Trash and Marine Debris

BIGHT '23

Southern California Bight
2023 Regional Monitoring Program
Volume V

SCCWRP Technical Report 1473

Southern California Bight 2023 Regional Monitoring Program: Volume V. Trash and Marine Debris

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FORWARD

The 2023 Southern California Bight Regional Monitoring Survey (Bight ’23) is part of a collaborative effort to provide a large-scale, integrated assessment of the Southern California Bight (SCB). The Bight ’23 survey is a continuation of previous regional monitoring surveys conducted on a five-year cycle since 1994. This collaboration represents the joint efforts of over 100 organizations. Bight ’23 is organized into six elements: 1) Sediment Quality, which includes Toxicity, Chemistry and Benthic Infauna, 2) Microbiology, 3) Shellfish Bioaccumulation 4) Trash and Microplastics, 5) Ocean Acidification, and 6) Estuarine Assessment. Copies of this report on macrodebris, or “trash”, as well as the other Bight ’23 reports, workplans and quality assurance plans, are available for download at https://www.sccwrp.org/about/research-areas/regional-monitoring/southern-california-bight-regional-monitoring-program/bight-program-documents/.

The trash element of Bight ’23 is the outcome of an invaluable and longstanding partnership between the Bight Program and the Southern California Stormwater Monitoring Coalition (SMC). The Bight Program was responsible for all of the regional monitoring in the ocean environment and the SMC was responsible for all of the regional monitoring in the coastal stream environment.

Raw data for the Bight Program and SMC is available at https://dataportal.sccwrp.org/

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CHAPTER 1: EXECUTIVE SUMMARY

Background

Macrodebris or “trash” is a global environmental challenge. Trash has been found in almost all areas of the globe, from urban areas to polar regions to remote ocean islands (Diva et al. 2020). Plastic pollution models estimate between 1 and 15 million metric tons of plastic are discharged to the ocean from rivers annually, with large variations in plastic discharge explained by the riverine systems and countries selected to make these predictions (Law et al. 2020, Meijer et al. 2021). Plastic pollution has resulted in environmental and economic impacts. Plastic ingestion has been documented in hundreds of marine species, especially seabirds and marine mammals, causing a range of negative effects from damage to the digestive system to infections to mortality (Gall and Thompson 2015, Roman et al. 2021). Economically, a 2013 survey of beachgoers during the summer months reported an estimated $148 million loss in annual tourism from Orange County as residents avoided littered beaches (Legget et al. 2014).

California is implementing management strategies and policies to reduce trash in both inland and marine environments. Since 2001, regulatory-focused Total Maximum Daily Loads (TMDL) have prohibited municipalities from discharging trash larger than 5 millimeters (mm) (Los Angeles RWQCB Resolution R01-013). In 2014, California voters passed a statewide single-use plastic bag ban (SB270, 2014). In 2015, California passed the Statewide Trash Provisions, which mirrored many trash TMDL requirements (SWRCB Resolution 2015-0019). Most recently, the single-use plastic bag ban was reaffirmed by enforcing a more strict definition of “reusable bag” to close a loophole in previous legislation that allowed the sale of thick plastic bags at the point of sale (SB 1053, 2024).

Despite the multitude of management policies in place, trash pollution remains a concern in aquatic habitats. The Southern California Bight (SCB) Regional Monitoring Program, which has been monitoring trash on the ocean floor for the past 30 years and inland streams for the past 14 years, provides a means to assess long-term trends in trash pollution and the effectiveness of management strategies in reducing trash pollution.

This document reports the findings of the most recent Bight Regional Monitoring in 2023 (Bight ’23). The regional monitoring program focuses on addressing two primary questions:

1) What is the extent and magnitude of trash on the ocean floor and inland streams?
2) What is the trend of trash on the ocean floor and inland streams?

Additional questions are addressed with the resulting data including extent and magnitude by habitat, land use, watershed or other “strata”. Other details such as the types or sources of trash are described. Finally, where possible, details associated with changes in trash extent and magnitude are related to the impact (or lack of impact) of different policies and management actions.

This document is structured in four chapters. This first chapter provides a high-level summary for management-level audiences and synthesizes the key information from this dynamic and complex monitoring program covering thousands of samples and decades of data. The second and third chapters focus on extent and magnitude of trash from the ocean floor and inland streams and rivers, respectively. Both chapters dive into the technical details of the separate but related monitoring programs. The last chapter includes the appendices with raw data tables and available for download at https://dataportal.sccwrp.org/ for scientists wishing to dive even deeper into the topic of regional trash in southern California. Microplastics contamination in sediment and shellfish will be addressed in separate reports.

General Study Design

Trash assessments of the seafloor were conducted using a stratified probabilistic study design, with samples randomly drawn among various non-overlapping strata. These study designs are well-established and important for making unbiased estimates of environmental conditions (Stevens 1997). During the summer of 2023, 89 unique sites were sampled and stratified into bays (e.g., Los Angeles – Long Beach Harbors, San Diego Bay), the inner continental shelf (3-30 m depth), or the middle continental shelf (30-120 m depth). Samples were collected using benthic otter trawls, which are nets with 1.3 cm mesh towed behind boats at slow speeds (i.e., 1.0 m/sec). All the trash items captured in the nets were categorized and counted. These same sampling methods have been used in regional Bight monitoring of the seafloor at 5-year intervals dating back to 1994.

Trash assessments in inland waterways were also conducted using a stratified probabilistic study design. Between 2020 and 2024, 270 unique sites were selected for spring sampling to maximize the possibility of measuring flowing water in perennial and ephemeral streams. Across southern California, there are 7,400 km of stream miles stratified into 15 watersheds that were subsequently divided into three overarching land uses: urban, agricultural, and open. Samples were collected by walking 30 m (100 feet) of stream reach while counting and categorizing every piece of trash encountered within the bankfull width.

In both oceans and streams, sampling teams were trained and audited prior to sample collection. All data were submitted through online data portals and subjected to multiple rigorous quality assurance checks.

Major Conclusions

Because the Bight Program is one of the largest monitoring programs of its kind in the country, there is a wide array of context for interpreting the multitude of results. These discussions are presented in the subsequent chapters of this report. Here, we present the high-level takeaway conclusions from years of effort and collaborative interactions among dischargers, regulators, academics, and non-governmental organizations:

Anthropogenic trash is widespread across southern California's waterbodies.

Based on sampling 30-m stream reaches, an estimated 83% of the 7,400 km of stream reaches across southern California contain at least one piece of trash. Based on 5- to 10-minute trawls, an estimated 19% of the seafloor down to 120 m depth contains at least one piece of trash. An average seafloor trawl in the region's seafloor contained about 130 anthropogenic trash items per km^2.

The greatest extent and magnitude of trash occurs in areas with the largest amount of anthropogenic activity.

While trash was widespread in streams and on the seafloor, the greatest extent and magnitude of trash was in areas with the most human activity. For example, a trawl would incidentally collect at least one piece of trash across 40% of the seafloor in the bays nearest the land-sea interface, and the trash concentrations in bays were about 20-fold greater than the trawls on the continental shelf further offshore. Similarly, a 30-m transect would find at least one piece of trash in 98% of the stream-km surrounded by urban land use, and urban land use concentrations were triple the measurements in streams surrounded by agricultural or open land uses.

Plastic is the most abundant type of trash in the ocean and in streams.

In streams and on the seafloor, plastic was the most commonly observed trash item. Where trash was measured on the seafloor, half of the extent was due to plastic. In streams, plastic was triple the abundance of any other trash type and exceeded the concentration of all other trash categories combined, including glass, metal and cloth. Most of the plastic observed was categorized as "pieces", or plastic bits broken down from larger items. However, when the plastic could be identified, it was most frequently categorized as single-use, food-related items such as food containers, wrappers, utensils, and/or bottles. In contrast, marine-related trash such as fishing line, nets, or ropes was rare (<5% of items identified).

Management actions have made a measurable difference in trash abundance.

There have been several policies and subsequent management actions to reduce trash pollution. A statistically significant reduction in plastic bag concentrations was observed before versus after the plastic bag ban in 2014. Similarly, decreasing concentrations of all trash – including plastic – were observed after promulgating the Statewide Trash Policy in 2015. These reductions in concentration have remained consistent throughout the years post-implementation, indicating that management actions can make a lasting impact.

Limitations

While the Bight ‘23 regional monitoring is unique and extensive, there are still limitations to our understanding of the results. Here, we list a few of the overarching limitations:

We lack information on trash fate and transport.

Trash does not stand still. Trash may enter waterbodies through direct littering or wind dispersion. It can be transported in streams when it rains or in the ocean by waves and currents. This complicates our understanding of extent and magnitude, which can change when trash moves about the environment over time. For example, Bight ‘23 data showed that the extent of trash in bays was much greater than the inner or middle continental shelf located offshore. This may have been the result of a strong summer rainstorm prior to the sampling campaign mobilizing trash from urban streams to the coast. However, quantification of this transport from streams through estuaries to the coast is not well understood. Moreover, once trash enters the ocean, we do not know the myriad of transport mechanisms that can move trash into deeper waters or beyond the Bight.

We lack information on impacts in southern California habitats.

Bight ‘23 provides conclusive evidence that trash is pervasive and persistent in both our streams and coastal zone. The program also concludes that management actions can reduce the abundance of trash. But what remains uncertain is what effects trash may have in the environment. These effects can be biological (individual organisms or species), ecological (populations or ecosystems), or economical (property values or lost tourism). Having a better understanding of these impacts can help assess extent and magnitude, and help mobilize the necessity and effectiveness of further management actions.

We likely underestimate trash within the Bight region.

Bight ‘23 did not measure the same habitats as previous Bight surveys. For example, Bight ‘23 did not assess the extent and magnitude of seafloor trash on the outer continental shelf, but this habitat was sampled in all Bight surveys dating back to 1998. This missing data is particularly critical because previous surveys indicated that trash extent and magnitude on the outer shelf was greater than the inner or middle continental shelf, likely due to secondary transport (see limitation above). Moreover, others have identified that trash can accumulate in rocky areas as a result of the high relief, associated plants and algae, and changing currents. Bight '23 did not sample rocky habitats for trawl-captured trash because trawling is not feasible in rocky areas. Visual surveys (Pierdomenico et al. 2023; Schlining et al. 2013; Watters et al. 2010), including some in previous Bight programs (Moore et al. 2016), have identified trash accumulating in rocky reefs and submarine canyons. Subtidal rocky reef habitat comprises about 20% of the seafloor in the Bight (Pondella et al. 2010). It should also be noted that this survey focuses on trash on the seafloor though trash may also be floating or suspended in the water column.

We lack information on microplastics.

The largest single category of trash items in either streams or the seafloor was plastic pieces. Plastic can breakdown into smaller and smaller pieces. The Bight Program sampled trash, typically 0.5-3.5 cm and larger. We assume that microplastics, typically defined as less than 0.5 cm, have an equal or greater extent and magnitude than the larger plastic measured in this report.

Major Recommendations

Research the fate and transport of trash between streams, estuaries, and oceans.

Being able to link trash accumulation, transport, and fate of trash across Southern California will provide three important aspects of trash management. Accumulation rates, particularly in streams, will help generate necessary information on clean-up rates such as street sweeping and catch basin cleaning. Understanding transport mechanisms and fate will also assist managers in identifying the key times or locations for the most effective and efficient actions to reduce trash. This may require sampling habitats or times/seasons not historically sampled in the Bight Program.

Focus on microplastics.

Since the last Bight survey, standardized monitoring procedures for microplastics have become available, and microplastics are now a focal point of the Bight Trash Regional Survey and will be reported in a future publication. However, the effort to assess extent and magnitude of microplastics in the current Bight survey will be just a start. Undoubtedly, a regional survey of microplastics will generate as many questions as it answers. Given the significant challenge of microplastics, the Bight Program should anticipate continued investment in this understudied pollutant.

CHAPTER 2: EXTENT, MAGNITUDE, AND TRENDS OF SEAFLOOR TRASH IN THE SOUTHERN CALIFORNIA BIGHT

Abstract

Trash is widespread in the marine environment and has known impacts on marine ecosystems. From July to September 2023, we conducted 123 benthic trawls on the soft-bottom seafloor across the Southern California Bight to capture, quantify, and categorize the extent and magnitude of trash. Data collected during this survey is directly comparable to regionwide data from the past three decades, enabling regional trend analysis of benthic trash. Trawl success was sufficient to draw representative conclusions from three of the targeted strata: bays, and the inner and middle continental shelves (n = 89). Overall, trash was found to cover an estimated 19% of these three strata, with the greatest relative extent and magnitude in bays. Approximately 40% of the seafloor in bays contained trash at an abundance of nearly 1,900 trash items per km^2, which is 16 to 28 times higher than on the inner or middle shelf, respectively. Plastic items were the most abundant and widespread trash type. Bight-wide plastic abundance was 101 items/km^2. By comparison, all trash categories comprised 132 items/km^2. Among identifiable plastics, single-use food packaging was most common, while trash related to fishing activities was rarely observed. Over the past 25 years, anthropogenic trash has remained relatively stable, ranging from 19% to 22% of the seafloor from these same strata between 1998 and 2023. These findings demonstrate that trash is widespread and persistent in the Southern California Bight, with trash hotspots and observations of single-use plastic pointing toward land-based sources as primary inputs.

Introduction

Trash in the marine environment is a widely recognized global and pervasive environmental pollutant. Environmental concern about marine trash can be traced back to the 1970s as scientists began to document the widespread occurrence of plastics in marine habitats and its impacts on marine life (Carpenter and Smith 1972, Carpenter et al. 1972). Concerns were elevated further upon discovery of the Great Pacific Garbage Patch (Moore et al. 2001). Most recently, extensive documentation of microplastics across all types of ecosystems has created an even broader sense of urgency amongst scientists and the public about anthropogenic trash and plastic pollution in the ocean (Thompson et al. 2004; Thompson et al. 2024).

Trash can enter coastal and ocean habitats in many ways. The primary sources of trash are often land, marine, or disaster-related (NOAA 2025). Land-based sources may include littering, aerial deposition, waste mismanagement, and storm runoff whereas marine-based sources are often associated with derelict fishing gear and the release of waste items from vessels. Natural disasters such as tsunamis and hurricanes may also generate a large number of marine trash as land-based materials are washed into the ocean from heavy rains, flooding, or wave action (Murray et al. 2011; Hu et al. 2023).

Regardless of its source, marine trash can impact wildlife, primarily through entanglement and ingestion. Marine mammals and sea turtles are particularly vulnerable to entanglement, which often results in injury and mortality (Murphy et al. 2024). Trash items may also snag and cover corals, causing physical tissue damage and breakage (Nama et al. 2023). Corals draped in plastic trash may be stressed by light deprivation, smothering, and increased susceptibility to disease (Lamb et al. 2018, Nama et al. 2023). Plastic ingestion has been documented in hundreds of marine species, particularly seabirds (Savoca et al. 2022; Murphy et al. 2024; Hanifen et al. 2025). Trash items may become lodged in the gut, causing tissue damage, food dilution, and possibly mortality (Roman et al. 2019).

As scientists, governments, and environmental managers work to prevent anthropogenic trash from entering the ocean and causing harm to wildlife, there remains a critical need for robust environmental monitoring, particularly as plastic trash inputs in aquatic systems are predicted to potentially double by 2030 (Borelle et al. 2020). Most monitoring is localized and designed to inform specific research and management questions. Given the potential ubiquity and pervasiveness of marine trash, comprehensive assessments of marine trash at larger, regional scales are relatively rare. Repeated monitoring at regional scales to track changes in the abundance or types of marine trash is even more infrequent.

Here, we present a regional assessment of marine trash across approximately 3,700 km^2 of near-coastal ocean from the Southern California Bight based on repeated surveys extending over 30 years with a five-year sampling interval. The study was designed to answer two primary questions: (1) What is the extent and magnitude of marine trash in the Southern California Bight (SCB)? and (2) What is the trend in extent and magnitude of marine trash in the SCB?

Methods

Study design

The survey used a probabilistic study design to make unbiased estimates of spatial extent. Multiple sub-populations, or strata, were used to quantify different marine habitats including bays (5-30m), inner continental shelf (5-30m depth), middle continental shelf (31-120m), outer continental shelf (121-200m), and upper continental slope (201-500m). Sampling sites were selected using a generalized random tessellation stratified (GRTS) procedure (Stevens 1997). Thirty sites were selected in each stratum so more than one hundred sites were sampled per survey.

To assess trends, the survey data were compared across seven monitoring events in roughly 5-year intervals (1994, 1998, 2003, 2008, 2013, 2018, 2023). Approximately half of the sites were re-sampled in each survey and half the sites were newly selected, never previously sampled sites.

Sample collection

The 2023 survey data collection occurred during the dry weather season between July 1 and September 30, 2023. Trash samples were collected over soft-bottom (i.e., mud) using standardized scientific semi-balloon otter trawls (Bight'23 Field Technical Committee 2023). Soft-bottom represents three-quarters of the SCB seafloor (Pondella et al. 2015). Semi-balloon otter trawls had a 7.6 m headrope (25 ft), 8.8 m footrope (29 ft), 3.8 cm (1.5 in) body mesh, and a 1.3 cm cod-end mesh (0.5 in). The trawls were towed along isobaths for 5 minutes in bays and harbors and for 10 minutes in all other strata. An over-ground speed was maintained at 0.8 to 1.0 m/second (1.5 to 2 kts). Data quality objectives also required trawls to come within 100m of the designated site latitude and longitude, to be within 10% depth of the designated latitude and longitude, and not to change depth by more than 10% during the trawl. Stations were re-trawled if the appropriate sample site accuracy, depth, speed, and duration were not maintained. The final data quality objective was completeness; all strata were required to have a minimum of 27 trawls to maintain desired levels of statistical confidence.

Trash enumeration and categorization

After completing the trawl, the catch was deposited into a holding tank and debris was immediately separated from any trawl-caught organisms. Trash (>1.3 cm) was then quantified and categorized according to **Appendix A**. The major categories were plastic, glass, metal, miscellaneous items, as well as natural debris of marine origin (e.g., kelp) and terrestrial origin (e.g., tree branches). Within each broad category, trash was enumerated within subcategories chosen based on items commonly found in previous surveys. Several subcategories were added to the 2023 survey including COVID-19 pandemic related items (i.e., masks), and to distinguish between mylar and latex balloons. When an item was found that did not fit into the established subcategories, it was classified as "other" and a comment added describing the item. When an item fit into multiple subcategories, the item was counted according to the subcategory of its primary material, and the other applicable subcategories were recorded in the comments field. Additional information about the trash, such as brand name, was recorded in the comments section. Natural debris were enumerated when the count was less than 10, but estimates of quantity were utilized where counts were >10 defined as moderate abundance (M; 11-100 items) and high abundance (H; >100 items). If a count of natural debris could not be made, the reason was described in the comments. Additional comments were included to help estimate the size and condition of the debris (e.g., the size of a basketball, decayed kelp fronds, etc.).

Data analysis

Data analyses were performed with R 4.4.3 (R Core Team, 2025) using the tidyverse (Wickham et al. 2019), spsurvey (Dumelle et al. 2023), ggbreak (Shuangbin Xu et al. 2021), and patchwork (Pedersen, 2024) packages. Area weights were assigned to each station to account for its relative contribution to the total area of the stratum based on its inclusion probability. Area weights were determined by calculating the total area (km^2) represented by each stratum, divided by the number of assigned stations within that stratum (30 stations per stratum). These area weights were used to estimate the extent of trash coverage (percent of seafloor area) and associated 95% confidence intervals using the spsurvey package (Dumelle et al. 2023). The spatial coverage (percent seafloor area) of a trash type in a stratum was defined as the occurrence of at least one piece of trash in a trawl. Trash data were also expressed as counts per km^2 by multiplying the trawl distance by the width of the trawl opening (7.6 m). Area-weighted mean abundance, standard errors, and confidence intervals (95%) for all mean count per km^2 estimates were estimated using the spsurvey package (Dumelle et al. 2023).

Trends in trash extent and magnitude were assessed by comparing the results across survey years. Since plastic trash items found in the trawl surveys may be linked to land-based sources, the influence of regional precipitation on the extent of trash across each stratum in each Bight survey (1998 to 2023) was investigated. The sum of wet season precipitation (October to April) immediately prior to the survey was obtained from the National Oceanic and Atmospheric Administration (NOAA, 2025) and averaged from Long Beach Daugherty Airport, CA (Station ID: USW00023129), and San Diego International Airport, CA (Station ID: USW00023188). The relationship between trash extent and precipitation was examined using a linear regression. The effect of the summer 2023 tropical storm Hillary on trash abundance in the inner shelf and middle shelf, as observed in trawls conducted before and after the storm, was tested using a Wilcoxon rank-sum test.

Results & Discussion

Sampling success

In total, 123 sites were successfully trawled in 2023 (**Figure 1**). All 123 trawls met data quality objectives for accuracy, duration, and precision.

