Identifying and Mapping Inputs and Hotspots of Plastic Waste into the Pacific Ocean and Marine Protected Areas in the San Diego Region in California, USA

White Paper

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About this White Paper

This white paper was developed in the framework of the 2021 Scripps-Rady Ocean Plastic Pollution Challenge. The Challenge was designed as a unique, 6-month, accelerator program focused on identifying effective, evidence-based approaches that would curb the flow of plastic into the ocean, with a specific focus on marine conservation and marine cultural preservation areas along California's coast.

A key component of the Challenge was team-based research conducted from March - May, 2021. Four teams conducted targeted research to address four distinct gaps in solving the plastics problem: changing human behavior, evaluating policy solutions, data mapping, and assessing residents' attitudes towards plastic consumption and plastic waste reduction initiatives in the Challenge's hometown of San Diego.

By design, participants were a mix of graduate students and professionals from different disciplines and with a wide variety of expertise and experience. A mentor worked closely with each team to provide guidance and feedback. Teams produced a suite of 4 white papers based on their research; each paper includes a current state of the team's topic related to plastic pollution in California, an analysis of major knowledge gaps, and a novel contribution to the topic.

The Scripps-Rady Ocean Plastic Pollution Challenge was produced through a partnership between the Center for Marine Biodiversity and Conservation (CMBC) at Scripps Institution of Oceanography and the Center for Social Innovation and Impact (CSII) at the Rady School of Management at University of California San Diego. The Challenge was led by Stuart Sandin, professor and director of the CMBC, and Ayelet Gneezy, professor and faculty director of CSII at Rady.

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Other white papers in this series: https://cmbc.ucsd.edu/plastic-challenge-2021/plastic-challenge-2021-white-papers/

1. Key Recommendations of the White Papers Produced During the 2021 Scripps-Rady Ocean Plastic Pollution Challenge
2. Evaluating Efficacy of Plastic Pollution Solutions in the Southern California Bight
3. Leveraging Behavioral Intervention Frameworks to Change Households' Plastic Consumption and Disposal Behaviors
4. San Diego County Residents' Attitudes Towards Plastic Consumption and Plastic Waste Reduction Initiatives

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Photo credits, clockwise from top left: Holly Rindge; Holly Rindge; Scripps Institution of Oceanography; Jules Jackson. Cover photo: Pixabay.

Glossary of Terms

Term/abbreviation	Description
CA	California
EPS	Expanded Polystyrene
GIS	Geographic Information System
GPS	Global Positioning System
km	Kilometer
MPA	Marine Protected Area
MS4	Municipal separate storm sewer systems
MT	Metric tonnes
NGO	Non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
SAV	Submerged Aquatic Vegetation

Datasets used in this paper

Dataset shortname	Dataset original name / short description / link
Airbnb	http://insideairbnb.com/san-diego/ and https://public.opendatasoft.com/explore/dataset/airbnb-listings/
Coast	Coastline shapefile layer, ESRI, 2021 \\gaskill\data\DVD_Data\DVD1 Misc\Hydrology\coast.shp
CoastalCleanup	Coastal Cleanup Debris Dataset from the Ocean Conservancy https://www.coastalcleanupdata.org/
Jurisdictions	Local jurisdictions in the San Diego region based on the MUNICIPAL_BOUNDARIES layer in the Regional GIS Data Warehouse, 2018, ArcGIS Hub, 2021, https://gissd.sandag.org/rdw/rest/services/Jurisdiction/Jurisdictions/MapServer
MarineDebris	Marine Debris tracker dataset on plastic debris (Jambeck & Johnsen, 2015) https://marinedebris.noaa.gov/partnerships/marine-debris-tracker
MPA	Data sub-set for San Diego County from the Southern California MPA dataset from CENCOOS: Marine protected areas (MPAs) for the state of California. https://data.cencoos.org/#search?type_group=all&query=MPA&page=1, These data include all of California's state marine protected areas (MPAs) as of December 19, 2012. California's MPA network includes three MPA designations (State Marine Reserve, State Marine Conservation Area, and State Marine Park) and one additional MMA designation (State Marine Recreational Management Area); special closure areas, established by the Fish and Game Commission, are also managed within the California MPA network. This dataset reflects the Department of Fish and Game's best representation of marine protected areas based upon current California Code of Regulations, Title 14, Section 632: Natural Resources, Division 1: FGC- DFG. This dataset is not intended for navigational use or defining legal boundaries. Metadata URL: https://map.dfg.ca.gov/marine/

RiversStreams	Dataset Major Rivers and Creeks from the U.S. Geological Survey, National Geospatial Technical Operations Center, 2020, http://earthexplorer.usgs.gov, https://prd-tnm.s3.amazonaws.com/StagedProducts/Hydrography/NHD/State/HighResolution/GDB/NHD_H_California_State_GDB.zip
RiverinePlastic	Riverine input of plastics to oceans, Lebreton et al., 2017a, This dataset includes estimations for riverine input of plastics to oceans. There are low, mid and high estimates of plastic in tonnes per year and per month available for river outfall locations of 40,760 rivers worldwide. Calculations are based on a global model using data of waste management (mismanaged plastic waste in a certain area in kg/year) and hydrology (precipitation runoff in mm/day).
SAV	Datasets of Submerged Aquatic Vegetation zones, i.e. eelgrass and kelp of the San Diego coast.
SpecialEvents	https://data.sandiego.gov/datasets/special-events/

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I. EXECUTIVE SUMMARY

The impacts of plastic pollution continue to gain significant attention, in turn leading to a significant increase in relevant data. In this paper we present a variety of information regarding plastic pollution data related to San Diego Marine Protected Areas (MPAs). The work involved collecting, mapping and ensuring quality of the data. Additionally, statistical analysis was used to infer relationships among the various data sets. This work intends to facilitate the development of local solutions and can be used as a blueprint for data collection in other regions.

First efforts involved data discovery from a wide variety of sources. This included data on beach plastic litter, marine ecology, coastal geomorphology, ocean currents, riverine and estuarine fluxes of plastic waste, and socio-demographic conditions and policies. The main sources of data on the quantities of plastic pollution were two citizen group data portals: The Coastal Cleanup Debris portal from the Ocean Conservancy and the Marine Debris tracker portal from the National Oceanic and Atmospheric Administration (NOAA). This study's goals were to combine and analyze data on the inputs of plastic pollution with data on mitigation efforts, to point out and determine spatial correlations between sources, pathways, impact zones and plastic waste mitigation efforts, and to identify potential "hotspots" of plastic waste pollution.

Statistical analyses and geographic information system (GIS) software were used for data mining and data mapping. Before the acquired data could be used, it was put through quality assurance/quality control (QA/QC) processes. Once data of sufficient quality was obtained, it was combined with geographic (spatial) data to produce a series of maps showing how plastic pollution correlates with a number of factors, including areas impacted by tourism, coastal geomorphology, aquatic environments, ocean currents, and rivers and streams. Additionally, the data was used to evaluate the effectiveness of government interventions to mitigate plastic pollution including plastic bans and stormwater trash capture.

The conclusions of this paper are:

1. The CoastalCleanup data portal provides a more detailed dataset that can be standardized more effectively but comprises a narrower temporal and spatial context compared to the MarineDebris data portal.
2. Geomorphology of the coast impacts the retention of plastic waste. Plastic trapping efficiency is high for the coastal geomorphology types that exist in the San Diego area (rocky, wave and tide-dominated).

3. The submerged aquatic vegetation (SAV) zones in and adjacent to MPAs in the San Diego region are potential hotspots for riverine, land-based, and marine plastic waste.
4. Bans on plastic bags appear to have reduced the proportion of plastic bags collected in clean-ups in the San Diego area indicating that bans could be a valuable tool to mitigate plastic pollution.
5. Ocean currents affect the distribution of plastic in the ocean and along coastlines, as evidenced by marine-sourced debris (e.g., fishing gear) found on beaches. However, analyzing and visualizing plastic pollution and its distribution in coastal environments while accounting for regional oceanic conditions is challenging and requires large amounts of data. Future efforts are needed to develop easily accessible data and tools to estimate (real-time) marine plastic fluxes.

The information and conclusions presented in this paper should be used by the public, policy makers and government administrators in designing mitigation strategies for ocean plastic pollution in the San Diego region.

A number of suggestions are offered for future research to aid in the design of mitigation measures, including:

- Standardizing (if possible) the data available regarding plastic pollution clean-ups by citizen groups and harmonizing data collection with other clean-up programs.
- Increase research on the effectiveness of and methods for removing plastic waste from inland waterways prior to their reaching the coast. Moreover, investigate the potential impacts of plastic accumulation in valuable coastal ecosystems, such as vegetated aquatic zones, and assess the potential for novel removal techniques at plastic waste hotspots.
- Improve the trash infrastructure in coastal areas visited by high numbers of tourists and residents, with special attention to seasonal variability.
- Extend and monitor plastic bans both geographically within San Diego County and also include more items, such as plastic straws, food containers, etc., as part of the bans.
- Investigate the influence of ocean currents on marine plastic distribution at a larger scale and analyse potential impacts on the San Diego MPAs. Develop prediction models and make data easily accessible. As the scale of global plastic pollution expands, waste influxes from other areas may increase along the coast of the western U.S.

II. INTRODUCTION

Overproduction of plastic and mismanagement of plastic waste is an issue of critical concern, with noticeable impacts on freshwater and marine environments worldwide. An estimated 4.8 to 12.7 million metric tons (MT) of plastic waste enter the ocean each year (Jambeck et al., 2015), with approximately 1.15 to 2.41 MT per year contributed by rivers (Lebreton et al., 2017). This is particularly concerning in the State of California-designated Marine Protected Areas (MPAs) where efforts have been made to protect marine wildlife and flora. Even with government regulations and protections, MPAs are still subject to influxes of plastic waste, which impedes conservation efforts.

Plastic waste in marine environments is referred to as marine plastic and is a subcategory of marine debris. Plastic waste, and hence marine plastic, include (intentionally and unintentionally) discarded objects made of polymers (NOAA, 2018). Plastic waste entering the oceans includes plastic bags, beverage cups, bottles, cigarette butts or Styrofoam food containers (NOAA, 2018). Additionally, there are smaller plastic items that are pervasive and difficult to keep from getting into waterways and the ocean, such as microbeads from personal care products, and nurdles used to make plastic products (Lebreton et al., 2018; NOAA, 2015; NOAA, 2018). Plastics can be categorized by color, size, item, polymer type. Common size categories for marine plastic are: >1m (megaplastic), 1m-25cm (macroplastic), 25cm-5mm (mesoplastic), 5mm-1µm (microplastic), <1µm (nanoplastic) (Lippiatt et al., 2013). The polymer types, i.e. the plastic material, often found in marine ecosystems are Polypropylene (PP), Polyethylene (PE), Polyethylene Terephthalate (PET), Polyvinyl Chloride (PVC), and Polystyrene (PS) (Lebreton et al., 2018; NOAA, 2018; Sanchez-Vidal et al, 2021).

Plastic waste has multiple negative effects on the environment such as the relocation of invasive species by transport on plastic waste, habitat degradation, entanglement or ingestion by marine life, and the bioaccumulation of toxic chemical compounds that can deteriorate the health of organisms (Everaert et al., 2020; Haegerbaeumer et al., 2019; Mato et al., 2001; Nelms et al., 2017; Talley et al., 2020). Targeted strategies to mitigate plastic fluxes into the ocean and into MPAs require analyses of the sources, quantities and transport pathways of plastics.

Despite plastic pollution being a global problem, some solutions need to be tackled and implemented locally (Derraik 2002). Although large-scale estimations and global models (Jambeck et al. 2015; Lebreton et al. 2017; Onink et al. 2021) help decipher the processes contributing to marine plastic pollution, there is a lack of small-scale models accounting for the environmental conditions where solutions need to be developed. For example, the management of MPAs in San Diego County, and in particular the control of ecosystem disturbances, such as pollution, ocean acidification, or illegal fishing, is regulated and maintained via regional networks. Hence, regionality is a crucial factor in the development of solutions (Kroeker et al, 2019), and regional data concerning plastic pollution needs to be acquired and analyzed to account for local characteristics influencing plastic pollution.

Here, we aim to identify and map regional inputs of plastic waste into the Pacific Ocean areas adjacent to and inside of the MPAs in San Diego County, California, USA. Thus, this white paper presents a new approach to identify regional plastic waste hotspots using data mapping. The goals of this study are:

- To collect and analyze available data on beach litter (focusing on plastics), marine ecology, coastal geomorphology, ocean currents, riverine and estuarine fluxes of plastic waste, and socio-demographic conditions. Based on availability of data and knowledge, gaps will be identified as focus areas for future research and data generation.
- To combine and analyze data on the inputs of plastic pollution with data on mitigation efforts, such as the implementation of plastic bans.
- To point out and determine spatial correlations between sources, pathways, impact zones and plastic waste mitigation efforts in the San Diego region with a focus on MPAs.
- To identify potential "hotspots" of plastic waste pollution.

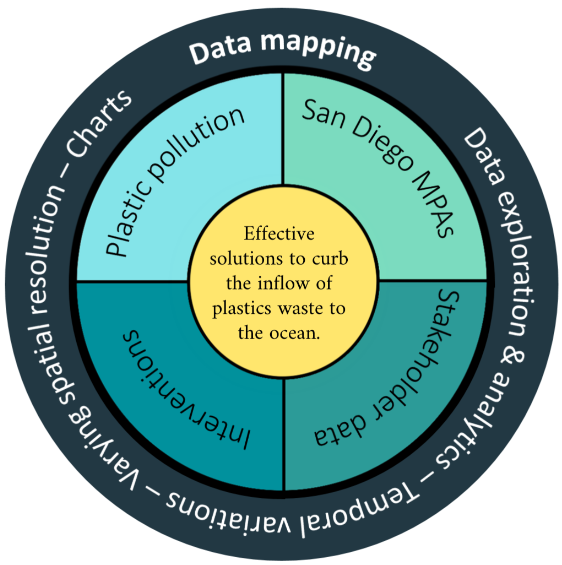
The results of this study can be used to better understand the problems and pinpoint potential solutions to plastic waste in the San Diego MPAs and greater San Diego region.

III. MAPPING AND MINING PLASTIC POLLUTION DATA

This study presents a geospatial analysis (data mapping) of plastic waste data in the San Diego region to contribute to effective solutions to curb the inflow of plastics to the oceans (Figure 1).

This analysis reveals plastic waste "hotspots" near and inside of MPAs. This study defines a plastic waste "hotspot" as an area with high potential for exposure to plastic waste inflows and accumulation. The maps presented in this study combine a variety of data with a focus on the past decade, including data from scientific studies, legislative and policy interventions, environmental initiative history, and ecological habitat. This study targeted subjects that are based on science and are relevant to strengthen the development of solutions to the plastic pollution problem in the San Diego MPAs. The maps and data analyses are displayed separately for four different topics, i.e. riverine plastic inputs, plastic waste correlated to socio-demographic features, government interventions to reduce plastic waste pollution and marine-based plastic waste. This study may be of interest to the general public, policymakers, and regional administrators in San Diego County.

Figure 1. Representation of the data mapping framework.



A. Data Mapping as a Tool

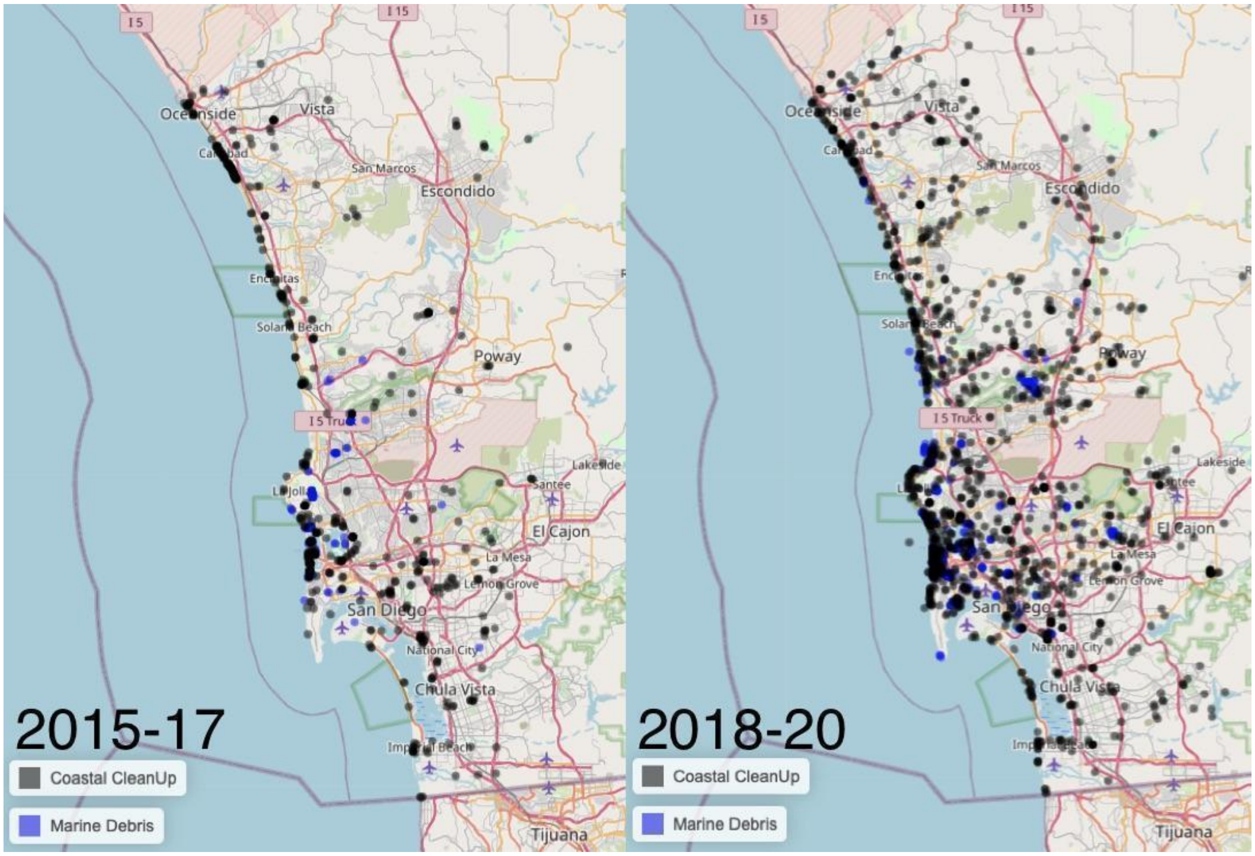
Data mapping can be an ideal tool to enhance an understanding of the processes underlying the entry of plastic waste in marine systems. It can also be used to quantify and analyze plastic waste across temporal and spatial scales (Lebreton et al, 2017; PEW, 2020). Data mapping specifically in the context of this study is the process of extracting and integrating data from sources and matching them to targeted geospatial points or areas on a map (Figure 2).

