Pathways Project: Developing a Citizen Science Program Model to Engage Underrepresented Minority Groups.

Final Report for the Citizen Science Program as part of NSF AISL Award No. 1324962

Testing the sources and pathways of trash through an urban watershed.

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Introduction

There has been growing attention as to the effects of urban trash on coastal and oceanic ecosystems, with less attention being paid to identifying sources and assessing pathways through coastal rivers and streams (but see Lee, 2011, Thompson *et al*. 2009, Hollein *et al*. 2014). Plastics trash are of particular concern because they are the most dominant trash type in our oceans (Rochman 2013, Derraik *et al*. 2002), and California's coastal waterways (SCCWRP 2016), and are known to accumulate toxins from the environment, such as metals, PCBs, DDTs and POPs (Koelmans et al., 2013; Mato, 2001; Rochman et al., 2013a; Holmes et al., 2012; Ogada et al., 2009; Cole et al., 2011; Hirai et al., 2011). Photodegradation and leaching of plastics releases the very compounds used in their manufacturing, including the broken down polymers,unpolymerized residual monomers, and additives (Rochman et al., 2013a; Lithner et al., 2011; Rochman, 2013; Teuten et al., 2009; Cole et al., 2011).

Urban plastics trash infiltrating coastal waterways is a significant problem in Southern California where networks of canyons reticulate urban neighborhoods and act as downhill pathways to the coast. Urban trash pollution is, however, preventable (Sheavly & Register, 2007) with an improved understanding of types and amounts of trash entering the coastal watershed, and the pathways trash follows to the coast.

The goal of this project was, therefore, to reduce urban trash in our coastal waterways by collecting information that can inform scientifically-based community management strategies. To meet our project goal, we addressed the following three objectives:

Objective 1- Determine the locations, quantities and types of meso- and small plastics debris found along an urban, coastal watershed.

Objective 2. Determine the temporal inputs of mesoplastics throughout the year.

Objective 3. Determine the pathways of several common plastic trash items.

Study site.

Research was conducted in four canyons, Manzanita, Swan, Hollywood, and Olivia Canyons (Figure 1), all located within the Chollas Creek sub-watershed, an impaired water body that has been declared the most degraded sub-watershed in San Diego County (EPA, 2010).

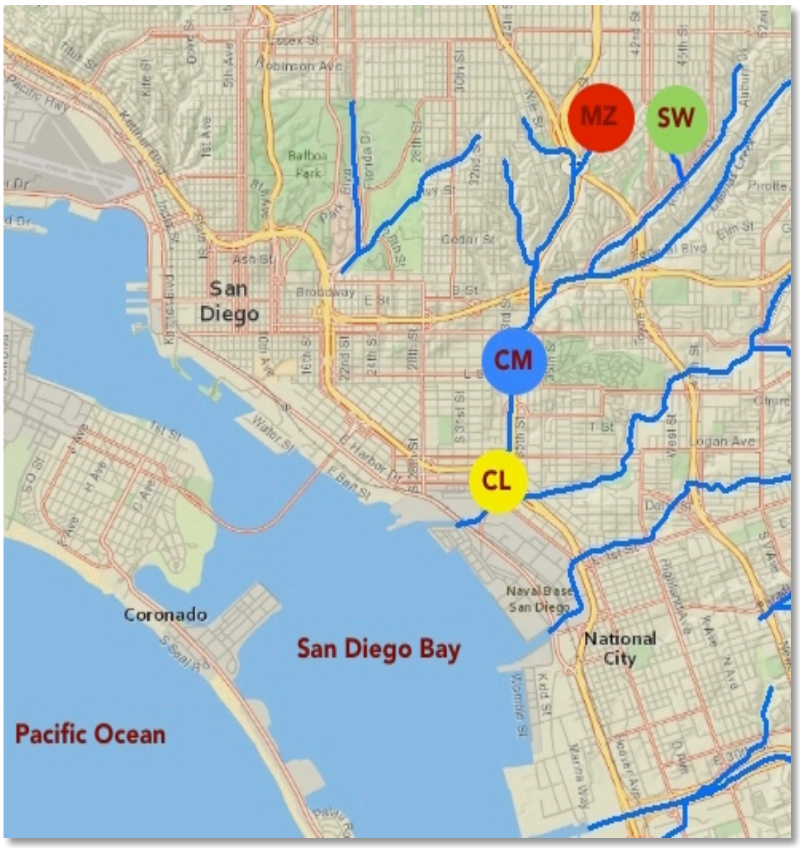


Figure 1. Study sites in the Chollas Creek Subwatershed where mesoplastics (SW, MZ, OL, HW) and microplastics (SW, MZ, CM, CL) were sampled. Each site contained three 30-m transects except for CM, which contained 1 transect. SW-Swan Canyon, MZ-Manzanita Canyon, CM-Mid Chollas Creek, CL-Lower Chollas Creek. Note HW occurs between SW and MZ, while OL occurs the east of SW.

Methods

Meso-plastic trash distributions. Within each canyon, 30-m long transects were established equidistantly and longitudinally along the floor of the canyon from the upstream head to the downstream drainage point. Each 30 meter long transect included the adjacent reach of flood plain, or bank-full width. Sites were evenly and longitudinally distributed along each seasonal creek to capture the trash gradients from the input locations to the confluence with the Chollas Creek main stem. The selection process resulted in 25 sites located among the four canyons (9 sites in each of Swan and Manzanita Canyon, 4 sites in Olivia Canyon, 3 sites in Hollywood Canyon; Figure 1). The average width of each transect ranged from 7.2±0.26 to 8.6±0.5 m wide for a range of 216-258m^2. Swan Canyon and an additional 3.5-km reach of Chollas Creek were used for the trash tracking study.

Surveys were performed during an initial dry season (March and Sept/Oct 2014), the wet season (Nov 2014-February 2015), and again during a second dry season (March-July 2015) (Table 1- sites and sampling dates). All 25 transects were sampled in the initial dry season, Swan 101-106 were sampled throughout the 2014/2015 rainy season, and 15 of the transects were sampled again in the dry season following the rains (Hollywood 102,105; Manzanita 101, 104, 106, 107, 109; Olivia 109; Swan 101-107).

During each survey, plastic meso-trash (1 cm-50 cm in length) was collected, identified and counted, and sorted by general trash category (Bags and packaging, Construction and auto, Food and kitchen, Home and office, Other unidentifiable pieces, Outdoor and sports, Personal health). The total volume of each general trash category was measured at the end of the survey. Transect conditions were recorded for each transect including average creek characteristics (e.g., width, depth), substrate type (earthen/cement, texture, presence of plants), nearest distance to features (e.g., homeless encampments, storm drain), adjacent land uses, and ease of public access of the transect.