The completeness data quality objective (i.e., ≥90%) was met for the bay, inner shelf, and middle shelf strata, but not for the outer shelf and upper slope strata (**Table 1**). Therefore, the data analysis for this report relies on 89 trawls successfully sampled and meeting strata completeness objectives, that is, for bays, inner shelf, and middle shelf, respectively. The remaining 34 successfully sampled stations on the outer shelf and upper slope had to be excluded because those strata did not meet completeness requirements due to an insufficient number of stations per respective stratum. The trash data from the trawls in the outer shelf and upper slope strata are available in **Table A1**.

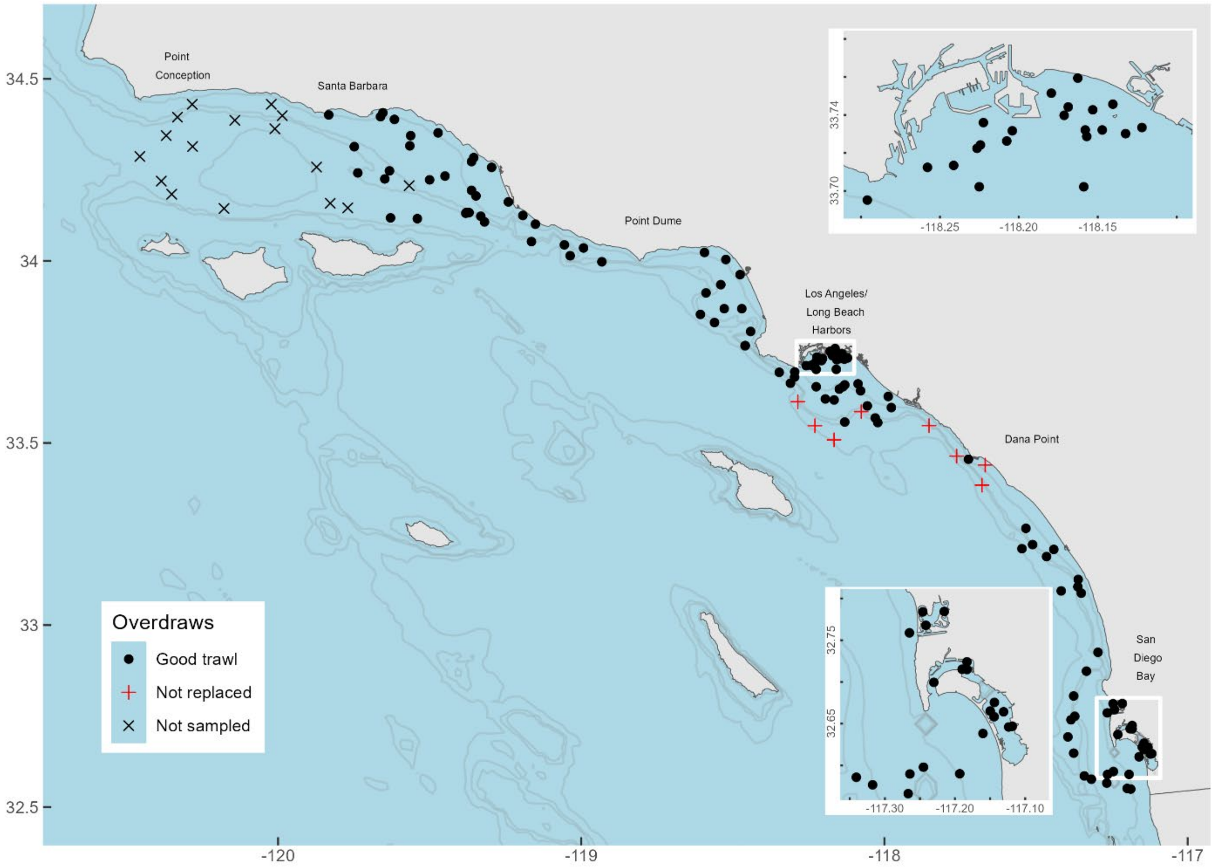


Figure 1. Map of trawl stations targeted during the Bight '23 survey.

Table 1. The number of targeted stations and completed trawls that passed trawl acceptability criteria.

STRATUM	TRAWLS TARGETED	TRAWLS ATTEMPTED	TRAWLS COMPLETED	PERCENT COMPLETED (%)	TRAWLS INCLUDED IN ANALYSIS
BAYS	30	30	30	100	30
INNER SHELF	30	30	30	100	30
MIDDLE SHELF	30	29	29	97	29
OUTER SHELF	30	22	22	73	0
UPPER SLOPE	30	12	12	40	0
TOTAL	150	123	123	82	89

What is the extent and magnitude of anthropogenic trash on the seafloor?

Anthropogenic trash occurred in trawls from an estimated 19% of the soft-bottom seafloor area represented by the bays, the inner shelf, and the middle shelf of the Southern California Bight (5-120 m depth) (**Figure 2, Table A2**). The greatest aerial map view of trash occurred in the bays where trawls from an estimated 40% of the seafloor had trash.

The area-weighted average trash magnitude across bays, the inner shelf, and the middle shelf was 132 trash items/km^2 (95% CI: 55-208; **Figure 3, Table A3**). Similar to extent estimates, the greatest trash abundance was detected in the bays (1,900 trash items/km^2, 95% CI: 0-3,913), which was 16- and 28-fold greater than the inner and middle shelves, respectively. Among trawls with detected trash, the sites comprising the highest 25th percentile of trash abundance were all located in the Los Angeles and Long Beach Harbor complex (**Figure 4**). These harbors receive inputs from the Los Angeles and San Gabriel Rivers, which flow through heavily urbanized watersheds. A 13.7 km breakwater shields the Los Angeles and Long Beach harbors, which reduces circulation and subsequent trash transport, likely enhancing trash settling.

The increased extent and magnitude of trash in the bays relative to inner and middle shelves contrasts with previous regional surveys. Bight ’13 and Bight ’18 reported trash extending across 15% of the bays’ seafloor and that the extent of trash increased with increasing distance from shore (McLaughlin et al. 2022; Moore et al. 2016). In Bight ’23, the aerial extent of trash in the bays was estimated at 40% and at least double the values previously reported for the inner or middle shelf.

The extent of trash found in this survey is broadly consistent with other studies in Southern California and along the West Coast. Watters et al. (2010) previously reported trash in 33% of video transects off southern California. Benthic trawls in 2007 and 2008 along the West Coast found trash in 15% to 67% of trawls, depending on the region (Keller et al. 2010). Those trawls reported very similar trash densities to those observed in 2023, with an average abundance of approximately 140 items/ km^2 in the area that included the Southern California Bight. The magnitude of trash density also falls within ranges previously observed in other parts of the world, including the Mediterranean and Black Seas where densities ranged from 24-1,211 items/ km^2 (Ioakeimidis et al., 2014).

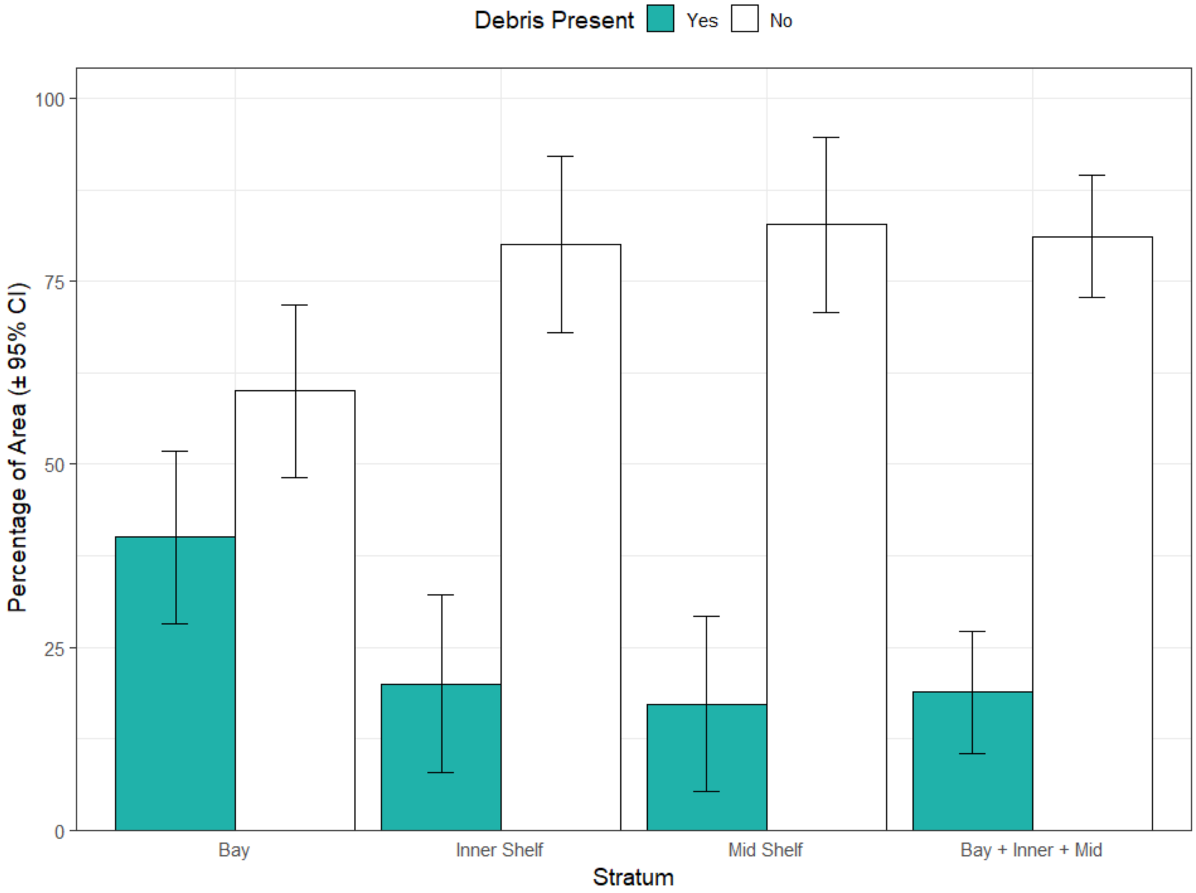


Figure 2. Percent of seafloor where anthropogenic trash was found (turquoise) or not found (white). Data include debris recovered in benthic trawls during 2023 for each stratum (i.e., bay, inner shelf, mid shelf) and the Southern California Bight, excluding the outer shelf and upper slope. Error bars represent the mean ± 95% confidence interval.

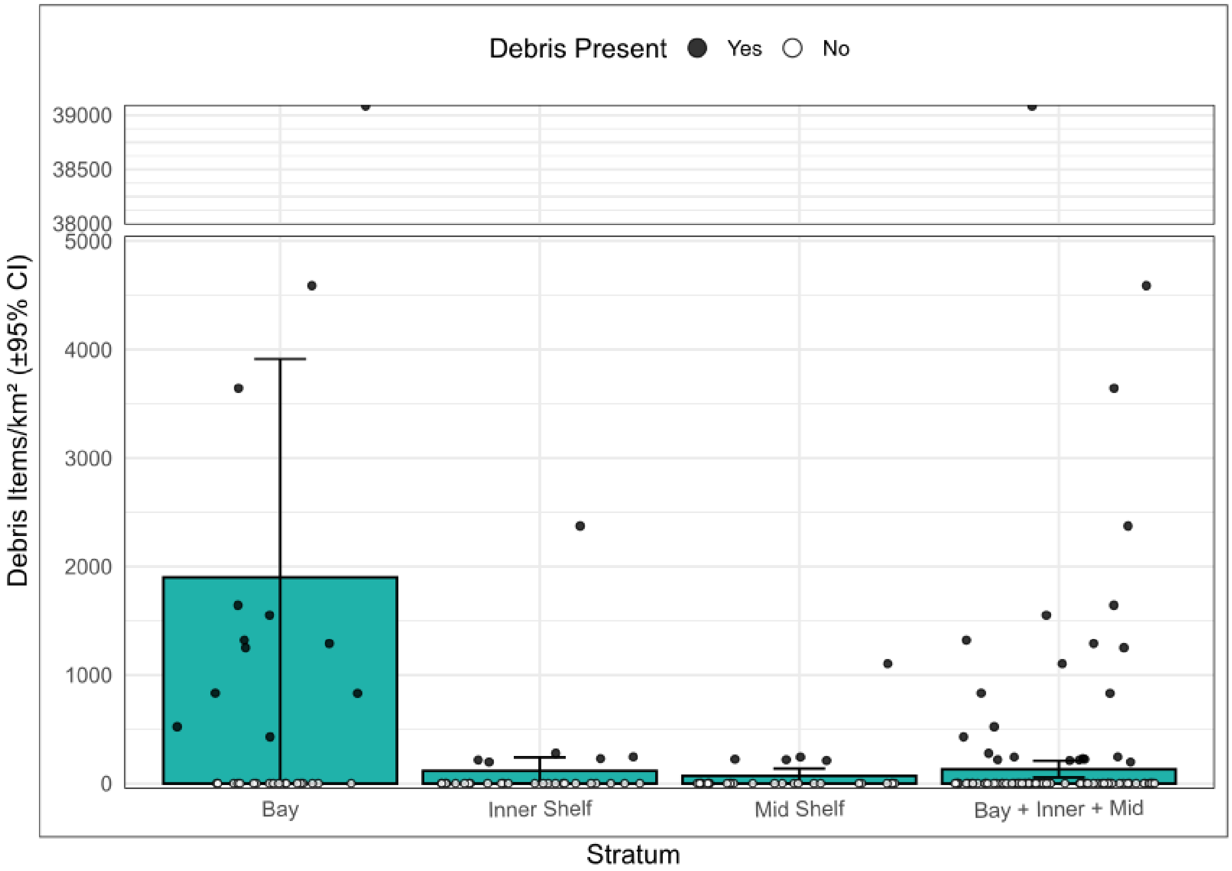


Figure 3. Area-weighted mean number of anthropogenic trash items per km^2. Data include debris recovered in benthic trawls during 2023 for each stratum (i.e., bay, inner shelf, mid shelf) and the Southern California Bight, excluding the outer shelf and upper slope. Bars represent the area-weighted mean number of trash items per km^2. Points represent individual sites. Error bars represent the area-weighted mean ± 95% confidence intervals.

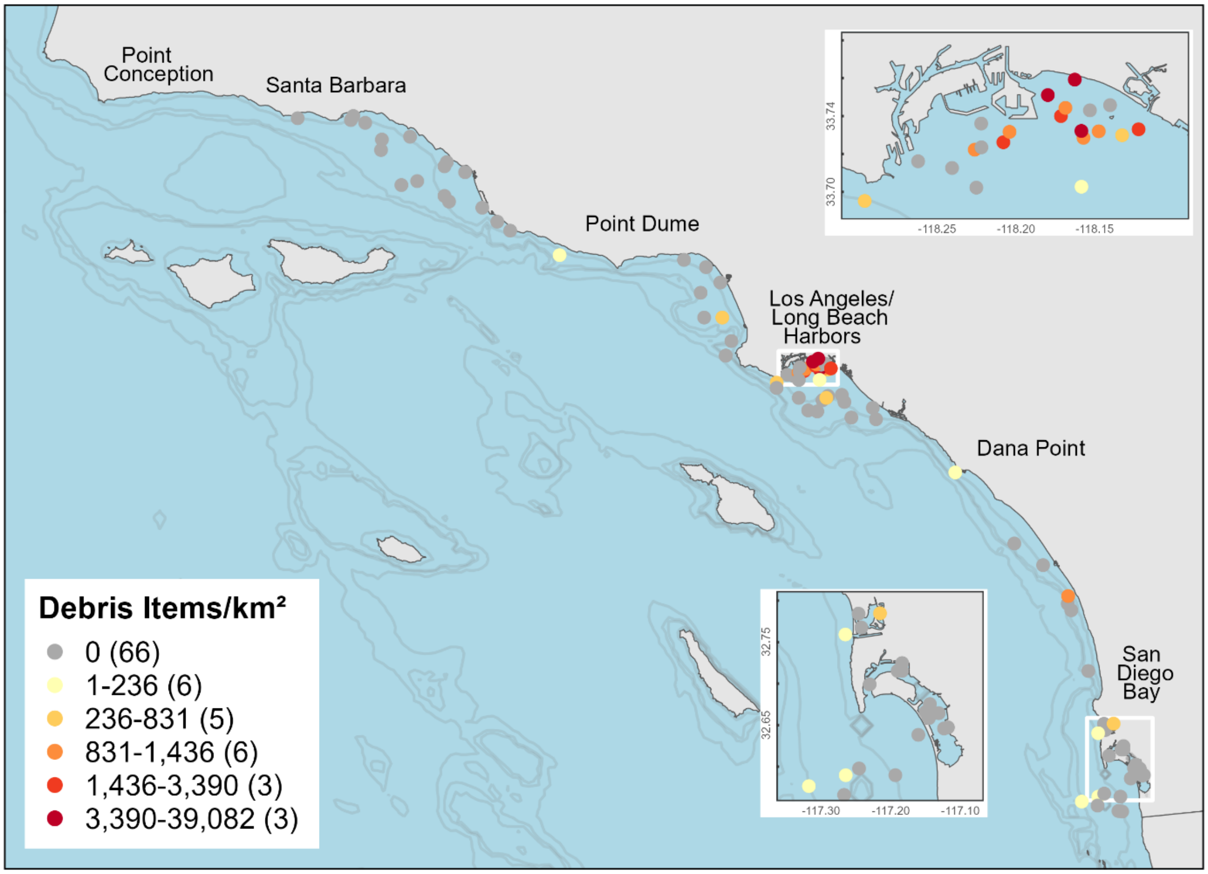


Figure 4. Map of the mean number of anthropogenic trash items per km^2 at each trawl station (not area-weighted). Sites with debris detected (>0) are binned by percentiles with bins representing the minimum to the 25th percentile, the 25th to the 50th percentiles, the 75th to 90th percentiles, and the 90th percentile to the maximum. The number of sites in each bin is displayed in parentheses after the abundance range of each bin.

Types of trash on the seafloor

Plastic trash had the greatest aerial extent compared to all other types of trash, regardless of strata (**Figure 5, Table A4, Table A5**). Accounting for trawls containing only plastic and plastic and non-plastic items, plastics were estimated to occur in trawls from 11% of the entire survey area, over half the area with any type of trash. In the bays, where the extent of trash was the greatest, plastics in trawls extended across 37% of the area, nearly all of the area where any trash was measured. Bight-wide plastic abundance was 101items/km^2. In comparison, all trash categories comprised 132 items/km^2 (**Table A3**). Thus, on average, plastic makes up 77% of the trash abundance in Southern California. This is not surprising as plastic is persistent the most commonly found type of marine trash across all geographies and habitat types (Morales-

Caselles et al. 2021). Globally, it is estimated that plastics make up approximately 64% of nearshore benthic trash (Morales-Caselles et al. 2021). The characterization of trash type during the Bight '23 survey is consistent with previous Bight surveys and other trash assessments conducted on the West Coast (McLaughlin et al. 2002; Keller et al. 2010; Watters et al. 2010; Moore et al. 2016).