Data mapping has been used to help solve complex issues, including public health, internet equity, environmental justice, natural resource management, and invasive species. For example, during the COVID-19 pandemic, data mapping enabled public policy makers and health care providers to assess high-risk nursing homes and regions where prevention and mitigation efforts (tests and vaccines) should be prioritized (Sugg et al., 2021). Also, during the pandemic, when the need for widespread remote learning became critical, Zandiatashbar et al. (2021) mapped the exacerbated disparities in internet access in an area of California. In conjunction with this work, politicians introduced the “Internet for All Act of 2021”, to help mend the digital divide.

Collaborations among community organizers, government agencies and researchers, such as the Los Angeles Collaborative for Environmental Health and Justice, resulted in the development of environmental justice mapping tools (Sadd et al., 2013). These mapping tools (e.g., CalEnviroScreen and the United States Environmental Protection Agency's EJSCREEN) have been critical in demonstrating environmental justice disparities to the public and government. This has resulted in numerous legislative changes to decrease hazards, pollution, and environmental injustice (Lee, 2020). From these examples, it is clear that data mapping is an effective tool that can provide both visualization and insight into complex problems, often paving the way for actions and solutions.

Projects where plastic data is mapped to identify and counter sources of pollution are increasing. For example, Surfrider Foundation US released a plastic reduction policy map (https://www.surfrider.org/coastal-blog/entry/the-surfrider-foundation-releases-interactive-map-of-u.s-plastic-reduction-policies) to inform citizens about plastic bans and Surfrider Foundation Europe implemented a new clean-up map application (https://www.plasticorigins.eu/) encouraging people to collect data.

Figure 2. An example of data mapping used in this study to compare two different data sets and two different time ranges. Data points are standardized plastic waste from 2015 to 2017 and 2018 to 2020. Clean-up activity data was accessed via the Marine Debris Tracker and Coastal Cleanup data portals.



B. Methodology and Acquisition of Plastic Pollution Data

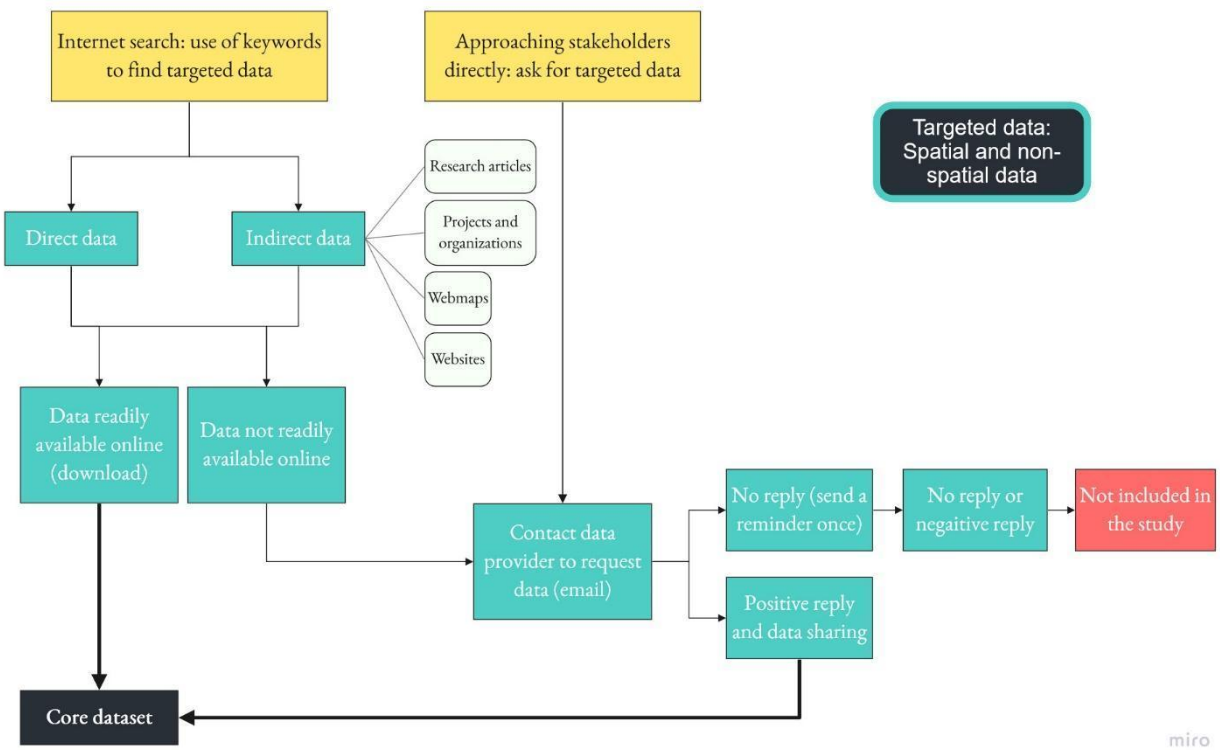
Appropriate regional data was acquired on plastic pollution and input it into GIS applications for analysis and data mining. Data visualization and spatial analyses with ArcGIS, QGIS and R-Shiney were conducted as a final step.

Data mining is a method to gather, process and validate data, to reveal new linkages and correlations via data clustering and statistical analyses. The advantage of data mining is that existing data is used to generate new knowledge. While one variable alone (i.e., estimated annual amount of plastic discharged to the ocean by the Tijuana river) has limited substantive scope, novel representations and analytical combinations of a number of data sets can uncover patterns and relationships between different variables.

Spatial resolution is an important aspect when it comes to problems that impact ecosystems on a regional scale. Therefore, mapping data to highlight spatio-temporal changes and correlations is key to assess the underlying processes. For example, single-use plastic bag bans were implemented in San Diego County in the past years, and policy-makers as well as the general public would be interested in the effectiveness of these bans. Correlating the date of ban implementation to plastic bags found from clean-ups in maps could reveal the effectiveness of bans.

Figure 3 summarizes the workflows for the data acquisition. After obtaining a core dataset, the information was corrected and/or standardized to produce a workable dataset (Figure 4). Data included in the workable dataset was then analyzed and mapped.

Figure 3. Workflow Chart 1. Processes of data mining to obtain a core dataset. Arrows indicate workflow direction. Image developed using miro application.



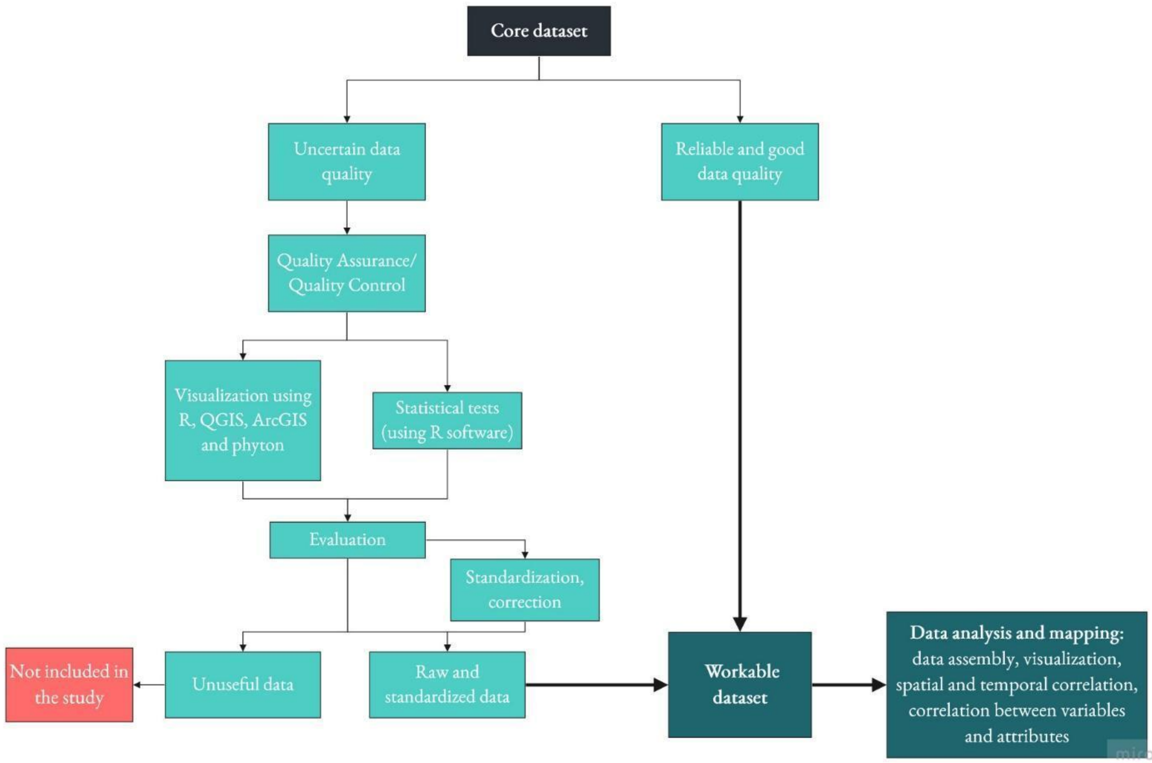
The search for the core dataset was based on keyword internet search and by directly approaching stakeholders. Keywords were chosen with respect to the objectives of this study. Existing data was collected on the San Diego MPAs, quantities of plastic waste clean-up efforts, types of interventions, relevant geological, ecological and hydrological data, and socio-demographic aspects to visualize and identify connections and correlations. An overview of the keywords used is given in the appendix. When data was not readily available the data providers were directly contacted. If no (positive) reply was received, or if the data was deemed unusable, then the data was excluded from the study. Part of the data was directly accessible (direct download from the provider), while other specific data was not directly available. One example of "indirect" data is supplementary datasets of research papers.

Different types of data were targeted: (1) Raster and vector data with geographic coordinate references for GIS implementation and mapping (e.g., Shapefiles or Geodatabase-files, including points (latitude/longitude), polygons; (2) Non-spatial data (i.e. numeric, text, others) referring to different kind of attributes and features (e.g., plastic bans, MPA ecological information); and (3) count data of plastic waste with additional point data attributes, including geospatial and temporal information.

Some data were deemed to be low quality and required Quality Assurance/Quality Control (QA/QC) before inputting it into this analyses. Figure 4 shows the QA/QC procedures implemented. GIS and statistical tools were used to identify any drawbacks of the data (such as outliers, missing data, limitations) and evaluate the data. Useful data was corrected and standardized whereas unusable data was excluded from the study.

Tabular data with spatial positions and attributes were turned into geographic data using ArcGIS Pro and R. To account for up-to-date information and the time-dependent processes related to the topic of plastic pollution, data covering several years within the past decade (2010-2020) was selected.

Figure 4. Work flow Chart 2. Processes of data quality assessment of the core dataset to obtain a workable dataset. Arrows indicate workflow direction. Image developed using miro application.



IV. BACKGROUND: SAN DIEGO COUNTY AND NEARBY MPAs

A. Climate, Watershed and Coastal Processes

San Diego County, situated in southern California on the US west coast, has about 3.35 million inhabitants with a population increase of about 7.8% in the last decade (Census, 2021). The County comprises 10,893 square km of land area with 113km of coastline. The coastal cities (from north to south) are Oceanside, Carlsbad, Encinitas, Solana Beach, Del Mar, the City of San Diego and Imperial Beach.

The climate in Southern California is mild, dry, and subtropical, and is strongly influenced by ocean temperatures (The Pacific Energy Center, 2006). Air temperatures (San Diego County annual average: 18.3°C) have shown an increase in warm anomalies since the mid 1970s due to climate change. Droughts are rather common, and dry periods have increased. Nevertheless, Southern California temporarily experiences several days of heavy precipitation that can cause local flooding events, causing severe damage to infrastructure and increased runoff of plastic and trash from river banks and land to the rivers (WWRC, 2021). The sum of precipitation in SD County between mid-April 2016, and mid-April 2021 ranged between 50-100 inches (High Plains, 2021).

The major rivers that traverse San Diego County are (from north to south) the Santa Margarita, San Luis Rey, San Dieguito, San Diego, Sweetwater, Otay, and Tijuana Rivers (Figure 5). These rivers connect to other smaller streams and tributaries to make up a larger drainage area, or watershed. Each watershed can be divided into areas that have distinct hydrological and environmental features including habitats, varying land uses and amount of open space, population density, topography and rainfall, all of which can contribute to the sediment and trash load, and influence the type and size of trash that a river can carry (e.g., Ryan et al., 2009; Moore et al., 2011; San Diego Bay Debris, 2016; Harris et al., 2021).

California's ocean current system is exposed to alternating El Nino and La Nina phenomena (referred to as the El Niño Southern Oscillation (ENSO)), causing warm periods, with increased swell and low wind, or strong winds with high upwelling conditions, respectively. Sea surface temperatures in Southern California range between 11.8-23.6°C, (average: 17.1°C) and warm temperature anomalies ('The Blob') associated with the Southern California Warm Anomaly (SCWA) and El Niño phenomena occurred in 2012 through 2016 (Ocean Spaces, 2021).

Coastal management projects include the enrichment and restoration of submerged aquatic vegetation (SAV), such as eelgrass and kelp, along the Southern California coast (Nielsen et al., 2018). Such projects enhance the protection and restoration of SAV along the coast to increase ecosystem benefits and protect marine life. A characteristic of SAV is that it changes local conditions, for example slowing ocean currents and trapping sedimentary particles (including plastic). The proximity of SAV habitats to estuaries and their distribution along the coast where riverine land-based plastics enter the ocean makes them prone to trap and accumulate plastic waste. In addition, plastic waste from the open ocean and coastal activities (fishing, kayaking) can enter SAV zones, making them potential coastal hotspots for plastic waste accumulation.

Wind, current, and wave transport, as well as the proximity to storm drain outflows, dense human population areas and tourist beaches, are the greatest contributors to the density of plastic waste deposition in upstream and downstream urban estuaries (Willis et al., 2017). Also, strong storm surge can contribute to the backwashing of macro- and microplastic materials toward the shore (Sanchez-Vidal et al., 2021).

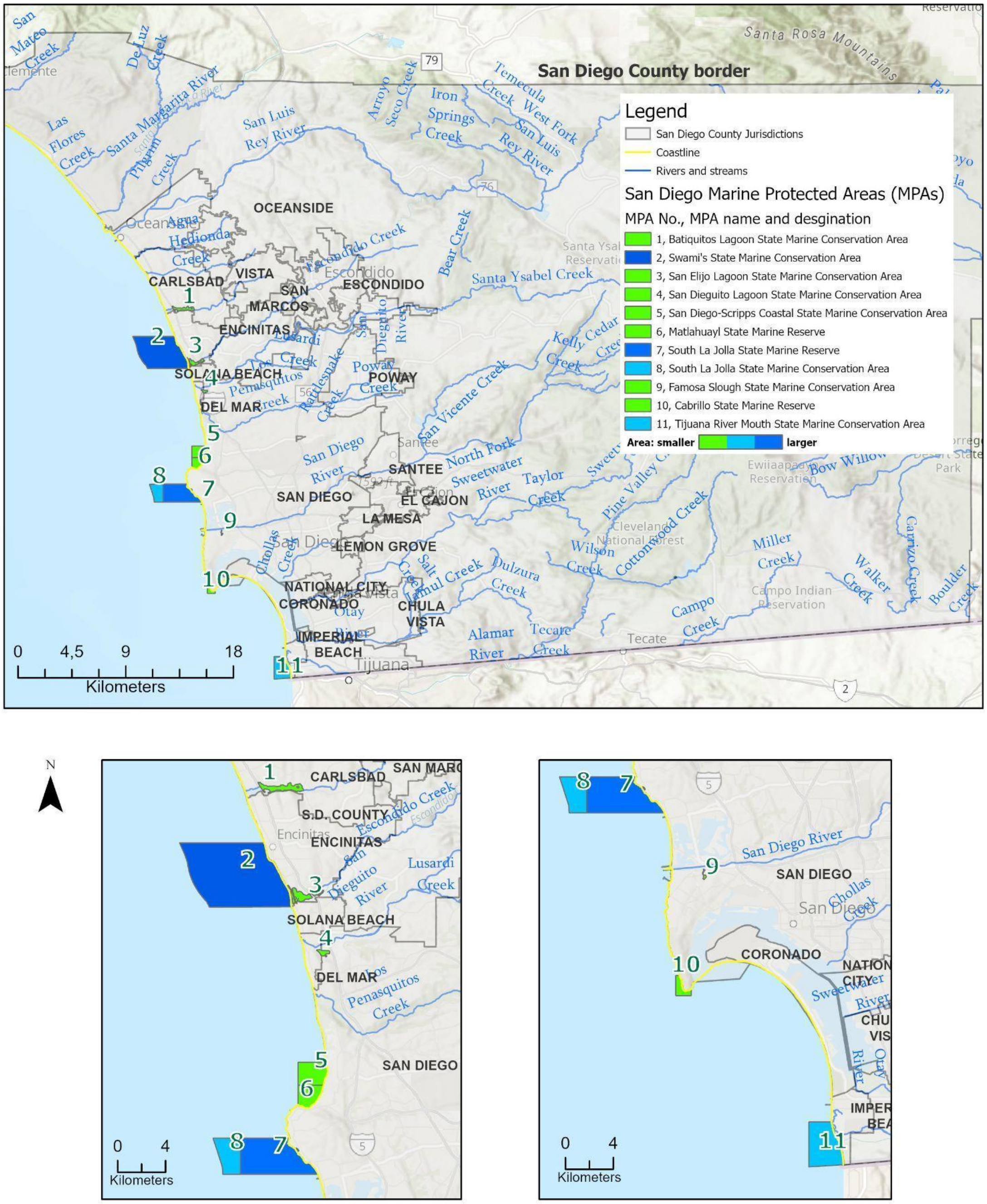
B. San Diego Marine Protected Areas (MPAs)

To protect and preserve sensitive and ecologically valuable marine ecosystems, the California Legislature passed the Marine Life Protection Act (MLPA) in 1999. The purpose of this act is "to redesign its pre-existing system of marine protected areas (MPAs) to function as a state-wide network to increase its coherence and effectiveness at protecting the state's marine life, habitats, and ecosystems" (MPA Monitoring Action Plan, 2018). As a result of the planning and re-designing process, including modification to the Marine Life Protection Program (now referred to as the MPA Management Program) in 2012, 124 MPAs and 15 special closures were created in California, encompassing 16% of California's jurisdictional waters (MPA Monitoring Action Plan, 2018).