Small plastic trash distributions. In June 2015, three of the 30-m transects established in Swan Canyon and Manzanita Canyon, (head:101, mid:105 and downstream:109), were sampled for small plastics. In addition, three 30-m transects were also established in the mid and downstream reaches of Chollas Creek. Due to unsafe conditions, only one transect could be sampled in the mid Chollas Creek reach (total of 10 transects; Fig. 2). One core (235 cm^2 x 5cm depth) of soil was collected each at the upstream end, middle and downstream end of each transect (total of 30 cores). In a 10 x 10 m quadrat around the core collection point, site data were collected that included percent ground cover (e.g., % plant cover, %cover of boulders, rocks, cobbles, gravel, cement, and/or sand/mud), creek width and depth, distance to features (e.g., storm drains, homeless encampments). The cores were analyzed throughout summer 2016 for small plastics and soil texture. Small plastics were sorted from soil samples by spooning one tablespoon of sediment at a time into a petri dish and searching for plastics using a dissecting microscope. All plastics were classified by color and type (fiber, hard piece, soft piece or film) and were counted and measured (length). Synthetic items were distinguished from natural items by checking for a lack of cell structure under a compound microscope (up to 100x). Minimum length of plastics found using this method was 0.5 mm and maximum length was set at 10 mm. Soil texture was measured using the texture by feel method and ranked numerically according to coarseness (clay=1, silty clay=2, sandy clay=3, sand=4).

Three trials to control for potential contamination of plastics particles from the environment were conducted on 20 June, 20 July and 19 August 2016. During each trial, six clean Petri dishes were set out for 15 min on the lab countertops, the approximate time it took for each petri dish of sample to be sorted. Three or four people were present in the lab each time (during sample sorting in 2015, 2-3 people were present at any one time). At 15 min, dishes were covered with clean, clear lids and examined for particle settlement using a dissecting microscope. Only fibers were found at an average of 0.5±0.3, 0.5±0.2 and 0.5±0.3 fibers per dish for the June, July and August trials, respectively (grand average = 0.5±0.0 fibers per dish per 15 min time period.) Fiber contamination for each fiber color (type) was then calculated using the following steps. The average number of fibers per dish (0.5) was multiplied by the number of dishes likely sorted for each sample core (393 cu cm core / 15 cu cm spoonful per dish = ~26 dishes per core) for an estimated total of 13.1 fibers contaminating each sample core. Since the color of fibers causing contamination in 2015 could not be determined after the fact, the estimate of 13.1 fibers per core was divided by the seven fiber color categories for an estimate of 1.87 fibers contaminating each fiber color. This value (1.87 fibers) was then subtracted from each fiber color category of each core before analyses and summary statistics were calculate. If the result was a negative number, the value was assigned a 0.

Precipitation data for City Heights, San Diego during the project period were obtained from a weather station located at the head of Manzanita Canyon available from www.weathercurrents.com. Community trash clean up data for Swan Canyon during the study period were obtained from San Diego Canyonlands (www.sdcanyonlands.org).

Trash tracking.

In February 2016, 10 each of 295-ml non-refundable plastic bottles, 31x2-cm plastic bags and 118-ml polystyrene cups were well labeled for identification and detection. Six each of the bags and bottles received TrackR devices to aid with detection. Four of each item were set at the head of Swan Canyon on February 2, 2015, and six of each item were set at the upstream end of the Chollas Creek reach on February 20 2015. Surveys for the items were conducted weekly through the first week of March, and then monthly until July 13 2015. The entire stretch of each creek was searched during each survey, usually taking 1-2 days. No rain events took place in the middle of search effort. If items could not be found, they were recorded as missing but searches continued to be conducted in the following surveys. At the starting location and then at each subsequent location, coordinates were recorded using a GPS, and site data were recorded from within a 10 x 10 m quadrat set around each item (i.e., the item was the centroid). Site data included percent ground cover (e.g., % plant cover, %cover of boulders, rocks, cobbles, gravel, cement, and/or sand/mud, creek width and depth). At the end of the project, when the stretch had been thoroughly searched for a final time for any missing items, the missing items were assigned a distance-traveled value of 3.5 km (the length of the stretch searched.)

Data analyses.

Plastic distributions. The abundances and composition of plastic meso-trash from initial dry season samples were visualized using ArcGIS 10. Descriptive statistics and graphs summarizing abundances and compositions of initial dry, rainy season, and/or post-rainy/dry season meso-plastics, small plastics, as well as precipitation and community trash clean-up data, were created in Microsoft Excel. All mesoplastics abundances (density, volume) were standardized to 200 m^2, while small plastics abundances were standardized to $1m^2$. Abundance data were log10(x+1) transformed before analysis, unless otherwise noted, to normalize data and homogenize variances.

Relationships between meso- and small plastics abundance and environmental variables, including transect condition, site data, and soil texture, were tested using forward, stepwise multiple regressions in JMP Pro 12, with criteria for inclusion of a variable in the model set at $p \leq 0.06$ and $r^2 \geq 0.03$.

Comparisons of plastics abundance before and after the rainy season were made using paired t-tests in JMP Pro 12. Comparisons of plastics trash composition before and after the rainy season were carried out with multivariate analyses using Primer 7 (Clarke and Gorley 2015). Comparisons of plastics trash composition were visualized using non-metric multidimensional scaling (nMDS) on the Bray Curtis similarity indices of standardized, 4th root transformed data to reduce the dominant contributions of abundant items (Clarke 1993, Clarke and Gorley 2015). Six different random starting points with up to 1,000 steps were used. The stress values from the six runs were examined for stability to determine whether a global solution had been found. Only analyses with stress values of <0.2 were used; stress is a measure of how well the solution (in this case the two-dimensional MDS plots) represents the multidimensional distances between the data. Clarke (1993) suggests values <0.1 are good and <0.2 are useful.

Significance testing for differences in plastic trash composition between seasons was performed using an analysis of similarity (ANOSIM) procedure on the Bray Curtis similarity matrices. This is a randomized permutation test based on rank similarities of samples (Clark 1993). Analyses of dissimilarities in trash composition found between seasons, and the particular items contributing to the dissimilarity, were carried out using SIMPER (Clarke 1993). The SIMPER results specify which variables, or trash items, are responsible for the ANOSIM results by comparing the average abundances of each trash item between each season. The average dissimilarity between samples from the two seasons (before and after rainy season) is computed and then broken down into contributions from each variable/trash item. Those variables or items with high average terms relative to the standard deviation are important in the differentiation of trash assemblages.

