CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

Solid Waste Contamination on
Southern California Coastal Beaches

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By
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Abstract

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The global phenomenon of beach pollution by solid waste contamination is widespread. Recreational beaches that attract millions of visitors each year are especially impacted. Similarly, beaches that have fewer visitors still contain a significant amount of solid waste. This study examined the amount and type of solid wastes that are found on Zuma Beach and Nicholas Canyon Beach by comparing the common types, quantity, and temporal changes of debris accumulation over two months in 2018 and three months in 2020 at both sites. This study used the standing-stock survey method to analyze the spatiotemporal distribution of solid waste. This method was conducted once a week throughout September to October in 2018 and August to October in 2020 at both sites. It was hypothesized that the spatiotemporal analysis would show a higher amount of solid waste at Zuma Beach compared to Nicholas Canyon Beach owing to increased visits of beachgoers. Also, it was hypothesized there would be a significant difference found between 2018 and 2020 for the individual sites owing to increased use in 2020. Additionally, it was expected that significant differences would be found between the plastic material type with the other major material types collectively. This study used a t-test to determine the differences of debris between both beaches and individual beaches between the years as well as an analysis of variance (ANOVA) to determine the differences of major material types. The mean density of marine debris was 0.036 ± 0.026 items/m^2 and the major types were plastic and processed lumber. The average count of the individual pieces of debris was lower at Nicholas Canyon Beach than at Zuma Beach, which could be attributed to fewer beachgoers. This study will help researchers, coastal managers, and non-profit organizations to organize beach clean-ups suitable for the coast of southern California based on beach characteristics including tourism and the potential sources of debris accumulation. Also, the results of this study provide a foundation for educational campaigns to bring awareness to locals and tourists to reduce beach waste contributing to degradation of coastal ecosystems.

Chapter 1: Introduction

1.1 Background

Global solid waste generation has become a significant problem associated with rapid urban growth during the past 120 years. In 1900, there were 220 million residents that lived in urban areas, which created 300,000 tons of solid waste per day (Hoornweg, Perinaz, and Kennedy 2013). By 2000, 49% of the world's population created at least 3 million tons of solid waste per day. This article concludes the amount will be doubled by 2025. The increase in waste is prevalent in urbanized areas due to the growing population's demand in goods resulting in the growth of a consumer and throw-away society leading to mismanaged waste, further degrading the environment (figure 1). Solid waste management has become the 21st century's most crucial issue owing to industrialized and developing countries' increasing rate of solid waste production, along with the concern for the protection of the environment (Ghiani et al. 2014).

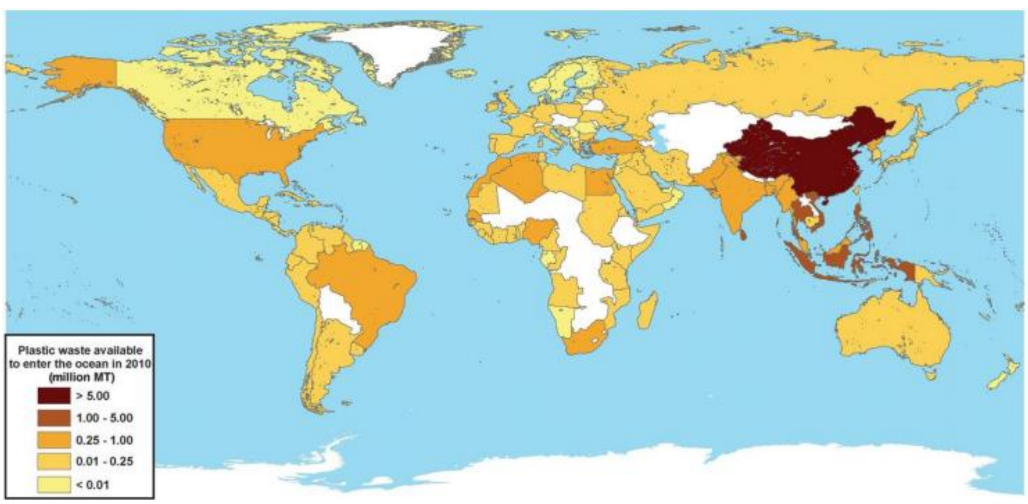

Figure 1: Estimated mass of mismanaged plastic waste (millions of metric tons) available to enter the ocean based on populations living within 50 km of the coast in 2010 for 192 countries (Jambeck et al. 2015).