As of today, there are 11 MPAs in and adjacent to San Diego County categorized as State Marine Conservation Areas (SMCA) and/or State Marine Reserves (SMR). Figure 5 displays the MPAs, numbered from 1-11 from north to south. The MPAs differ greatly in area: the largest is Swami's SMCA measuring 20.33 square km; Famosa Slough SMCA is the smallest, measuring only 0.02 square km in size (Figure 6).

The MPA Management Program manages the MPA network. It has four focal areas: research and monitoring, enforcement and compliance, outreach and education, and policy and permitting. Two key stakeholders in the research and monitoring focal area, the California Department of Fish and Wildlife (CDFW) and the California Ocean Protection Council (OPC), are conducting long-term monitoring to enhance the understanding and protection of MPAs ecology, biodiversity and ecosystems (MPA Monitoring Action Plan, 2018).

Figure 5. This map displays the eleven designated MPAs within San Diego County (MPAs labeled from 1-11 and size of MPA area indicated by color gradient), the County's jurisdictions, and major rivers and streams. Datasets: MPA, RiversStreams, Jurisdictions, Coast.



San Diego County MPAs

SanGIS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS; Esri, NASA, NGA, USGS; Esri, CGIAR, USGS; Esri, FAO, NOAA; Esri, USGS

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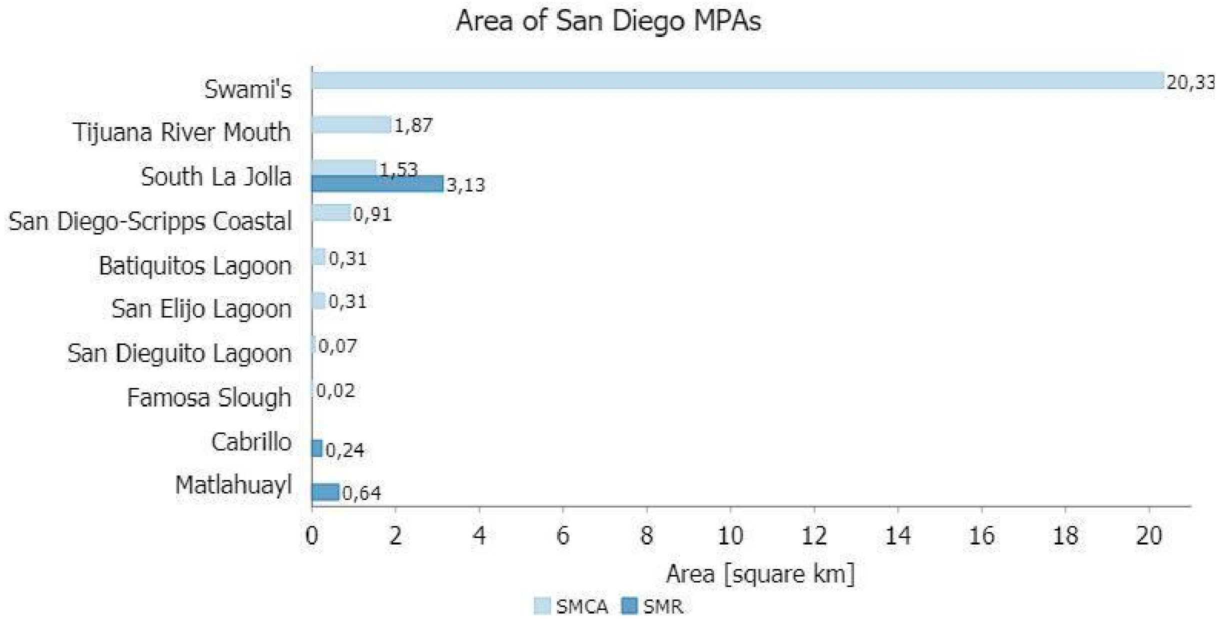
created: May 2021

Figure 6. Areas of San Diego MPAs, descending from larger to smaller.

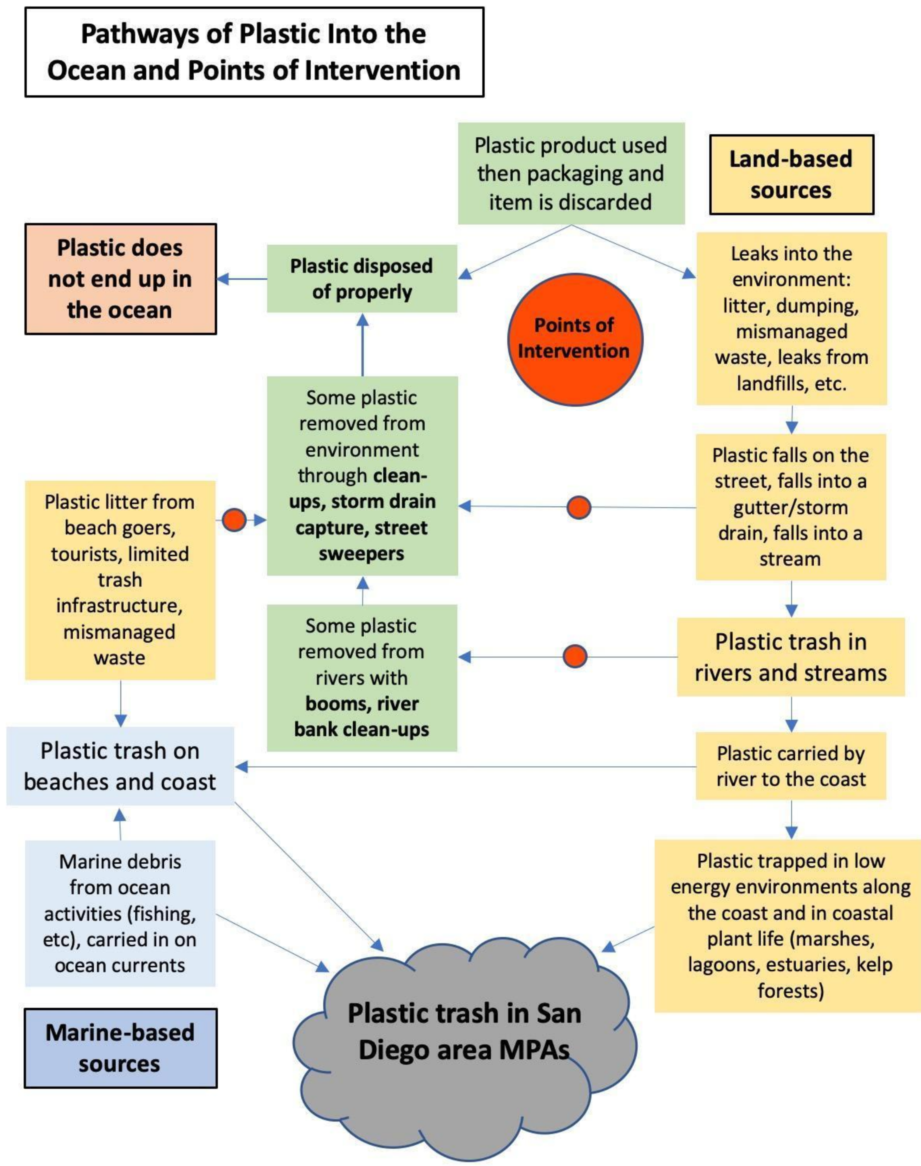


C. Plastic pollution in San Diego County

Several studies have looked at land-based sources of plastic pollution, globally (Lebreton et al., 2017; Jambeck et al., 2015a), and locally in the San Diego area (San Diego Bay Debris Study, 2016). The latter found that monitoring of plastic waste in streams was useful for locating hotspots and identifying significant pathways for trash to flow into the San Diego Bay. Similar studies for other areas of San Diego County are needed, but have yet to be undertaken. Regular trash clean-ups are carried out by local non-profit organizations such as the San Diego River Park Foundation, who report information about the location of the clean-ups, the weight of trash and, in some instances, the types of trash collected (http://immappler.com/sandiegorivertrash/).

Figure 7 shows pathways for land- and marine-based plastic waste into the oceanic environment around the San Diego region, focusing on mesoplastic (>0.5cm-25cm) and macroplastic (>25cm). Points of intervention, at which plastic waste can be removed from the environment and disposed of properly so that ocean pollution is averted, are highlighted. Currently, this study does not have data on the proportion of waste generated by each path for the San Diego region. These quantities would be a valuable input for developing intervention strategies, and assessing these quantities could be a useful project for future work. This study presents data along the pathways and at intervention points and discusses what is known so far about these predicted pathways and the efficacy of the interventions.

Figure 7. Overview of plastic waste sources, pathways and intervention points in the coastal region of San Diego County.



Currently, over 1.125 million households in San Diego County contribute to the production of waste. It was estimated that the US contributes 0.9 % of the worldwide total mismanaged plastic waste, and that 0.04-0.11 million MT end up in ocean environments as marine plastic debris every year, considering the population within a 50 km radius of the coasts (Jambeck, 2015a). Due to the high volume of plastic pollution, the State of California was one of the leading states implementing plastic bag bans (Wagner, 2017; Morath, 2011). Where and how plastic waste is found in natural and urbanized environments is critical to assess to shed light on plastic waste sources, transport pathways, and impacts.

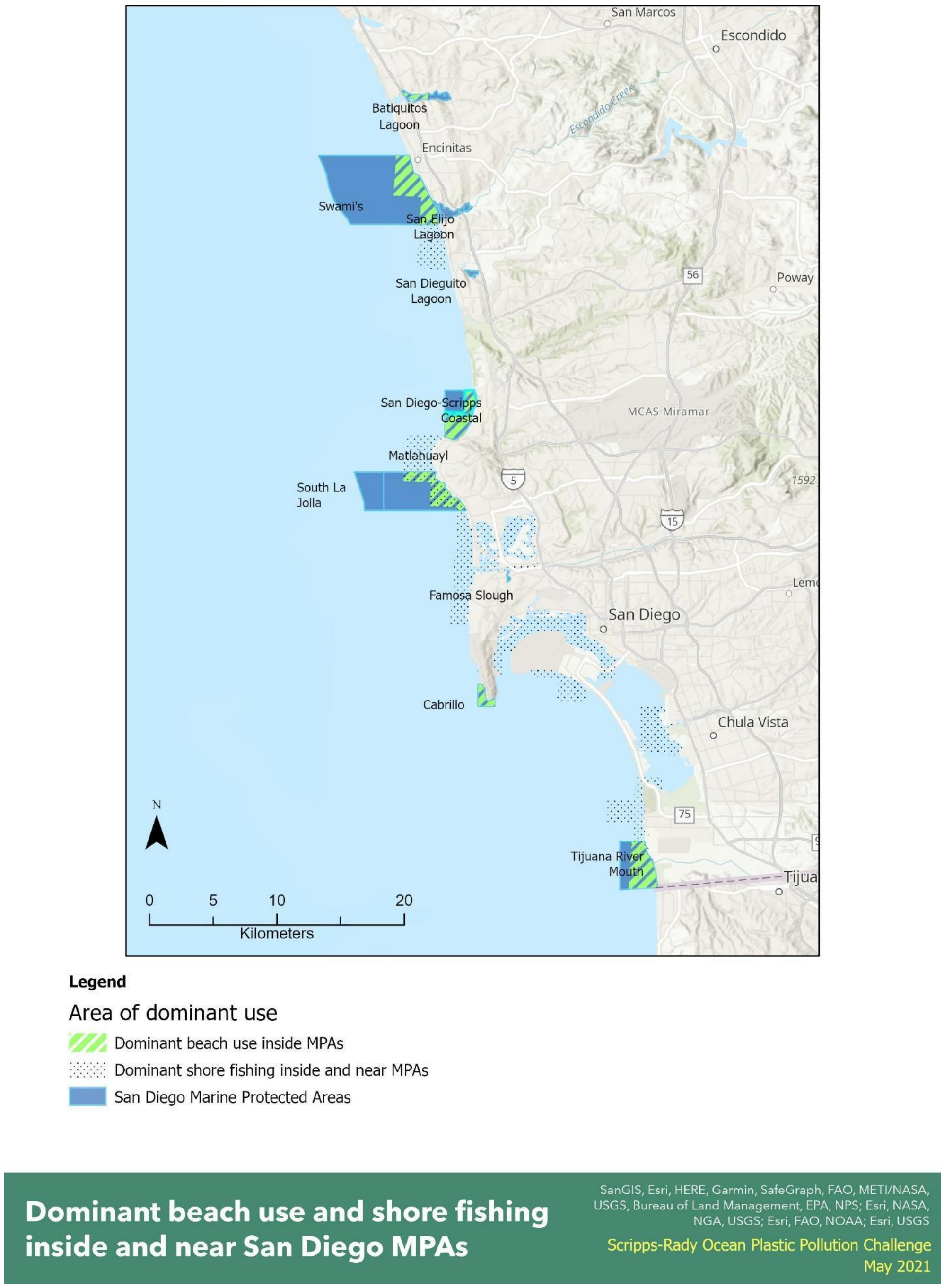
MPAs are favorable areas for recreational activities leading to a large human footprint in the San Diego region (Ver Steeg, 2019). Eight out of the eleven MPAs in this region were identified as being exposed to dominant beach use (Chen et al., 2015) which includes the following activities: walking, running, digging, resting, shell collecting, wildlife viewing, driving, camping, kite flying, bonfires, picnicking, dog walking (Ver Steeg, 2019). The Matlahuayl SMR experiences the most dominant beach use and Famosa Slough SMCA the least (Table 1).

Table 1. Dominant beach use in MPAs in San Diego County. NA = Not Available, percent values were rounded.

MPA name	**Percent (%) of MPA area exposed to dominant beach use**
Matlahuayl	50
Cabrillo	50
Tijuana River Mouth	40
Batiquitos Lagoon	29
San Diego-Scripps Coastal	29
South La Jolla SMR	25
Swami's	17
Famosa Slough	<1
San Dieguito Lagoon	NA
San Elijo Lagoon	NA
South La Jolla SMCA	NA

Also, fishing is known to be a source of plastic pollution and contributes to the pollution with abandoned or lost fishing gear. Dominant beach use and dominant shore fishing activities in and near to the San Diego MPAs are displayed in Figure 8. The MPAs Matlahuayl, Tijuana River Mouth, Swami's and the San Elijo lagoon are mostly exposed to shore fishing activities, as well as larger parts around Famosa Slough and parts of the San Diego Bight.

Figure 8. Dominant beach use and shore fishing in spatial relation to San Diego MPAs.



V. RIVERINE PLASTIC INPUTS TO SAN DIEGO MPAs

Estimates of riverine input of plastics (RiverinePlastic data set) to oceans have been modeled by Lebreton et al. (2017a). Low, midpoint and high estimates of plastic in tonnes per year and per month are available for river outfall locations of 40,760 rivers worldwide, with datasets from 2017 to 2020. Calculations are based on a global model using data of waste management (mismanaged plastic waste in a certain area in kg/year), hydrology (precipitation runoff in mm/day) and population density. The maximal plastic input by rivers at the coast of Southern California is estimated to be between July and September (Lebreton et al., 2017). Due to the climate and seasonality of rain, the midpoint mass estimates are not representative of actual plastic flow at any one time but are useful for representing annual averages of riverine plastic waste into the ocean. New data just made available by The Ocean Cleanup (theoceancleanup.com) shows midpoint mass estimates of riverine plastic waste influx in the San Diego region range from 100 kg/year and 300 kg/year for the smaller creeks (Buena Vista and Agua Hediondo, respectively) to 5,500 kg/year and 73,600 kg/year for San Diego and Tijuana Rivers, respectively. These modeled estimates are considerably larger than previous estimates calculated by Lebreton et al., (2017). Meijer et al., (2021) used additional variables, including land use, precipitation, and a probabilistic approach to calculate their estimates of plastic waste entering rivers. As more information about pathways and more data is collected, better models can be made and tested to estimate plastic influxes and to help guide intervention strategies.

Figure 9. Location of riverine inputs of plastic in the San Diego region. RiverinePlastic data set (Lebreton et al., 2017a).

A. Coastal Geomorphology and Implications for Plastic Pollution

As documented by Harris et al. (2021), the geomorphology of the coast at a given location has an impact on the efficiency of plastic trapping and the mass of plastic received (Figure 10). River-dominated coastal areas are susceptible to the greatest percent of global plastic pollution (52%) but do not trap as much plastic along the coast because of the moderate wave/tide energy regime. The other three coastal geomorphology types (rocky-, wave-, and tide-dominated), are exposed to a total of 48% of global estimated plastic pollution brought in by the rivers that flow to these coast types (Harris et al., 2021). Because these areas have mostly low wave/tide energy environments, they have more sediment and plastic deposition. The San Diego coast around the areas of the MPAs has mostly rocky and wave-dominated estuaries, deltas and lagoons (Table 2, see also Figure 11).

Table 2. Geomorphology of the coastal regions of the MPAs, characterized according to Harris et al. (2021).

MPA ID	MPA Name	Geological characteristics (identified after Harris, et al., 2021)
1	Batiquitos Lagoon SMCA	Lagoon, wave impact is minimal, strongly tidally influenced
2	Swami's SMCA	Rocky (along northern portion), southern portion is influenced by San Elijo Lagoon
3	San Elijo Lagoon SMCA	Lagoon, wave impact is minimal, strongly tidally influenced
4	San Dieguito Lagoon SMCA	Lagoon, wave impact is minimal, strongly tidally influenced
5	San Diego-Scripps Coastal SMCA	Rocky, wave impact dominants
6	Matlahuayl SMR	Rocky, wave impact dominants
7	South La Jolla SMR	Rocky, wave impact dominants
8	South La Jolla SMCA	Offshore of the South La Jolla SMR, so geomorphology doesn't apply
9	Famosa Slough SMCA	Tidal Marsh, near mouth of San Diego River
10	Cabrillo SMR	Rocky, wave impact dominants but is also at entrance of San Diego Bay
11	Tijuana River Mouth SMCA	Wave dominated delta, distribution of sediments is mostly by dispersal north via currents

For wave-dominated coasts, the research from Harris et al. (2021) implies that these areas would efficiently trap plastic coming from local rivers along the coast, especially in estuaries and lagoons, which are low wave/tide energy environments (Figure 10). Even though wave-dominated areas account for only 12% and rocky shores for 6% of the estimated global river-borne plastic burden, the low wave/tide energy and salt marsh habitats conspire to trap more of the plastic coming from rivers on the coast (Harris et al. 2021). Local studies confirm this global finding. In a study of San Diego Bay carried out in Fall 2014 to Spring 2015 (San Diego Bay Debris Study, 2016), plastic debris was present in about 88% of the intertidal zones. At least one piece of plastic debris was found in mudflats and saltmarsh habitats in each survey. They concluded that mudflats and saltmarsh habitats are significant reservoirs for plastic debris in the San Diego Bay.

