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Anthropogenic debris on beaches in the SE Pacific (Chile): Results from a national survey supported by volunteers

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ABSTRACT

Anthropogenic marine debris (AMD) is an ubiquitous problem, which has motivated public participation in activities such as beach surveys and clean-up campaigns. While it is known that beaches in the SE Pacific are also affected by this problem, the quantities and types of AMD remain largely unknown. In the context of an outreach project, volunteers (~1500 high-school students) participated in a nation-wide survey of AMD on 43 beaches distributed randomly along the entire Chilean coast (18°S to 53°S). The mean density of AMD was 1.8 items m^{-2} and the major types were plastics, cigarette butts and glass. Densities in central Chile were lower than in northern and southern Chile, which could be due to different attitudes of beach users or to intense beach cleaning in central regions. We suggest that public participation in surveys and cleaning activities will raise awareness and thereby contribute to an improvement of the situation.

1. Introduction

Litter in the environment is a problem that affects beaches throughout the world (Derraik, 2002; Gregory and Andrady, 2003; Ivar do Sul and Costa, 2007). Anthropogenic marine debris (AMD) is associated with diverse human activities that might take place on the beach itself or far away in the case of floating marine debris, which is transported via marine currents towards the sea shore. The amounts of AMD have increased in a way that this is currently recognized as a worldwide problem (e.g. Frost and Cullen, 1997; Santos et al., 2008).

AMD causes particular concerns because its potential impacts on marine wildlife and biodiversity. Animals often confuse plastic bags, plastic pellets and Styrofoam with their food causing severe damage and even death (Sheavly, 2005; Mallory, 2008; Ryan, 2008). Floating marine debris may also serve as transport vector for a wide diversity of marine organisms, which rapidly colonize these substrata. Due to the high longevity of most plastic debris, these objects together with their inhabitants may travel over long distances along the sea surface, possibly invading new, previously uncolonized, habitats (e.g. Gregory, 1991; Winston et al., 1997). Besides the environmental impacts, AMD in the oceans can also cause problems to other human activities by fouling ship propellers or clogging intake filters of powerplants or aquaculture systems (Sheavly, 2005). AMD can also negatively affect local tourism (Ballance et al., 2000; Sheavly, 2005).

In parallel to growing amounts of AMD, public awareness has also increased. This is reflected in beach surveys carried out in many countries of the world such as e.g. Jordan (Abu-Hilal and Al-Najjar, 2004), Japan (Kusui and Noda, 2003), Australia (Cunningham and Wilson, 2003) and Brazil (Oigman-Pszczol and Creed, 2007), among many others. Beach clean-ups involving many volunteer participants are commonly conducted on beaches throughout the world. This is the case of *The Ocean Conservancy*, an international organization that established the *Annual International Coastal Cleanup*, and *Clean Up the World*, an organization supported by the *United Nations Environment Programme* that also conducts frequent clean-up activities. Community participation in beach clean-up and survey activities has been valued by several authors who consider it as an important strategy of increasing public awareness (Rees and Pond, 1995; Jackson et al., 1997; Storrier and McGlashan, 2006). Volunteer participation also facilitates extensive samplings and thereby helps to obtain more information from a wider range of sites (Rees and Pond, 1995).

Even though AMD is a worldwide problem, it has been little studied in Latin America. In the SE Pacific region, there are only two countries (Colombia, Chile) for which studies about AMD in the environment have been published and these mainly focused on floating marine debris (Thiel et al., 2003; Ivar do Sul and Costa, 2007). Little is known about the reality of AMD on beaches from

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this part of the world and even less is known about the sources of this problem.

Beach surveys have been done in different parts of the world (e.g. Moore et al., 2001; Otley and Ingham, 2003; Shimizu et al., 2008). However, most of these studies are focused on limited sectors and often do not include many beaches. The present survey encompasses a range of 35° of latitude, covering a coastline >4000 km in the SE Pacific, where AMD was surveyed at 43 sites in a systematic and repeatable way. Knowledge of the abundances and types of AMD is important to identify possible sources, thereby facilitating the search for solutions (Santos et al., 2008). Also, being a cooperation between scientists and high-school students, such a public survey permits students, teachers and common people to visualize the dimensions of the AMD problem on their local beaches (Jackson et al., 1997). This raises their awareness about this problem, which helps to motivate them in getting involved with the possible solutions.

2. Materials and methods

2.1. Volunteer participation

We contacted social organizations, citizen groups and schools in cities and villages along the entire Chilean coast. At each institution that agreed to participate in the survey, one person acted as local coordinator of the activity. Sampling instructions and work sheets were sent to each local coordinator (information available at http://www.cientificosdelabasura.cl/MuestreoNacionalguias.htm).

