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Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California *

Quantidades e tipos de plásticos provenientes de dois rios urbanos que escoam para águas costeiras e praias do Sul da Califórnia (Estados Unidos) #

C.J. Moore ^{@,1}, G.L. Lattin ¹, A.F. Zellers ¹

ABSTRACT

Plastic debris is a common persistent pollutant in marine and coastal environments worldwide. Questions naturally arise among those dealing with the debris as to its source. Here we quantify the contribution of a large urban area, the Los Angeles basin, to the problem via the two main rivers draining its watershed. Samples of river water were taken with a variety of nets during both rainy and dry conditions from mass emission sites above the reach of tidal influence in the Los Angeles and San Gabriel Rivers. The samples were from different strata in the flowing rivers using nets with less than 1mm mesh. Laboratory analysis of the samples divided the plastic debris into two size classes: $\geq 1\text{mm}$, $< 4.75\text{mm}$, and $\geq 4.75\text{mm}$. A reason for the two size classes, in addition to providing a distinction between macro and micro debris, was that under California law, debris less than 5mm is not considered trash subject to regulation. The debris was first sorted into natural, plastic, and non-plastic manmade items. The plastic debris was then classified by type; either fragments, foams (mainly polystyrene), pre-production resin pellets, line, or films. Results extrapolated for 24 hours of flow from one moderate and one heavy rain day and one dry day when added together produced the following for 72 hours: Total number of plastic objects and fragments, 2,333,871,120.0 (2.3 billion), total weight of plastic objects and fragments 30, 438.52 kg (30 metric tons). In terms of the number of pieces, the majority, 71% were foams, with miscellaneous fragments at 14%, pre-production resin pellets at 10% and whole items at 1%. In terms of weight, however, whole items were the heaviest, at 37% of the total, followed by fragments at 29%, pellets at 13% and foamed polystyrene at 11%.

Keywords: fragments, polystyrene, urban runoff, solid wastes legislation.

RESUMO

O lixo marinho plástico é um poluente persistente e comum em ambientes costeiros de todo o mundo. Naturalmente nos questionamos sobre quais são as fontes desse poluente. Neste trabalho quantificamos a contribuição de uma grande área urbana, a bacia do rio Los Angeles, para esse problema através da descarga dos dois principais rios de sua área de drenagem. Amostras de água do rio foram tomadas com vários tipos de redes,

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durante a estação seca e a estação chuvosa, em locais de grande emissão a montante da influência da maré nos rios Los Angeles e San Gabriel. As amostras eram de diferentes profundidades da coluna d'água, usando redes de 1mm de abertura. As análises no laboratório dividiram os plásticos em duas classes de tamanho: $\geq 1\text{mm}$ a $< 4,75\text{mm}$ e $\geq 4,75\text{mm}$. A razão para esse corte das classes de tamanho, além de proporcionar uma distinção entre macro e micro fragmentos, advém da lei da Califórnia, que diz que fragmentos menores do que 5mm não devem ser considerados lixo sujeito à regulamentação. Inicialmente uma separação foi feita entre fragmentos naturais, plásticos e de origem antropogênica não-plásticos. Os plásticos foram então classificados como fragmentos, isopor, esférulas plásticas pré-produção, fios e filmes. Os resultados, quando extrapolados para 24 horas de fluxo resultante de chuvas, moderadas e pesadas (72 horas) de fluxo, foram um número total de itens plásticos e fragmentos 2.333.871.120,0 (~2,3 milhões); e um peso total de itens plásticos e fragmentos 30.438,52g (~30 toneladas métricas). Em termos de número de itens, a maioria eram isopor/espumas (71%); fragmentos indefinidos eram 14%; , esférulas plásticas pré-produção eram 10% e; itens inteiros 1%. Em termos de peso, no entanto, itens inteiros eram os mais pesados (37%), seguidos dos fragmentos (29%), por sua vez seguidos das esférulas plásticas pré-produção (13%) e finalmente do isopor/espumas (11%).

