Community Science

PROJECT REPORT
10.1029/2022CSJ000017

Key Points:

- Created a framework for conducting policy informing community science research on trash in creeks through the Thriving Earth Exchange
- Assessed creek trash data in collaboration with the community who led the research priorities and collected the data
- Used community science to inform local City Council policy

Correspondence to:
W. Cowger,
wincowger@gmail.com

Citation:
Cowger, W., Gomez, I., Martinez-Rubin, N., Moriarty, A., Harwell, T., & Anich, L. (2023). Community science-informed local policy: A case study in Pinole Creek Litter Assessment. *Community Science*, 2, e2022CSJ000017. https://doi.org/10.1029/2022CSJ000017

Received 23 SEP 2022
Accepted 29 JAN 2023
Corrected 5 JUN 2023

This article was corrected on 5 JUN 2023. See the end of the full text for details.

Author Contributions:
Conceptualization: Win Cowger, Itzel Gomez, Norma Martinez-Rubin, Ann Moriarty, Todd Harwell, Lisa Anich
Data curation: Win Cowger, Ann Moriarty, Lisa Anich
Formal analysis: Win Cowger, Itzel Gomez, Norma Martinez-Rubin, Ann Moriarty, Lisa Anich
Funding acquisition: Itzel Gomez, Norma Martinez-Rubin, Ann Moriarty, Lisa Anich
Investigation: Win Cowger, Itzel Gomez, Norma Martinez-Rubin, Ann Moriarty, Lisa Anich

Community Science-Informed Local Policy: A Case Study in Pinole Creek Litter Assessment

Win Cowger[1,2], Itzel Gomez[3], Norma Martinez-Rubin[4,5], Ann Moriarty[6], Todd Harwell[7,8], and Lisa Anich[9]

[1]Moore Institute for Plastic Pollution Research, Long Beach, CA, USA, [2]University of California, Riverside, Riverside, CA, USA, [3]EarthTeam, Richmond, CA, USA, [4]Pinole Creek Thriving Earth Exchange, Pinole, CA, USA, [5]Pinole City Council, Pinole, CA, USA, [6]Friends of Pinole Creek Watershed Board of Directors, Pinole, CA, USA, [7]Thriving Earth Exchange, American Geophysical Union, Washington, DC, USA, [8]UC Davis Center for Community and Citizen Science, Davis, CA, USA, [9]Contra Costa Resource Conservation District, Concord, CA, USA

Abstract California is one of the only states actively managing trash in its rivers. Several community groups in Pinole, CA, USA collaborated on a Thriving Earth Exchange community science project. Its purpose was to assess the trash in Pinole Creek and identify policy development opportunities for the community. The key scientific questions were: how much trash was in the creek at the time of the study, what types of trash were most abundant, and where should the community be most concerned about trash in the creek? The team enlisted additional community volunteers at local events. A randomized sampling design and a community science-adapted version of The San Francisco Estuary Institute's Trash Monitoring Playbook was used to survey the trash in the creek. The Thriving Earth Team estimated there were 37 m^3 and 47,820 pieces of total trash in the creek channel with an average concentration of 2 m^3 per km and 2,697 pieces per km. The community gained an understanding of the scale of the problem. Plastic and single-use trash were most abundant, and the community members expressed high concern about plastic single-use food packaging and tobacco-related waste. The community identified locations in the creek where trash was abundant and prioritized follow-up study locations. Seven new recommendations were presented to the Pinole City Council. The City Council unanimously voted to further discuss ordinance-related recommendations. And that was when community science contributed to local policy development.

Plain Language Summary A community science project was conducted in Pinole California to assess trash in Pinole Creek and propose policies for mitigation. The community surveyed trash in the creek and collected data in collaboration with a scientist. The community recommended several policies and actions to the Pinole City Council which were welcomed for advancement by the City Council.

1. Introduction

1.1. Community

1.1.1. Project Origins

In the fall of 2019, over coffee at a local shop, three stakeholders, Lisa Anich (Watershed Manager, Contra Costa Resource Conservation District [CCRCD]), Norma Martinez-Rubin (Community member and Pinole Council member), and Ann Moriarty (Board member, Friends of Pinole Creek Watershed), met to discuss how they might work together and address an ongoing set of problems: trash in Pinole Creek and unconsolidated local action. The aforementioned members plus Itzel Gomez (Earth Team) are referred to as "The Core Community Team" throughout (Figure 1). When "The Community" is mentioned, it refers to The Core Community Team and their networks and partners in Pinole. The Core Community Team, composed of environmentally conscious and civically oriented volunteers, saw the value of using a standardized methodology to survey trash in the creek that would be defensible to others. The group decided to submit a proposal to Thriving Earth Exchange for support and assistance in direction. Thriving Earth Exchange (TEX), an initiative and program within the American Geophysical Union (AGU), strives to unite communities, scientists, partners, and stakeholders to engage in a community science process that addresses community-level issues related to natural hazards, natural resources, and climate change. The group formalized their project as a Thriving Earth Team (including all authors of this manuscript) with the title "Engaging community to protect the Pinole Creek Watershed: Assessment of trash impacts to promote a thriving ecosystem."

Methodology: Win Cowger, Itzel Gomez, Norma Martinez-Rubin, Ann Moriarty, Todd Harwell, Lisa Anich
Project Administration: Itzel Gomez, Norma Martinez-Rubin, Ann Moriarty, Todd Harwell, Lisa Anich
Resources: Itzel Gomez, Norma Martinez-Rubin, Lisa Anich
Software: Win Cowger
Supervision: Win Cowger, Ann Moriarty, Todd Harwell, Lisa Anich
Validation: Win Cowger, Lisa Anich
Visualization: Win Cowger
Writing – original draft: Win Cowger, Itzel Gomez, Norma Martinez-Rubin, Ann Moriarty, Todd Harwell, Lisa Anich
Writing – review & editing: Win Cowger, Itzel Gomez, Norma Martinez-Rubin, Ann Moriarty, Todd Harwell, Lisa Anich

1.1.2. Pinole Creek Trash Policies

As a Municipal Separate Storm Sewer System (MS4) permittee, Pinole is responsible for its water quality and compliance with the state of California Trash Amendments (State Water Resources Control Board, 2015). Pinole opted to use track 1 compliance which requires the city to identify locations of priority (high waste generation) on the roadsides and capture trash that runs into the storm drain system using "Total Trash Capture Devices." Total trash capture devices are metal grates inside the storm drain that filter trash out of the storm drains down to 5 mm in size and are periodically cleaned by maintenance workers. By the time the Pinole Creek litter assessment began, Pinole was fully compliant with the trash amendments. But years prior, Pinole was the subject of a Grand Jury Report that revealed they were out of compliance, which they subsequently corrected (Nakano, 2019). In addition to the trash amendment regulations, Pinole is active in trash abatement and supports city-sponsored community cleanup service days, organizes annual "dumpster days" in partnership with its trash hauling franchisee, operates a street sweeper, and has an ordinance that bans the use of polystyrene-based disposable food ware among food providers and users of city facilities. On a “dumpster day,” the trash hauling franchisee sets up multiple dumpsters for residents to drop off household items (e.g., glass, clothing, small appliances and furniture, mats and rugs, metal) that are not ordinarily picked up curbside during weekly service. For 4 hr, the franchisee hauls filled dumpsters to the local landfill, thus reducing the possibility of illegal dumping of the bulky trash items collected. A Pinole beautification ad-hoc committee formed in 2019, composed of two council members and two planning commissioners, recommended the targeted placement of solar-powered trash bins at popular recreational sites. Pinole's litter abatement efforts have been primarily at the staff level for compliance with regulatory requirements. Community efforts to assess litter in Pinole Creek complemented those efforts and were greatly motivated by residents' interest in enhancing the watershed ecosystem's water quality.