Solid waste contamination on beaches is a worldwide phenomenon (Araújo and Costa 2007). The pollution found includes plastics, polystyrene, different types of paper, a variety of metals, glass, organic debris, and nylon (Araújo and Costa 2007). Two primary sources of solid waste contamination that are commonly found on beaches worldwide are marine debris, which is transported by currents and tides and generally consists of litter from other regions, ocean vessel dumping, as well fishing-related debris. The second source of solid waste contamination is litter from land contributed by beach goers, sewers, and rivers (Amos 2015).

Ocean gyres, which are a large system of ocean currents driven by global circulation can deposit marine debris onto the coasts. Ocean currents move pollutants from the point sources and non-point sources and transport it to other parts of the world's coasts (Santos et al. 2005). Some of the debris may be trapped at the center of the gyre where it is a calm and stable state and may not reach the coasts. For example, the North Pacific Subtropical Gyre, also known as the Great Pacific Garbage Patch, carries pollutants across the North Pacific Ocean spanning from the West Coast of North America to Japan (National Geographic Society 2012). The North Pacific Subtropical Gyre is composed of four currents that move in a clockwise direction, including the California, North Equatorial, Kuroshiro, and North Pacific currents (National Geographic Society 2012).

Locals and tourists who visit beaches are prominent sources of solid waste as well (Widmer and Reis 2010). The common types of solid waste that are left behind by beach visitors are toys, plastic pieces, aluminum cans, glass bottles, and cigarette stubs (Widmer and Reis 2010). Furthermore, many studies have shown that the distance of tourist sources controls the amount of trash found on beaches (Santos et al. 2005). For example, trash found on the beach during the summer months is contributed by tourism owing to increased visits, whereas tourism is less likely to occur during the winter months owing to the presence of fishing debris being dominant on the coast. California beaches tend to have cigarette butts as the typical litter, mainly found by beach entrances (Santos et al. 2005).

Another source of debris is due to poor solid waste management, disposal and collection of municipal solid waste which is then transported by rivers or storm drains (Widmer and Reis 2010). Storm drains transport litter to beaches when it is not disposed of correctly (Environmental Protection Agency 2017). Storm drain pollutants consist of fast-food wrappers, Styrofoam cups, cigarette butts, fertilizers, car oil, chemicals, and litter from paint and construction (Environmental Protection Agency 2018). This type of pollution is important because stormwater flows directly to the river, stream, or ocean without being treated (Environmental Protection Agency 2018).

Solid waste found in coastal and marine ecosystems negatively impacts marine fauna (Santos et al. 2005). Marine fauna that scavenge for food may be entangled in debris or suffocated ingested litter (Armitage and Rooseboom 2000). According to the National Oceanic and Atmospheric Administration (NOAA), one million seabirds and 100,000 marine mammals and turtles die from solid waste found in the ocean through ingestion and entanglement, yearly (Ocean Conservancy 2008). Furthermore, cigarette butts have been found in the stomachs of birds, whales, fish, and other marine fauna as they confuse them as a source of food (Environmental Protection Agency 2018).

Litter has a significant impact on the aesthetic factor of tourist beaches by decreasing the scenic potential of the area, as well as the risks associated with visitor's health (Santos et al. 2005). Litter on the beaches is not aesthetically pleasing to the human eye (Armitage and Rooseboom 2000). When visitors notice cigarette stubs on a beach, it is visually unpleasant (Widmer and Reis 2010). Furthermore, solid waste can put beach visitors’ health and safety at risk (Widmer and Reis 2010). Humans must be particularly wary of the potential health hazard of used needles that may have attached pathogenic organisms and the decaying contents inside used bottles and tins (Armitage and Rooseboom 2000). Also, beach visitor health is at an increased risk when there are stormwater drains nearby owing to inadequately treated water that affects local marine water quality (Environmental Protection Agency 2018). Common symptoms associated with exposure to polluted water include fever, rashes, earaches, diarrhea, and sinus problems (Environmental Protection Agency 2018).