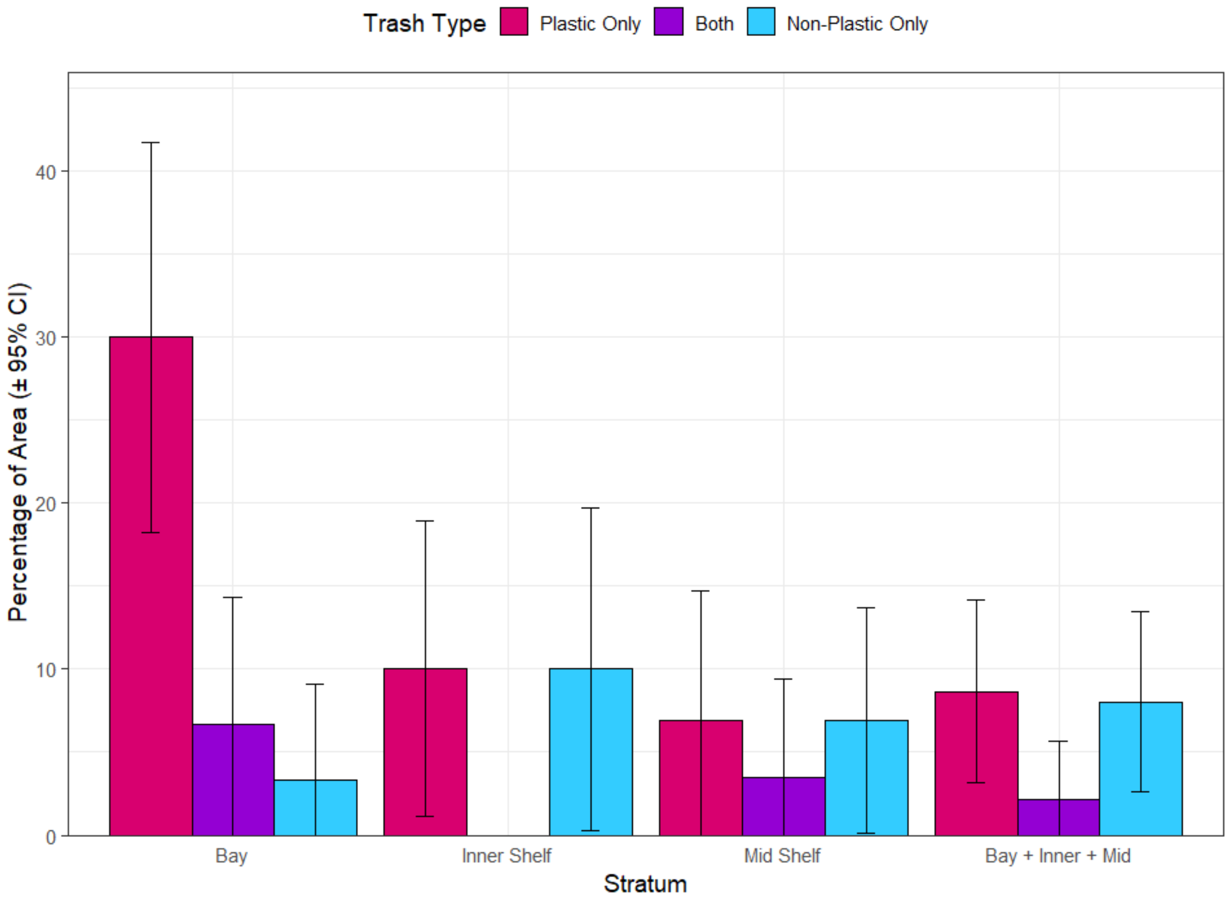
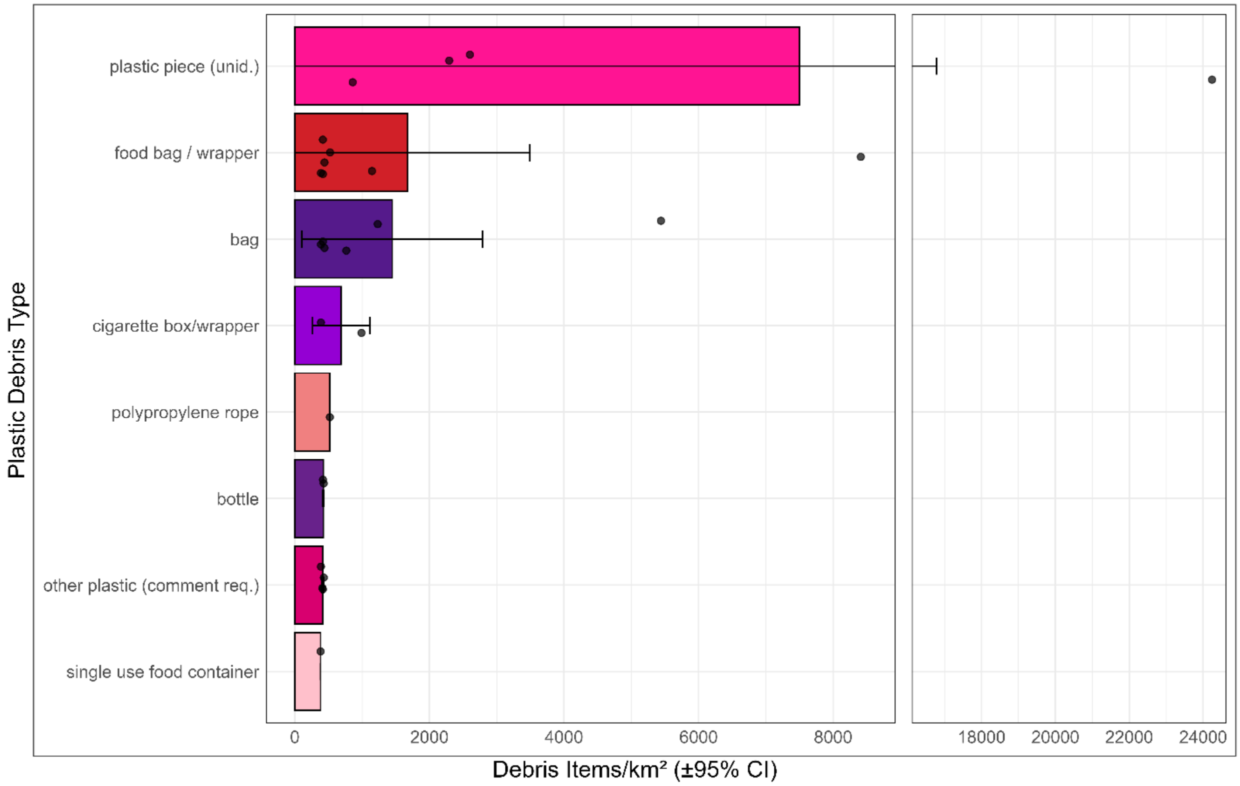


Figure 5. Percent of seafloor where only plastic trash was detected (plastic; pink), both plastic and non-plastic trash were detected (both; purple), or only non-plastic trash was detected (non-plastic; blue). Data include trash recovered in benthic trawls during 2023 for each stratum (i.e., bay, inner shelf, mid shelf) and the Southern California Bight, excluding the outer shelf and upper slope. Error bars represent the 95% confidence interval.

Plastic pieces (> 1.3 cm) were by far the most common type of plastic measured in Bight '23, and most of these items were found in the bays (**Figure 5**). When the source of plastic in the bays could be identified, single-use food packaging was the most common (**Table A5**). For example, single-use food items such as food bags, food wrappers, plastic bottles, and single-use food containers comprised 2,483 items/km^2, roughly equivalent to all other subcategories of identifiable plastic trash combined. Notably, all of these items are associated with land-based uses or activities, and only 3% of items across the surveyed strata could be associated with marine-based fishing activities. Globally, large volumes of fishing gear are lost at sea each year (Richardson et al. 2022), and the low amounts found in the Southern California Bight may be underestimated due to our sampling design including collection method and strata surveyed. For example, this survey did not sample rocky reefs where fishing gears may be entangled. Some fishing gear may also remain buoyant or sink to the deeper oceans (Kaandorp et al. 2023) where we did not sample. Derelict fishing gear in the Southern California Bight may also be lower than global averages due to the enforcement of relatively strict regional recreational and commercial regulations.

Previous studies have also found single-use food-related items to be the most prevalent type of identifiable plastic, particularly in near-shore environments. A recent meta-analysis of anthropogenic litter across seven major aquatic environments found that single-use food packaging plastics comprise anywhere from 50% to 88% of all trash items across all habitat types (Morales-Caselles et al. 2021). However, the same analysis reported that globally about 20% of nearshore seafloor trash originates from ocean and waterway-based activities, a higher contribution than observed in the Southern California Bight (Morales-Caselles et al. 2021), likely because of different sampling methods.



Mean number of debris items per km² in the Southern California bay stratum by plastic debris type in 2023. Bars represent the mean number of debris items km². Points represent individual sites. Error bars represent the 95% confidence interval.

Figure 6. Mean number of plastic trash items per km^2 in the Southern California bays by plastic trash type in 2023. Bars represent the mean number of trash items per km^2. Points represent individual sites. Error bars represent the 95% confidence interval.

What are the trends of trash on the seafloor?

The aerial extent of trash on the seafloor in bays the inner shelf, and the middle shelf has remained relatively consistent over the last 25 years (**Figure 7, Table A6**). Across these three strata, the aerial extent of anthropogenic trash from 1998 to 2023 ranged from 18.9% to 22.3%. In contrast, the aerial extent of plastic has been more variable with no discernable trend over the last 25 years (**Figure 7, Table A6**). Across these three strata, the aerial extent of plastic trash from 1998 to 2023 ranged from 5.7% to 16.9% of the seafloor.

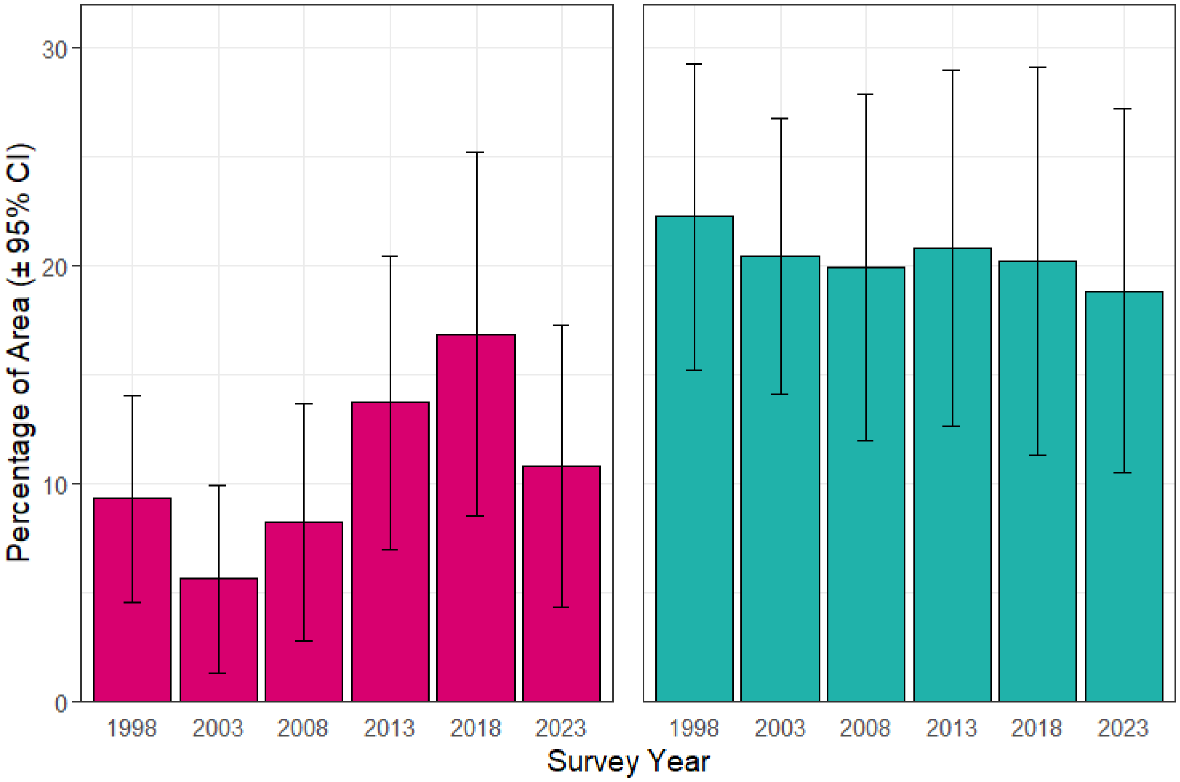


Figure 7. Percent of seafloor where plastic (pink) or trash (turquoise) was detected. Data include trash recovered in benthic trawls 1998-2023 for select stratum (i.e., bays, inner shelf, mid shelf). Error bars represent the 95% confidence interval.

Previous Bight surveys reported steady increases in anthropogenic trash and plastic on the three shelf strata (inner shelf, middle shelf, and outer shelf) over the last 25 years (McLaughlin et al. 2023; Moore et al. 2016). The difference in results between previous regional surveys and the current survey is the set of strata included in the trends analysis (i.e., exclusion of the outer shelf and the inclusion of bays). Because the 2023 survey did not include the outer shelf due to insufficient sampling completeness, we cannot extend the shelf-wide trends in the current survey. Though the extent and magnitude of marine trash is often greatest in coastal areas near land-based sources, in some habitats, trash may be transported further offshore due to local wind patterns, currents, or submarine geography (Hernandez et al. 2022). The results of previous Bight trash surveys, as well as reports on the transport of natural trash, provide evidence that most trash items are transported and may accumulate offshore rather than close to the coast in the Southern California Bight (McLaughlin et al. 2022; Moore et al. 2016; Allen et al. 2011; Moore and Allen 2000). The elevated extent and magnitude of trash in the bays in the current survey may be reflective of more recent inputs that have not yet been transported offshore.

The extent of anthropogenic trash observed in bays during each Bight survey was significantly correlated with the sum of wet season precipitation (October to April) from the season prior to the survey ($r^2 = 0.81$, $p = 0.0145$; **Figure 8, Table A7**). However, there was no significant relationship between wet season precipitation and regional trash extent or with trash extent within other individual strata (i.e., inner shelf, middle shelf, outer shelf, upper slope), likely a result of the secondary transport discussed previously.

Unlike previous survey years, a rare mid-summer storm event, Hurricane Hilary, occurred during the survey on August 20, 2023. This storm produced an average 2 inches of rain at the Long Beach and San Diego airports (**Table A8**). Given the relationship observed between wet season precipitation and trash extent, it is possible that the increased aerial extent and magnitude of trash in the bays in 2023, relative to previous Bight surveys, was in part due to land-based trash mobilized during this storm event. However, the specific effect of this storm on trash in the bays could not be evaluated because the majority (90%) of the bay trawls were conducted after this event (**Figure A4**). Trawls on the inner and middle shelves were more evenly split, with 47% and 41% of trawls being conducted prior to and after the storm, respectively. Despite this, trash densities did not differ significantly between trawls conducted before versus after the storm in either shelf stratum (Wilcoxon test, $p > 0.1$).

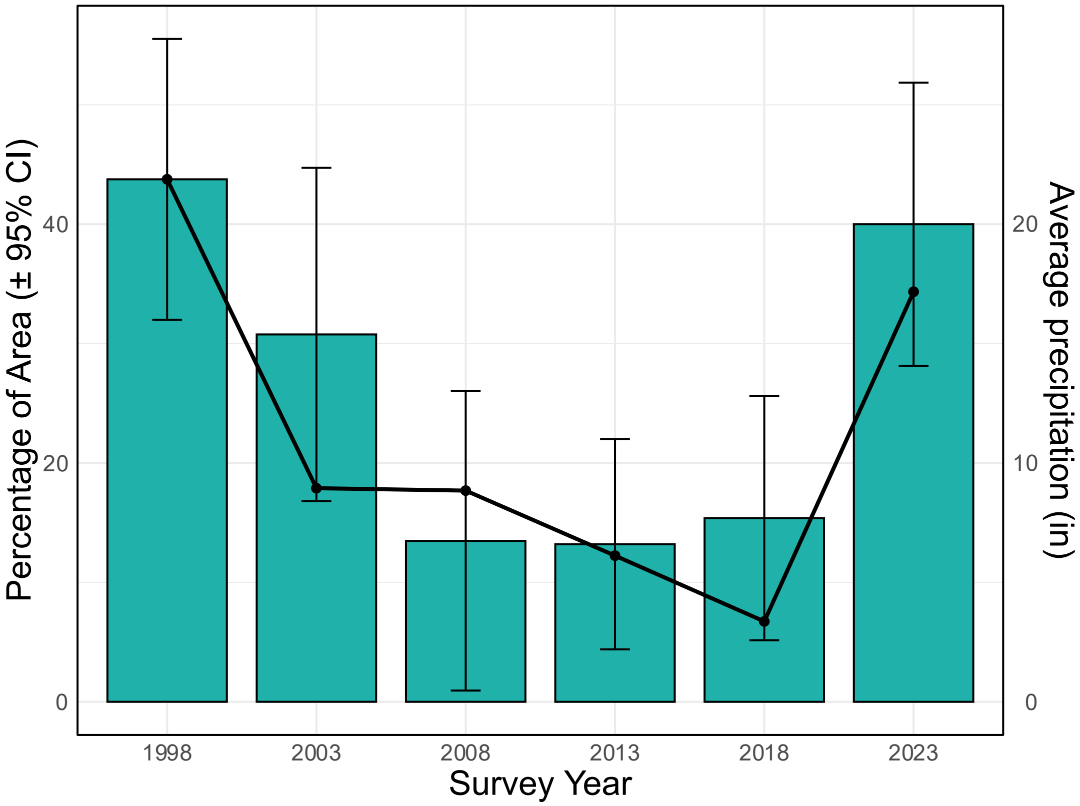


Figure 8. Percent of seafloor area in bays where trash was detected (turquoise bars) from benthic trawls 1998-2023. Error bars represent the 95% confidence interval. The sum of wet season precipitation (October to April) from the year prior to the survey is averaged from Long Beach Daugherty Airport, CA (Station ID: USW00023129) and San Diego International Airport, CA (Station ID: USW00023188), from October to April is overlaid (black line).

Conclusions

Anthropogenic trash extends over large portions of the southern California seafloor.

Based on trawling, an estimated 19% of SCB seafloor in the bays, inner and middle continental shelf (to 120m depth) contain anthropogenic trash. An average trawl captured over 1,300 anthropogenic trash items per km^2.

Bays had the largest extent and magnitude of anthropogenic trash compared to inner and middle continental shelf areas.

At 40%, the extent of trawl-caught trash in the bays was double the extent of trash on the inner or middle shelf. Similarly, the Bay stratum had nearly 2,000 trash items per km^2, which was 16- to 28-fold greater than the inner or middle shelf, respectively.

Plastic is both the most abundant and pervasive of all trash types.

An estimated 11% of seafloor in the bays, inner and middle shelf areas contained at least one trawl-caught plastic item. Plastic had the greatest abundance compared to all other trash items combined.

Single-use food packaging was the most abundant type of identified plastic trash.

Plastic pieces of unknown origin were the most common type of plastic enumerated. Where trash sources could be identified, however, the abundance of single-use food packaging such as food bags, food wrappers, food containers, and plastic bottles far exceeded the abundance of any other type of plastic. Plastics of marine origin such as rope, nets, or fishing line were infrequent.

The extent of anthropogenic trash has remained stable over the last 25 years.

The spatial extent of anthropogenic trash sampled by trawl from bays, inner and middle continental shelf ranged from 19% to 22% of the seafloor between 1998 – 2023. This statement is in contrast to previous regional surveys that have measured increasing trends in both trash and plastic extent on the continental shelf during this same time period. However, this difference is attributed to the lack of sampling on the outer continental shelf during 2023, a habitat where the extent of trash has historically been the greatest, and the inclusion of bays in the trends analysis.

Anthropogenic trash in bays is positively correlated with rainfall.

The sum of wet season precipitation immediately prior to the survey was positively correlated with the amount of trash in bays but no other strata. This suggests that a large proportion of trash is washed into bays during storms.

Recommendations

Secure sufficient effort to sample priority Bight habitats, including the outer shelf.

For the first time in three decades, an insufficient level of effort was applied to make Bight-wide assessments of the entire continental shelf. There was so little effort that trawl data from the outer continental shelf could not be used in the Bight ‘23 trash assessment. This QA deviation occurred for several reasons: (1) too many habitats (strata) and not enough effort, (2) instances where agencies did not follow up trawling at contingency overdraw sites when trawl failures occurred at original sites, (3) lack of planning for some agencies to complete their trawling during the sampling window, even after extending the window to accommodate their field challenges, and (4) lack of communication among field teams when deviations occurred in order to correct course and achieve the desired level of effort to meet predefined Data Quality

Objectives. This was particularly problematic for the trash assessment because the outer continental shelf has historically been where the majority of trash accumulates. While there are many potential solutions to overcome these deviations, the Planning Committee and Field Committee must take these factors, and others, into consideration during planning so this does not happen in future surveys.

Improve our understanding of transport between land-based sources of trash and the ocean.

It was clear from the data that land-based sources were the primary origin of marine-collected trash. There were hints of relationships between land and the ocean. For example, the extent and magnitude of trash in the bays significantly correlated with cumulative rainfall in the previous wet season. However, detailed mechanistic linkages will dramatically improve the effectiveness of any management actions taken on land to protect the sea.

Focus on microplastics as an important type of anthropogenic trash.

Since plastic had the greatest extent and magnitude of anthropogenic trash, it makes sense to invest additional effort into microplastics assessment. The plastic trash measured in this survey were >1.3 cm diameter, but microplastics are considered plastic trash <0.5 cm and were evaluated separately. As microplastics were included in the Bight ‘23 survey for the first time, initial efforts are now being made to assess its extent and magnitude (data and report to follow in another Volume). However, many unanswered questions remain, including relationships between habitats, fate and transport, and biological effects, amongst others. Monitoring, sampling, and analytical methods are constantly being developed. The latest methodological advancements should be evaluated and considered prior to the next Bight cycle to continuously improve efficiency and data quality.

CHAPTER 3: EXTENT, MAGNITUDE, AND TRENDS OF TRASH IN SOUTHERN CALIFORNIA INLAND WATERSHEDS

Abstract

Trash in rivers and streams poses ecological, aesthetic, and economic challenges, with documented impacts on aquatic life and community well-being. In the highly urbanized Southern California coastal region, home to more than 22 million people, ongoing management efforts aim to reduce and prevent the transport of trash into rivers and streams. In this study, regional partners conducted 384 trash surveys at 270 unique stream reaches from 2020-2024 to assess the extent and magnitude of trash in the region. At least one piece of trash was present in our 30-m transects at an estimated 83% of the 7,400 stream-km across the region, with a mean abundance of 0.63 items per meter (95% CI: 0.45-0.81). Urban areas exhibited the highest occurrence (98% of stream-km) and densities of trash (1.27 items per meter, 95% CI: 0.91-1.62). Plastic was the largest component of trash region-wide, accounting for roughly 70% of all trash types in Southern California streams. At 74% of stream km (95% CI: 69-72%), the estimated extent of trash in southern California streams has remained consistent during surveys from 2011-2024. Similarly, plastic has been identified as the dominant trash category in each survey. There was a slight negative relationship between area-weighted mean trash abundance (items per stream meter) and survey year (Pearson correlation $r^2 = 0.47$, $p = 0.03$). Continued annual monitoring may reveal whether this decreasing trend in trash abundance is sustained. Consistent with findings from the 2018-2019 stream surveys, we observed a sustained reduction (approximately 70%) in single-use bag abundance after a statewide ban on plastic bags was implemented in 2016, demonstrating the effectiveness of source control in preventing trash from entering the environment.