Palavras-chave: fragmentos plásticos, isopor, aporte urbano, legislação ambiental sobre resíduos sólidos

1. INTRODUCTION

The most abundant type of debris impacting coastal beaches in Southern California's Orange County is pre-production resin pellets, the thermoplastic industry's principal feedstock. Hard plastic objects and pieces are over a hundred times less common but weigh one and a half times as much as the pellets (Moore, S.L. et al 2001). The presence of pre and post consumer plastics in the marine environment and on beaches is a worldwide phenomenon. "The literature on marine debris leaves no doubt that plastics make-up most of the marine litter worldwide" (Derraik, 2002). Murray Gregory showed in 1989 that plastic debris can be found throughout the southwest Pacific, with high densities of plastic in surface waters north of New Zealand, and abundant plastic pellets on New Zealand beaches adjacent to manufacturing centers (Gregory, 1990). Algalita Marine Research Foundation (AMRF) has documented land based sources of plastic and debris in neuston samples from the North Pacific Central Gyre (NPCG) (Moore *et al.*, 2001) as well as along the Southern California Coast (Moore *et al.*, 2002). Plastic debris has also been shown to occur at subsurface depths of 10m and 30m in the NPCG (Moore *et al.*, 2005), Southern California coastal waters, and near the bottom of the sea floor off Ballona Creek (Lattin *et al.*, 2004).

Most studies of marine debris have focused on easily visible and identifiable plastic objects. The studies by AMRF and Southern California Coastal Water Research Project (SCCWRP), however, have shown that plastic fragments less than 5mm have a mass that is 30% of the mass of the associated zooplankton in the NPCG. In near coastal waters off the San Gabriel River, the mass of plastic less than 5 mm was found to be 60% of the mass of the associated zooplankton (Lattin *et al.*, 2004).

Policies in California have been established to restrict trash and plastic greater than 5 mm in size through the process of regulating Total Maximum Daily Loads (TMDLs). In order to quantify debris not subject to regulation by TMDLS, this study analyzed plastic trash between 1 and 5mm in size as well as that $> 5\text{mm}$ from two Southern California Rivers; the Los Angeles River and the San Gabriel River. The goal of this study was to answer the following questions:

- 1) What are the amounts of different types of debris flowing down the rivers to the sea?
- 2) What are the quantities of debris in two size classes (1-4.75mm and $> 4.75\text{mm}$) flowing down the rivers to the sea?

- 3) What is the weight of the debris flowing down the rivers to the sea?
- 4) What differences in the above quantities are observed in dry vs wet conditions?

2. METHODS

Monitoring sites were selected in each watershed that represented a point at which all materials coming down the river from the watershed have to pass before reaching the ocean. Such sites are known as "mass emission" sites. Each was also chosen because it had access for sampling, and was above the area of tidal influence.

In the Los Angeles River one mass emission site was adequate, however, in the San Gabriel River two mass emission sites were necessary. One was located on the San Gabriel River and the other its tributary, Coyote Creek (see Fig. 1 and Fig. 2). These two sites are slightly upstream from where the Creek and the River merge. The reason for having two sites is that after they merge, they are subject to tidal influence.

The mass emission sites were sampled during both a dry and a wet period. The dry period was considered to be at least two weeks without 0.25" (0.6cm) of rain, after which the dry period sample could be taken. The wet period samples were taken within 24 hours of a 0.25" (0.6cm) rainfall. At each site samples were collected at the middle and edge of the channel, and at the surface and near the bottom. For both wet and dry weather sampling, surface samples were collected at the center of the river using a manta trawl (see Table 1). Surface samples were also collected at the river/bank interface, and in laminar flow near the mid channel (Nov. 22 only) using two different sized hand nets. All nets used had less than a 1mm mesh. Mid-depth to bottom samples were collected using a heavy streambed sampler. A large crane was used to lower the manta net and the streambed sampler for sampling. During the high flow of the wet period, the use of a crane was not possible, instead, a heavily weighted rectangular net was dropped from an upstream bridge nearby, allowed to extend to the length of the rope, then pulled along the bottom to the side of the river for the collection of the sample. The hand nets were again used along the side of the river/bank interface. Table 1 summarizes the characteristics of our collection devices.