Figure 10. From Harris et al. (2021). A global study of coastal areas and river discharge of plastic. Percentages refer to rivers worldwide and the global coastline. Note that plastic trapping efficiency is higher for the coastal geomorphic types that exist in the San Diego area (rocky, wave and tide-dominated; see also Table 4).

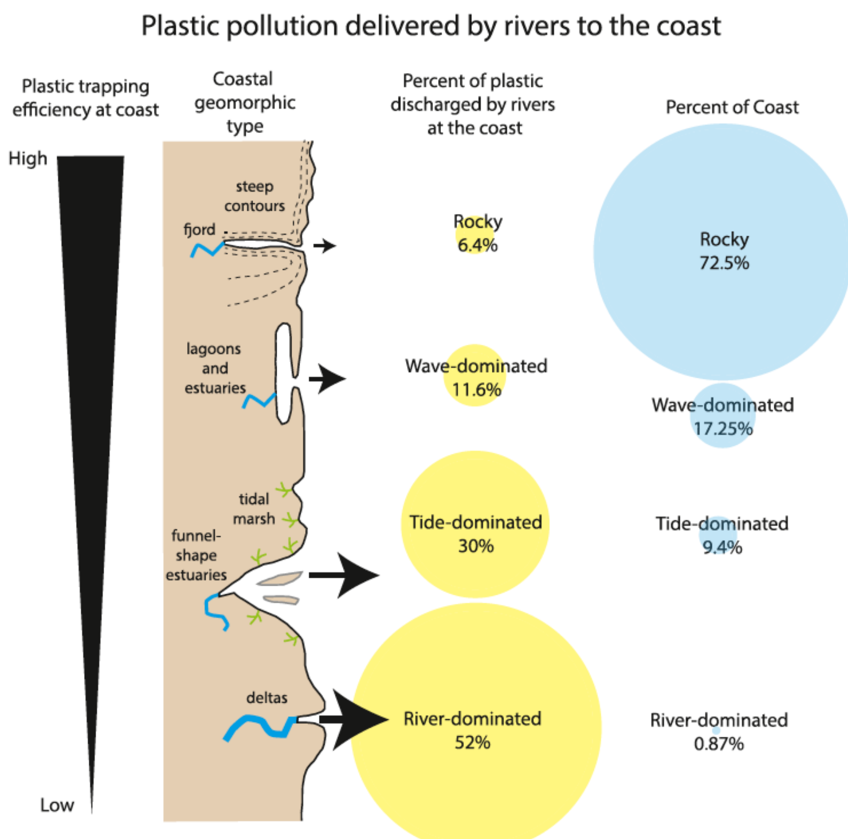
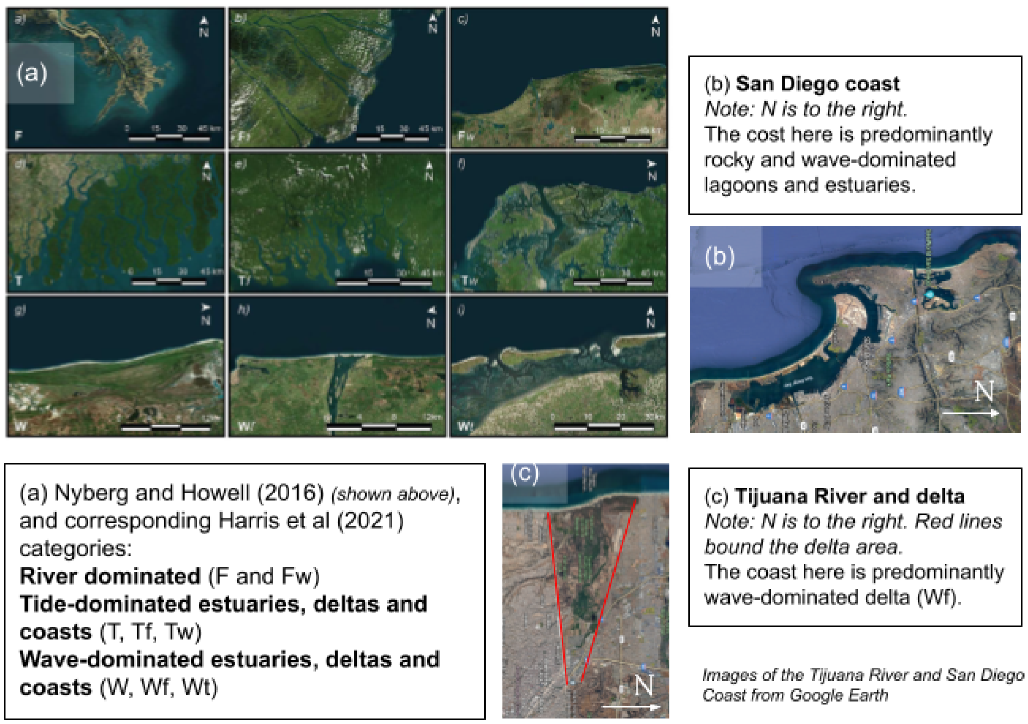


Figure 11. Coastal geomorphology in the San Diego area. Aerial images of the Tijuana River and central San Diego coast in comparison to Nyberg and Howell (2016) coastal geomorphology classifications.



This analysis of the MarineDebris dataset shows high numbers of clean-ups and significant trash accumulation in the Mission Bay area and within the Matlahuayl SMR and San Diego-Scripps Coastal SMCA (Figure 12, Figure 13). Mission Bay is an estuary at the mouth of the San Diego River, and trash tends to be prevalent near Mission Bay, in and around the mouth of the river, suggesting a possible connection between trash coming in from the river and being deposited along the proximal coast. The coastal geomorphology around both the San Diego-Scripps Coastal SMCA and the Matlahuayl SMR is rocky and wave-dominated. Matlahuayl SMR shows a cluster of clean-up sites and accumulated trash, though considerably less than in Mission Bay, possibly because of the lack of a large river discharging in that area. As mentioned previously, though, Matlahuayl SMR is one of the MPAs that experiences the most dominant beach use (Table 4). This analysis supports the coastal geomorphic findings by Harris et al. (2021), although interpretations using the MarineDebris data set should be made carefully due to data limitations (see section VII A).

Figure 12. Map of potential plastic waste hotspots in the Mission Bay Estuary. Data of collected trash using the Marine Debris cleanup dataset displayed as pale green circles. Circle size

increases with increased amounts of trash. Amounts were derived by dividing the amount of plastic over the number of clean-up attempts.

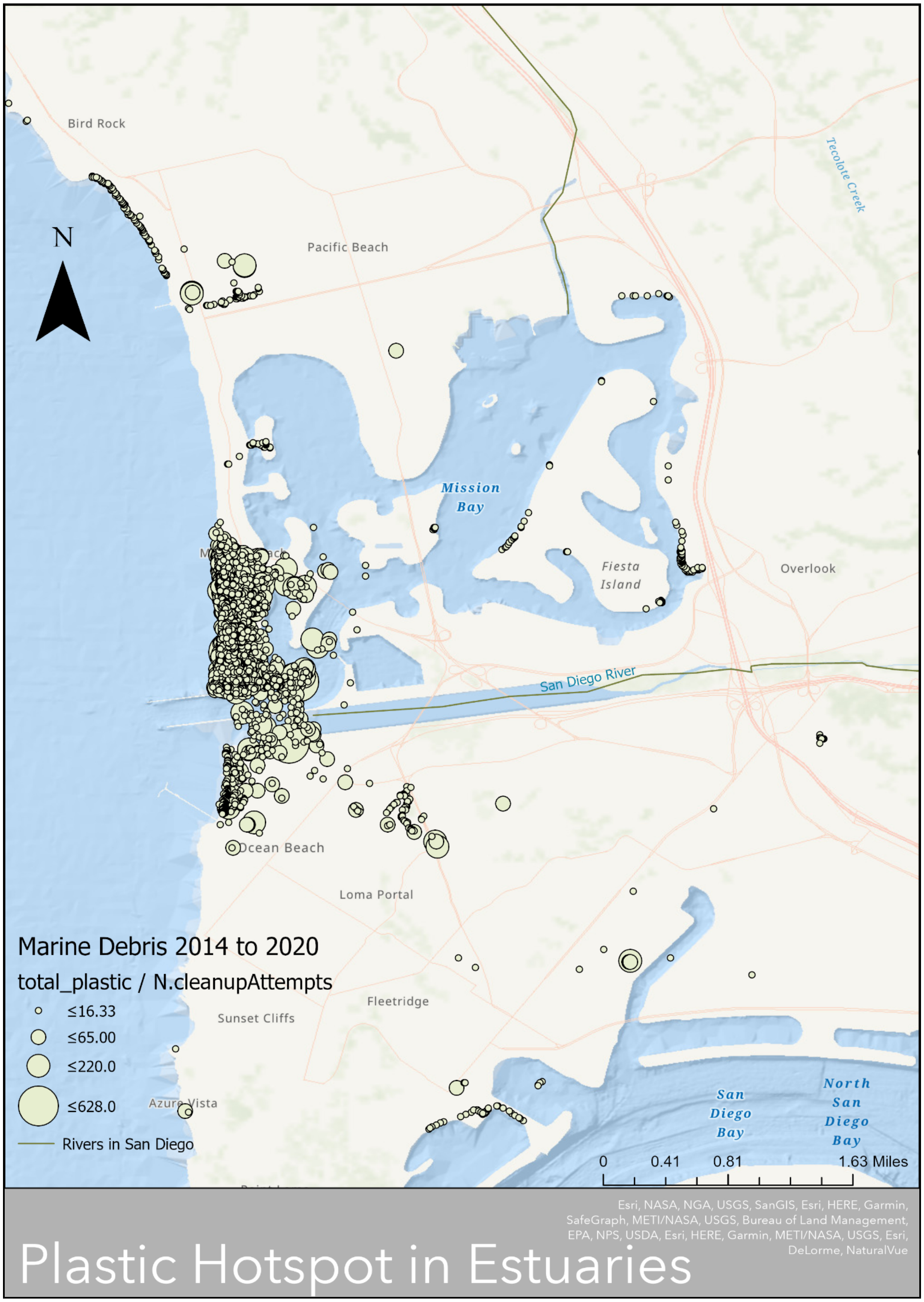
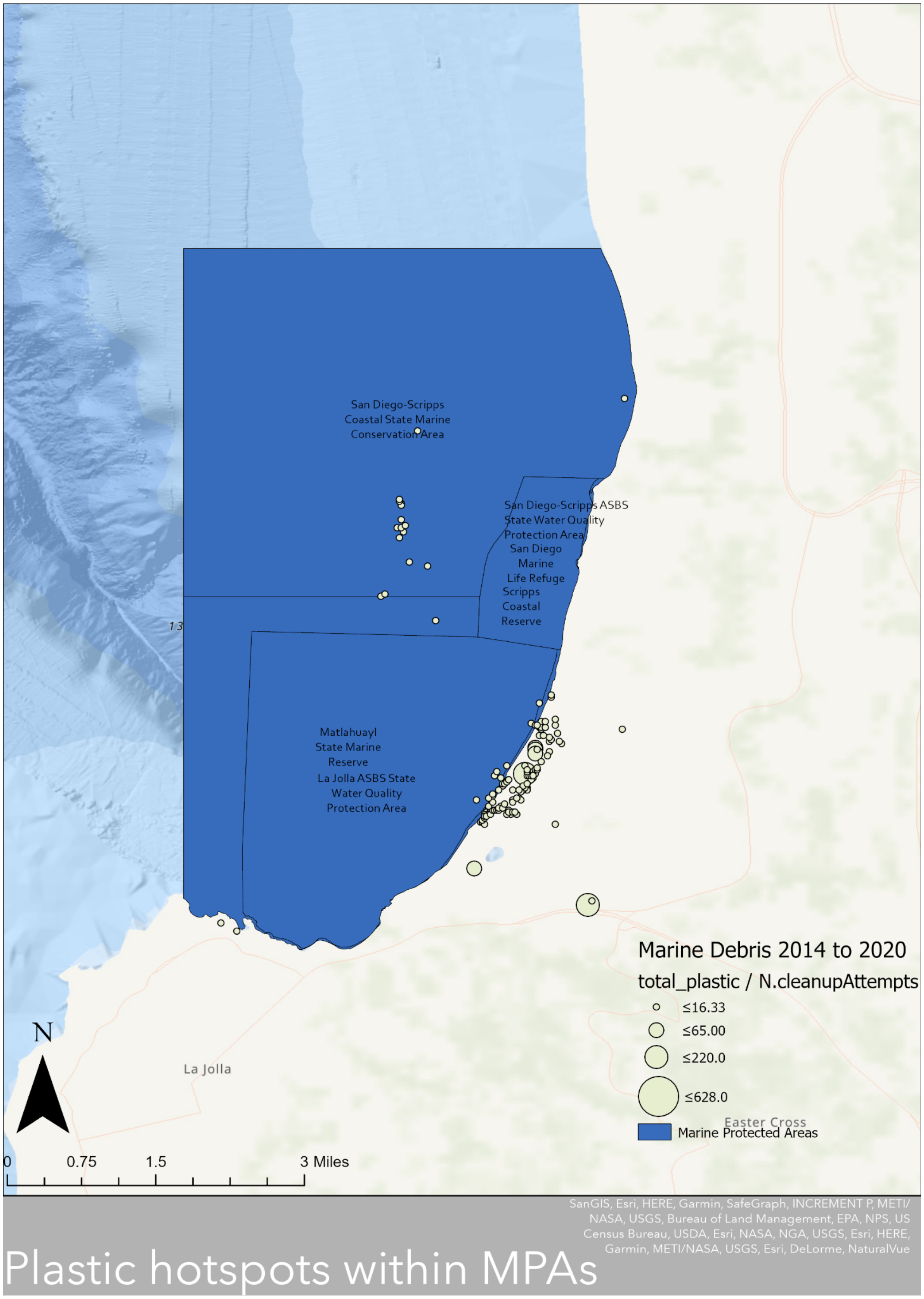


Figure 13. Clustering of MarineDebris data is also prevalent within the Matlahuayl State Reserve (MPA) and Scripps - Conservation Area. Data from Marine Debris Cleanup dataset.



B. Plastic Capture and Potential Impacts on SAV

As discussed earlier, there are several rivers and streams in San Diego County discharging plastic to the coastal zone and the oceanic environment. Five streams directly influence several of the MPAs: San Marcos Creek flows through the Batiquitos Lagoon SMCA; Escondido Creek flows along the San Elijo Lagoon SMCA and into the Swami's SMCA; the San Dieguito River passes San Dieguito Lagoon; The San Diego River passes the Famosa Slough SMCA; and, the Tijuana River Mouth SMCA is influenced directly by the Tijuana River (see Figure 9 and Figure 14).

Coastal wetlands such as Batiquitos Lagoon are not only a conduit for the emission of plastic waste via river discharge into bays and oceans, but there is new documentation of their capacity to accumulate macro and microplastic waste (San Diego Bay Debris Study, 2016; Harris et al., 2017; Cozzolino et al., 2020). Coastal wetlands are ecologically-important ecosystems; they are spawning grounds and provide special habitats for a multitude of aquatic species (Willis et al., 2017). Here, submerged aquatic vegetation (SAV) plays a key role. Kelp forests, for example, are specialized ecosystems that are experiencing a decline in California due to climate change, disease, and other factors (Filbee-Dexter & Wernberg, 2018), and are considered to be a Habitat Area of Particular Concern (HAPC) for Pacific Coast groundfish (NOAA, 2020).

The potential impacts of plastic waste aggregation on these important ecosystems is a relatively new topic of inquiry. Vegetation and macroalgae zones have a high potential for plastic trapping (Figure 15), especially when influenced by direct riverine plastic discharge (Cozzolino et al., 2020).

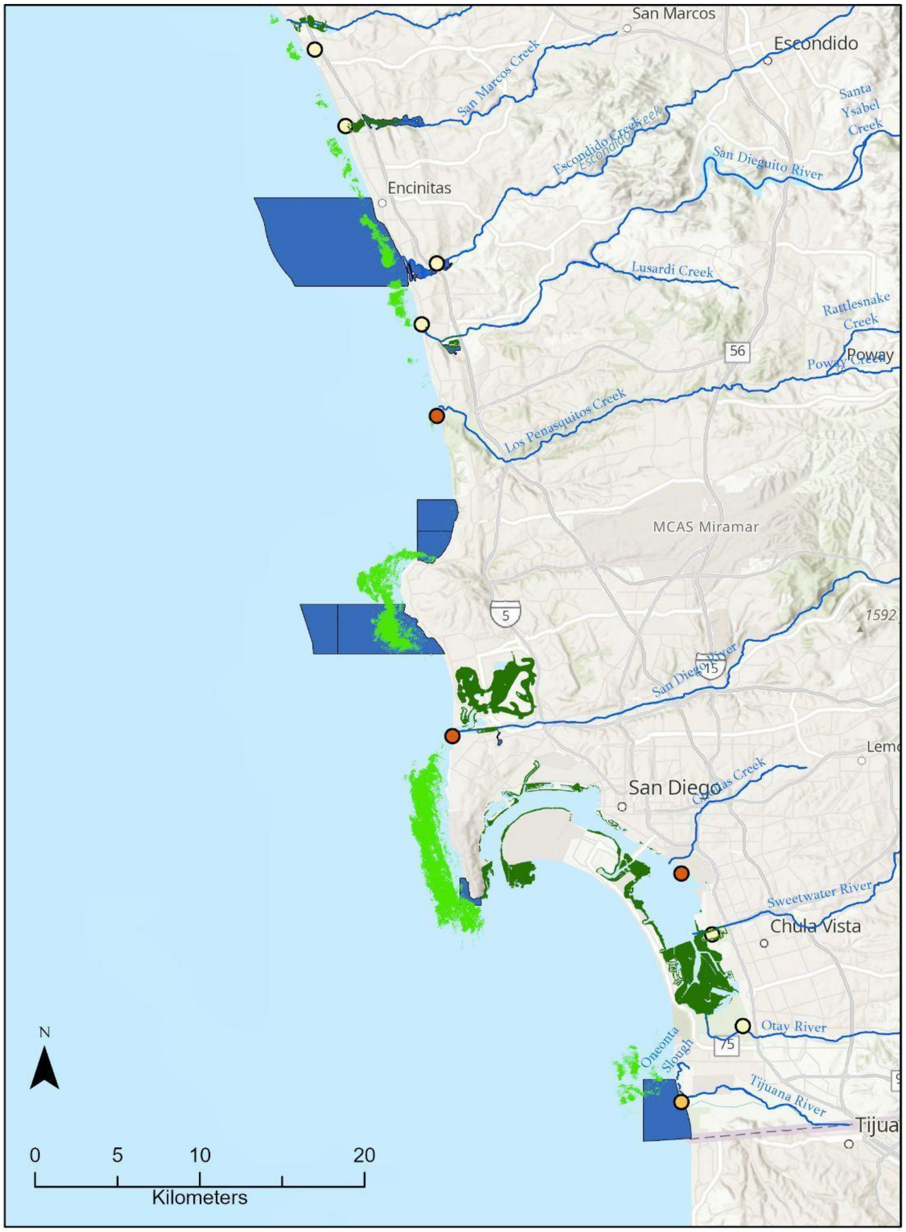
To assess potential hotspots of SAV in and near San Diego MPAs, eelgrass and kelp data were obtained and mapped in correlation to MPAs and the riverine midpoint mass input estimates from Lebreton et al. (2017). Rivers discharging at MPAs and into the ocean were identified by GIS Near analysis tools, assuming rivers and streams within 1km of the coastline are discharging into the ocean or bays. Visual inspection of the results was done to assure correct results. Rivers and streams with direct impact on MPAs were identified using the GIS spatial join tool with settings of identifying rivers and streams closer than 100 meters from MPAs. The distance of 100 meters was used to account for layer geospatial point reference variations.