Introduction

Anthropogenic macrodebris or “trash” in rivers and creeks is an aesthetic problem and a potential hazard to aquatic life and public health. Trash reduces the value of recreational areas (Leggett et al. 2014), impacting tourism and housing values. Trash, and particularly plastic, has been shown to impact wildlife in freshwater habitats through ingestion and entanglement (Roman et al. 2022). Trash has also modified freshwater habitats, changing the physical characteristics of streams and lakes (Honingh et al. 2020), which can lead to habitat loss.

Streams and rivers are also major pathways for trash to reach coastal habitats such as estuaries and the coastal ocean. More than 30 metric tons of trash were discharged from three urban watersheds in southern California over 72h (Moore et al. 2011), and globally it is estimated that between 1 and 15 million metric tons of plastic are discharged from rivers each year (Law et al. 2020, Meijer et al. 2021). Not only is trash an important stressor impacting freshwater habitats, but urban streams and rivers can also serve as transport and storage corridors for trash to the ocean during rainstorms.

Trash in streams and rivers in Southern California is particularly challenging. With a population of 22 million, this urbanized coastal region contains over 7,400 stream km and 28,051 km^2 of watershed area (McLaughlin et al., 2023). However, the large impervious area, and straightened and smoothed flood control channels promote trash transport. Additionally, the mediterranean climate of Southern California has a major effect on rapid trash transport. With an average of 10 storms per year, there may be no rain for 6 to 9 months enabling large quantities of trash to accumulate prior to rainstorm transport and be highly concentrated in resulting flows.

The State of California has implemented policies to reduce or eliminate trash from entering streams, rivers, and the ocean. State regulatory agencies promulgated amendments to the State's Water Quality Plan to capture all pieces of trash >5 mm in the largest urban areas (California Environmental Protection Agency, 2015). Municipalities with >100,000 residents are required to install certified trash capture devices in storm drains and catch basic inlets. A combination of alternate methods may be used if they are equally effective in capturing trash as demonstrated by more intensive monitoring.

One of the biggest challenges that Southern California municipalities face is quantifying the amount of trash in streams and rivers to assess the need for management actions, source control measures, and other potential regulatory options. Moreover, monitoring is necessary to determine if the management actions taken in response to regulations are effective at reducing trash in streams and rivers. The goal of this project is to answer three basic questions: (1) What is the extent and magnitude of trash in Southern California streams? (2) What are the trends in the magnitude and extent of trash in Southern California streams? and (3) Are the trends in trash extent and magnitude from Southern California streams related to management actions in the region's watersheds?

Methods

Study Design

This study used a stratified probabilistic study design to produce unbiased estimates of trash extent (stream-kilometers) and magnitude (abundance). The trash assessment leveraged a larger study conducted by the collaborative Stormwater Monitoring Coalition (SMC) program to assess the biological condition of streams throughout Southern California, establish linkages with stressors causing poor condition, and track changes through time (Mazor 2015). Briefly, the sampling frame included all wadeable, second-order and higher streams in Southern California coastal watersheds from Ventura County to the U.S.-Mexico border (NHD Plus, US Geological

Survey and US Environmental Protection Agency 2005). Wadeable streams are those that, during dry weather, are shallow enough to sample without boats (i.e., by “wading”). Stream sites were selected from the sampling frame using a spatially balanced, stratified random, master list design (Stevens and Olsen, 2004, Larsen et al.2008). Each site included a 150-m reach, the first 30.5 m of which were assessed for trash.

Trash was surveyed during three sampling periods at 270 sites over 5 years from 2020-2024. Trends were assessed by comparing results to previously conducted surveys using the same methods (204 sites over 3 years in 2011-2013 and 166 sites over 2 years in 2018-2019). Fifteen watersheds were delineated in Southern California, roughly approximating hydrologic unit code (HUC) 18 from National Hydrography Dataset Plus (NHDPlus) (United States Geological Survey and United States Environmental Protection Agency, 2005). County stratification included the 6 counties that comprise these coastal watersheds: Ventura, Los Angeles, Orange, Riverside, San Bernardino, and San Diego counties. Three land uses —urban, agriculture, and open — were based on the National Oceanic and Atmospheric Administration’s Coastal Change Analysis Program (C-CAP, NOAA 1995, 2001). For purposes of site selection, land use was assigned to each stream segment using a 500-m streamline buffer. If the buffer was more than 75% natural or open land, that segment was considered open space. Otherwise, land use was classified as urban or agricultural, depending on which land use dominated.

Data Collection

All sites were sampled during the spring-summer season (April-August) in 2011-2013, in 2018-2019, and in 2020-2024. Sampling followed the qualitative and quantitative trash assessment protocols described in the California Trash Monitoring Playbook (Moore et al. 2020). Briefly, each site was defined as a stream reach with a length of 30.5 m (100 ft) and a width equal to the bankfull width. Trash assessment included a combination of qualitative assessment and an associated quantitative item tally. The qualitative assessment rated each site with a visual assessment score based on the amount of trash seen while walking the 30.5 m reach: low (1-3), moderate (4-6), high (7-9), very high (10-12). The quantitative assessment included an enumeration and classification of all visible trash within the stream reach. The nine general trash classifications were: plastic (e.g., wrappers, bags, pieces, bottles), glass, metal (e.g., aluminum cans), fabric and cloth, biohazard (e.g., diapers, pet waste), biodegradable (e.g., paper), construction (e.g., concrete, asphalt), large (e.g., refrigerators, sofas), and miscellaneous (e.g., sports balls, ceramics), with each category further divided into subcategories on the tally sheet (Appendix B). If an item fit multiple categories, the category that fit the greatest proportion of material was recorded, with comments made on any additional categories for minor material types.

The project met all QA/QC criteria for sampling, including sampling completeness (>90% of sites), field audits of crews, and intercalibration of trash counts to ensure standardization.

Data Analysis

Data analyses were performed with R 4.4.3 (R Core Team, 2025), using the tidyverse (Wickham et al. 2019), broom (Robinson et al. 2025), and ggpubr (Kassambara, 2023) packages. Sampling weights were assigned to each site within each stratum definition to account for differences in the total number of stratum stream sites/length. These weights were used when estimating magnitude (area-weighted mean abundances), spatial extent (percent of stream kilometers), and associated confidence intervals (CIs) using spsurvey (Dumelle et al. 2023). The average trash count was used to calculate trash extent and magnitude at sites that were surveyed multiple times during the 2020-2024 sampling period. Differences in abundance among trash categories were assessed using a one-way analysis of variance (ANOVA). Pairwise comparisons were assessed using Tukey's Honest Significant Difference (HSD) test. Linear regression analysis of mean trash abundance and mean single-use bag abundance relative to the survey year was conducted to evaluate trends of trash and bags through time in relation to the implementation of the California State Trash Amendments (effective 2015) and the California single-use plastic bag ban (effective 2015).

Results & Discussion

Survey completeness

A total of 384 surveys were completed at 270 unique sites across 15 watersheds and 6 counties between 2020-2024. Urban-dominated stream reaches were most surveyed (n=186), followed by open land (n=149) and agricultural areas (n=49; **Table 1**).

Table 1. The number of sites sampled from 2020-2024 for each watershed and land use type. Note that some stations were revisited during this period.

STRATA TYPE	STRATA	2020	2021	2022	2023	2024	TOTAL SITE VISITS	TOTAL UNIQUE SITES
WATERSHED	Santa Clara	2	3	7	10	11	33	25
	Ventura	0	0	5	6	7	18	12
	Calleguas	0	0	4	8	8	20	11
	Santa Monica Bay	3	5	3	4	6	21	14
	Los Angeles	9	10	12	12	14	57	38
	San Gabriel	13	15	16	18	18	80	62
	Upper Santa Ana	0	0	3	5	7	15	12
	Middle Santa Ana	2	1	5	6	3	17	11
	Lower Santa Ana	2	2	4	4	6	18	13
	San Jacinto	3	1	3	1	6	14	9
	San Juan	4	1	2	1	4	12	10
	Northern San Diego	6	5	6	6	4	27	18
	Mission Bay and San Diego River	4	3	4	6	2	19	12
	Central San Diego	4	3	3	4	3	17	12
	Southern San Diego	4	3	3	3	3	16	11
LAND USE	Agricultural	8	3	8	15	15	49	37
	Open	24	22	34	29	40	149	96
	Urban	24	27	38	50	47	186	137
COUNTY	Ventura	0	0	14	23	27	64	40
	Los Angeles	25	30	31	32	34	152	109
	San Bernardino	0	0	4	9	8	21	17
	Orange	8	6	8	8	13	43	36
	Riverside	7	4	9	5	8	33	20
	San Diego	16	12	14	17	12	71	48
TOTAL SITE VISITS	All strata	56	52	80	94	102	384	270

What is the extent and magnitude of trash in streams?

Based on 30-m transects, trash occurred in an estimated 83% of the 7,400 stream km in Southern California (**Figure 1, Table B1)**. Almost all stream km surveyed in urban land use had trash (98%), followed by 86% of stream km in agricultural land use and 68% of stream km in open land use.

The area-weighted trash abundance across the region averaged 0.63 (95% CI: 0.45-0.81) items per stream meter (**Figures 2, 3, Tables B2-B4).** Urban land use had the highest trash abundance, averaging 1.27 (95% CI: 0.91-1.62) items per stream meter (range 0 to 9 items per stream meter). Open land use had the lowest trash abundance, averaging 0.16 (95% CI: 0.09-0.24) items per stream meter (range 0 to 5 items per stream meter).

Most of the sites in the top 90th percentile for trash density were found in urbanized sections of the Los Angeles and San Gabriel watersheds (**Figure 2**). Conversely, the sites with the lowest densities of trash were found in the mountainous national forest sections east of the urbanized land uses on the coastal plain.

This pattern of occurrence by land use is consistent with previous surveys of riverine trash in Southern California. In 2018-2019, McLaughlin et al. (2023) found urban land use had the highest frequency of trash detection compared to agricultural or open land uses, and that trash abundance was correlated with road density. McLaughlin et al. (2023) also found an average trash abundance of 1.45 items per meter in streams with urban land uses, roughly 13% higher than the abundance measured in our study (2020-2024). Results from both Southern California studies fall within the range of trash abundance observed in urban streams from other areas of the country, including Cleveland, OH, and Charlotte, NC, where trash abundance varied from 0.18 to 4.7 pieces per meter, with an average abundance of 1.67 items per meter (Farooq et al. 2025).

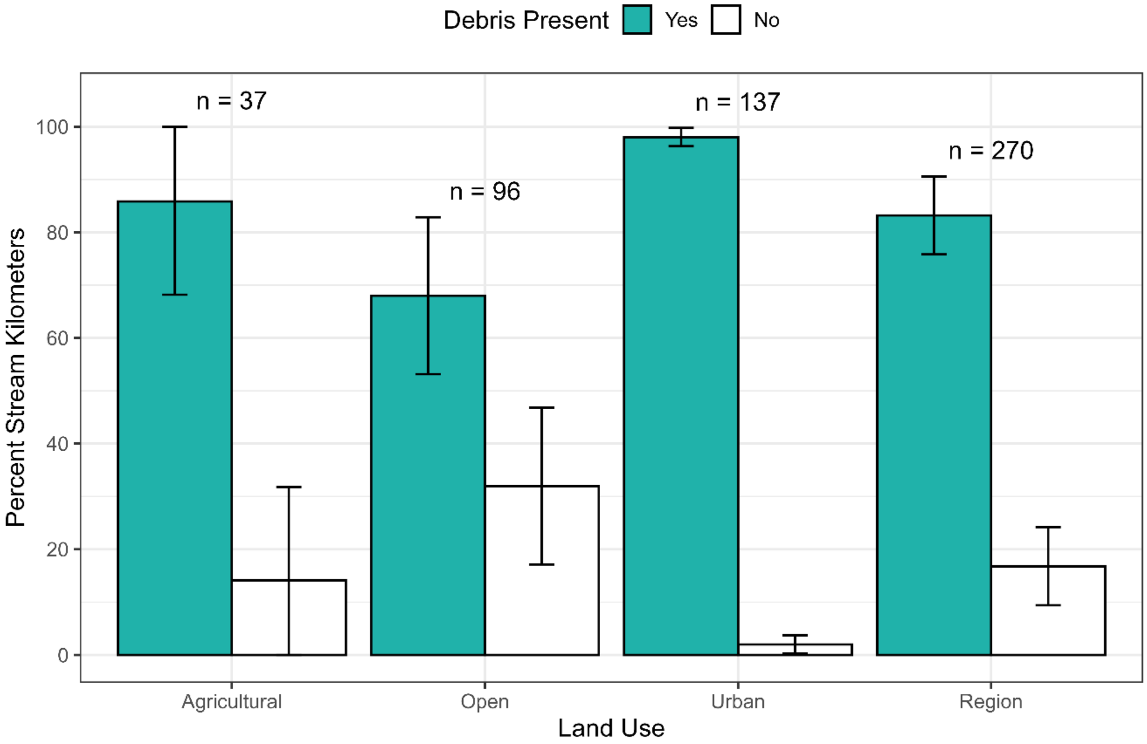


Figure 1. Percent of stream kilometers where anthropogenic trash was found (turquoise) or not found (white) by land use. Error bars represent the area-weighted 95% confidence interval. Data labels represent the number of unique sites assessed from 2020-2024.

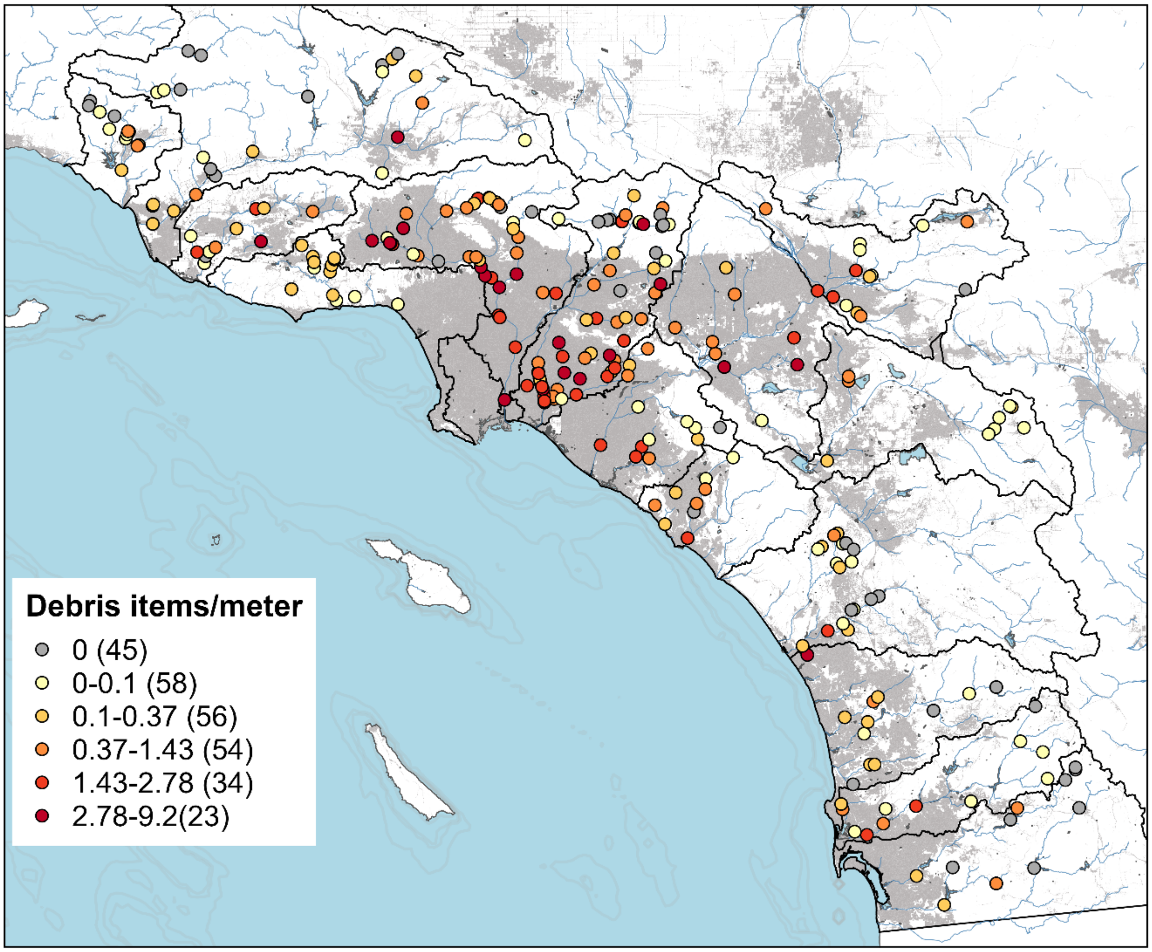


Figure 2. Average number of trash items per stream meter at each survey site. Sites with trash detected (>0) are binned by percentiles with bins representing the minimum to the 25th percentile, the 25th to the 50th percentiles, the 75th to 90th percentiles, and the 90th percentile to the maximum. The number of sites in each bin is displayed in parentheses after the abundance range of each bin. Developed land (gray).

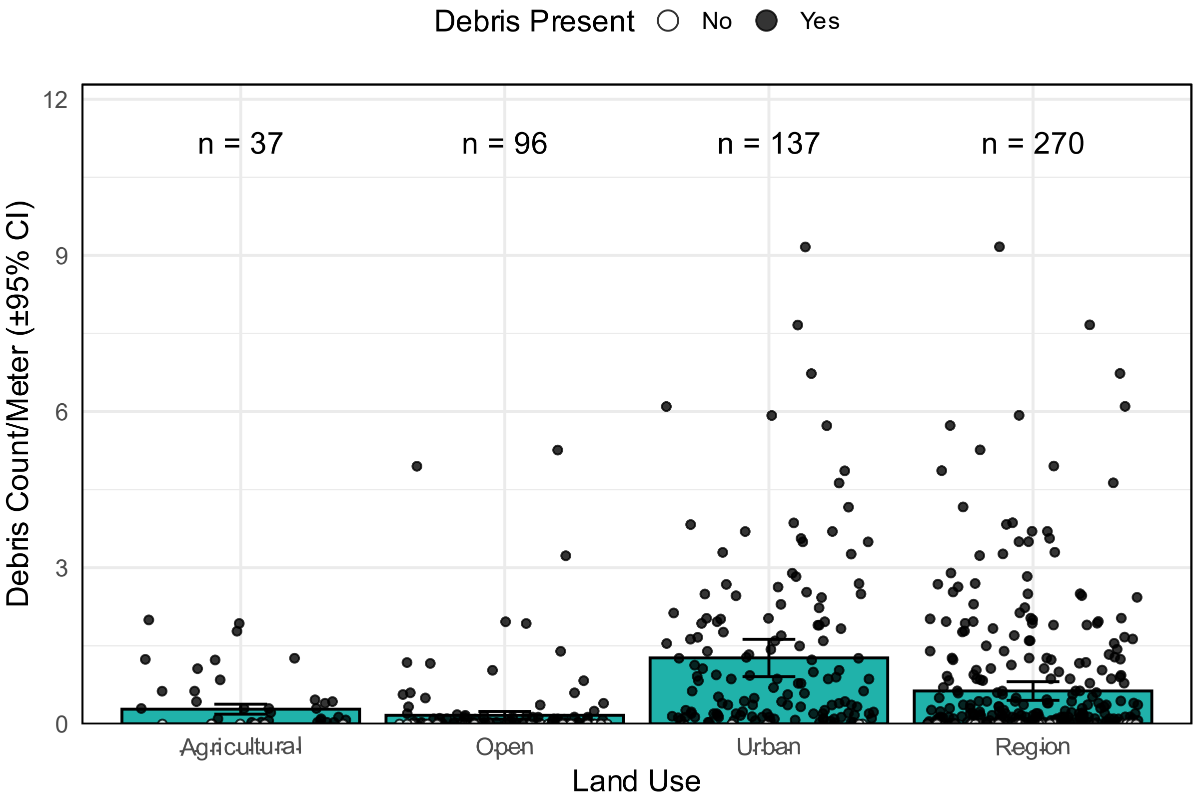


Figure 3. Trash abundance (trash items/meter of stream length) by land use type. Bars represent the area-weighted mean trash abundance. Points represent unique sites and sampling events. Error bars represent the 95% confidence interval.

Regionally, plastic trash abundance in streams was significantly greater than the abundance of any other trash category, including glass, paper, or metal ($p < 0.0001$). Plastic occurred at nine times the rate of any other trash category (**Figure 4, Table B5**). Additionally, plastic was also the most abundant trash category regardless of land use, ranging from an average of 0.9 items per stream meter in urban land use to an average of 0.12 and 0.22 items per stream meter in open and agricultural land uses, respectively.