Flow rate was determined by using a General Oceanics flowmeter, or the time and distance method of a floating object. The original sampling time was 15 minutes; however, due to fouling of the net and flowmeter by algae and debris in the Spring samples, some deployment times were as short as 30 seconds. Three sample replicates were collected with each

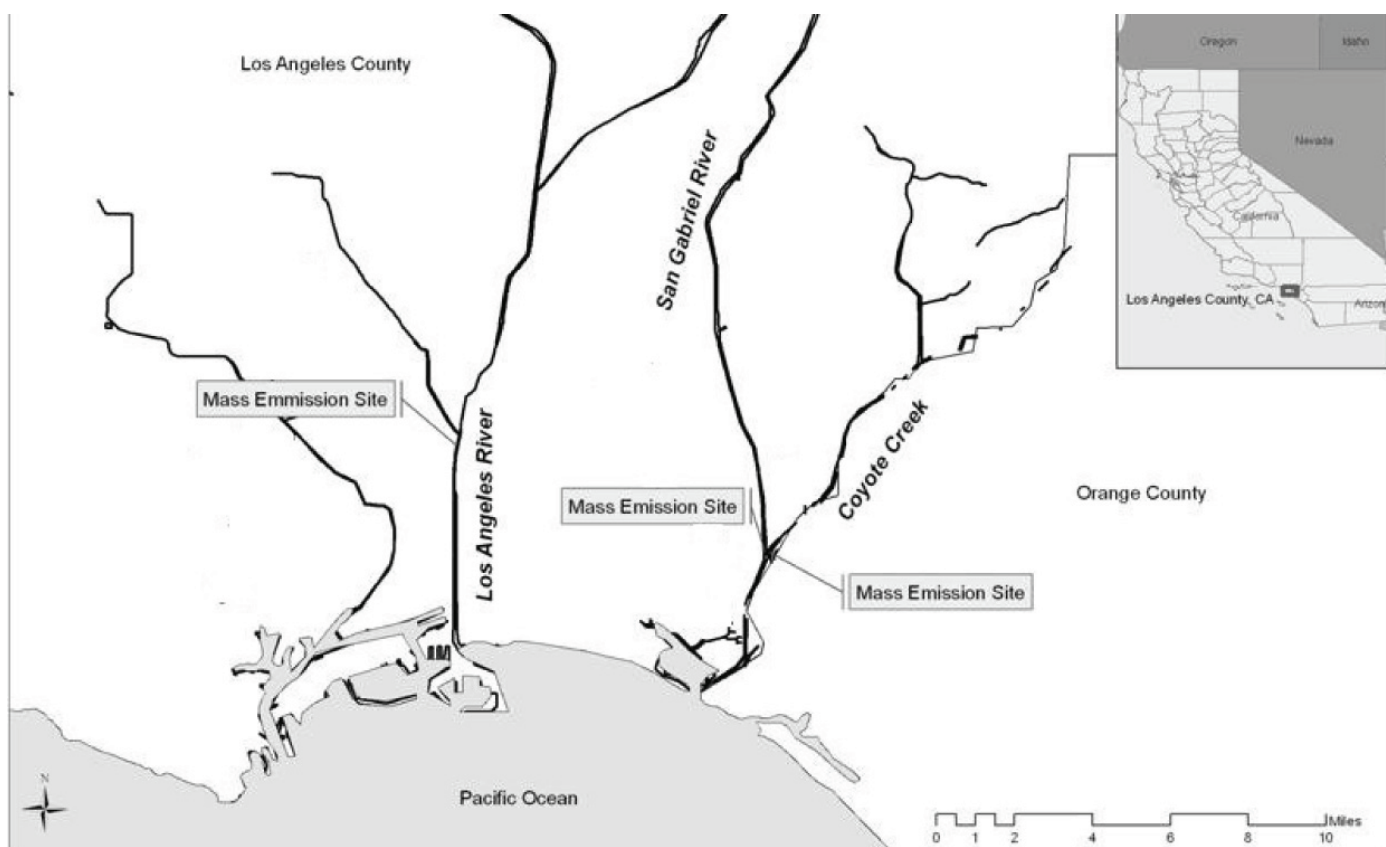


Figure 1. Mass Emission Sites.

