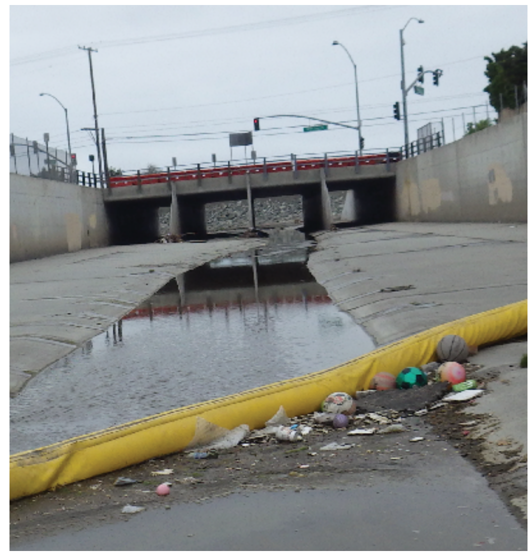
BIGHT '18

# Trash and Marine Debris



## Southern California Bight 2018 Regional Monitoring Program Volume IX

SCCWRP Technical Report 1263

# Southern California Bight 2018 Regional Monitoring Program: Volume IX. Trash and Marine Debris

Karen McLaughlin, Raphael Mazor, Kenneth Schiff, Leah Thornton Hampton

*Southern California Coastal Water Research Project, Costa Mesa, CA*

**May 2022**
Technical Report #1263

## Bight '18 Trash Committee

| Member | Affiliation |
|---|---|
| Karen McLaughlin (Chair) | Southern California Coastal Water Research Project |
| Jaime Favila | State Water Resources Control Board |
| Lori Webber | State Water Resources Control Board |
| Anika Ballent | Moore Institute for Plastic Pollution Research |
| Ilan MacAdam-Somer | Moore Institute for Plastic Pollution Research |
| Charles Moore | Moore Institute for Plastic Pollution Research |
| Alexis Wallengren | Aquatic Bioassay and Consulting Laboratories |
| Karin Wisenbaker | Aquatic Bioassay and Consulting Laboratories |
| Kaitlyn Kalua | CA Ocean Protection Council |
| Kenneth Chong | City of Los Angeles |
| Jennifer Smolenski | City of Los Angeles |
| Justin Gamble | City of Oceanside |
| Ryan Rodman | City of Oceanside |
| Robin Gartman | City of San Diego |
| Ryan Kempster | City of San Diego |
| Ami Latker | City of San Diego |
| Kelly Hahs | Ventura County Watershed Protection District |
| Phil Markle | Los Angeles County Sanitation Districts |
| Shelly Walther | Los Angeles County Sanitation Districts |
| Jun Zhu | Los Angeles Regional Water Quality Control Board |
| Michelle Lin | Los Angeles Water Keeper |
| Melissa von Mayrhauser | Los Angeles Water Keeper |
| Katie Nichols | Orange County Coast Keeper |
| Chris Crompton | Orange County Public Works |
| James Fortuna | Orange County Public Works |
| Michael Mori | Orange County Public Works |
| George Robertson | Orange County Sanitation District |
| Karen Holman | Port of San Diego |
| Kelly Tait | Port of San Diego |
| Kristin Kuhn | San Diego Coast Keeper |
| Doug Shibberu | Santa Ana Regional Waterboard |
| Ken Schiff | Southern California Coastal Water Research Project |
| Leah Thornton Hampton | Southern California Coastal Water Research Project |
| Steve Weisberg | Southern California Coastal Water Research Project |
| Win Cowger | University of California, Riverside/Moore Institute for Plastic Pollution Research |
| Owen Damon | Weston Solutions |
| Terra Miller-Cassman | Wood Environment & Infrastructure Solutions, Inc. |
| John Rudolph | Wood Environment & Infrastructure Solutions, Inc. |
| Theodore Von Bitner | Wood Environment & Infrastructure Solutions, Inc. |

## FOREWORD

The Southern California Bight 2018 Regional Monitoring Program (Bight ’18) is an integrated, collaborative effort to provide large-scale assessments of the Southern California Bight (SCB). The Bight ’18 survey is an extension of previous regional assessments conducted every 5 years dating back to 1994. The collaboration represents the combined efforts of nearly 100 organizations. Bight ’18 is organized into 5 elements: 1) Sediment Quality (formerly Contaminant Impact Assessment/ Coastal Ecology); 2) Microbiology; 3) Ocean Acidification; 4) Harmful Algal Blooms; and 5) Trash and Marine Debris. This assessment report presents the results of Trash and Marine Debris portion of the survey. In addition to the collaborating agencies of the Bight Program, this Trash Assessment is a collaboration with agencies participating in the Southern California Storm Water Monitoring Coalition (SMC), providing a synthesis of anthropogenic waste from land and sea. Chapters in this report will be published as manuscripts in peer reviewed journals.

Copies of this and other Bight ’18 reports, as well as work plans and quality assurance plans, are available for download at SCCWRP’s website: https://www.sccwrp.org/about/research-areas/regional-monitoring/southern-california-bight-regional-monitoring-program/bight-program-documents/bight-18/.

### Citation

McLaughlin, K., R. Mazor, K. Schiff, and L. Thornton-Hampton. 2022. Southern California Bight 2018 Regional Monitoring Program: Volume IX. Trash and Marine Debris. Technical Report #1263. Southern California Coastal Water Research Project. Costa Mesa, CA.

## ACKNOWLEDGEMENTS

This report is a result of the dedication and hard work of many individuals who share a common goal of improving our understanding of the environmental quality of the Southern California Bight and its coastal watersheds. The authors wish to thank the members of the Bight ’18 Trash and Marine Debris Committee for their assistance with study design, sample analysis, data analysis and report review. We also thank the Bight ’18 Sediment Quality Planning Committee and the Stormwater Monitoring Coalition for their guidance and support of trash and marine debris measurements in regional monitoring. This study would not have been possible without the expertise in sample collection from the following organizations participating in the Bight Marine Monitoring Program: City of Los Angeles, City of San Diego, Orange County Public Works, Orange County Sanitation District, The San Diego County Regional Harbor Monitoring Program, Sanitation Districts of Los Angeles County, and the Southern California Coastal Water Research Project; as well as those agencies participating in the Southern California Storm Water Monitoring Coalition (SMC): Aquatic Bioassay and Consulting Laboratories, California Regional Water Quality Control Board, Los Angeles Region, California Regional Water Quality Control Board, San Diego Region, California Regional Water Quality Control Board, Santa Ana Region, California State Water Resources Control Board, California Department of Transportation, City of Long Beach Public Works, City of Los Angeles Public Works, Los Angeles County Public Works, Orange County Public Works, San Diego County Public Works, Southern California Coastal Water Research Project, Ventura County Public Works, and Weston Solutions.

## EXECUTIVE SUMMARY

### Background

The pollution of oceans and watersheds by anthropogenic litter has been recognized as a serious global environmental concern. On land and in freshwater habitats, this litter is typically referred to as trash, and as marine debris in ocean habitats. Trash and marine debris affect aesthetics as well as habitat quality and aquatic life. Marine debris in southern California significantly influences the decision of the public to go to beaches, costing Orange County residents alone an estimated $148 million per year just to travel to cleaner beaches. Trash and debris present entanglement and ingestion dangers for organisms. Additionally, plastics in the environment can transport other contaminants, creating a bioaccumulation pathway by which aquatic organisms accumulate contaminants when they consume plastic.

Trash and marine debris have become a policy focus throughout the State of California, with several policies and management actions implemented to reduce trash. These policies include bans of specific items (e.g., single-use plastic bags), establishing total maximum daily loads (TMDLs) in watersheds, and implementation of Statewide Trash Amendments and the California Ocean Litter Strategy designed to mitigate trash and debris.

The Southern California Bight (SCB) 2013 Regional Marine Monitoring Program (Bight '13) included the first, coordinated regional assessment of trash and marine debris in the Southern California Bight. This study found that trash was pervasive in both streams and offshore, observing trash in three quarters of SCB wadeable streams and one third of the seafloor. This study also found offshore marine debris has been increasing from 1994 to 2013. Trends were not assessed for watershed trash because 2013 was the first time a coordinated watershed trash assessment was conducted.

To evaluate the effectiveness of management actions and establish linkages with regional factors which may result in changing amounts of trash and marine debris, continued monitoring of trash and marine debris is required. Long-term data on trash types as well as trash extent and magnitude can be used to target items for bans as well as track the effectiveness (or lack thereof) of specific management actions (including bans as well as trash mitigation strategies), identify hotspots, and generate enough statistical power to evaluate sources and pathways for trash pollution in receiving waters. The Bight '18 Trash and Marine Debris Program was designed to meet this need.

### Study Objectives and Approach

The objectives of the Bight '18 Trash Program were to characterize the extent and magnitude of debris in SCB watersheds and marine environments and to determine any linkages with local factors. The program focused on answering three main questions:

1. What is the extent and magnitude of trash on the seafloor and inland waterways?
2. What are the trends of trash types and amounts on the seafloor and inland waterways?

3. Are there any factors that may be contributing to larger amounts of trash in watersheds?

Seafloor marine debris was estimated using similar protocols to previous Bight surveys dating back to 1994. Watershed trash was estimated across 7,400 kilometers of SCB coastal watersheds. Sites were selected using a probability-based, stratified-random sampling. In total, trash was assessed at 138 sites offshore and 166 sites in SCB watersheds.

## Study Findings

The Bight ’18 Program found that trash continues to be pervasive in watersheds and in offshore epi-benthic environments. Over 75% of stream kilometers and 30% of offshore area were estimated to have trash present at the time of sampling. Stock assessments indicate the presence of over 7 million pieces of trash in watersheds and over 250,000 trawl-caught pieces of trash offshore. Of the types of trash assessed, plastic trash was the most pervasive with 69% of stream kilometers and 27% of offshore area estimated to have plastic trash present. Offshore, plastic trash is increasing over time, having increased from 4% to 17% of area between 1994 and 2018. Both the areal extent of watershed trash and the abundance of trash in watersheds were similar to the 2013 Bight Trash survey.

Management actions may have decreased trash and plastic in SCB watersheds. Santa Monica Bay watershed saw a significant decrease in both trash and plastic abundance, perhaps due to the trash TMDL in the watershed. In addition, abundance of plastic bags significantly decreased between 2013 and 2018, perhaps due to the statewide bag ban implemented in 2016.

Watershed factors indicative of human activity were predictive of trash abundance in waterways. Road density, paved intersections, proximity to roads and parking lots, and human disturbance metrics were associated with higher trash abundance in watersheds. Some physical habitat metrics such as slope and sinuosity were also associated with higher trash abundance, perhaps aiding local retention in the reach.

## Recommendations

Managers have made significant investments in trash mitigation strategies and policies; therefore, regional assessments of trash and marine debris should continue to determine if trash or specific trash items have decreased over time in response to management actions and to guide additional trash management strategies. Future surveys should also consider offshore marine debris assessment methods that better align with watershed assessments so standing stocks can be directly compared and to enable studies of sources, transport, and fate of trash from land to sea. Investments in standardization of data collection and data management now will enable future monitoring efforts to detect changes in trash pollution more readily and powerfully.

Given that plastic had the greatest extent and magnitude of any trash type, managers should invest in plastic effects-based research to determine the extent to which plastic is causing impacts to aquatic life or human health beneficial uses. In addition, given the abundance of small plastic pieces in our watershed survey, the next regional assessment should include an assessment of the regional extent and magnitude of microplastics.

## TABLE OF CONTENTS

## List of Figures

## List of Tables

# CHAPTER 1: BIGHT 18 REGIONAL TRASH AND MARINE DEBRIS ASSESSMENT: SYNTHESIS FROM LAND TO SEA

## Introduction

The pollution of oceans and watersheds by anthropogenic litter has been recognized as a serious global environmental concern (Amon et al. 2020). On land and in freshwater habitats, this litter is typically referred to as trash, and as marine debris in ocean habitats. Trash and marine debris affect aesthetics as well as habitat quality and aquatic life. Leggett et al. (2014) found that marine debris in southern California significantly influences the decision of the public to go to beaches, costing Orange County residents alone an estimated $148 million per year just to travel to cleaner beaches. In marine environments, debris presents entanglement and ingestion dangers for marine organisms (Boerger et al. 2010; Goldstein and Goodwin 2013; Lusher et al. 2013; Anastasopoulou et al. 2013; Bond et al. 2013; Di Beneditto and Ramos 2014; Gall and Thompson 2015). Furthermore, plastics in the environment can transport other contaminants, creating a bioaccumulation pathway by which aquatic organisms take up contaminants when they consume plastic (Rios et al. 2007; Farrington and Takada 2014).

Because trash and marine debris have the potential to adversely impact freshwater and marine beneficial uses, California state and local agencies have proposed and implemented trash mitigation strategies for California waterways, including recycling programs, plastic bag bans, and other regulations and legislation. In 2011, California Assembly Bill 341 established a goal of reaching 75% recycling statewide by 2020 through source reduction, recycling, and composting (CalRecycle 2015). State and federal regulators also have established total maximum daily loads (TMDLs) for the Los Angeles River and Santa Monica Bay watersheds specifying that their rivers contain zero trash pieces greater than 5 mm in diameter (CRWQCBLAR 2007, 2010, 2015, 2019). The State Water Board adopted similar statewide regulations as part of its Water Quality Control Plan (SWRCB 2015). California Senate Bill 270 in 2014 issued a statewide ban on single-use plastic bags and California voters approved Proposition 67, confirming their support of the ban which was implemented state-wide in 2016.

To begin to track the effectiveness of these and other management actions, the Southern California Bight (SCB) 2013 Regional Marine Monitoring Program (Bight '13) included the first coordinated regional assessment of trash and marine debris in the Southern California Bight (SCB, Moore et al. 2016). This study found that trash was pervasive in both streams and offshore, with trash observed in three-quarters of SCB wadeable streams and one-third of the seafloor. The 2013 study also found offshore marine debris increased from 1994 to 2013. Because 2013 was the first Bight Program coordinated watershed trash assessment, we did not assess trends for rivers and streams in the 2018 program using only 2 time points. A recommendation from the Bight '13 program was to continue to monitor trash and marine debris to evaluate the effectiveness of management actions and establish linkages with regional factors which may affect trash and marine debris throughout the region. The Southern California Bight 2018 Regional Marine Monitoring Program (Bight '18) was designed to continue to meet this need.

## Goal of this study

The Bight ’18 Program built upon the Bight ’13 regional trash and debris assessment, with the goal of assessing the extent and magnitude of trash and marine debris in southern California waterways, from wadeable streams to the marine habitats of the SCB. The study leveraged the resources and expertise of dozens of Bight ’18 participating agencies, and asked three key questions:

1. **What is the extent, magnitude, and types of trash in rivers and streams and on the seafloor?** Quantifying the regional footprint of trash and debris illustrates the scope of the problem. By identifying differences among habitats, managers can potentially identify hotspots of trash generation or accumulation. Determining the most pervasive types of trash/debris enables managers to focus future management efforts effectively and target specific items for policy measures.

2. **What are the trends in extent and magnitude of trash and types of trash in rivers and streams and on the seafloor?** Evaluating trends establishes whether trash and debris pollution is increasing or decreasing and provides a baseline with which to indicate the effectiveness of management actions in the future.

3. **Are there any site-specific factors that may be contributing to larger amounts of trash in rivers and streams?** Characterizing site-specific factors which may contribute to higher or lower levels of trash within given areas can enable managers to design more effective trash management strategies in coastal waterways.

## Study Approach

The Bight ’18 Trash element estimated trash in watersheds and marine debris on the seafloor (Figure 1.1). Sites were selected using a probability-based stratified-random design (Stevens 1997) that allows unbiased estimates of extent (% of stream-kilometers or % of seafloor) and magnitude (average abundance).

**Watershed Trash Assessment**: Trash in streams was estimated by leveraging sampling efforts of the Southern California Stormwater Monitoring Coalition (SMC), a collaborative monitoring program that includes regulated and regulatory agencies working together to answer scientific questions relevant to stormwater management *(*www.SoCalSMC.org). A total of 166 sites were sampled from 2018 to 2019, typically in the summer dry weather period (April to August), following a modification made to the California State Rapid Trash Assessment protocol (San Francisco Bay Regional Water Quality Control Board 2004). Each site was defined as a stream reach 30.5 m (100 ft) in length and a width of high-water mark (or bankfull height if a high-water mark was not discernable). All trash pieces within this stream reach were counted and categorized. Please refer to Chapter 3 for further details.

**Seafloor Marine Debris Assessment**: Macro-debris on the seafloor (also referred to as epibenthic macro-debris) of the SCB was estimated by leveraging the sampling efforts of the Bight ’18 Sediment Quality Assessment trawl survey (Bight ’18 Demersal Fish and Megabenthic

Invertebrate Assessment). A total of 138 trawls were collected at depths ranging from 5 m to 500 m from July to September 2018. Trawls were conducted by hauling nets (7.6-m headrope semi-balloon otter trawl, 1.3 cm cod-end mesh) behind the research vessel at approximately 1.0 m/sec for 10 minutes. Debris caught in the net were counted and categorized. Please refer to Chapter 3 for further details.

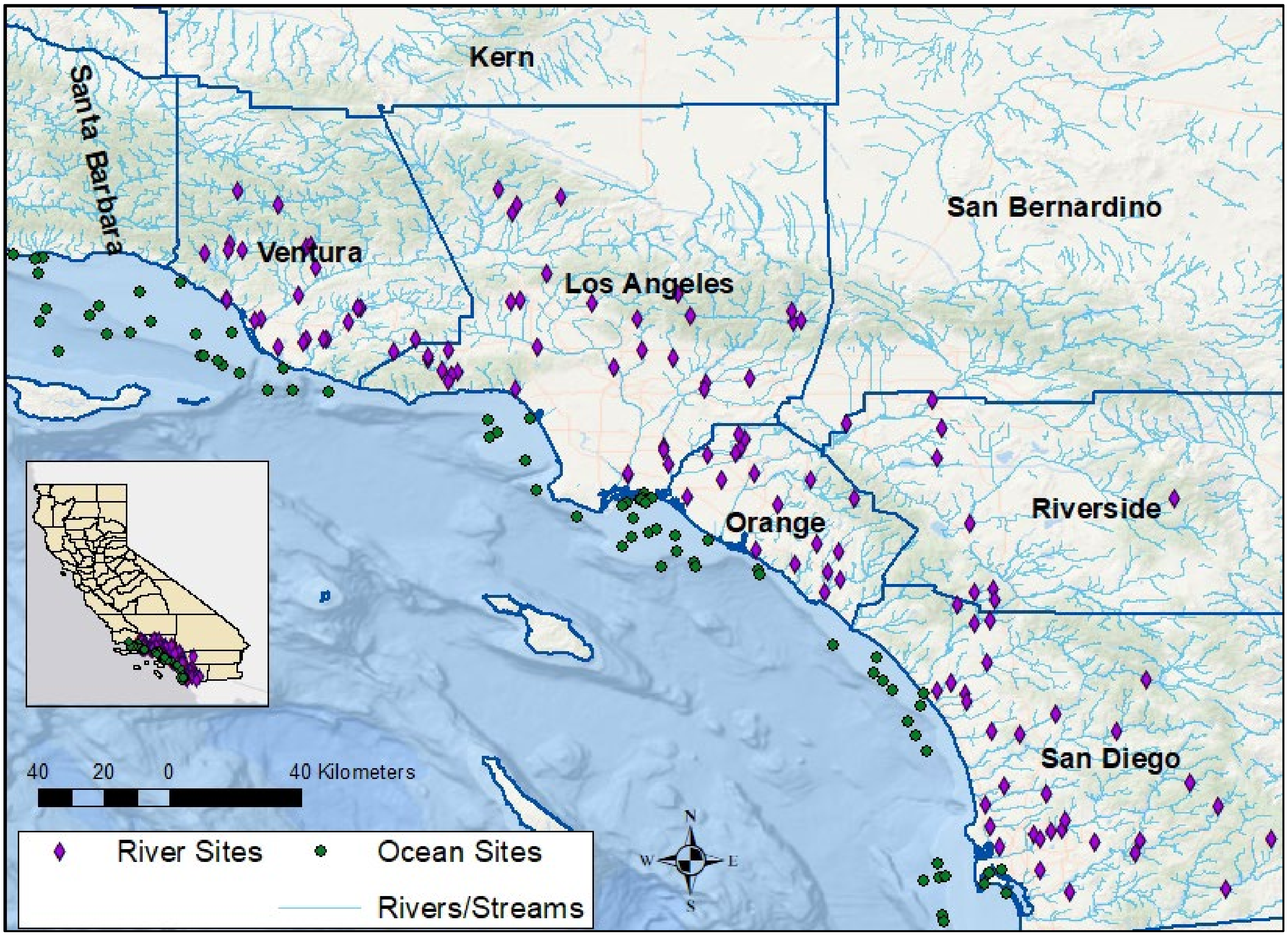



**Figure 1.1. Bight '18 Trash and Marine Debris sampling locations.**

## Results

The integrated findings of the Bight '18 trash and marine debris study are as follows:

- **Trash and marine debris were pervasive in watersheds and offshore. Plastic was the most prevalent item found across all habitats.**
  Over three-quarters (77%) of the more than 7,400 km of southern California wadeable streams contained trash (Figure 1.2) with plastic trash the most common type found (70% of stream kilometers). In Bight coastal watersheds, the 5 most frequently encountered items were: wrappers, paper/carboard, plastic pieces, bags, and foam pieces. In Bight bay and offshore marine habitats (5 – 500 m depths), trash was found on 31% of the seafloor and macro-plastic debris was found on 27% of the seafloor.

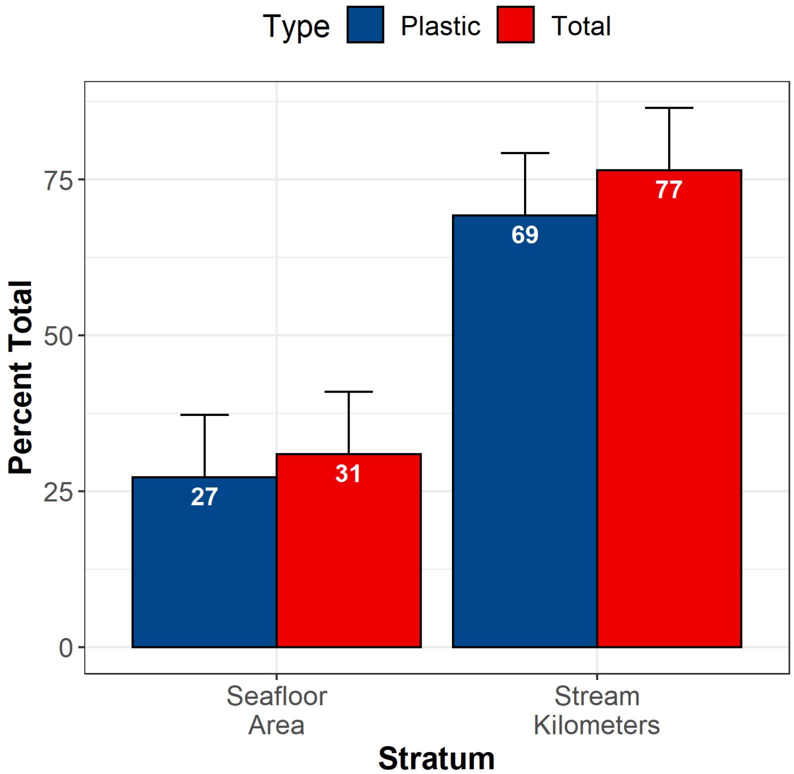



**Figure 1.2. Percent of seafloor and percent stream kilometers where any trash item(s) (red) and plastic trash item(s) (blue) were encountered in the Southern California Bight during the Bight '18 Trash Assessment. In rivers and streams, trash is defined as that which is visible. On the seafloor, trash is defined as that which is caught in a 1.5-inch mesh net.**

- **Areal extent of marine debris in coastal habitats, particularly plastic, has been increasing since 1994.**
  The Bight Program has noted the presence of specific trash types caught during the trawl surveys since the start of the Bight Program in 1994. Historical Bight data shows that the extent of seafloor trawl-caught debris doubled from 1994 and 2018 and that plastic increased nearly threefold (Figure 1.3). Temporal analysis was conducted only on seafloor habitats that were consistently monitored between 1994 and 2018: inner shelf, middle shelf, and outer shelf (5 – 200 m water depth).