It is estimated that the San Marcos Creek discharges 0.000515 MT of plastic per year into the ocean (Lebreton et al., 2017) influencing the Batiquitos Lagoon SMCA (Figure 14). There is an abundance of eelgrass in the Batiquitos Lagoon and the associated estuary and the near-shore marine zone toward the south supports stands of kelp. Large kelp vegetation is located along the coast inside of Swami's SMCA, as well. The smaller San Dieguito Lagoon is inhabited by eelgrass that potentially can trap the 0.0024 MT per year arriving via the San Dieguito river. The San Diego River transports annually about 0.0094 MT of plastic entering the ocean where a larger kelp forest zone is located south of the estuary stretching down to the Cabrillo MPA. Chollas Creek, Sweetwater River, and the Otay River flow into the San Diego Bight adding annually on average 0.0127 MT into the Bight waters, where eelgrass is abundant. The larger Tijuana River flows directly into the Tijuana River Mouth SMCA with an annual average flux of 0.0044 MT of plastic. Calculations from the more recent study by Meijer et al. (2021) estimate even greater amounts of plastic waste entering these waterways on an annual basis (midpoint mass): San Marcos (0.800 MT), San Dieguito (0.500 MT), San Diego (5.500 MT), Sweetwater (1.400 MT), Otay (0.900 MT).

The analysis shows that several SAV zones are inside and or near to MPAs, of which some are directly influenced by riverine plastic fluxes. The influence of oceanic conditions should be considered in future studies that investigate the actual trapping capacity in SAV zones and further transport of plastic from SAV zones in the open ocean. The San Diego Bight might be less exposed to oceanic currents, and plastic trapping could potentially be higher in this area. The plastic influxes to SAV zones and MPAs in the San Diego region represent a high potential impairment to the local ecosystems.

Moreover, in further studies the SAV map could be used as a basis to add information about anthropogenic activities and tourism close to the SAV zones, as shore use and sociodemographic aspects influence ocean plastic pollution (see also section VII).

Figure 14. Identification of potential plastic accumulation hotspots in and near MPAs related to submerged aquatic vegetation (SAV) and riverine plastic inflows. SAV, RiverStreams, MPA, RiverPlastic data sets.



Legend

Kelp vegetation
Eelgrass vegetation
San Diego MPAs

Riverine plastic inputs
Medium annual estimates (MT)
0,000000 - 0,001271
0,001272 - 0,004389
0,004390 - 0,010867
Rivers and streams

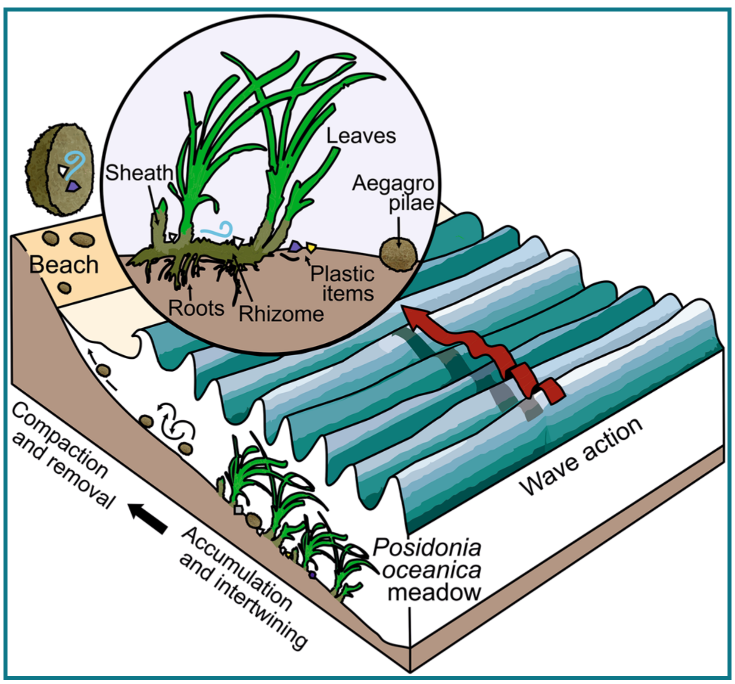
Submerged aquatic vegetation (SAV) as a potential plastic hotspot in San Diego MPAs

SanGIS, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS; Esri, NASA, NGA, USGS; Esri, FAO, NOAA; Esri, USGS

Scripps-Rady Ocean Plastic Pollution Challenge
May 2021

Cozzolino et al. (2020) found that plastic is trapped mostly in intertidal salt marshes (83%), subtidal macroalgae habitats (50%) and subtidal seagrasses (33%). In over 58% of intertidal and in over 41% of subtidal vegetated zones, macroplastic was present and most commonly plastic fragments and films between 0.5-30 cm were found, similar to findings by Sanchez-Vidal et al. (2021). PET, PE and PP are the most abundant plastic polymers found in vegetated areas, and the more negatively buoyant forms are prone to settlement (Sanchez-Vidal et al., 2021). Also, microplastics (items <5cm) are present in the canopy structure and in the sediment of intertidal and subtidal vegetated zones.

Figure 15. From Sanchez-Vidal et al. (2021). Original caption: "Trapping of plastic debris by seagrasses. Representation of the processes involved in the accumulation and intertwining of plastic items and sheath fibers to form plastic-rich aegagropilae (EG) found stranded in beaches."



Plastic pollution significantly slowed nitrogen liberation from the detritus of both of these macrophytes (Litchfield et al., 2020). These findings have implications for secondary productivity, carbon cycling, and nutrient dynamics for the regional marine ecosystem (Litchfield et al., 2020).

The results of the referenced studies have implications for the San Diego area, as SAV habitats are common to the region, and there are regional efforts to restore and expand these ecosystems for the purpose of offsetting ocean acidification and habitat restoration (Nielsen et al., 2018). It is possible that the accumulation of plastic waste in San Diego eelgrass meadows and kelp forests could be exploited to enhance future trash removal efforts in the region. Aggregations could foster the ability for aquatic removal, as eelgrass and kelp forest ecosystems become focal habitats for investment of time and money toward plastic waste clean-up efforts.

VI. CLEANUP DATA AND SOCIO-DEMOGRAPHIC INFLUENCES

A. Plastic Waste Cleanup Data

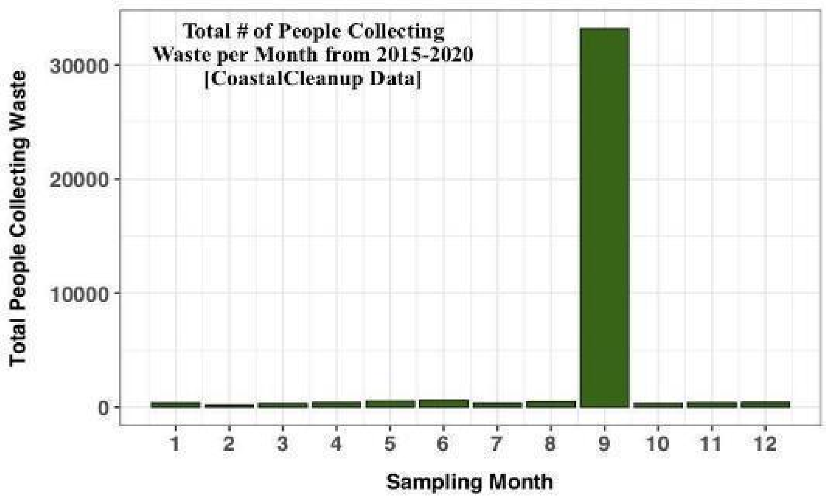
Some data on plastic waste is available through citizen science data portals which gather data from cleanup activities. These data portals are supported by individuals, NGOs and environmental organizations, and/or local government agencies. Frequently, these beach cleanups and awareness campaigns do not follow a sound scientific design but can still provide useful information and data. One benefit of these data portals is that the data are open-source, readily available and span broad temporal and spatial scales. These data portals typically collect data via the use of public apps, such as the two portals of focus on in this study: (1) the Marine Debris Tracker App (Jambeck and Johnsen, 2015) and (2) the Clean Swell App (Coastal Cleanup Data via the Ocean Conservancy). These data sets each provide the date and GPS coordinate location of each clean-up activity and quantify and characterize the litter collected.

Several notable differences exist between the two data portals. The Coastal Cleanup data portal receives the majority of data entries from larger organizations that participate in the "International Coastal Cleanup Day" (the third week of September each year) and only more recently has started to encourage individual clean-ups year-round through their Clean Swell App. In contrast, the MarineDebris portal tends to be primarily citizen-based (Jambeck & Johnsen, 2015) and, thus, comprises data entries from individuals and smaller clean-up organizations that collect waste throughout the year. The CoastalCleanup portal includes details on the total distance surveyed and the number of people involved in the clean-up activity for each data entry at each location and date (Ocean Conservancy), whereas the MarineDebris portal does not. Whether or not data are collected and entered depends on the awareness and resources of the organization and volunteer participants. Biases can occur, including: accessibility (e.g., areas that are not accessible may not be targeted), desirability (pristine vs heavy littered areas), and weather (e.g., clean-ups are less likely to occur during very hot, cold or rainy days). Thus, downstream data standardization is necessary to use the data in a practical manner (Nelms et al, 2017).

To process, standardize and visualize the data prior to mapping, this study used R version 4.0.2 (R Core Team, 2019), and the R packages: dplyr vs. 1.0.4 (Wickham et al., 2021), plyr vs. 1.86 (Wickham, 2011), tidyverse vs. 1.3.0 (Wickham et al, 2019), reshape2 vs. 1.4.4 (Wickham et al., 2007) and ggplot2 vs. 3.3.3 (Wickham et al., 2016). For both the 'MarineDebris' and 'CoastalCleanup' datasets, annual data was downloaded from the data portals based on this study's region and time frame of interest. For the MarineDebris datafile, this study was able to download a plastic waste dataset (not including paper, cloth, glass or metal debris) ranging from 2014-20, and for the CoastalCleanup datafile, this study downloaded each yearly-data file from 2015-20 separately, and subsequently cleaned and joined the CoastalCleanup annual data files together using the 'plyr' package (Wickham, 2011) in R.

The data cleaning process entailed standardizing the column names for each annual datafile (to ensure the same punctuation and syntax). Subsets of each of the data sets were separately created to solely contain the San Diego County region, and then created new columns that tallied the total amount of plastic waste, the total amount of takeout-related waste, the total amount of tobacco-products (and other smoke related waste), and the total amount of fishing-related debris. For standardization of plastic waste in the CoastalCleanup dataset, this study followed a modified version of the technique published by Nelms et al. in 2017, whereby: [$A = C/(V*(L+1))$], where C = total count (number of items of interest), L = survey linear distance (m), V = number of volunteers (people), and A = the unit of the adjusted count: *items collected per meter per person.* As the distance metric in the CoastalCleanup data was originally in kilometers, it was converted to meters and added 1 meter to the distance metric in this study's standardization technique noted above in order to fix any zero distance values that were entered originally. Prior to mapping and analyzing the data, this study further subsetted the CoastalCleanup dataset to the month of September since that was when most of the data entries were uploaded into the data portal for International Cleanup Day (Figure 16). Once subsetted, the date range of this dataset was from 2016-2020. Figure 17 displays the variation of the CoastalCleanup data over the years standardized by effort.

Figure 16. The total number of people collecting waste per month from 2015-2020 was the highest in the month of September due to the International Coastal Cleanup Day.



To deal with the debris counts in the MarineDebris dataset (this study did not have data on the number of volunteers, or the survey linear distance), this study standardized the debris count based on: **[A =C/(N)],** where **N = the number of clean-up activities for the time period and location of interest**. One clean-up attempt was based on one entry into the app by a person or group, and may have included more than one person helping to collect the debris (that information was not provided from the data portal). The number of clean-up attempts in the MarineDebris data frame varied from 2014-2020 (Figure 18). For all analyses and mapping, this study used the standardized count values (adjusted count values).

Figure 17. Total plastic debris (mean ± SE) standardized by effort varied across years in the CoastalCleanup dataset.

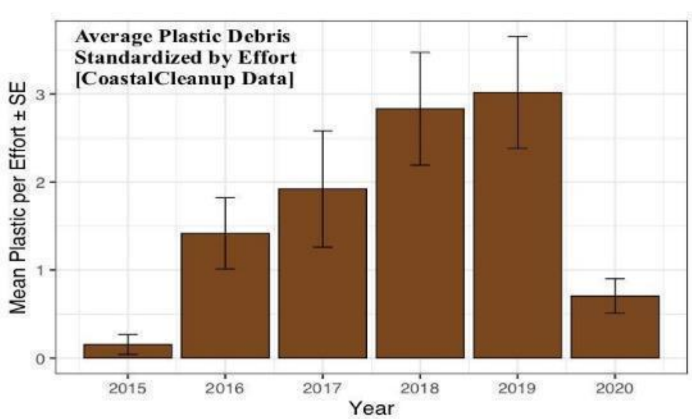
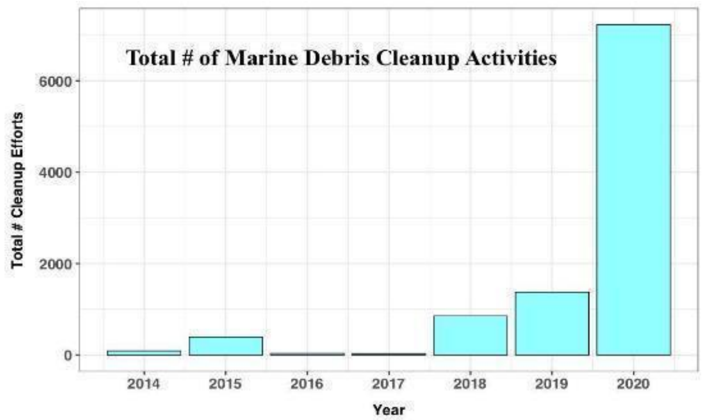


Figure 18. The total number of marine debris clean-up activities (effort) varied across years from 2014-2020 for the MarineDebris dataset.



Plotting the MarineDebris and CoastalCleanup data (Figure 19 and Figure 20) this study sees coincident "hot spots" in the Mission Bay area (also discussed in section VI A). There are also different "hot spots" in other coastal areas, rivers and creeks. MarineDebris (Figure 19) shows a cluster of points along the Poway Creek in Mira Mesa, and CoastalCleanup (Figure 20) has a cluster of points along Forester Creek (a major tributary of the San Diego River) in El Cajon, and another cluster near the Sweetwater River in Chula Vista. The San Diego River Park Foundation has a project in the Forester Creek area to create more and better recreation space for the surrounding community and perhaps this has drawn the attention of clean-up groups (https://www.sandiegoriver.org/forester_creek.html). Both maps as shown here are helpful for looking at larger regional trends and for comparing datasets.

Figure 19. The total amount of plastic (standardized by the number of clean-up activities) from 2014-2020 via the MarineDebris dataset in San Diego County.