Figura 1. locais de maior emissão amostrados.



Figure 2. Concrete lined Coyote Creek, showing streambed sampler and hand net.

Figura 2. Coyote Creek, um rio canalizado, o amostrador de fundo e sua rede.

Table 1. Collection Device Characteristics.

Tabela 1. Características dos amostradores.

Collection Device	Handnets	Manta Trawl	Streambed	Rectangular net
Net Aperture Dimensions (m)	0.46 x 0.25 0.43 x 0.22	0.9 x 0.15	0.15 x 0.15	0.46 x 0.25
Mesh Size (mm)	0.800 0.500	0.333	0.333	0.333
Usage	Surface Edge	Surface Middle	Bottom Middle	Surface Middle Subsurface Bottom(mostly)

device. All sampling times and devices were normalized to obtain count or weight per cubic meter of river water.

All samples were taken to the AMRF Lab and analyzed. The samples were sorted wet. The large debris was sorted out first and placed in the appropriate category, either natural, plastic, or manmade items. A dissecting scope was used to sort out the rest of the smaller plastic and manmade items from the natural debris. Tyler sieves (4.75mm, 2.8mm, 1.0mm) were then used to size class the small plastic items. The sieved items were oven dried at 65°C. Further sorting separated the plastic into types (fragments, foams, pellets, line, and films). Each type was counted, weighed, and recorded.

After each sample was sorted, the density or load of plastic per cubic meter of river water was determined by dividing the quantity of plastic (count or mass) by the product of the flow rate of the river, the area of the opening of the sampling device and the length of time the device was deployed. The three replicate samples were then averaged for that sampling device.

Wet period samples were collected first (November 22 and December 28, 2004) at all three sites. Dry period samples were collected on April 11, 2005.

3. RESULTS

The greatest abundance and density of debris occurred on November 22, 2004 in the LA River after a light rain. Particles less than 5mm in size were 16 times more abundant than those greater than 5mm, and weighed three times more than the larger particles. During this rain event, Coyote Creek and the San Gabriel River each showed a similar trend with smaller particles approximately three times more abundant. In total, the most abundant debris type in Coyote Creek was plastic fragments, whereas in the neighboring San Gabriel River foamed plastic was most abundant. In the LA River, foamed plastic was orders of magnitude more abundant than any other type. The total abundance of particles in the Los Angeles River between 1 and 4.75mm in size, collected on 11-22-04 from all sampling devices was 12,932 pieces/m³, while particles and whole objects greater than 4.75 mm from all sampling devices was 819/m³. The highest abundance from any sampling device used in the Los Angeles River was on 11-22-04 with the hand net in laminar flow near mid-channel at 12,652 pieces/m³ between 1 and 4.75mm.

The total abundance of particles in the San Gabriel River, including the Coyote Creek tributary, between 1 and 4.75mm in size, collected on 11-22-04 from all sampling devices was 411 pieces/m³, while particles and whole objects greater than 4.75 mm from all sampling devices was 125/m³. The highest abundance from any sampling device used

in the San Gabriel River or its Coyote Creek tributary was on 11-22-04 with the manta net; 153 pieces/m³ between 1 and 4.75 mm in size. The Los Angeles River in November had the greatest number of particles, with foam as the most abundant material. Foamed plastics were also the most abundant particles in the San Gabriel River on that date.

The two river systems differed in the density of debris, with the Coyote Creek/San Gabriel River complex having a greater density of whole objects, whereas on the LA River, pre-production plastic pellets, had greatest density. Pellets were found in both rivers, and were the second most abundant material found after expanded polystyrene in the LA River. Small plastics, 1-4.75mm diam. were the most common debris item in this study, constituting 81% of all plastics sampled, but were outweighed 7 to 1 by debris >4.75 mm in diameter.