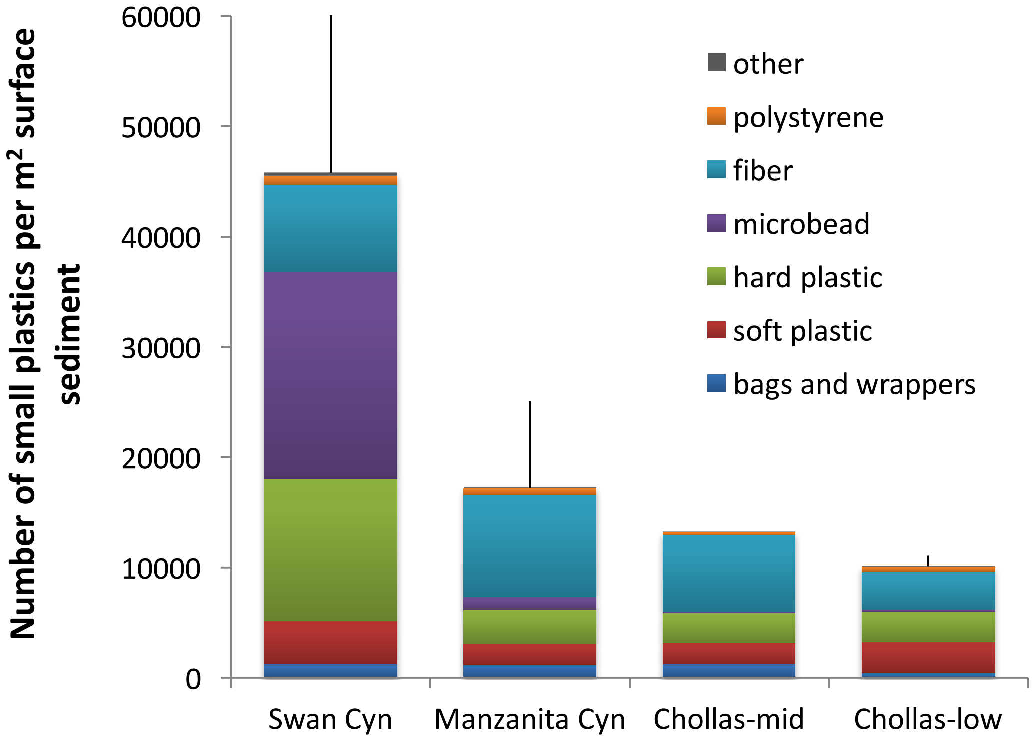
Trash tracking.

The distances that items moved during each sampling period and the number of days items spent in the system were calculated in Microsoft Excel. Relative distances were calculated (proportion of total length of the stretch) and square-root transformed to normalize data and reduce dominance effects of longer distances. The differences with site and trash item of (1) trash movement distances (relative distance) per sampling period and (2) retention time (maximum number of days each item was retained in the system) were tested using Two-way ANOVA in JMP Pro 12. Relationships between movement distances per sampling period and corresponding environmental variables (site and weather variables) were tested using forward, stepwise multiple regressions in JMP Pro 12, with criteria for inclusion of a variable in the model set at $p \leq 0.06$ and $r^2 \geq 0.03$.

Results.

Small plastic distributions.

All surface sediments (0-5 cm depth) observed contained small plastics ranging in density from 10,127±933 pieces m^{-2} in lower Chollas Creek to 45,787±31,380 pieces m^{-2} in Swan Canyon (Figure 2). The average minimum length of plastics across all transects was 0.57±0.07 mm, and maximum length was set at 10 mm. Tiny bits of larger plastic items, including synthetic fibers, hard pieces, and soft pieces including fragments of bags and wrappers when they could be distinguished, were common in all soils tested (Figure 2) indicating that breakdown and retention occurs throughout the watershed. Microbeads were also abundant in upstream canyons, especially Swan Canyon (Figure 2); with pillows, toys and personal care products as likely sources. Total small plastics was most strongly correlated with number of nearby trash point sources (storm drains and/or an illegal dump sites) and %cover of rocks, which trap debris ($P<0.001$, $R^2=0.89$, $F_{2,7}=28.8$).



Initial mesoplastic distributions.

Trash was found in every transect examined (Fig. 1). The greatest volume (and density) of trash was at the head of each canyon except Manzanita. Average volume and density of trash were highest in Olivia Canyon (31±23 L and 267±97 pieces per 200 m^2) and Swan Canyon (14±2 L and 234±45 pieces per 200 m^2), intermediate in Manzanita Canyon (10±2 L and 180±38 pieces per 200 m^2), and lowest in Hollywood Canyon (2.4±0.5 L and 95±56 pieces per 200 m^2) (Figure 1).