1.1.3. Community Objectives

The Community's primary goals were to improve the Pinole Creek Watershed's environmental stewardship and make it as clean as possible. Critical to the success of these goals were two components. (a) Using a scientifically established methodology to collect data to inform the creation of new policies at the Pinole City Council. (b) To engage the broader Pinole community throughout the project.

1.2. Scientific

1.2.1. Stream Trash Research Background

Riparian river trash research is still nascent (Emmerik & Schwarz, 2020). There is variability in the abundance of trash from river to river (Baldwin et al., 2016) and trash abundance correlates with urban land use near the stream and within the entire watershed upstream from the river corridor (Cowger et al., 2019). There can also be variation in trash composition from reach to reach of the same river, but the mechanisms controlling litter composition within a river are not well understood (McCormick & Hoellein, 2016). Trash composition has been studied globally, with food packaging prevailing in nearly every environment that has been studied, including rivers (Morales-Caselles et al., 2021). Areas of concern (i.e., highly abundant locations of trash) exist due to river process (Hoellein & Rochman, 2021) and variation in human input processes (Meijer et al., 2021) and are commonly prioritized as locations for mitigation of trash in rivers (Helinski et al., 2021).

Trash composition and concentration are highly variable worldwide; therefore, mitigation priorities should be acted on locally (Rochman et al., 2020). To apply science to community priorities, scientists must work with community members during the scientific process (McKinley et al., 2017; Watkins, 2022). Plastic pollution research has a long history of community collaboration on data collection (Cârstea et al., 2022; Cook et al., 2021; Rambonnet et al., 2019). Still, much of this appears to be driven by researchers, not the community itself, as in this project. This research project was not led by the scientists involved, it was led by The Community. More detail about this paradigm is available in the methodology and results to demonstrate what is meant by community science. At the start of the Pinole litter assessment, The Thriving Earth Team was unaware of other cases where community-driven science on creek trash was leveraged to inform local policies focused on reducing creek trash. The Thriving Earth Team aims for this study to lay the groundwork for similar studies elsewhere.

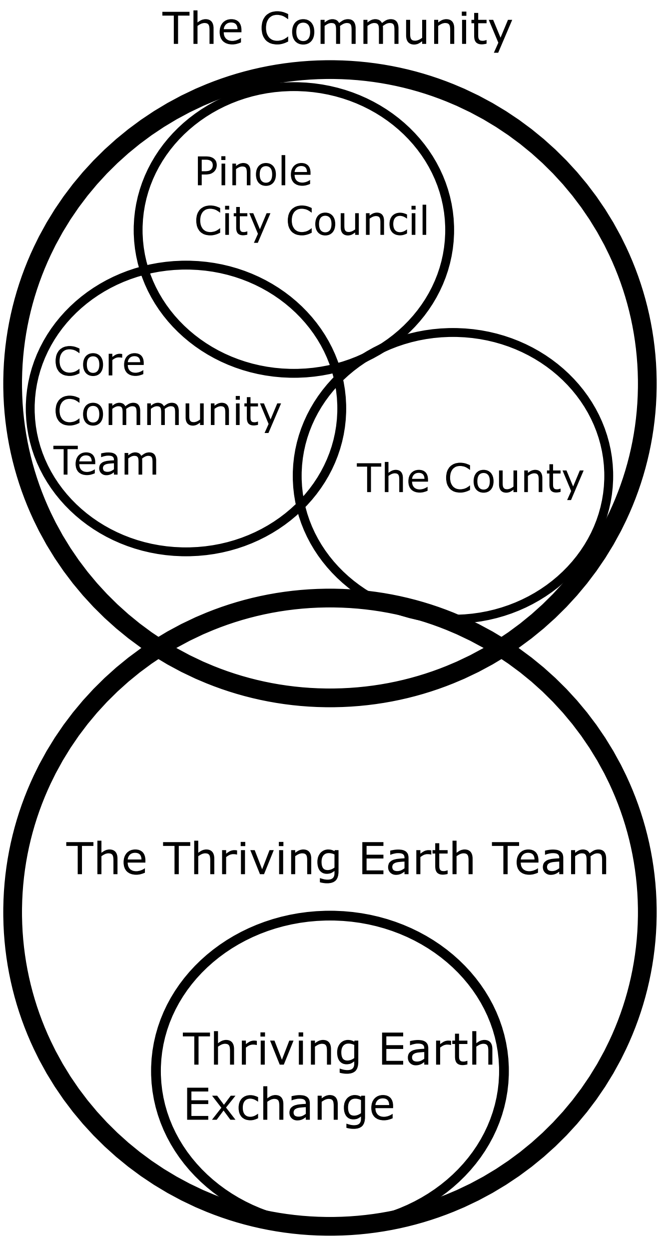

Figure 1. A diagram showing the project participants' roles that are referenced throughout the manuscript. Overlapping circles means that one or more individuals would consider themselves in both groups. Completely encompassed circles mean that all individuals from that group consider themselves part of the larger group. For example, some of The Core Community Team members are considered part of The County, and others as part of the Pinole City Council. Everyone within these three groups is referred to as The Community. Some of the members within The Community are considered part of the Thriving Earth Team, and Thriving Earth Exchange is solely part of the Thriving Earth Team.

1.2.2. Trash Monitoring Playbook

The Core Community Team decided that they wanted to survey for trash using the most robust standardized methodology available. By doing so, they could compare their results with other studies in California and have results that would be publishable in scientific literature. River trash methodologies were recently standardized. The Trash Monitoring Playbook was designed and published in 2021 by the San Francisco Estuary Institute to allow for a California-wide assessment of trash in rivers in a way that is readily comparable with other studies throughout the state (S. Moore et al., 2020). The Trash Monitoring Playbook was developed by rigorous field testing of the methodology in collaboration with many trash monitoring groups throughout California. The intended audience for the Trash Monitoring Playbook was scientists, environmental monitoring contract groups, and municipal staff. The Thriving Earth Team aimed for this study to improve the utility of the Trash Monitoring Playbook for community science projects by modifying it for community use (Rambonnet et al., 2019).

1.2.3. Scientific Questions

The Core Community Team identified three scientific questions to guide data collection: (a) How much trash was in the creek at the time of the study? (b) What types of trash were most abundant? (c) Where should the Community be most concerned about trash in the creek?

2. Methods

2.1. Community

2.1.1. Project Team Meetings and Roles

Thriving Earth Team meetings happened twice a month for 2 hr each meeting, starting on 8 March 2021 and ending on 30 June 2022. Lisa Anich represented the Contra Costa Resource Conservation District (CCRCD) which provides staff support for the Friends of Pinole Creek Watershed and conducts trash assessments for Contra Costa County's Watershed Program. Itzel Gomez represented Earth Team, which introduces youth to the environment and previously conducted many cleanups with youth. Norma Martinez-Rubin was city mayor and acted in the capacity of a concerned citizen while also functioning as a liaison between the groups and city staff to facilitate communication and presentations. Ann Moriarty represented Friends of Pinole Creek Watershed, which engages with The Community to improve the watershed health of Pinole creek. Todd Harwell was the Community Science Fellow (a volunteer trained by Thriving Earth Exchange) whose role was to convene the meetings and keep the group progressing toward its goals. Win Cowger was the Scientist who developed the scientific methodology based on The Community objectives and conducted the data analysis. All aforementioned members are referred to as "The Thriving Earth Team" (Figure 1).

During the meetings, the Core Community Team would drive the priorities for the meeting agenda. Planning for the project took approximately 40 hr in total. Meetings continued every other week throughout the project to discuss nuances of the methodology, strategies for broader community engagement, and plan workshops and presentations. The meetings concluded when the Thriving Earth Exchange project's goals initially agreed upon by the group were fulfilled.