The greatest density of plastic of any size class with any particular sampling device was found in the San Gabriel River on 11-22-04, with the manta net at 81 g/m³ for items greater than 4.75mm. The handnet data for the same date, size class and location was half as much (40 g/m³), and the laminar hand net on the LA River for the same parameters was 13 g/m³.

Extrapolation of the data in tables 2-5, using flow rates taken from available Flood Control Agency mean cubic feet per second (cfs) for each river on the date samples were taken, yields a 72 hour total abundance from all sampling devices of 2.33 x 10⁹ plastic objects and particles, with a corresponding weight of 3.04 x 10⁴ kg, or 30.4 metric tons. (Tables 8-9)

Table 2. Total Count Density (number/m³).Tabela 2. Densidade total (itens.m³).

	Coyote Creek		San Gabriel River		Los Angeles River	
	1.0 - 4.75 mm	> 4.75 mm	1.0 - 4.75 mm	> 4.75 mm	1.0 - 4.75 mm	> 4.75 mm
November 22, 2004 (wet)						
Handnet	74	10	61	76	271	42
Manta	< 1	< 1	153	18	9	< 1
Streambed	< 1	< 1	123	21	< 1	< 1
Handnet Laminar	----	----	----	----	12652	777
Total	74	10	337	115	12932	819
December 28, 2004 (wet)						
Handnet	14	2	26	4	35	4
Thrownet	4	< 1	4	< 1	1	< 1
Total	18	2	30	4	36	4
April 11, 2005 (dry)						
Handnet	2	< 1	< 1	0	22	22
Manta	5	< 1	< 1	0	0	< 1
Streambed	< 1	0	0	0	< 1	< 1
Total	7	0	0	0	22	22

Table 3. Total Weight Density (g/m³).Tabela 3. Peso total (g.m³).

	Coyote Creek		San Gabriel River		Los Angeles River	
	1.0 - 4.75 mm	> 4.75 mm	1.0 - 4.75 mm	> 4.75 mm	1.0 - 4.75 mm	> 4.75 mm
November 22, 2004 (wet)						
Handnet	< 1	2	< 1	40	< 1	< 1
Manta	< 1	< 1	< 1	81	< 1	< 1
Streambed	< 1	2	< 1	< 1	< 1	< 1
Handnet	----	----	----	----	43	13
Total	0	4	0	121	43	13
December 28, 2004 (wet)						
Handnet	< 1	< 1	< 1	1	< 1	1
Thrownet	< 1	< 1	< 1	< 1	< 1	< 1
Total	0	0	0	1	0	1
April 11, 2005 (dry)						
Handnet	< 1	< 1	< 1	0	< 1	1
Manta	< 1	< 1	< 1	< 1	< 1	< 1
Streambed	< 1	0	0	0	0	< 1
Total	0	0	0	0	0	1

Table 4. Count Averages (number/m³) by Type.*Tabela 4. Densidades médias (itens.m³) por tipo de item.*

Coyote Creek							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.01	17.67	3.61	0.00	3.46	3.47	28.22
December 28, 2004	0.10	6.12	1.24	0.93	0.88	0.90	10.15
April 11, 2005	0.01	0.08	2.36	0.04	0.00	0.01	2.49
Total	0.12	23.86	7.21	0.97	4.34	4.38	40.86
San Gabriel River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	5.98	59.08	69.43	0.00	3.97	12.11	150.57
December 28, 2004	0.34	9.75	4.86	1.57	0.42	1.88	18.81
April 11, 2005	0.00	0.04	0.12	0.00	0.00	0.00	0.16
Total	6.32	68.87	74.41	1.57	4.39	13.98	169.54
Los Angeles River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.00	205.90	2,852.54	364.76	5.88	8.87	3,437.94
December 28, 2004	0.28	2.79	14.03	2.17	0.18	0.76	20.20
April 11, 2005	0.00	0.10	7.67	0.00	0.01	7.51	15.28
Total	0.28	208.79	2,874.23	366.92	6.06	17.13	3,473.42

Table 5. Weight Averages (grams/m³) by Type.*Tabela 5. Pesos médios (g.m³) por tipo de item.*