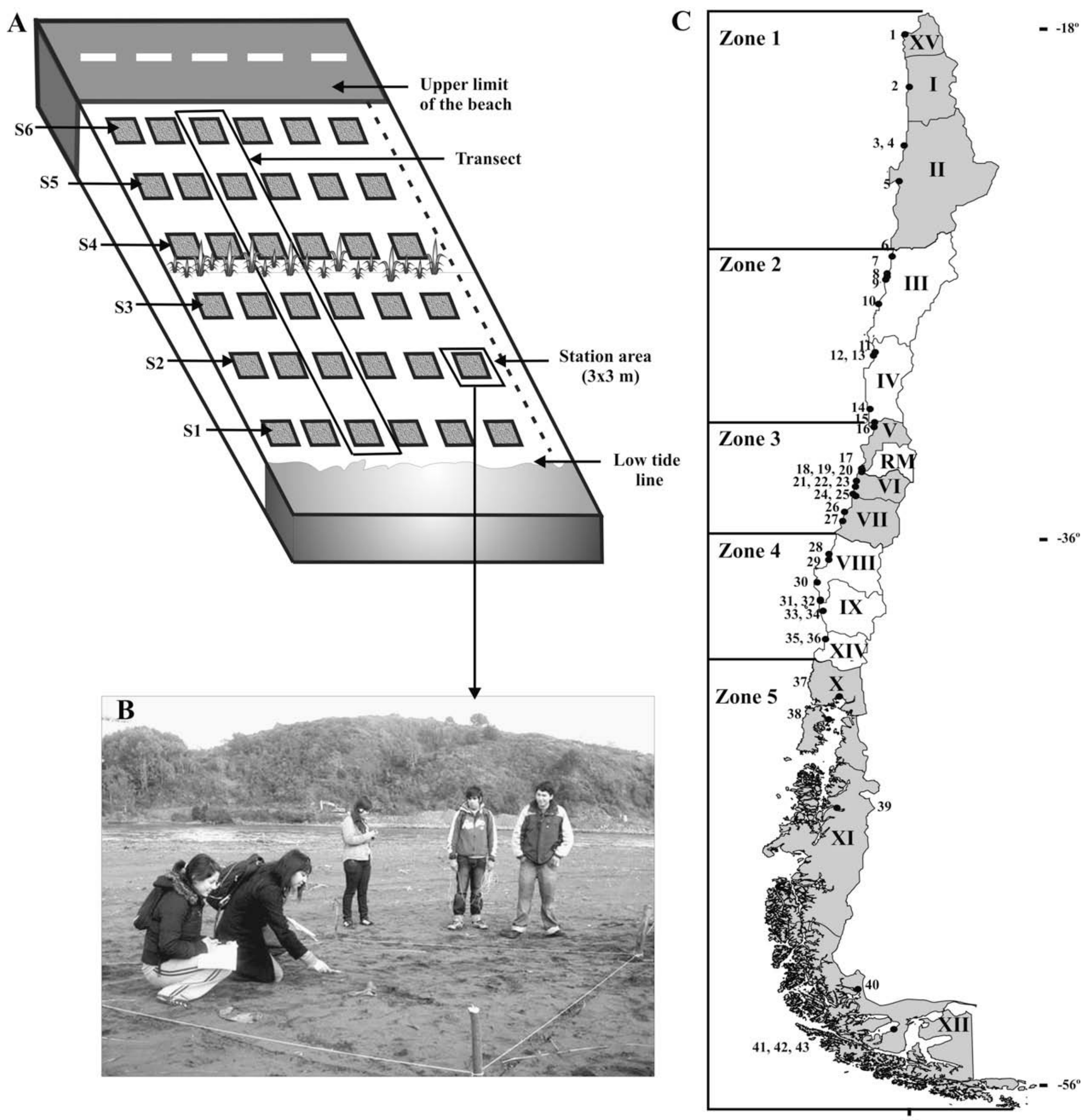

Fig. 1. (A) Schematic overview of beach survey design. Station 1 (S1) corresponds to the "low station" and station 6 (S6) to the "high station" of each transect. (B) Example of a station being surveyed by volunteer participants. (C) The five geographic zones along the Chilean coast. Large roman numbers in the map refer to the administrative regions of Chile. Small Arabic numbers next to the map indicate survey sites.

Additionally, we provided printed guidelines with information about AMD and its impact on the marine environment. Booklets with an educational story informing about the fate of plastic bags in the marine environment were provided to motivate and inform participants; this booklet is directed at school kids from ages 5–15.

2.2. Beach surveys of anthropogenic debris

Beach surveys were conducted between August and September 2008 (i.e. during austral winter), and each local coordinator selected one or several beaches within the neighborhood of their school or organization. Most of the surveyed sites were sandy beaches, but some of them were pebble beaches; rocky shores were not surveyed. At most sites, several transects were surveyed (up to 26 transects in Punta Arenas). These transects were perpendicular to the coastline, i.e. from the low tide line (low station) to the base of dunes (high station). On each transect a minimum of two stations were surveyed (between 2 and 6 stations, depending on the width of the beach) (Fig. 1a). Each station covered an area of 3 m × 3 m, which was delimited by ropes or measuring tape (Fig. 1b). All types of AMD within these 9 m^2 were counted and classified. This methodology is similar to the one that had been successfully used by Jackson et al. (1997) with students from the secondary school level (ages 15–17).