10.1029/2022CSJ000017

2.1.2. Public Engagement Strategy

Pinole is an ethnically diverse community. The Core Community Team employed several strategies to engage volunteers in assessing trash. They set up a table at the local Coastal Cleanup Day in September 2020 and took down names and contact information. They met cars bringing trash to a Dumpster Day, asking for contact info, and passing out flyers. They reached out to two local elementary schools adjacent to the creek. Lastly, they gave presentations to city commissions and a group of mayors from neighboring cities, two of which, like Pinole, also have local creeks. Additional volunteer involvement and engagement beyond the Thriving Earth Team was a project goal to expand the project scope. This was important to expand community awareness of litter in the creek and to invite participation in a community-oriented response to addressing the litter problem. The litter assessment project was an opportunity for adult-guided teams to learn of and implement a data-collection protocol alongside high-school aged youth. Thus extending the use of the Trash Monitoring Playbook while simultaneously reinforcing the importance of environmental stewardship in partnership with city-led activities specifically conducted for regulatory compliance.

2.1.3. Fieldwork Preparation

The fieldwork was relatively inexpensive to conduct. The Thriving Earth Team purchased waders, buckets, trash grabbers, and gloves for project participants and paid for transportation to the field site and meetings. The estimated total cost for the fieldwork was $9,500 USD which was funded by the Thriving Earth Exchange.

The Trash Monitoring Playbook included useful resources for planning, equipping, and training trash assessment teams but was not specifically designed for community members who may not all be experts in fieldwork or research. The Thriving Earth Team modified and expanded these materials to suit our unique training and assessment situations by creating simplified layperson variations of the materials and detailed instructions for use (Supplemental Information).

The COVID-19 pandemic restrictions were in constant flux throughout the project due to local and state regulations. The Thriving Earth Team adapted to them while prioritizing the health and safety of The Community. The Thriving Earth Team primarily conducted outdoor site meetings with groups of 5–6 people. Workshops were virtual due to restrictions on having many people indoors.

2.1.4. Council Engagement

The Thriving Earth Team wanted the Pinole City Council as a partner in the project. Two presentations about the project were given to the City Council. The first presentation was given on 19 October 2021, to introduce the City Council to the project and seek their input on directions at early project onset. On 22 April 2022, a presentation was given to the City Council where The Thriving Earth Team presented the study's final results and The Community joined to provide verbal testimony and support for the proposed policies.

2.1.5. Community Workshop

Before its final presentation to the City Council, the project team conducted a workshop via Zoom to share the study results with The Community. The workshop's goal was to form policy recommendations based on the study findings in collaboration with The Community members that participated in the study. The Thriving Earth Exchange team presented the study findings and the entire group broke into small groups to discuss policies that might prevent or mitigate the problems The Thriving Earth Team observed. Groups highlighted areas for further research. Afterward, policy and action recommendations were finalized by the Pinole Thriving Earth Exchange team.

2.2. Scientific

2.2.1. Site Description

The Pinole Creek watershed is a small (39 km^2) coastal watershed that hosts a perennial stream (Figure 2). The climate in Pinole is Mediterranean, with most of the rainfall occurring in the winter and dry hot summers. Pinole creek is the 18 km mainstem of the watershed and is home to steelhead trout. Pinole Creek flows directly into San Pablo Bay without dams or other impeding structures. Approximately one-quarter (10 km^2) of the creek watershed is within the Pinole city limits. Pinole city is 13 km^2 so most of the city is within the Pinole creek watershed. The rest of the creek watershed upstream is in county jurisdiction. Approximately 19,343 people live

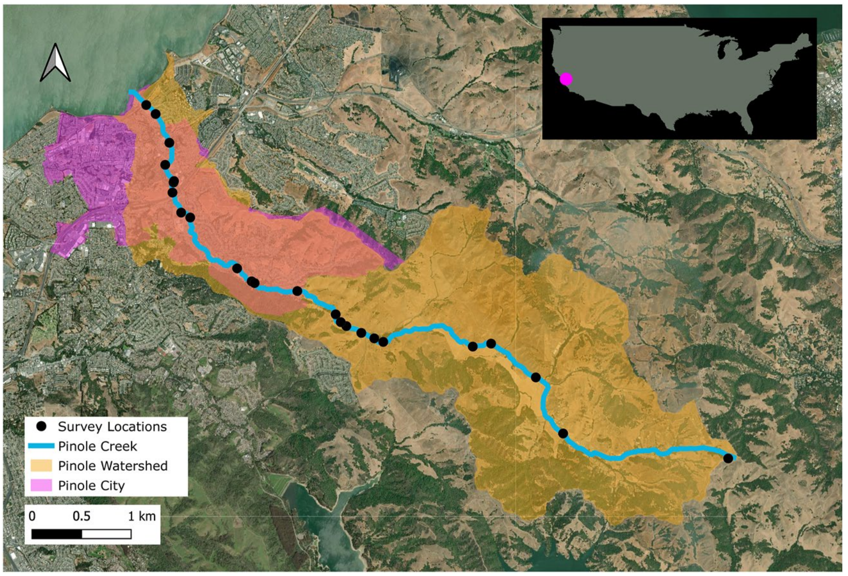

Figure 2. The 23 survey locations (black dots) were randomized across the Pinole creek channel. The yellow area is the Pinole watershed. The pink area is the Pinole city limits. Both areas are slightly transparent, so their overlap can be visualized in the orange area. The blue line is Pinole Creek. An inset map of the United States shows where Pinole, CA is in the country with a pink dot. The basemap is satellite imagery from QGIS basemaps. The north arrow points to the top of the image.

in Pinole. Most of the city is contained within the bottom highly urbanized quarter of the watershed with the top three-quarters being rural county land with low population density and agriculture (primarily grazing).

2.2.2. Description of Trash Monitoring Playbook Methodology

The Trash Monitoring Playbook method consists of four types of methodologies: qualitative, quantitative, semi-quantitative, and drone imaging. Using the playbook, a project team will choose the suite of methods that help them achieve their study objectives. The Thriving Earth Team decided that the quantitative and semi-quantitative approaches would be the most useful to address The Community's questions because The Thriving Earth Team felt that quantitative data provided the most detailed information about the source of the trash. The quantitative approach would provide a count of the trash, and the semi-qualitative would provide its volume, both metrics were thought important. These methods include surveying a 30 m stretch of the creek corridor from a high water line (typical maximum creek height) on one side of the creek to a high water line on the other side, where trash was assessed in the water column or creek bed and outside of the water in the adjacent floodplain. Trash was categorized using the terms established in the Trash Monitoring Playbook. Three volunteers worked together to measure and flag the assessment area, the bankfull width and transect cross sections, take photos, and record spatial coordinates. The other volunteers were tasked with documenting vegetation, storm drains, and encampments. All team members collected and tallied trash. The total number of team members per assessment ranged from 3 to 10 and included adults and youth of a range of ages, with volunteers attending single or multiple assessments. Trash was tallied when found and collected if not submerged or embedded in soil or substrate. If objects were present in number larger than 10 then counts were allowed to be estimated as between 11 and 100 or between 100 and 200 and this happened on 4 occasions. Those counts were estimated afterward using a uniform probability density function, where a random number was chosen between the range of possible values. Collected trash was sorted into the categories used for volume assessment in the Trash Monitoring Playbook using buckets. Buckets were visually assessed for volume using the semi-quantitative methodology. Large items were estimated for volume visually. At two sites, the volume of trash was immeasurable because it was too small, and the smallest recorded volume was 200 ml. Volume at these sites was recorded as zero.

