many countries of the world, such as Australia (Edyvane et al., 2004), Japan (Shimizu et al., 2008), United States (Ribic et al., 2010, 2012), and Chile (Bravo et al., 2009), among others. However, the accumulation of small plastic debris on beaches has never been examined with the aid of citizen scientists, although this would be an ideal approach to achieve a wide geographic coverage. Furthermore, the basic distribution of small plastic debris can be studied without sophisticated equipment or specific scientific education. Nevertheless, an important requirement for these projects is the inclusion of quality control, in order to identify possible errors and to determine the accuracy of the data provided by volunteers (Worthington et al., 2012; Peckenham et al., 2012).

Herein we tested whether schoolchildren are capable of collecting samples to assess the distribution and abundance of small plastic debris on beaches. We used the extensive coasts of continental Chile and Easter Island to determine the distribution and abundance of small plastic debris. Also, we assessed the validity of the data obtained by the students in order to determine whether they can be used for a scientific evaluation of small plastic debris from the shores of the SE Pacific.

## 2. Materials and methods

### 2.1. Volunteer participation

A nationwide call was made to participate in the “First Small Plastic Debris Sampling on Chilean Beaches”. In particular, we approached schools and social associations that are part of the citizen science project “Científicos de la Basura” (Litter Scientists). We also invited marine scientists at the different study sites to serve as local advisors to teachers and students during the activity.

### 2.2. Development and testing of protocols

To ensure the quality of the data obtained in citizen science projects, three key elements must be provided: clear sampling protocols, simple data forms, and support material for the activity (Bonney et al., 2009). Therefore, a pilot protocol was tested with three schools from the Coquimbo Region, three months before the national activity. The corresponding improvements were incorporated in the final version of the sampling protocol, which comprised three principal phases: (1) a preparatory motivation and introduction, (2) the field sampling, and (3) a concluding activity.

### 2.3. Sampling protocol

#### 2.3.1. Motivation and introduction

A children’s story was especially designed for this activity, entitled “The Journey of Jurella and the Microplastics” (Nuñez and

Thiel, 2011). In this 28-page picture story a local Chilean fish (“Jurella”) faces the problem of small plastic debris in the ocean (see <http://www.cientificosdelabasura.cl/docs/jurella.pdf>). During the motivation phase the schoolchildren read the story together in class. Each participating student received her/his personal copy of this story. During this phase, the students also read the sampling protocol and became familiar with the data table in which to register the final data. They also could see and handle all the sampling materials (lines to delimit sampling quadrats, shovels, sieves, bags), which were then kept by the teacher until the sampling date.

#### 2.3.2. Sampling activity

On the beach, the schoolchildren were divided into groups of 3–5 students. The sampling comprised three steps: (i) identification of the sampling area, (ii) marking of the sampling quadrat, and (iii) sorting and counting of small plastic debris. In step (i), the high tide line was identified and a 30-m transect with 6 sampling stations was determined. Then in step (ii), at each of the six stations a 50 × 50 cm quadrat was marked. Larger natural items (algae and wood > 10 mm diameter) were removed from the sampling quadrats. From each quadrat approximately 2 cm of the sand surface were taken with a spatula and placed on a tray. The sample was sieved (1 mm mesh opening) to separate small plastic debris from other objects and the sand. If the sand was wet and sieving was not possible, samples were placed in a labeled plastic bag, sealed and brought to the school. They were put on labeled trays and left in a ventilated room until the samples were dry and could be sieved. In the final step (iii) all materials retained on the sieve were placed again in the tray. The small plastic pieces were separated from the rest of the items. They were classified as fragments or pellets and counted and the data form was completed. Then all objects retained on the sieve (the small plastic pieces and all other debris) were placed in a sealed and labelled plastic bag. The samples were then sent to the central laboratory of the project.

#### 2.3.3. Concluding activity

A final activity took place back in the classroom, where the students entered their data in spreadsheets of an interactive website that was created exclusively for the activity (<http://www.cientificosdelabasura.cl/microplasticos/>). Using the results uploaded on the website the teachers initiated a final reflection. At the end, the participating schoolchildren filled out a survey to evaluate the activity. On a scale from 1 to 7 points (7 being the best, corresponding to the grading system in the Chilean school system) they scored their opinion of the different activities.