Data from each site were sent by the local coordinator via e-mail or regular mail to the coordinating office at Universidad

Table 1
Institutions and numbers of volunteer participants in the survey of AMD in each administrative region from the Chilean coast. Names of local coordinators are also presented.

Zone	Region	City	School or institution	Number of students	Regional number of students	Coordinators
1	Arica y Parinacota	Arica	ONG Borde Río	23	23	José López
	Tarapacá	Iquique	Colegio Maria Reina	71	71	Rossana Cáceres
						Norma Ponce
	Antofagasta	Tocopilla	Esc. Estados Unidos de Norteamérica	12	62	Sonia Aranciabia
			Esc. Diferencial Las Buganvillias	10		Julia Leo
		Antofagasta	Colegio Chañares	40		–
2	Atacama	Chañaral	Esc. Diferencial José Luís Arancibia F103	15	103	Ernesto Tolmo
						Juan Carlos Pinto
		Caldera	Escuela Villa las Playas	40		"Científicos de la Basura"
			Escuela Byron Gigoux	25		
		Huasco	Escuela Mireya Zuleta	23		
	Coquimbo	Coquimbo	Colegio Los Carrera	120	190	"Científicos de la Basura"
			Colegio Santa María de Belén			
			Escuela La Herradura			
		La Serena	Colegio Los Héroes de la Concepción	35		Milenko Alvarado
		Los Vilos	Colegio Diego de Almagro	35		Nelson Vásquez
3	Valparaíso	Puchuncaví	Escuela Básica de Maitencillo	40	76	Javier Travelli
		Zapallar	Escuela de Cachagua	36		Clara Köhnenkampf
	L. Bdo. O'Higgins	Navidad	Escuela Divina Gabriela	15	147	Ximena Morar
			Escuela Fco. Chávez Cifuentes Rapel	17		
			Liceo Pablo Neruda	28		
		Pichilemu	Esc. Unión de Mujeres Americanas	17		Vilma Leiva
			Charly's School	70		
			Escuela Digna Camilo			
	Maule	Llico	Liceo Entre Aguas de Llico	24	73	Viviana Contreras
		Bolleruca	Escuela Ema Cornejo de Cardoén	20		
		Chanco	Escuela de Loanco	7		Claudio Vergara
		Constitución	Escuela Barra Barrios Claudio Antonio	22		Jenny Soto
4	Bío-Bío	Concepción	Colegio Alemán de Concepción	140	263	Mónica Rodríguez
						Cynthia Valenzuela
			Colegio Sagrados Corazones	38		Daniela Fuentealba
		Lebu	Escuela Fresia Graciela Muller	27		Orlando Cayupe
						Jorge Guzmán
		Tirúa	Liceo C90 Trapaqueante	14		Juan Francisco Gaete
						Juan Carlos Molina
			Escuela Eloísa González F866	44		Doris Salgado
						Gabriela Quilodrán
	La Araucanía	Carahue	Liceo Llaguey N° 51	40	65	Martha Lidia Morales
						Silva Melo Necul
		Pto. Saavedra	Liceo Gabriela Mistral	25		Olga San Martín
	Los Ríos	Valdivia	Escuela de Niebla	30	61	Patricio Manríquez
			Colegio Domus Mater	31		Álvaro Volpi
5	Los Lagos	Pto. Montt	Colegio de Lenguaje Amapola	50	63	Alex Arismendi
		Quemchi	Escuela Borde Mar	13		Cristian Gaete
	Aysén	Chacabuco	Escuela de Chacabuco	22	22	Gonzalo Hormazabal
	Magallanes	Pto. Natales	Liceo Politécnico Luís Cruz Martínez	312	312	Pablo Araya
			Colegio Puerto Natales			
			Escuela Coronel Santiago Bueras			
			Escuela Capitán Juan Ladrillero			
			Liceo Gabriela Mistral			
			Colegio Maria Mazzarello			
		Pta. Arenas	Escuela Bernardo O'Higgins			
			Escuela España			
			Grupo Scout Don Bosco			
			Colegio Pierre Faure			
	Total				**1531**	**36**

Católica del Norte in Coquimbo, where they were analyzed. In this study we only used data of AMD, excluding debris of natural origin. In order to explore regional variations in the densities of AMD the entire Chilean coast was subdivided into five zones (Fig. 1c). Zone 1 includes the extreme northern regions, which are characterized by a dry desert climate and the absence of large rivers. Zone 2 covers the northern-central region with a semi-arid climate, with some local rivers, while zone 3 corresponds to the central regions of the country with a Mediterranean climate. Zone 4 includes the southern region with a temperate-cold climate, high precipitation and large rivers, and zone 5 covers the extreme south regions, characterized by high rainfall, windy climate and deep fjords. The highest population density with intense tourism is found in zone 3, followed by zones 2 and 4. The beaches of zone 3 are in close reach of the metropolitan region of Santiago, where about 7 million people (half the population of Chile) are living.