1.2 Plastic Policies

The City of Malibu has been proactive in their approach to eliminating plastic waste on their beaches. The City Council of Malibu established ordinance no. 432, which became effective on June 1, 2018, banning the use, sale, and distribution of single-use plastic as well as bioplastic within the city limits by all retail stores and restaurants including fast food restaurants. Single-use plastic includes stirrers, straws, and cutlery items that are used one time then thrown away by customers. The city has encouraged all retail stores and restaurants to find alternatives that are safer for the environment such as paper, sugar cane, or bamboo for the above items. In addition, the ban of polystyrene foam has been effective since 2005, prohibiting the sale or distribution of food containers and packing materials. On January 1, 2017, this ordinance was modified to include beach toys, seafood trays, egg cartons, coolers, and navigational markers. This law requires that alternatives for food ware and packing materials must be recyclable or compostable such as paper, cardboard, loose foam, molded plastic, or compostable starch. Since 2008, the city prohibited the dispersal of single-use plastic shopping bags, which impact the local watershed and storm drain system as well as directly harming marine life. The city amended the Plastic Bag Ban on March 27, 2018, to include a fee when the customers need a recycled paper bag. The fee is a 10-cent charge that is applied to all stores in compliance with this ordinance. Given these various ordinances, the City of Malibu made considerable efforts to protecting their coastal beaches, oceans, and waterways to reduce the harmful impacts of plastic on the environment (Malibu City).

1.3 Significance of Research

Beaches globally are widely impacted by tourism. The spatiotemporal analysis of this study will help researchers, coastal managers, and non-profit organizations to organize beach clean-ups that are suitable for the coast of southern California. Identifying issues such as the amount and type of solid waste will help determine which specific areas of the beach need attention. The additional focus on banned plastics will ensure that the presence of these types of plastics found on Malibu Beaches are reduced significantly. The desired result is to highlight how debris load changes throughout time and the main type of material found to inform other interested individuals who visit southern California beaches on solid waste contamination.

1.4 Research Questions and Hypotheses

This study addressed solid waste contamination at two southern California beaches. Specifically, it asked: 1) How was the debris type and quantity changing over two months in 2018 and three months in 2020 at Zuma Beach and Nicholas Canyon Beach?, and 2) How did the debris load change on a weekly basis for the two sites?, and 3) How did the plastic material type quantity differ to the other major material types of metal, glass, rubber, processed lumber, cloth/fabric, and unclassified?

This study hypothesized a spatiotemporal analysis would show a higher number of solid waste at populated recreational beaches compared to less populated recreational beaches owing to a higher number of visits. It was expected that the highest amount of solid waste occurred at Zuma Beach due to its high concentration of visitors compared to the more remote Nicholas Canyon Beach. Also, it was expected that significant differences would be found for the individual beaches between 2018 and 2020 owing to increased use in 2020. Additionally, it was expected that significant differences would be found in average debris counts by both material type and beach location. This study concentrated on municipal solid waste, which included waste such as plastics, paper, cardboard, aluminum foil, food wrappers, and other common non-hazardous items that humans dispose of when finished. Additionally, other major categories of metal, glass, rubber, processed lumber, cloth/fabric, and unclassifiable items were identified. It was suspected that the solid waste was contributed by beachgoers.