### 2.4. Evaluation of the samples and data validation

Upon receipt in the central laboratory, all samples were re-evaluated with the aid of a dissecting microscope (8–32 magnifications). All items were re-examined, including the previously selected objects defined as small plastic debris as well as the rest of the material. The small plastic pieces were re-counted, and the numbers from the laboratory re-counts were compared with the data recorded by the students in the field. This was done to verify the accuracy of the data obtained by the students. The data validation was based on a simple linear regression model and its 95% confidence interval based on the mean abundance for each location. The values that lie outside the confidence interval were identified as implausible values, and carefully re-examined in order to establish the possible sources of errors for these data. Those schools that did not enter their data on the website were not included in this comparison. After excluding the questionable data, we compared the two data sets (laboratory re-counts and values

from schoolchildren) with a paired samples Student's *t*-test for final validation.

2.5. Occurrence and abundance of small plastic debris

The data used to determine the occurrence and abundance of small plastic debris in the SE Pacific were the validated data (see previous section) obtained in the laboratory. The small plastic pieces were subdivided into two main size categories: 1–4.75 mm and 4.75–10 mm. To explore variations in small plastic debris abundances along the continental coast of Chile and Easter Island, continental Chile was subdivided into five geographic zones (for separation of zones see also Bravo et al., 2009) that were compared with the Easter Island zone. An ANOVA was applied to compare the mean value of small plastic debris abundances between the six studied zones. Because our data set has problems with normality and homogeneity of variance, we used Monte Carlo simulation to obtain a permutational F-value using 9999 permutations. When differences were detected, a non-parametric post-hoc Tukey test was applied to identify which zones differed from each other.

3. Results

3.1. Participation of the students

The sampling activity was conducted during the months of October and November 2011. It included 39 schools, 983 students (from 8 to 16 years old), 43 teachers and 24 scientific advisors from the continental coast and Easter Island. The final evaluation survey was answered by 704 students. Participants rated the activity with an average grade of 6.3, in which 61% of all students qualified it with a 7 (the best possible grade). The favorite part of the activity was the field sampling (76% of the students). The children's story "El Viaje de Jurella y los Microplásticos" (The Journey of Jurella and Microplastics) also obtained favorable responses. The majority of the students (83%) read the story, which was classified with an average grade of 6.0, and received the best grade by 52% of the students. Most students (73%) had never heard of small plastic debris before the activity. Also 62% of the students had never participated in an environmental activity, but 96% expressed the desire to participate in future activities of this kind (Table 1).

3.2. Accuracy of data

Seven out of all 39 participating schools did not enter their data via the website; these schools were mostly from rural areas or

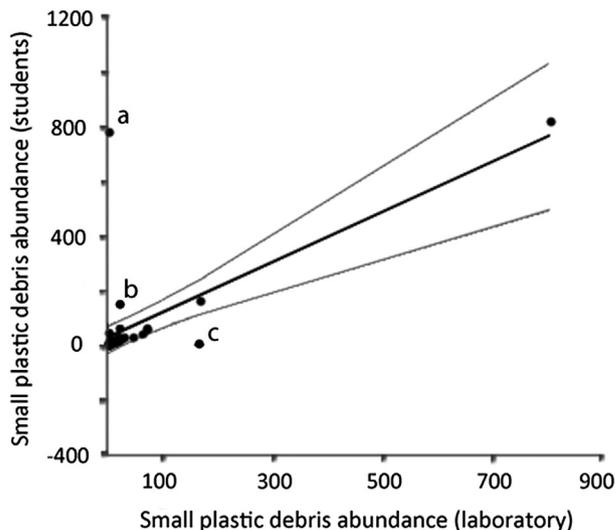
**Table 1**  
Results from the final evaluation survey applied to students.

Question	Majority response	Percentage (%)
On a score from 1 to 7, how much fun was this small plastic debris project?	7	61.1
Had you heard about small plastic debris before this project?	No	73.1
Had you participated in an activity related to the environment before this project?	No	61.7
Did you read the story "The journey of Jurella and the microplastics"?	Yes	83.0
On a score from 1 to 7, how interesting did you find the story of Jurella?	7	51.8
Would you like to participate in other environmental activities in the future?	Yes	96.1
What was your favorite part of the project? Please mark one option	Field work on the beach	76.2