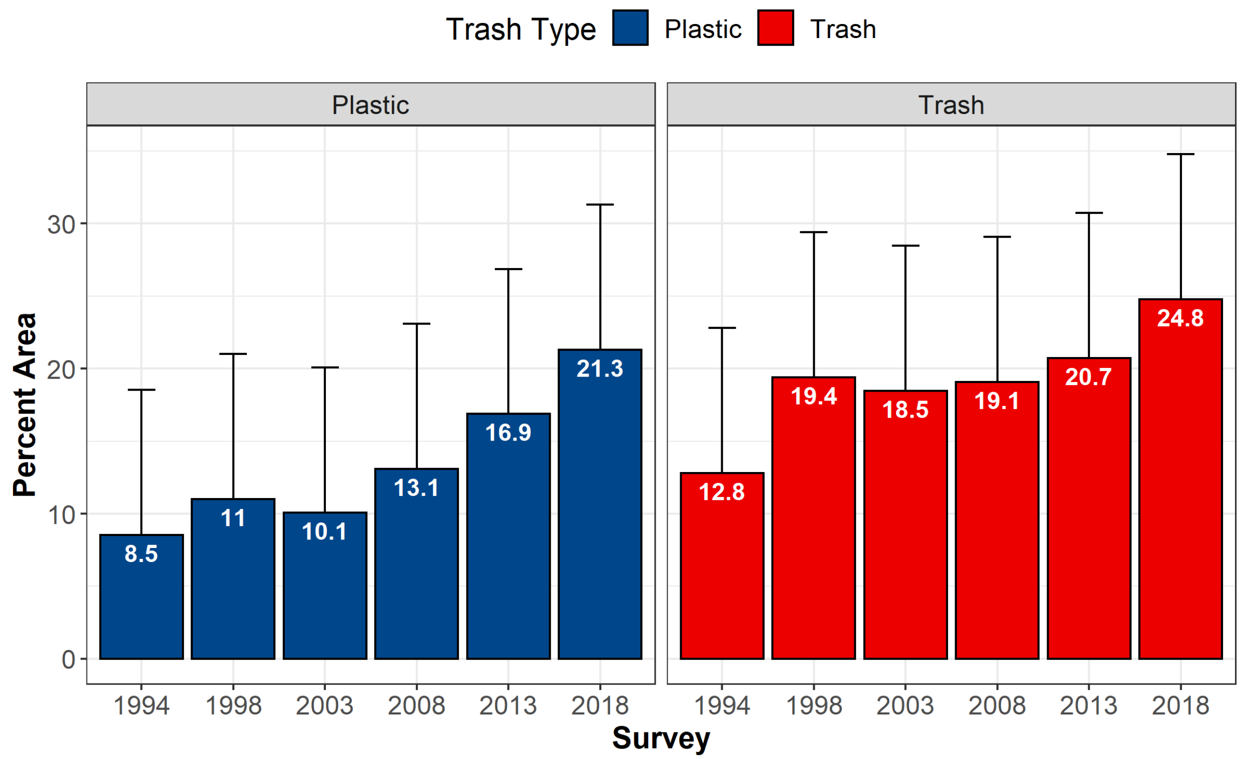



**Figure 1.3. Percent of continental shelf where any plastic trash item(s) (blue) and trash item(s) (red) were encountered in Southern California Bight trawls during historical surveys between 1994 and 2018.**

- **Trash distribution in Southern California Bight Watersheds is associated with factors associated with human activity.**
  Trash was found in more than 89% of the stream kilometers in urban watersheds, compared to 56% of stream kilometers in open (undeveloped) watersheds (Figure 1.4A). Factors associated with human disturbance were the most predictive of trash abundance in watersheds. Increased trash abundance in streams was correlated with increased road density and the number of paved intersections within 5 km of the site (Figure 1.4B). Trash abundance in streams was also highest if the roads and parking lots were close to the survey reach, with highest abundances within 250 m of the reach. In addition to human disturbance metrics, some channel characteristics were correlated with trash abundance. Wider channels were associated with more trash and steeper channels were associated with less.

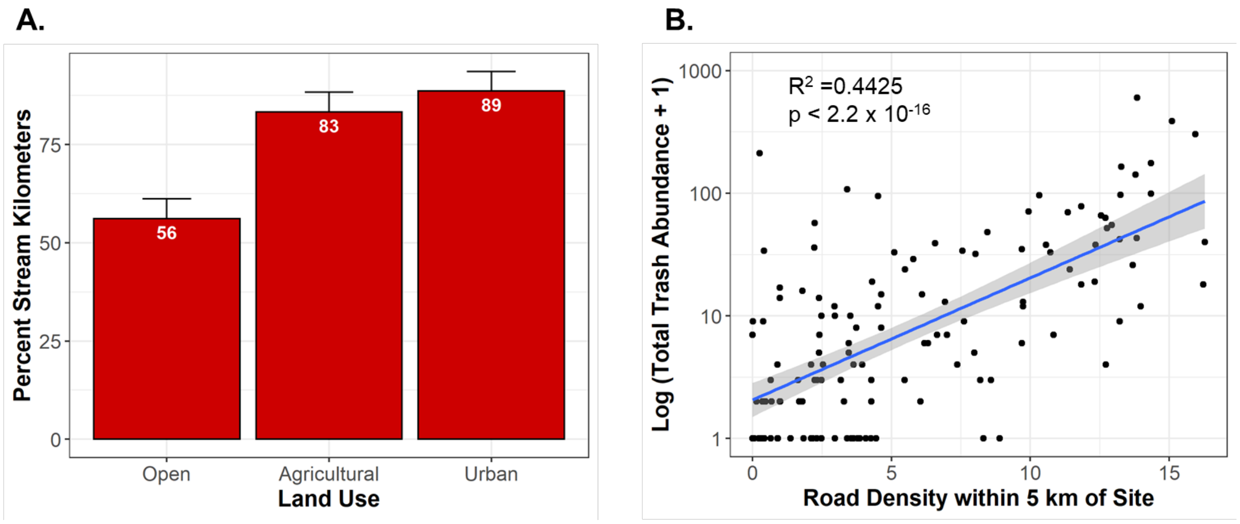



**Figure 1.4. Trash impacts related to human disturbance. Percent of stream kilometers where any trash item(s) were encountered by land use type (A) and the correlation between trash abundance and road density within 5 km of the site (B).**

- **Extent and magnitude of trash in watersheds during the Bight '18 survey was like Bight '13; however, management actions may be having an impact on reducing trash.** While overall trash extent and magnitude were similar between the Bight '13 and Bight '18 surveys, there was a significant decrease in plastic bags (Figure 1.5A), likely due to the implementation of the state-wide bag ban in 2016. In addition, Santa Monica Bay Watershed also saw a significant decrease in trash, possibly due to the Trash TMDL which was implemented in 2012 (Figure 1.5B). These data provide preliminary evidence that source control and mitigation measures may be an effective strategy for trash reduction in watersheds.

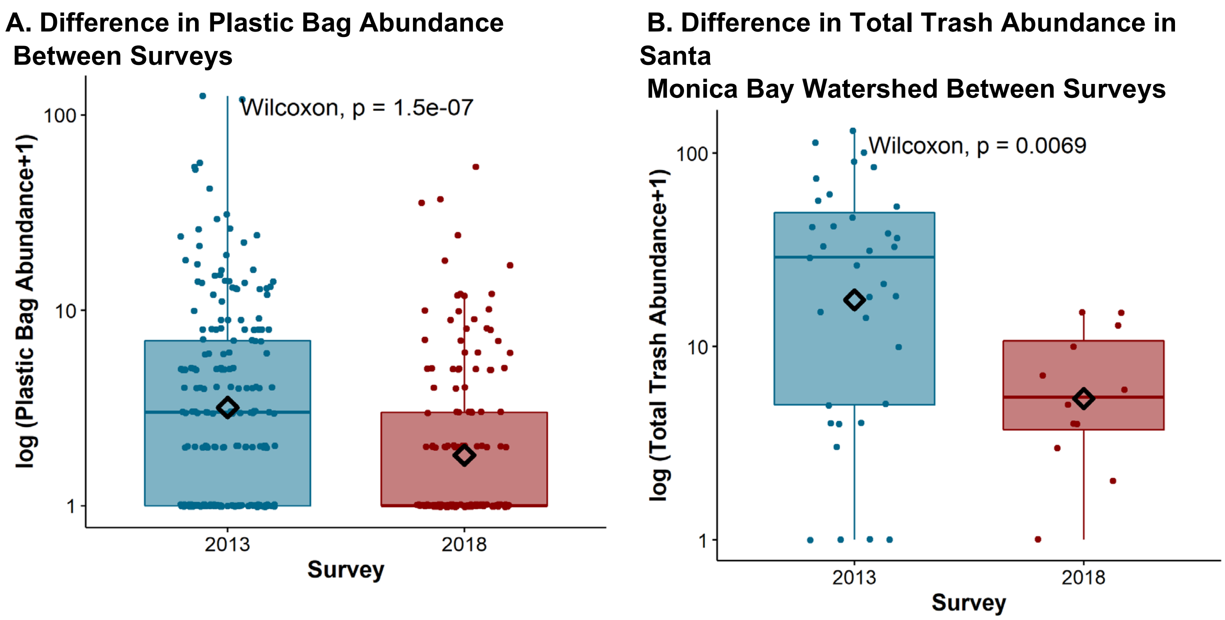



**Figure 1.5. Plastic bag abundance in all watersheds (A) and total trash abundance in the Santa Monica Bay watershed (B) between the Bight '13 Survey (blue) and the Bight '18 Survey (red). Box plots represent the median and quartiles, black diamonds represent the mean plastic bag abundance during each survey. Individual points represent abundance data from all sites sampled in each survey. Plastic bag and total trash abundance are log transformed (base 10). Plastic bag abundance was significantly greater during the 2013 survey in all watersheds (Wilcoxon Test, $p = 1.5 \times 10^{-7}$) and total trash was significantly higher in Santa Monica Bay watershed in 2013 (Wilcoxon Test, $p = 0.0064$).**

While these findings are striking, there is uncertainty in how they should be interpreted and their relevance for management action. First, the watershed and ocean assessments measured standing stock of trash and marine debris at a single point in time. The rates of transport into these habitats, accumulation and breakdown, and subsequent loss cannot be inferred from standing stock or information on size or type of debris. Second, while it is readily apparent that there is a linkage between watershed trash and marine debris, the linkage between Bight habitats and land-based sources is poorly understood, particularly with respect to seasonality of the linkage and the transport of debris. Third, it is not clear how much of the debris is coming from southern California watersheds vs. other ocean-derived sources. Finally, because this study of trash and debris was leveraged with other Bight and SMC regional monitoring program study components, the study does not fully characterize all habitats or all trash types. For example, watershed assessments count what is visible to sampling crews, whereas offshore assessments count only what is caught in a 1.5-inch mesh net (likely missing debris that can slip through the mesh). The offshore assessment methods were likely significantly underestimating marine debris on the seafloor. Tremendous effort was expended to ensure sampling comparability amongst the many participating organizations in Bight and SMC surveys, building a baseline of data that can be used to evaluate management actions into the future. However, while standardized methods for trash sampling and monitoring are being implemented in California watersheds (Moore et al. 2021), there are no standardized methods for marine debris, and more importantly, no consensus on trash taxonomy, making comparisons with other datasets within the state, and even across Bight survey years, challenging.

## Recommendations

Recommendations based on the results from this study have both management and technical implications regarding future trash and marine debris assessments. These recommendations are presented below.

- **Monitoring for watershed trash and marine debris should be continued to evaluate the effectiveness of source control and source reduction management policies.**
  The State of California is implementing trash source control and reduction policies (SWRCB 2015), including Trash Amendments adopted by the State Water Resources Control Board (State Water Board) in April 2015 to control trash in state waters. In response to these policies, local stormwater agencies have spent large amounts of money and dedicated many resources implementing trash mitigation measures, including catch basin inserts, trash booms and litter separation devices as part of their Municipal Separate Storm Sewer System (MS4) Discharge Permits. Continued monitoring of stream trash will document effectiveness of these management actions on trash reduction (e.g., as with the Plastic Bag Ban). To do this effectively, assessment methods, particularly in the categorization of trash types, should be consistent from survey to survey to support long-term trends analysis. Furthermore, managers should invest in data management now so that future monitoring efforts can more readily and powerfully detect changes in trash pollution.

- **Offshore marine debris assessment methods that are more comparable to watershed methods should be considered to improve understanding of fate and transport and relative trash stock assessments.**
  One key limitation of the Bight ’18 Trash Program was the sampling methodologies applied to offshore sites. These were leveraged onto the Bight ’18 Demersal Fish and Epibenthic Macroinvertebrate assessment which employs 1.5-inch mesh otter trawls to assess epibenthic communities. Unfortunately, this technology is known to underestimate benthic trash (Moore et al. 2016; Pasquini et al. 2016) compared to methodologies applied to inland waterways. While trash assessments in trawls should continue to document trends, additional methods should be considered to better characterize the magnitude and extent of trash and marine debris, establish the linkage to sources, and quantify transport, accumulation, and loss rates. A model monitoring program for trash and marine debris that is driven by identification of key management questions and metrics to evaluate the implementation of source control and reduction strategies should be developed for the Bight. The advantages and disadvantages of different measurement methods should be weighed, balancing precision of information vs. cost. Disparate monitoring by stormwater agencies should be unified to compare the effects of localized management efforts with regional trends and information. Such a monitoring program can be applied to characterize relative stock assessments between the land and sea

and be used for fate and transport studies to identify trash impacts in receiving waters, identify linkages to specific sources, and target areas for remediation.

- **Managers should invest in plastic monitoring and effects-based research.** While plastic had the greatest extent and magnitude of any trash type in both the Bight '13 and Bight '18 surveys, both in watersheds and offshore areas, the extent to which it is causing impacts to beneficial uses like aquatic life or human health is poorly understood. Furthermore, this survey did not include an assessment of microplastics—neither from the degradation of larger plastics nor from intact microplastics from personal care products, fibers, preproduction pellets, etc. The extent and magnitude microplastics should be monitored to aid in our understanding both of the impact of direct discharges of microplastics, the degradation of plastic in the environment, and its fate and transport through waterways. Human and aquatic life effects of plastic should be characterized so we can better understand the implications of plastic pollution on marine and freshwater habitats.

## References


Amon, D.J., Kennedy, B.R., Cantwell, K., Suhre, K., Glickson, D., Shank, T.M. and Rotjan, R.D. 2020. Deep-sea debris in the central and western Pacific Ocean. Frontiers in Marine Science, 7, p.369.

Anastasopoulou, A., Mytilineou, C., Smith, C.J., and Papadopoulou, K.N. 2013. Plastic debris ingested by deep-water fish of the Ionian Sea (Eastern Mediterranean). Deep-Sea Res. I 74, 11–13.

Bond, A.L., Provencher, J.F., Elliot, R.D., Ryan, P.C., Rowe, S., Jones, I.L., Robertson, G.J., Wilhelm, S.I., 2013. Ingestion of plastic marine debris by Common and Thick- billed Murres in the northwestern Atlantic from 1985 to 2012. Mar. Pollut. Bull. 77, 192–195.

CalRecycle (California Department of Resources Recycling and Recovery. 2015. State of Recycling in California. Retrieved from http://www.calrecycle.ca.gov/publications/Documents/1522%5C20151522.pdf.

CRWQCBLAR. 2007. Trash Total Maximum Daily Loads for the Los Angeles River Watershed. California Regional Water Quality Control Board, Los Angeles Region. *http://www.waterboards.ca.gov/losangeles/board_decisions/basin_plan_amendments/technical_documents/2007-012/09_0723/L.%20A.%20River%20Trash%20TMDL_Final%20%20Staff%20Report_August%209,%202007.pdf*

CRWQCBLAR. 2010. Santa Monica Bay Nearshore and Offshore Debris TMDL. California Regional Water Quality Control Board, Los Angeles Region. *https://www.waterboards.ca.gov/losangeles/board_decisions/basin_plan_amendments/technical_documents/72_New/SMB%20Debris%20Staff%20Report%20073010.pdf*

CRWQCBLAR. 2015. Amendment to the Water Quality Control Plan for the Los Angeles Region to Revise the Total Maximum Daily Load for Trash in the Los Angeles River Watershed and the Total Maximum Daily Load for Trash in the Ballona Creek Watershed. California

Regional Water Quality Control Board, Los Angeles Region. Resolution Number R15-006. *http://63.199.216.6/bpa/docs/R15-006_RB_RSL.pdf*

CRWQCBLAR. 2019. Reconsideration of the Santa Monica Bay Nearshore and Offshore Debris TMDL and the Machado Lake Trash TMDL. California Regional Water Quality Control Board, Los Angeles Region.
*https://www.waterboards.ca.gov/losangeles/board_decisions/basin_plan_amendments/technical_documents/131_New/trashreconsiderationstaffreportSMB121918(rap)posted010819.pdf*

Di Beneditto, M.A.P. and R.M. Arruda Ramos. 2014. Marine debris ingestion by coastal dolphins: what drives differences between sympatric species? Mar. Pollut. Bull. 83, 298–301.

Farrington, J.W. and H. Takada. 2014. Persistent organic pollutants (POPs), polycyclic aromatic hydrocarbons (PAHs), and plastics: Examples of the status, trend, and cycling of organic chemicals of environmental concern in the ocean. Oceanography 27(1):196–213, *http://dx.doi.org/10.5670/oceanog.2014.23*.

Gall, S.C. and R.C. Thompson. 2015. The impact of debris on marine life. Marine Pollution Bulletin 92:170-179.

Goldstein, M.C., and D.S. Goodwin. 2013. Gooseneck barnacles (Lepas spp.) ingest microplastic debris in the North Pacific Subtropical Gyre. PeerJ 1, 184. http:// dx.doi.org/10.7717/peerj.184.

Leggett, C., Scherer, N., Curry, M., Bailey, M., & Haab, T. 2014. Assessing the Economic Benefits of Reductions in Marine Debris: A Pilot Study of Beach Recreation in Orange County, California. Report to the National Oceanic and Atmospheric Association (NOAA), Marine Debris Division. Industrial Economics, Inc., Cambridge, MA.
*http://marinedebris.noaa.gov/sites/default/files/publications-files/MarineDebrisEconomicStudy_0.pdf*

Lusher, A.L., McHugh, M., and Thompson, R.C. 2013. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. Mar. Pollut. Bull. 67, 94–99.

Moore, S., T. Hale, S. B. Weisberg, L. Flores, and P. Kauhanen. 2021. California Trash Monitoring Methods and Assessments Playbook. SFEI Contribution No. 1025. San Francisco Estuary Institute: Richmond, Calif.

Moore, S., M. Sutula, T. Von Bitner, G. Lattin, and K. Schiff. 2016. Southern California Bight 2018 Regional Monitoring Program: Volume III. Trash and Marine Debris. Technical Report #928. Southern California Coastal Water Research Project. Costa Mesa, CA.

Pasquini, G., Ronchi, F., Strafella, P., Scarcella, G. and Fortibuoni, T. 2016. Seabed litter composition, distribution and sources in the Northern and Central Adriatic Sea (Mediterranean). *Waste management*, *58*, pp.41-51.

Rios, L.M., C.J. Moore, and P.R. Jones. 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. *Marine Pollution Bulletin* 54(8):1230-7.

San Francisco Bay Regional Water Quality Control Board. 2004. *http://www.swrcb.ca.gov/rwqcb2/water_issues/programs/stormwater/muni/mrp/WaterBoard%20 Trash%20Assessment%20Method%20SWAMP_v8.pdf*

Stevens, D. L., Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics 8:167-195.

# Chapter 2. Regional Assessment of Trash in Southern California Coastal Watersheds


## Abstract

Trash impairment of watersheds has been recognized as a worldwide environmental problem. Trash monitoring in streams and rivers is needed to understand the potential effect on freshwater habitats and examine the role of streams as a conduit for transport to marine environments. Southern California, with a population of over 22 million, is home to nearly 7,400 km of wadeable streams in watersheds spanning a variety of land uses, making it an ideal region to study the extent and magnitude of trash and trash types (plastic, metal, glass, etc.) found in southern California's coastal watersheds and identify relationships between land use and trash. We found that 77% of southern California's coastal stream kilometers contained trash, with an estimated stock of 7 million pieces of trash. Of the types enumerated, plastic trash was the most ubiquitous, present in 69% of stream kilometers, and the most abundant, with an estimated stock of over 4.3 million pieces of plastic. The most common items were single-use plastic containers, wrappers, and plastic bags. Urban land use was associated with the greatest extent and magnitude of trash, with levels nearly double those found in open land uses. Trash was strongly associated with indicators of human activity and development in watersheds. Road density and proximity to roads and parking lots were strongly correlated with increased trash in watersheds. This survey also suggested that management actions were having a positive effect on trash abundance. Since the previous trash survey in southern California streams in 2011-2013, a statewide ban on plastic bags was implemented and this survey found a significant decrease in bag abundance within streams in the present survey compared to the previous survey. In addition, trash in the Santa Monica Bay watershed, which implemented a trash total maximum daily load (TMDL) in 2012, saw a significant reduction in trash abundance since the last survey.


## Introduction

Trash, particularly plastic, has become a pollutant of global concern found not only in populated areas, but also on remote shorelines and in mid-oceanic gyres thousands of miles from shore (Derraik 2002; NRC 2009; Amon et al. 2020). Trash is both an aesthetic pollutant as well as a risk to wildlife and habitat quality (Ryan et al. 2009; Boerger et al. 2010; Gall and Thompson 2015) and possibly human health (Thompson et al. 2009). Plastic waste is the dominant type of anthropogenic litter in both freshwater and marine environments, comprising as much as 60-80% by number (Derraik et al. 2002; Lebreton et al. 2017), and the amount of plastic marine debris in the North Pacific Gyre has increased by an order of magnitude between 1980s and 1990s (Day et al. 1990; Moore et al. 2001a). Without waste management infrastructure improvements, plastic waste in the ocean is expected to increase by an order of magnitude between 2010 and 2025 (Jambeck et al. 2015).

Although marine studies have been nearly universal in their claim that a large fraction of oceanic debris comes from land-based sources (UN Environmental Programme 2017), sources of ocean debris are generally not well quantified, and few studies have supported this assertion by assessing the abundance of trash in rivers and streams (Thompson et al. 2009; Hollein et al. 2014). The few studies of riverine environments generally focus on quantifying the sources of trash, rather than the abundance of trash within the channel (Lebreton et al. 2017; Jambeck et al.

2015). Estimates of magnitude, abundance, and types of trash in streams and rivers are important because they convey to managers and policymakers a need for action or demonstrate the success of current actions. Such information could also convey priority sources and land uses that can be targeted for intensive management action.

Southern California is a region where trash would be expected to be prevalent in streams and rivers. With a population of 22 million, this urbanized coastal region contains over 7,800 $km^2$ of developed landscape. Terrestrial waterways are considered the main pathway by which trash is transported from the land to the ocean in urbanized coastal environments (Sheavly and Register 2007; Willis et al. 2017). Moreover, this region has a Mediterranean climate with sparse rainfall, particularly during the dry months of April to October, which make for long dry periods in which trash can accumulate in watersheds. The coastal watersheds of southern California drain into the Southern California Bight, a coastal zone prized for its beaches and other ecotourism, as well as for the biodiversity and endemism of its marine and estuarine ecosystems (Claisse et al. 2018; Schiff et al. 2019). In such a region, quantifying the extent, magnitude and types of trash found in watersheds is an important step towards guiding management actions and evaluating the effect of trash policies. In some parts of the region, state and federal regulators have established total maximum daily loads (TMDLs) for trash greater than 5 mm in diameter (CRWQCBLAR 2007, 2015). The State of California recently adopted similar regulations for extending comparable trash reduction policies statewide and in 2016 implemented a state-wide ban on single-use plastic bags (SB270/Proposition 67). Regional monitoring of trash abundance in stream channels can serve as a mechanism to evaluate the efficacy of such management actions.

This study was part of a collaborative effort by many agencies over a 2-year period to assess overall biological condition of rivers and streams in southern California. As part of this wider study, trash was assessed to provide the first regional scale study of extent and magnitude in rivers and streams. The goal of this study was three-fold: 1) to assess the extent and magnitude of trash found in southern California's wadeable streams; 2) to quantify the types of trash; and 3) to identify relationships between the intensity of land use, presence of trash management policies (e.g., single-use plastic bag bans) and trash.

## Methods

### Study Design

This study used a 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"). This represents approximately 28,051 $km^2$ of watershed area and over 7,400 km of stream length (Figure 2.1). 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) using the SPSurvey package in R

(Kincaid and Olsen 2013). Each site included a 150-m reach, the first 30.5 m of which were assessed for trash.