2.2.3. Randomized Sampling

Survey locations were randomized throughout the Pinole creek main channel. Simple randomization was used instead of stratified randomization because The Thriving Earth Team was unsure how best to stratify the points to

10.1029/2022CSJ000017

represent the channel's variability. In hindsight, the points may have been better dispersed if points were distributed in distance intervals across the total channel length. Tributaries in the watershed were not assessed because access was too difficult in these smaller channels, they were typically either on private property or overgrown. In total, 23 locations were selected based on available effort from the volunteers. There is currently no guidance on the minimum number of survey locations to sample for a given creek, but The Thriving Earth Team felt this was adequate for a single channel based on the variability observed in other studies (S. Moore et al., 2016). Randomized locations were created along Pinole creek using QGIS (version 2.24.3) and the random points along line function. Assessment sites were each evaluated by the project team by conducting site visits and taking photos to ensure accessibility and safety for the volunteers. Evaluations assessed how accessible each site was, how safe it was, and if it was on private or public property. Private landowners were contacted when possible to discuss entering their property. Any sites deemed inaccessible, unsafe, or illegal to enter were removed from the list of sites to visit. Another randomized site was generated and assessed if a site was deemed unsuitable or inaccessible to survey. Six locations were moved a maximum of 295 m, in line with the recommendations from the Trash Monitoring Playbook, to increase accessibility since the initial randomized locations were on private property. Accounting for these considerations resulted in some creek regions being less represented than others (Figure 2).

2.2.3.1. *Trash Abundance*

Trash abundance by count and volume was quantified by dividing the trash amount found at each site by the total site length. This normalization procedure allows for comparison of these results to studies that use different creek lengths and for easy extrapolation of results to the whole channel. Then The Thriving Earth Team assessed site conditions by taking the mean of the site trash abundances. Mean trash abundance was used to estimate the total trash abundance in the whole creek by multiplying the mean abundance by the total creek length. Mean trash abundance was bootstrapped with replacement ($n = 10{,}000$) to derive the confidence intervals around the total and mean abundance of trash in Pinole creek.

2.2.3.2. *Composition*

Trash composition at each site was categorized using the categories defined in the Trash Monitoring Playbook, which defines trash by material type and morphology. Mean total creek trash composition was assessed using bootstrapping (resampling with replacement $n = 10{,}000$) of the trash composition proportions at all sites to compute the 95% confidence intervals using the 95% quantiles of the bootstrapped distribution. Sites with fewer than 10 pieces of trash ($n = 5$) were not used for this part of the analysis as they may have added to the variability of the analysis. Trash compositions were said to be distinguishable if confidence intervals did not overlap. Proportions for all sites were plotted longitudinally across the river to assess locations with unique types of trash in high abundance.

2.2.3.3. *Areas of Concern*

All survey locations were assessed to determine whether they were in an area of concern. Locations where trash was elevated above other nearby locations and where high concentrations were close together were said to be areas of concern. A unit that could simultaneously account for count and volume concentration would equally weigh both data sets (volume and count) collected in this study. The count and volume abundances were min-max normalized separately and then multiplied together. These values were plotted as quantiles ($n = 5$) on a map and the Thriving Earth Team scientist drew bounding boxes around amplified regions. These regions would be recommended for future targeted research and management.

2.2.3.4. *Statistical Analysis*

All statistics were created in R (R Core Team, 2020) using R Studio (RStudio Team, 2020). Packages dplyr (Wickham et al., 2020), openxlsx (Schauberger & Walker, 2022), data.table (Dowle & Srinivasan, 2020), ggplot2 (H Wickham, 2016), ggrepel (Slowikowski, 2021), NADA (Lee, 2020), and tidyr (Hadley Wickham & Girlich, 2022) were used during the analysis. See Open Research Section for details on the source code and open data produced in this study.

Table 1
Table of Actions Recommended by the Community to the City Council and Associated Scientific Evidence or Rationale

Recommended action/ordinance	Supporting evidence/rationale
Develop and/or update city food packaging and cigarette ordinances	Food and tobacco-related trash were prevalent in the creek. (Figure 7)
Assess areas of concern and address the litter problem as necessary given the area's characteristics (i.e., outdoor recreation use, encampments, commercial and residential property)	Areas of concern were identified but still high uncertainty as to their causes. (Figure 11)
Create a city-owned trash bin inventory. Use project data to inform new trash bin locations in areas of concern	There was an active action by the City Council to place new solar powered trash bins throughout the city and The Community wanted this data to inform the bin placement
Initiate monthly trash cleanups harnessing the power of community groups	Trash in the creek within the city limits appeared to be largely from litter (Figures 5–7, 9, 10), and regular cleanups can target litter. The Community wanted to continue to build local momentum
Institute an "Adopt-a-Street" or "Adopt-a-Spot" Program (Create Pinole Creek Allies)	Trash in the creek within the city limits appeared to be largely from litter (Figures 5–7, 9, 10), adopt-a-street programs target litter
Initiate litter-awareness outreach & educational programs in schools and the community (creative media campaign)	Trash in the creek within the city limits appeared to be largely from litter (Figures 5–7, 9, 10). The Community felt that more awareness around litter could be raised
Fund a follow-up trash assessment in 5 years (2026)	The Community wanted to build from this baseline data in the future to assess whether their recommendations had an improvement

2.2.4. Scientific Reporting

Community members were taught how to interpret the data and derive conclusions from the data using these figures. The figures in this manuscript were similar to the community and Pinole city council, with stylistic modifications made to the figures for printing the manuscript. Additional figures beyond those shown in this manuscript were created at the request of The Community. These were not deemed critical to include in this manuscript because they were not prioritized by The Community for action or did not have enough information to advance scientific discussion adequately. This included an analysis of the effect of stormflow on creek trash, a longitudinal analysis of trash material types, tire prevalence, and site proximity to storm drains.

3. Results and Discussion

3.1. Community

3.1.1. New Community Science Materials and Skills Developed

The Friends of Pinole Creek Watershed and CCRCD trained adult volunteers to conduct assessments. Earth Team trained high school student interns to conduct assessments; interns also planned and supervised an assessment engaging elementary students. For the adult team, The Thriving Earth Team created a double-sided handout illustrating two types of roles for volunteers. The Thriving Earth Team also streamlined the Trash Monitoring Playbook's trash tally spreadsheet for use as both a field worksheet (hard copy) and data tabulation (online) (Supplemental Information). Materials were adapted from the Trash Monitoring Playbook to make them simpler without compromising the richness or compatibility of the data for comparison with other studies.

3.1.2. Data-Informed Policy Recommendations and Proposed Actions

The Pinole City Council's involvement was on 19 October 2021 ("Pinole City Council Meeting," 2021) and 22 April 2022 ("Pinole City Council Meeting," 2022) as an audience of project presentations. During the 19 October 2021 meeting, the Council expressed support for the project and interest in a follow-up presentation when the team had results to share. At its 19 April 2022 meeting, the consensus among the Council was that ordinance-related recommendations presented by the Pinole Thriving Earth Exchange Project team members (Table 1) be considered by its Municipal Code Ad-Hoc Committee. Other recommended actions, listed below, await future City Council deliberation and decisions to become publicly funded items and/or operational policies.

10.1029/2022CSJ000017

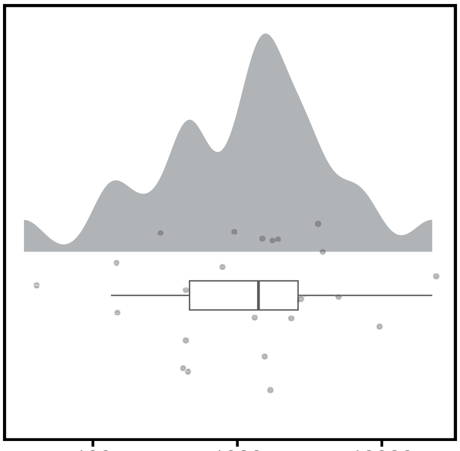

Figure 3. A raincloud plot for the 23 data points of counts of trash per kilometer found at each site. The top gray area is the probability density function. The box plot is displayed below. The centerline on the box plot is the median and the central box is the interquartile range. Jittered raw data points overlay the figure. The *X*-axis is the count concentration in $\log_{10}$ scale. The *y*-axis only applies to the gray area and is the relative density of points in the region.