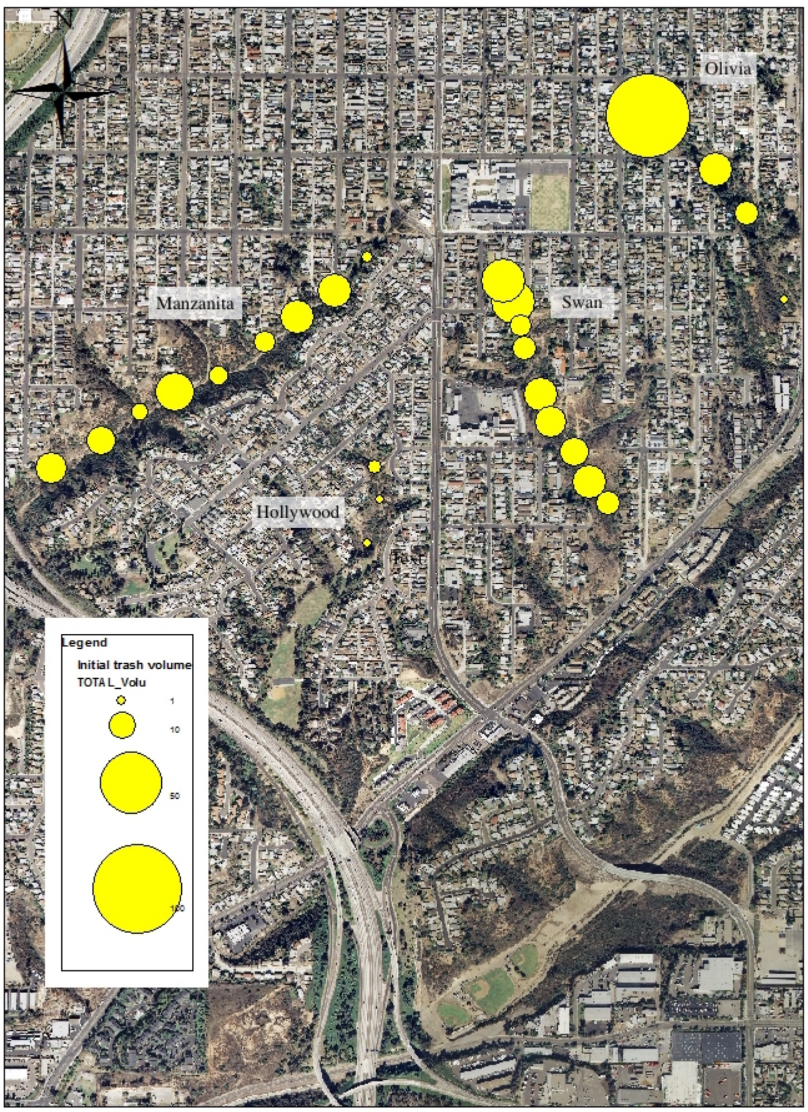


Figure 1. Volume (per $200m^2$) of plastic mesotrash in the four canyons in City Heights, San Diego. Data are from dry season (March, Sept-Oct) 2014.

Trash density in all canyons consisted mostly of bags and packaging (from 50±1% in Hollywood Canyon to 64±4% in Swan Canyon), from 14±3% to 25±5% small plastic pieces (unidentifiable, small items), from 7±2 to 18±2% home and office items, and from 7±1 to 14±4% food and kitchen goods (Figure 2). Trash volume mirrored density patterns with bags and packaging making up 50-60% of total trash volume. The two most common items across all canyons were wrappers (Avg±1SE: 63±10 per $200m^2$) and single use grocery bags (18±4 per 200 m^2) comprising 32% and 10%, respectively, of the total composition of plastics found in these initial dry season surveys.

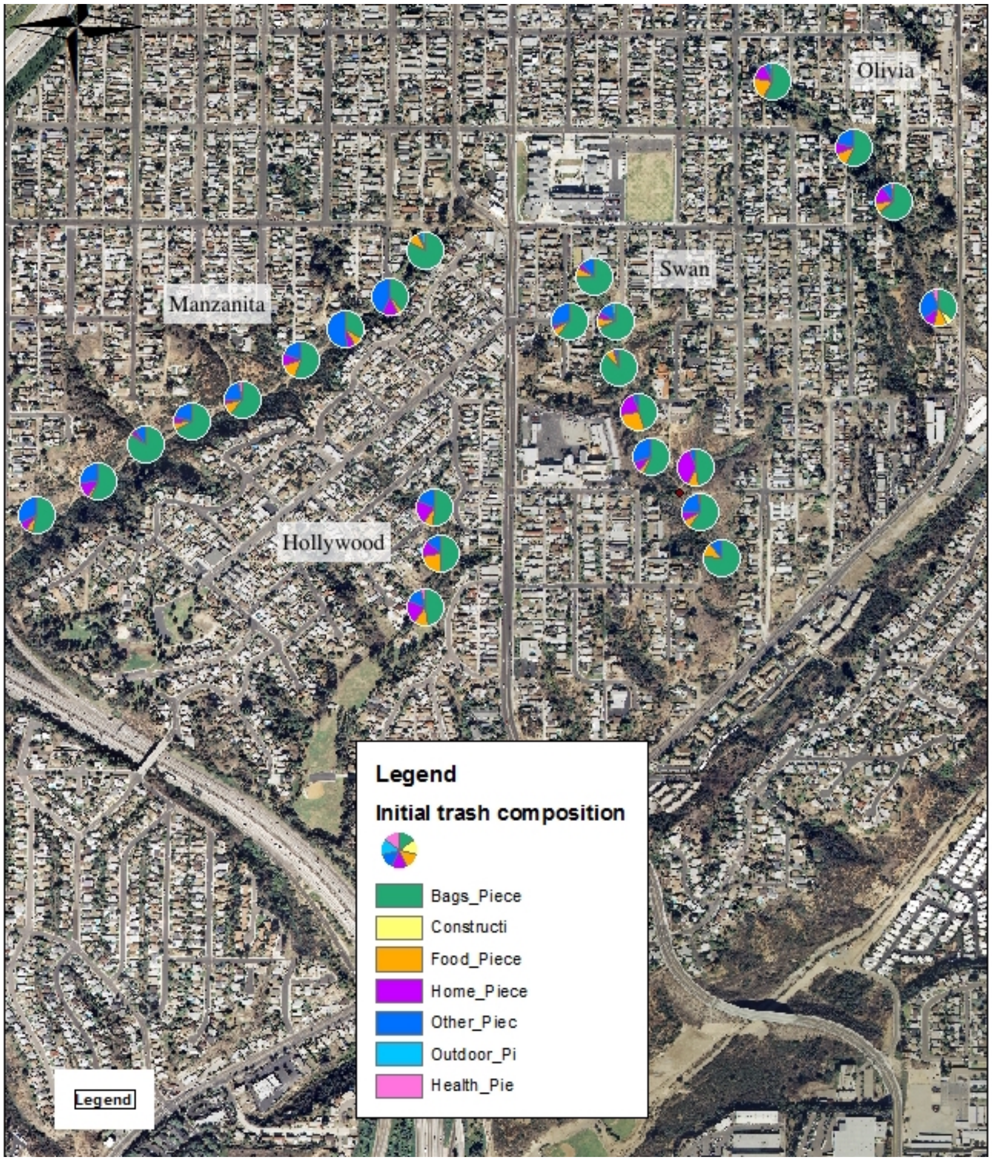


Figure 2. Composition of total plastic trash densities found within the four canyons in City Heights, San Diego. Note that composition of total plastics volume was similar so that only densities are shown. Data are from dry season 2014 (March, Sept, October).

The high densities of trash were correlated with flat (vs. vertical) creek banks and the presence of plants in the streambed (R^2=0.49, P<0.001, $F_{2,22}$=10.5). The volume of trash also increased with flat (vs. vertical) creek banks and the number of storm drains in or immediately upstream of the transect (R^2=0.54,

$P<0.001$, $F_{2,22}=13.1$). Amounts of trash were neither correlated with other features of the creek bed (e.g., substrate texture), nor other features of the surrounding landscape (e.g., public access, adjacent landuse.)

Seasonal Trash Patterns.