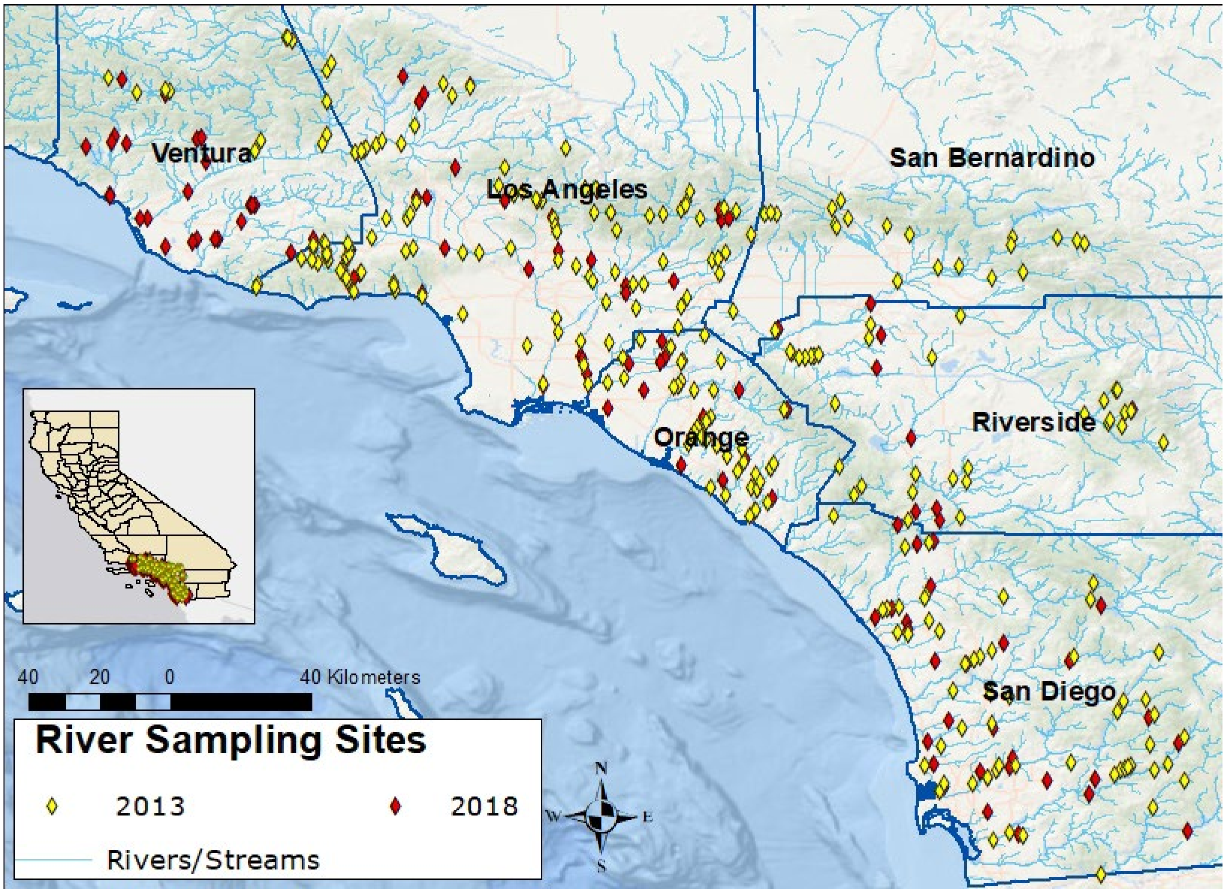



**Figure 2.1. Watershed Trash sampling locations. Sites sampled in the Bight ’13 survey are yellow and sites sampled in the Bight ’18 Survey are in red.**

Trash was surveyed at 204 sites over 3 years in Bight ’13 and at 166 sites over 2 years in Bight ’18 stratified by county or land use (Table 2.1). Sixteen watersheds were delineated in southern California, roughly approximating HUC 18 from NHD Plus. 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 were defined - urban, agriculture, and open - based on the National Oceanic and Atmospheric Association’s Coastal Change Analysis Program (C-CAP, NOAA 1995, 2001). For the 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.

**Table 2.1. Sites sampled in Bight ’13 and Bight ’18 Surveys by watershed and land use type.**

| Strata Type | Strata | # Sites in Bight ‘13 | # Sites Bight ‘18 |
|---|---|---|---|
| Watershed | Calleguas | 0 | 13 |
| | Central San Diego | 11 | 11 |
| | Los Angeles | 22 | 20 |
| | Lower Santa Ana | 22 | 8 |
| | Middle Santa Ana | 19 | 5 |
| | Mission Bay and San Diego River | 7 | 9 |
| | Northern San Diego | 13 | 12 |
| | San Gabriel | 24 | 30 |
| | San Jacinto | 7 | 3 |
| | San Juan | 13 | 8 |
| | San Luis Rey | 0 | 0 |
| | Santa Clara | 13 | 19 |
| | Santa Monica Bay | 32 | 12 |
| | Southern San Diego | 9 | 8 |
| | Upper Santa Ana | 12 | 0 |
| | Ventura | 0 | 8 |
| Land Use | Agricultural | 12 | 30 |
| | Open | 64 | 57 |
| | Urban | 128 | 79 |
| **Total Sites** | | **204** | **166** |

## Data Collection

*Trash.* All sites were sampled during the dry season, spring-summer (April-August), in 2018-2019. Sampling followed a modification of the Bight ’13 Riverine Trash Survey (Moore et al. 2016) and the Bay Area Stormwater Management Agencies Association (BASMAA) Trash Monitoring Program Plan (BASMAA 2017) protocols. Briefly, each site was defined as a stream reach with a length of 30.5 m (100 ft) and a width equal to the high-water mark, also referred to as the ordinary high-water mark if a visible high-water level was not discernable. 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, moderate, high, very high). The quantitative assessment included an enumeration and classification of all visible trash within the stream reach. The 10 general trash classifications were: plastic (e.g., wrappers, bags, pieces, bottles), glass, metal (e.g., aluminum cans), cloth, biohazard (e.g., diapers, pet waste), biodegradable (e.g., paper), construction (e.g., concrete, asphalt), large (e.g., refrigerators, sofas), toxic (e.g., cigarette butts, spray paint cans), and miscellaneous (e.g., sports balls, ceramics). 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. Field audits were conducted for a subset of samples to ensure standardization of sample collection.

*Site Factors.* Data on site factors was collected using the physical habitat assessment and landscape variables collected from GIS and Google Earth. The physical habitat assessment is described in Mazor (2015) and is based on Ode (2007) and Fetscher et al. (2009). Briefly, the entire 150-m reach was divided into 11 equidistant transects, with 10 inter-transects located halfway between them. At each transect, channel parameters (e.g., bank dimensions, wetted width, water depth, sinuosity), substrate size and type, riparian vegetation, and human influence parameters (e.g., storm drains, structures) were measured. A subset of these variables were measured at each inter-transect. The slope of the water surface was measured across the entire reach at each site. Metrics based on physical habitat data were calculated using custom scripts in R, based on those presented in Kaufmannet et al. (1999). The index of physical integrity (IPI) is a multi-metric index based on physical habitat measurements and was calculated using custom R scripts according to Rehn et al. (2018).

Using a GIS, watersheds were delineated for each site from 30-m digital elevation models (USGS 1999), and visually corrected to reflect local conditions. For sites draining ambiguous watersheds with minimal topography, delineations were modified using CALWATER boundaries (California Department of Forestry and Fire Protection 2004) or by consulting local experts. Watersheds were clipped at 5 km around each site to evaluate local conditions for road density and number of paved intersections. Distance to nearest road, type of nearest road, and nearest parking lot for each site was estimated from Google Earth Pro.

## Data Analysis

Sampling weights were assigned to each site for each stratum definition, to account for differences in total stratum stream sites/length. These weights were used when estimating magnitude (area-weighted mean abundances) and spatial extent (percent of stream kilometers) using the Horvitz-Thompson estimator (Horvitz-Thompson 1952). Confidence intervals (CIs) were based on local neighborhood variance estimators (Stevens and Olsen 2004). Trash stock in the Southern California Bight was calculated by first determining the number of trash items per meter of stream at each site and then multiplying by the length of stream represented by each site (length weighted) and summing the stocks by land use type and for the region.

Data analyses were performed with R 4.0.2 (R Core Team 2020), using the tidyverse (Wickham et al. 2019), IDPmisc (Locher and Ruckstuhl 2012), and ggpubr packages (Kassambara 2018). Statistical analyses were conducted using the rstatix package (Kassambara 2020). Trash abundance was log-transformed for analysis ($\log_{10}$(abundance + 1)). Kruskal-Wallis one-way analyses of variance (ANOVA) were used to test differences in trash abundance among the 3 land use categories and by county. Quantile regressions were used to evaluate relationships between trash abundance and site factors using the R package quantreg. A boosted regression tree was used to determine the relative influence of site factors on trash abundance at each site using the following R packages: rsample, caret, gbm, Metrics, here, and stringr.

## Results

### Extent and Magnitude

Trash was pervasive in Southern California Bight watersheds. Over three-quarters (77%) of the more than 7,400 km of southern California wadeable streams contained at least 1 trash item (Figure 2.2). Trash was most common in urban streams, present in 89% of stream kilometers and least common in open streams (56% of stream kilometers). Trash was found in a portion of all stream kilometers in every watershed assessed (Figure 2.3), ranging from 100% of stream kilometers in the Middle Santa Ana River and San Jacinto River watersheds to 53% of stream kilometers in the Santa Clara River watershed.

Plastic trash was the most common trash type in all land uses and all watersheds with an estimated 70% of stream kilometers having plastic trash (Figures 2.2, 2.3, 2.6A). Patterns in plastic trash extent mirrored that of total trash, with urban streams most affected (89% of stream kilometers) and open areas least affected (46% of stream kilometers). Within watersheds, stream length affected by plastic trash ranged from 100% of stream kilometers in the Middle Santa Ana and San Jacinto watersheds to 42% of stream kilometers in the Santa Clara River watershed (Figure 2.3).

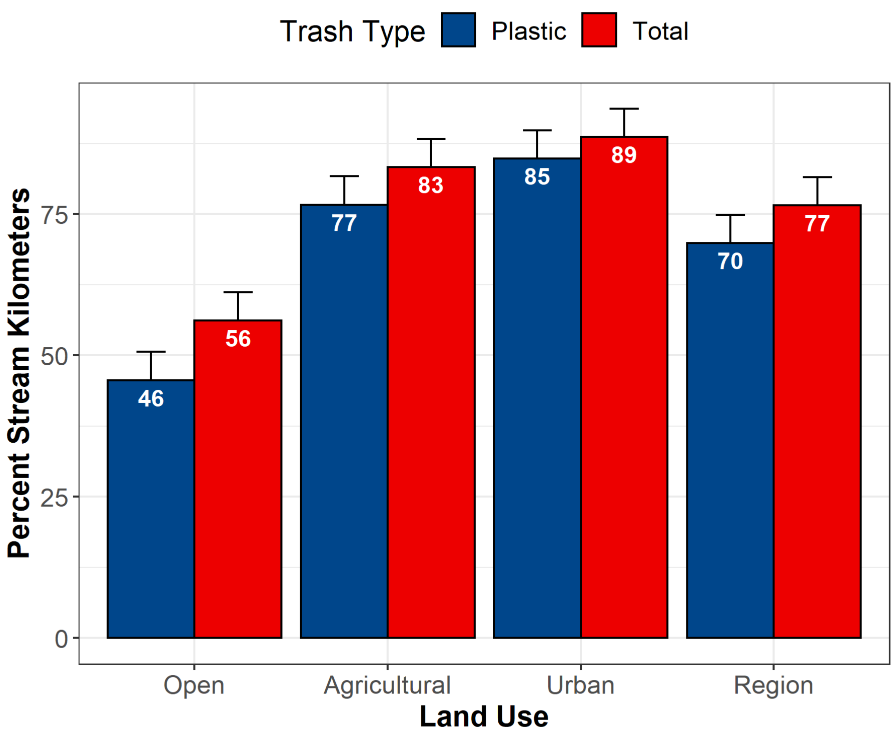



**Figure 2.2. Percent of stream kilometers in which at least 1 piece of plastic (blue) or trash (red) was found in 30.5 m reaches from open, agricultural, and urban land uses and in the entire Southern California Bight region during the Bight '18 survey.**

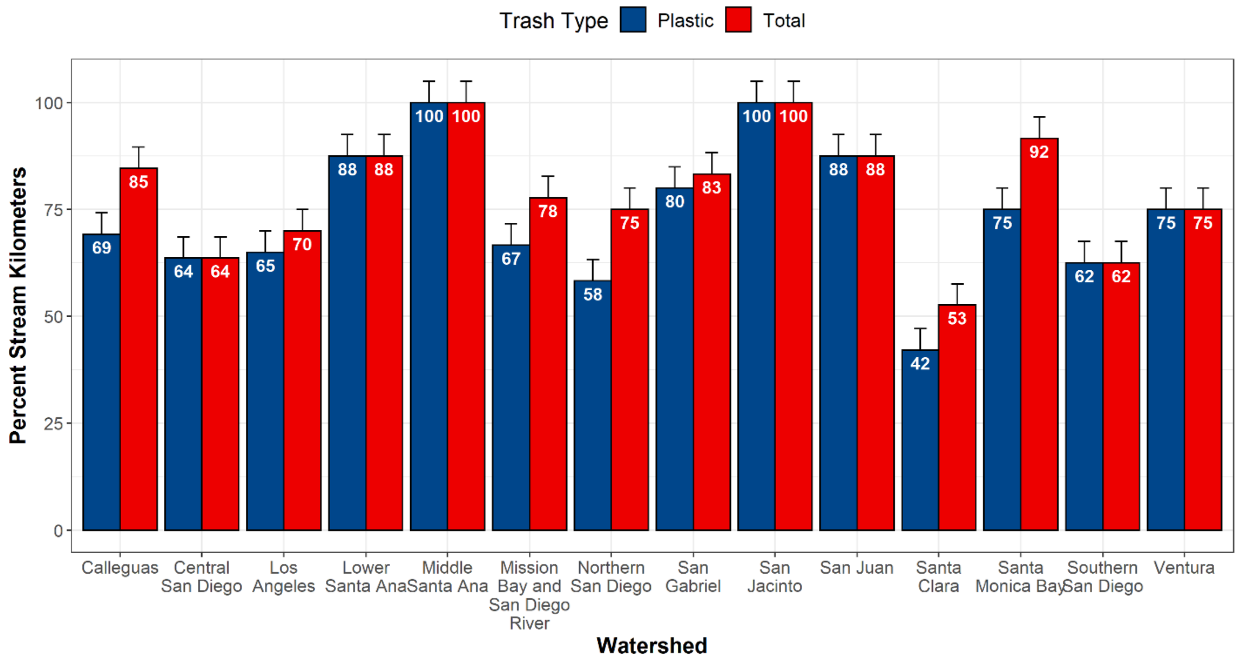



**Figure 2.3. Percent of stream kilometers in which at least 1 piece of plastic (blue) or trash (red) was found in each watershed during the Bight '18 survey.**

The amount of trash counted along any stream reach was variable within and among the land use (Figure 2.4). The number of trash items counted along a stream reach ranged from a high of 600 items in an urban stream (Lower Santa Ana Watershed) to no trash found (25 open streams, 5 agricultural streams and 9 urban streams). The area-weighted mean trash count was highest in urban land streams (44 ± 89 items per reach, mean ± standard deviation), followed by agricultural (16 ± 24 items), and then open (9 ± 30 items). The top 5 watersheds with the highest trash abundance were Lower Santa Ana (with a mean of 95 ± 205 trash items counted per reach), Los Angeles River (mean 47 ± 97 trash items), San Gabriel River (mean 47 ± 66 trash items), Middle Santa Ana River (mean 31 ± 38 trash items), and Calleguas Creek (mean 20 ±30 trash items).

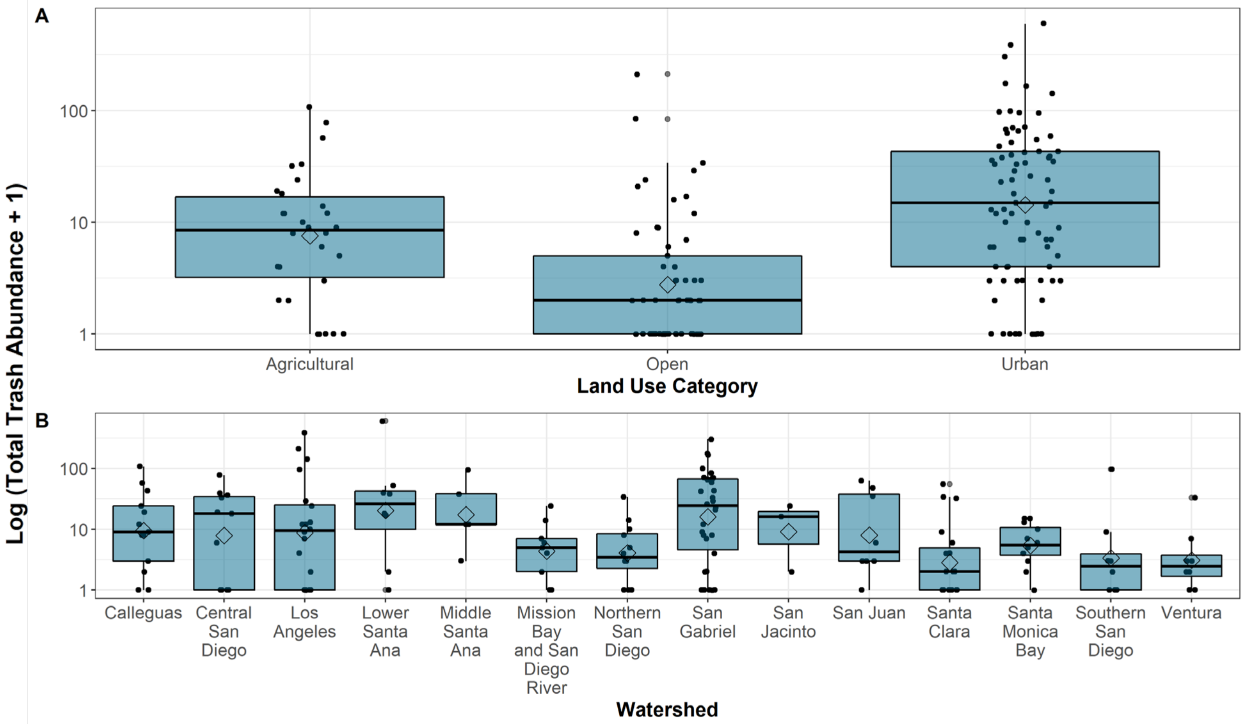



**Figure 2.4. Total trash abundance ($log_{10}$ transformed) by land use (A) and by watershed (B) in the Southern California Bight region. Individual points represent trash/plastic abundance at each site sampled during the Bight '18 survey. Bars represent area weighted average trash abundance and error bars are the standard deviation.**

A stock assessment of trash indicated greater than 7 million pieces of trash were present in streams in southern California coastal watersheds (Figure 2.5). Over 4 million of those pieces of trash were plastic. There were nearly 4 million pieces of trash in urban streams alone, which represent only 25% of total watershed area in the region, and over 2 million of those pieces were plastic.

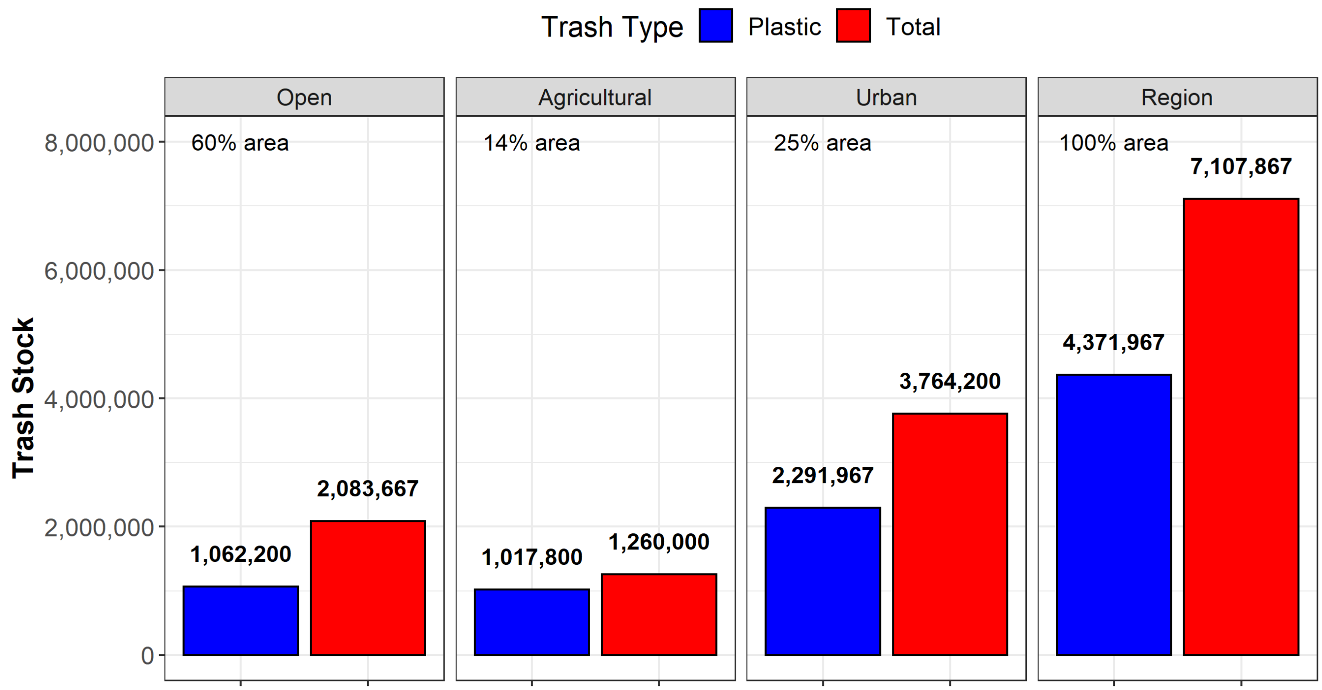



**Figure 2.5. Stock assessment of total plastic (blue) and total trash (red) in southern California wadeable streams. Facets represent land use categories and the region overall. The percent area in each land use category is given and the numbers represent the total stock of each trash type.**

## Types of Trash

In southern California coastal watersheds, plastic trash was the most frequently encountered trash type (found in 69% of stream kilometers), followed by metal (43% of stream kilometers), biodegradable items such as paper (34% of stream kilometers), and fabric (33% of stream kilometers) (Figure 2.6). These 4 trash types were the most common in all land use categories, although the ordering was slightly different. For example, biodegradable items, especially paper and cardboard, were the second most common trash type in urban streams (found in 53% of stream kilometers) after plastic (in 85% of stream kilometers). These 4 item types were generally the most common among watersheds as well, although some watersheds had high percentages of stream kilometers affected by glass or miscellaneous items (items that could not neatly fit into 1 category or another such as rubber, ceramics, and sports balls). Large items (such as appliances and tires) and biohazard items (such as dog waste bags and diapers) were least common in all land uses.

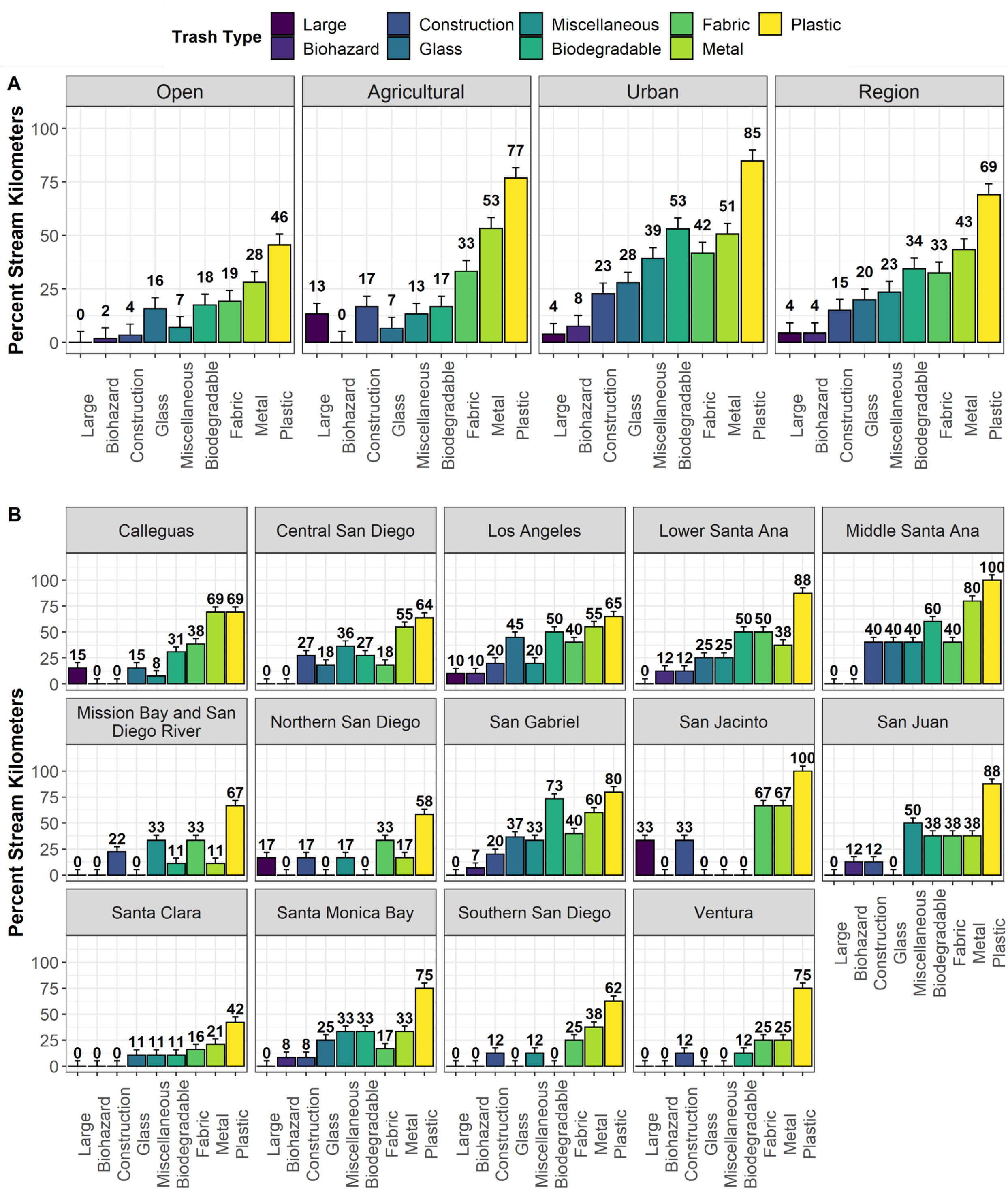



**Figure 2.6. Percent of stream kilometers where each trash type was present during the Bight '18 survey by land use category for the region overall (A) and by watershed (B).**

The amount of trash counted of any type along stream reaches was variable within and among the land uses (Figure 2.7). In addition to being present in the greatest number of stream kilometers, plastic trash items also had the highest mean counts for all land uses, ranging from a mean count of 27 ± 53 plastic items per reach in urban streams (nearly 1 piece of plastic encountered for every meter of stream) to 4 ±10 items in open streams (1 piece of plastic encountered every 7.5 meters of stream). The high variability in the counts is partly due to high numbers of items (e.g., pieces of broken glass, metal nails, plastic fragments, etc.) at some sites and the number of 'whole' items represented by the pieces was impossible to discern in the field. Pieces of items were particularly common for plastics where the numbers of whole plastic items (entire plastic bags, intact plastic bottles, etc.) accounted for 5% of the total plastic counts; 95% were pieces.