Chapter 2: Literature Review

2.1 Introduction

It is critical to monitor solid waste contamination at beaches due to problems that persist within the coastal and marine environments. The litter found on beaches has a negative impact on human health because it degrades water quality, poses the danger of injury from sharp objects, and can potentially spread diseases. Marine fauna is impacted by entanglement, suffocation, and choking from human-introduced debris. This topic is relevant because the prominent litter found is plastic. The problem will continue to persist since there is high consumption of plastic usage in modern society. The high rate of plastics in the 21st century has a negative impact on the coastal and marine environment because it is highly durable and does not biodegrade over time but gets smaller in size until it becomes microplastic (smaller than 5 mm in size). Tiny plastic pieces carry pollutants such as methylmercury, which can travel up the food chain from phytoplankton to fish and humans due to bioaccumulation where marine organisms accumulate high levels of toxins in their tissues over time by the ingestion of plastic. This paper discusses the sources of litter, human perceptions on contaminated beach sites, the economic impact on coastal beaches, the impact of litter on marine fauna and human health risks as well as the distribution and density of litter on the backshore, berm, and foreshore related to seasonal variation.

2.2 Common Types and Sources of Litter

Globally, numerous studies commonly found plastics as the predominant type of litter on beaches **(**Santos et al. 2005; Araújo and Costa 2007; Kusui and Noda 2003; Debrot, Tield, and Bradshaw 1999; Topcu et al. 2013). Purba et al. (2018) found that the dominant debris types were plastic food wrappers and plastic bags due to their presence in every transect across the beaches in Savu Sea Marine National Park, Indonesia. In different regions of the U.S. Pacific Coast and Hawaii, the study primarily found plastic bottles most commonly, categorized as general source-debris (land or ocean-based sources) consistent in all regions (Ribic et al. 2012), which is similar to the Gulf of Mexico coasts of the U.S. (Ribic, Sheavly, and Rugg 2011) and the Atlantic (Ribic et al. 2010). Locally, studies found high amounts of hard plastics, foamed plastics, pre-production pellets, and single-use plastic on southern California beaches (Miller et al. 2018; Moore et al. 2001).

Another common type of litter found on coastal beaches worldwide was cigarette butts (Widmer and Reis 2010). A study conducted on the Brazilian coasts observed that smokers did not have any concern when they threw away their cigarette butts in the sand at the beach (Santos et al. 2005; Widmer and Reis 2010). Many beach communities had attempted to control the proliferation of cigarette waste on beaches by installing portable beach ashtrays (Widmer and Reis 2010). Portable beach ashtrays were devices used by beachgoers to store small debris items such as cigarette stubs (Widmer and Reis 2010). For example, Widmer and Reis (2010) found that 154,800 cigarette butts were disposed of correctly with the use of portable beach ashtrays instead of contaminating the beaches of Parana, Brazil. Furthermore, Purba et al. (2018) reported cigarette butts as the dominant type of debris with a total percentage of 63% found in the tourism season (May and August) on Pangandaran Beach, Indonesia. Additionally, Scisciolo et al. (2016) found cigarette butts to be the most common debris collected accounting for 2,560 pieces on the coastlines of Aruba in the Caribbean. The cigarette butts have a direct impact on marine fauna due to ingestion as well as by unsupervised children mistaking it as a food source. Cigarette butts are composed of over 165 toxic chemicals, such as nicotine and heavy metals that are mainly carcinogenic, which are contaminating the marine environment (Castaldi, Cecere, and Zoli 2020).

Studies found that plastic litter originated from marine-based and land-based sources internationally (Corcoran, Biesinger, and Grifi 2009). Plastic fragments on beaches came from inland sources and were carried away to the coast by rivers, wind, urban storm drains or activities associated with humans (Corcoran, Biesinger, and Grifi 2009; Araujo and Costa 2007; Barnes et al. 2009). Also, oceans carry low-density plastics across long distances through currents (Corcoran, Biesinger, and Grifi 2009; Araujo and Costa 2007). This study found that on the eastern coast of the island of Kauai, there was an accumulation of plastic debris from the North Central Pacific Gyre due to the clockwise rotation of the current and nearby longshore currents around the island. The study explained that the floating marine debris became trapped in the longshore currents and was transported and deposited along the strandlines (Corcoran, Biesinger, and Grifi 2009). Natural geographic elements had an impact on the movement and increase of litter.