Before and After Rainy Season. Average density and volume of trash were 9-10 times greater after as compared to before the rainy season (1607±713 vs. 187±36 pieces per 200 m^2 and 106±49 vs. 10±2 L per 200 m^2; Paired t-tests $p\leq0.001$, $t_{14}\geq6.11$; Figure 3). Increases were particularly pronounced in Swan Canyon (Figure 3). Amounts (volume and density) of trash in all categories were greater after the rainy season (Paired t-tests, $p\leq0.005$, $t_{14}\geq3.35$; Figure 3) except for unidentifiable plastic pieces, which did not change (Paired t-test for density and volume both: $p=0.075$, $t_{14}=1.5$). This pattern remained after controlling for the potential over-estimation of post-rain trash amounts by removing sites for which trash amounts were cumulatively added throughout the rainy season (Swan 1-7).

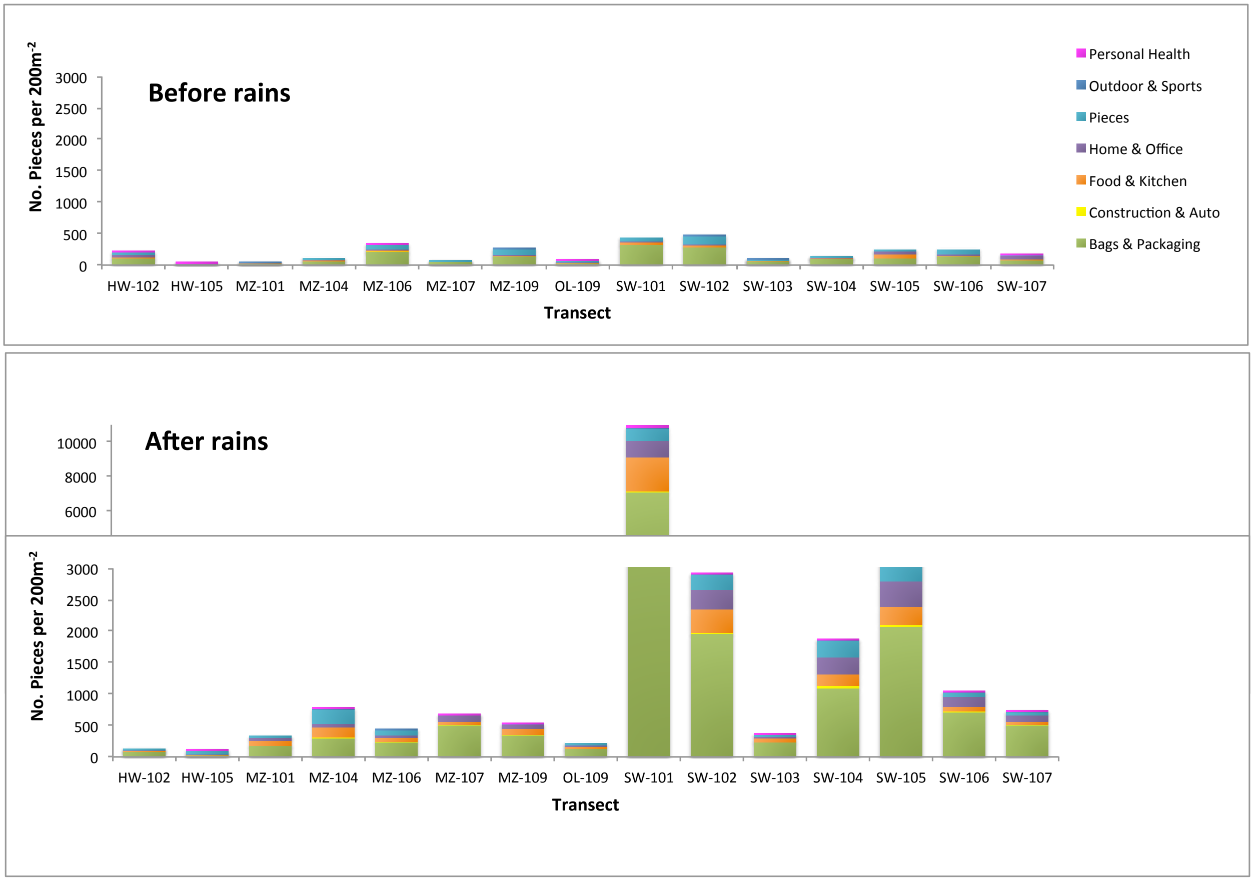


Figure 3. Plastic trash density before and after the 2014/2015 rainy season in the four City Heights Canyons. Note that there were similar patterns for trash volume so only density is shown. Canyon abbreviations are: HW=Hollywood, MZ=Manzanita, OL=Olivia, SW=Swan.

Composition of plastics after the rainy season remained broadly dominated by bags and packaging across all canyons (Figure 3), but the individual items differed (ANOSIM Global P=0.001; Figure 4). Composition before the rainy season was also more variable (SIMPER; 55% similarity) than after (71% similarity) across all canyons (Figure 4). After-rainy season samples, as compared to before, contained higher abundances of certain bags and packaging, and food and kitchen items, including polystyrene foam pieces and take-out containers, single use grocery and trash bags, cigarette butts, single use cups and plates, drinking straws and lids, utensils, bottles and caps, pieces of tape (electrical and duct), small plastic toys, personal care items (e.g., cotton swabs, bandages), soft and hard plastic pieces, and ribbons. Electronic parts (e.g., cords, phones, casings), CD/DVDs, pens/pencils/markers and synthetic clothes and fabrics were also more abundant after rains (SIMPER, items contributing to 65% of variation between seasons).

There were slightly fewer take-out/retail bags, six pack rings, and straw/utensil wrappers after the rainy season (SIMPER, items contributing to 65% of variation between seasons), while abundances of wrappers remained high and similar before and after the rainy season.