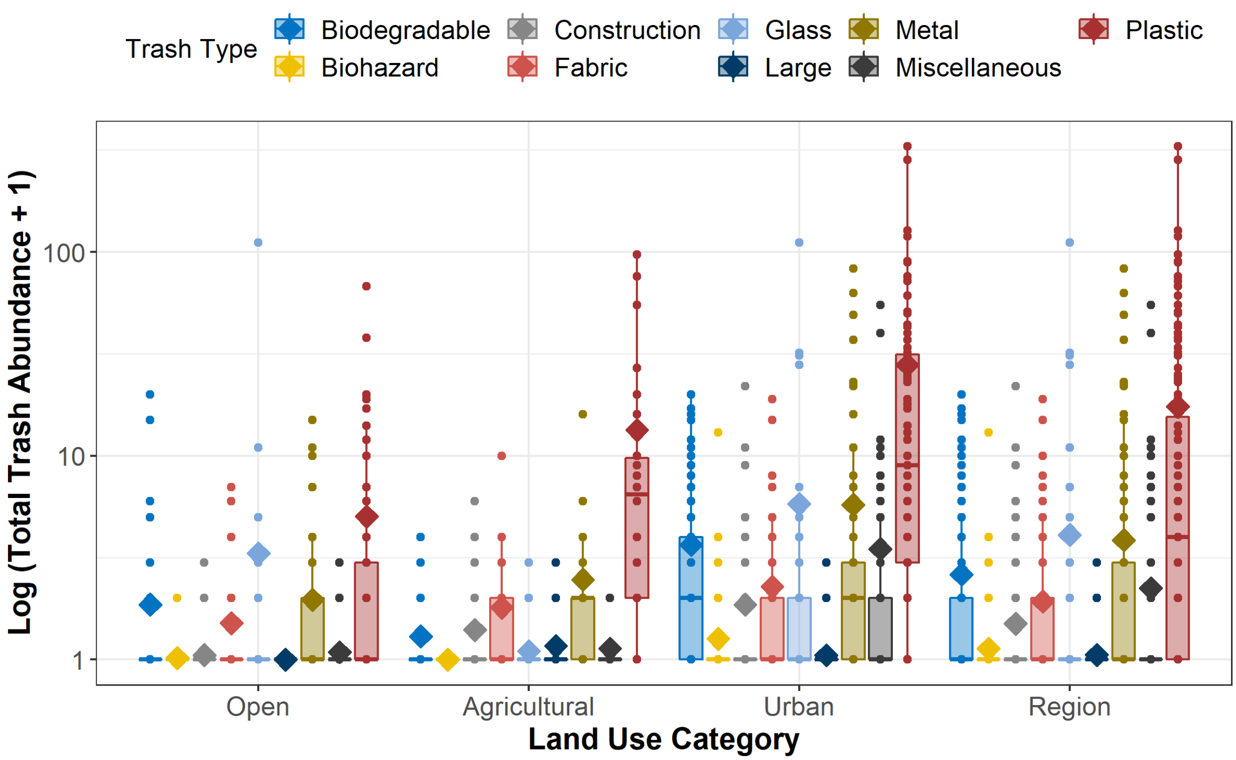



**Figure 2.7. Abundance of different trash types by land use category during the Bight '18 survey. Abundance is the $\log_{10}$ transformed of the total counts of all items plus 1. Diamonds are the mean counts of each type in each land use category.**

Across land use types, the 5 most frequently encountered items were: wrappers, paper/cardboard, plastic pieces, bags, and foam pieces (Table 2.2). Other items often found were aluminum or steel cans, glass, plastic bottles, single-use containers, and synthetic fabrics. We also evaluated the relative percentages of plastic items found (Figure 2.8). Wrappers and container pieces had the greatest relative percentages of the total counts of items, followed by foam/foam pieces and plastic bags/bag pieces and tobacco related items (cigarette butts, cigar tips, etc.).

**Table 2.2. Ten most common trash items by each land use type and for the region.**

| Land Use | Trash Item | % Stream Kilometers | Rank |
|---|---|---|---|
| Agricultural | Plastic Bags/Pieces | 58 | 1 |
| | Container/Pieces | 46 | 2 |
| | Plastic Other | 38 | 3 |
| | Synthetic Fabric | 38 | 3 |
| | Foam/Pieces | 29 | 4 |
| | Wrapper/Pieces | 29 | 4 |
| | Aluminum or Steel Cans | 25 | 5 |
| | Metal Other | 21 | 6 |
| | Natural Fiber | 21 | 6 |
| | Single-use Container | 21 | 6 |
| Open | Aluminum or Steel Cans | 24 | 1 |
| | Plastic Other | 22 | 2 |
| | Synthetic Fabric | 22 | 2 |
| | Container/Pieces | 20 | 3 |
| | Foam/Pieces | 20 | 3 |
| | Glass | 20 | 3 |
| | Paper/Cardboard | 20 | 3 |
| | Wrapper/Pieces | 20 | 3 |
| | Plastic Bottles | 17 | 4 |
| | Plastic Bags/Pieces | 9 | 5 |
| Urban | Wrapper/Pieces | 68 | 1 |
| | Container/Pieces | 61 | 2 |
| | Foam/Pieces | 58 | 3 |
| | Plastic Bags/Pieces | 57 | 4 |
| | Paper/Cardboard | 50 | 5 |
| | Plastic Bottles | 44 | 6 |
| | Plastic Other | 39 | 7 |
| | Metal Other | 33 | 8 |
| | Synthetic Fabric | 33 | 8 |
| | Aluminum or Steel Cans | 32 | 9 |
| Region | Wrapper/Pieces | 46 | 1 |
| | Container/Pieces | 45 | 2 |
| | Plastic Bags/Pieces | 42 | 3 |
| | Foam/Pieces | 41 | 4 |
| | Paper/Cardboard | 35 | 5 |
| | Plastic Other | 33 | 6 |
| | Plastic Bottles | 31 | 7 |
| | Synthetic Fabric | 30 | 8 |
| | Aluminum or Steel Cans | 28 | 9 |

| | | |
|---|---|---|
| Glass | 24 | 10 |

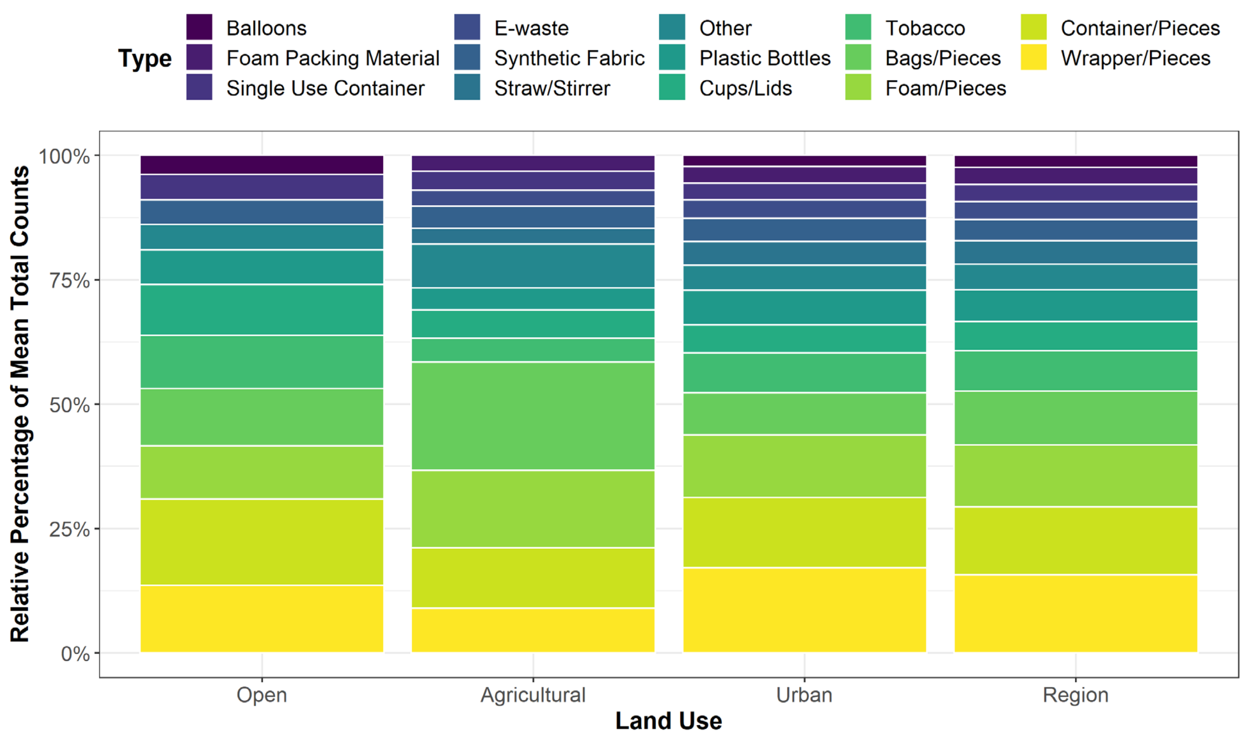



**Figure 2.8. Relative percentage of the total types of plastic trash by count found during the Bight '18 survey.**

## Influence of Site Factors

Proximity to roads and parking lots, as well as in stream metrics of human disturbance were all correlated with increased trash abundance in a stream reach. Some non-human disturbance metrics were also correlated with increased trash abundance, although more investigation is needed.

**Infrastructure near the reach.** Trash distribution and abundance in Southern California Bight Watersheds was strongly associated with proximity to roads and parking lots. Increased trash abundance within a stream reach was well correlated with increased road density ($R^2 = 0.44$, $p < 2.2 \times 10^{-16}$) and the number of paved intersections ($R^2 = 0.036$, $p = 0.021$) within 5 km of the site (Figure 2.9). Trash abundance in streams was highest if the road or parking lot was close to the survey reach, with highest abundances within 250 m of the reach (Figure 2.10). Whether the road or parking lot was upstream, downstream or alongside the stream reach did not seem to affect the abundance of trash in the reach, only the proximity. There were significant differences in the amount of trash by type/size of road nearest the reach (ANOVA on log-transformed data where $p = 0.010$ and $0.014$ for all trash and plastic trash respectively), with dirt and 1-lane roads having significantly lower amounts of trash than other types of roads (Tukey HSD; Figure 2.11). There were no significant patterns in relationship to roads by land use or survey year (Tukey HSD).

Whether the stream was fenced or not did not appear to affect the amount of trash found within the stream (Figure 2.12).

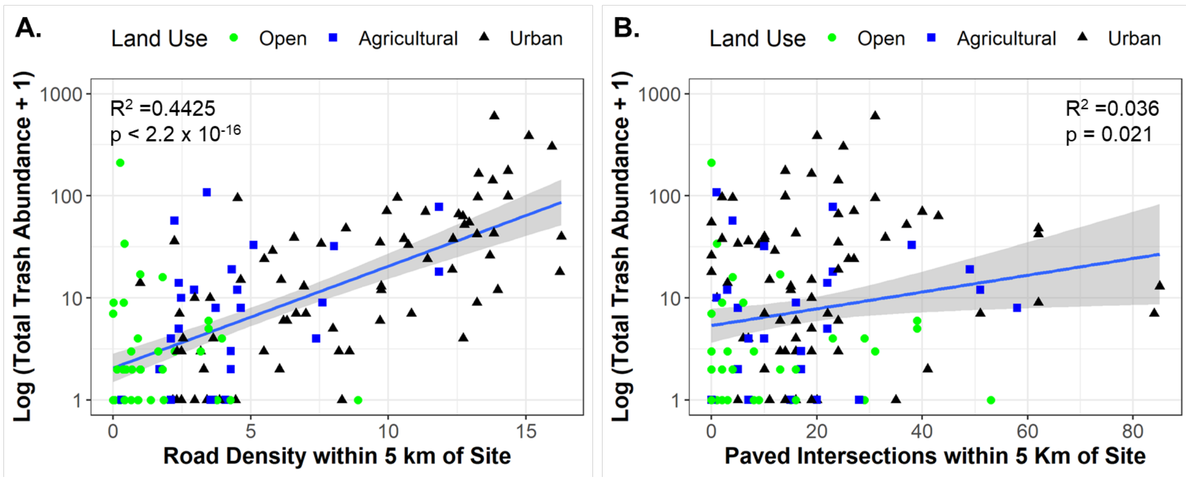



**Figure 2.9. Total trash abundance ($log_{10}$ transformed) as a function of roads within the watershed for the Bight '18 survey. A.) Total trash abundance as a function of the road density within 5 km of the site and B.) total trash as a function of the paved intersections within 5 km of the site. Each point is an individual stream reach, color/shape is the land use type, the blue line is the linear model, and the blue shading is the 95% confidence interval of the fit. The $R^2$ and p-value for each fit are given.**

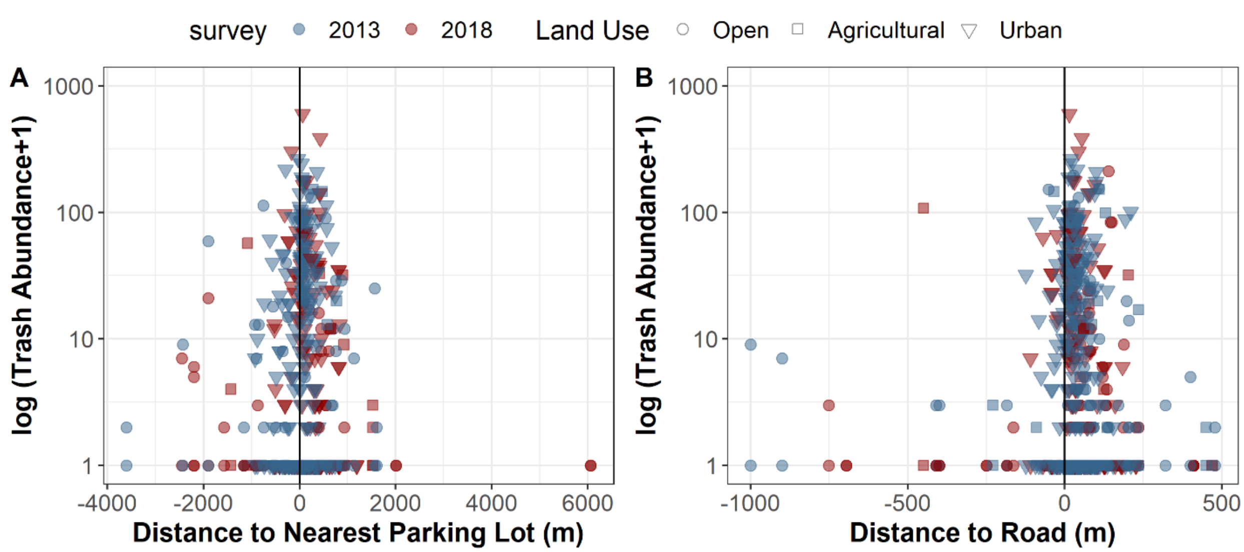



**Figure 2.10. Trash abundance ($log_{10}$ transformed) as a function of the distance to nearest parking lot (A) or nearest road (B) during the Bight '13 (blue) and Bight '18 (red) surveys. Positive values are where stream site is located upstream of the road/parking lot, and negative values are where the site is located downstream of the road/parking lot. Shape of the point is the land use category of each stream site.**

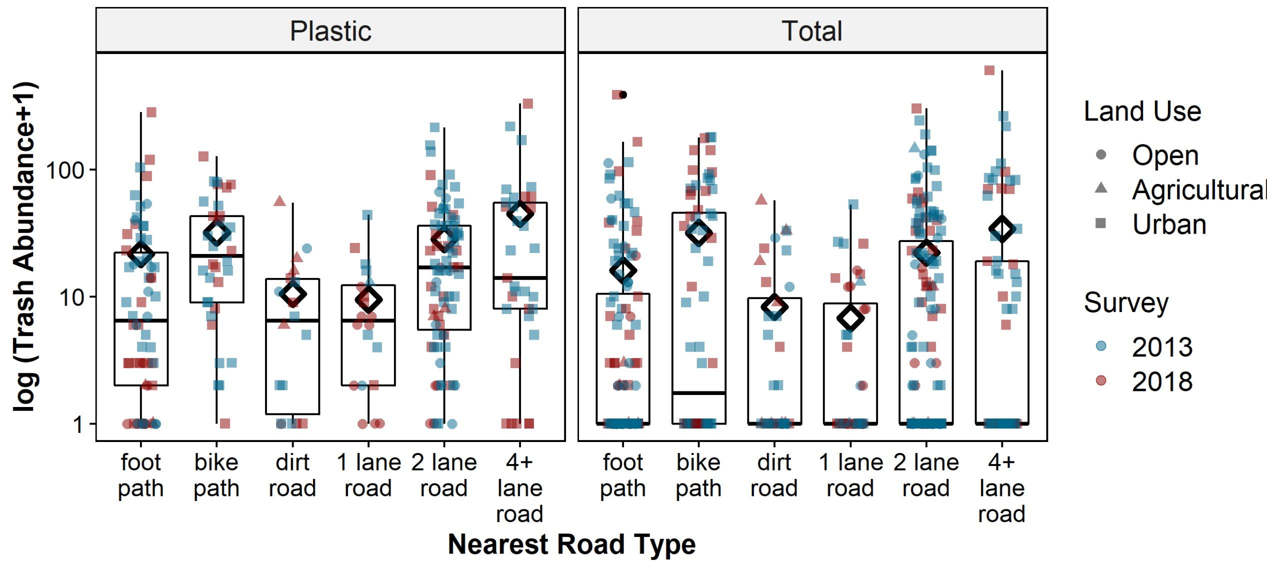



**Figure 2.11. The trash abundance ($log_{10}$ transformed) for the nearest road type within 100 m of the reach in the Bight '13 (blue) and Bight '18 (red) surveys. The shape of the points represents the land use type, the box plots represent the median, $25^{th}$ and $75^{th}$ percentile, and the diamonds are the mean trash abundance of the untransformed data for all sites near that road type for plastic and total trash.**

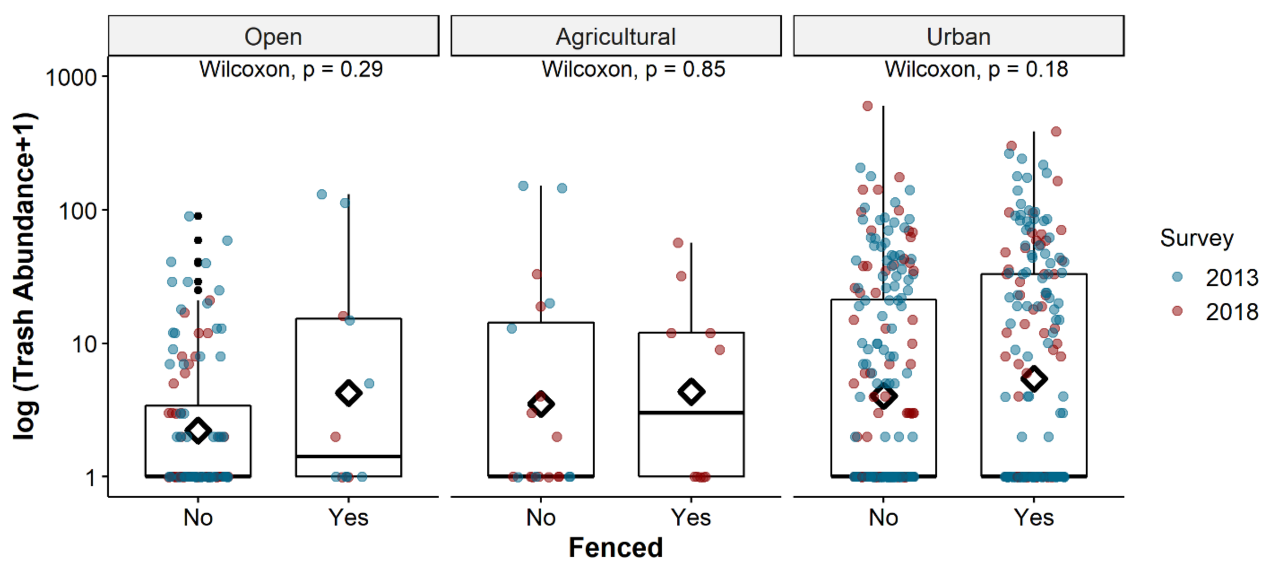



**Figure 2.12. The trash abundance (log10 transformed) for sites that are fenced (yes) compared to sites that are not fenced (no) in the Bight '13 (blue) and Bight '18 (red) surveys. The shape of the points represents the land use type, the box plots represent the median, 25th and 75th percentile, and the diamonds are the mean total trash abundance of the untransformed data for all sites near that road type.**

**Instream human disturbance metrics.** Instream indicators of human disturbance assessed by the California Regional Bioassessment Program were well-correlated with increased trash abundance within a stream reach (Figure 2.13). The Index of Physical Integrity (IPI), a measure of the relative habitat "referenceness" of a stream was negatively correlated with trash abundance in streams for the 75th and 90th percentiles of trash abundance ($\tau = 0.9$, $p < 1 \times 10^{-16}$; $\tau = 0.75$, $p < 1 \times 10^{-16}$). The SWAMP combined riparian human disturbance index (Rehn et al. 2018) was strongly positively correlated with stream trash abundance for the 75th and 90th percentiles of trash abundance ($\tau = 0.9$, $p = 0.024$; $\tau = 0.75$, $p = 0.0015$). Buildings ($\tau = 0.9$, $p = 3.3 \times 10^{-5}$; $\tau = 0.75$, $p < 1 \times 10^{-16}$), pavement & cleared lots ($\tau = 0.9$, $p = 1.7 \times 10^{-12}$; $\tau = 0.75$, $p = 8.7 \times 10^{-8}$), pipes ($\tau = 0.9$, $p = 1.6 \times 10^{-7}$; $\tau = 0.75$, $p = 4.7 \times 10^{-5}$), anthropogenic channel alteration ($\tau = 0.9$, $p = 0.0014$; $\tau = 0.75$, $p = 0.0072$), and walls/rip-rap ($\tau = 0.9$, $p = 3.4 \times 10^{-7}$; $\tau = 0.75$, $p = 4.4 \times 10^{-16}$) within the stream reach were positively correlated with increased trash for the 75th and 90th percentiles of trash abundance. Bridges and abutments were also positively correlated but the relationships for trash abundance were not significant for any quantile.