2.3. Data evaluation

To determine whether densities of AMD differed significantly among the regions of the Chilean coast, we conducted a nonparametric Kruskal-Wallis analysis. When differences were detected, the nonparametric post-hoc Dunn's test for unequal sample size was applied. To examine whether the distribution of AMD within a beach differed, and whether this pattern was consistent along the Chilean coast, we compared the AMD densities of the highest and lowest station of each transect across the five zones. We applied a nested ANOVA, where stations (highest and lowest) were nested within the five zones. Since variances were not homogenous across the groups, data were transformed to the reciprocal root ($1/\sqrt{x+1}$). This transformation method was selected after applying the protocol suggested by Fry (1993), which consists of several steps to select the most appropriate transformation method depending on the relationship between means and variances across the groups to be compared. After transformation, variances across the groups were found to be homogeneous (Bartlett's test, $X^2 = 14.932$, $p = 0.093$) and residuals were close to normality (Lilliefors test $p = 0.04$). To adjust for unequal sample size a General Linear Model (Zar, 1999) was applied using SYSTAT, which was used for all statistical analyses. When differences were detected (at $\alpha = 0.05$), a post-hoc Tukey test was carried out to identify which zones and stations differed among each other. Finally, the means of AMD densities and standard deviations were back-transformed.

3. Results

3.1. Participation and characteristics of survey participants

A total of 1531 students from 46 schools covering the 14 coastal regions of Chile participated in the survey of AMD. The participating schools and groups were supported by 46 different institutions, including local city governments, corporations, private foundations and other NGO's. The highest number of participants was in the Magallanes region (312 volunteers), followed by the Bío-Bío (263) and Coquimbo regions (190) (Table 1).

For most volunteers this was the first time that they participated in a scientific survey. However, the local coordinators were familiar with the scientific method and in particular with quadrat counts (many of them had studied marine biology). When reporting their data, some of the survey participants also expressed surprise about the amounts of AMD found on their local beaches. In addition to the data, we had requested photographs of the beaches and the activity from the local coordinators. Without being particularly asked, many participants also inferred about the possible sources of AMD on their local beaches. For example, a group from northern Chile associated the abundance of bottles and glass fragments with the carelessness of beach goers. Several local coordinators also mentioned that during the activity, participants started discussing about possible ways of mitigating the problem. These observations suggest that the sensitivity of the volunteers towards the problem of AMD on their local beaches increased during the participation in the survey.

3.2. Anthropogenic Marine Debris on the beaches in the SE Pacific

On all beaches surveyed in this study a total of 21,146 items of AMD were found and classified. The highest percentages of AMD on most beaches were plastics, cigarette butts and glass fragments. The proportions of the different types of AMD varied between the five geographic zones of the Chilean coast (Fig. 2). Plastics were very common in all five zones. In the northern zones (zones 1 and 2) cigarette butts predominated, while in zone 3 coal (classified under *other items*) was very common. In the two southern zones (4 and 5) metal, glass pieces, plastic and other items (mostly Styrofoam and cloths) abounded (Fig. 2).

The average density of AMD on beaches from the SE Pacific was 1.8 items m^{-2} (Fig. 3). Densities of AMD were significantly different between the regions along the Chilean coast (Kruskal-Wallis, $Hc = 165.6$, $p < 0.001$). Dunn's nonparametric multiple range test separated the regions into three statistically different groups: (i) Antofagasta; (ii) Tarapaca, Aysen and Magallanes and (iii) Arica and all other regions from Atacama to Los Lagos. The Antofagasta region featured the highest densities of AMD with most stations above 2 items m^{-2} and some stations even exceeding 20 items