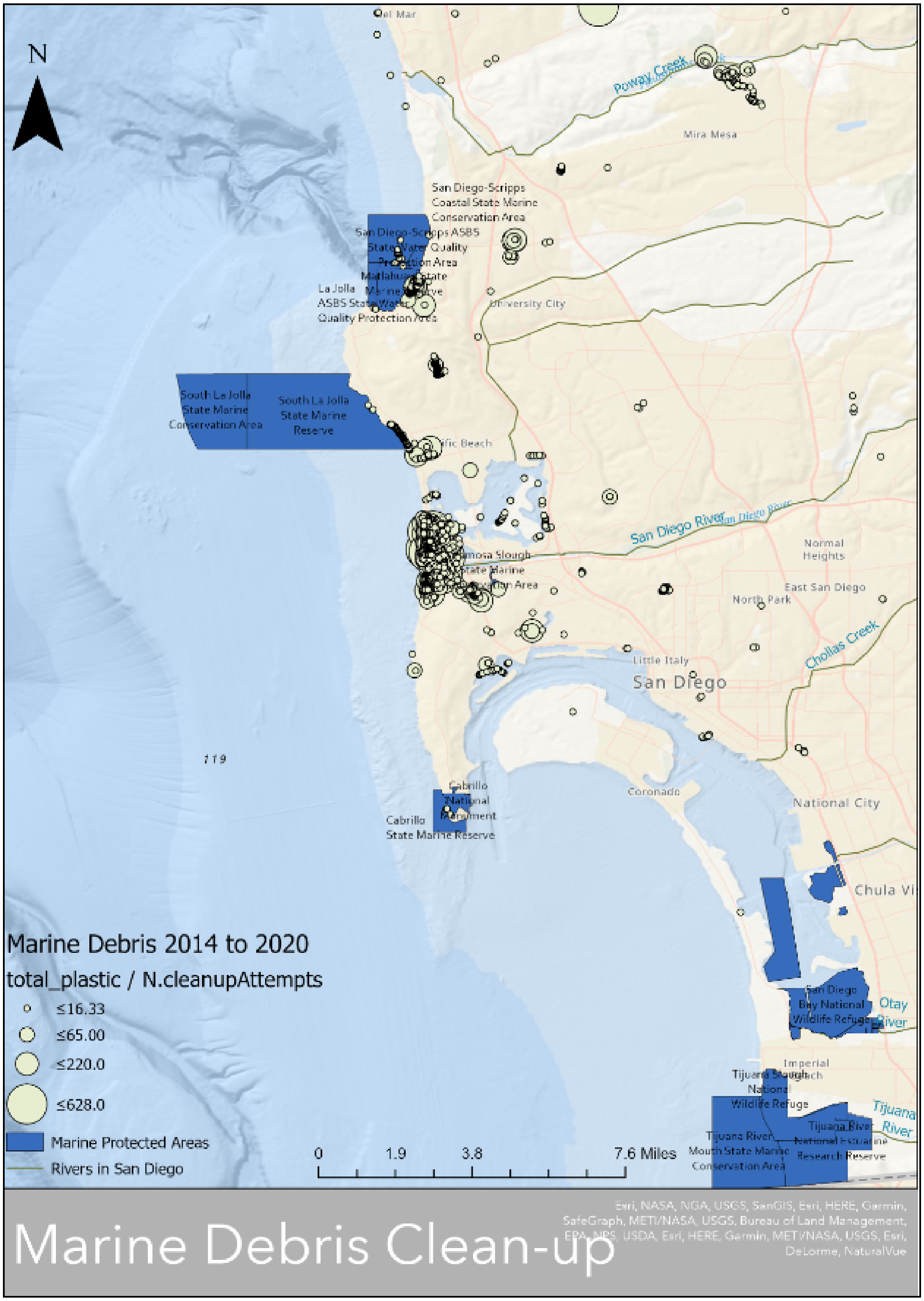
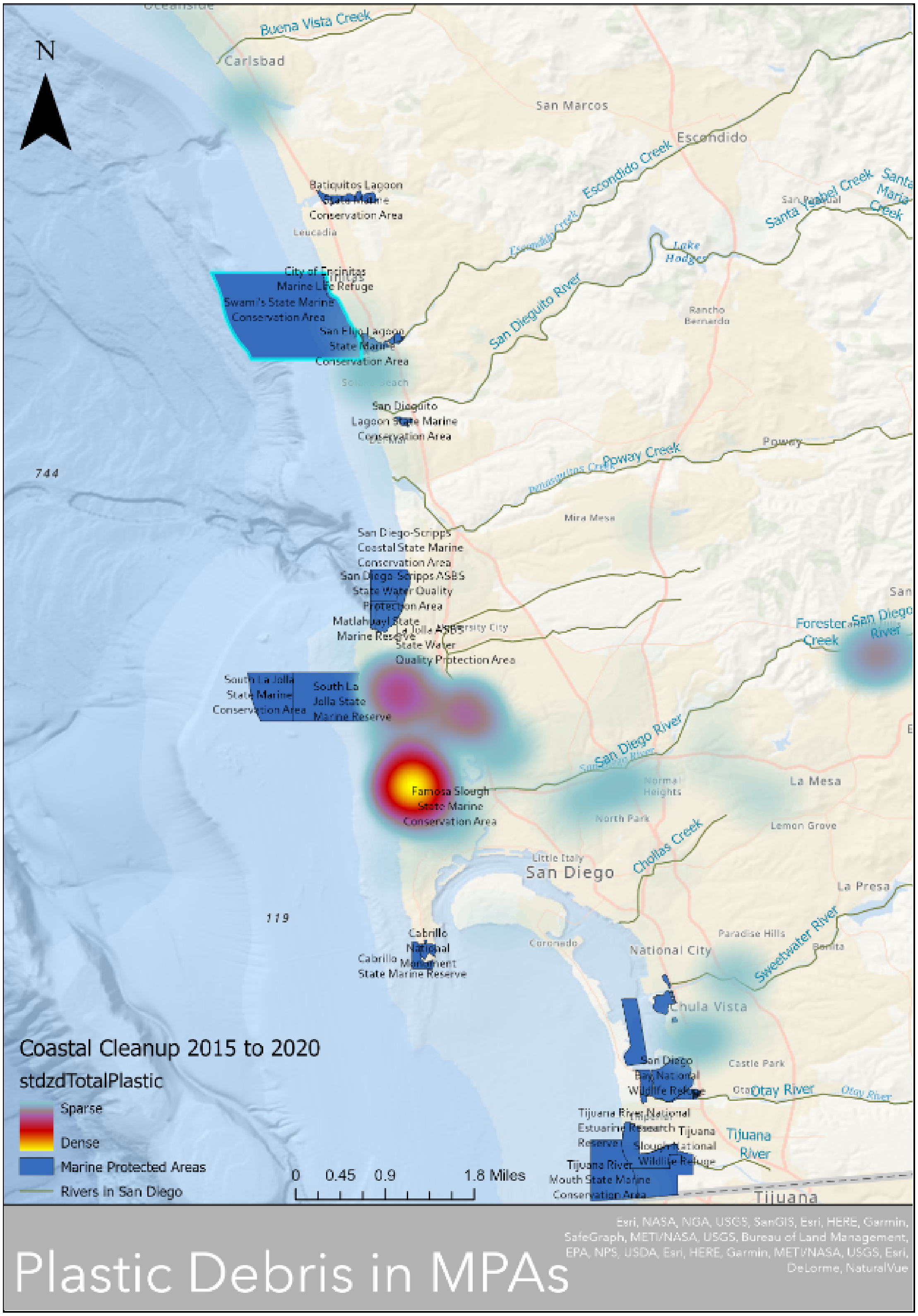


Figure 20. The total amount of plastic (standardized) from 2015 to 2020 via the Coastal Cleanup dataset from the Ocean Conservancy in San Diego County.

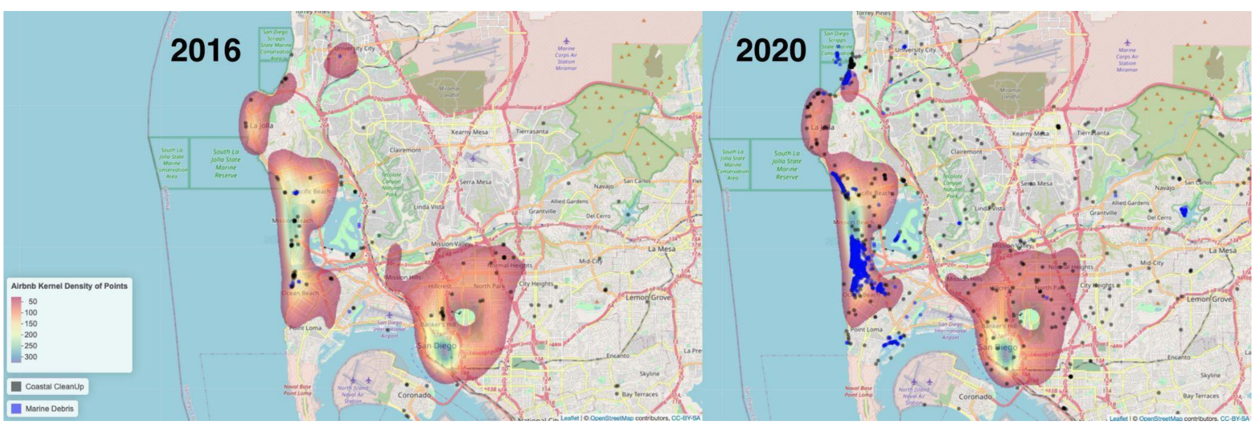


B. Socio-demographic Influences on Plastic Pollution

San Diego County has a significant population inhabiting coastal areas. Communities along the coastline, such as La Jolla, Pacific Beach, Mission Beach, Ocean Beach, and Point Loma are also popular tourist destinations. This study sought to investigate the effect of tourism on occurrences of plastic pollution. With the limited anthropogenic data available, this study used readily available datasets for Airbnb listings and special events as this study's benchmark for locations with high levels of tourism (Airbnbs) and sharp increases in population over short periods of time (special events). The Airbnb listing data contains one dataset of listings preceding 2017 and another dataset preceding 2021. The special event data encompasses the special events recorded in the city of San Diego Data Portal. In this section, the study focuses on the visible hot spots in this study's clean-up datasets, which occur near the San Diego-Scripps Coastal State Marine Conservation Area, Matlahuayl State Marine Reserve, South La Jolla State Marine Reserve, and South La Jolla State Marine Conservation Area.

Figure 21 shows density maps of Airbnb and special events data, produced with the R package leaflet (Graul, 2016), set to the recommended bandwidth size (0.0045, 0.0068) and grid size (100, 100) for Airbnb data, and (500, 500) for special event data (Open data, 2020; City of San Diego, 2021). The blue points plotted on the maps represent the clean-up data for that year of each dataset, MarineDebris and CoastalCleanup. The radius of each point is calculated by the standardized plastic collected and given a weightage of five.

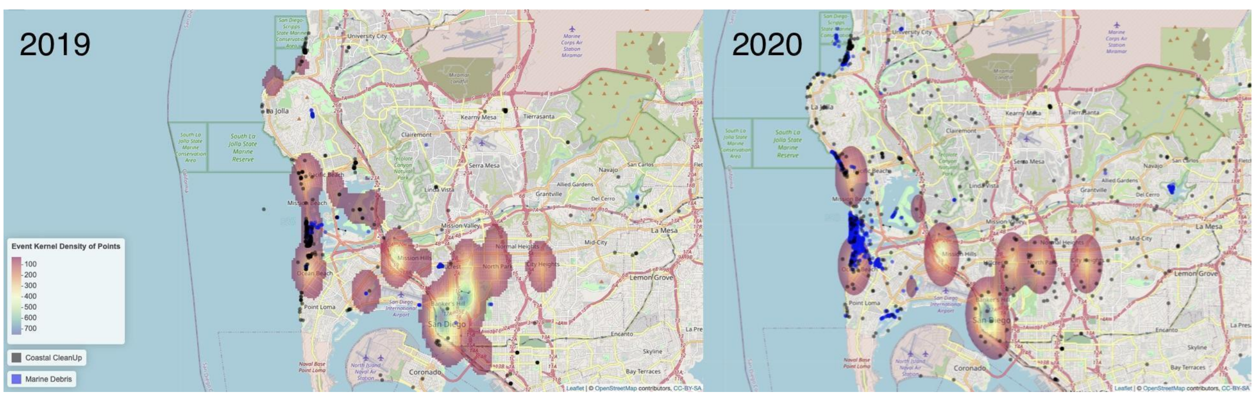
Figure 21. The amount of plastic waste (standardized) in relation to the kernel density of Airbnb listings in 2016 and 2020. Clean-up activity data was accessed via the Marine Debris Tracker and Coastal Cleanup data portals. Data sets: MarineDebis, CoastalCleanup, Airbnb.



From these maps, the sharp increase in intensity is apparent--the expanding yellow areas seen most prominently from Pacific Beach to Ocean Beach and Downtown San Diego-- for Airbnb listings in 2020 compared with 2016. There was roughly a 50% increase in Airbnbs over this period, from roughly 6,000 to 9,000 rental listings. In terms of the number of data points, it is difficult for us to determine whether the rapid increase in clean-up points, over both time periods, is a result of an increase in plastic pollution, an increase in clean-up attempts, or an effect of both.

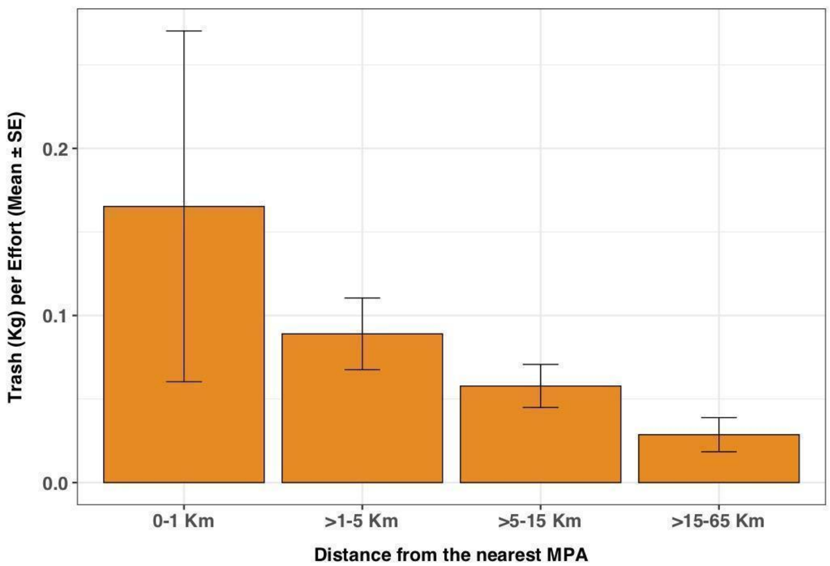
As a result of the COVID-19 pandemic, this study noticed a decrease in the intensity of special events, except for the outlier at the center of Downtown San Diego. However, there is a noticeably sharp increase in clean-up data points from 2019 to 2020 in both datasets (Figure 22). Clusters of increased clean-up activity are especially prominent in Mission Beach and areas near the MPAs: Scripps Beach, La Jolla Shores, Tourmaline, and North Pacific Beach.

Figure 22. The amount of plastic waste (standardized) in relation to the kernel density of events, based on permit applications, in 2019 and 2020. Cleanup activity data was accessed via the Marine Debris Tracker and Coastal Cleanup data portals. Data sets: MarineDebris, CoastalCleanup, SpecialEvents.



Additionally, this study analyzed the clean-up efforts and the amount of trash in relation to the distance of each clean-up site to the nearest MPA. As mentioned previously, MPAs are often used for recreation purposes and can draw crowds of locals and tourists (Table 4). This study sought to see if there was a trend in plastic trash collected relative to the location of the MPAs.

Figure 23. Trash (kg per person per m) found in relation to the distance from the nearest MPA in San Diego Co. California. The amount of standardized trash significantly varied across the binned distances from the nearest MPAs (GLMM (Poisson), $\chi 2$= 22327, *df* = 3, P < 0.001). Conversion: kg = 2.2 lbs.

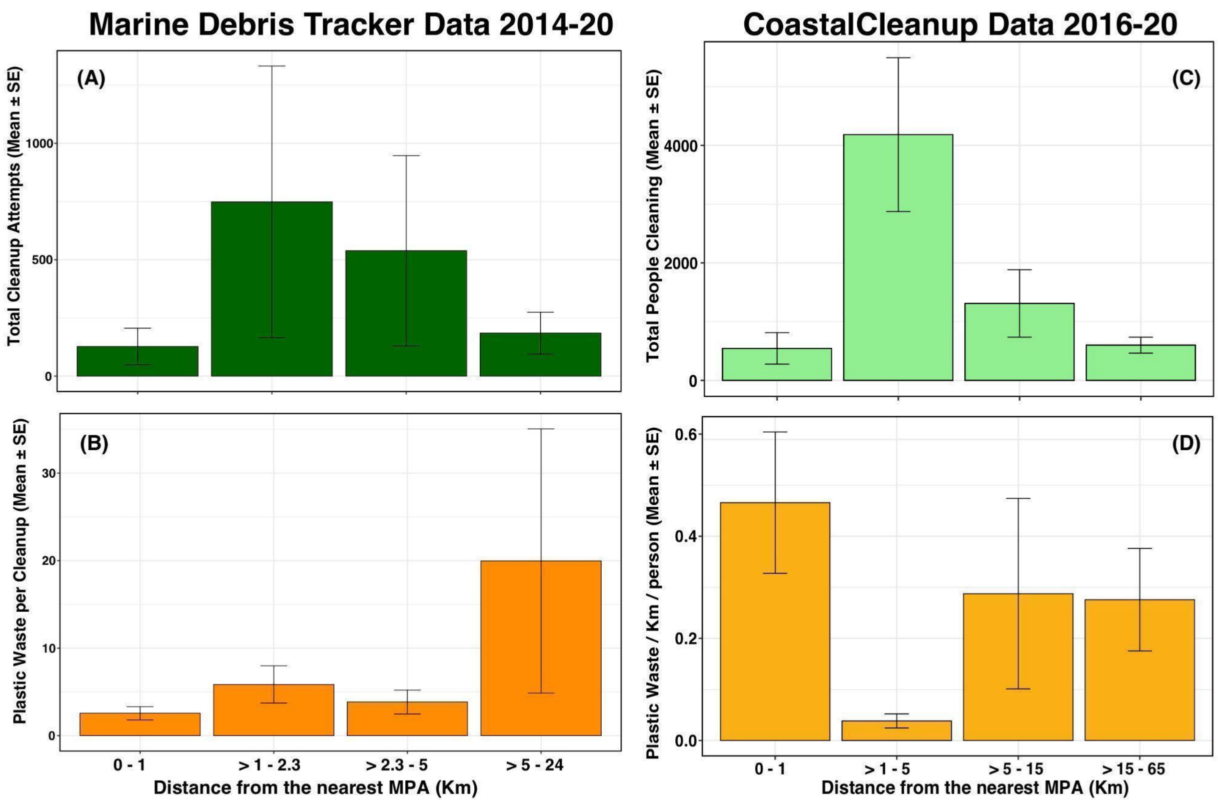


Proximity of each clean-up location to the closest MPA was calculated using the ArcGIS "Near" tool using the geodesic distance measurement. This means that the shortest distance of the clean-up point (using latitude and longitude) from a MPA border (using a polygon outline) was calculated, and the identifier for the respective MPA (e.g., name) was added to each line of clean-up data point in the original data frame, which then was exported to an excel file for statistical analysis and visualization in R (Figure 23 and Figure 24). The data was binned based on the distance to the nearest MPAs, with binned distances varying for the MarineDebris and CoastalCleanup datasets.

The number of clean-up activities (events from MarineDebris data) did not significantly differ in relation to the binned distances from the nearest MPAs (GLMM (Poisson), $\chi 2= 2.37$, $df = 3$, P = 0.50, Figure 24A). In contrast, using the CoastalCleanup data, the number of people actively cleaning up plastic waste at a given location did vary in relation to the binned distances from the nearest MPA (GLMM (Poisson), $\chi 2= 6002.4$, $df = 3$, $P < 0.001$, Figure 24C). Thus, it appears that while the amount of trash collected increases in proximity to the nearest MPA, the clean-up activities peak outside of a 1 km buffer from the MPA, and then decrease thereafter.