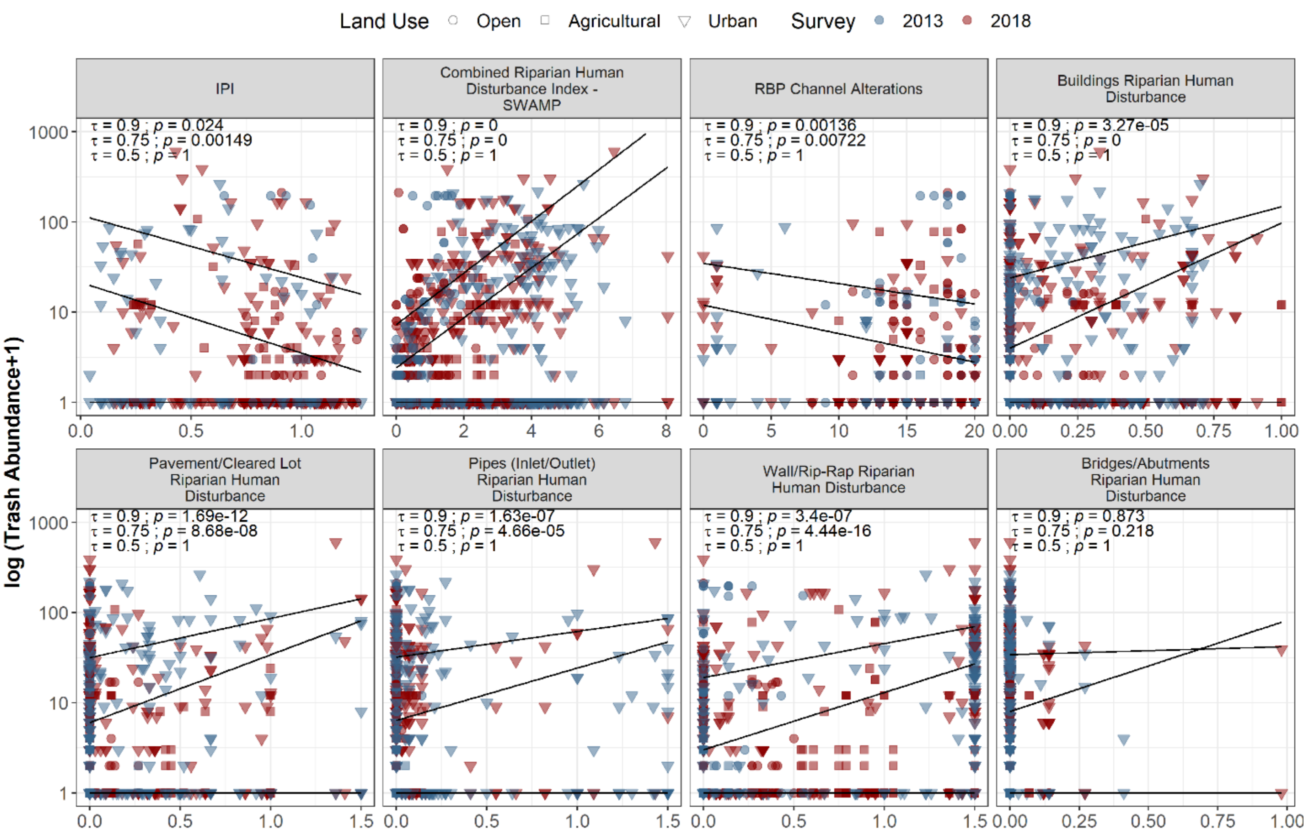



**Figure 2.13. Quantile regressions of trash abundance ($\log_{10}$ transformed) as a function of instream human disturbance metrics collected during physical habitat assessments in the Bight '13 (blue) and Bight '18 (red) surveys. Shape of the point is the land use category of each stream site. Lines represent linear regressions of quantile data (50th, 75th and 90th percentiles). The p-values for each quantile are also provided.**

**Channel characteristics.** In addition to human disturbance metrics some channel characteristics were also correlated with trash abundance (Figure 2.14). Both mean bankfull width and the mean wetted width were associated with increased trash abundance ($\tau = 0.9$, $p = 4.5x10^{-5}$ and 0.019, respectively) for the 90$^{th}$ percentile of trash abundance and steeper channels were associated with less trash abundance ($\tau = 0.9$, $p = 6.2x10^{-10}$; $\tau = 0.75$, $p = 1.8x10^{-6}$) for both the 90$^{th}$ and 75$^{th}$ percentile of abundance data. Increased sinuosity was associated with less trash ($\tau = 0.9$, $p = 1.3x10^{-5}$; $\tau = 0.75$, $p = 7.5x10^{-6}$), though this may be confounded by the fact that urban streams are hydrologically altered to be less sinuous.

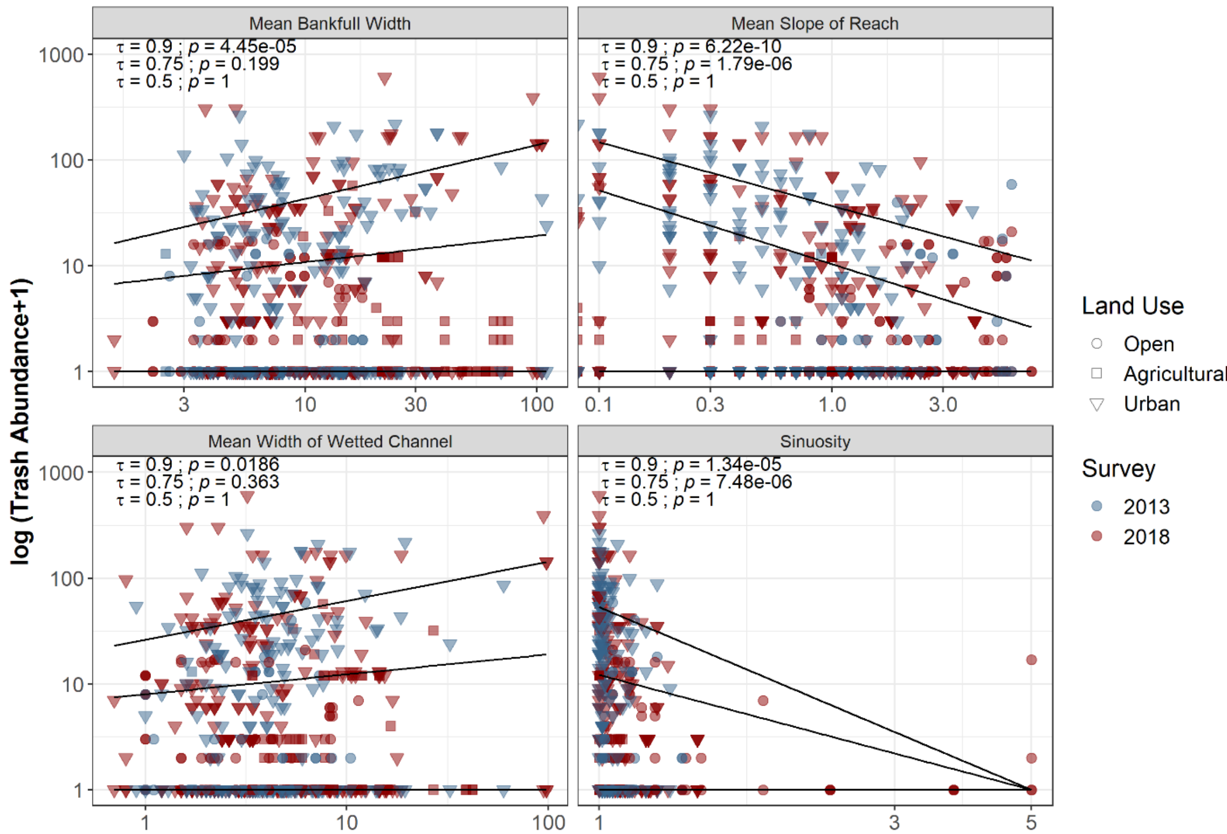



**Figure 2.14. Quantile regressions of trash abundance ($log_{10}$ transformed) as a function of channel characteristics collected during physical habitat assessments in the Bight '13 (blue) and Bight '18 (red) surveys. Shape of the point is the land use category of each stream site. Lines represent linear regressions of quantile data (50$^{th}$, 75$^{th}$, and 90$^{th}$ percentiles). The p-values for each quantile are also provided.**

**Time of sampling.** Time of sampling did not appear to have a significant influence on the abundance of trash at any given site. Program participants were concerned that trash abundance in streams would increase as the time since the last flushing event increased, which may lead to bias in the dataset wherein sites sampled later in the season would have significantly higher trash abundances. We therefore conducted an analysis of the trash abundance at a site as a function of the date of sampling and found no significant trend in the mean trash abundance in streams through time for any of the sampling years associated with either the 2013 or 2018 surveys (Figure 2.15). However, all sampling years were in a period of extended drought in southern California (Apurv and Cai 2021).

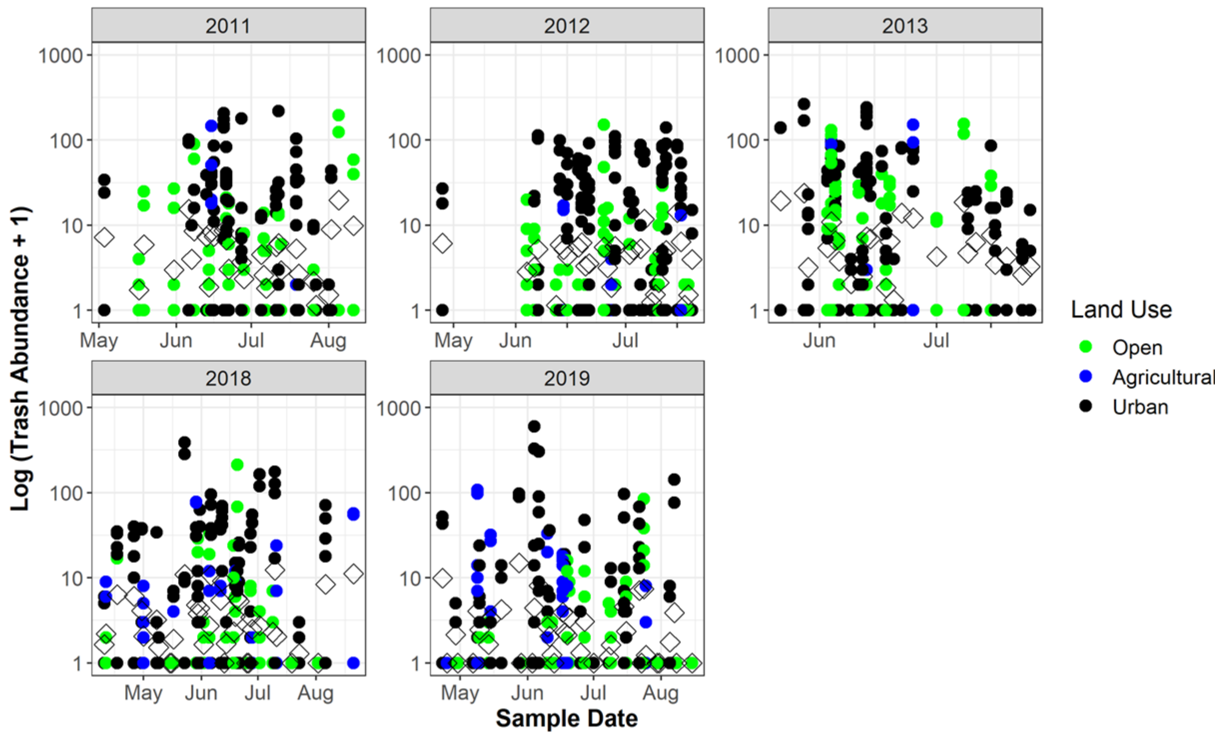



**Figure 2.15. Total trash abundance ($log_{10}$ transformed) at each site by sample date. Colors represent land uses, open (green), agricultural (blue) or urban (black). Diamonds are the mean trash abundance for that date across all sites.**

## Trends

Overall trash extent and magnitude were similar between the Bight '13 and Bight '18 surveys (2.16), with no significant differences in either trash abundance within streams or the percent of stream kilometers containing trash between the two surveys. However, there was a significant decrease in plastic bag abundance throughout the region, particularly in the open land use category (Figure 2.17), possibly due to the implementation of the state-wide bag ban in 2016. Despite the decrease in plastic bags, the overall plastic trash extent and magnitude was not significantly different between the two surveys (Figure 2.16), with no significant difference in either trash abundance or percent of stream kilometers containing trash.

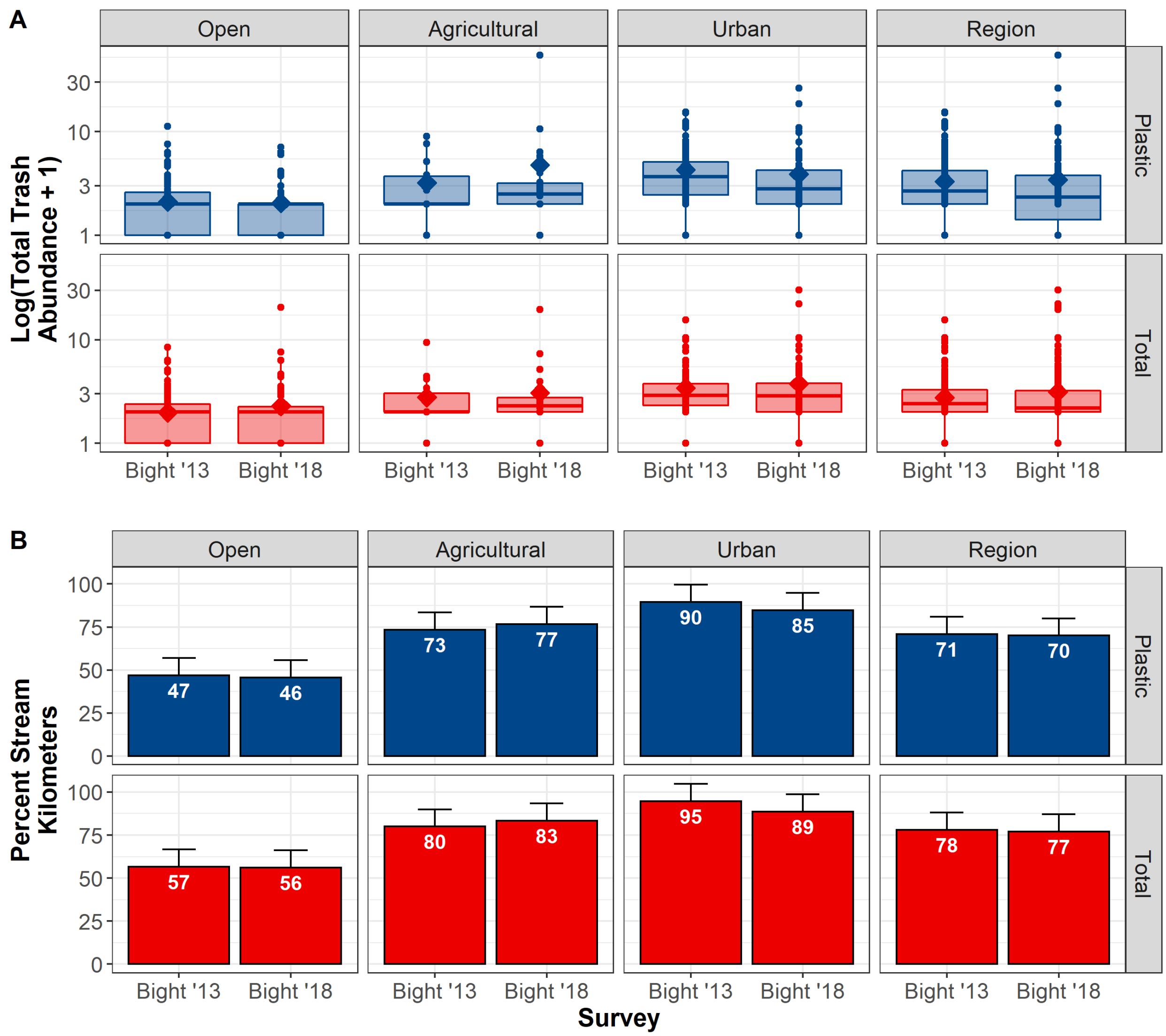



**Figure 2.16. Difference in watershed total trash abundance (A) and extent (B) between the Bight '13 and Bight '18 surveys. Abundance is the log (base 10) of the total counts of all items plus 1. Diamonds are the mean counts of each type in each land use category and for the region overall. Percent of stream kilometers is based on presence of at least 1 piece of trash (or plastic trash) in sampled 30.5 m reach.**

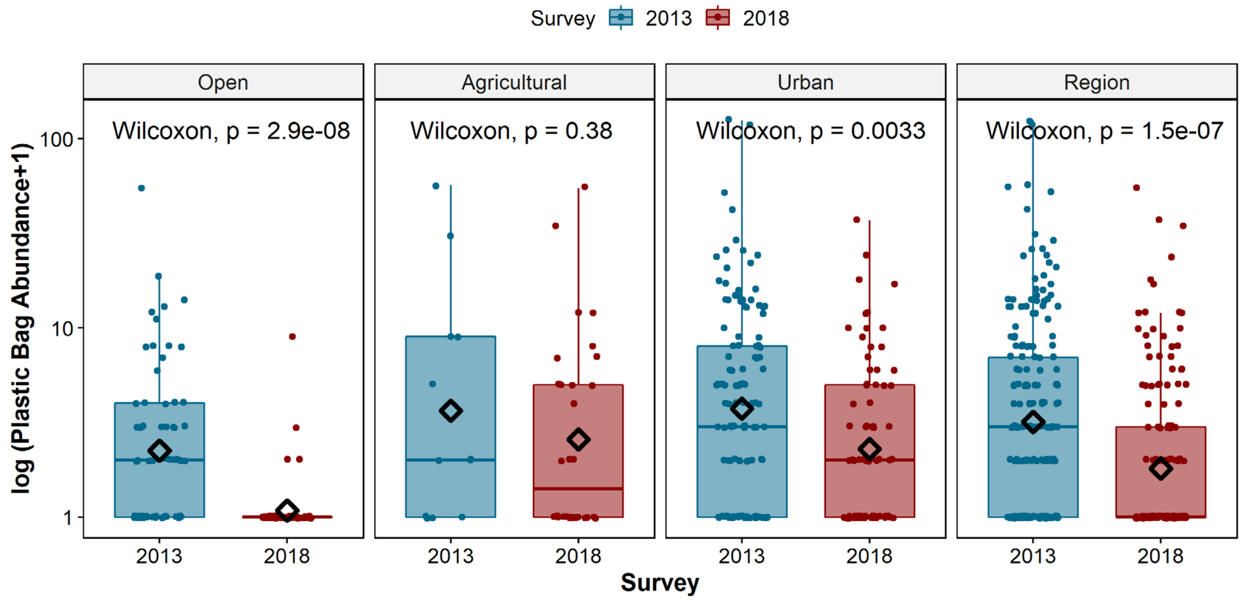



**Figure 2.17. Abundance of plastic bags in each land use category and for the region overall in Bight '13 (blue) and Bight '18 (red). Abundance is the log (base 10) of the total counts of all items plus 1. Diamonds are the mean counts of each type in each land use category and for the region overall. Significance of the difference in mean abundance is given by Wilcoxon test.**

While not many watersheds have implemented trash total maximum daily loads (TMDLs), 3 watersheds within the study area have: Santa Monica Bay Watershed, Los Angeles River Watershed, and Ventura River. Both the Los Angeles River and the Santa Monica Bay watersheds were monitored in both Bight '13 and Bight '18. While there was no significant difference in the extent of trash in these two watersheds (Figure 2.18B), there was a significant decrease in the abundance of trash in Santa Monica Bay ($p < 0.007$, Figure 2.18A). Los Angeles River had neither a significant decrease in trash abundance nor extent. The Ventura River was not monitored in Bight '13.

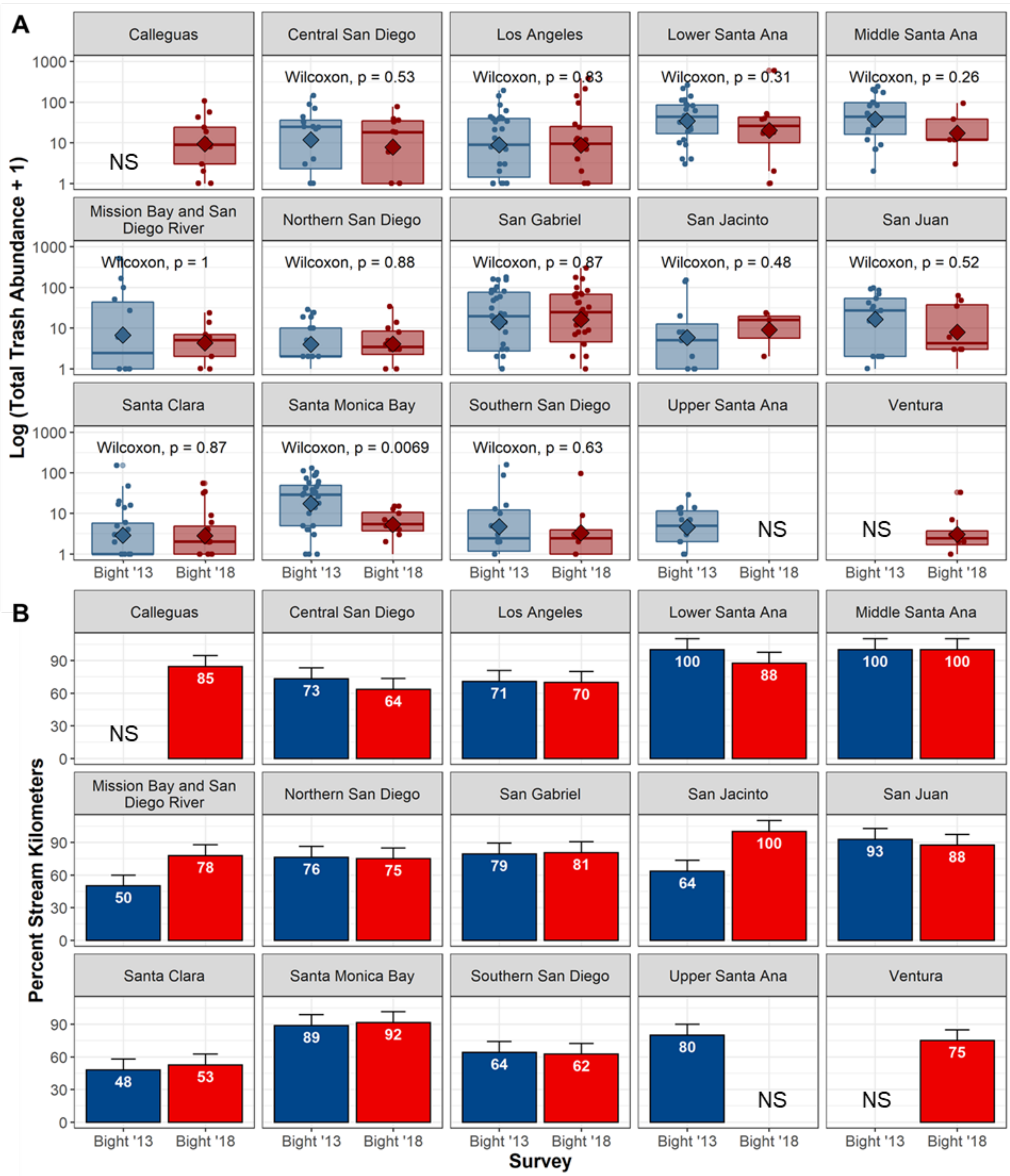



**Figure 2.18. Difference in watershed total trash abundance (A) and extent (B) between the Bight '13 and Bight '18 surveys. Abundance is the log (base 10) of the total counts of all items plus 1. Diamonds are the mean counts of each type in each land use category and for the region overall. Percent of stream kilometers is based on presence of at least 1 piece of trash in sampled 30.5 m reach. "NS" indicates watershed wasn't sampled during the program.**

## Discussion

Trash was pervasive throughout southern California watersheds, present in an estimated 77% of the nearly 7,400 stream kilometers with an estimated stock of over 7 million pieces. The large extent and magnitude observed in this survey is consistent with the large quantities of trash discharged to the marine environment from southern California's river mouths during storm events. Moore et al. (2011) estimated that 2.3 x $10^9$ pieces of trash, cumulatively weighing at least 30 metric tons, were discharged from 3 of southern California's urban watersheds during a range of typical storm events. While it is tempting to compare our abundance estimates (7 x $10^6$ trash pieces) to those of Moore et al. (2011), we note that the latter represents a wet weather transport process (fluxes) rather than dry weather accumulation (standing stock), which was the focus of this study. A better understanding of accumulation rates during dry weather and immediately following storm events is needed to characterize the wet weather measured fluxes (e.g., Moore et al. 2011) within the context of estimates of standing stock (this study).