Similarly, the other common litter found on beaches came from marine-based and land-based sources globally (Nelms et al. 2017). Marine-based sources include fishing-related debris and shipping waste, while land-based sources include recreational and tourism-related debris, as well as waste from drainage networks and river run-off (Santos et al. 2005; Hengstmann et al. 2017; Nelms et al. 2017; Purba et al. 2018). Maritime activities associated with commercial fishing, recreational fisheries, and shipping tend to dispose items into the ocean such as ropes, fishing line, nets, buoys, cages, and nets (Nelms et al. 2017; Purba et al. 2018). Additionally, land-based sources came from agricultural, industrial, and domestic activities (Nelms et al. 2017). These litter items such as food-packaging related litter, plastic, toys, cigarettes, car parts, and building material got to the marine environment by public littering, fly-tipping (dumping waste illegally), and lack of proper waste management in which the trash gets transported in urban storm drains or rivers (Nelms et al. 2017).

2.3 Human Perceptions of Coastal Litter

Individual perceptions vary based on various factors of solid waste contamination at beaches. On the Brazilian coasts, beachgoers that were interviewed claimed the primary source of litter was from people that visit the beach (Widmer and Reis 2010). A study on Lloret Centre Beach, Spain found that 13% of litter collected was discarded on the sand by beach users (Ariza, Jimenez, and Sarda 2008). Furthermore, most beach visitors had a common misconception that the source of trash was from other visitors (Santos et al. 2005; Widmer and Reis 2010). Based on the Brazilian study, only 25% of people admitted to littering on the beach (Santos et al. 2005). The rest of the interviewees blamed the wind, children, or other beach visitors. The study found that beach visitors believed humans were the prominent source of litter and suggested to raise educational awareness to reduce beach contamination.

Beachgoers' perception of polluted beaches influence beach visitation due to the lack of cleanliness. Beaches that are known to be heavily polluted or are associated with items that are harmful to humans can lead to a reduction of tourism, which is followed by financial problems for the local communities which rely on business supporting visitor use (William and Tudor 2003). This study found that people’s perception of syringes and sewage-related debris were found to be highly rated offensive forms of litter, with the least offensive being natural debris found on coastal beaches (William and Tudor 2003). Beach contamination is critical owing to the health effects associated with debris that leads to the reduction of beach visitation. In addition, a study conducted by NOAA Marine Debris Program and Industrial Economics, Inc.

aimed to understand how beach visitation by beachgoers was influenced by the presence of marine debris found at local Orange County beaches in California (Legget et al. 2018). This study found that 66% of respondents reported that the lack of marine debris and good water quality were important factors in local beach visitation, as well as 62% of respondents were concerned of the presence of garbage or manmade debris on the sand of their local beaches (Legget et al. 2018). Furthermore, trash on the beach diminishes the beach visitors' enjoyment and the natural beauty of the beaches (Ofiara and Brown 1999; Krelling, Williams, and Turra 2017; Leggett et al. 2018). Also, first time visitors to polluted beaches are less likely to return to the beach (Ballance et al. 2000).

2.4 Economic Impacts of Litter on Coastal Beaches

Marine debris affects the local economies associated with tourism in the coastal communities (NOAA). Studies found when marine debris increased on coastal beaches there would be an economic loss in tourism (Krelling, Williams, and Turra 2017; Legget et al. 2018). NOAA funded a study with Abt Associates that found when marine debris was doubled at the beaches there was a decrease in beach visitation, which resulted in a reduction of tourism dollars that lead to a loss of local jobs available for the local community (Abt Associates 2019). The model found that when the number of marine debris doubled at Orange County beaches there was an estimated 4.6 million fewer beach visitations, an economic loss of $414 million tourism dollars in local communities, and a significant decrease in 4,300 jobs (Abt Associates 2019). Conversely, NOAA Marine Debris Program and Industrial Economics conducted a local case study on the economic impacts of marine debris at Orange County, California and found that when marine debris was reduced by 75 percent, the six beaches that were in close approximation to the outflow of the Los Angeles River would have an increase in visitation by 43 percent as well as a profit of $53 million (Legget et al. 2018). Studies found that litter on beaches lessened visitor’s enjoyment and reduced the recreational value on coastal beaches (Ofiara and Brown 1999; Krelling, Williams, and Turra 2017; Leggett et al. 2018).