Figure 24. (A) Mean # clean-up activities (± SE) and **(B)** Mean standardized plastic waste (± SE) in relation to the distance (km) from the nearest MPA in San Diego County. **(A-B)** Based on MarineDebris data from 2014-20 (https://debristracker.org/). **(C)** Mean # people (± SE) collecting waste and **(D)** Mean standardized plastic waste (± SE) in relation to the distance from the nearest MPA. **(C-D)** are based on the waste collected and entered into the Coastal Cleanup database (https://www.coastalcleanupdata.org/) for the month of September from 2016-20. For

each figure, data were summed across all clean-up sites and then averaged across years. Conversion: 1 km = 0.62 miles



The San Diego region coastal areas are highly susceptible to accumulation of plastic waste due to their popularity among residents, attractiveness as a site for public events, and as tourist destinations. With the many takeout eateries along these beaches and inefficient waste management (as evidenced for example by overflowing trash cans), these coastal areas have become vulnerable to plastic waste. Plastics deposited in these areas pose a significant threat to the San Diego coastal environment (Moore et al., 2011, San Diego Bay Debris Study, 2016). When left on the beaches, buoyant plastic waste can wash into the ocean at high tide, and spread over long distances. As these plastic polymers are broken down by UV radiation in sunlight and breakdown into smaller particles; they increase in abundance in the ocean, are accessible to plankton and marine life (Vikas & Dwarakish, 2015), and can settle in sediments for centuries (Vikas, 383). The San Diego MPAs are also susceptible to in-situ plastic waste generated by tourists, and this study finds more trash and clean-up activities occurring closer to the MPAs than further away.

VII. GOVERNMENT INTERVENTIONS: PLASTIC BANS AND WASTE COLLECTION

Recognition that plastic pollution has a negative impact on the environment has been growing over the last two decades as the public has been made aware of the deleterious effects on sea life (Talley et al., 2020; Ryan et al., 2009; Pietrelli et al., 2017; Eriksen et al., 2014). Widely publicized photos of wildlife being impaired by mismanaged plastic material (Figure 25) have spurred the public to lobby governments to act to eliminate plastic items (PEW, 2020; Wagner, 2017).

Figure 25. Example of mismanaged waste. Photo: Maurice Roper, from a beach clean-up led by J. Hopper in 2020 at Playa Del Rey Beach, Los Angeles (USA).

In the United States, San Francisco was the first large city to act on this when the city council approved a ban on take-out plastic bags at grocery stores and pharmacies in 2007 (Wagner, 2017). In San Diego County, government interventions have included progressively stricter bans on plastic items starting with plastic bags and moving to plastic straws and food containers. Other efforts to reduce plastic input to the environment have included trash and stormwater trash capture efforts and river booms.

A. Plastic Bans

Bans of plastic items have been implemented in numerous cities in the San Diego region beginning in 2012 when the City of Solana Beach passed and implemented a ban on single-use plastic bags at retail establishments. Since then, a number of other cities in the San Diego Region have implemented similar bans. In addition, since the 2012 ban on single-use plastic bags, the City of Solana Beach and others in the region have implemented bans on other plastic items. Table 3 below provides a summary of each of the bans enacted by municipalities in San Diego County. Note, however, local plastic bag bans were superseded by the State of California ban originally passed as SB 270 and approved as Proposition 67 in November of 2016.

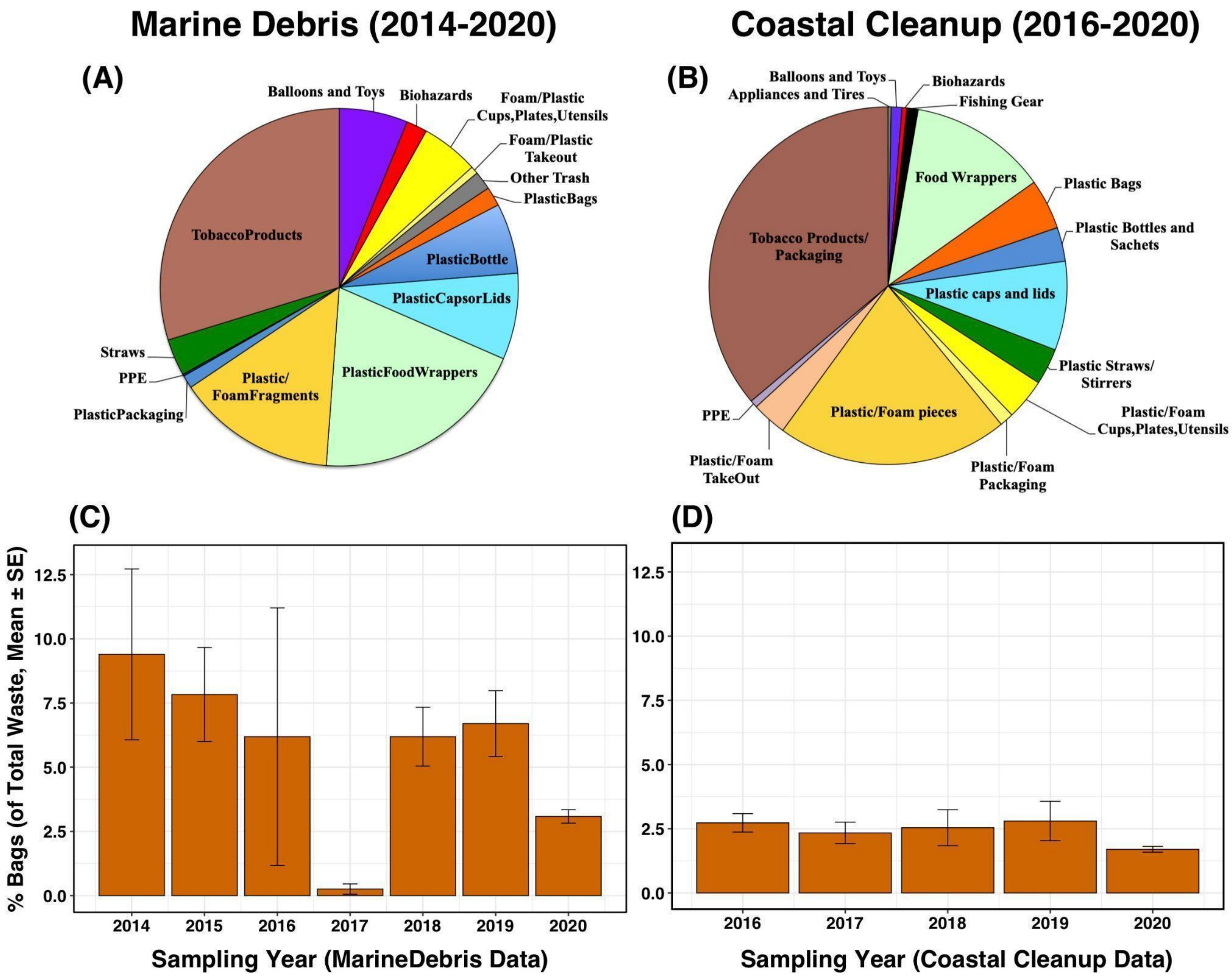
Table 3. Table of plastic bans. Cities are listed from north (left) to south (right), color corresponds to year of implementation, with lighter colors representing earlier bans, darker colors representing later bans. EPS = Expanded Polystyrene. * includes utensils, splash & cocktail sticks; ^ includes dock floats; ** Date reflects the state ban enacted in 2016.

Items banned or controlled by ordinances	**San Diego County Ocean-Front Cities**					
	Oceanside	Encinitas	Solana Beach	Del Mar	City of San Diego	Imperial Beach
Single-use plastic bags	2016	2014	2012	2016	2016	2016**
EPS disposable food service ware		2020	2015	2019	2019	2019
EPS egg cartons & food trays		2020	2020		2019	
EPS exposed coolers and containers		2020	2020		2019	2019
Polystyrene packing materials		2020	2015	2019		2019
EPS beach toys			2020^		2019^	2019
Plastic beverage bottles		2020				
Plastic straws			2020*	2019		
Non-biodegradable/ compostable/ recyclable Food service container						2019

According to the Ocean Conservancy, which hosts the International Coastal Cleanup Day, prior to 2016, 8-10% of items collected during the annual Coastal Cleanup Day in California were plastic or paper bags. Prior to the ban implementation, Californians used 703 plastic bags per person annually (Wagner, 2017). In 2017, after the adoption of approximately 150 local ordinances and final implementation of SB 270, only 3% of items collected were plastic or paper bags (Wagner, 2017). The County of Santa Clara Clean Water Program has been collecting data from regular creek clean-ups since 2007, and they have documented a reduction of single-use plastic grocery bags after local agencies enacted “bag ban” ordinances. In 2019, fewer than 30 single-use plastic grocery bags were collected in creek clean-ups, down from an average of over 2,100 single-use plastic grocery bags per year before the bans (County of Santa Clara, 2020). A report by the Southern California Coastal Water Research Project (SCCWRP) on conditions in the southern California Bight confirmed the efficacy of plastic bag bans in reducing plastic bag debris in adjoining areas (Moore et al., 2016). Specifically, they found that plastic bags and plastic bag pieces were found in significantly lower numbers in areas with bans than in areas without bans.

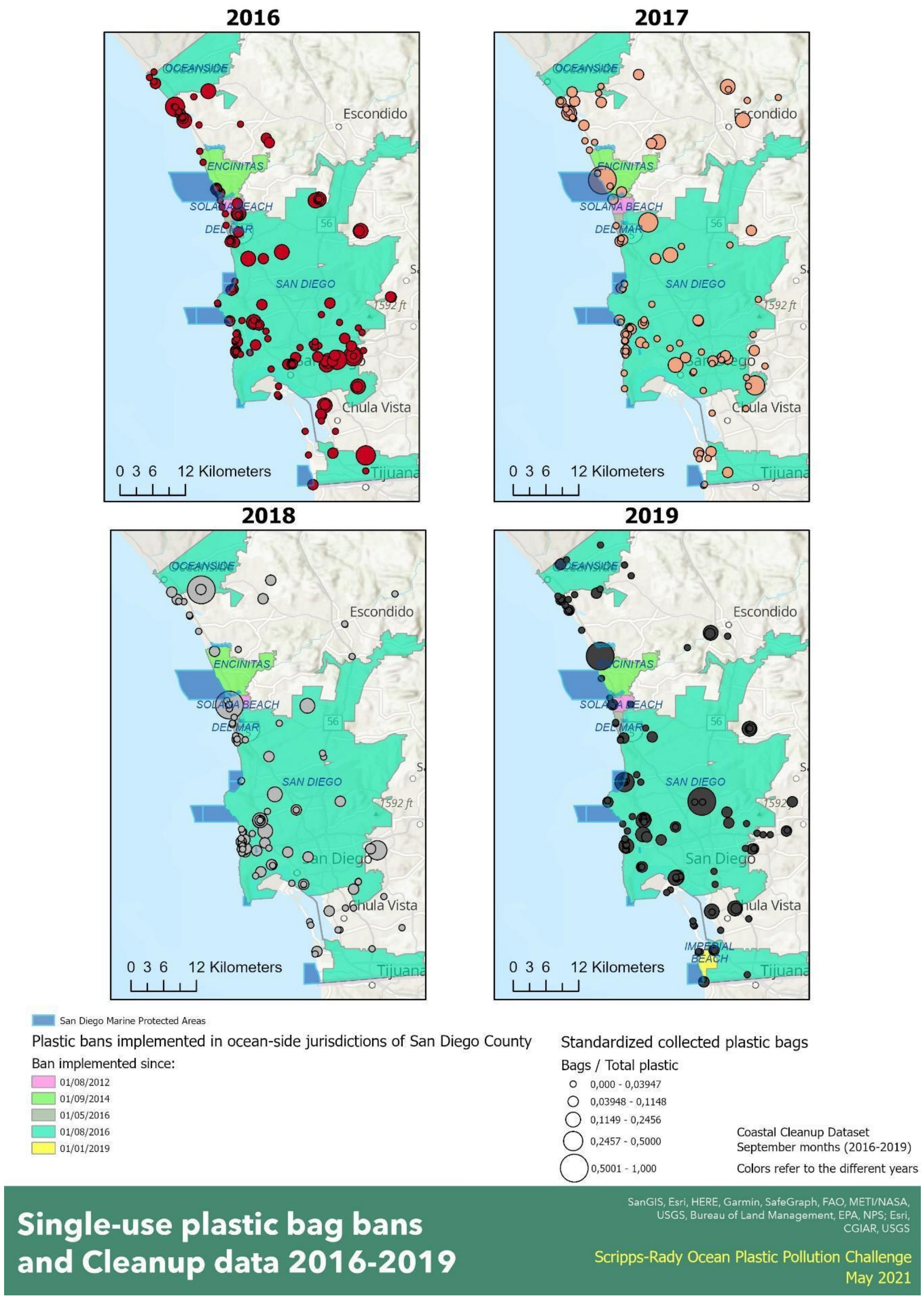
The types of plastic trash collected from clean-up activities are presented in Figure 26. The relative abundance of polystyrene (foam-based) materials and plastic bags has decreased through time, potentially related to state-wide and/or local bans on plastic bags and Styrofoam/EPS products (Table 5). Figure 26C shows a lower percent of plastic bags collected in 2020 compared to the percent of plastic bags in 2014, 2015, 2018 or 2019 for the MarineDebris data (ANOVA, TukeyHSD: $P < 0.05$). Figure 26D shows a lower percent of plastic bags collected in 2020 compared to that in 2016 to 2019 for the CoastalCleanup data (KruskalWallis: $P < 0.01$, TukeyHSD: $P < 0.05$).

Figure 26. A, B: Proportion of types of plastic waste found in the MarineDebris 2014-20 and CoastalCleanup 2016-20 data, San Diego Co. California, USA. **C, D:** Percent of waste that is plastic grocery bags (mean ± SE), by year.



To assess the implications of single-use plastic bag bans in the San Diego region on the plastic waste inside and near MPAs, this study mapped the jurisdictions that implemented plastic bag bans along a timeline, using the data of ban implementation and overlaid this with annual cumulated and standardized collected plastic bags found based on the September Coastal Cleanup data. The results are displayed per year from 2016-2019 (Figure 27). For example, while in 2016 and 2017 relatively more plastic bags were found along the area of Imperial Beach, where the Tijuana River Mouth MPA is located, fewer plastic bags were found the following year. This suggests that the implementation of single-use plastic bag bans, effective since 2016 in San Diego City and Imperial Beach, are potentially effective. Further analyses should be conducted to assess the effectiveness of local plastic bans, which will ultimately help citizens, policymakers and the economic sector to make decisions.

Figure 27. Single-use plastic bag bans and plastic bags collected from September Coastal Cleanup events from 2016-2019. Note that the amount of collected plastic bags are standardized by total collected plastic.



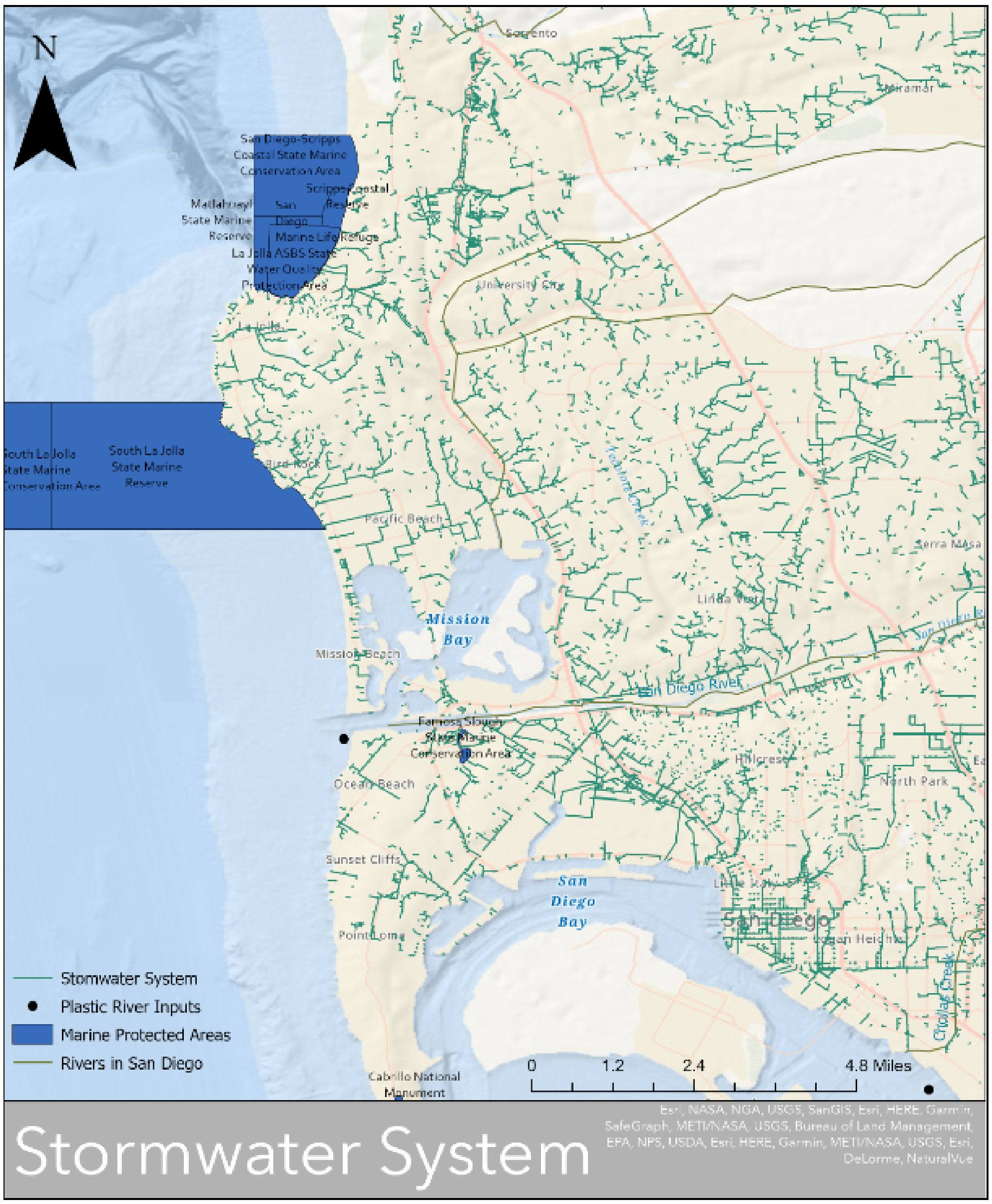
B. Stormwater Trash Collection

Stormwater pollution occurs when waste (e.g., plastic particles), chemicals, sediment or other pollutants are washed into storm drains and flow into water bodies including rivers, creeks, bays, and the Ocean. In the San Diego area stormwater runoff contributes to plastic pollution in and near San Diego MPAs (San Diego Coastkeeper, 2021).