This survey found that plastic was the leading type of trash in both extent and magnitude, consistent with findings from many other freshwater and oceanic systems [e.g., the Seine River (Gasperia et al. 2014), Chicago River (Hollein et al. 2014), the Danube River (Lechnera et al. 2014) and southern California watersheds (Moore et al. 2011)]. Globally, between 1.15 and 2.41 million tons of plastic waste enters the ocean annually from rivers (Lebreton et al. 2017). Moreover, of the plastic items found, over 90% of the items were broken pieces from a larger item. This visible degradation of plastics suggests that continued degradation to microplastics is occurring in the watersheds. The weathering and breakdown of larger plastic particles from land-based sources is one mechanism for microplastic contamination of marine habitats and is a source of concern for marine microplastic pollution (Andrady 2011). Microplastics have been identified in southern California river surface waters (Moore et al. 2011; Talley and Whelan 2020). Though the extent of the problem in the southern California region is poorly understood. An estimated 80% of microplastic pollution in the ocean comes from land and rivers, making them one of the dominant pathways for microplastics to reach the oceans (Rochman 2018), it is likely that the loading of plastic trash from southern California coastal watersheds is contributing to the region's high density of marine shoreline (Moore et al. 2001b), floating (Moore et al. 2002), epibenthic (Chapter 3), and benthic (Moore et al. 2016) plastic trash.

In addition to its impacts of trash on freshwater habitats, urban stormwater has been implicated as a primary source of debris in the marine environment (Conley et al. 2019). Particularly along urbanized coastlines, terrestrial waterways are considered the primary sources that transport trash from the land to the coastal ocean (Sheavly and Register 2007; Willis et al. 2017). Consequently, efforts at trash management have been increasing globally to mitigate trash pollution (Willis et al. 2017; Jambeck et al. 2015). Local solutions, such as improvements in infrastructure (e.g., trash booms), public outreach and trash receptacles at popular beaches decrease the amount of debris on shorelines (Frost and Cullen 1997; Ribic et al. 2012; Willis et al. 2017). Similarly, stormwater traps have been shown to significantly reduce debris entering the coastal margin, capturing up to 44% of litter before it enters the coast (Whitehead et al. 2010; Schlining et al. 2013).

Southern California's management community has proposed and implemented measures to minimize the amount of trash in waterways, including recycling programs, plastic bag bans, and other regulations and legislation. Senate Bill 270, which established a statewide ban on plastic bags, was implemented in 2016 between Bight Trash surveys. We found a significant reduction in plastic bags since the 2013 survey, which indicates that management actions can be effective at combating trash abundance in watersheds. The Bight '18 survey saw a significant decrease in the abundance of plastic bag and bag pieces between the 2013 and 2018 surveys, from an area-weighted mean of 6 ± 15 bags per site to 2 ± 6 bags per site region-wide, with most of that decrease occurring in urban land uses.

Trash extent and magnitude was closely tied to human activity. Similar relationships between trash and plastic concentrations in watersheds and human population density and proportion of urban development in catchments have been identified in other regions (Yonkos et al. 2014; Galgani et al. 2015; Carpenter and Wolverton 2017). Southern California urban land use sites contained the greatest extent and magnitude of trash compared to other land uses, present in over 40% more stream kilometers and having an average of 5 times as many pieces of trash within a reach compared to open land uses. Increased trash was also correlated with key indicators of urban development such as nearby roads and parking lots, as well as instream human disturbance metrics, relationships that were consistent across land uses. Increased trash density has been linked to site accessibility in urban areas and these high-density, high-accessibility sites represent a particularly important source area of receiving water trash occurrence (Carpenter and Wolverton 2017). Indeed, survey sites located near bike paths with direct access to a waterway had some of the highest abundances of trash present compared to other types of roadways. Limiting accessibility using fencing did not seem to be a significant deterrent, because we did not see a difference in trash abundance at stream sites with fencing compared to stream sites without.

Management strategies should consider mechanisms through which trash is deposited in streams. Trash deposited in stream corridors occurs through several primary sources and pathways including, but not limited to: 1) land use based sources, 2) incidental or wind-blown trash from adjacent areas, and 3) direct deposit of trash through homeless encampments, littering, illegal dumping, and trash mismanagement (Ryan et al. 2009; Jambeck et al. 2015). Roadways seem to play a role in trash source accumulation processes for streams, either as a mechanism for transport to waterways or as a proxy for human activity near the site. The relationship between stream trash and roadway contribution suggests that management strategies to address roadway-associated trash may increase the cost-effectiveness of trash source reduction efforts. Survey results indicated that trash abundance was higher in sites that were within 250 m of either a road or parking lot, suggesting management strategies to mitigate direct deposits associated with roadways or trash washed off or blown off from roadways may reduce instream trash. That the largest roads had higher trash abundances than areas with smaller roads would suggest that such actions should be prioritized for larger roadways.

Evaluating the most prevalent types of trash as well as their distribution can provide insight into where focused environmental management actions may be most effective for trash mitigation. For example, plastic container pieces, plastic bags, plastic wrappers, and Styrofoam ranked as the top 4 most abundant trash items in the region. Source control of these items could be achieved through alternative material selection or reduction of packaging materials. Alternative materials are currently being explored as a mechanism to reduce marine plastic litter globally, with a focus on replacement materials for single-use plastics utilizing a combination of natural fibers, synthetic, degradable biopolymers, and reusable containers (UN Environment Programme 2017). Given the success in reduction with plastic bags, similar actions for other materials might be expected to have similar outcomes.

One limitation of this study is the lack of trash mass data. The study design sacrificed weighing trash to measure more sites, which was an important tradeoff to increase confidence in estimates of extent and magnitude. However, mass estimates will be one key attribute for linking land-based trash and trash measured in the near coastal oceans, although methodological challenges such as subtracting water, sediment and biological material from the trash must be overcome. This linkage becomes especially important for plastics that can break into smaller pieces, thereby increasing abundance, but will not increase total mass. Now that this survey has measured extent and trash counts, future studies focused on accumulation rates, and especially accumulation rates of trash mass, are logical next steps.

## Conclusions

- **Trash was pervasive in southern California coastal watersheds.** Over three-quarters (77%) of the more than 7,400 km of southern California wadeable streams contained trash. In the most severely impacted watersheds (Middle Santa Ana and San Jacinto), 100% of stream kilometers had trash and in the least impacted watershed (Santa Clara), 53% of stream kilometers had trash. The 5 most frequently encountered items were: wrappers, paper/cardboard, plastic pieces, bags, and foam pieces.

- **Plastic trash was the most prevalent item found.** Plastic trash was the most common trash type found in all land uses and all watersheds with nearly 70% of stream kilometers having plastic trash region wide. Of the plastic items found, over 90% of the items were pieces of a larger item. This visible degradation of plastics suggests that continued degradation to microplastics is occurring in the watersheds, though no assessment of their extent and magnitude has been conducted to date.

- **Trash distribution in Southern California Bight Watersheds is associated with indicators of human activity.** Trash was found in greater than 89% of the stream kilometers in urban watersheds, compared to 56% of stream kilometers in undeveloped watersheds. Watershed indicators of human disturbance were the most predictive of trash abundance in watersheds. Increased trash abundance in streams was correlated with increased road density and the number of paved intersections within 5 km of the site. Trash abundance in streams was also highest if the roads and parking lots were close to the survey reach, with highest abundances within 250 m of the reach. In addition to human disturbance metrics some channel characteristics were correlated with trash abundance. Wider channels were associated with more trash and steeper channels were associated with less.

- **Extent and magnitude of trash in watersheds during the Bight ’18 survey was similar to Bight ’13; however, management actions may be having an impact on reducing trash.** While overall trash extent and magnitude were similar between the Bight ’13 and Bight ’18 surveys, there was a significant decrease in plastic bags (Figure 1.4), likely due to the implementation of the state-wide bag ban in 2016. In addition, Santa Monica Bay Watershed also saw a significant decrease in trash, possibly due to the Trash TMDL. These data provide preliminary evidence that source control measures may be an effective strategy for trash reduction in watersheds.

## References


Apurv, T. and Cai, X. 2021. Regional Drought Risk in the Contiguous United States. *Geophysical Research Letters*, *48*(5), p.e2020GL092200.

Boerger, C.M., G.L. Lattin, S.L. Moore, and C.J. Moore. 2010. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Marine Pollution Bulletin 60:2275-2278.

Claisse, J.T., Blanchette, C.A., Dugan, J.E., Williams, J.P., Freiwald, J., Pondella, D.J., Schooler, N.K., Hubbard, D.M., Davis, K., Zahn, L.A., and Williams, C.M. 2018. Biogeographic patterns of communities across diverse marine ecosystems in southern California. *Marine Ecology*, *39*, p.e12453.

Conley, G., Beck, N., Riihimaki, C.A. and Hoke, C. 2019. Improving urban trash reduction tracking with spatially distributed Bayesian uncertainty estimates. *Computers, Environment and Urban Systems*, *77*, p.101344.

CRWQCBLAR. 2007. Trash Total Maximum Daily Loads for the Los Angeles River Watershed. California Regional Water Quality Control Board, Los Angeles Region.

CRWQCBLAR. 2015. Amendment to the Water Quality Control Plan for the Los Angeles Region to Revise the Total Maximum Daily Load for Trash in the Los Angeles River Watershed and the Total Maximum Daily Load for Trash in the Ballona Creek Watershed. California Regional Water Quality Control Board, Los Angeles Region. Resolution Number R15-006.

Day, R.H., D.G. Shaw, and S.E. Ignell. 1990. The quantitative distribution and characteristics of neustonic plastics in the North Pacific Ocean. Pp. 247-266 *In:* RS Shomura, ML Godfrey (eds) Proceedings of the Second International Conference on Marine Debris. April 27-29, Honolulu, HI. United States Department of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-SWFC-154.

Derraik, J. 2002. The pollution of the marine environment by plastic debris. Maine Pollution Bulletin 44:842-852

Frost, A. & Cullen, M. 1997. Marine debris on northern New South Wales beaches (Australia): Sources and the role of beach usage. Marine Pollution Bulletin 34, 5, 348–352.
Gall, S.C. and R.C. Thompson. 2015. The impact of debris on marine life. Marine Pollution Bulletin 92:170-179.

Gasperia, J., R. Drisa, T. Bonina, V. Rocherb, and B. Tassin. 2014. Assessment of floating plastic debris in surface water along the Seine River. Environmental Pollution 195:163-166

Hollein, T, M Rojas, A Pink, J Gasior, J Kelly. 2014. Anthropogenic litter in freshwater systems: Distribution and microbial interactions. PLOS One 9(6): e98485. doi:10.1371/journal.pone.0098485

Horvitz, D. G. and Thompson, D. J. 1952 "A generalization of sampling without replacement from a finite universe", *Journal of the American Statistical Association*, 47, 663–685.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R. and Law, K.L., 2015. Plastic waste inputs from land into the ocean. *Science*, *347*(6223), pp.768-771.

Kincaid, T. M. and Olsen, A. R. 2013. spsurvey: Spatial Survey Design and Analysis. R package version 2.6. URL: http://www.epa.gov/nheerl/arm/.

Larsen, D.P., A.R. Olsen and D.L. Stevens. 2008. Using a master sample to integrate stream monitoring programs. Journal of Agricultural, Biological, and Environmental Statistics 13:243-254

Lechnera, A., H. Keckeisa, F. Lumesberger-Loisla, B. Zensa, R. Kruscha, M. Tritthartb, M. Glasb, and E. Schludermanna. 2014. The Danube so colourful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river. Environmental Pollution 188:177-188

Mazor, R. 2015. Bioassessment of perennial streams in southern California: A report on the first five years of the Stormwater Monitoring Coalition’s regional stream survey. Southern California Coastal Water Research Project. Costa Mesa, CA.

Moore, CJ, SL Moore, MK LeeCaster, SB Weisberg. 2001a. A comparison of plastic and plankton in the north pacific central gyre. Marine Pollution Bulletin 42:1297-1300

Moore, C.J., S.L. Moore, S.B. Weisberg, G.L. Lattin, and A.F. Zellers. 2002. A comparison of neustonic plastic and zooplankton abundance in southern California's coastal waters. Marine Pollution Bulletin 44:1035-1038.

Moore, C.J., G.L. Lattin, and A.F. Zellers. 2011. Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of southern California. Journal of Integrated Coastal Zone Management 11:65-73.

Moore, S.L., D. Gregorio, M. Carreon, S.B. Weisberg, and M. Leecaster. 2001b. Composition and distribution of beach debris in Orange County, California. Marine Pollution Bulletin 42:241-245.

Moore, S., M. Sutula, T. Von Bitner, G. Lattin, and K. Schiff. 2016. Southern California Bight 2018 Regional Monitoring Program: Volume III. Trash and Marine Debris. Technical Report #928. Southern California Coastal Water Research Project. Costa Mesa, CA.

National Oceanic and Atmospheric Administration. 1995. Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation. Technical Report NMFS 123. Department of Commerce.

National Oceanic and Atmospheric Administration. 2001. Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation. Technical Report NMFS 123. Department of Commerce.

National Research Council (NRC). 2009. Tackling Marine Debris in the 21st Century. National Academies Press, Washington, DC.

R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0.

Rehn, A.C., R.D. Mazor, P.R. Ode. 2018. An Index to Measure the Quality of Physical Habitat in California Wadeable Streams. SWAMP Technical Memorandum. SWAMP-TM-2018-0005. August 2018

Ribic, C., Sheavly, S. B., Rugg, D. J. & Erdmann, E. S. 2012. Trends in marine debris along the U.S. Pacific Coast and Hawai'i 1998–2007. Marine Pollution Bulletin 64, 994–1004.

Rochman, CM. 2018. Microplastics research: From sink to source. Science 2018;360(6384):28–29. pmid:29622640

Ryan, P. G., C. J. Moore, J.A. van Framneker, and C. L. Moloney. 2009. Monitoring the abundance of plastic debris in the marine environment. Philosophical Transactions of the Royal Society B 364: 1999- 2012.

Schiff, K., McLaughlin, K., Moore, S. and Cao, Y. 2019. Southern California Bight. In *World Seas: an Environmental Evaluation* (pp. 465-482). Academic Press.

Schlining, K., S. von Thun, L. Kuhnz, B. Schlining, L. Lundsten, N.J. Stout, L. Chaney, and J. Connor. 2013. Debris in the deep: Using a 22-year video annotation database to survey marine litter in Monterey Canyon, central California, USA. Deep-Sea Research I 79, 96–105.

Sheavly, S. B. & Register, K. M. 2007. Marine debris & plastics: Environmental concerns, sources, impacts and solutions. Journal of Polymers and the Environment 15, 301–305

Stevens, D. L., Jr. and A. R. Olsen. 2004. "Spatially-balanced sampling of natural resources." Journal of American Statistical Association 99(465): 262-278.

Talley, T.S., Venuti, N. and Whelan, R. 2020. Natural history matters: Plastics in estuarine fish and sediments at the mouth of an urban watershed. *Plos one*, *15*(3), p.e0229777.

Thompson, R.C., C.J., Moore, F.S. von Saal, and S.H. Swan. 2009. Plastics, the environment and human health: current consensus and future directions. Philosophical Transactions of the Royal Society B 364: 2153- 2166.

United Nations Environment Programme. 2017. Exploring the potential for adopting alternative materials to reduce marine plastic litter.

United States Geological Survey and United States Environmental Protection Agency. 2005. National Hydrography Dataset Plus. Reston, VA.

Whitehead, J., C. Coughanowr, J. Agius, J. Chrispijn, U. Taylor, and F. Wells. 2010. State of the Derwent Estuary 2009: a review of pollution sources, loads and environmental quality data from 2003 –2009. Derwent Estuary Program, DPIPWE.

Yonkos, L., Friedel, E., Perez-Reyes, A., Ghosal, S. & Arthur, C. 2014. Microplastics in four estuarine rivers in the Chesapeake Bay, USA. Environ. Sci. Technol. 48, 14195–14202 (2014).

# Chapter 3. Regional Assessment of Epibenthic Marine Debris in the Southern California Bight


## Abstract

Anthropogenic marine debris has become a global environmental concern, with well-documented social-economic costs as well as ecological impacts. In this study, we assessed the extent and magnitude of trawl-caught epibenthic debris in the Southern California Bight (SCB) by type and by habitat, and characterized the trends in epibenthic debris from 1994 to 2018 on the continental shelf. The SCB is an urban ocean with a well-developed coastline that is home to a coastal population of over 22 million. Anthropogenic marine debris was present on an estimated 31% of SCB seafloor area (5-500 m depths). Trawl-caught debris items were typically found in low abundances within trawls and the extent of area where debris was found generally increased with depth. Plastic had the greatest extent and magnitude of debris types; present on an estimated 27% of the SCB seafloor area. The extent of anthropogenic debris on the SCB continental shelf seafloor (the subset of SCB seafloor sampled during every Bight program) has been increasing over the 25 years since trash enumeration in trawl surveys began, with all debris types increasing from 13% to 25%. Plastic trash was consistently the most frequently encountered debris type with extent on the shelf increasing from 9% to 21% since 1994.


## Introduction

Marine debris is defined as “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment” (Arcangeli et al. 2018; Galgani et al. 2013). Marine debris has been documented in many different habitats, including estuaries, bays, shorelines, and open ocean waters at the surface, water column and benthos (United Nations 2017). Numerous studies document its prevalence and impacts on both aesthetics and aquatic life, not only in populated coastal areas but also the remote parts of the world’s oceans (Gall and Thompson 2015; United Nations 2017; Diva et al. 2020). Sources of marine debris can be either ocean- or land-based, often through illegal dumping and waste mismanagement, accidental loss, or natural disasters (EPA 2008; Sheavly 2007; Jambeck 2015). Plastics represent the largest fraction of marine debris because of their poor degradability, often representing up to 95% of the debris accumulated in some environments (Ryan et al. 2009; Engler 2012; Maes et al. 2018). Every year in the world, 8 million tons of solid plastic debris are introduced into the marine ecosystem (Jambeck et al. 2015; United Nations 2017; Villarrubia-Gómez et al. 2018), and their increasing amounts and low degradation rates lead to accumulation in the oceans where they cause a serious threat to the marine environment, human health, and the economy (Barnes et al. 2009; Brouwer et al. 2017; Ioakeimidis et al. 2017; Ioakeimidis et al. 2014). The social-economic costs caused by litter on coastlines and at sea can be substantial (Mouat et al. 2010; Newman et al. 2015), affecting local economies through loss of tourism revenue (Legget et al. 2014). However, the ecological impacts have been generating greater public awareness (Kühn and van Franeker 2020). Marine debris can harm marine organisms and seabirds through ingestion and entanglement (see reviews by Laist 1997, Gall and Thompson 2015, and Kühn and van Franeker 2020). Marine debris has also been noted to affect behavior of marine species (Barros et al. 2020) as well as species dispersal and biodiversity (Carlton et al. 2017; Shabani et al. 2019). An estimated 914 species have had detrimental encounters with marine debris in some form and an estimated 92% of these encounters were with plastic debris (Gall and Thompson 2015; Kühn and van Franeker 2020).

The problem of marine debris is ubiquitous, concerns all sizes of litter, and affects all marine habitats from shorelines to deep ocean basins (Palatinus et al. 2019; Renzi et al. 2019). Most studies have focused on abundance, spatial distribution, and the analysis of debris types, providing information on sources that are either land- or ocean-based (Gerigny et al. 2019). Such regional assessments of marine debris are necessary to document the extent and magnitude of debris occurrence in coastal habitats, identifying habitats that are most severely impacted and documenting trends through time. These datasets are becoming increasingly important as environmental managers adopt mitigation strategies to regulate the amounts of debris entering marine environments (i.e., CRWQCBLAR 2015).

Since 1994, trawl surveys of marine debris have been conducted approximately every 5 years as part of the Southern California Bight (SCB) Regional Marine Monitoring Program (Allen et al. 1998, 2002, 2007, 2011; Walther et al. 2016; Wisenbaker et al. 2021). These surveys are an integrated, collaborative effort by regulatory and regulated agencies to assess environmental conditions on a region-wide scale (Schiff et al. 2016). Included in this effort were scientific trawls for environmental monitoring which typically examine demersal fish and benthic invertebrate assemblages. These trawls also present the opportunity to enumerate the extent and magnitude of marine debris caught in each trawl sample. Thus, the goals of this study were to: (1) assess the extent and magnitude of trawl-caught epibenthic debris in the SCB by debris type and by habitat; and (2) characterize the trends in debris on the continental shelf over the period between 1994 and 2018.

## Methods

### Study Design

This study used a probabilistic design to produce unbiased estimates of trash extent (percent of area) and magnitude (abundance). The trash assessment leveraged a larger study conducted by the collaborative Bight ’18 Trawl Program to assess demersal fish and megabenthic invertebrate communities in the SCB (Wisenbaker et al. 2021). Briefly, the design of this study followed those of the previous Bight trawl surveys, of which this is the fifth. The survey area for Bight ’18 covered the SCB from Point Conception, CA in the north, to the U.S.-Mexico border in the south, and from coastal embayments (5 m depth) out to the upper slope (500 m) (Figure 1). The trawlable soft bottom portions of this region were divided into 5 strata based upon established biogeographic breaks in community composition (Table 1). These strata include: Embayments (Bays & Harbors, 5-30 m); Inner Shelf (5-30 m); Middle Shelf (31-120 m); Outer Shelf (121-200 m); and Upper Slope (201-500 m). A stratified random sampling design was selected to ensure an unbiased sampling approach to generate areal assessments of environmental condition (Stevens 1997). Stratification ensured that an appropriate number of samples were allocated to each stratum to characterize the strata with adequate precision. The goal was to sample approximately 30 stations to each stratum, yielding a 90% confidence interval of about ±10% around estimates of areal extent. Area weights were used for calculating unbiased areal assessments of condition in the survey area (Stevens 1997). To assist in assessing temporal trends between surveys, nearly half of the stations were revisited from previous surveys (Table 1).

**Table 3.1. Summary of strata sampled during the Bight '18 trawl survey.**

| Habitat | Stratum | Depth Range (m) | Area (km$^2$) | Percent Area of Region | Number of Stations | Percent Revisit Sites |
|---|---|---|---|---|---|---|
| Bays | Bays & Harbors | 4-30 | 7 | 0.00% | 28 | 50% |
| Continental Shelf | Inner Shelf | 4-30 | 1172.5 | 17.00% | 29 | 45% |
| | Middle Shelf | 31-120 | 2019.8 | 29.00% | 30 | 40% |
| | Outer Shelf | 121-200 | 605.5 | 9.00% | 26 | 38% |
| Continental Slope | Upper Slope | 201-500 | 3130.6 | 45.00% | 25 | 44% |
| Bight Total | | | 6935.4 | 100.00% | 138 | 43% |

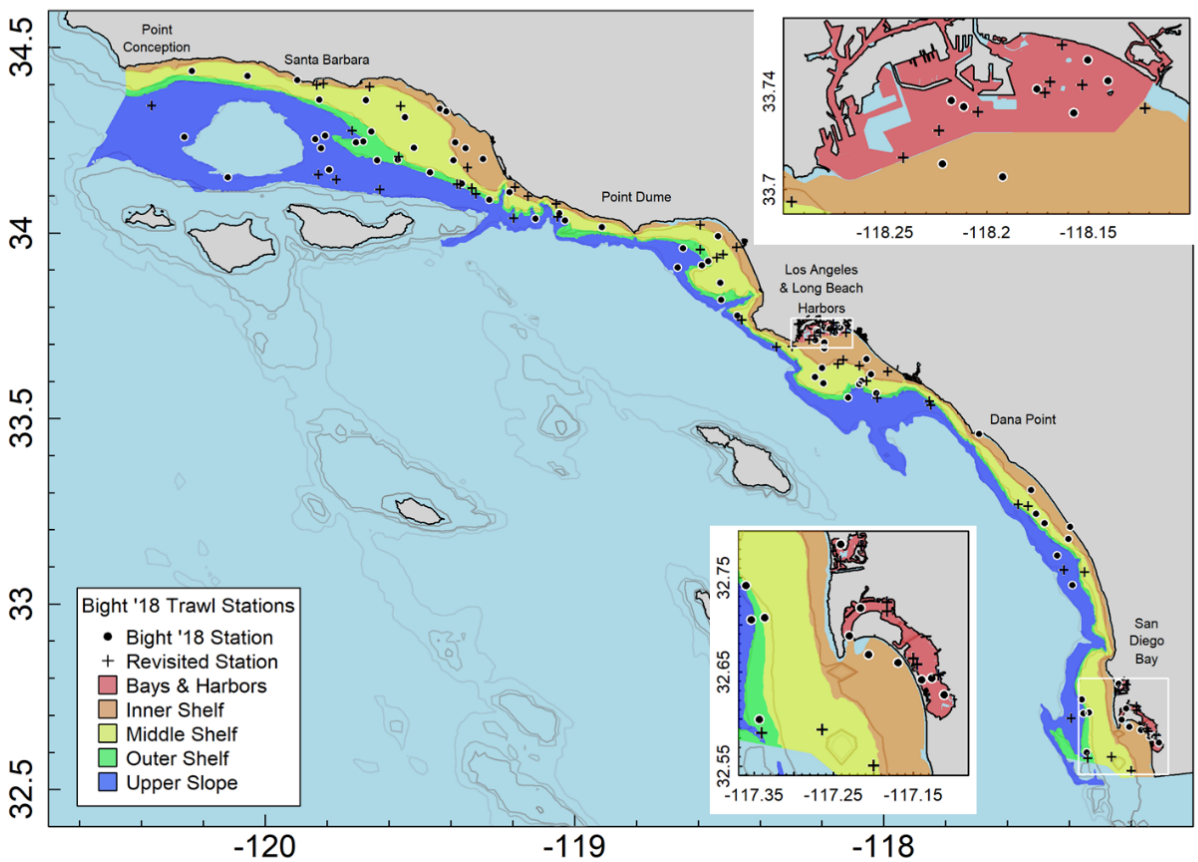



**Figure 3.1. Distribution of subpopulations sampled during the Bight '18 trawl survey.**

## Field Methods

***Trawling.*** Marine Debris were collected from 138 trawl stations between July 1 and September 30, 2018 (Table 1, Figure 1). Station coordinates, depths, and the stratum classification of each station are given in Appendix A. Trawl samples were collected according to standard methods described in the Bight '18 Sediment Quality Assessment Field Operations Manual (Bight '18 Sediment Quality Planning Committee 2018). Stations were located by global positioning system (GPS) via the research vessel's differential global positioning system (DGPS) or wide area augmentation system (WAAS). If a station could not be trawled or was too deep, it was relocated up to 100 m from the nominal station coordinates not to exceed 10% of the nominal station depth. Overdraw sites were assigned to sites that were unacceptable and therefore abandoned.