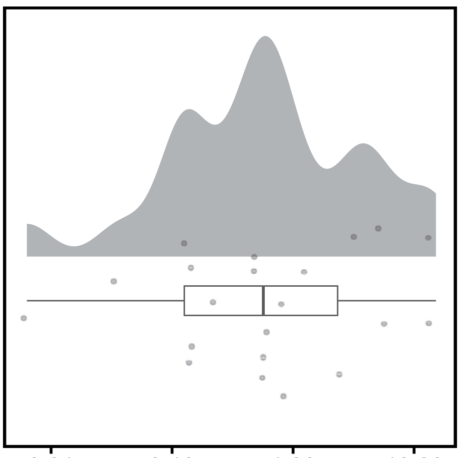

Figure 4. A raincloud plot for the 23 data points on volume of trash per kilometer found at each site. The top gray area is the probability density function. The box plot is displayed below. The centerline on the box plot is the median and the central box is the interquartile range. Jittered raw data points overlay the figure. The *X*-axis is the volume concentration in $\log_{10}$ scale. Two data points were zero values, so they could not be plotted on $\log_{10}$ scale and are not visible in the plot or used to derive the graphic. The *y*-axis only applies to the gray area and is the relative density of points in the region.

3.2. Scientific

3.2.1. Abundance

Trash abundance was first assessed as the mean count and volume of trash at each site surveyed (Figures 3 and 4). Mean trash count was 2,697 (95% CI 1,237–4,890) pieces of trash per kilometer. This value is similar to the mean trash abundance recently reported in Southern California streams (~1,000–2,000 pieces of trash per km) using a similar methodology (McLaughlin et al., 2022). Mean trash volume was 2 (95% CI 0.7–4) cubic meters per kilometer. The Thriving Earth Team estimated that there were 47,820 (21,933–86712) pieces and 37 (13–68) cubic meters of trash in the creek in 2021–2022. Some of the highest count concentrations were located within the city limits, while some of the highest volume concentrations were found above the city limits (Figures 5 and 6). Both spatial relationships had high variability.

3.2.2. Composition

Trash composition was assessed to identify the sites' most common types of trash by bootstrapping the mean count proportions for each type (Figure 7). The most prevalent morphologies were fragments of bags, wrappers, foam, glass, and soft plastic. Only trash morphologies with greater than 1% mean composition were visualized so that Figure 7 could be referenced directly as a top priorities list (Cowger et al., 2022). Generally, there was wide variability around the mean estimates, and few comparisons between the morphology types are significantly different in the top list. By material type, plastic stood out as the most prevalent material for count and volume proportions (Figure 8). These observations are consistent with others studies in California (5 Gyres and EOA inc., 2016; S. Moore et al., 2016; S. L. Moore et al., 2001).

The Community learned that the waste in the city limits primarily came from littering instead of dumping. Dumping (high volume concentration) was less often observed in the city limits than above, where illegal dumping is a problem recognized by the county (Figure 6). Dumping was characterized when large objects existed in the channel (e.g., couches and household appliances). Waste typically associated with littering was highly prevalent in the city limits (food and tobacco products) (Figure 7). These facts encouraged The Community to propose and support ordinances and actions that targeted littering.

The Community determined that their top priorities were to reduce cigarette-related litter and single-use plastic food packaging, which seemed prevalent by material and morphological type (Figures 7 and 8). The Thriving Earth Team produced spatial graphs for each of these categories so that The Community could identify regions where preventative measures would likely be successful (Figures 9 and 10). The Thriving Earth Team did not observe a specific region where single-use food packaging was most abundant; it was prevalent throughout the watershed. This suggested that broad-scale measures like bans might be successful in reducing waste. However, The Thriving Earth Team did observe elevated levels of tobacco product waste isolated near the mouth of the creek. The Community decided that combining cleanup/education activities focused on those locations and updated cigarette

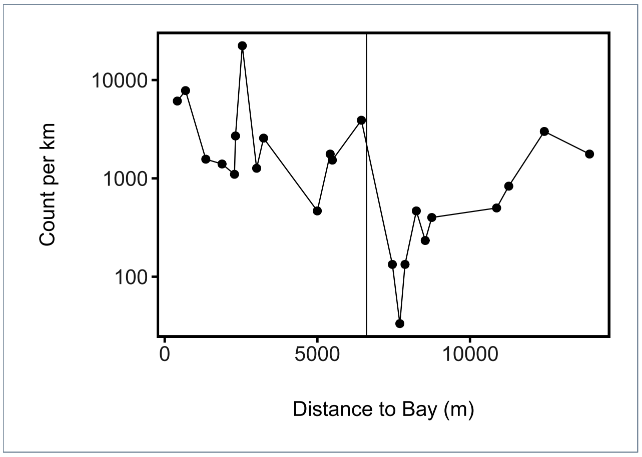

Figure 5. Litter count per kilometer at each of the sites. The *x*-axis is the distance the survey location is from the outlet at the bay. The *y*-axis is the count concentration of trash at the site and is in $\log_{10}$ scale. The points are the values at the sites. There are 23 survey locations in total. The line connects the sites as a tool for visual interpolation. Everything to the left of the line is within the city limits; everything to the right is above the city limits.

ordinances would likely be the most effective at improving environmental and human health.

3.2.3. Areas of Concern

The Community wanted to identify areas of concern with high litter load in the creek that they could prioritize for future mitigation and policy efforts (Figure 11). The Thriving Earth Team identified near the mouth of the stream, near where the highway intersects the creek, and near the top of the city limit as locations with elevated concentrations of count and volume combined. The Community recommended these sites be further investigated in future studies and prioritized by the City Council for mitigation activities. Sites above the city limits also could be classified as areas of concern but were not focused on for this study because The Thriving Earth Team did not have a policy partner with jurisdiction there.

4. Next Steps

4.1. Community

4.1.1. Continued Community Engagement and Policy Development

The work is certainly not over after this initial assessment. The Core Community Team will follow up with the City Council, the City Manager, the city's Public Works Director, and other city staff. Follow-up will consist of requesting updates on policy and action recommendations, including city-led programs or cleanup activities in partnership with relevant parties. If public funding is needed for future work, the City Council would need to either integrate it as line items in the city budget or the 5-year City's Capital Improvement Plan (CIP). CIP aligns capital and infrastructure projects with public funding by the City and other agency partners. It shows multi-year funding needs and planned implementation timelines for long-term projects. For example, at the time of this writing, the FY 2021–2026 CIP included recommendations made by the Pinole Beautification Ad-hoc committee formed by the City Council prior to the start of the community-science project. That committee, composed of two council members and two planning commissioners, was an outcome of council-led discussions following public comments about unacceptable amounts of litter on city streets and freeway on and off ramps. After a year of committee and staff discussions, staff presented the committee's recommendations, including installing new solar-powered trash bins for approximately $425,000 and a community education program with a budget of approximately $60,000. Now, with those items on the CIP, the project results can help inform the best placement of such trash bins.