In the current study, plastic was the largest component of trash region-wide comprising roughly 70% of all trash types in southern California streams. Similarly, plastic trash comprised 71.8% of collected trash in Cleveland, OH and Charolette, NC (Farooq et al. 2025). Plastic trash ranged from 44.6 to 89% of all counted trash items in urban streams from Baltimore, MD and Chicago, IL (Hoellein et al. 2024).

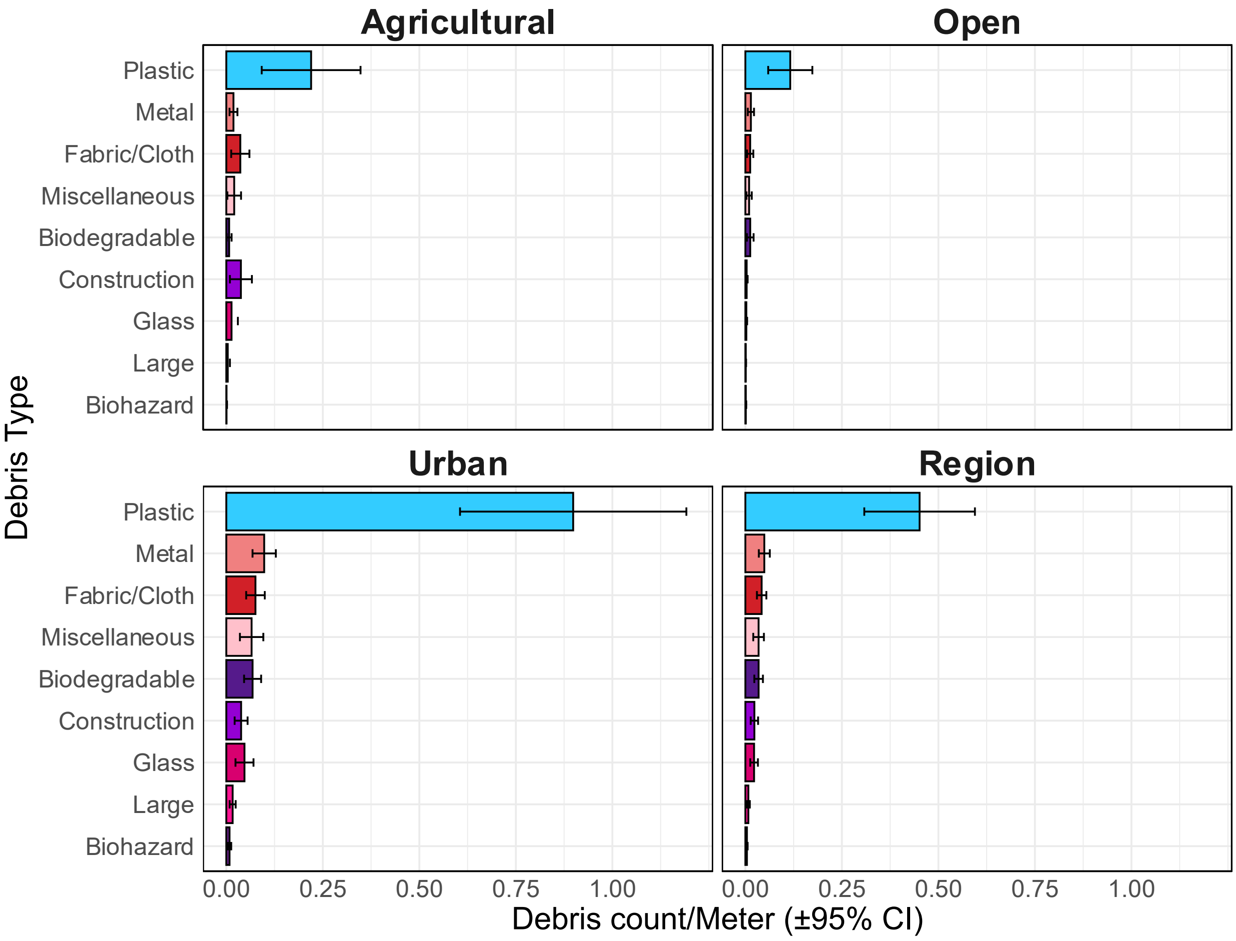


Figure 4. Area-weighted mean trash abundance (trash items/meter of stream length) by land use type and trash category. Bars represent the area-weighted mean trash abundance. Error bars represent the 95% confidence interval.

What is the trend in the extent and magnitude of trash in streams?

The extent of trash in southern California streams has been variable but has not significantly increased or decreased over the previous 14 years (Figure 5, p = 0.51). Trash extent ranged from a maximum of 100% of stream km in 2011 and 2012 to a low of 44% in 2013 (**Figure 5, Table B6**). The average extent of trash between 2011 and 2024 was 74% (95% CI 69-79%) of southern California stream km.

Regardless of survey year, plastic comprised the majority of the quantified trash (**Figure 5, Table B6**), with an average of 67% (95% CI 61-72%) of the stream km with trash present. Unsurprisingly, the temporal patterns in plastic extent largely mirrored those for all trash.

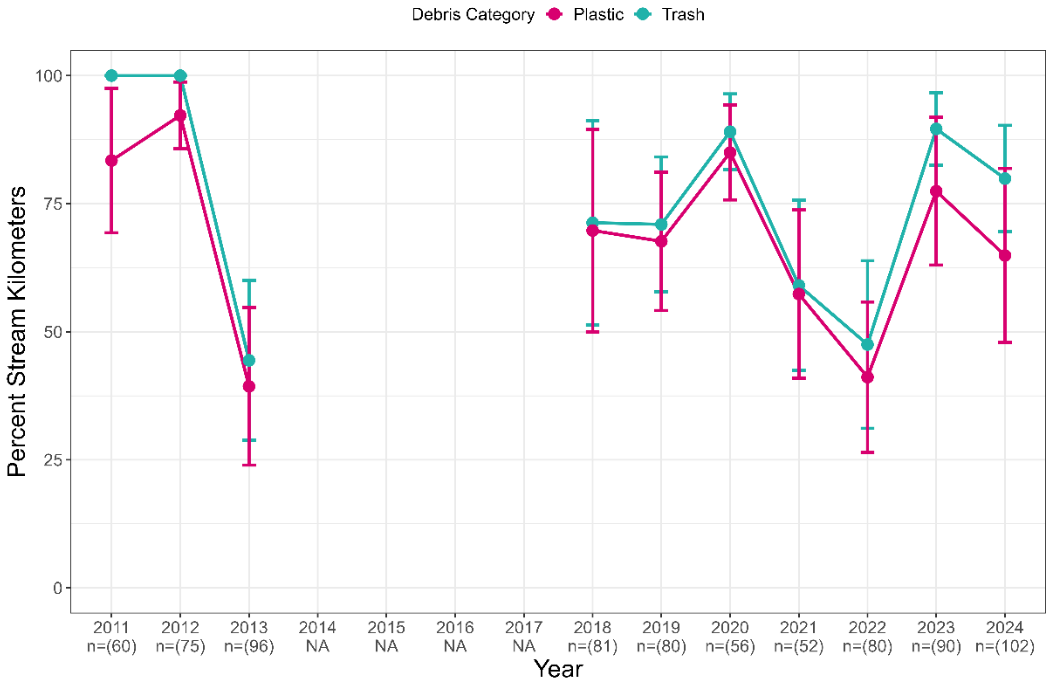


Figure 5. Percent of stream kilometers where trash (turquoise) or plastic (pink) was in surveys conducted from 2011-2013 and 2018-2024. Error bars represent the 95% confidence interval. Data labels represent the number of unique sites assessed in each year.

While the extent of trash has remained variable across survey years, there was a slight negative relationship between area-weighted mean trash abundance (items per stream meter) and survey year (Pearson correlation $r^2 = 0.47$, $p = 0.03$) (**Figure 6**).

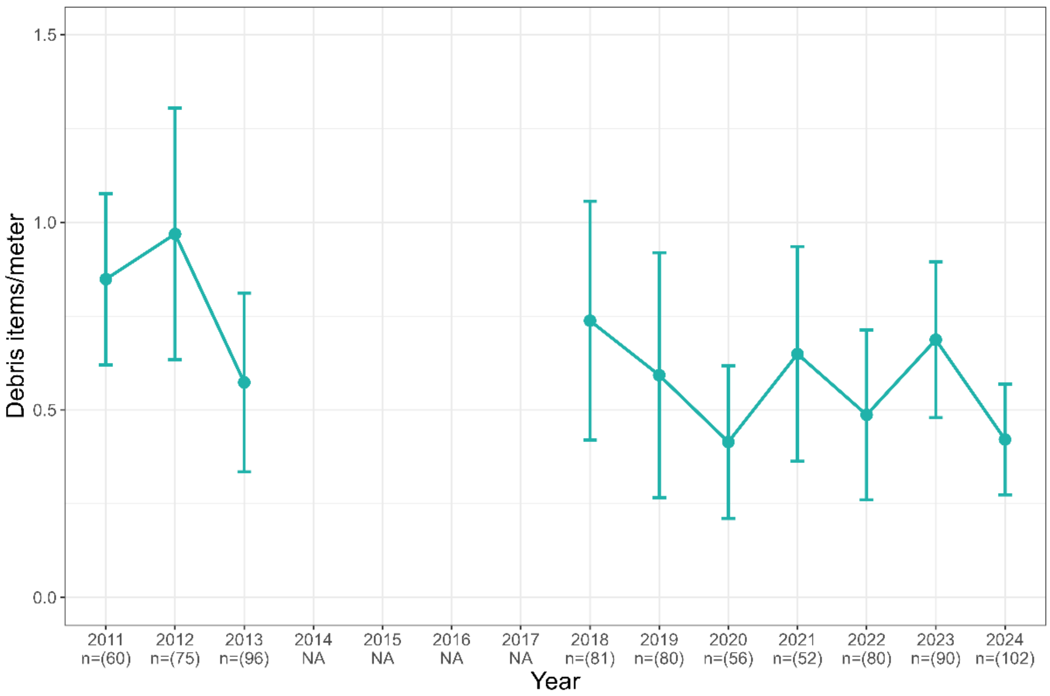


Figure 6. Area-weighted mean trash abundance (items per meter of stream reach) from 2011-2013 and 2018-2024. Error bars represent the 95% confidence interval. Data labels represent the number of unique sites assessed in each year.

Are the trends in trash extent and magnitude from Southern California streams related to management actions?

Long-term monitoring of trash in streams across Southern California offers a foundation for assessing the success of management actions aimed at reducing trash inputs. The decreasing trend in trash abundance (**Figure 5**) may in part be due to the ongoing implementation of the California Statewide Trash Amendments. The Trash Amendments require capturing all trash greater than 5 mm areas designated as Priority Land Uses in California. A common option being pursued under this policy, which went into effect at the end of 2015 and requires compliance by 2030, involves installation of trash-capture devices in storm drains. While trash capture has been shown to remove debris (San Francisco Estuary Partnership, 2014), storm drains are not the only conduits for trash entering waterways. Additionally, trash capture systems must withstand the peak flow from a one-year, one-hour storm event, but the implemented systems may not effectively capture trash at higher flows (SWRCB, 2025). As trash treatment systems continue to be implemented, continued annual monitoring may reveal whether the decreasing trend in trash abundance is sustained and help identify additional measures needed to achieve trash goals.

In recent years, California has also adopted product-specific policies to prevent the release of certain products into the environment. Beginning in 2016, a statewide ban on single-use plastic bags went into effect. The abundance of single-use bags before the ban (2011 to 2013) averaged 0.12 (95% CI 0.07-0.16) bags/meter, while post-ban abundance (2018 to 2024) declined by 69% to 0.04 (95% CI 0.03-0.04) bags/meter. A significant negative relationship between area-weighted mean bag abundance and sample year ($p = 6.3E-4$, $r^2 = 0.79$) indicates a sustained decline following policy implementation (**Figure 7; Table B7**). This decline in bag abundance in streams across Southern California demonstrates the effectiveness of source control at preventing trash from entering the environment. The California bag ban continues to evolve. Beginning January 1, 2026, thicker reusable plastic bags, which replaced single-use bags in some cases after the 2016 ban, will also be prohibited. In 2018, the category "reusable plastic bag" was added to the trash survey tally sheet, yet so far, the density of reusable bags has been an order of magnitude lower than single-use bags observed over the same time period. From 2018 to 2024, area-weighted average reusable bags were found at a density of 0.003 bags/meter (95% CI 0.002 – 0.005; **Table B8**). As trash policies continue to evolve, continued stream monitoring can be a tool for evaluating the policy's effectiveness.

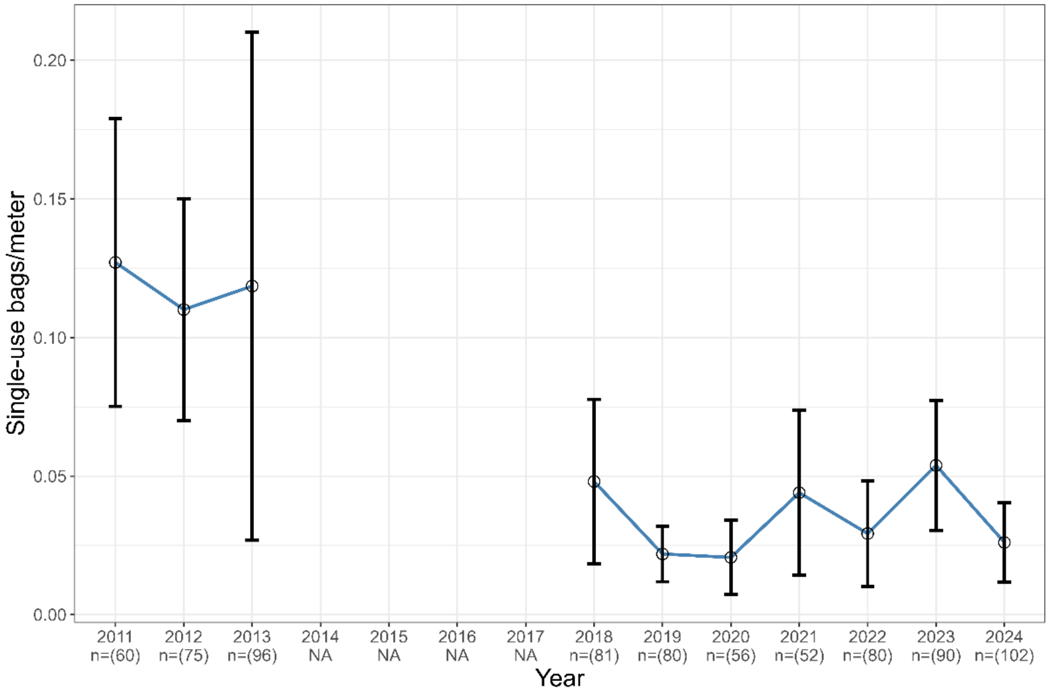


Figure 7. Area-weighted mean single-use bag abundance (items per meter of stream reach) from 2011 to 2024. Error bars represent the 95% confidence interval. Data labels represent the number of unique sites assessed in each year.

Exploring New Modelling and Statistical Approaches to Inform Future Monitoring Efforts and Management Actions for Trash in Streams

Bight and SMC monitoring efforts have generated over a decade's worth of regional trash data in streams. Previous assessments have largely focused on high-level summaries of trash extent and magnitude within the Bight program, but this wealth of data may also serve as a foundation for predictive models and new types of statistical analyses to answer novel monitoring and management questions. These novel approaches could quantify the drivers of trash type and abundance, refine future monitoring efforts, and better inform management decisions. As such, two new approaches for analyzing trash data in streams were explored as a first step in evaluating if these novel approaches.

A predictive model to identify the drivers of trash abundance in streams

Identifying the biggest factors driving the abundance of trash in streams has been a repeated monitoring goal of the Bight program. Bight '18 found that trash abundance was positively correlated with increasing road density and indicators of human disturbance as assessed by the California Regional Bioassessment Program (McLaughin et al., 2022). While informative, this analysis only considered a limited number of selected variables one-by-one for one Bight cycle. A predictive multi-variate based model would expand upon this previous work by assessing whether trash abundance could be predicted using a greater number of variables with more complex interactions.

For this exercise, over 190 variables pertaining to hydrology, land use, or socioeconomic factors were considered. First, Spearman's rank correlation coefficient was used to determine the strength of the relationship between each variable and trash abundance. Then, three different model scenarios were tested: 1) a generalized additive model only using variables with strong relationships to trash abundance, 2) a simple random forest model only using variables with strong relationships to trash abundance, and 3) a complex random forest model with all variables tested. Model performance was evaluated by comparing model predictions of trash abundance at each site against historical averages.

The socioeconomic variables with the strongest relationship to trash abundance in the upstream catchment were percent minority population ($\rho = 0.40$) and percent population below poverty level ($\rho = 0.37$). The top hydrologic variables were mean basin slope ($\rho = -0.38$) and precipitation ($\rho = -0.33$) within the upstream catchment. The top land use variables were percent developed land use in the upstream catchment ($\rho = 0.50$) and road proximity to the site ($\rho = -0.37$). The highest performing model was the complex random forest model, which accounted for 45% of the variability in the trash data. However, the simple random forest model performed similarly (43%) whereas the generalized additive model was the lowest performing model (26%).

These results indicate that a simple random forest model may be a powerful tool for identifying the drivers and predicting trash abundance in streams. It is likely that performance may be further improved by adding new time-dependent (e.g., trash input pulses, cleanup activities) and spatial (e.g., hydrologic connectivity) data to account for the remaining ~50% of the variability. Additional model development could allow for key insights to targeting site selection for management actions and identifying new or improved management actions for reducing trash in streams.

A statistical approach to define trash "communities"

Bight and SMC trash surveys provide a broad regional assessment of trash in streams, but this data may also reveal patterns in how different types of trash may occur together based on selected site characteristics. Identifying and describing these trash "communities" may help managers develop more efficient trash remediation strategies based on the location and characteristics of a stream and the types of trash that are most likely to occur there.

Trash community structures were visualized for trash surveys conducted in 2023 using nonmetric multidimensional scaling (NMDS) by trash category (e.g., plastic, metal) and by category item type (e.g., plastic wrapper, aluminum can). An analysis of distance/similarity (ADONIS) test was used to determine if trash community composition was statistically significantly unique across different types of land uses, counties, and watersheds. Finally, indicator species analyses were conducted to identify which trash items were significantly associated with specific land uses, counties, or watersheds.

The results showed that land use, county, and watershed all had a significant impact on trash community patterns at the category level (all $p < 0.05$) but not for individual trash items. Trash communities were significantly different between open and agricultural sites ($p = 0.001$), with construction material significantly indicative of urban sites (IV: 35.27%, $p = 0.047$). Trash communities were also significantly unique between Orange and San Diego counties ($p = 0.049$). In addition, plastic beverage bottles were indicative of urban areas (31.76%; $p = 0.028$), while plastic cigarette butts were indicative and San Bernardino County (39.94%; $p = 0.022$).

The results show that trash communities could be distinct amongst land uses, counties, and watersheds and could be used to inform local trash management decisions at these levels. Future analyses could be expanded to include additional years which could provide insights into how these communities changed over time, potentially in response to litter policies and management efforts. In addition, geospatial statistical analysis could be conducted to determine geographic litter community patterns and hotspots (e.g., hotspot analysis, average nearest neighbor analysis), which might help to narrow down geographic regions that span political (e.g., county) and ecological (e.g., watersheds) boundaries.

Conclusions

The extent of trash in streams of southern California is pervasive.

Based on this study of 270 sites over four years, on average, a person would see at least 1 piece of trash every 30 meter of stream in 83% of the 7,400 km of stream reaches across Southern California.

The extent and magnitude of trash is greatest in urban land uses.

Trash was estimated to occur in 98% of the streams surrounded by urban land use. This compares to 86% and 68% in agricultural and open land uses, respectively. Similarly, streams surrounded by urban land uses had four to eight times the abundance of trash compared to streams surrounded by agricultural or open land uses (an average of 1.27 pieces/stream meter compared to 0.28 or 0.16 pieces/stream, respectively).

Plastic is the most common type of trash.

At 0.45 pieces/stream meter, the abundance of plastic trash was nine times the abundance of any other individual category of trash. In fact, the abundance of plastic was greater than glass, cloth, and metal combined.

The extent of trash has not declined between 2011 and 2024.

Trash has been extensive in Southern California, ranging from a low of 44% of stream km in 2013 to 100% of stream km in 2011 and 2012. However, there has been no statistically significant trend in trash extent over the 14 years of the monitoring program. The one common trend is that the largest component of trash has been plastic regardless of survey year.

Management actions appeared to have reduced trash abundance between 2011 and 2024.

There was a statistically significant decline in trash abundance in southern California streams prior to the 2015 Statewide Trash Amendment compared to after the Amendment was promulgated. Similarly, the abundance of single-use plastic bags dropped by 70% following the 2014 plastic bag ban.

Recommendations

The recommendations from Bight '23 are research-focused recommendations, largely to help understand the questions arising from the current effort.