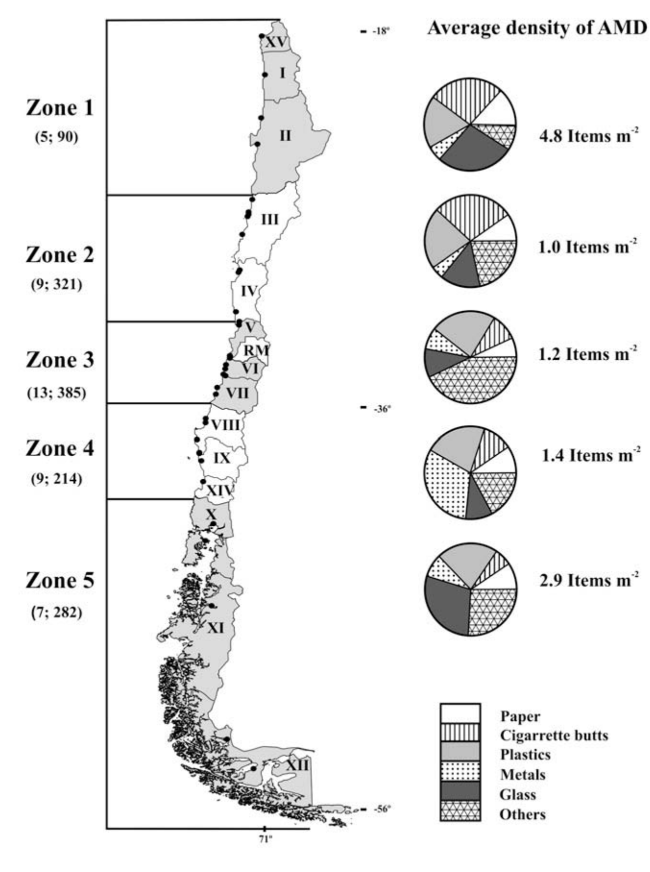

Fig. 2. Type and percentages of different categories of Anthropogenic Marine Debris in each of the five zones of the Chilean coast (average density of AMD for each zone is also presented). Numbers in parentheses correspond to the number of sites and stations surveyed in each zone. Black dots in the map indicate surveyed sites in each region.

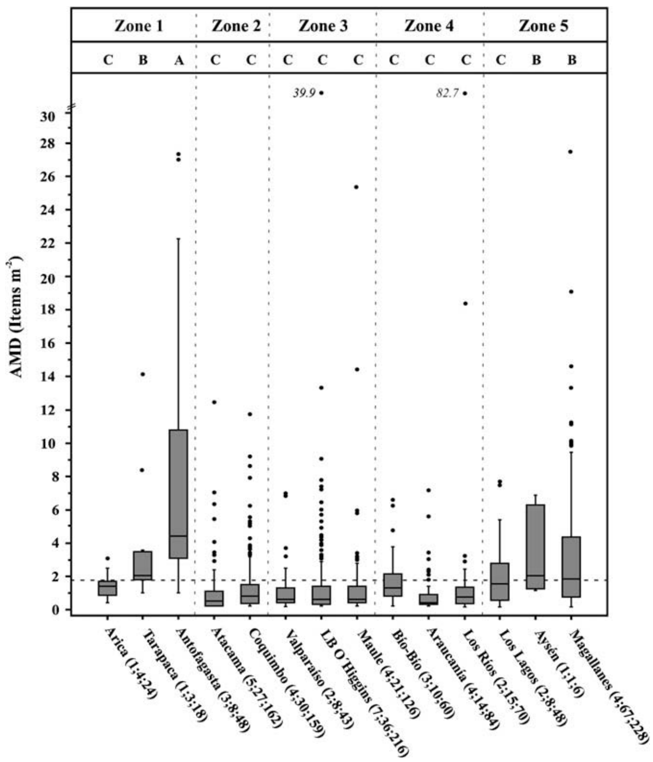

Fig. 3. Density of AMD in each administrative region along the Chilean coast. The interrupted line indicates the global average of AMD density for the Chilean coast. Box plots show the mean, percentiles, range and outliers. Capital letters A–C indicate significant differences between regions (Dunn's test, $p < 0.05$). Numbers behind the name of each region correspond to the number of sites surveyed; the number of transects; number of stations.

m^{-2}, clearly above the national average (Fig. 3). In the group of regions with low AMD densities, the regions of Atacama and Araucanía were the ones with the lowest densities, not exceeding 2 items m^{-2} at most stations. However, in some of the regions within this group, there were also stations with AMD densities above 10 items m^{-2}. Of the 43 surveyed sites along the country, the cleanest beaches of Chile were Playa Grande from the Atacama region in zone 2, Playa Tirúa and Playa Cura from the Bío-Bío region in zone 4, with an average of 0.3 items m^{-2}. Despite low densities, also on those beaches plastics are the most common AMD.

Table 2
Results of nested ANOVA for mean densities of AMD transformed to the square root between zones and among stations (highest and lowest) within a zone.

Source	Type III SS	df	MS	*F*-ratio	*p*-value
Zone	3.225	4	0.806	16.198	**<0.001**
Station (zone)	1.900	5	0.380	7.632	**<0.001**
Error	24.592	494	0.050	–	–

Mean AMD densities differed between zones and also among stations within a zone (Table 2). The post-hoc Tukey test indicated that the mean of zone 1 was significantly higher than that of the other zones (Fig. 4). The lowest abundances were reported from zones 2 and 3. Significant differences were found between the high and low stations in zones 1, 2 and 5, but not between the high and low stations in zones 3 and 4 (Tukey's test; Fig. 4). At most of the studied sites the highest densities of AMD were found at the upper transect stations with an overall average of 2.1 items m^{-2}. This average was lower at the lowest station of each transect, i.e. close to the water line (1.7 items m^{-2}).