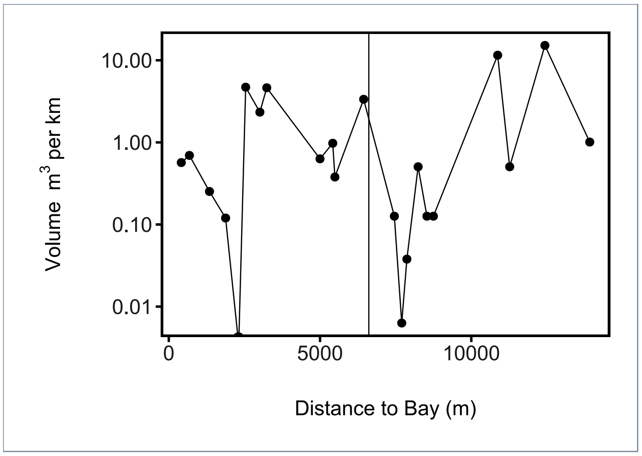

Figure 6. Volume per kilometer at each of the survey locations. The *x*-axis is the distance the survey location is from the outlet at the bay. The *y*-axis is the volume concentration of trash at the site and is in $\log_{10}$ scale. The points are the values at the sites. The line connects the sites as a tool for visual interpolation. Everything to the left of the line is within the city limits, and everything to the right is above. There are 21 data points visualized in total because two of the values were zero which cannot be plotted in log scale. The first zero point can be seen near 2,500 m as a dip and the second one is the furthest point away from the bay, which is not visible in the plot.

In Pinole, an ordinance is a piece of local legislation enacted by a municipal authority such as a city council. The process for developing a citywide ordinance, whether new or as an update, may be a months-long or multi-year process. This depends on the situation the ordinance will address and the priority given to it by City Council and staff relative to other city business, related assignments, and their respective responsibilities. The project findings about types of litter found in Pinole Creek could help inform an update to the city ordinance that bans styrene food ware so that compostable food ware becomes the norm among food providers and city facilities. Developing an ordinance requires city staff to research its legalities and to assess associated risks, prepare staff reports with analysis and recommendations to City

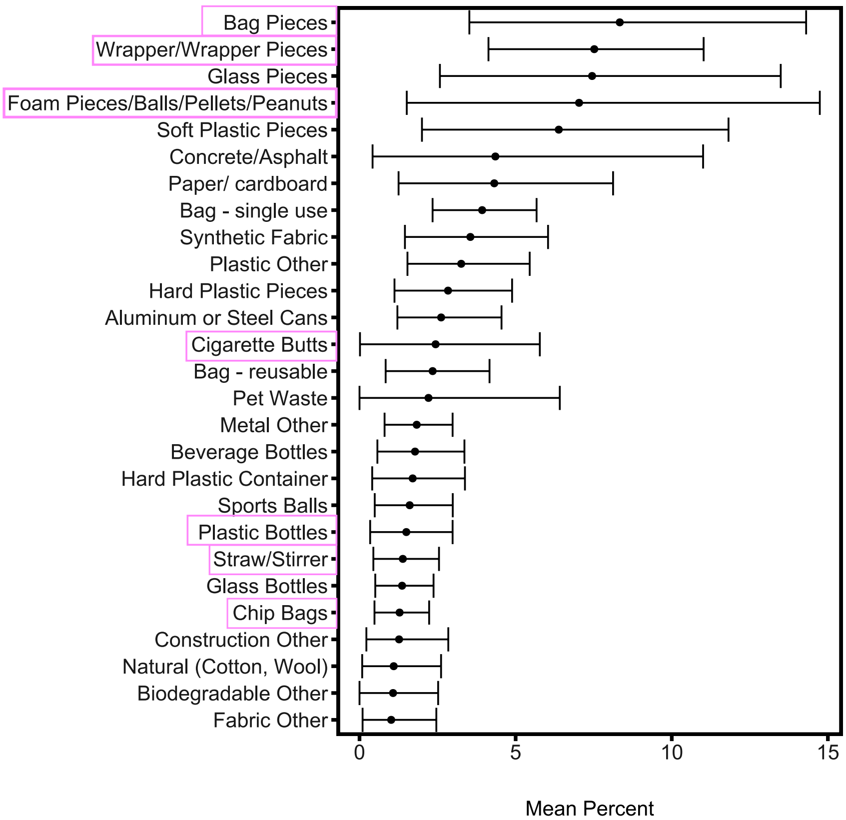

Figure 7. Morphology composition by mean count percent. Highly abundant trash types in Pinole Creek by morphology type. Only trash morphologies with greater than 1% mean composition are plotted. 18 of the 23 survey data points were used to make this plot as the others had fewer than 10 objects analyzed at the site and would add too much variability. Pink boxes mark the morphologies that The Community indicated they were especially concerned about and wanted a further investigation. Error bars represent uncertainty around the mean percent of these trash types (bootstrapped 95% confidence intervals). The *x*-axis represents each morphology's mean percent from all the survey sites. The *y*-axis is the morphology type.

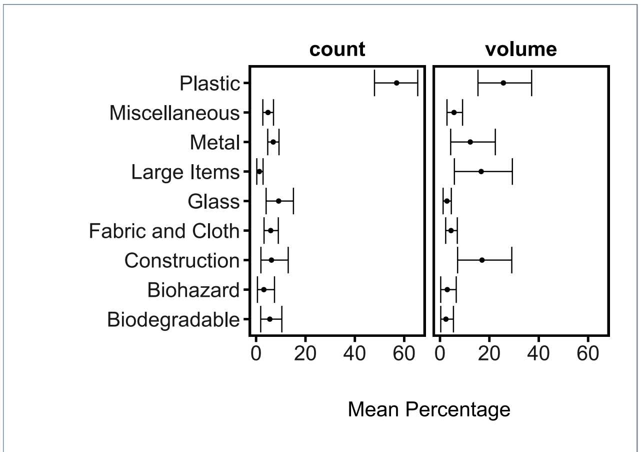

Figure 8. Material composition by count and volume. *X*-axis is the mean percent of the material type at all sites. *Y*-axis is the material type. 18 of the 23 survey data points were used to make this plot as the others had fewer than 10 objects analyzed at the site and would add too much variability. Top axis is the data split up by count or volume, respectively. The point is the mean and the whiskers are the 95% confidence intervals from the bootstrap simulation. Plastic has the highest mean percentage across the material types by count and volume.

Council, and present the draft ordinance at a first and second public hearing where City Council deliberates and public input is received. Eventually, the Council votes in favor or against the ordinance's adoption.

Additional to engagement with the City Council and staff, project team members and volunteers continue to be active in Pinole, engaging through presentations to local nonprofits and scientific conferences, and conducting cleanups monthly. As these activities continue, they create opportunities to increase public awareness of community-wide responsibilities for the care of Pinole Creek.

Although project assessment results showed there was litter where the creek passes through county property outside of the City's jurisdiction, the team could not adequately engage with management at the county to propose policies for that level of government. Community members noted elevated levels of illegal dumping on the county property compared to the city property, which was also prevalent in the data with the highest volume abundances observed above the city boundary (Figure 6). Litter there ultimately flows to the Pinole City creeks. Therefore, The Community would welcome a collaborative relationship with county management. Community members involved with this project recommend that on a countywide level,