Quantify trash accumulation rates at select sites

While Bight '23 provided the most detailed information on trash extent and magnitude of any program in the country, it lacks a key piece of information – trash accumulation rates. Trash accumulation rates quantify how quickly trash builds up in streams and along stream banks. This process-based study should not be conducted regionally since repeated sampling over time is better conducted at representative sites. Knowing trash accumulation rates will help quantify trash mass in a watershed and help define maximally efficient management actions including enforcement efforts or street sweeping frequencies.

Assess trash impacts in streams

While this regional monitoring study identified a large extent of trash in the streams of southern California, we do not know what ecological impact(s) the trash might have. Ecological impacts could include direct toxicological effects, indirect chronic toxicological effects, or changes to physical habitat and flow that could result in ecological effects. Understanding the range of effects in aquatic or riparian ecology will help define the ecological risk from trash, thus motivating additional management actions when these risk levels are exceeded.

Prioritize describing a relationship between trash in watershed, estuaries and ocean and consider modifying the regional monitoring study design to do so

While Bight '23 identified the extent and magnitude of trash in streams, it did not quantify trash transport downstream. Streams are likely a major contributor to trash found in estuaries and ocean habitats downstream, particularly after storm events. Dedicated fate and transport studies are needed for better quantifying how much trash in estuaries and oceans comes from land-based sources such as streams.

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Appendix A: Extent, magnitude, and trends of benthic macrodebris in the Southern California Bight

BIGHT '23 TRAWL DEBRIS FORM **Agency:**________________________ **Page**______**of**______

Station:__________________ **Trawl #:**________________________ **Date:**________________ **CHECK HERE IF NO DEBRIS PRESENT IN SAMPLE** ☐

Anthropogenic Debris – include Brand names in Comments if known

Plastic	**Count**	**Comment**
Bag		
Bandaid		
Balloon (mylar/latex)/Ribbon		
Bottle		
Buoy		
Cap/Lid		
Cigarette Box/Wrapper		
Cup		
Filmstrip (movie)		
Fishing Line/Net		
Food Bag/Wrapper		
Polypropylene Rope		
Single use food container		
Toy		
Utensil		
Plastic Piece (unid.)		
Other Plastic (comment req.)		
Glass		
Beer Bottle		
Other Glass Bottle/Jar		
Glass Piece (unid.)		
Other Glass (comment req.)		

Misc. Items/Pieces	**Count**	**Comment**
Boat/Engine/Engine Part		
Clothing		
Concrete/Asphalt		
Fiberglass		
Food		
Latex/nitrile gloves		
Leather		
Lumber		
Mask–specify single use or cloth		
Paper		
Rag/Cloth		
Rubber		
Shoe		
Tape		
Tire		
Other misc. (comment req.)		
Metal		
Drink Can		
Can – other		
Fishing Gear		
Wire		
Metal piece (unid.)		
Other metal (comment req.)		

Natural Debris

Marine Origin	**Count**	**Est.***	**Comment**
Foliose Algae – not kelp			
Gorgonian Sea Fan (dead)			
Kelp Holdfast			
Kelp Stripe/Blade			
Other Foliose Algae			
Rock			
Seagrass			
Other Marine (comment req.)			

Terrestrial Vegetation	**Count**	**Est.***	**Comment**
Leaves/Seed Pod			
Stick/Branch/Driftwood			
Other Terrestrial (comment req.)			

***For Natural Debris only**, if the count >10 and an exact count cannot be made, leave the "Count" column blank and estimate the amount (M or H) in the "Est." column.

Moderate:	**M = 11-100**
High:	**H = >100**

Completed by: ______________________________ (name, agency)

Table A1. Summary of debris counts for all trawled stations in the 2023 Bight Regional Monitoring Program. Note that bays had a shorter trawl time (i.e., 5 minutes) as compared to other strata (i.e., 10 minutes). For debris items where an exact count could not be made, counts were estimated (Est.) as moderate (M, 11-100 items) or high (H, >100 items).

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
BAY	B23-12008	natural	marine	foliose algae - not kelp	-	H
BAY	B23-12009	natural	marine	foliose algae - not kelp	-	M
BAY	B23-12011	natural	marine	foliose algae - not kelp	-	M
BAY	B23-12012	no debris	-	-	0	-
BAY	B23-12014	no debris	-	-	0	-
BAY	B23-12019	no debris	-	-	0	-
BAY	B23-12020	natural	marine	foliose algae - not kelp	-	M
BAY	B23-12021	no debris	-	-	0	-
BAY	B23-12022	natural	marine	foliose algae - not kelp	-	M
BAY	B23-12022	natural	marine	kelp holdfast	1	-
BAY	B23-12022	natural	marine	seagrass	-	H
BAY	B23-12022	natural	terrestrial vegetation	stick/branch/driftwood	1	-
BAY	B23-12023	natural	marine	foliose algae - not kelp	-	M
BAY	B23-12023	natural	marine	seagrass	-	M
BAY	B23-12024	anthropogenic	plastic	bottle	1	-
BAY	B23-12024	natural	marine	foliose algae - not kelp	-	M
BAY	B23-12024	natural	marine	seagrass	-	M
BAY	B23-12024	natural	terrestrial vegetation	stick/branch/driftwood	2	-
BAY	B23-12027	natural	marine	kelp stipe/blade	-	M
BAY	B23-12028	no debris	-	-	0	-
BAY	B23-12030	anthropogenic	misc. items/pieces	concrete/asphalt	2	-
BAY	B23-12030	natural	marine	foliose algae - not kelp	3	-
BAY	B23-12030	natural	marine	kelp stipe/blade	5	-
BAY	B23-12030	natural	marine	other marine (comment req)	4	-

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
BAY	B23-12030	natural	terrestrial vegetation	leaves/seed pod	1	-
BAY	B23-12031	no debris	-	-	0	-
BAY	B23-12032	anthropogenic	plastic	bag	3	-
BAY	B23-12032	anthropogenic	plastic	other plastic (comment req.)	1	-
BAY	B23-12032	natural	marine	kelp stipe/blade	7	-
BAY	B23-12033	anthropogenic	plastic	other plastic (comment req.)	1	-
BAY	B23-12033	anthropogenic	plastic	plastic piece (unid.)	2	-
BAY	B23-12033	natural	marine	kelp stipe/blade	3	-
BAY	B23-12033	natural	marine	seagrass	1	-
BAY	B23-12033	natural	terrestrial vegetation	leaves/seed pod	9	-
BAY	B23-12033	natural	terrestrial vegetation	stick/branch/driftwood	3	-
BAY	B23-12034	anthropogenic	plastic	food bag / wrapper	1	-
BAY	B23-12034	natural	marine	kelp stipe/blade	3	-
BAY	B23-12034	natural	marine	seagrass	1	-
BAY	B23-12034	natural	terrestrial vegetation	leaves/seed pod	-	M
BAY	B23-12034	natural	terrestrial vegetation	stick/branch/driftwood	5	-
BAY	B23-12035	anthropogenic	plastic	bag	1	-
BAY	B23-12035	anthropogenic	plastic	food bag / wrapper	1	-
BAY	B23-12035	anthropogenic	misc. items/pieces	other misc. (comment req.)	1	-
BAY	B23-12035	natural	marine	foliose algae - not kelp	1	-
BAY	B23-12035	natural	terrestrial vegetation	stick/branch/driftwood	1	-
BAY	B23-12036	anthropogenic	plastic	food bag / wrapper	1	-
BAY	B23-12036	anthropogenic	plastic	other plastic (comment req.)	1	-
BAY	B23-12036	natural	marine	kelp stipe/blade	1	-
BAY	B23-12036	natural	terrestrial vegetation	leaves/seed pod	3	-
BAY	B23-12037	anthropogenic	plastic	bag	2	-
BAY	B23-12037	anthropogenic	plastic	food bag / wrapper	3	-

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
BAY	B23-12037	anthropogenic	plastic	plastic piece (unid.)	6	-
BAY	B23-12037	anthropogenic	plastic	single use food container	1	-
BAY	B23-12037	natural	marine	kelp stipe/blade	5	-
BAY	B23-12037	natural	marine	seagrass	1	-
BAY	B23-12037	natural	terrestrial vegetation	leaves/seed pod	4	-
BAY	B23-12037	natural	terrestrial vegetation	stick/branch/driftwood	2	-
BAY	B23-12038	natural	marine	kelp stipe/blade	2	-
BAY	B23-12039	anthropogenic	plastic	bag	1	-
BAY	B23-12039	anthropogenic	plastic	cigarette box/wrapper	1	-
BAY	B23-12039	anthropogenic	plastic	food bag / wrapper	1	-
BAY	B23-12039	anthropogenic	plastic	other plastic (comment req.)	1	-
BAY	B23-12039	natural	marine	foliose algae - not kelp	1	-
BAY	B23-12039	natural	marine	kelp stipe/blade	3	-
BAY	B23-12039	natural	marine	seagrass	3	-
BAY	B23-12039	natural	terrestrial vegetation	leaves/seed pod	-	M
BAY	B23-12039	natural	terrestrial vegetation	other terrest. (comment req)	1	-
BAY	B23-12039	natural	terrestrial vegetation	stick/branch/driftwood	3	-
BAY	B23-12040	natural	marine	foliose algae - not kelp	1	-
BAY	B23-12040	natural	marine	kelp stipe/blade	1	-
BAY	B23-12040	natural	terrestrial vegetation	stick/branch/driftwood	1	-
BAY	B23-12041	anthropogenic	plastic	bag	1	-
BAY	B23-12041	anthropogenic	plastic	bottle	1	-
BAY	B23-12041	anthropogenic	plastic	food bag / wrapper	1	-
BAY	B23-12041	natural	marine	kelp stipe/blade	1	-
BAY	B23-12041	natural	terrestrial vegetation	leaves/seed pod	1	-
BAY	B23-12041	natural	terrestrial vegetation	stick/branch/driftwood	2	-
BAY	B23-12042	natural	marine	foliose algae - not kelp	2	-

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
BAY	B23-12042	natural	marine	kelp stipe/blade	2	-
BAY	B23-12042	natural	terrestrial vegetation	stick/branch/driftwood	1	-
BAY	B23-12043	anthropogenic	plastic	plastic piece (unid.)	5	-
BAY	B23-12043	anthropogenic	plastic	polypropylene rope	1	-
BAY	B23-12043	anthropogenic	misc. items/pieces	other misc. (comment req.)	1	-
BAY	B23-12043	natural	marine	foliose algae - not kelp	5	-
BAY	B23-12043	natural	marine	kelp stipe/blade	2	-
BAY	B23-12043	natural	terrestrial vegetation	leaves/seed pod	2	-
BAY	B23-12043	natural	terrestrial vegetation	stick/branch/driftwood	4	-
BAY	B23-12044	anthropogenic	plastic	bag	11	-
BAY	B23-12044	anthropogenic	plastic	cigarette box/wrapper	2	-
BAY	B23-12044	anthropogenic	plastic	food bag / wrapper	17	-
BAY	B23-12044	anthropogenic	plastic	plastic piece (unid.)	49	-
BAY	B23-12044	natural	marine	kelp stipe/blade	-	M
BAY	B23-12044	natural	marine	other marine (comment req)	1	-
BAY	B23-12044	natural	marine	seagrass	3	-
BAY	B23-12044	natural	terrestrial vegetation	leaves/seed pod	3	-
BAY	B23-12044	natural	terrestrial vegetation	stick/branch/driftwood	2	-
BAY	B23-12819	no debris	-	-	0	-
BAY	B23-12884	natural	marine	foliose algae - not kelp	-	H
MIDDLE SHELF	B23-12217	natural	marine	foliose algae - not kelp	9	-
MIDDLE SHELF	B23-12217	natural	marine	kelp stipe/blade	-	M
MIDDLE SHELF	B23-12218	anthropogenic	misc. items/pieces	other misc. (comment req.)	1	-
MIDDLE SHELF	B23-12219	anthropogenic	misc. items/pieces	other misc. (comment req.)	1	-
MIDDLE SHELF	B23-12219	natural	marine	kelp stipe/blade	4	-
MIDDLE SHELF	B23-12219	natural	marine	other marine (comment req)	3	-
MIDDLE SHELF	B23-12220	natural	marine	foliose algae - not kelp	1	-

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
MIDDLE SHELF	B23-12220	natural	marine	kelp stipe/blade	2	-
MIDDLE SHELF	B23-12220	natural	marine	rock	1	-
MIDDLE SHELF	B23-12220	natural	marine	seagrass	-	M
MIDDLE SHELF	B23-12221	natural	marine	foliose algae - not kelp	1	-
MIDDLE SHELF	B23-12221	natural	marine	kelp holdfast	2	-
MIDDLE SHELF	B23-12221	natural	marine	kelp stipe/blade	3	-
MIDDLE SHELF	B23-12222	natural	marine	kelp stipe/blade	2	-
MIDDLE SHELF	B23-12222	natural	marine	seagrass	-	M
MIDDLE SHELF	B23-12223	anthropogenic	plastic	fishing line/net	1	-
MIDDLE SHELF	B23-12223	anthropogenic	plastic	other plastic (comment req.)	1	-
MIDDLE SHELF	B23-12223	anthropogenic	misc. items/pieces	clothing	2	-
MIDDLE SHELF	B23-12223	natural	marine	foliose algae - not kelp	-	M
MIDDLE SHELF	B23-12224	natural	marine	foliose algae - not kelp	1	-
MIDDLE SHELF	B23-12224	natural	marine	kelp holdfast	1	-
MIDDLE SHELF	B23-12224	natural	marine	kelp stipe/blade	4	-
MIDDLE SHELF	B23-12224	natural	marine	seagrass	1	-
MIDDLE SHELF	B23-12228	no debris	-	-	0	-
MIDDLE SHELF	B23-12229	natural	marine	kelp stipe/blade	15	M
MIDDLE SHELF	B23-12230	natural	marine	kelp holdfast	1	M
MIDDLE SHELF	B23-12230	natural	marine	kelp stipe/blade	1	M
MIDDLE SHELF	B23-12230	natural	terrestrial vegetation	stick/branch/driftwood	1	M
MIDDLE SHELF	B23-12231	natural	marine	kelp stipe/blade	1	-
MIDDLE SHELF	B23-12231	natural	marine	other marine (comment req)	1	-
MIDDLE SHELF	B23-12231	natural	marine	seagrass	3	-
MIDDLE SHELF	B23-12235	anthropogenic	plastic	food bag / wrapper	1	-
MIDDLE SHELF	B23-12235	natural	marine	kelp stipe/blade	2	-
MIDDLE SHELF	B23-12236	natural	marine	other marine (comment req)	-	H

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
MIDDLE SHELF	B23-12236	natural	marine	rock	1	-
MIDDLE SHELF	B23-12236	natural	marine	seagrass	3	-
MIDDLE SHELF	B23-12236	natural	terrestrial vegetation	stick/branch/driftwood	1	-
MIDDLE SHELF	B23-12237	anthropogenic	plastic	bottle	1	-
MIDDLE SHELF	B23-12237	natural	marine	foliose algae - not kelp	-	M
MIDDLE SHELF	B23-12237	natural	marine	kelp holdfast	4	-
MIDDLE SHELF	B23-12237	natural	marine	kelp stipe/blade	5	-
MIDDLE SHELF	B23-12237	natural	marine	seagrass	-	M
MIDDLE SHELF	B23-12238	natural	terrestrial vegetation	stick/branch/driftwood	1	-
MIDDLE SHELF	B23-12239	natural	marine	kelp stipe/blade	1	-
MIDDLE SHELF	B23-12240	natural	terrestrial vegetation	stick/branch/driftwood	2	-
MIDDLE SHELF	B23-12242	natural	marine	kelp stipe/blade	2	-
MIDDLE SHELF	B23-12242	natural	terrestrial vegetation	leaves/seed pod	3	-
MIDDLE SHELF	B23-12242	natural	terrestrial vegetation	stick/branch/driftwood	1	-
MIDDLE SHELF	B23-12244	natural	marine	kelp stipe/blade	-	M
MIDDLE SHELF	B23-12258	natural	marine	kelp stipe/blade	2	-
MIDDLE SHELF	B23-12258	natural	marine	seagrass	1	-
MIDDLE SHELF	B23-12259	natural	marine	rock	2	-
MIDDLE SHELF	B23-12259	natural	marine	seagrass	1	-
MIDDLE SHELF	B23-12523	natural	marine	kelp stipe/blade	2	-
MIDDLE SHELF	B23-12523	natural	terrestrial vegetation	stick/branch/driftwood	2	-
MIDDLE SHELF	B23-12572	natural	marine	other marine (comment req)	-	H
MIDDLE SHELF	B23-12572	natural	marine	rock	3	-
MIDDLE SHELF	B23-12572	natural	marine	seagrass	-	H
MIDDLE SHELF	B23-12575	natural	marine	foliose algae - not kelp	1	-
MIDDLE SHELF	B23-12575	natural	marine	kelp stipe/blade	9	-
MIDDLE SHELF	B23-12575	natural	marine	other marine (comment req)	-	H

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
MIDDLE SHELF	B23-12575	natural	marine	seagrass	7	-
MIDDLE SHELF	B23-12610	natural	marine	foliose algae - not kelp	-	M
MIDDLE SHELF	B23-12610	natural	marine	kelp stipe/blade	1	-
MIDDLE SHELF	B23-12610	natural	marine	seagrass	-	M
MIDDLE SHELF	B23-12612	natural	marine	foliose algae - not kelp	-	M
MIDDLE SHELF	B23-12612	natural	marine	kelp holdfast	1	-
MIDDLE SHELF	B23-12612	natural	marine	kelp stipe/blade	4	-
MIDDLE SHELF	B23-12612	natural	marine	seagrass	-	M
MIDDLE SHELF	B23-12667	natural	marine	foliose algae - not kelp	2	-
MIDDLE SHELF	B23-12667	natural	marine	kelp stipe/blade	1	-
MIDDLE SHELF	B23-12667	natural	marine	seagrass	1	-
MIDDLE SHELF	B23-12667	natural	terrestrial vegetation	stick/branch/driftwood	1	-
MIDDLE SHELF	B23-12770	no debris	-	-	0	-
INNER SHELF	B23-12187	natural	marine	kelp stipe/blade	4	-
INNER SHELF	B23-12187	natural	marine	seagrass	10	-
INNER SHELF	B23-12188	anthropogenic	plastic	plastic piece (unid.)	1	-
INNER SHELF	B23-12188	natural	marine	foliose algae - not kelp	-	M
INNER SHELF	B23-12188	natural	marine	kelp stipe/blade	-	M
INNER SHELF	B23-12188	natural	marine	seagrass	-	H
INNER SHELF	B23-12188	natural	terrestrial vegetation	leaves/seed pod	2	-
INNER SHELF	B23-12191	natural	marine	seagrass	2	-
INNER SHELF	B23-12194	no debris	-	-	0	-
INNER SHELF	B23-12195	natural	marine	foliose algae - not kelp	-	M
INNER SHELF	B23-12195	natural	marine	kelp stipe/blade	3	M
INNER SHELF	B23-12196	natural	marine	kelp holdfast	10	M
INNER SHELF	B23-12196	natural	marine	kelp stipe/blade	-	H
INNER SHELF	B23-12197	no debris	-	-	0	-

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
INNER SHELF	B23-12198	natural	marine	gorgonian sea fan (dead)	1	M
INNER SHELF	B23-12199	anthropogenic	misc. items/pieces	lumber	1	-
INNER SHELF	B23-12199	natural	marine	kelp stipe/blade	3	-
INNER SHELF	B23-12199	natural	marine	seagrass	3	-
INNER SHELF	B23-12199	natural	terrestrial vegetation	stick/branch/driftwood	3	-
INNER SHELF	B23-12200	anthropogenic	plastic	plastic piece (unid.)	1	-
INNER SHELF	B23-12200	natural	marine	foliose algae - not kelp	-	M
INNER SHELF	B23-12200	natural	marine	seagrass	1	-
INNER SHELF	B23-12200	natural	terrestrial vegetation	leaves/seed pod	1	-
INNER SHELF	B23-12200	natural	terrestrial vegetation	stick/branch/driftwood	1	-
INNER SHELF	B23-12201	anthropogenic	plastic	bottle	2	-
INNER SHELF	B23-12201	anthropogenic	plastic	food bag / wrapper	3	-
INNER SHELF	B23-12201	anthropogenic	plastic	other plastic (comment req.)	1	-
INNER SHELF	B23-12201	anthropogenic	plastic	plastic piece (unid.)	3	-
INNER SHELF	B23-12201	natural	marine	foliose algae - not kelp	-	M
INNER SHELF	B23-12201	natural	terrestrial vegetation	leaves/seed pod	-	H
INNER SHELF	B23-12201	natural	terrestrial vegetation	stick/branch/driftwood	-	M
INNER SHELF	B23-12202	natural	marine	foliose algae - not kelp	4	-
INNER SHELF	B23-12202	natural	marine	other marine (comment req)	10	-
INNER SHELF	B23-12202	natural	marine	seagrass	6	-
INNER SHELF	B23-12202	natural	terrestrial vegetation	leaves/seed pod	10	-
INNER SHELF	B23-12202	natural	terrestrial vegetation	stick/branch/driftwood	1	-
INNER SHELF	B23-12203	natural	marine	foliose algae - not kelp	-	M
INNER SHELF	B23-12203	natural	marine	other marine (comment req)	4	-
INNER SHELF	B23-12203	natural	marine	seagrass	4	-
INNER SHELF	B23-12203	natural	terrestrial vegetation	stick/branch/driftwood	1	-
INNER SHELF	B23-12204	natural	marine	kelp stipe/blade	3	-