Samples were collected with 7.6-m head-rope, semi-balloon otter trawls with 3.8 cm mesh, and a 1.3 cm cod-end mesh. Trawls were towed along isobaths for 10 minutes (5 – 10 minutes in Bays & Harbors) at 0.8 – 1.0 m/sec (1.5 – 2 kts) as determined by GPS/DGPS. These tows covered an estimated distance of 300 and 600 m for 5- and 10-minute trawls, respectively. Agencies used a pressure-temperature (PT) sensor attached to 1 of the otter boards throughout the survey to provide net on-bottom data. Stations were re-trawled if the on-bottom time, as measured by the PT sensor, was less than 8 minutes for a 10-minute trawl. Once on deck, the cod-end was opened and the catch deposited into a tub or holding tank for processing. Any debris caught on the cable/doors/chain was noted, but not included in the tally.

***Trash Enumeration.*** Trawl debris was immediately sorted for processing along with the fish and invertebrate community composition. Trawl debris was sorted and quantified by recording the specific types of material and the number of pieces of each type. Only debris larger than 1.3 cm was collected and sorted. The broad debris categories match those used in the watershed trash evaluation (Chapter 2), to make comparisons of land-based trash versus ocean-based debris. The major categories include plastic, glass, metal, large Items (e.g., tires), construction materials (e.g., bricks, lumber), biodegradable materials (e.g., cardboard), fabric and cloth, as well as "natural" debris of marine origin (e.g., kelp) and terrestrial origin (e.g., tree branches). Types of items within each of these categories was counted and recorded as well as a description of each item. If an item is not on the list, it was placed in the appropriate "Other" category with a comment describing the item. In the case of items that could fit into multiple categories, the item was counted in the category that best represented the item, and other categories were documented in the comments field.

## Quality Assurance and Quality Control (QA/QC)

A Quality Assurance/Quality Control (QA/QC) plan was developed to ensure comparability among participating organizations within the survey. QA/QC activities included training in trash identification and an on-board field audit. Other QA/QC checks involved checking station data relative to nominal survey design strata. Detailed standardized field protocols and QA/QC procedures are described in the Contaminant Impact Assessment QA Manual (Bight '18 Sediment Quality Planning Committee 2018) and Field Operations Manual (Bight '18 Sediment Quality Planning Committee 2018).

Participating organizations met or exceeded the measurement quality objectives established for the Bight ’18 regional survey (Appendix B). Trawl sampling was complete and representative. Trash analysis was complete, accurate, and precise. No deviations in procedures occurred that required exclusion of data.

### Information Management

Collection of trawl debris data was a field activity, with exception of some renaming of item types (not categories) to increase consistency among agencies. Agencies were permitted to use field computers or standardized datasheets for data collection. Sampling agencies submitted their data electronically to a centralized Southern California Coastal Water Research Project (SCCWRP) database through a data portal with a series of data checkers designed to expedite the QA/QC process. Submitted datasets were provided to the Bight ’18 Trash Committee for review, additional QA/QC checks, and analysis.

### Data Analysis

Area weights were assigned to each site for each stratum definition, to account for differences in total stratum area. These weights were used when estimating magnitude (area-weighted mean abundances) and spatial extent (percent of seafloor area) using the Horvitz-Thompson estimator (Horvitz-Thompson 1952). Confidence intervals (CIs) were based on local neighborhood variance estimators (Stevens and Olsen 2004).

Data analyses were performed with R 4.0.2 (R Core Team 2020), using the tidyverse (Wickham et al. 2019), IDPmisc (Locher and Ruckstuhl 2012), and ggpubr packages (Kassambara 2018). Statistical analyses were conducted using the rstatix package (Kassambara 2020). Debris abundance was log-transformed for analysis ($\log_{10}$(abundance + 1)). Kruskal-Wallis one-way analyses of variance (ANOVA) were used to test differences in trash abundance among the strata and years. R code is available from SCCWRP upon request.

Data analysis focused on determining spatial extent (percentage of area) and magnitude (abundance) of debris in the SCB. Spatial extent was calculated using a ratio estimator (Thompson 1992; Stevens 1997; Allen et al. 1998). Debris data were expressed as counts per standard 10-min trawl haul (Allen et al. 1998). In the Bay stratum, 14 stations had trawls that were 5 minutes in length. Abundance estimates for these stations were therefore doubled to be more comparable to 10-minute trawls. The spatial coverage (percent area) of a debris type in a stratum was defined as the occurrence of at least one piece of a debris type in a standard trawl haul collected at a station, where each station represented a percentage of the total stratum (e.g., depth or location) area.

For analysis of trends, results from trawl surveys conducted every 5 years between 1994 and 2018 were used. For comparability among years, the extent and magnitude of debris was based on the 3 strata sampled in all years (Inner Shelf, Middle Shelf, and Outer Shelf). The number of samples for each year ranged from 113 in 1994 to 314 in 1998. Sampling methods for all trawl surveys were the same throughout each of the years evaluated, although in earlier trawls abundance of each item was not assessed, only its presence.

## Results

### Extent and Magnitude

Anthropogenic debris occurred in an estimated 31% of the SCB seafloor area (5-500 m depth) (Figure 3.2). Generally, the extent of habitat where anthropogenic debris was present increased with distance from the shore. Areal extent ranged from 42% of area in the deepest habitat sampled, the upper slope of the continental shelf, decreasing to 15% of area in the bays and harbors.

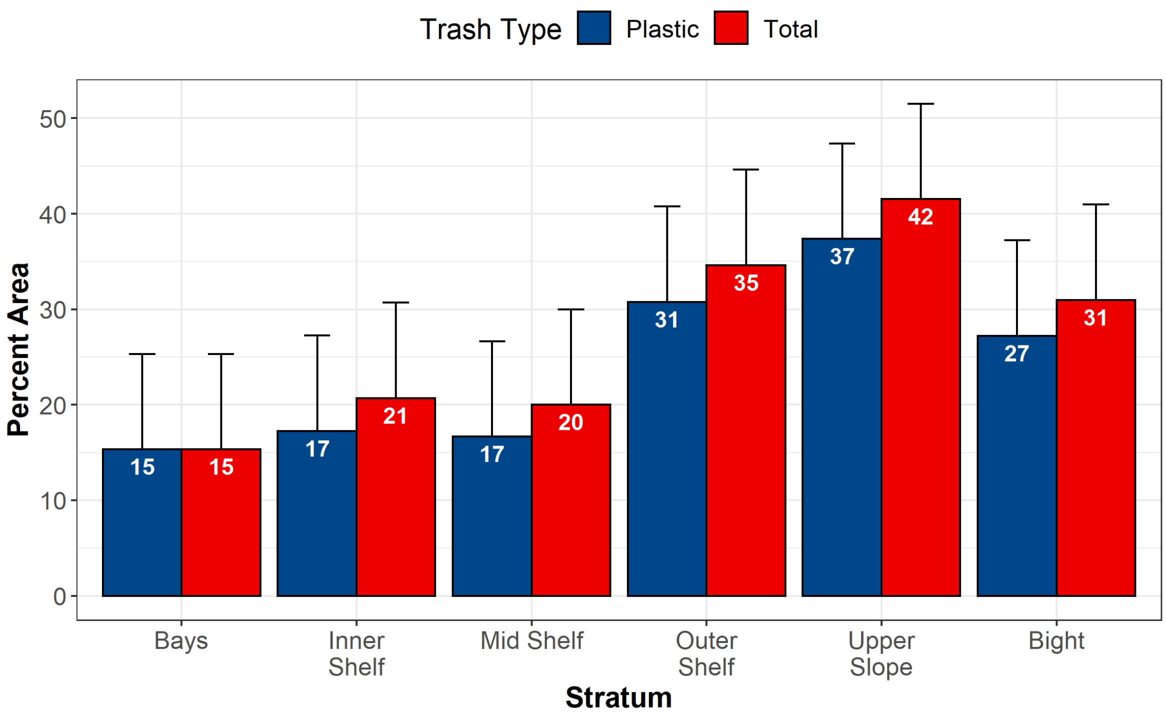



**Figure 3.2. Percent of seafloor surface area where debris (red) and plastic debris (blue) were recovered in trawls by strata and for the Bight overall.**

Plastic was both the most ubiquitous debris category recovered from trawls, as well as the most numerous (Figures 3.2 and 3.3). Plastic debris occurred on an estimated 27% of the SCB seafloor area, and like general trash trends, changed in areal extent with distance from shore from a low of 15% of area in bays and harbors to a high of 37 % of area on the upper slope. Of the other debris categories, fabric was the second most prevalent, consisting of 10% of SCB area, followed by metal and construction materials (2% of area) and glass (1% of area) (Table 3.2).

In general, the abundance of debris recovered from trawls was low (Figure 3.3). Where debris was found, abundance numbered 1 item per trawl at 54% of sites. The highest total count of debris items recovered in a trawl was 6 pieces from the Port of Los Angeles/Long Beach. The largest count of any single item type was fishing line/nets (4 pieces). Other items in which more than 1 was recovered in a trawl were food wrappers, plastic bags, drink cans, glass bottles, rope, fabrics, and in one trawl, 2 car tires (Table 3.3).

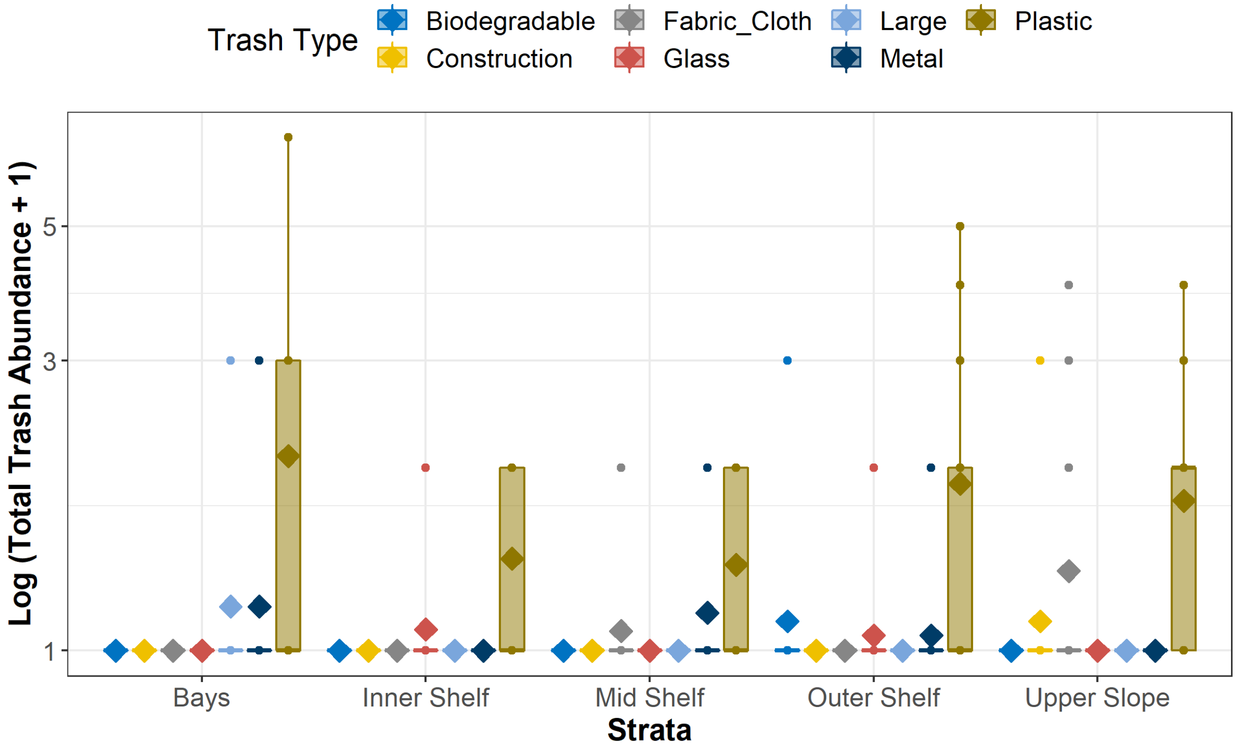



**Figure 3.3. Abundance of trash recovered from trawl nets in each stratum. Abundance is the log (base 10) of the total counts of all items plus one. Box and whiskers show percentiles. Diamonds are the mean counts of each type in each land use category and for the region overall.**

**Table 3.2. Percent of Bight seafloor area containing at least one trawl caught item of each debris type for the region and each stratum.**

| Stratum | Debris Category | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | Large | Metal | Plastic | Glass | Fabric | Biodegradable | Construction | |
| Bays | 3.8 | 3.8 | 19.1 | 0.0 | 0.0 | 0.0 | 0.0 | 15 |
| Inner Shelf | 0.0 | 0.0 | 17.2 | 3.4 | 0.0 | 0.0 | 0.0 | 21 |
| Mid Shelf | 0.0 | 6.7 | 16.7 | 0.0 | 3.3 | 0.0 | 0.0 | 20 |
| Outer Shelf | 0.0 | 3.8 | 46.2 | 3.8 | 0.0 | 3.8 | 0.0 | 35 |
| Upper Slope | 0.0 | 0.0 | 49.8 | 0.0 | 20.8 | 0.0 | 4.2 | 42 |
| Region | 0.0 | 2.3 | 34.2 | 0.9 | 10.2 | 0.3 | 1.9 | 31 |

**Table 3.3. Most common items found in each stratum for the Bight by rank and percent area.**

| Stratum | Debris Item | Frequency Rank | Percent Area |
|---|---|---|---|
| Bays | Bags/Bag Pieces | 1 | 18 |
| | Wrapper/Wrapper Pieces | 1 | 18 |
| | Aluminum/Steel Cans | 2 | 9 |
| | Fishing Gear | 2 | 9 |
| | Tire | 2 | 9 |
| Inner Shelf | Plastic Pieces (soft/hard) | 1 | 17 |
| | Cups/Lids | 2 | 8 |
| | Fishing Line/Net | 2 | 8 |
| | Glass Bottles | 2 | 8 |
| | Wrapper/Wrapper Pieces | 2 | 8 |
| Mid Shelf | Natural Fiber (Cotton, Wool) | 1 | 15 |
| | Plastic Pieces | 1 | 15 |
| | Aluminum/Steel Cans | 2 | 8 |
| | Fishing Gear | 2 | 8 |
| | Plastic Pipe | 2 | 8 |
| | Rope | 2 | 8 |
| Outer Shelf | Plastic Pieces | 1 | 24 |
| | Bags/Bag Pieces | 2 | 12 |
| | Fishing Gear | 2 | 12 |
| | Wrapper/Wrapper Pieces | 2 | 12 |
| | Glass Bottles | 3 | 6 |
| | Paper/ cardboard | 3 | 6 |
| | Rope | 3 | 6 |
| Upper Slope | Plastic Pieces | 1 | 24 |
| | Natural (Cotton, Wool) | 2 | 18 |
| | Wrapper/Wrapper Pieces | 2 | 18 |
| | Balloon | 3 | 6 |
| | Cups/Lids | 3 | 6 |
| | Fabricated Wood | 3 | 6 |
| | Plastic Container/Cap/Pieces | 3 | 6 |
| | Plastic Pipe | 3 | 6 |
| | Rope | 3 | 6 |
| Bight | Plastic Pieces | 1 | 21 |
| | Natural Fiber (Cotton, Wool) | 2 | 13 |
| | Wrapper/Wrapper Pieces | 3 | 12 |
| | Rope | 4 | 6 |
| | Fishing Gear | 5 | 5 |
| | Plastic Pipe | 6 | 5 |
| | Cups/Lids | 7 | 4 |
| | Balloon | 8 | 3 |
| | Fabricated Wood | 8 | 3 |
| | Plastic Container/Cap/Pieces | 8 | 3 |

## Trends

The extent of anthropogenic debris in the SCB epibenthos has increased over the last 25 years (Figure 3.4). Between 1994 and 2018, the percent of area with anthropogenic debris increased from 13% to 25% (continental shelf only; bays and upper slope were excluded because they were not sampled in all surveys). Likewise, plastic has increased in extent from 9% to 21% of the area. It is important to note that this increase was not associated with changes in sampling frequency or sampling methods as these were held consistent throughout all surveys.

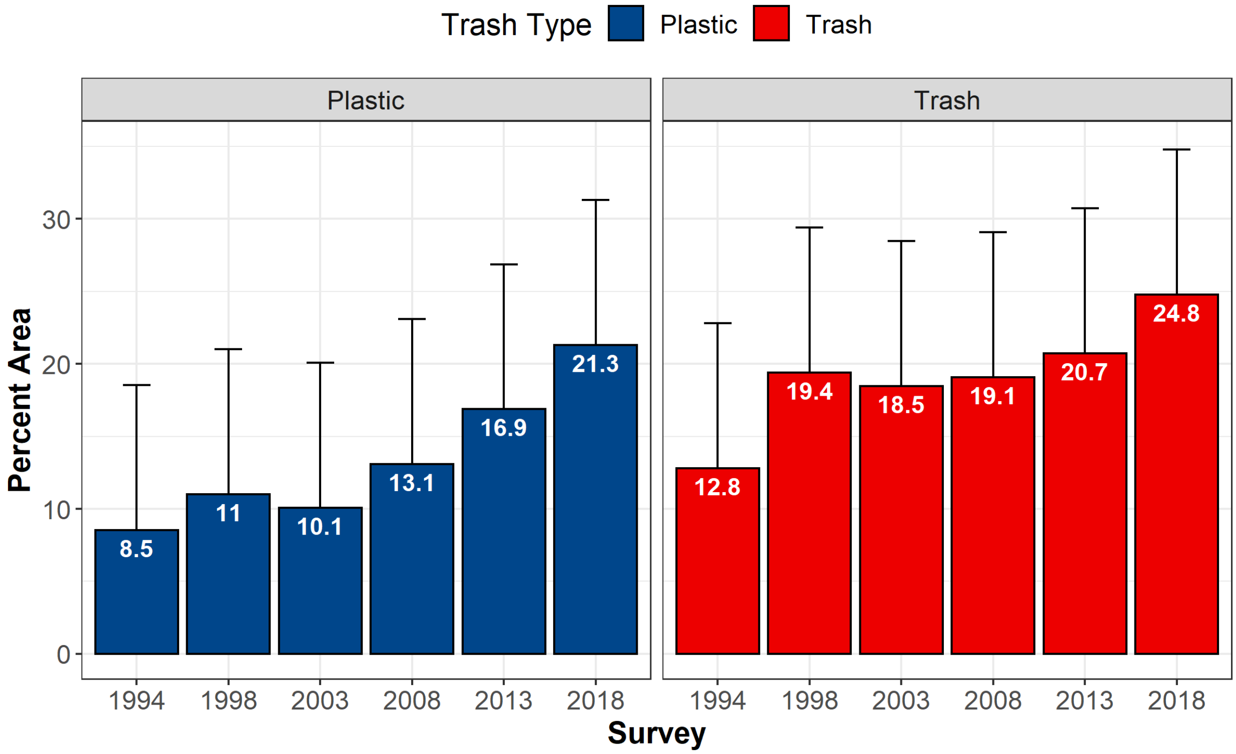



**Figure 3.4. Percent of seafloor where any plastic trash item(s) (blue) and trash item(s) (red) were encountered in Southern California Bight trawls in the shelf strata (inner shelf, middle shelf, and outer shelf) during historical surveys between 1994 and 2018.**

## Discussion

In 2018, anthropogenic debris was estimated to be sampled in epibenthic trawls in one-third of the SCB seafloor. Debris was recovered from trawls in every strata and every region of the SCB, although its extent generally increased with depth. Accumulation of debris at depth is common in areas where there are strong bottom currents or intense storm activity, as debris may be pushed farther out on the continental shelf, accumulate around rocky ledges and outcrops, or be deposited in offshore canyons or other depressions (e.g., Galgani et al. 1996; Bauer et al. 2008; Wei et al. 2012; Schlining et al. 2013). In the SCB, down-shelf movement is likely because this same phenomenon occurs with naturally occurring terrestrial (i.e., branches and leaves) and nearshore kelp debris (Allen et al. 2011). The naturally slow biological and chemical processes operating at depth, coupled with the types of materials that are used commercially, suggest that debris is likely to persist in these deeper areas for long periods of time, ranging from hundreds to thousands of years (Amon et al. 2020).

One of the primary sources of anthropogenic debris to the SCB marine environment is land-based inputs. Large quantities of anthropogenic debris were found in coastal watersheds of the SCB, extending to nearly 80% of SCB stream kilometers with a standing stock assessment of over 7 million items (Chapter 2). Large quantities of anthropogenic debris are discharged during the infrequent, but intense storm events that occur in the SCB. Moore et al. (2011) measured over 100 items cumulatively weighing over 100 metric tons discharged during a single storm event from the Los Angeles urban area alone. The most frequently occurring and most abundant debris type in the SCB's coastal watersheds was plastic, consistent with results from the epibenthos. Plastic debris has been noted as the dominant debris type in a multitude of other marine habitats around the world, including beaches, surface of the ocean, and the water column (Derraik 2002; Galgani et al. 2015). Globally, between 1.15 and 2.41 million tons of plastic waste enters the ocean annually from rivers (Lebreton et al. 2017). Moreover, the degradation of plastics from macro to micro (particles less than 5mm) has been of increasing concern globally (Galgani et al. 2015), with the weathering and breakdown of these larger particles seen as a mechanism for microplastic contamination of marine habitats (Andrady 2011). Microplastics are capable of absorbing and transporting organic contaminants, metals and pathogens from the environment into organisms (Alimba and Faggio 2019). However, the extent and magnitude of microplastic impacts on the marine environment have not been characterized in the Southern California Bight.

Not only does anthropogenic debris extend across a large area of the SCB, but this potential environmental threat has generally worsened over the last two decades. The estimate of debris extent has doubled on the continental shelf between 1994 and 2018 and this estimate does not include the strata with the greatest extent of debris measured in 2018 (Upper Slope). Recently, regulatory actions have been taken to stem the tide of land-based debris, including a state-wide ban on single-use plastic bags and a total maximum daily load for trash in the Los Angeles area (CRWQCB 2007). Preliminary evidence suggests that these actions may be having an impact on reducing watershed trash (Chapter 2), but we did not see evidence of reduced trash through time offshore. However, specific measures like the bag-bans cannot be evaluated because bags have not historically been caught in trawls. Despite the limitations, continued monitoring can be helpful in identifying general trends in trawl caught trash.

While the trawl surveys showed that anthropogenic debris was present in trawls conducted in an estimated 31% of the SCB epibenthos in 2018, and that the debris extent has grown worse with time, trawl surveys likely underestimate the true extent and magnitude of debris for several reasons. First, the mesh size of the net (1.5 inches) limits the trawl-collected debris to only larger items. Smaller debris likely passes through the net or is pushed out of the way during sampling. This is problematic because smaller items were more numerous than larger items in most debris surveys (Ryan et al. 2009; Andrady 2011) and small items, particularly plastic, were the most ubiquitous and abundant items found in SCB watersheds (Chapter 2). Second, trawling is limited to the smoother, flatter, more easily sampled areas of the seafloor, and these are not the typical areas where debris accumulates (Galgani et al. 1995a). Third, when conducting trawl sampling, variability in the vessel, crew, depth sampled, and weather can affect capture efficiency (Ribic et al. 1992). Despite these recognized limitations in methodology, trawl surveys provide at least a minimum estimate of debris extent and abundance and, because net types and trawl methodology remained constant between 1994 and 2018, one can have confidence in identified trends.