Coyote Creek							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.57	0.02	0.00	0.00	0.00	0.70	1.30
December 28, 2004	0.20	0.08	0.00	0.02	0.00	0.01	0.30
April 11, 2005	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Total	0.77	0.10	0.01	0.02	0.00	0.71	1.61
San Gabriel River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	39.58	0.10	0.66	0.00	0.00	0.01	40.35
December 28, 2004	0.21	0.42	0.06	0.04	0.00	0.00	0.72
April 11, 2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	39.79	0.52	0.72	0.04	0.00	0.01	41.07
Los Angeles River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.00	2.43	3.73	7.98	0.00	0.04	14.18
December 28, 2004	0.16	0.36	0.13	0.06	0.00	0.05	0.75
April 11, 2005	0.00	0.00	0.00	0.00	0.00	0.32	0.33
Total	0.16	2.79	3.86	8.03	0.00	0.41	15.25

Table 6. Average Count (number * 104) by Size Class in 24 hours.

*Tabela 6. Numero médio de itens (numero * 104) por classe de tamanho em 24 horas.*

	Coyote Creek		San Gabriel River		Los Angeles River		Total
	1.0 - 4.75 mm	> 4.75 mm	1.0 - 4.75 mm	> 4.75 mm	1.0 - 4.75 mm	> 4.75 mm	
November 22, 2004	4,999.71	694.83	51,603.00	17,609.33	1,146,418.36	72,647.05	1,293,972.29
December 28, 2004	153,741.92	19,644.80	23,883.99	3,295.29	741,059.47	90,509.18	1,032,134.66
April 11, 2005	1216.96	54.39	158.28	0.00	3147.09	3187.46	7,764.17

Table 7. Average Weight Density (kg) by Size Class in 24 hours.

Tabela 7. Peso médio (kg) por classe de tamanho em 24 horas.

	Coyote Creek		San Gabriel River		Los Angeles River		Total
	1.0 - 4.75 mm	> 4.75 mm	1.0 - 4.75 mm	> 4.75 mm	1.0 - 4.75 mm	> 4.75 mm	
November 22, 2004	4.06	257.59	106.86	18,429.41	3,851.81	1,175.42	23,825.15
December 28, 2004	778.51	4,346.23	36.59	998.38	34.80	280.85	6,475.36
April 11, 2005	0.00	0.01	0.95	0.05	0.94	136.06	138.01
Total	782.58	4,603.83	144.40	19,427.84	3,887.54	1,592.34	30,438.52

Table 8. 24 Hour Average Count ($N \times 10^3$) estimate by type.*Tabela 8. Numero médio de itens ($n \times 10^3$) em 24 horas estimado por tipo de item.*

Coyote Creek							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	2.69	3564.98	727.79	0.00	698.20	700.89	5,694.54
December 28, 2004	1622.83	104544.51	21096.81	15886.67	14947.13	15288.78	173,386.73
April 11, 2005	3.40	39.09	1205.06	18.70	0.00	5.10	1,271.35
Total	1,628.92	108,148.58	23,029.66	15,905.36	15,645.33	15,994.77	180,352.62
San Gabriel River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	2748.59	27139.81	31894.33	0.00	1823.71	5561.49	69,167.93
December 28, 2004	492.15	14106.03	7027.68	2272.60	607.96	2714.09	27,220.51
April 11, 2005	0.00	39.57	122.00	0.00	0.00	0.00	161.57
Total	3,240.74	41,285.41	39,044.02	2,272.60	2,431.67	8,275.58	96,550.02
Los Angeles River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.00	73,009.62	1,011,487.21	129,340.12	2,083.23	3,145.23	1,219,065.41
December 28, 2004	11,527.59	114,658.37	577,614.69	89,132.99	7,410.59	31,083.33	831,427.56
April 11, 2005	0.00	43.78	3,248.35	0.00	2.82	3,180.56	6,475.52
Total	11,527.59	187,711.77	1,592,350.25	218,473.11	9,496.65	37,409.12	2,056,968.49
Grand Total	16,397.26	337,145.76	1,654,423.93	236,651.07	27,573.65	61,679.46	2,333,871.12

Table 9. 24 Hour Average Weight (kg) estimate by type.