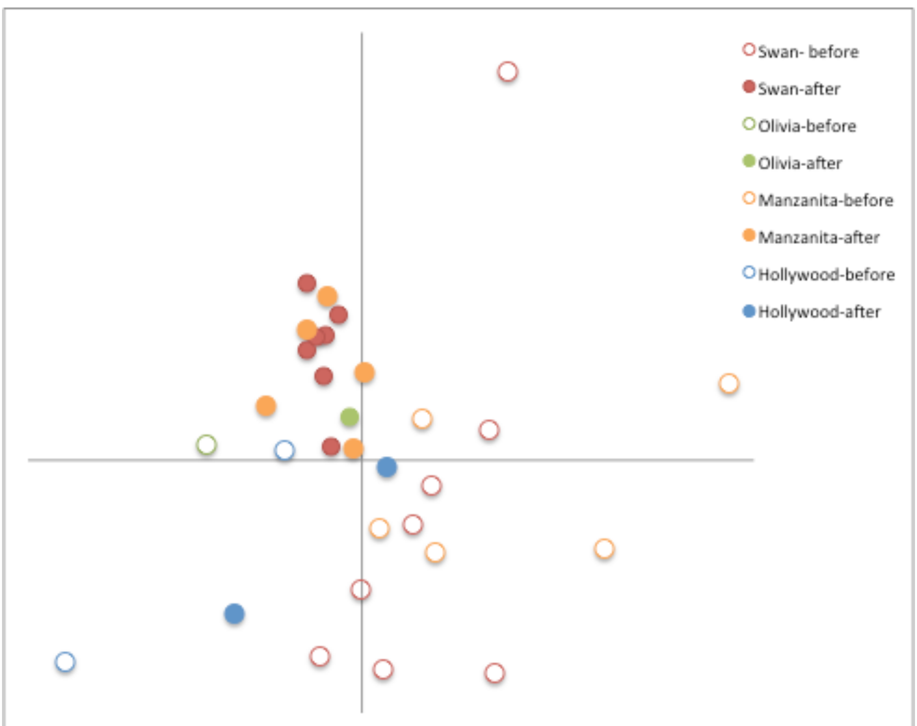


Figure 4. Non-metric multidimensional scaling of plastic trash assemblages before and after the 2014/2015 rainy season in each of the four canyons in City Heights. Data are from the dry season 2014 (March, Sept. & Oct. 2014) and dry season 2015 (March-July 2015).

Rainy Season Pulses.

The largest plastics inputs within each transect occurred with large rain events (amount and duration; Dec-Feb. in Swan 104 and 105; June in Swan 101; Figure 5) and/or after longer duration between surveys (e.g, November in Swan 102 and March in Swan 106; Figure 5). An exception was the first rainy season sampling in Swan 101 which had among the lowest abundance for that transect likely due to year-round community trash clean up efforts (e.g., June 2014-January 2015 clean-ups; Figure 5). Plastic input abundances were consistently highest at the head of Swan Canyon (101 and 102), lowest in Swan 103, and intermediate and similar in the mid-canyon (104-105). The presence of plastics in the early wet season samplings (November in Swan 102, 103, 104) indicates dry season inputs of plastics also occur.

The composition of plastics within and between transects throughout the rainy season remained similar and dominated by bags and packaging, unidentifiable plastic pieces, food and kitchen items, and home and office items (Figure 5).

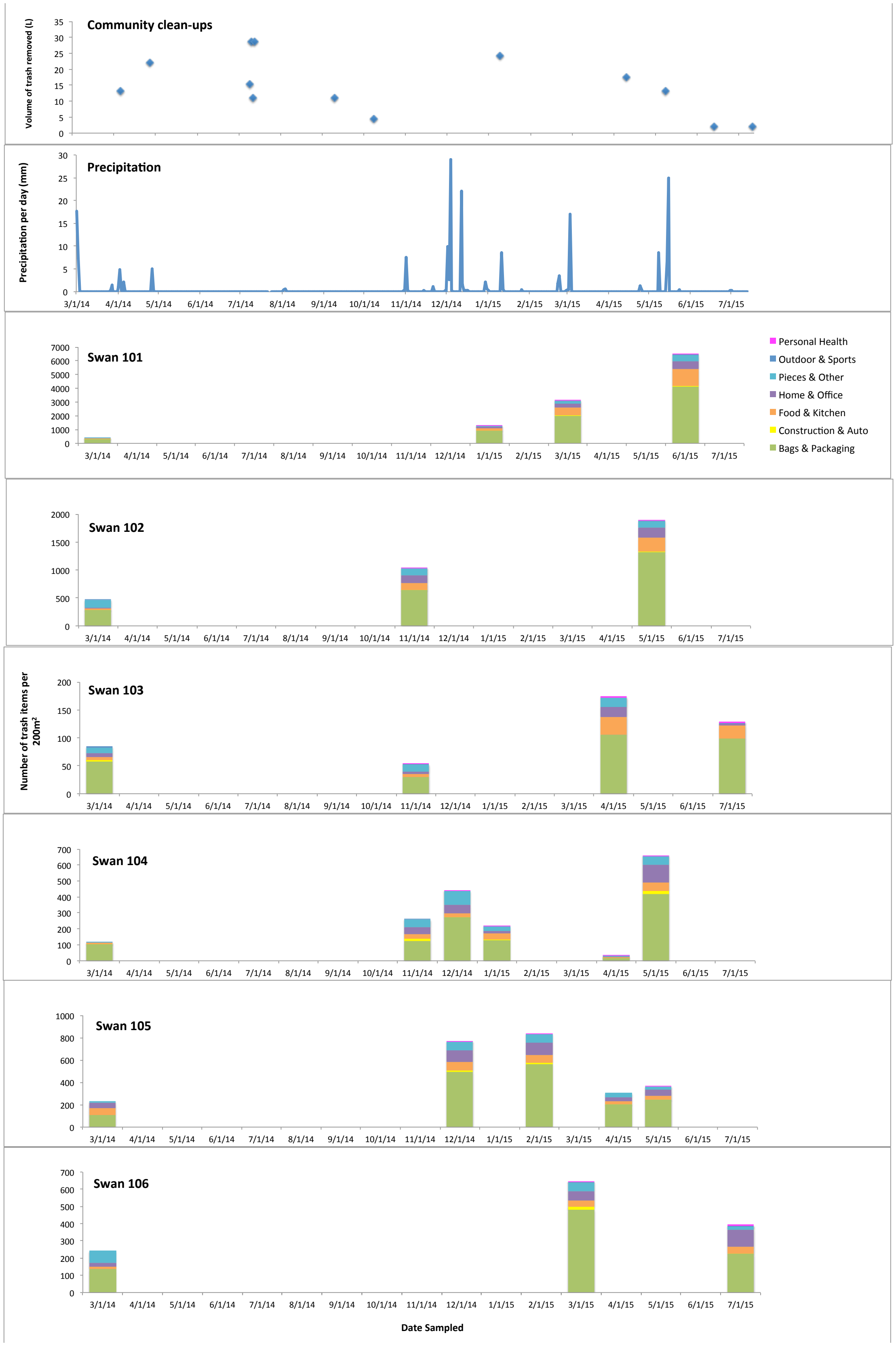

Community clean-ups
Volume of trash removed (L)
Precipitation
Precipitation per day (mm)
Swan 101
Personal Health
Outdoor & Sports
Pieces & Other
Home & Office
Food & Kitchen
Construction & Auto
Bags & Packaging
Swan 102
Swan 103
Number of trash items per 200m²
Swan 104
Swan 105
Swan 106
Date Sampled

Figure 5. Density and composition of plastics entering Swan Canyon throughout the 2014/2015 rainy season. Bars indicate survey dates- there was never no trash found during surveys. Initial dry season spanned 3/1/14 to 10/31/14; rainy season was 11/1/14 to 02/28/15; post-rainy, dry season was 03/01/2015 and later. Note the different density scales on each graph.