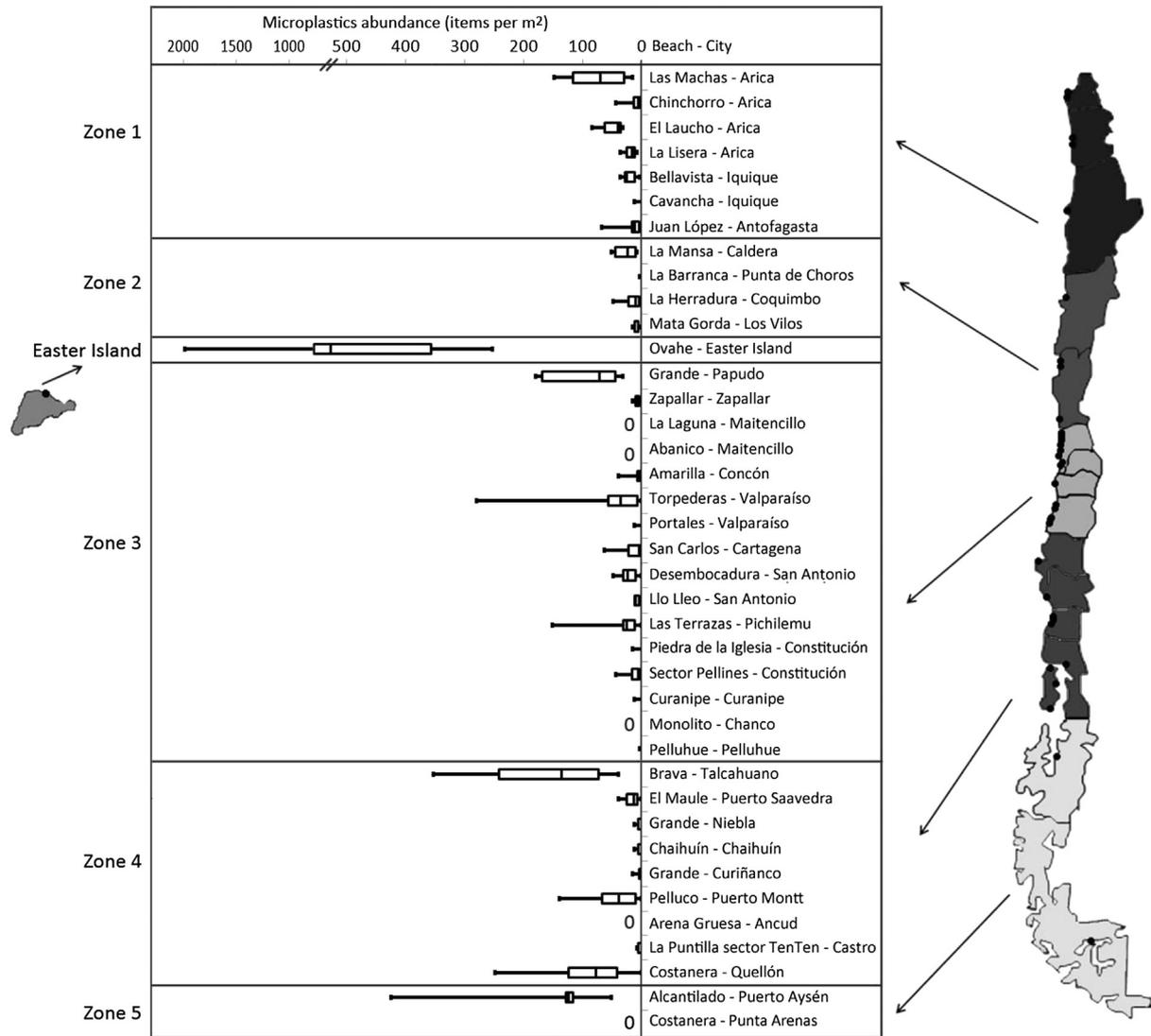
remote locations with little access to internet. For the 32 schools that initially communicated their data via the website, the simple regression analysis revealed three data points outside the confidence interval (Fig. 1). During the re-analysis of the samples from these values, it was found that two of the schools committed mistakes with the identification of small plastic debris: in one case, fragments of glass were counted as small plastic pieces (Fig. 1a) and in the other case, styrofoam items were not considered as plastics (Fig. 1c). The third data point outside the confidence interval was from a school that apparently made mistakes when entering the data via the website, with values that were one order of magnitude higher than the ones obtained in the laboratory re-counts (Fig. 1b). Including these three erroneous values, the linear model had a linear coefficient of 0.917 and a  $R^2$  of 0.464, but after excluding them the linear coefficient and  $R^2$  of the model increased to 1.001 and 0.968, respectively. The results of Student's *t*-test ( $t = -1.517$ ,  $df = 31$ ,  $p = 0.139$ ) indicate that the data obtained by the students did not differ significantly from the laboratory re-counts.