4. Discussion

The national survey of AMD on beaches from the SE Pacific was well received by the volunteer participants, indicating that many people are concerned about the problem and willing to do something about it. All participants recognized and valued that this activity was not a clean-up campaign but rather a survey to provide a first diagnosis. The participation of experienced local coordinators ensured that data were comparable across the surveyed sites and zones, despite the different backgrounds of the volunteer participants.

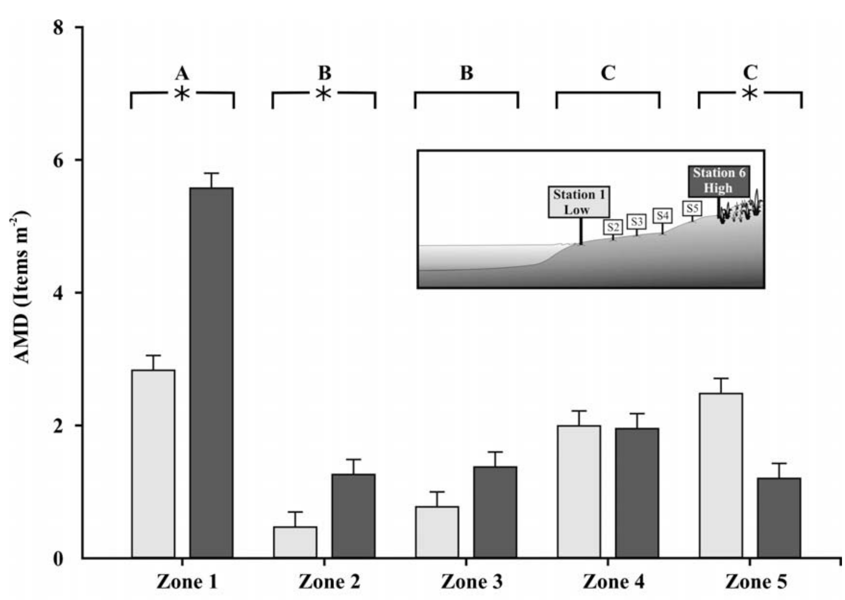

Fig. 4. Density of AMD (Mean + Standard deviation, back-transformed) at the low and high stations in the five zones along the Chilean coast. Capital letters A–C indicate significant differences between zones, stars (*) indicate significant differences between high and low stations within a zone (Tukey, $p < 0.05$). n = Number of transects surveyed in each zone. Small insert shows a schematic cross section of a beach transect showing the low and high station (numbers of intermediate stations was variable at the different sites, which is why we only considered the highest and the lowest station for this analysis).

The analysis of the data indicated a relatively uniform distribution of AMD across the beaches from the SE Pacific with some regional variations, the reasons for which will be discussed in the following.

4.1. Volunteer participation in AMD survey – data reliability

The present study employed a similar methodology as previously used in other surveys of AMD on local beaches (e.g. Jackson et al., 1997). As highlighted by Rees and Pond (1995), this kind of study has the potential to ensure wide geographic coverage without the necessity of extensive financial support, because it is based on the help of volunteer participants. Our study confirmed this, because with the aid of volunteers a large part of the SE Pacific could be covered. A synchronized survey, such as the one reported herein, would have been virtually impossible without the help of volunteers.

Materials used for this survey were simple (lines to delimit the 9 m^2 area at each station, gloves for sorting the AMD and paper forms), and most of these items were available in the local schools or could be acquired at moderate costs. In some cases transporting volunteers to the beaches and mailing the filled forms were among the major costs, which usually were assumed by the schools. The minimal requirements for equipment and transport have been previously emphasized as a major advantage of volunteer-based beach surveys (Rees and Pond, 1995).

In general, since most items that make up the bulk of AMD are very common in any household garbage bin, it is relatively easy even for untrained volunteers to classify and count the principal types of AMD. However, with the purpose of improving data quality, volunteers were also provided with a chart that highlighted the different types of AMD. Detailed and easily understandable instructions and guidance are considered essential in volunteer-based surveys (Rees and Pond, 1995). These instructions helped to avoid classification errors that could foul the collected data. Herein we only focused on AMD and we excluded natural marine debris such as e.g. wood, because these could either be of anthropogenic (manufactured) or natural (branches, trees) origin, thereby potentially introducing confusion (Alkalay et al., 2007).