2.5 Harmful Impacts of Litter on Coastal Beaches

The literature mentioned the environmental impacts of solid waste contamination on beaches due to their direct impact on marine fauna such as biodiversity loss. Marine organisms were under constant threat from plastic debris such as virgin plastic pellets, tiny fragments, and microplastics (Corcoran, Biesinger, and Grifi 2009; Costa et al. 2009). The marine fauna widely impacted include birds, fish, turtles, benthic organisms, marine invertebrates, and mammals (Santos et al. 2005; Corcoran, Biesinger, and Grifi 2009; Costa et al. 2009). The marine fauna tends to get entangled in the solid waste or to ingest the materials, causing severe internal damage and eventually death (Santos et al. 2005; Corcoran, Biesinger, and Grifi 2009; Costa et al. 2009; Kusui and Noda 2003; Franeker et al. 2018; Merrell 1980). A study found that 21 of the 38 bird species analyzed from the coast of North Carolina from 1975 to 1989 had ingested plastic fragments (Moser and Lee 1992). Also, plastic packing loops threatened marine and coastal wildlife due to strangulation as a result of the plastic loops tightening and cutting into the flesh as the animals matured (Gregory 2009).

Solid waste contamination on beaches can potentially affect human health as well (Leite et al. 2014). Human health was at risk because plastic litter was a reservoir for pathogens due to the plastisphere (living microorganisms on plastic) (Keswani et al. 2016). Furthermore, solid wastes that were categorized as medical and unsanitary were hazardous (Keswani et al. 2016; Williams et al. 2016; Armitage and Rooseboom 2000). Beachgoers often cut themselves with solid waste that had been buried in the sand such as glass or other types of cutting material (Santos et al. 2005). In addition, Costa et al. (2009) found that unsupervised children can mistake the small plastic fragments as consumable items due to their different shapes and colors. Another public health concern was the ingestion or potential mouth contact of cigarettes left on the beach for children that were playing (Costa et al. 2009). Overall, the impact on marine fauna and humans showed the risks associated with litter found on the beaches due to entanglement, strangulation, and ingestion related to marine fauna and human health, ingestion, and injuries related to humans.

2.6 Distribution Pattern of Marine Debris on Shoreline

Many studies found that the distribution of trash on the shoreline was attributed to local land-based or distal marine-based origins. The common distribution pattern of anthropogenic marine debris densities was highest on the upper zones of the beach compared to the lower zones of the beach (Bravo et al. 2009; Silva Iniguez and Fischer 2003; Jackson, Cerrato, and Elliot 1997; Cunningham and Wilson 2003; Claereboudt 2004). A study found that most anthropogenic marine debris (AMD) were commonly found on the upper zones of the transects near the entrance compared to lower densities of AMD on the lower zones of the transects closer to the water line on forty-three beaches of the coast in Chile (Bravo et al. 2009). This type of distribution pattern proposed local sources due to the upper zones of the beach being highly frequented by beach goers (Bravo et al. 2009). Furthermore, the spatial distribution pattern of debris on the beach in Ensenada, Mexico was mainly concentrated in the vegetation line of the higher transect (6,945 objects) compared to the high tide line of the lower transect near the water (435 objects) with the abundance of various litter types that declined relatively proportionally from the vegetation level to the high tide level (Silva-Iniguez and Fischer 2003). In addition, tides and waves can contribute to the movement of trash being found on the highest parts of the beaches (Taffs and Cullen 2005). In contrast, Scisciolo et al. (2016) found the concentration of macro-debris (greater than 2.5 cm) tend to be closer to the shoreline on the windward coast of Aruba, Southern Caribbean. This study proposed that marine debris found on the wrack-lines close to the waterfront on the beaches came from distal marine-based origins (Scisciolo et al. 2016). It is common to find debris on the wrack line of the shoreline due to the ocean waves transporting the debris during high tide. Furthermore, Purba et al. (2018) found that most of the litter was distributed along the high tide line for each of the beach sites as well as near the entrance areas at the popular tourist beaches located at Savu Sea Marine National Park, East Nusa Tenggara, Indonesia. In addition, another general distribution pattern may be related to the different sections of the beach. A study found that the highest amount of solid waste contamination was found at the most northern and southern ends of the beach, compared to the lowest amount of solid waste at the middle of the study area at Tamandare Beach, Brazil (Araujo and Costa 2007).