3.3. Occurrence and abundance of small plastic debris on Chilean beaches

Most (90%) of the 39 sampled beaches presented small plastic debris, comprising both fragments and pellets. Most items were fragments (89%), except in one case (Papudo Beach) where 94% of all small plastic pieces were pellets. Five beaches had no small plastic debris in any of the samples (Fig. 2). The majority (85%) of all small plastic debris had a particle size from 1 to 4.75 mm, while the remaining 15% ranged from 4.75 to 10 mm in size. The average abundance of small plastic debris for the Chilean continental coast was 27 items  $m^{-2}$  ( $\pm 2.6$  SE). The highest abundances were obtained in the regions of Aysén (169 items  $m^{-2}$ ) and Bío Bío (165 items  $m^{-2}$ ). The regions with the lowest abundances of small plastic debris were Magallanes ( $<1$  item  $m^{-2}$ ), Los Ríos and El Maule (4 items  $m^{-2}$ ). Easter Island had the highest abundances of all sampling sites, with 805 items  $m^{-2}$  ( $\pm 320.1$  SE; Fig. 2). The results of the ANOVA test indicated that the abundances in the different zones of the country significantly differed from each other ( $F = 54.75$ ,  $p < 0.001$ ) (Table 2). The permutational F value was equal to 55.36, very similar to the calculated 54.75 and greater than the critical value of 2.25. Thus, highly significant differences



**Fig. 1.** Linear regression analysis for small plastic debris abundance (items per  $m^2$ ) comparing the data obtained by the students and the laboratory re-counts. The confidence interval limits are marked by the grey lines.



**Fig. 2.** Box-plot graph representing the abundance of small plastic debris items (fragments and pellets) for every beach sampled. Dots on the map of Chile represent beaches where sampling took place.

were found between zones ( $p < 0.0001$ ). The post-hoc Tukey test indicated that the abundance of small plastic debris from Easter Island was higher than the abundances from all other zones ( $p < 0.001$ ).

**4. Discussion**

**4.1. Evaluation of the survey**

The study of small plastic debris was well received by the participants, even though most of them had not heard of this problem before. The positive results obtained by the final evaluation survey indicate that a high percentage of students were enthusiastic about

their participation in the activity and that they obtained new knowledge about small plastic debris. Similar results have been obtained by other citizen science projects (e.g. Bogner, 1999). Identifying the potential effect of citizen science projects on the attitude of participants towards scientific and environmental issues has not been well studied (Dickinson and Bonney, 2012). Nevertheless, it has been shown that schoolchildren participating in citizen science projects can engage in a scientific thinking process, experience an effective learning process, and that their attitude towards science might be changed positively (Lawless and Rock, 1998; Trumbull et al., 2000; Roth and Lee, 2002; Trautmann et al., 2012; Phillips et al., 2012).

**4.2. Validation of data collected by schoolchildren**

The methodologies for measuring the abundance of small plastic debris in the marine environment are highly variable and complex (Hidalgo-Ruz et al., 2012). Citizen science projects should consider the basic observation skills of the participants (Bonney and Dickinson, 2012). Therefore, to simplify the sampling methodology and the identification of small plastic debris, herein we

**Table 2**  
Results of the ANOVA test for mean value of small plastic debris abundances in the different zones of continental Chile and Easter Island.

Source	df	Mean Sq	F value	p
Zone	5	605,867	54.75	<0.001
Residuals	246	11,066		

**Table 3**  
Average abundances of small plastic debris, mesh size used for sampling, and types of small plastic debris reported from beaches throughout the world. F = Fragments, P = Pellets; values marked in bold correspond to this study.

Country	Abundance (items per m <sup>2</sup> )	Mesh size (mm) employed for sampling	Types of small plastic debris	Reference
Russia	29	1	F, P	Kusui and Noda (2003)
Chile (continental coast)	<b>30</b>	<b>1</b>	<b>F, P</b>	This study
Easter Island	<b>800</b>	<b>1</b>	<b>F, P</b>	This study
United States	1200	1	P	Wilber (1987)
Japan	2600	1	F, P	Kusui and Noda (2003)
Malta	36	2	P	Turner and Holmes (2011)
Japan	500	2	P	Kuriyama et al. (2002)
Oman	9000	2	P	Khordagi and Abu-Hilal (1994)
Jordan	44000	2	P	Abu-Hilal and Al-Najjar (2009)
Malaysia	18	3	P	Ismail et al. (2009)
England	100	3	P	Ashton et al. (2010)

decided to sample only items >1 mm, which can be identified by naked eye without the need for expensive equipment. For the identification of plastic debris <1 mm (microplastics) specific laboratory analyses such as infrared spectrometry are required (Browne et al., 2010). Despite the simplified approach used herein, there were schools that presented difficulties during the identification of small plastic debris in the field. Inaccurate data are likely to arise from identification/observation errors (Oberhauser, 2012), e.g. mistaking small plastic pieces with glass as in the present study. To avoid these errors, we recommend preparing an illustrative guide to identify the different types of small plastic debris (rigid fragments, pieces of plastic bags, styrofoam and monofilaments) and to explain the differences between small plastic debris and other small objects in beach samplings (e.g. glass, calcium-carbonate shells, other debris).