## Conclusions

- **Trash is pervasive in offshore habitats.** An estimated 31% of SCB seafloor area (5-500 m) contained at least one trawl-caught debris item; although the abundance of trash caught in each trawl was generally low. Spatial extent generally increased with distance from shore, from 15% of area in bays to 42% of area in the upper slope. The most frequently encountered items were plastic pieces, plastic bags, fabric, and wrappers.

- **Plastic is both the most abundant and pervasive of all debris types.** An estimated 27% of SCB seafloor area contained at least one trawl-caught plastic item. Plastic had both the highest abundance as well as the greatest spatial extent of all debris types in all offshore strata.

- **Marine debris, particularly plastic, is increasing over time.** The spatial extent of trawl-caught marine debris increased from 13% of continental shelf area in 1994 to 25% of shelf area in 2018. Plastic trash increased from 9% to 21% of continental shelf area between 1994 and 2018.

## References

Alimba, C.G. and Faggio, C. 2019. Microplastics in the marine environment: current trends in environmental pollution and mechanisms of toxicological profile. *Environmental toxicology and pharmacology*, *68*, pp.61-74.

Allen, M.J. 2006. Continental shelf and upper slope in: LG Allen, DJ Pondella and MH Horn (eds.), The Ecology of Marine Fishes: California and Adjacent Waters. University of California Press Berkeley, CA.pp. 167-202.

Allen, M.J., S.L. Moore, K.C. Schiff, S.B. Weisberg, D. Diener, J.K. Stull, A. Groce, J. Mubarak, C.L. Tang, and R. Gartman. 1998. Southern California Bight 1994 Pilot Project: V. Demersal fishes and megabenthic invertebrates. Technical Report 308. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. 2002. Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Technical Report 380. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J., T. Mikel, D. Cadien, J.E. Kalman, E.T. Jarvis, K.C. Schiff, D.W. Diehl, S.L. Moore, S. Walther, G. Deets, C. Cash, S. Watts, D.J. Pondella II, V. Raco-Rands, C. Thomas, R. Gartman, L. Sabin, W. Power, A.K. Groce, and J. L. Armstrong. 2007. Southern California Bight 2003 Regional Monitoring Program: IV. Demersal Fishes and Megabenthic Invertebrates. Technical Report 505. Southern California Coastal Water Research Project, Costa Mesa, CA.

Allen, M.J., D. Cadien, E. Miller, D.W. Diehl, K. Ritter, S.L. Moore, C. Cash, D.J. Pondella, V. Raco- Rands, C. Thomas, R. Gartman, W. Power, A.K. Latker, J. Williams, J. L. Armstrong, and K. Schiff. 2011. Southern California Bight 2008 Regional Monitoring Program: Volume IV. Demersal Fishes and Megabenthic Invertebrates. Technical Report 655. Southern California Coastal Water Research Project, Costa Mesa, CA.

Allen, M.J., and G.B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and Northeastern Pacific. NOAA Technical Report NMFS 66. 151 p.

Andrady, A.L., J.E. Pegram, and Y. Song. 1993. Studies on enhanced degradable plastics. II. Weathering of enhanced photodegradable polyethylenes under marine and freshwater floating exposure. J. Environ. Polym. Degrad. 1 (2), 117–126.

Andrady, A.L. 2011. Microplastics in the marine environment. *Marine pollution bulletin*, *62*(8), pp.1596-1605.

Environmental Protection Agency (EPA). 2008. Planning for Natural Disaster Debris.

Gall, S.C. and Thompson, R.C. 2015. The impact of debris on marine life. *Marine pollution bulletin*, *92*(1-2), pp.170-179.

Moore, C.J., G.L. Lattin, and A.F. Zellers. 2011. Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. Journal of Integrated Coastal Zone Management 11(1):65-73.

Ribic, C. A., T. R. Dixon, I. Vining. 1992. Marine debris survey manual. National Marine Fisheries Service's Marine Entanglement Research Program (MERP). U. S. National Oceanic and Atmospheric Administration Technical Report NMFS-108. 94 p.

Sheavly, S.B. 2007. "National Marine Debris Monitoring Program: Final Program Report, Data Analysis and Summary." Prepared for U.S. Environmental Protection Agency by Ocean Conservancy, Grant Number X83053401-02. 76 pp.

Southern California Bight 2013 Regional Marine Monitoring Survey (Bight '18). 2018. Sediment Quality Field Operations Manual.

Stevens, D. L., Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. Environmetrics 8:167-195.

Stevens, D. L., Jr. and A. R. Olsen. 2004. "Spatially-balanced sampling of natural resources." Journal of American Statistical Association 99(465): 262-278.

Thompson, S.K. 1992. Sampling. J. Wiley and Sons, New York, NY.

United Nations (ed.) 2017. Marine Debris. in The First Global Integrated Marine Assessment: World Ocean Assessment I. Cambridge: Cambridge University Press, pp. 389–408. doi: 10.1017/9781108186148.028.

## APPENDIX

**Table A1. Percent of watershed stream kilometers containing at least one item of each debris type for the region and each land use type.**

| Land Use | Trash Type | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | Biodegradable | Biohazard | Construction | Fabric | Glass | Large | Metal | Misc | Plastic | |
| Agricultural | 17 | 0 | 17 | 33 | 7 | 13 | 53 | 13 | 77 | 56 |
| Open | 18 | 2 | 4 | 19 | 16 | 0 | 28 | 7 | 46 | 83 |
| Urban | 53 | 8 | 23 | 42 | 28 | 4 | 51 | 39 | 85 | 89 |
| Region | 34 | 4 | 15 | 33 | 20 | 4 | 43 | 23 | 69 | 77 |

**Table A2. Mean and standard deviation of the watershed abundance of each trash type for the region and each land use type.**

| Trash Type | Region | | Open Land Use | | Agricultural Land Use | | Urban Land Use | |
|---|---|---|---|---|---|---|---|---|
| | Mean Count | Standard Deviation | Mean Count | Standard Deviation | Mean Count | Standard Deviation | Mean Count | Standard Deviation |
| Biodegradable | 4 | 4 | 5 | 6 | 2 | 1 | 4 | 4 |
| Biohazard | 2 | 3 | 1 | NA | 0 | NA | 2 | 3 |
| Construction | 2 | 3 | 2 | 1 | 2 | 1 | 3 | 4 |
| Fabric | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Glass | 14 | 30 | 13 | 34 | 2 | 1 | 15 | 30 |
| Large | 1 | 0 | 0 | 0 | 1 | 1 | 1 | NA |
| Metal | 3 | 5 | 2 | 2 | 2 | 3 | 3 | 5 |
| Miscellaneous | 3 | 6 | 1 | 0 | 1 | 0 | 4 | 7 |
| Plastic | 4 | 9 | 3 | 5 | 4 | 7 | 5 | 10 |

**Table A3. Percent of watershed stream kilometers containing at least one item of each debris type for each watershed.**

| Watershed | Trash Type | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | Biodegradable | Biohazard | Construction | Fabric | Glass | Large | Metal | Misc | Plastic | |
| Calleguas | 31 | 0 | 0 | 38 | 15 | 15 | 69 | 8 | 69 | 85 |
| Central San Diego | 27 | 0 | 27 | 18 | 18 | 0 | 55 | 36 | 64 | 64 |
| Los Angeles | 50 | 10 | 20 | 40 | 45 | 10 | 55 | 20 | 65 | 70 |
| Lower Santa Ana | 50 | 13 | 13 | 50 | 25 | 0 | 38 | 25 | 88 | 88 |
| Middle Santa Ana | 60 | 0 | 40 | 40 | 40 | 0 | 80 | 40 | 100 | 100 |
| Mission Bay and San Diego River | 11 | 0 | 22 | 33 | 0 | 0 | 11 | 33 | 67 | 78 |
| Northern San Diego | 0 | 0 | 17 | 33 | 0 | 17 | 17 | 17 | 58 | 75 |
| San Gabriel | 73 | 7 | 20 | 40 | 37 | 0 | 60 | 33 | 80 | 81 |
| San Jacinto | 0 | 0 | 33 | 67 | 0 | 33 | 67 | 0 | 100 | 100 |
| San Juan | 38 | 13 | 13 | 38 | 0 | 0 | 38 | 50 | 88 | 88 |
| Santa Clara | 11 | 0 | 0 | 16 | 11 | 0 | 21 | 11 | 42 | 53 |
| Santa Monica Bay | 33 | 8 | 8 | 17 | 25 | 0 | 33 | 33 | 75 | 92 |
| Southern San Diego | 0 | 0 | 13 | 25 | 0 | 0 | 38 | 13 | 63 | 63 |
| Ventura | 13 | 0 | 13 | 25 | 0 | 0 | 25 | 0 | 75 | 75 |

**Table A4. Mean and standard deviation of item counts in watersheds by region and land use**

| Land Use | Trash Category | Item | Mean Count | Standard Deviation |
|---|---|---|---|---|
| Region | Biodegradable | Food Waste | 2 | 1 |
| Region | Biodegradable | Other | 1 | 1 |
| Region | Biodegradable | Paper/ cardboard | 5 | 5 |
| Region | Biohazard | Condoms | 1 | NA |
| Region | Biohazard | Dead Animals | 1 | NA |
| Region | Biohazard | Human Waste/Diapers/TP | 1 | 0 |
| Region | Biohazard | Medical waste | 1 | NA |
| Region | Biohazard | Other | 5 | 6 |
| Region | Biohazard | Pet Waste | 1 | NA |
| Region | Construction | Bricks | 5 | 6 |
| Region | Construction | Concrete/Asphalt | 2 | 2 |
| Region | Construction | Fabricated Wood | 1 | 1 |
| Region | Construction | Other | 2 | 1 |
| Region | Construction | Rebar | 2 | 2 |
| Region | Fabric_Cloth | Natural (Cotton, Wool) | 3 | 2 |

| Land Use | Trash Category | Item | Mean Count | Standard Deviation |
|---|---|---|---|---|
| Region | Fabric_Cloth | Other | 2 | 1 |
| Region | Fabric_Cloth | Shoes | 1 | 1 |
| Region | Fabric_Cloth | Synthetic Fabric | 2 | 1 |
| Region | Fabric_Cloth | Tent/Sleeping bag | 1 | 0 |
| Region | Glass | Glass Bottles | 2 | 1 |
| Region | Glass | Glass Pieces | 21 | 37 |
| Region | Large | Furniture/Appliances | 1 | NA |
| Region | Large | Other | 1 | 0 |
| Region | Large | Tires | 1 | 1 |
| Region | Metal | Aluminum Foil Pieces | 2 | 2 |
| Region | Metal | Aluminum/Steel Cans | 3 | 5 |
| Region | Metal | Auto Parts | 2 | 1 |
| Region | Metal | Metal Bottle Caps | 2 | 2 |
| Region | Metal | Metal Pipe/Bar Segments | 3 | 4 |
| Region | Metal | Nails, Screws, Bolts, etc. | 3 | 6 |
| Region | Metal | Other | 4 | 5 |
| Region | Metal | Small Batteries | 6 | 6 |
| Region | Metal | Spray Paint Cans | 3 | 7 |
| Region | Metal | Wire (barb, chicken, etc.) | 1 | 1 |
| Region | Miscellaneous | Ceramic Pots/Shards | 15 | 18 |
| Region | Miscellaneous | E-waste | 2 | 1 |
| Region | Miscellaneous | Foam rubber | 2 | 1 |
| Region | Miscellaneous | Hose/Hose Pieces | 1 | 0 |
| Region | Miscellaneous | Other | 3 | 3 |
| Region | Miscellaneous | Rubber/Rubber Pieces | 1 | 1 |
| Region | Miscellaneous | Sports Balls | 3 | 3 |
| Region | Miscellaneous | Waxed Paper Cups/Plates | 1 | 1 |
| Region | Plastic | Bags/Bag Pieces | 4 | 7 |
| Region | Plastic | Balloons | 1 | 0 |
| Region | Plastic | Cups/Lids | 2 | 3 |
| Region | Plastic | Foam Cup/Container | 2 | 1 |
| Region | Plastic | Foam Packing Material | 1 | 1 |
| Region | Plastic | Foam Pieces/Pellets | 8 | 18 |
| Region | Plastic | Other | 2 | 3 |
| Region | Plastic | Plastic Bottles | 3 | 4 |
| Region | Plastic | Plastic Container/Cap/Pieces | 2 | 2 |
| Region | Plastic | Plastic Pieces (soft/hard) | 7 | 14 |
| Region | Plastic | Plastic Pipe | 1 | 0 |
| Region | Plastic | Single Use Container | 1 | 1 |
| Region | Plastic | Straw/Stirrer | 2 | 1 |

| Land Use | Trash Category | Item | Mean Count | Standard Deviation |
|---|---|---|---|---|
| Region | Plastic | Tarp | 2 | 1 |
| Region | Plastic | Tobacco (Butt/Lighter/Wrapper) | 3 | 6 |
| Region | Plastic | Wrapper/Wrapper Pieces | 6 | 10 |
| Open | Biodegradable | Paper/ cardboard | 5 | 6 |
| Open | Biohazard | Human Waste/Diapers/TP | 1 | NA |
| Open | Construction | Bricks | 2 | NA |
| Open | Construction | Rebar | 1 | NA |
| Open | Fabric_Cloth | Natural (Cotton, Wool) | 5 | 2 |
| Open | Fabric_Cloth | Other | 1 | NA |
| Open | Fabric_Cloth | Shoes | 1 | NA |
| Open | Fabric_Cloth | Synthetic Fabric | 1 | 1 |
| Open | Fabric_Cloth | Tent/Sleeping bag | 1 | NA |
| Open | Glass | Glass Bottles | 2 | 1 |
| Open | Glass | Glass Pieces | 31 | 53 |
| Open | Metal | Aluminum Foil Pieces | 3 | 2 |
| Open | Metal | Aluminum/Steel Cans | 2 | 2 |
| Open | Metal | Metal Bottle Caps | 4 | 1 |
| Open | Metal | Metal Pipe/Bar Segments | 1 | 0 |
| Open | Metal | Nails, Screws, Bolts, etc. | 1 | NA |
| Open | Metal | Other | 2 | 1 |
| Open | Metal | Spray Paint Cans | 1 | NA |
| Open | Miscellaneous | Ceramic Pots/Shards | 1 | NA |
| Open | Miscellaneous | Hose/Hose Pieces | 1 | 0 |
| Open | Miscellaneous | Other | 1 | 0 |
| Open | Plastic | Bags/Bag Pieces | 3 | 3 |
| Open | Plastic | Balloons | 1 | NA |
| Open | Plastic | Cups/Lids | 3 | 3 |
| Open | Plastic | Foam Cup/Container | 1 | 0 |
| Open | Plastic | Foam Pieces/Pellets | 5 | 2 |
| Open | Plastic | Other | 1 | 1 |
| Open | Plastic | Plastic Bottles | 2 | 2 |
| Open | Plastic | Plastic Container/Cap/Pieces | 2 | 1 |
| Open | Plastic | Plastic Pieces (soft/hard) | 5 | 10 |
| Open | Plastic | Plastic Pipe | 1 | NA |
| Open | Plastic | Single Use Container | 1 | 1 |
| Open | Plastic | Tarp | 1 | 1 |
| Open | Plastic | Tobacco (Butt/Lighter/Wrapper) | 3 | 3 |
| Open | Plastic | Wrapper/Wrapper Pieces | 4 | 4 |
| Agricultural | Biodegradable | Food Waste | 2 | 1 |
| Agricultural | Biodegradable | Paper/ cardboard | 2 | 1 |

| Land Use | Trash Category | Item | Mean Count | Standard Deviation |
|---|---|---|---|---|
| Agricultural | Construction | Bricks | 1 | NA |
| Agricultural | Construction | Concrete/Asphalt | 3 | 3 |
| Agricultural | Construction | Fabricated Wood | 1 | NA |
| Agricultural | Construction | Other | 1 | 1 |
| Agricultural | Fabric_Cloth | Natural (Cotton, Wool) | 2 | 3 |
| Agricultural | Fabric_Cloth | Other | 1 | 0 |
| Agricultural | Fabric_Cloth | Synthetic Fabric | 2 | 1 |
| Agricultural | Fabric_Cloth | Tent/Sleeping bag | 1 | 0 |
| Agricultural | Glass | Glass Bottles | 2 | NA |
| Agricultural | Glass | Glass Pieces | 1 | NA |
| Agricultural | Large | Other | 1 | 0 |
| Agricultural | Large | Tires | 2 | NA |
| Agricultural | Metal | Aluminum Foil Pieces | 2 | 1 |
| Agricultural | Metal | Aluminum/Steel Cans | 4 | 6 |
| Agricultural | Metal | Auto Parts | 1 | NA |
| Agricultural | Metal | Metal Pipe/Bar Segments | 1 | 0 |
| Agricultural | Metal | Nails, Screws, Bolts, etc. | 1 | NA |
| Agricultural | Metal | Other | 2 | 1 |
| Agricultural | Metal | Wire (barb, chicken, etc.) | 2 | 1 |
| Agricultural | Miscellaneous | E-waste | 1 | NA |
| Agricultural | Miscellaneous | Hose/Hose Pieces | 1 | NA |
| Agricultural | Miscellaneous | Other | 1 | NA |
| Agricultural | Miscellaneous | Rubber/Rubber Pieces | 1 | NA |
| Agricultural | Plastic | Bags/Bag Pieces | 7 | 12 |
| Agricultural | Plastic | Cups/Lids | 2 | 1 |
| Agricultural | Plastic | Foam Cup/Container | 3 | 2 |
| Agricultural | Plastic | Foam Packing Material | 1 | NA |
| Agricultural | Plastic | Foam Pieces/Pellets | 6 | 11 |
| Agricultural | Plastic | Other | 3 | 3 |
| Agricultural | Plastic | Plastic Bottles | 1 | 1 |
| Agricultural | Plastic | Plastic Container/Cap/Pieces | 1 | 1 |
| Agricultural | Plastic | Plastic Pieces (soft/hard) | 4 | 8 |
| Agricultural | Plastic | Plastic Pipe | 1 | NA |
| Agricultural | Plastic | Single Use Container | 1 | 0 |
| Agricultural | Plastic | Straw/Stirrer | 1 | 0 |
| Agricultural | Plastic | Tarp | 1 | 1 |
| Agricultural | Plastic | Tobacco (Butt/Lighter/Wrapper) | 2 | 1 |
| Agricultural | Plastic | Wrapper/Wrapper Pieces | 3 | 2 |
| Urban | Biodegradable | Food Waste | 2 | 1 |
| Urban | Biodegradable | Other | 1 | 1 |

| Land Use | Trash Category | Item | Mean Count | Standard Deviation |
|---|---|---|---|---|
| Urban | Biodegradable | Paper/ cardboard | 5 | 5 |
| Urban | Biohazard | Condoms | 1 | NA |
| Urban | Biohazard | Dead Animals | 1 | NA |
| Urban | Biohazard | Human Waste/Diapers/TP | 1 | 0 |
| Urban | Biohazard | Medical waste | 1 | NA |
| Urban | Biohazard | Other | 5 | 6 |
| Urban | Biohazard | Pet Waste | 1 | NA |
| Urban | Construction | Bricks | 5 | 7 |
| Urban | Construction | Concrete/Asphalt | 2 | 1 |
| Urban | Construction | Fabricated Wood | 1 | 1 |
| Urban | Construction | Other | 2 | 2 |
| Urban | Construction | Rebar | 3 | 2 |
| Urban | Fabric_Cloth | Natural (Cotton, Wool) | 2 | 2 |
| Urban | Fabric_Cloth | Other | 2 | 2 |
| Urban | Fabric_Cloth | Shoes | 2 | 1 |
| Urban | Fabric_Cloth | Synthetic Fabric | 2 | 2 |
| Urban | Glass | Glass Bottles | 1 | 1 |
| Urban | Glass | Glass Pieces | 20 | 34 |
| Urban | Large | Furniture/Appliances | 1 | NA |
| Urban | Large | Other | 1 | NA |
| Urban | Large | Tires | 1 | 0 |
| Urban | Metal | Aluminum Foil Pieces | 2 | 2 |
| Urban | Metal | Aluminum/Steel Cans | 4 | 6 |
| Urban | Metal | Auto Parts | 3 | 1 |
| Urban | Metal | Metal Bottle Caps | 2 | 2 |
| Urban | Metal | Metal Pipe/Bar Segments | 4 | 4 |
| Urban | Metal | Nails, Screws, Bolts, etc. | 4 | 7 |
| Urban | Metal | Other | 4 | 6 |
| Urban | Metal | Small Batteries | 6 | 6 |
| Urban | Metal | Spray Paint Cans | 3 | 8 |
| Urban | Metal | Wire (barb, chicken, etc.) | 1 | 1 |
| Urban | Miscellaneous | Ceramic Pots/Shards | 19 | 19 |
| Urban | Miscellaneous | E-waste | 2 | 1 |
| Urban | Miscellaneous | Foam rubber | 2 | 1 |
| Urban | Miscellaneous | Hose/Hose Pieces | 1 | 1 |
| Urban | Miscellaneous | Other | 3 | 3 |
| Urban | Miscellaneous | Rubber/Rubber Pieces | 1 | 1 |
| Urban | Miscellaneous | Sports Balls | 3 | 3 |
| Urban | Miscellaneous | Waxed Paper Cups/Plates | 1 | 1 |
| Urban | Plastic | Bags/Bag Pieces | 4 | 5 |

| Land Use | Trash Category | Item | Mean Count | Standard Deviation |
|---|---|---|---|---|
| Urban | Plastic | Balloons | 1 | 0 |
| Urban | Plastic | Cups/Lids | 2 | 3 |
| Urban | Plastic | Foam Cup/Container | 2 | 1 |
| Urban | Plastic | Foam Packing Material | 1 | 1 |
| Urban | Plastic | Foam Pieces/Pellets | 9 | 20 |
| Urban | Plastic | Other | 2 | 4 |
| Urban | Plastic | Plastic Bottles | 3 | 5 |
| Urban | Plastic | Plastic Container/Cap/Pieces | 2 | 2 |
| Urban | Plastic | Plastic Pieces (soft/hard) | 8 | 16 |
| Urban | Plastic | Plastic Pipe | 1 | 1 |
| Urban | Plastic | Single Use Container | 2 | 1 |
| Urban | Plastic | Straw/Stirrer | 2 | 1 |
| Urban | Plastic | Tarp | 2 | 1 |
| Urban | Plastic | Tobacco (Butt/Lighter/Wrapper) | 4 | 6 |
| Urban | Plastic | Wrapper/Wrapper Pieces | 8 | 12 |

**Table A5. Percent of Bight seafloor area containing at least one trawl caught item of each debris type for the region and each stratum.**

| Stratum | Debris Category | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | Large | Metal | Plastic | Glass | Fabric | Biodegradable | Construction | |
| **Bays** | 3.8 | 3.8 | 19.1 | 0.0 | 0.0 | 0.0 | 0.0 | 15 |
| **Inner Shelf** | 0.0 | 0.0 | 17.2 | 3.4 | 0.0 | 0.0 | 0.0 | 21 |
| **Mid Shelf** | 0.0 | 6.7 | 16.7 | 0.0 | 3.3 | 0.0 | 0.0 | 20 |
| **Outer Shelf** | 0.0 | 3.8 | 46.2 | 3.8 | 0.0 | 3.8 | 0.0 | 35 |
| **Upper Slope** | 0.0 | 0.0 | 49.8 | 0.0 | 20.8 | 0.0 | 4.2 | 42 |
| **Region** | 0.0 | 2.3 | 34.2 | 0.9 | 10.2 | 0.3 | 1.9 | 31 |

**Table A6. Mean and standard deviation of trawl caught debris item counts in the region and each strata.**

| Debris Type | Region | | Strata | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bays | | Inner Shelf | | Mid Shelf | | Outer Shelf | | Upper Slope | |
| | Mean Count | SD | Mean Count | SD | Mean Count | SD | Mean Count | SD | Mean Count | SD | Mean Count | SD |
| Biodegradabl e | 0.03 | 0.24 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.49 | 0 | 0 |
| Construction | 0.03 | 0.24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.49 |
| Fabric_Cloth | 0.1 | 0.46 | 0 | 0 | 0 | 0 | 0.08 | 0.28 | 0 | 0 | 0.35 | 0.86 |
| Glass | 0.03 | 0.17 | 0 | 0 | 0.08 | 0.29 | 0 | 0 | 0.06 | 0.24 | 0 | 0 |
| Large | 0.031 | 0.24 | 0.18 | 0.60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Metal | 0.07 | 0.31 | 0.18 | 0.60 | 0 | 0 | 0.15 | 0.38 | 0.06 | 0.24 2 | 0 | 0 |
| Plastic | 0.71 | 1.09 | 1.09 | 1.87 | 0.42 | 0.51 | 0.38 | 0.50 637 | 0.88 | 1.22 | 0.76 | 0.90 |