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
INNER SHELF	B23-12204	natural	marine	other marine (comment req)	5	-
INNER SHELF	B23-12204	natural	marine	seagrass	-	M
INNER SHELF	B23-12204	natural	terrestrial vegetation	leaves/seed pod	-	M
INNER SHELF	B23-12204	natural	terrestrial vegetation	stick/branch/driftwood	9	-
INNER SHELF	B23-12206	no debris	-	-	0	-
INNER SHELF	B23-12207	no debris	-	-	0	-
INNER SHELF	B23-12208	natural	marine	kelp stipe/blade	1	-
INNER SHELF	B23-12209	natural	marine	foliose algae - not kelp	1	-
INNER SHELF	B23-12209	natural	marine	other marine (comment req)	3	-
INNER SHELF	B23-12209	natural	terrestrial vegetation	other terrest. (comment req)	1	-
INNER SHELF	B23-12210	natural	marine	kelp stipe/blade	1	-
INNER SHELF	B23-12211	natural	marine	kelp stipe/blade	3	-
INNER SHELF	B23-12212	natural	marine	kelp stipe/blade	2	-
INNER SHELF	B23-12213	natural	marine	kelp stipe/blade	1	-
INNER SHELF	B23-12214	natural	marine	kelp stipe/blade	1	-
INNER SHELF	B23-12214	natural	terrestrial vegetation	leaves/seed pod	2	-
INNER SHELF	B23-12214	natural	terrestrial vegetation	stick/branch/driftwood	1	-
INNER SHELF	B23-12216	natural	marine	kelp stipe/blade	2	-
INNER SHELF	B23-12507	natural	terrestrial vegetation	stick/branch/driftwood	1	-
INNER SHELF	B23-12590	natural	marine	kelp stipe/blade	2	-
INNER SHELF	B23-12591	natural	marine	foliose algae - not kelp	5	-
INNER SHELF	B23-12591	natural	marine	kelp stipe/blade	2	-
INNER SHELF	B23-12591	natural	marine	seagrass	15	-
INNER SHELF	B23-12647	natural	marine	kelp stipe/blade	1	-
INNER SHELF	B23-12647	natural	marine	seagrass	1	-
INNER SHELF	B23-12750	anthropogenic	misc. items/pieces	other misc. (comment req.)	1	-
INNER SHELF	B23-12755	anthropogenic	misc. items/pieces	rubber	1	-

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
OUTER SHELF	B23-12248	natural	marine	seagrass	1	-
OUTER SHELF	B23-12249	no debris	-	-	0	-
OUTER SHELF	B23-12250	anthropogenic	plastic	fishing line/net	1	-
OUTER SHELF	B23-12250	anthropogenic	plastic	other plastic (comment req.)	1	-
OUTER SHELF	B23-12250	anthropogenic	glass	beer bottle	1	-
OUTER SHELF	B23-12250	natural	marine	other marine (comment req)	2	-
OUTER SHELF	B23-12250	natural	marine	rock	8	-
OUTER SHELF	B23-12250	natural	terrestrial vegetation	stick/branch/driftwood	-	M
OUTER SHELF	B23-12251	anthropogenic	plastic	cap/lid	1	-
OUTER SHELF	B23-12251	natural	marine	kelp stipe/blade	2	-
OUTER SHELF	B23-12255	natural	marine	gorgonian sea fan (dead)	1	M
OUTER SHELF	B23-12255	natural	marine	kelp stipe/blade	-	M
OUTER SHELF	B23-12255	natural	marine	other marine (comment req)	-	H
OUTER SHELF	B23-12256	no debris	-	-	0	-
OUTER SHELF	B23-12260	natural	marine	kelp stipe/blade	2	-
OUTER SHELF	B23-12260	natural	marine	other marine (comment req)	3	-
OUTER SHELF	B23-12260	natural	marine	rock	2	-
OUTER SHELF	B23-12261	natural	marine	kelp stipe/blade	2	-
OUTER SHELF	B23-12261	natural	marine	rock	1	-
OUTER SHELF	B23-12262	natural	marine	kelp stipe/blade	2	-
OUTER SHELF	B23-12262	natural	terrestrial vegetation	stick/branch/driftwood	4	-
OUTER SHELF	B23-12263	natural	marine	kelp stipe/blade	5	-
OUTER SHELF	B23-12263	natural	terrestrial vegetation	leaves/seed pod	3	-
OUTER SHELF	B23-12263	natural	terrestrial vegetation	stick/branch/driftwood	4	-
OUTER SHELF	B23-12267	natural	terrestrial vegetation	stick/branch/driftwood	5	-
OUTER SHELF	B23-12269	natural	marine	rock	2	-
OUTER SHELF	B23-12269	natural	terrestrial vegetation	stick/branch/driftwood	13	-

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
OUTER SHELF	B23-12270	natural	marine	foliose algae - not kelp	1	-
OUTER SHELF	B23-12270	natural	terrestrial vegetation	stick/branch/driftwood	3	-
OUTER SHELF	B23-12271	anthropogenic	plastic	plastic piece (unid.)	1	-
OUTER SHELF	B23-12271	natural	marine	kelp stipe/blade	3	-
OUTER SHELF	B23-12271	natural	terrestrial vegetation	stick/branch/driftwood	1	-
OUTER SHELF	B23-12272	natural	marine	foliose algae - not kelp	1	-
OUTER SHELF	B23-12272	natural	terrestrial vegetation	stick/branch/driftwood	2	-
OUTER SHELF	B23-12278	natural	terrestrial vegetation	stick/branch/driftwood	1	-
OUTER SHELF	B23-12283	anthropogenic	plastic	other plastic (comment req.)	1	-
OUTER SHELF	B23-12283	natural	marine	kelp stipe/blade	3	-
OUTER SHELF	B23-12534	anthropogenic	plastic	other plastic (comment req.)	1	-
OUTER SHELF	B23-12534	natural	marine	kelp stipe/blade	-	M
OUTER SHELF	B23-12535	natural	marine	kelp stipe/blade	1	-
OUTER SHELF	B23-12535	natural	marine	seagrass	5	-
OUTER SHELF	B23-12535	natural	terrestrial vegetation	stick/branch/driftwood	1	-
OUTER SHELF	B23-12674	natural	marine	foliose algae - not kelp	2	-
OUTER SHELF	B23-12674	natural	marine	kelp stipe/blade	2	-
OUTER SHELF	B23-12679	natural	marine	kelp stipe/blade	1	-
UPPER SLOPE	B23-12264	anthropogenic	plastic	food bag / wrapper	3	-
UPPER SLOPE	B23-12264	natural	marine	kelp holdfast	1	-
UPPER SLOPE	B23-12264	natural	terrestrial vegetation	leaves/seed pod	1	-
UPPER SLOPE	B23-12264	natural	terrestrial vegetation	stick/branch/driftwood	7	-
UPPER SLOPE	B23-12285	anthropogenic	plastic	cap/lid	1	-
UPPER SLOPE	B23-12285	anthropogenic	plastic	plastic piece (unid.)	1	-
UPPER SLOPE	B23-12285	natural	marine	foliose algae - not kelp	2	-
UPPER SLOPE	B23-12285	natural	marine	kelp stipe/blade	1	-
UPPER SLOPE	B23-12285	natural	marine	seagrass	8	-

STRATUM	STATION ID	ORIGIN	CATEGORY	ITEM	COUNT	EST.
UPPER SLOPE	B23-12289	natural	marine	seagrass	-	M
UPPER SLOPE	B23-12289	natural	terrestrial vegetation	stick/branch/driftwood	2	-
UPPER SLOPE	B23-12296	anthropogenic	plastic	plastic piece (unid.)	1	-
UPPER SLOPE	B23-12298	natural	marine	rock	1	-
UPPER SLOPE	B23-12301	natural	marine	seagrass	2	-
UPPER SLOPE	B23-12301	natural	terrestrial vegetation	stick/branch/driftwood	2	-
UPPER SLOPE	B23-12630	natural	marine	seagrass	4	-
UPPER SLOPE	B23-12631	anthropogenic	plastic	other plastic (comment req.)	1	-
UPPER SLOPE	B23-12631	natural	marine	rock	1	-
UPPER SLOPE	B23-12632	natural	marine	rock	1	-
UPPER SLOPE	B23-12685	anthropogenic	misc. items/pieces	lumber	11	-
UPPER SLOPE	B23-12685	natural	marine	seagrass	3	-

Table A2. Percent of seafloor where anthropogenic debris was found or not found by stratum. Data include debris recovered in benthic trawls during 2023 for each stratum (i.e., bay, inner shelf, mid shelf) and the Southern California Bight, excluding the outer shelf and upper slope.

STRATUM	NUMBER OF TRAWLS	DEBRIS PRESENT	PERCENT AREA (95% CI)
BAY	18	No	60.0 (48.1-71.9)
	12	Yes	40.0 (28.1-51.9)
INNER SHELF	24	No	80.0 (67.9-92.1)
	6	Yes	20.0 (7.9-32.1)
MIDDLE SHELF	24	No	82.8 (70.8-94.7)
	5	Yes	17.2 (5.3-29.2)
BAY + INNER SHELF+ MIDDLE SHELF	66	No	81.1 (72.8-89.5)
	23	Yes	18.9 (10.5-27.2)

Table A3. Area-weighted mean number of anthropogenic debris items per km^2 by debris category. Data include debris recovered in benthic trawls during 2023 for each stratum (i.e., bay, inner shelf, mid shelf) and the Southern California Bight, excluding the outer shelf and upper slope.

STRATUM	NUMBER OF TRAWLS	DEBRIS CATEGORY	MEAN NUMBER OF DEBRIS ITEMS PER KM^2 (95% CI)
BAY	30	Non-plastic	60 (0-120)
BAY	30	Plastic	1,840 (0-3,859)
BAY	30	All trash	1,900 (0-3,913)
INNER SHELF	30	Non-plastic	25 (0-49)
INNER SHELF	30	Plastic	93 (0-218)
INNER SHELF	30	All trash	118 (0-242)
MIDDLE SHELF	29	Non-plastic	34 (0-70)
MIDDLE SHELF	29	Plastic	35 (0-73)
MIDDLE SHELF	29	All trash	69 (0-139)
BAY + INNER SHELF+ MIDDLE SHELF	89	Non-plastic	31 (8-54)
BAY + INNER SHELF+ MIDDLE SHELF	89	Plastic	101 (33-169)
BAY + INNER SHELF+ MIDDLE SHELF	89	All trash	132 (55-208)

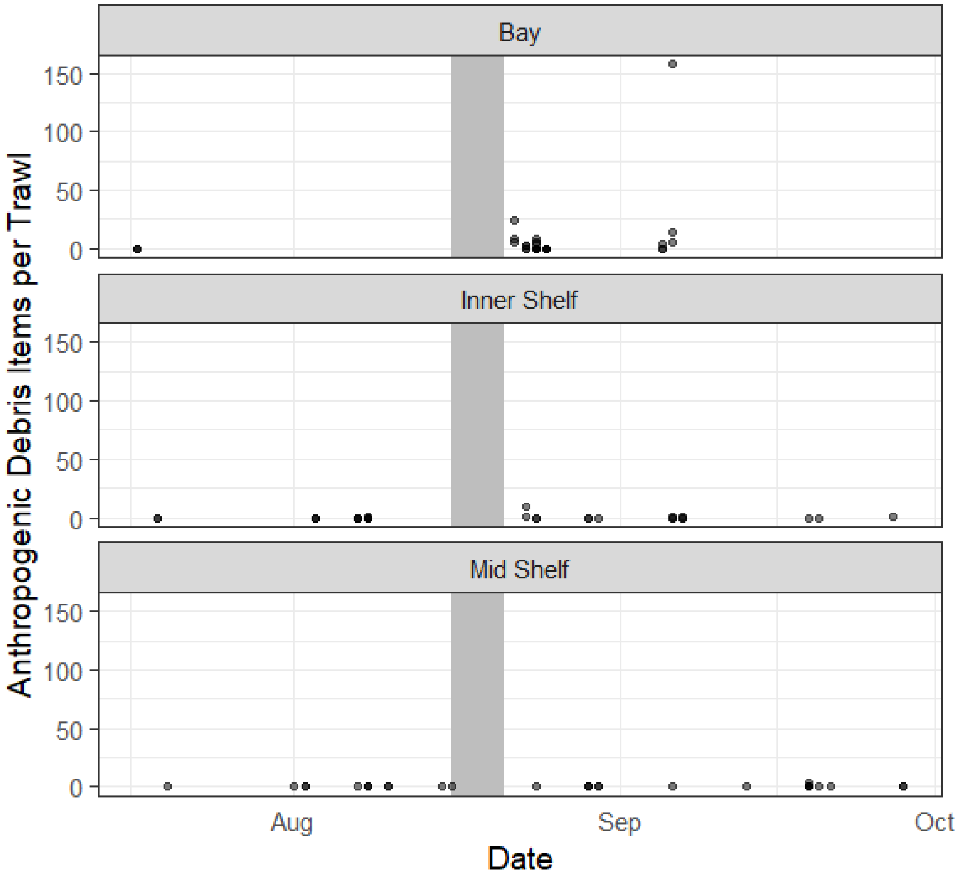


Figure A1. Number of anthropogenic debris items per trawl relative to Tropical Storm Hilary (grey shaded area; August 16, 2023-August 21, 2023). Debris counts in the bays were doubled to correct for shorter trawl time (i.e., 5 minutes) as compared to other strata (i.e., 10 minutes).

Table A4. Percent of seafloor where only plastic debris was detected (plastic), both plastic and non-plastic debris were detected (both), or only non-plastic debris was detected (non-plastic). Data include debris recovered in benthic trawls during 2023 for each stratum (i.e., bay, inner shelf, mid shelf) and the Southern California Bight, excluding the outer shelf and upper slope.

STRATUM	NUMBER OF TRAWLS	DEBRIS CATEGORY	PERCENT AREA (95% CI)
BAY	9	Plastic Only	30.0 (18.2-41.8)
	2	Both	6.7 (0-14.3)
	1	Non-Plastic Only	3.3 (0-9.1)
INNER SHELF	3	Plastic Only	10 (1.1-18.9)
	0	Both	0 -
	3	Non-Plastic Only	10.0 (0.3-19.7)
MIDDLE SHELF	2	Plastic Only	6.9 (0-14.7)
	1	Both	2.2 (0-5.7)
	2	Non-Plastic Only	6.9 (0.1-13.7)
BAY + INNER + MID	14	Plastic Only	8.7 (3.1-14.2)
	3	Both	2.2 (0-5.7)
	6	Non-Plastic Only	8.0 (2.6-13.5)

Table A5. Top debris items recovered in benthic trawls in select strata in the Southern California Bight. Total counts represent the total number of items recovered per stratum. Note that bays had a shorter trawl time (i.e., 5 minutes) as compared to other strata (i.e., 10 minutes) but counts are not doubled.

STRATUM	ITEM NAME	TOTAL COUNT
BAY	Unidentified Plastic Piece	62
	Food Bag/Wrapper	25
	Bag	19
	Other Plastic Item	4
	Cigarette Box/Wrapper	3
	Bottle	2
	Concrete/Asphalt	2
	Other Miscellaneous Item	2
	Polypropylene Rope	1
	Single Use Food Container	1
INNER SHELF	Unidentified Plastic Piece	5
	Food Bag/Wrapper	3
	Bottle	2
	Lumber	1

STRATUM	ITEM NAME	TOTAL COUNT
	Other Miscellaneous Item	1
	Other Plastic Item	1
	Rubber	1
MIDDLE SHELF	Clothing	2
	Other Miscellaneous Item	2
	Bottle	1
	Fishing Line/Net	1
	Food Bag/Wrapper	1
	Other Plastic Item	1
BAY+ INNER SHELF + MIDDLE SHELF	Unidentified Plastic Piece	67
	Food Bag/Wrapper	29
	Bag	19
	Other Plastic Item	6
	Bottle	5
	Other Miscellaneous Item	5
	Cigarette Box/Wrapper	3
	Clothing	2
	Concrete/Asphalt	2
	Fishing Line/Net	1
	Lumber	1
	Polypropylene Rope	1
	Rubber	1
	Single Use Food Container	1

Table A6. Percent of seafloor where trash or plastic were detected. Data include debris recovered in benthic trawls 1998-2023 for select stratum (i.e., bays, inner shelf, middle shelf).

DEBRIS CATEGORY	SURVEY	NUMBER OF STATIONS	PERCENT AREA (95% CI)
TOTAL DEBRIS	1998	245	22.3 (15.3-29.3)
	2003	154	20.5 (14.2-26.8)
	2008	86	20 (12-27.9)
	2013	103	20.8 (12.7-29)
	2018	85	20.2 (11.4-29.1)
	2023	89	18.9 (10.5-27.2)
PLASTIC DEBRIS	1998	245	9.3 (4.6-14.1)
	2003	154	5.7 (1.4-9.9)
	2008	86	8.3 (2.8-13.7)
	2013	103	13.7 (7-20.5)
	2018	85	16.9 (8.5-25.2)
	2023	89	10.8 (4.4-17.3)

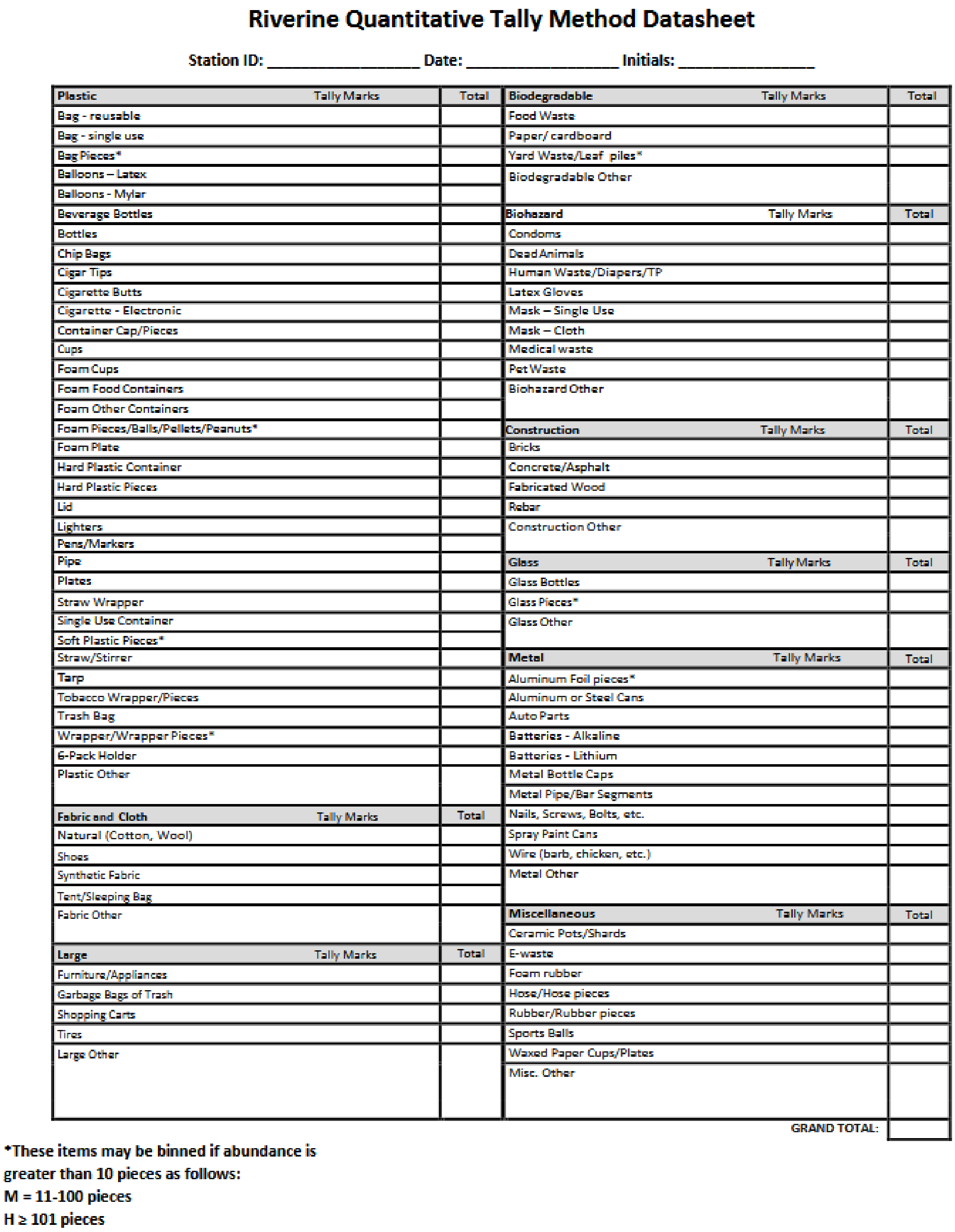
Table A7. The sum of wet season precipitation (October to April) from the year prior to the Bight survey from Long Beach Daugherty Airport, CA (LGB airport; Station ID: USW00023129) and San Diego International Airport, CA (SAN airport; Station ID: USW00023188), and the average of the two locations for each of the Bight survey years (1998-2023).