Tabela 9. Peso médio (kg) de itens em 24 horas estimado por tipo.

Coyote Creek							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	115.69	4.04	0.00	0.00	0.00	141.93	261.66
December 28, 2004	3416.49	1281.18	0.00	341.65	0.00	85.41	5,124.73
April 11, 2005	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Total	3,532.18	1,285.22	0.01	341.65	0.00	227.34	5,386.40
San Gabriel River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	18,183.55	44.41	304.72	0.00	0.00	4.59	18,537.27
December 28, 2004	296.74	607.96	79.61	50.66	0.00	0.00	1,034.97
April 11, 2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	18,480.29	652.36	384.33	50.66	0.00	4.59	19,572.24
Los Angeles River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.00	862.55	1,322.63	2,828.76	0.00	13.30	5,027.23
December 28, 2004	67.79	152.53	52.96	23.30	0.00	19.07	315.65
April 11, 2005	0.00	0.00	0.00	0.00	0.00	137.00	137.00
Total	67.79	1,015.08	1,375.59	2,852.06	0.00	169.36	5,479.88
Grand Total	22,080.26	2,952.66	1,759.93	3,244.37	0.00	401.29	30,438.52

DISCUSSION

California policy defines trash as debris of human origin that is trapped by a 5 mm mesh screen (Trash TMDL). Our data confirm the abundance of plastic debris greater than 5 mm; however, our data show that plastic particles less than 5 mm in size are far more abundant. The most common plastics found were bits of foamed polystyrene (commonly but incorrectly called Styrofoam, which is a patented insulation made by Dow Chemical Co.), followed by pre-production resin pellets, hard plastic fragments, thin films, line, and whole items. Our findings indicate that there is a significant amount of plastic debris, which, due to its size, is not subject to regulation under current TMDLs for trash, passing our sampling stations and discharging to the coastal ocean.

Abundant plastic debris was found in both rivers, during wet and dry periods. The first wet period sampling in November 2004 was after a couple of rain events had moved through the area, so a lot of debris that had been collecting in the rivers since the last notable rain had already washed down to the sea. Also, the samples were not taken at the crest of each river's flood stage, so our estimates likely underestimate the actual storm water loading of plastic debris. The dry period sample was taken after the highest annual rainfall in over 100 years, which was the second highest annual rainfall in recorded history for this area. Again, a lot of debris had passed through the rivers before samples were taken, and there was considerable loading from the masses

of filamentous algae that proliferated and broke loose along the river's course, filling sampling nets quickly and making debris separation and quantification difficult. Short deployment times may have allowed nets to miss debris present in the rivers. Nevertheless, there were substantial amounts of plastic debris in both rivers during each of the sampling events, including the Spring sampling when flow was low and algae abundant.

Based on data furnished by the Los Angeles Department of Public Works, the mean flow for 24 hours on the LA River, at Stream Gauge No. F319-R on November 22, 2004, near where our samples were collected was 354,592 cubic meters. Applying the total flow to our average collected debris counts per cubic meter on that day yields that data set in Table 8. Applying the same flow total to our average weight density yields the weights for LA River debris listed in Table 9. Appropriate Stream Gauges were used for the remaining sampling stations. With more systematic and comprehensive monitoring it should be possible to obtain a fairly complete picture of how much debris is being transported by the rivers. Such data could form a baseline to support decisions by policy makers regarding how to reduce trash and plastic entering our rivers and estuaries. Unless measures are taken to control debris less than 5 mm in diameter, billions of plastic particles per day can make their way to the marine ecosystem, where they exist in all strata of the water column (Lattin *et al.*, 2004), have

been observed to be readily ingested by a wide variety of marine invertebrates (Thompson *et al.*, 2004), firmly embed themselves in the tissue of filter feeding organisms (Moore *et al.*, 2001), accumulate hydrophobic pollutants (Rios *et al.*, 2007), and appear in the stomach contents of many species of marine fishes and birds (Derraik, 2002).

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