Trash Tracking.

Plastic trash items moved more quickly through the Chollas Creek reach than Swan Canyon (Figure 6, Table 2A,B). Bottles in Chollas Creek moved longer relative distances within each sampling period and more quickly washed out of the system than cups or plastic bags in the same system. These same items displayed similar movement and retention patterns in Swan Canyon (Figure 6, Table 2A,B). In each system, plastic bags were more likely to become entangled and therefore had the highest retention times with one bag in Chollas and two bags in Swan remaining at the end of the study in July 2015 (145 and 157 days, respectively; Figure 6). Items moved longer distances in Swan Canyon with more hours of rain within the sampling period and narrower creek widths (Table 3A). In the Chollas Creek system, items moved greater distances with shallower creeks and less plant cover (Table 3B).

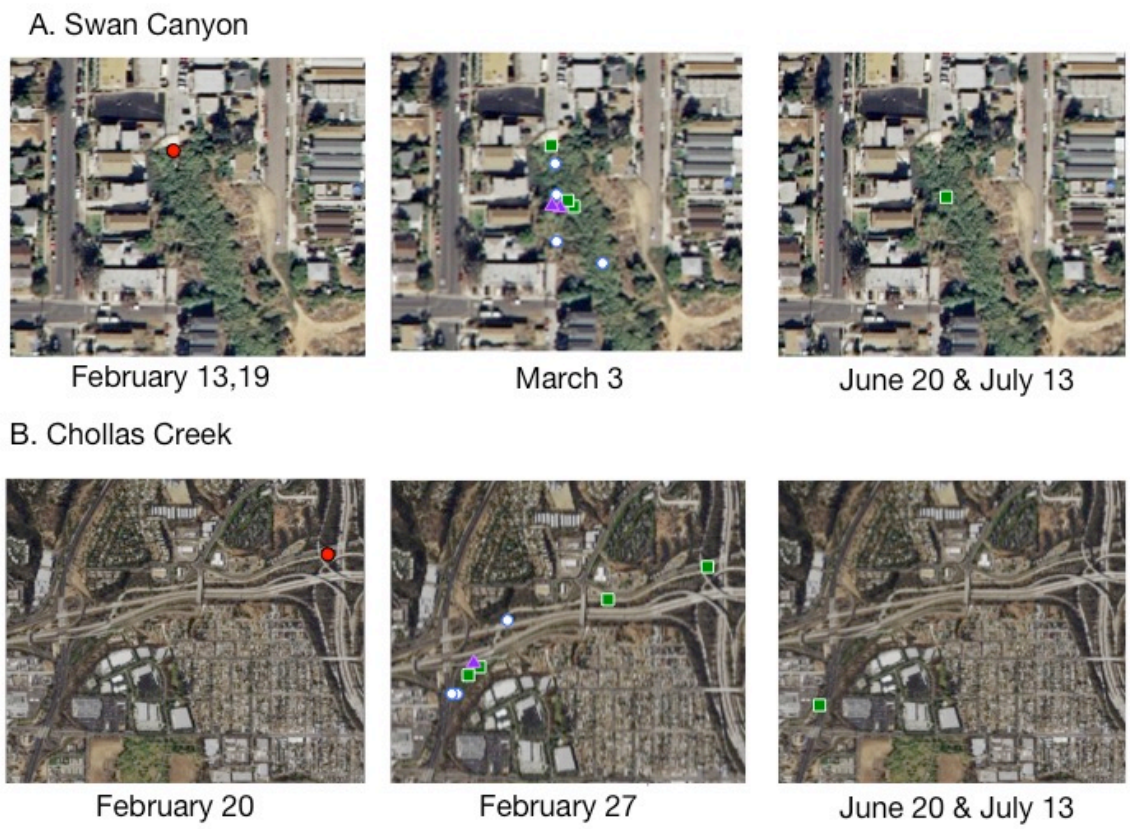


Figure 6. Movement of three common plastic trash items through Swan Canyon and Chollas Creek, San Diego, California. Red circles show starting locations; white circle = polystyrene cups, purple triangle=plastic bottle, green square=plastic bag. Note that bags are the only trash items to be retained in the systems until the end of the study on July 13, 2015. Scale: Swan Canyon stretch shown is 0.1 km, Chollas Creek stretch shown is 1.5 km. Between February 19/20th and the end of February/early March, there was a total of 8 hrs of rain with a max intensity of 1.25 mm/hr which was needed to mobilize items Swan Canyon, and to wash many items out of the Chollas Creek stretch. Symbols overlap in Swan Canyon, March 3- no items were missing.

Table 2. Relationships between sites, trash item type and (A.) the relative distance moved in each sampling period; and (B.) the maximum days retained in each system. Pairwise relationships are significant at $p \leq 0.05$ (Student's t-test). Data are from February 6th to July 13th 2015.

A. Relative distance that items moved in each sampling period

P or p	F	df(n)	Site	Trash	Site X trash
<0.001	8.72	5,109 (114)	Chollas>Swan	bottle≥cup≥bag	Chollas-bottle>Chollas-cup≥Chollas-bag≥Swan-bottle,Swan-cup≥Swan-bag

B. Maximum number of days items were retained in each system

P or p	F	df(n)	Site	Trash	Site X trash
<0.001	10.52	5,25 (30)	Swan>Chollas	bag=bottle=cup	Swan-bag, Swan-bottle, Swan-cup > Chollas-bag, Chollas-cup, Chollas-bottle

Table 3. Relationships between the distance plastic items moved in each sampling period and environmental variables (site characteristics, precipitation patterns) in (A.) Swan Canyon and (B.) Chollas Creek. Data are from February 6 –July 13 2015. + or – indicates the direction of the relationship.

A. Swan Canyon

Variables	R^2 or r^2	+ or -	P or p	F	df(n)
Whole model	0.61		<0.001	62.5	2,79 (81)
total hours of rain	0.59	+	<0.001		
creek width	0.03	-	0.037		

B. Chollas Creek

Whole model	0.33		0.003	7.3	2,30 (32)
creek depth	0.22	-	0.007		
%plant cover	0.11	-	0.034		

Discussion.

Background levels of plastics in canyons.