10.1029/2022CSJ000017

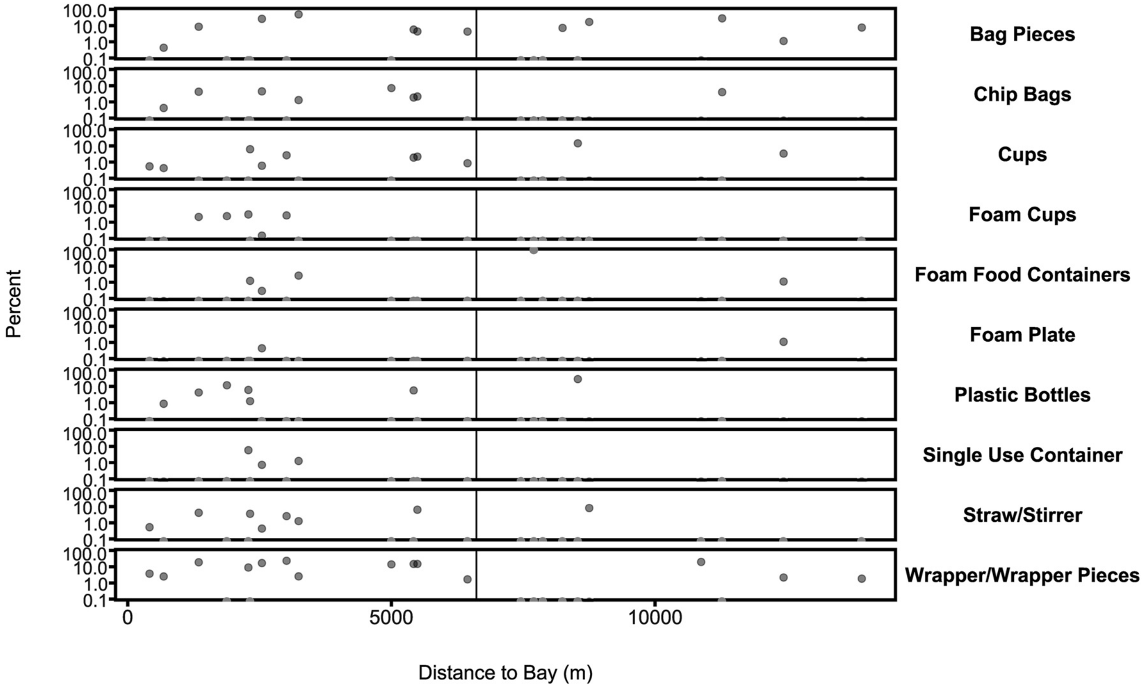

Figure 9. Food related morphologies and their percent found in the creek. *X* axis is the distance in meters upstream from the outlet at the bay. *Y* axis is the percentage of all morphologies found in the category listed on the right axis. Points are survey locations. Locations with zero trash of that type were omitted from the plot. Vertical line is the city limits. Everything to the left is in the city limits and everything to the right is outside. Twelve data points were within the city limits and 11 were above.

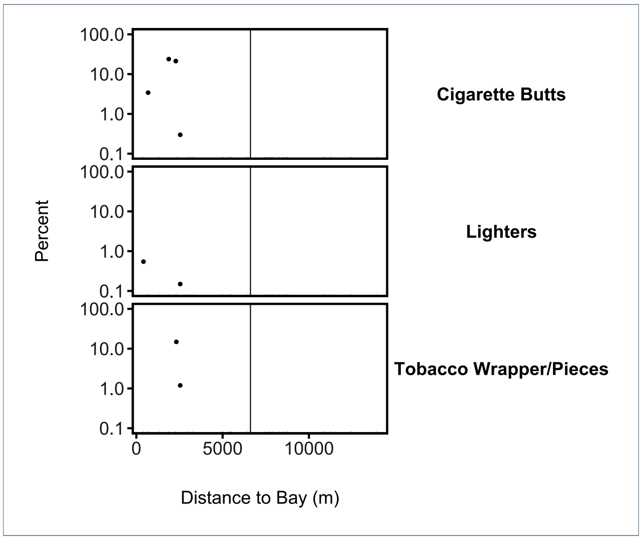

Figure 10. Tobacco-related morphologies found at the survey locations. *X* axis is the distance in meters upstream from the outlet at the bay. *Y* axis is in log scale with the percentage of all morphologies found in the category list on the right axis. Points are survey locations. Locations with zero trash of that type were omitted from the plot. The vertical line is the city limits. Everything to the left is in the city and everything to the right is outside of the city. Twelve data points were within the city limits and 11 were above.

ordinances and litter-prevention and abatement actions similar to what they proposed to the Pinole City Council will serve as examples that the county could enact and follow to improve litter conditions on county property.

4.2. Scientific

4.2.1. Follow-Up Study in 5 years

Trash conditions in creeks can change over time. Those changes could inform us about how effective the policy actions were at improving the creek quality. The Community recommended a follow-up study to be conducted in 5 years to assess changes resulting from the policy actions.

4.2.2. Targeted Focus on Areas of Concern and Sources

A limitation of the study design was not being able to thoroughly assess the trash sources at some of the most problematic areas of concern. For example, the location near the highway had homeless encampments, highway runoff, parking lot windblown trash, and upstream sources all interacting at that location. Surveyors would need to conduct a site-specific study to identify the most important sources at that site. In such a study, surveyors would look at the composition of the trash coming from each source and compare that to the trash in the creek. The Thriving Earth Team recommended this as a potential action City Council could take.

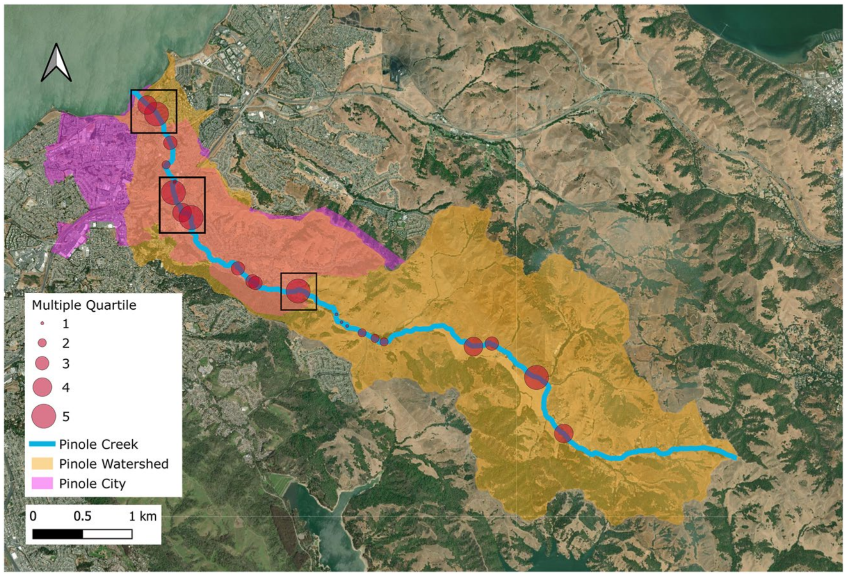

Figure 11. Areas of concern were identified by transforming count and volume concentrations using maximum normalization, multiplying them together, and mapping the five quartiles as different-sized circles (multiple quartile). Blue line is the Pinole Creek mainstem. Yellow area is the Pinole watershed. Pink area is the Pinole city limits. Both areas are slightly transparent, so their overlap can be visualized in the orange area. Locations with large circles near each other were outlined with a black box and described as an area of concern that warrants future investigation. Basemap is satellite imagery from QGIS basemaps. North arrow points to the top of the image.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

All training, survey, and data collection resources mentioned in the text are available on OSF at https://osf.io/ghswp/ and Zenodo https://doi.org/10.5281/zenodo.7586455. All raw data and data analysis from the survey is available on Github at https://github.com/wincowgerDEV/pinole_creek.