Under Clean Water Act regulations, municipal separate storm sewer systems (MS4) are required to obtain coverage for their stormwater discharges under a National Pollutant Discharge Elimination Systems permit and to put measures in place to prevent discharges of pollutants in stormwater runoff (Figure 29). Municipalities in California are required to have trash capture devices on storm drains in areas of high impact. In the San Diego region, the Regional Water Quality Control Board (RWQCB) regulates discharges from Phase I municipal separate storm sewer systems (MS4s) under the Regional MS4 Permit. The Regional MS4 Permit covers 39 municipal, county government, and special district entities (referred to jointly as Copermittees) located in San Diego County, southern Orange County, and southwestern Riverside County, who own and operate large MS4s that discharge storm water runoff and non-storm water runoff to surface waters throughout the San Diego Region (Figure 28). However, these regulations only cover trash coming from storm drains; in-creek dumping, wind-blown trash or other mechanisms of pollution into local waterways are not regulated. Thus, interventions that target collecting waste directly from rivers and streams would still be beneficial.

In a recent study conducted by the Project Clean Water, a total of 35 kg (440 gallons) of trash was removed during the 12-month period monitored. In addition to quantifying the trash, the study's objective was to also monitor the performance of full capture systems including feasibility of maintenance and susceptibility to flooding in regards to maintenance efforts. A select number of full capture devices were installed throughout the County among priority land use areas such as: high-density residential, industrial, and commercial. Quantitative trash measurements were done quarterly and drive-by visual assessments were done monthly. Trash measurements were conducted by collecting trash found at drain inlets, removing debris, and characterizing the remaining material by weight and volume. Visual assessments were conducted by driving through the drainage area of each monitoring site and observing the amounts of trash in a consistent manner. Results from the quantitative monitoring indicate that commercial priority land use had the highest generation rate followed by industrial and high-density residential priority land uses (Project Clean Water Trash Capture Report). These findings are consistent with other studies where retail/commercial and industrial areas generally produce higher trash generation rates than residential areas. Based on these findings, this study deduces that urban trash capture devices can be an effective and efficient trash management practice.

Figure 28. The map above provides a schematic of the City of San Diego stormwater system in close proximity to the trash hotspot near Mission Bay (Figure 12). Stormwater Data: projectcleanwater.org



Other technologies used to intercept plastic waste (and other debris) from impacting surface waters include the placement of booms. The WILDCOAST environmental group raised money to install a boom in Los Laureles Canyon, a tributary into the Tijuana River (Figure 30). The boom was installed in January 2021.

Figure 29. Example of installed Full Capture Device at one of the monitoring stormwater sites in San Diego County.

There had been similar booms installed in Smuggler's Gulch and Goat Canyon in previous years. The Tijuana River watershed includes areas in both Mexico (the city of Tijuana and surrounding areas) and the United States. Sewage and stormwater facilities in Mexico are often unable to handle the volume of water during storm events and large volumes of debris are often swept into the Tijuana River. This is exacerbated by the occasional breakdown of sewage facilities in Mexico and the concomitant dispersal of sewage and trash into the Tijuana River.

Figure 30. A boom in the Tijuana River valley used to capture debris and prevent it from flowing into the ocean. Photo credit: CA State Parks.

C. Effectiveness of Government Interventions

As this study has documented, there is a correlation between the implementation of plastic bag bans and the quantity of plastic bags collected in coastal clean-ups (Figure 26 and Figure 27). This is a highly encouraging result and strongly suggests that other government interventions (e.g., further bans on the use and sale of other plastic items) can have a significant impact in reducing the amount of plastic going into the marine environment. It may be too early to measure the impacts of some of the other items subject to such bans (e.g., plastic straws, food containers, beach toys, etc.) but the evidence is strong that they could have a positive effect in reducing the amount of plastic debris in the marine environment.

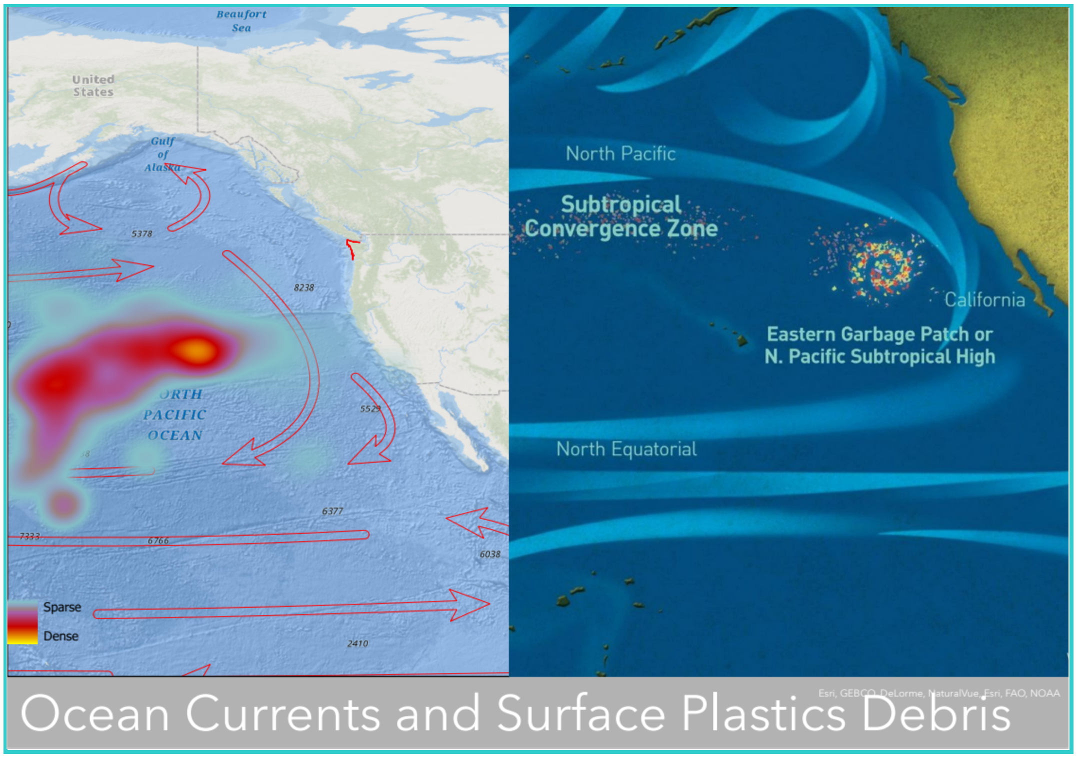
Similarly, progressively stronger requirements on stormwater capture and debris reduction have been implemented throughout California and the San Diego Region, and these have also reduced the flow of debris (including plastic) to the marine environment. Other governmental and NGO interventions (e.g trash capture systems, see section VIII B) have also been shown to be effective in reducing trash into the marine environment. Taken together, this study shows that government policy can help to reduce plastic accumulation in San Diego's waters including its MPAs.

VIII. DISCUSSION

A. Ocean Currents and Marine-based Plastic Pollution

Oceanic plastic debris is found throughout the world's oceans, and often impacts coastlines and habitats regardless of proximity to the polluting source. Figure 31 highlights remote locations far from direct human influence that are linked with plastic that travels from thousands of miles away. This is due to oceanic currents and gyres. While they circulate ocean waters, they also draw in the pollution that travels towards coastal shorelines. The most infamous example of plastic debris circulation is the North Pacific Garbage Patch, also referred to as the Great Pacific Garbage Patch. The patch is primarily plastic marine debris and is anticipated to double in size within the next couple of years. This study indicates that plastic waste found along the coast of San Diego could partially be sourced from oceanic gyres, such as the Great Pacific Garbage Patch.

Figure 31. Shown on the right are the North Pacific Ocean Currents in relation to the California coastline. Heat Analysis on the left highlights the dense/sparse amount of trash found circulating within the Pacific Ocean (Data from Erikson et al., 2014).



Other approaches such as by Liubartseva et al. (2019) used 2D Lagrangian modeling to estimate the flux of plastic waste entering MPAs. They found that a large part (55-88%) of the plastic waste entering MPAs was attributed to the shipping industry. Fishing and shipping, both are important influences along the coast of San Diego County (Kroeker et al., 2019; Moore et al., 2011) and further research on the sources and distribution of plastic waste along the California coast is recommended. Recent data on surface currents in the coastal region of California is available via the Central and Northern California Ocean Observing System (CeNCOOS) and processed by the Coastal Observing Research and Development Center (CORDC). High-frequency radars (HFR) from 13 stations continuously (since 2006) monitor the ocean surface water movements and the data is publicly available (https://cordc.ucsd.edu/projects/mapping/maps/). This data could be used to develop models of plastic waste flow that would affect the San Diego MPAs, and would be a valuable study to undertake to further understand the inputs of plastic waste pollution in this area.

B. Socio-demographic Influences on Plastic Pollution

The visual correlation between mismanaged plastic waste and tourism, as depicted by Figure 21 and Figure 22, supports the findings from a previous study in the Great Barrier Reef, Australia (Wilson & Verlis, 2017). Wilson & Verlis (2017) determined that the greatest source of plastic waste on publicly accessible islands was attributed to tourism. The waste generated by tourism, coupled with the mismanagement of waste disposal units, has become an increasing contributor to ocean plastic debris, as evidenced by the Wilson & Verlis (2017) study. The study determined that distance from the pollution source and the protected area status (of the GBR Marine Park Preservation Zone) are not barriers to mobile marine pollutants, such as plastic waste that enters the ocean. Furthermore, one of the highest loads of plastic waste identified in the study was on a protected island with access restricted solely to park rangers and researchers (Wilson et al., 2017).

The tourism sector is San Diego's third-largest economic driver. The city's allure has only grown in the past decade, currently being listed as one of the top five travel destinations for U.S. residents and the 11th most visited city for international travellers, attracting over 35 million visitors a year (SDTMD 2021). While tourism is a major driver of San Diego's economy, generating $17.9 billion in regional economic impact, the considerable number of visitors bear consequences for the local environment (SDTMD 2021). The San Diego MPAs are not safeguarded by their classification from plastic waste generated by tourists. Multiple factors contribute to the flow of plastic waste left on beaches into the Pacific Ocean, such as wind patterns and tidal cycles, and further distribution through ocean currents.

Additionally, more trash and clean-up activities are found occurring closer to the MPAs than further away. Other studies have assessed inputs of plastic waste inside of MPAs compared to the waste outside of MPAs. A study by Nelms et al. (2020), conducted in the U.K., used citizen science beach clean-up data over 25 years and determined that there was no difference in the density of waste (primarily plastic) inside of MPAs compared to outside of MPAs. Rather the density of plastic waste in a given area was based on local accumulation processes, particularly the proximity to large rivers, estuaries and ocean currents (Nelms et al., 2020). This analysis of the San Diego region data shows that the amount of trash collected increases in proximity to the nearest MPA, the clean-up activities peak outside of a 1 km buffer from the MPA, and then decrease thereafter, probably also related to the proximity to cities. The simultaneous increase in plastic waste near the MPAs (standardized by clean-up effort) and decrease in the number of people collecting waste may be due to limited accessibility (lack of roads, land access, etc). This needs to be investigated further.

C. Implications for Marine Environments

The impact of plastic pollution on different types of environments and on different species can be severe. Not yet well understood are transformation processes of plastic in the environment, such as the trapping and degradation of plastics, breakdown into smaller pieces, and the release of chemical compounds and toxic additives which are used for the production of plastics with specific characteristics (e.g., fire-retardant plastic). Regional scientific data on plastic pollution and its impact on ecology is important, but scarce and/or limited to certain research questions. These results on SAV zones in proximity to MPAs show that the potential to trap plastic near the coast is high (see section VI B and Figure 14). MPAs, as protected ecosystems, should receive special attention to mitigate accumulation of plastics in vegetated areas to protect marine wildlife and maintain stable ecosystems. While SAV zones can be impaired by the accumulation of plastic, the capture of plastic in these zones presents an opportunity to develop novel, ecosystem-friendly plastic removal technologies in those areas. Removing plastic (promptly) would help prevent trapped plastic from further breakdown and flow to the open ocean environment.

One recent study on the impacts of microplastics to SAV has indicated that high levels of plastic pollution significantly reduced the decomposition rate of both kelp and eelgrass by 27% and 36%, respectively (Cozzolino et al., 2020). This study also discovered a positive linear relationship between the abundance of microplastics and the area of plant canopy surface (leaves or fronds). Plastic aggregations have been documented in mangrove ecosystems, estuaries and seagrass beds worldwide (Huang et al., 2020; Pietrelli et al., 2017; Harris et al., 2017) and microplastic concentrations in the water were 1.3 to 17.6 times greater in vegetated than adjacent unvegetated habitat (Huang et al., 2021).

It should be noted that the scientific methodologies in environmental plastic research are not yet all standardized (van Emmerik et al., 2018; Hartmann et al., 2019) and for certain areas, they are not yet developed or they are at an early stage of development (Cowger et al., 2020; Waldschläger et al., 2020). As a consequence, comparison of results is difficult and some answers about plastic pollution processes remain unanswered. Therefore, further regional studies are recommended to assess the impact of plastics in SAV zones and MPAs in the San Diego region and to investigate removal opportunities

D. Modeling Land-based and Oceanic Plastic Flows

It is clear that plastic waste entering moving water bodies, including the ocean, is subjected to oceanic forces such as waves, tides, currents, and wind. Several studies have demonstrated that the distribution of plastic debris in the ocean and in coastal zones is highly influenced by ocean currents, tides, and waves (Liubartseva et al., 2019; Eriksen et al., 2014; Everaert et al., 2020; Harris et al., 2021).

Modeling plastic transport and its distribution in marine and freshwater systems has been done in studies that estimate the annual load of riverine microplastics in the ocean (Lebreton et al., 2017), and studies that model microplastic fate along a river to an estuary (Buschman et al, 2020). Others have assessed land-based entry of plastic into estuary systems (Unice et al., 2018), or estimated differently-sized floating plastic debris in the open ocean (Eriksen et al., 2014).

Numerous studies have made use of numerical modeling to track the theoretical progression of plastic densities in the marine environment (Liubartseva et al., 2019; Onink et al., 2021; Van Sebille et al., 2019). Some of these studies are very broad while others target specific areas such as a small set of MPAs in the Mediterranean Sea (Liubartseva et al., 2019). The results of any of these types of theoretical models rely heavily on the types of input data, some of which are presented throughout this white paper. In addition to quantities of plastic at various entry points, other key drivers in these models include assumptions around ocean currents, the dynamics of the plastics once they enter the ocean (e.g., buoyancy), and resuspension processes (Onink et al., 2021). This white paper points out various sources of ocean current data and detailed information on plastic entry points. Studies such as Liubartseva et al. (2019) and Onink et al. (2021), offer ideas of how to approach other assumptions, as mentioned above.

Open source software packages such as Parcels (Lange & van Sebille, 2017; Delandmeter & van Sebille, 2019) and OpenDrift (Dagestad et al., 2018) can be used to develop detailed particle trajectory models. Less precise models, such as the transition matrix from PlasticAdrift (http://plasticadrift.org/), can be used to model flows at a more macro level. Modeling at a macro level is not useful on its own in capturing plastic waste flows into the MPAs as it lacks the granularity of flow data needed to precisely target the areas. This type of model is more useful as a tool to build the boundary condition assumptions for more targeted models such as Lagrangian transport models. A detailed discussion of ocean surface current datasets and how they can be used in the Lagrangian transport modeling can be found in Onink et al. (2021).

There are studies producing similar values to the simulations of Onink et al. (2021), of particular interest are those with measurements in the Southern California Bight (Ribic et al., 2012). Combining such models with the data presented in this paper would allow for a more focused analysis on the local MPAs to identify specifically where the plastic in the MPAs is coming from, and could be used to target the most relevant sources. Data from clean-ups, rivers and gyres (see also Figure 31) can be built into the model assumptions to simulate how much plastic comes from each source and then be used to weigh the impacts of various solutions. The data on plastic entry will always be incomplete. This white paper aims to present tools to help develop solutions to plastic waste in the San Diego MPAs. Various solutions, where data is available, can be implemented in different models in order to create a cost benefit analysis of each approach. Model simulations can also help identify what types of data would be most useful to collect in order to augment the data presented in this paper.

IX. TAKE-AWAYS AND RECOMMENDATIONS

These analyses and maps indicate that the CoastalCleanup data portal provides a more detailed dataset that can be standardized more effectively but comprises a narrower temporal and spatial context compared to the MarineDebris data portal.

The geomorphology of the coast impacts the retention of plastic waste. Plastic trapping efficiency is higher for the coastal geomorphic types that exist in the San Diego area (rocky, wave and tide-dominated).

The submerged aquatic vegetation zones in and adjacent to MPAs in the San Diego region are potential hotspots for riverine and land-based and marine plastic waste. Interventions that target cleaning up rivers and creeks would help reduce the flow of plastic to these coastal areas.

There is a significant amount of mismanaged waste related to tourism. Because tourism is the third most important driver of the economy in the San Diego region, special attention should be given to reducing trash impact to areas that experience high numbers of tourists. Better waste collection infrastructure and management, reduction of plastic food service items in neighbouring food service providers, and other interventions could help to keep more plastic from getting into the ocean.

Bans on plastic bags appear to have reduced the proportion of plastic bags collected in clean-ups in the San Diego area. Such bans and similar effects have also been noted in other places. Plastic bags especially can catch on coastal marine plants and remain a problem in the environment for some time. Bans on other items have been enacted more recently (many in 2019), and future studies could use this data to analyze the effects of those bans.

Ocean currents affect the distribution of plastic in the ocean and along coastlines, as evidenced from marine-sourced debris (e.g., fishing gear) found on beaches. Modeling this distribution requires extensive data input, modeling expertise, and model assumptions, several of which this study has presented and which could be used in a subsequent analysis on plastic flow coming in and from the ocean into MPAs in the San Diego area

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XI. Appendix

Data mining: Applied keywords and approached stakeholders

Major keywords applied for internet search of datasets targeting the region of San Diego, California, USA:

Plastic pollution; Marine litter/ marine debris; Plastic in rivers; Plastic in the ocean; Ocean plastic; Ocean currents; Coastal clean-up; Waste management; Stormwater debris; Stormwater trash capture.