Greater abundances of plastics in City Heights canyons were found on wider creek beds, likely due to slower water flows and greater likelihood of plant growth to entrap the trash, and in close proximity of storm drains. The canyons serve as the city's storm water system, where street runoff is channeled through to flow to San Diego Bay. The location and access to canyon heads also influenced trash levels. The head of Swan Canyon, situated at the end of an urban alley, experiences sporadic illegal dumping of trash. The thickly vegetated head of Olivia Canyon hosts homeless camps where trash and belongings (e.g., clothing, blankets) are left. The head of Manzanita Canyon is located next to a road and has an unpaved access road running throughout making it easily accessible. Despite the heavily littered, sloped road and two storm drains located within 200 m upstream, there was relatively little trash found in initial samples. The easy access also makes this canyon head the site of frequent clean-ups by local community groups.

The types of plastics found were similar within and between canyons, with a predominance of bags and packaging items, including wrappers, single use plastic bags and unidentifiable pieces of hard and soft plastics. The prevalence of wrappers, in particular wrapper pieces, and the small unidentifiable plastic pieces indicates that these items may be easily transported through storm drains and with water flows, and may be overlooked during community clean up efforts due to their generally smaller sizes. The common occurrence of plastic bags may be due to their prevalence in society and also that transport can occur with wind or rain, giving them year-round transport potential.

Seasonal plastics distributions.

Changes with rainy season. Greater amounts of plastics trash were measured in almost every transect after the rainy season than in the dry season before indicating that more trash may have flowed into the systems during the 2014/2015 rainy season than in the previous seasons, or that a loss of trash may occur during the dry season. Dry season losses may be due to plastics removal during clean-up efforts and/or the break down of plastic items. Infrequent summer storms may also wash plastics from the system but it is assumed that more trash would also be brought into the system during these events.

Post-rainy season composition of plastics remained broadly dominated by bags and packaging but the composition of individual items differed with greater densities many lightweight and/or buoyant items, such as polystyrene foam items and pieces, single use grocery bags, cigarette butts, food-related items (plates, cups, utensils), and personal care items (e.g., cotton swabs, bandages). The greater abundance of light weight items after the rainy season may be due to the ease at which these items are transported with rains and/or that these items were likely to have been removed during the previous community clean-up efforts because of their relatively large size and obvious position on top of plants and substrate.
There were also larger, heavier items found after the rains including electronics parts and related items (e.g., cords, phones, casings, CDs), pens and markers, and synthetic clothes and fabrics indicating that flows were strong enough to carry an assortment of larger trash items into the canyons and/or out of the homeless camps. A few items were more abundant *before* the rainy season, including take-out bags, six pack rings, and straw/utensil wrappers. It may be that some items are littered directly in the canyon and not predominantly brought in with rains (e.g., six pack rings). Wrappers were abundant both before and after the rainy season indicating that there may be inputs during the dry as well as rainy seasons, such as through wind dispersal or direct littering.

Plastic trash pulses. The largest inputs of plastics into Swan Canyon followed large rain events and/or multiple smaller rain events over long periods of time indicating that *most* plastics enter the canyons with storm water as compared to direct littering or wind inputs. The prevalence of plastics in the early wet season, however, indicated dry season inputs of plastics also occur. Likely vectors of dry season inputs include occasional summer storms and year-round street runoff, as well as some amount of wind and littering inputs. Inputs of plastics were greatest at the head and middle of Swan Canyon, where storm drains, drainages and, at the head of the canyon, illegal dumping occur. The inconsistency in these patterns, for example, lower trash abundances following a large rain, appeared to be due to year round community clean-ups for which specific location information and data on plastics items are not available.

Plastics pathways.

Water flow velocity and amounts were much less in Swan Canyon than Chollas Creek, which a larger, partially channelized waterway located farther downstream (i.e., receives more storm drain inputs). Therefore, urban runoff or small rain events provided enough energy to move trash items throughout this stretch, especially in regions of shallow, unvegetated creek bed, which tended to be channelized likely resulting in stronger sheet flows. Movement of plastic items in the upstream Swan Canyon tributary depended more upon greater amounts of rain, and narrower creek widths, which likely resulted in greater water velocity.

Bottles moved the fastest through both systems, being buoyant and least likely to entangle in plants or rocks. Polystyrene cups were the second fastest to move through the systems. These cups are highly buoyant but also lightweight and open on one end increasing the chance of entanglement, especially within dense plant stems. Plastic bags had the longest retention times being most likely to entangle among plants. One bag each in Chollas Creek and Swan Canyon were the only items to remain at the end of the study in July 2015 (145 and 157 days, respectively). This finding is consistent with the prevalence of plastic bags found in other waterways.

Plastics bans.

Despite the passing a California plastic bag ban (Senate Bill 270) in 2014, the plastic bag industry collected enough signatures needed to put bill to a referendum, which will be voted upon in November 2016 (Rooney 2015). The City of San Diego recently approved a ban on plastic bags that will begin to take effect in early 2017 (Smith 2016) making San Diego the 150th municipality in California to adopt such a ban. Studies like this one show that plastic bag bans are needed; the prevalence of bags entering coastal waterways throughout the year reveal that existing anti-litter laws and/or store credit for use of resusable bags are not sufficient to maintain clean coastal waters. Another incentivized strategy, the beverage bottle deposit/refund system, appears however to be effective, with very few refundable bottles found in the canyons during this study.

Further, focus on grocery bags and some beverage bottles do not appear to be enough. The great abundances of wrappers, other food related containers and utensils, and home and personal items reveal that more solutions are needed. Post-consumer solutions are beginning to emerge. For example, California state and federal regulators are beginning to establish total maximum daily loads (TMDL) for trash greater than 5 mm diameter in rivers and watersheds throughout California (EPA 2016, SWRCB 2016). San Diego recently declared street sweeping part of its best management practices to improve water quality (CSD 2016), although the effectiveness of this method is suspect in highly urban areas where parking enforcement is difficult and the car-lined streets result in street trucks sweeping the middle of the road instead of the gutters where debris accumulates (Talley pers obs).

Needed but more difficult to develop and enact are strategies for reducing pre-consumer production and use of plastics. Such strategies would require people, businesses and industries to reduce their purchase and use of plastics materials and goods, especially single use items. An example is to encourage businesses such as fast food restaurants to switch to compostable containers in order to reduce food related plastics trash (e.g., Rubio's, Jensen 2014), but few restaurants take these steps on their own and require incentives, consumer pressure and/or fines/bans. From a consumer standpoint, changes in habitats and behaviors such as a switch to fresh foods that do not require much if any packaging, would contribute to reductions in plastics but this is probably the most difficult strategy to enact.

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