One of the main concerns of surveys conducted with the help of volunteer participants is whether the data are reliable and comparable. For example, Moore et al. (2001) conducted a carefully designed study on litter densities from beaches in southern California, and they then compared their data with those obtained from volunteers during a beach clean-up campaign. Densities calculated from volunteer data were 50-times lower than densities based on their own data, which they attributed to the fact that: (i) volunteers focused on cleaning up the beach rather than on surveying densities and (ii) collected mainly larger items (Moore et al., 2001). In the instructions to our local coordinators, we emphasized that the present study was not a clean-up activity, but rather a survey of litter densities. This message was repeated in both verbal and written communications prior to the survey, and the photographic and written documentation that we received together with the data confirmed that all participants carefully adhered to these instructions. Thus, we consider that the data obtained in this study reliably reflect the densities of AMD on the surveyed beaches.

One potential problem of public beach surveys is the bias at the time of selecting a beach for the activity. This decision could be biased towards easy access or more contaminated beaches (Rees and Pond, 1995). Herein, the local coordinators usually chose the beaches according to beach access (i.e. walking distance to the school or availability of public transport), and preconceptions about the amounts of AMD were not part of the decision process. Overall, the nation-wide survey includes all types of beaches (i.e. within and outside of large cities, contaminated and relatively clean), thereby ensuring the representativeness of the data.

4.2. Beach debris in Chile and its origins

Following the global tendency (Derraik, 2002), plastics were among the most common debris types on almost all surveyed beaches in Chile. Plastics are used in almost all human activities (professional and recreational), and they are a very resistant material, persisting for long times in the environment, both under water as well as in the air (Pegram and Andrady, 1989). In general, in many parts of the world, and in particular on beaches used by tourists, a high proportion of AMD comes from beach users themselves (e.g. Abu-Hilal and Al-Najjar, 2004; Ariza et al., 2008). Several indicators, such as the specific composition of AMD and the distribution pattern on the beach, support this suggestion. For example, in some of the surveyed beaches glass fragments (mainly bottles) and cigarette butts were very common, which are two types of AMD usually directly attributed to local beach users (Silva-Iñiguez and Fischer, 2003; Taffs and Cullen, 2005). Similar as in the northern and central zones, Silva-Iñiguez and Fischer (2003) observed highest densities of AMD in the upper zones of the beach, a situation also reported from other parts of the world (Jackson et al., 1997; Cunningham and Wilson, 2003; Claereboudt, 2004). This distribution pattern within a beach suggests local sources of AMD, because beach goers typically frequent the highest parts of the beach. Additionally, AMD spread over the beach might be reshuffled by tides and waves, concentrating it high up on the beach (Taffs and Cullen, 2005).

Table 3
Densities of AMD reported from beaches throughout the world.

Country	Number of surveyed beaches	Average densities (items m^{-2})	Maximum densities (items m^{-2})	Reference
Scotland	16	0.4	2.3	Velander and Mocogni (1999)
Brazil	2	0.7	2.1	Araújo et al. (2006)
Brazil	10	0.14	~0.5	Oigman-Pszczol and Creed (2007)
Japan[a]	34	45,000	280,000	Fujieda and Sasaki (2005)
Japan[a]	18	3.4	2200	Kusui and Noda (2003)
Russia	8	0.2	16.7	Kusui and Noda (2003)
Oman	11	~0.4	~0.9	Claereboudt (2004)
Jordan	3	4.0	7.4	Abu-Hilal and Al-Najjar (2004)
Panama	19	3.6	–	Garrity and Levings (1993)
Australia	1	0.5	0.5	Foster-Smith et al., 2007
Australia	6	0.1	0.3	Cunningham and Wilson (2003)
Israel	6	–	0.9	Bowman et al. (1998)
Pitcairn Islands	2	0.2	0.4	Benton (1995)
Ireland	1	0.2	–	Benton (1995)
Indonesia	21	4.6	–	Evans et al. (1995)
Chile	43	1.8	82.7	This study

[a] These studies counted individual pellets of fragmented Styrofoam, an item usually not counted in most other studies.

Fig. 5. (A) Group of volunteers that participated in the survey. (B) Volunteers surveying AMD at one of the stations. (C) Newspaper article reporting on the preliminary results of the survey. (D) Sorting the different categories of AMD found in a station.

In general, there are moderate to high densities of AMD along the entire Chilean coast, but there is a tendency of lower densities in zones 2 and 3. This is surprising at first glance because the high population concentration in these zones is thought to produce strong impacts on coastal ecosystems (Barragán et al., 2005). Usually zones with high population densities and many human activities present higher amounts of AMD than other zones (Evans et al., 1995; Foster-Smith et al., 2007; Ariza et al., 2008). However, the frequent use may also be reason for low abundances of AMD. Beaches in these zones, especially in zone 3 (due to its vicinity to the Metropolitan Region, RM, with almost 50% of the Chilean population), are visited throughout the year by beach users. The low densities of AMD in the central zones (2 and 3) might result from a periodical regime of beach cleaning in these touristic regions. This type of management can lead to a considerable reduction of AMD compared to beaches without regular cleaning (Uneputty and Evans, 1997; Somerville et al., 2003; Araújo and Costa, 2007). Litter bins on the touristic beaches might also help in reducing the densities of AMD, even in areas with large numbers of beach goers (Frost and Cullen, 1997; Ballance et al., 2000). The educational level and socio-economic characteristics of beach users can also affect their behaviour and thereby also the presence of AMD on the beaches (e.g. Cunningham and Wilson, 2003; Santos et al., 2005), but at present it is not known whether and how attitudes of beach goers vary along the Chilean coast.