The results of the present study also confirmed that the students were able to follow simple sampling instructions and gather environmentally relevant data, obtaining results that were highly similar to the ones determined under laboratory conditions. Previous studies of citizen science projects with schoolchildren match these results: children from 8 to 12 years old were able to distinguish between two different invasive crab species, with 80% and 95% of correct identification, respectively (Delaney et al., 2008). Estimates by 6–13 year old schoolchildren of the number of ungulates coincided with the estimates of their supervisors (Galloway et al., 2011). A study on water sampling and analysis with 10–17 year old students found a good correlation between their data and those obtained by professionals (Peckenham et al., 2012).

#### 4.3. Small plastic debris along the Chilean coast

The results obtained in the present study revealed clear differences between the abundance of small plastic debris from the Chilean continental coast and Easter Island, where abundances were higher than in most other locations. The higher abundances found on some of the southern beaches (Quellón, Puerto Montt and Puerto Aysén) may be related to the intensive aquaculture activities in that area, where styrofoam, a material often used for buoys, was one of the most common items. A similar relationship between aquaculture and marine debris has also been reported in previous studies (Fujieda and Sasaki, 2005; Hinojosa and Thiel, 2009). The higher abundances of small plastic debris at some localities in northern and central-southern Chile, specifically in the cities of Arica and Talcahuano, are probably due to their proximity to industrial and urban centers, which act as local sources for small plastic debris. In central Chile, the high abundance of plastic pellets at Papudo Beach may also be due to nearby sources, particularly

plastic factories. Similar results were obtained by Gregory (1977), who found higher concentrations of plastic pellets near major industrial centers, and Browne et al. (2011), who reported greater amounts of small plastic debris in densely populated areas of different continents.

The average abundance of small plastic debris on the beaches of continental Chile reaches similar magnitudes as reported from other parts of the world, such as Russia and Malta (Table 3). In a comparative worldwide study, abundances varied between 2 (Australia) and 31 microplastics per 250 mL of sediment (Portugal and the United Kingdom) (Browne et al., 2011). In that same study, the abundances found for Chile at two sampling sites (Viña del Mar and Punta Arenas) ranged from 11 to 20 microplastics in 250 mL of sediment, confirming that microplastic abundances of continental Chile are indeed similar to those of other coasts reported in literature.

The high abundance of small plastic debris on Easter Island indicates that the beaches of the island might be acting as a filter for plastic debris that is transported by the oceanic surface currents towards the center of the South Pacific Subtropical Gyre, a region of accumulation of debris and microplastics (Lebreton et al., 2012; Maximenko et al., 2012; Eriksen et al., 2013). A similar situation has been reported for nonindustrial remote locations in the South Pacific such as Tonga, Rarotonga and Fiji (Gregory, 1999), Pitcairn Islands (Benton, 1995), and Hawaii in the North Pacific (McDermid and McMullen, 2004; Dameron et al., 2007; Corcoran et al., 2009; Cooper and Corcoran, 2010).

## 5. Conclusions

The results of the present study confirmed that the participants were able to follow the instructions and obtained valid data. Therefore, it can be concluded that the participation of schoolchildren in this project was an effective approach for achieving a large-scale sampling of small plastic debris.

The widespread occurrence and accumulation of small plastic debris on beaches of the SE Pacific is similar to the global situation. Most of the small plastic debris found on the continental coast probably comes from local sources, mainly depending on the proximity to urban centers and their economic activities. The high abundance of small plastic debris on Easter Island likely results from the transport of plastic particles through the oceanic current system to the South Pacific Subtropical Gyre (Eriksen et al., 2013). The island beaches thus act as a filter and a sink for small plastic debris coming from all around the South Pacific rim.

The present study is the first report of the occurrence and abundance of small plastic debris on SE Pacific and Chilean beaches.

It also confirms that citizen scientists may help to generate large-scale spatial (and temporal) data on the occurrence and abundance of small plastic debris. The results underscore the need for extending the research to other marine environments through monitoring over larger spatial and temporal scales, coupled with studies of the ecological impacts of plastic debris in marine ecosystems.

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