2.7 Marine Debris Densities

Globally, debris density, abundance and item count varied across the beaches in numerous studies. The equation of debris density was measured as the number of debris items/per meter squared (Bravo et al. 2009; Schmuck et al. 2017; Scisciolo et al. 2016; Laglbauer et al. 2014). Twenty-four Caribbean beaches that were sampled had a mean density of macro-debris (> 5mm) of 6.34 ± 10.11 items/m^2 (mean ± SD) (Schmuck et al. 2017). In addition, Bravo et al. (2009) found that the mean density of anthropogenic marine debris was 1.8 items/m^2 for forty-three beaches in south-east Pacific Chile known as the Chilean Coast accounting a total of 21,146 items found and classified. Furthermore, six beaches along the Slovenian coast had a median macro-debris density of 1.25 items/m^2 with a total of 5,870 items (Laglbauer et al. 2014). Additionally, studies found that the amount of marine debris was significantly higher in popular tourist beaches compared to non-tourist beaches in northern Argentina (Becherucci, Rosenthal, and Seco Pon 2017) as well as higher amounts being found in highly urbanized beaches compared to least urbanized beaches in southeastern Brazil (Andrades et al. 2016). The differing debris densities worldwide provide insights into the prevalent problem of our throw-away society of mismanaged waste further polluting the marine environment.

2.8 Seasonal Distribution of Debris

The seasons play a role in debris densities found across beaches because they are related to the peak tourism season in the summer as well as storm events in the fall. A study by Purba et al. (2018) conducted a beach survey at West Pangandaran Beach in May, August, and October in 2017 and found that October had the highest quantity of marine debris compared to the lowest quantity in May. Similarly, a study by Topcu et al. (2013) found higher litter concentrations in autumn due to possible factors such as intense rain, high waves and the strong northern winds that pushed surface currents to the coast before and during sampling on the Mediterranean Coast of the Black Sea. These studies showed that during the fall, there was an increase in debris on the shoreline worldwide. Conversely, summer months had a higher accumulation of debris which declined in the fall (Araújo and Costa 2007; Ariza, Jimenez, and Sarda 2008; Andrades et al. 2016). For example, the public beaches of the Catalan coast in Girona, Spain, had a decline of small-sized debris in September because of unfavorable weather conditions toward the transition to fall (Ariza, Jimenez, and Sarda 2008). Comparably, a study by Andrades et al. (2016) found that urbanized beaches had the highest accumulation of litter during the summer months due to the increase in visitors on touristic beaches of southeastern Brazil.

2.9 Summary of Literature

The contributions of this literature to the field were extensive to better understand the importance of plastic, human perceptions of coastal litter, the impacts on human health and marine fauna, the economic impact associated with tourism, and the concentration of debris on the shoreline related to seasonal variation. The literature emphasized grave concerns about plastic pollution in the coastal and marine ecosystem due to its persistent durability. Also, most beach users blamed others for the litter found on the beach. Beach communities suffer an economic loss due to the presence of marine debris found on the coast that influences the number of tourists who visit the beaches. Litter on beaches was a threat to people due to the risk of health issues and to marine fauna due to being trapped or suffocated. The distribution of litter on the shoreline is attributed to land and marine-based origins that were quantified as debris density that were related to differences between seasons. The overall weakness of this literature was that the direct pathways of litter found on beaches were difficult to assess due to the lack of a tracking device on each item discarded, so researchers had to assume if it originated from land-based or marine-based sources. The research needs to focus on finding the common types of debris found on the southern California coast and how debris changed temporally throughout the seasons.