Latitudinal variations in sources can also explain the observed differences in AMD densities. In northern Chile, where no large rivers exist, potential sources are either ocean-derived AMD, local shipping or beach users. Along the continental coast of Chile, densities of floating marine debris are highest in coastal waters near large cities, which suggests that AMD is derived from local sources (Thiel et al., 2003). It is unlikely that the high densities of AMD on beaches in zone 1 are from distant sources, because AMD released along the Chilean coast are concentrated on beaches in southern Chile, while AMD released in other sectors of the S Pacific accumulate in the eastern part of the subtropical gyre, but do not reach the Chilean coast (Martínez et al., 2009).

The large rivers in southern Chile can transport litter from inland sources to the coast thereby contributing to higher densities of AMD on local beaches, as also suggested by Araújo and Costa (2007) and Santos et al. (2008) for some beaches in Brazil. The input of AMD by rivers could be intensified by rain (Shimizu et al., 2008), and since the south of Chile is a rainy region, river input might be locally significant (see very high AMD density in one station of the region Los Ríos in Fig. 3). In the fjord region of southern Chile (zone 5), aquaculture activities appear to be another important source of AMD on local beaches (Hinojosa and Thiel, 2009).

Densities of AMD on beaches in the SE Pacific are similar to those reported from other parts of the world (Table 3). Even though the population density along the Chilean coast is much lower than in many other regions of the world, the densities of AMD on local beaches are comparable to those found in densely populated areas of the northern hemisphere. Since there exists strong indication that most AMD on beaches from the SE Pacific has local sources, the solutions should also be sought at the local level.

4.3. Volunteer participation

Most volunteers participating in this survey were students from the middle and high-school level (ages 10–16). The survey was part of an outreach project introducing the scientific method to school kids. While first contacts were made with the teachers and these took the decision to participate, students generally participated enthusiastically in the survey (Fig. 5a and b). One major feature of this survey is that students did not only repeat simple scientific experiments but they produced real data, which would not have been available otherwise. They were aware of this throughout and they also knew that they were part of a larger survey. At present, we do not know to which degree this knowledge might have fostered their willingness to participate, but the positive responses we received from the participating schools suggest that this could be a very promising model. Collaborative studies between scientists and school students such as this survey of AMD could be a powerful tool in increasing sample size and geographic coverage (see also Rees and Pond, 1995). There is a wealth of questions from all branches of natural sciences (biology, environmental ecology, geography, sociology) that could be tackled by scientist–teacher–student teams.

The call for volunteers in the beach survey was positively received by the contacted organizations, institutions and schools. Most people immediately declared their willingness to participate in this activity. This shows the potential of involving volunteers in activities related to environmental protection, which had also been highlighted by other authors (Jackson et al., 1997; The Ocean Conservancy, 2006; Storrier and McGlashan, 2006). Herein, volunteers were introduced to a common environmental problem, and by actively participating in the survey and noticing the large amounts of AMD, their awareness of the problem increased. The involvement of the general public in this kind of projects is considered very important at the moment of teaching citizens about the problem and impacts of AMD (Earll et al., 2000).

The volunteers participating in this study recognized, in an autonomous way, the causes that provoke the debris problem. This kind of discussion proves that volunteers became more sensitive to the problem of AMD at the end of the activity, an observation also highlighted by other authors (Jackson et al., 1997; Storrier and McGlashan, 2006). Publicity is considered an important part in the search for solutions (Velander and Mocogni, 1998). In this study, the preliminary results of the survey were published in national and local newspapers (Fig. 5c), thereby also reaching many people who did not actively participate in the survey. Future beach surveys and clean-up activities will show whether this type of publicity indeed helped raise awareness.

4.4. Conclusions and suggestions

This study is only the first step in revealing the reality of AMD on beaches of the SE Pacific. The obtained results can, however, already be used to mitigate the AMD problem in the SE Pacific. The causes for the high densities of AMD on the surveyed beaches are variable and often depend on local realities, including: (i) lack of conscience by beach users, (ii) insufficient garbage bins, (iii) no recycling and reutilization system, (iv) absence of inspection, (v) lack of information about the extent of the problem. Many of these causes are transversal and valid for anthropogenic debris in any environment. The principal solutions are better infrastructure and environmental education. Starting in local schools and getting the general public involved in these activities (Fig. 5d) appear to be some of the most promising avenues in resolving the common problem of AMD.

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