LOCATION	YEAR	SUM WET SEASON PRECIP (IN)
LGB AIRPORT	1998	27.5
LGB AIRPORT	2003	7.85
LGB AIRPORT	2008	10.7
LGB AIRPORT	2013	5.97
LGB AIRPORT	2018	3.52
LGB AIRPORT	2023	20.5
SAN AIRPORT	1998	16.2
SAN AIRPORT	2003	10.0
SAN AIRPORT	2008	6.95
SAN AIRPORT	2013	6.25
SAN AIRPORT	2018	3.2
SAN AIRPORT	2023	13.8
AVG SAN AND LGB AIRPORTS	1998	21.9
AVG SAN AND LGB AIRPORTS	2003	8.93
AVG SAN AND LGB AIRPORTS	2008	8.83
AVG SAN AND LGB AIRPORTS	2013	6.11
AVG SAN AND LGB AIRPORTS	2018	3.36
AVG SAN AND LGB AIRPORTS	2023	17.15

Table A8. Precipitation received during the summer storm on 8/20/2023 at Long Beach Daugherty Airport, CA (LGB airport; Station ID: USW00023129) and San Diego International Airport, CA (SAN airport; Station ID: USW00023188), and the average of the two locations.

LOCATION	DATE	PRECIP (IN)
LGB AIRPORT	8/20/2023	2.27
SAN AIRPORT	8/20/2023	1.82
AVG SAN AND LGB AIRPORTS	8/20/2023	2.05

APPENDIX B: EXTENT, MAGNITUDE, AND TRENDS OF MACRODEBRIS IN SOUTHERN CALIFORNIA WATERSHEDS



Riverine Quantitative Tally Method Datasheet

Station ID: ________________ Date: ________________ Initials: _______________

Plastic	Tally Marks	Total
Bag - reusable		
Bag - single use		
Bag Pieces*		
Balloons – Latex		
Balloons - Mylar		
Beverage Bottles		
Bottles		
Chip Bags		
Cigar Tips		
Cigarette Butts		
Cigarette - Electronic		
Container Cap/Pieces		
Cups		
Foam Cups		
Foam Food Containers		
Foam Other Containers		
Foam Pieces/Balls/Pellets/Peanuts*		
Foam Plate		
Hard Plastic Container		
Hard Plastic Pieces		
Lid		
Lighters		
Pens/Markers		
Pipe		
Plates		
Straw Wrapper		
Single Use Container		
Soft Plastic Pieces*		
Straw/Stirrer		
Tarp		
Tobacco Wrapper/Pieces		
Trash Bag		
Wrapper/Wrapper Pieces*		
6-Pack Holder		
Plastic Other		
Fabric and Cloth	**Tally Marks**	**Total**
Natural (Cotton, Wool)		
Shoes		
Synthetic Fabric		
Tent/Sleeping Bag		
Fabric Other		
Large	**Tally Marks**	**Total**
Furniture/Appliances		
Garbage Bags of Trash		
Shopping Carts		
Tires		
Large Other		

Biodegradable	Tally Marks	Total
Food Waste		
Paper/ cardboard		
Yard Waste/Leaf piles*		
Biodegradable Other		
Biohazard	**Tally Marks**	**Total**
Condoms		
Dead Animals		
Human Waste/Diapers/TP		
Latex Gloves		
Mask – Single Use		
Mask – Cloth		
Medical waste		
Pet Waste		
Biohazard Other		
Construction	**Tally Marks**	**Total**
Bricks		
Concrete/Asphalt		
Fabricated Wood		
Rebar		
Construction Other		
Glass	**Tally Marks**	**Total**
Glass Bottles		
Glass Pieces*		
Glass Other		
Metal	**Tally Marks**	**Total**
Aluminum Foil pieces*		
Aluminum or Steel Cans		
Auto Parts		
Batteries - Alkaline		
Batteries - Lithium		
Metal Bottle Caps		
Metal Pipe/Bar Segments		
Nails, Screws, Bolts, etc.		
Spray Paint Cans		
Wire (barb, chicken, etc.)		
Metal Other		
Miscellaneous	**Tally Marks**	**Total**
Ceramic Pots/Shards		
E-waste		
Foam rubber		
Hose/Hose pieces		
Rubber/Rubber pieces		
Sports Balls		
Waxed Paper Cups/Plates		
Misc. Other		
	GRAND TOTAL:	

*These items may be binned if abundance is
greater than 10 pieces as follows:
M = 11-100 pieces
H ≥ 101 pieces

Figure B1. Riverine Quantitative Tally Method Datasheet

Table B1. Percent of stream kilometers where anthropogenic debris was found or not found by land use at least once between 2020-2024.

STRATUM	NUMBER OF SITES	DEBRIS PRESENT	PERCENT STREAM KM (95% CI)
OPEN	33	No	32.0 (17.1-46.8)
	63	Yes	68.0 (53.2-82.9)
AGRICULTURAL	7	No	14.2 (0-31.8)
	30	Yes	85.8 (68.2-100)
URBAN	5	No	2.0 (0.2-3.7)
	132	Yes	98.0 (96.3-99.8)
REGION	45	No	16.8 (9.4-24.2)
	225	Yes	83.2 (75.8-90.6)

Table B2. Area-weighted mean debris abundance (debris items/meter of stream length) by land use type.

STRATUM	NUMBER OF SITES	DEBRIS ABUNDANCE (ITEMS/METER) (95% CI)
AGRICULTURAL	37	0.28 (0.18-0.38)
OPEN	96	0.16 (0.09-0.24)
URBAN	137	1.27 (0.91-1.62)
REGION	270	0.63 (0.45-0.81)

Table B3. Percent of stream kilometers where anthropogenic debris was found or not found by county. Debris presence was determined based on if a site had anthropogenic debris between 2020 and 2024.

COUNTY	SITES	DEBRIS PRESENT	PERCENT AREA (95% CI)
VENTURA	11	No	9.8 (3.0-16.7)
	29	Yes	90.2 (83.4-97.0)
LOS ANGELES	15	No	21.5 (4.0-39.0)
	94	Yes	78.5 (61.0-96.0)
SAN BERNARDINO	1	No	15.5 (0-39.2)
	15	Yes	84.5 (60.8-100)
ORANGE	2	No	18.8 (0-44.7)
	34	Yes	81.2 (55.3-100)
RIVERSIDE	2	No	22.9 (2.3-43.5)
	18	Yes	77.1 (56.5-97.7)
SAN DIEGO	13	No	11.3 (3.8-18.9)
	31	Yes	88.7 (81.1-96.3)

Table B4. Area-weighted mean debris abundance (debris items/meter of stream length) by county.

COUNTY	NUMBER OF SITES	DEBRIS ABUNDANCE (ITEMS/METER) (95% CI)
VENTURA	40	0.37 (0.2-0.54)
LOS ANGELES	109	0.76 (0.38-1.13)
SAN BERNARDINO	17	0.3 (0.12-0.49)
ORANGE	36	0.84 (0.51-1.18)
RIVERSIDE	20	0.61 (0.11-1.12)
SAN DIEGO	48	0.81 (0.13-1.5)

Table B5. Area-weighted mean debris abundance (debris items/meter of stream length) by debris category.

	DEBRIS ABUNDANCE (ITEMS/STREAM METER) (95% CI)			
DEBRIS CATEGORY	**Agricultural**	**Open**	**Urban**	**Regional**
PLASTIC	0.22 (0.09-0.35)	0.12 (0.06-0.17)	0.9 (0.61-1.19)	0.45 (0.31-0.59)
METAL	0.02 (0.01-0.03)	0.01 (0.01-0.02)	0.1 (0.07-0.13)	0.05 (0.03-0.06)
FABRIC/CLOTH	0.04 (0.01-0.06)	0.01 (0-0.02)	0.08 (0.05-0.1)	0.04 (0.03-0.05)
BIODEGRADABLE	0.01 (0-0.01)	0.01 (0-0.02)	0.07 (0.05-0.09)	0.03 (0.02-0.05)
MISCELLANEOUS	0.02 (0-0.04)	0.01 (0-0.02)	0.07 (0.04-0.1)	0.03 (0.02-0.05)
CONSTRUCTION	0.04 (0.01-0.07)	0 (0-0.01)	0.04 (0.02-0.06)	0.02 (0.01-0.03)
GLASS	0.01 (0-0.03)	0 (0-0)	0.05 (0.02-0.07)	0.02 (0.01-0.03)
LARGE	0 (0-0.1)	0 (0-0)	0.02 (0.01-0.02)	0.01 (0-0.01)
BIOHAZARD	0 (0-0)	0 (0-0)	0.01 (0-0.01)	0 (0-0.01)

Table B6. Area-weighted mean debris abundance (debris items/meter of stream length) by debris category.

YEAR	DEBRIS CATEGORY	NUMBER OF SITEs WITH CATEGORY PRESENT	PERCENT STREAM KM^2	LOWER 95% CI	UPPER 95% CI
2011	Trash	60	100	100	100
2011	Plastic	55	83	69	98
2012	Trash	75	100	100	100
2012	Plastic	67	92	86	99
2013	Trash	37	44	29	60
2013	Plastic	35	39	24	55
2018	Trash	67	71	51	91
2018	Plastic	63	70	50	90
2019	Trash	58	71	58	84
2019	Plastic	50	68	54	81
2020	Trash	43	89	82	96
2020	Plastic	36	85	76	94
2021	Trash	43	59	42	76
2021	Plastic	40	57	41	74
2022	Trash	55	47	31	64
2022	Plastic	51	41	26	56
2023	Trash	77	90	82	97
2023	Plastic	68	77	63	92
2024	Trash	77	80	70	90
2024	Plastic	70	65	48	82
ALL YEARS	Trash	592	74	69	79
ALL YEARS	Plastic	535	67	61	72

Table B7. Area-weighted mean single-use bag abundance (debris items/meter of stream length).

YEAR	NUMBER OF SITES ASSESSED	SINGLE-USE BAG ABUNDANCE (ITEMS/STREAM METER)	LOWER 95% CI	UPPER 95% CI
2011	60	0.127	0.075	0.179
2012	75	0.11	0.07	0.15
2013	96	0.119	0.027	0.21
2018	81	0.048	0.018	0.078
2019	80	0.022	0.012	0.032

YEAR	NUMBER OF SITES ASSESSED	SINGLE-USE BAG ABUNDANCE (ITEMS/STREAM METER)	LOWER 95% CI	UPPER 95% CI
2020	56	0.021	0.007	0.034
2021	52	0.044	0.014	0.074
2022	80	0.029	0.01	0.048
2023	90	0.054	0.03	0.077
2024	102	0.026	0.012	0.04
2011-2013	231	0.118	0.073	0.163
2018-2024	541	0.036	0.028	0.044
ALL YEARS	772	0.06	0.046	0.073

Table B8. Area-weighted mean reusable bag abundance (debris items/meter of stream length). The category "bag - reusable" was added to the tally sheet in 2018.

YEAR	NUMBER OF SITES ASSESSED	REUSABLE BAG ABUNDANCE (ITEMS/STREAM METER)	LOWER 95% CI	UPPER 95% CI
2018	81	0.002	0	0.004
2019	80	0.002	0	0.004
2020	56	0	0	0
2021	52	0.01	0	0.019
2022	80	0.005	0	0.012
2023	90	0.004	0	0.007
2024	102	0.003	0.001	0.006
ALL YEARS	541	0.003	0.002	0.005

APPENDIX C: DATA AVAILABILITY

Raw data are publicly available via the SCCWRP Data Portal https://dataportal.sccwrp.org/.

APPENDIX D: EXPLORATORY NMDS

Dr. Rae McNeish, California State University Bakersfield

NMDS Methods:

The anthropogenic litter (AL) 'community' structure was visualized with nonmetric multidimensional scaling (NMDS) to determine if land use/land cover (LULC), county, and watershed sampled explained 2023 AL 'community' patterns based on material type (e.g., plastic, metal, biohazard). NMDS was conducted using a sample-by-AL material category abundance matrix with *metaMDS()* (max try of 999 iterations, Bray-Curtis similarity distance, 'vegan' package; McCune and Grace 2002; Oksanen et al. 2015). A maximum of three NMDS ordinations were conducted on the AL-material categories dataset. The second and third ordinations were conducted from the previous best NMDS result. To ensure the final NMDS ordination was a stable solution, both Procrustes and Protest analyses were conducted (Jackson 1995). Ordinations were visually checked for outliers and outliers removed if deviated more than 4 score distance values from the main cloud of points. If outliers were found, then NMDS ordinations were rerun, and the final ordination was considered to have stable solutions relative to previous ordination solutions (all m^2 values < 0.001 via *protest()*, 'vegan' package; Oksanen et al. 2015). The effect of LULC, county, and watershed sampled on AL 'communities' were analyzed using ADONIS (*adonis2()*, 'vegan' package; Oksanen et al. 2015) via additive models. Indicator species analysis (ISA) was conducted to identify the degree of association of AL material types linked with LULC categories, counties, and watersheds sampled (*indval()*, 'labdsv' package; Roberts 2023). All analyses were duplicated for a second dataset that was focused on exploring AL 'communities' at the material-item type combination level (e.g., plastic-beverage bottle). All analyses were conducted in R version 4.5.2.

Results:

Results suggested that LULC, county, and watershed sampled all significantly explained 2023 AL 'community' patterns at the broader AL material type category, collecting explaining approx. 36.2% of the variation in these communities (Table 1). The AL material type 'community' was significantly unique between open and agricultural sites (Table 2; Fig. 1a), with construction material significanlty indicative of urban sites (35.27%; Table 3). These AL 'communities' were also significantly unique between Orange and San Diego Counties (Table 2), but these counties did not have materials that were significantly associated with them. There were several significantly unique AL material type 'communities' among watersheds sampled (Table 2). For example, the Santa Clara, Santa Monica, and Northern San Diego watersheds each supported unique materal type communities from other watersheds (4, 3, and 3 other watersheds, respectively; Table 2).

Results indicated that LULC, county, and watershed sampled did not significantly explain 2023 AL 'community' patterns at the more specific AL material-item type level (Table 1); however, several AL material-item types were found to be significantly associated with specific LULC, counties, and watersheds sampled (Table 3). For example, plastic beverage bottles were significanlty associated with urban sites (29.63%; Table 3). Orange Couty was significantly associated with construction – fabricated wood (27.95%) and plastic – beverage bottles (31.76%), while San Bernardino County was significantly associated with plastic – cigarette buts (39.94%; Table 3). Several plastic items were associated with the Southern San Diego watershed, which included trash bags (79.44%), soft plastic pieces (70.20%), lighters (62.01%), hard containers (53.61%), and wrapper pieces (46.32%; Table 3).

Table 1. ADONIS permutation analyses for anthropogenic litter (AL) 'communities' at the AL-material category level (e.g., plastic, construction) as explained by watershed, county, and land use/land cover (LULC). df = degrees of freedom, SS = sum of squares. The SS, R^2, and F-statistic values were rounded.

AL Community	Source of Variation	df	SS	R^2	F-Statistic	P-Value
Material Category	Watershed	13	4.71	0.209	1.508	0.0098
	County	4	1.57	0.070	1.637	0.0332
	LULC	2	1.88	0.083	3.915	0.0001
	Residuals	60	14.42	0.638		
	Total	79	22.59	1.000		
Material-Item Type	Watershed	13	5.20	0.164	0.979	0.5858
	County	4	1.53	0.048	0.936	0.6819
	LULC	2	0.95	0.030	1.163	0.1822
	Residuals	59	24.12	0.760		
	Total	78	31.80	1.000		

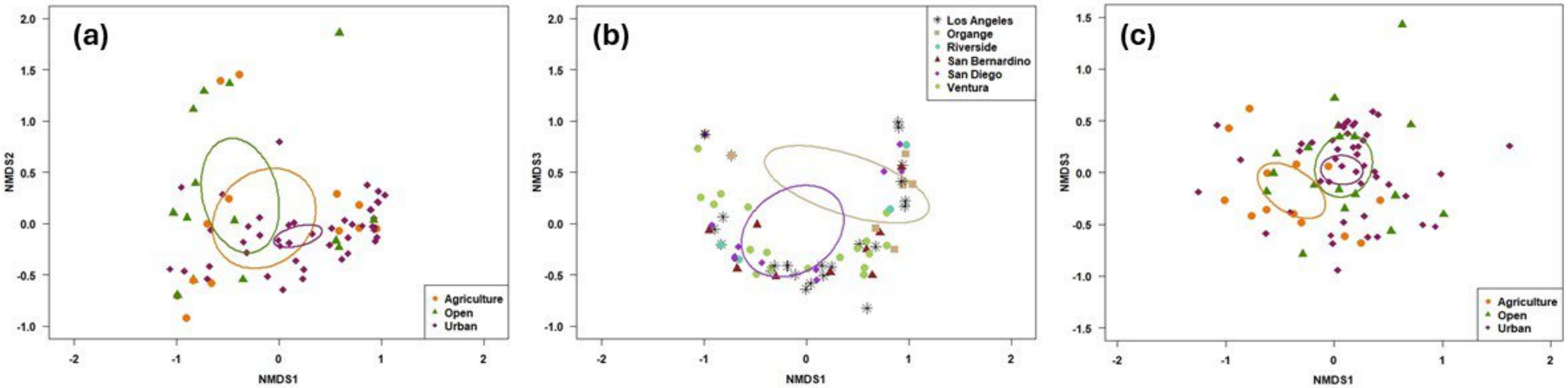


Figure 1. Anthropogenic litter material type 'community' relationship among (a) land use/landcover and (b) counties. Ellipses represent 95% confidence ellipses. Only two ellipses shown for counties to highlight the significant difference between pairwise comparisons without including ellipses for all counties.

Table 2. Anthropogenic litter material category ‘community’ significant pairwise comparisons among land use/land cover (LULC), county, and watershed sampled combinations. Statistical significance was determined as P < 0.05.

Variable	Comparisons	P-Value
LULC	Open vs Urban	0.001
County	Orange vs San Diego	0.049
Watershed	Santa Clara vs San Gabriel	0.004
	Santa Clara vs Calleguas	0.016
	Santa Clara vs Los Angeles	0.042
	Santa Clara vs Middle Santa Ana	0.026
	Santa Monica Bay vs San Gabriel	0.036
	Santa Monica Bay vs Middle Santa Ana	0.013
	Northern San Diego vs San Gabriel	0.010
	Northern San Diego vs Calleguas	0.018
	Northern San Diego vs Middle Santa Ana	0.021

Table 3. Indicator species analysis summary results for anthropogenic litter 'communities' based on material category (e.g., construction, plastic) and material-item type combinations (plastic-beverage bottles). IV = indicator value.

Community Type	Variable	Category	Material-Item Type	IV	P-Value
Material Category	LULC	Urban	Construction	0.3527	0.047
Material-Item Type	LULC	Urban	Plastic - Beverage Bottles	0.2963	0.028
	County	Orange	Construction - Fabricated Wood	0.2795	0.033
		Orange	Plastic - Beverage Bottles	0.3176	0.032
		San Bernardino	Plastic - Cigarette Butts	0.3994	0.022
	Watershed	Southern San Diego	Plastic - Trash Bags	0.7944	0.034
		Southern San Diego	Plastic - Soft Plastic Pieces	0.7020	0.003
		Southern San Diego	Plastic - Lighters	0.6201	0.004
		Southern San Diego	Plastic - Hard Containers	0.5361	0.032
		Southern San Diego	Plastic - Wrapper Pieces	0.4632	0.035

Discussion of Potential Applications:

The unique anthropogenic litter communities identified with these analyses indicates that LULC type, county, and watershed sampled may be important variables explaining litter patterns in streams. Different anthropogenic activities occurring across LULC types may be linked with the littering of specific materials and items in the envronment connected to streams. Watershed features (e.g., stream water dynamics, channel type, human populations density) may be important variables linked to the abundance, distribution, and transport of AL across the terrestrial-aquatic interface. Possibly unqiue AL policies associated with different counties could be impacting anthropogenic litter 'communities'.

Findings also provide suggestions for some targeted efforts at the LULC, county, and watershed levels. For example, contstruction materials were significantly associated with urban sites; therefore, local policies could be created (e.g., increase trash recepticals) at construction sites to reduce construction litter in streams. Plastic cigarette butts were significantly indicative of San Bernardino County, therefore, this county could develop an educational and smoking receptacle program to encourage the local population to properly dispose of cigarette butts. The San Diego watershed was significantly associated with multiple plastic items (e.g., trash bags, wraper pieces, containers) that were not associated with other watersheds. It is possible that the plastic AL policies are not similar in this watershed compared to the other watersheds sampled.

Future community-level analyses could be expanded to include all years sampled (2020-2024), which could provide insights into how these communities changed over time, potentially in response to litter policies and management efforts. In addition, geospatial statistical analysis could be conducted to determine geographic litter community patterns and hotspots (e.g., hotspot analysis, average nearest neighbor analysis), which might help to narrow down geographic regions that span political (e.g., county) and ecological (e.g., watersheds) boundaries.

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