Acknowledgment
We are thankful for the volunteers who helped in data collection, analysis, and reporting, Sherry Engberg, Charlotte Blodwynne-Heart, Arthur Blodwynne-Heart, Kelly Britton, Damien Grace, Megan Murphy, Mary Moffitt, Kent Moriarty, Paula Jarvis, Job Jarvis, Becky Robinson, Analucia Urias-Lopez, Angella Dayrit, Derek Manahan, Isabel Fernandez, Luis Fernandez, Natalie Szumlas, Nicole Castillo, Randy Snook, Samantha Zapanta, Simran Gurung, Sophia Ly, Terrence Clark Tecala, Vannapa Douangphrachanh, and Victoria Corona Espinosa. We would also like to thank Angela Howe from Surfrider, Miram Gordon from Upstream, and Pinole City Staff including Andrew Murray, Misha Kaur, and others, who provided policy consultations. This work was primarily funded through the Thriving Earth Exchange, a project of the American Geophysical Union with funds from the Gordon and Betty Moore Foundation. Win Cowger was funded partly by the McPike Zima Charitable Foundation and partly by the University of California Riverside.

References

Baldwin, A. K., Corsi, S. R., & Mason, S. A. (2016). Plastic debris in 29 Great Lakes Tributaries: Relations to watershed attributes and hydrology. *Environmental Science and Technology*, *50*(19), 10377–10385. https://doi.org/10.1021/acs.est.6b02917

Cârstea, E. M., Popa, C. L., & Donțu, S. I. (2022). Citizen science for the Danube River—Knowledge transfer, challenges and perspectives. In A. Negm, L. Zaharia, & G. Ioana-Toroimac (Eds.), *The lower Danube River* (pp. 527–554). Springer International Publishing. https://doi.org/10.1007/978-3-031-03865-5_18

Cook, S., Abolfathi, S., & Gilbert, N. I. (2021). Goals and approaches in the use of citizen science for exploring plastic pollution in freshwater ecosystems: A review. *Freshwater Science*, *40*(4), 567–579. https://doi.org/10.1086/717227

Cowger, W., Gray, A., Hapich, H., Osei-Enin, J., Olguin, S., Huynh, B., et al. (2022). Litter origins, accumulation rates, and hierarchical composition on urban roadsides of the Inland Empire, California. *Environmental Research Letters*, *17*(1), 15007. https://doi.org/10.1088/1748-9326/ac3c6a

Cowger, W., Gray, A. B., & Schultz, R. C. (2019). Anthropogenic litter cleanups in Iowa riparian areas reveal the importance of near-stream and watershed scale land use. *Environmental Pollution*, *250*, 981–989. https://doi.org/10.1016/j.envpol.2019.04.052

Dowle, M., & Srinivasan, A. (2020). data.table: Extension of `data.frame`. Retrieved from https://cran.r-project.org/package=data.table

Emmerik, T., & Schwarz, A. (2020). Plastic debris in rivers. *WIREs Water*, *7*(1). https://doi.org/10.1002/wat2.1398

5 Gyres and EOA inc. (2016). Testing trash "flux" monitoring methods in flowing water bodies (p. 70).

Helinski, O. K., Poor, C. J., & Wolfand, J. M. (2021). Ridding our rivers of plastic: A framework for plastic pollution capture device selection. *Marine Pollution Bulletin*, *165*, 112095. https://doi.org/10.1016/j.marpolbul.2021.112095

Hoellein, T. J., & Rochman, C. M. (2021). The "plastic cycle": A watershed-scale model of plastic pools and fluxes. *Frontiers in Ecology and the Environment*, *19*(3), 176–183. https://doi.org/10.1002/fee.2294

Lee, L. (2020). NADA: Nondetects and data analysis for environmental data. Retrieved from https://CRAN.R-project.org/package=NADA

McCormick, A. R., & Hoellein, T. J. (2016). Anthropogenic litter is abundant, diverse, and mobile in urban rivers: Insights from cross-ecosystem analyses using ecosystem and community ecology tools. *Limnology & Oceanography*, *61*(5), 1718–1734. https://doi.org/10.1002/lno.10328

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., et al. (2017). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*, *208*, 15–28. https://doi.org/10.1016/j.biocon.2016.05.015

McLaughlin, K., Mazor, R., Schiff, K., & Thornton-Hampton, L. (2022). *Southern California bight 2018 regional monitoring program: Volume IX. Trash and marine debris*. SCCWRP. Retrieved from https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1263_Bight-18Trash.pdf

Meijer, L. J. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80\% of global riverine plastic emissions into the ocean. *Science Advances*, *7*(18). https://doi.org/10.1126/sciadv.aaz5803

Moore, S., Hale, T., Weisberg, S. B., Flores, L., & Kauhanen, P. (2020). California trash monitoring methods and assessments playbook.

Moore, S., Sutula, M., Von Bitner, T., Lattin, G., & Schiff, K. (2016). Southern California Bight 20 regional monitoring program: Volume III. Trash and Marine Debris. https://doi.org/10.13140/RG.2.2.32214.04163

Moore, S. L., Gregorio, D., Carreon, M., Weisberg, S. B., & Leecaster, M. K. (2001). Composition and distribution of beach debris in Orange County, California. *Marine Pollution Bulletin*, *42*(3), 241–245. https://doi.org/10.1016/s0025-326x(00)00148-x

Morales-Caselles, C., Viejo, J., Mart'i, E., González-Fernández, D., Pragnell-Raasch, H., Ignacio González-Gordillo, J., et al. (2021). An inshore--offshore sorting system revealed from global classification of ocean litter. *Nature Sustainability*, *4*(6), 484–493. https://doi.org/10.1038/s41893-021-00720-8

Nakano, R. (2019). Stormwater trash reduction are we doing all that we can? (Grand Jury Report). *Contra Costa County Grand Jury*. Retrieved from https://pleasanthill.granicus.com/MetaViewer.php?view_id=&clip_id=1663&meta_id=126584

Pinole City Council Meeting. (2021). Retrieved from http://pinole.granicus.com/MediaPlayer.php?view_id=2&clip_id=1891

Pinole City Council Meeting. (2022). Retrieved from http://pinole.granicus.com/MediaPlayer.php?view_id=2&clip_id=1950&meta_id=54685

Rambonnet, L., Vink, S. C., Land-Zandstra, A. M., & Bosker, T. (2019). Making citizen science count: Best practices and challenges of citizen science projects on plastics in aquatic environments. *Marine Pollution Bulletin*, *145*, 271–277. https://doi.org/10.1016/j.marpolbul.2019.05.056

R Core Team. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Retrieved from https://www.r-project.org/

Rochman, C. M., Munno, K., Box, C., Cummins, A., Zhu, X., & Sutton, R. (2020). Think global, act local: Local knowledge is critical to inform positive change when it comes to microplastics. *Environmental Science & Technology*, *55*(1), 4–6. https://doi.org/10.1021/acs.est.0c05746

RStudio Team. (2020). *RStudio: Integrated development environment for R*. RStudio, PBC. Retrieved from http://www.rstudio.com/

Schauberger, P., & Walker, A. (2022). openxlsx: Read, write and edit xlsx files. Retrieved from https://CRAN.R-project.org/package=openxlsx

Slowikowski, K. (2021). ggrepel: Automatically position non-overlapping text labels with "ggplot2". Retrieved from https://CRAN.R-project.org/package=ggrepel

State Water Resources Control Board. (2015). *Amendment to the water quality Control plan for the ocean waters of California to control trash and Part 1 trash provisions of the water quality control plan for inland surface waters*. Enclosed Bays, and Estuaries of California.

Watkins, L. (2022). *Quantifying Plastic Pollution: An assessment of traditional and community science methods*. Cornell University Library. Retrieved from https://hdl.handle.net/1813/111811

Wickham, H. (2016). ggplot2: elegant graphics for data analysis.

Wickham, H., François, R., Henry, L., & Müller, K. (2020). dplyr: A grammar of data manipulation. Retrieved from https://cran.r-project.org/package=dplyr

Wickham, H., & Girlich, M. (2022). tidyr: Tidy messy data. Retrieved from https://CRAN.R-project.org/package=tidyr

Erratum

Since the original publication of this article some main and subheadings have been renumbered. This may be considered the authoritative version of record.