Chapter 3: Methodology

3.1 Malibu Beach Study Sites

The coast of Malibu, California is situated along the Southern California Bight, which is 260 mi (414 km) long, extending from Point Conception to San Diego (Meldahl 2015). The waters are warmer in the bight and waves predominantly approach from the west with impact varying from 30 to 130 degrees (perpendicular to the beach) compared to other areas of the Pacific Coast due to factors such as ocean currents and the blocking of incoming ocean swells (waves generated by distant weather systems) by the Channel Islands. The coast of Malibu has a longshore-current (local current) that roughly parallels the dominantly north to south flowing offshore California Current. The south and south-west orientation of the California Bight causes the California Current to create eddies (circular currents of water), which influences the water temperature.

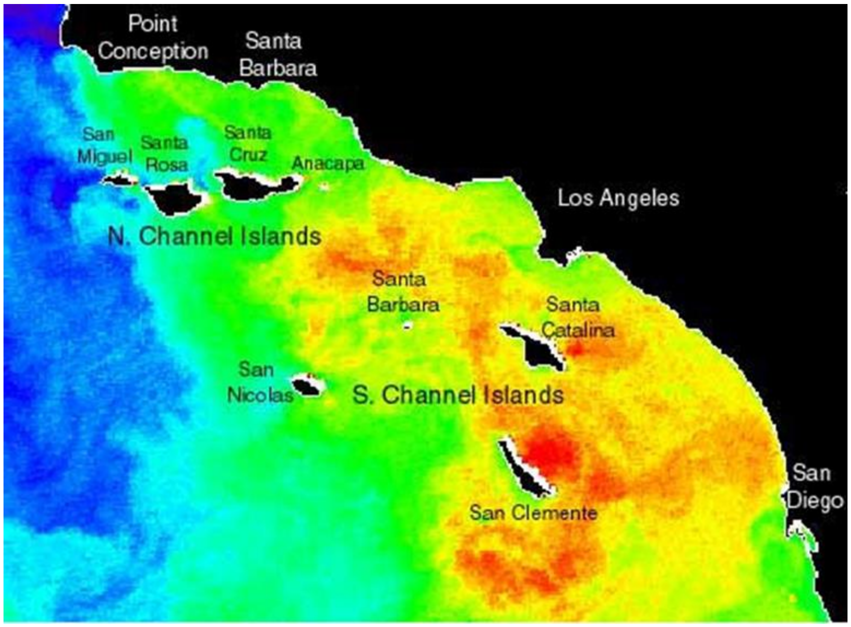

Figure 2: Satellite-derived Sea Surface Temperature image of the Southern California Bight, cold waters represented by blue pixels, whereas warm waters represented by red and orange pixels. (Image by California State University, Long Beach)

The California Current creates counterclockwise eddies as it drags the water nearby the southern California coast, which allows cool water from the north and warm water from the south to enter the Bight (figure 2). Also, during the fall, winter, and spring, the ocean waves come from the west and northwest direction. Conversely, during the summer, the waves periodically come from the south and southwest direction (Meldahl 2015). The different orientation in wave direction can make a significant impact to the landscape by shifting the placement of sand, boulders, and debris on the coastlines. Malibu, California has a Mediterranean climate, which is characterized by warm dry summers and rainy winters.

The beaches located in Malibu are owned and operated by Los Angeles County. According to Los Angeles County Beaches and Harbors, the beaches within Los Angeles County are reported as "some of the most recognizable and most popular beaches in the world". Yearly, at least 50 million visitors travel to Los Angeles County beaches, accounting for both tourists and locals due to the recreational activities and scenic beauty of over 25 miles of sandy-beaches (Los Angeles County Department of Beaches & Harbors). In 2002, tourism contributed to $7.1 billion in the economy, which accounted beach visits as the second dominant tourist activity for Los Angeles County (Schiff, Morton, and Weisberg 2003). In 2018, Los Angeles reached a record with tourism contributing $36.6 billion (Martin 2019). There are eight beaches within Malibu, which includes Nicholas Canyon and Zuma Beaches. In 1941, Los Angeles County acquired the Zuma Beach property as a foreclosure and created an immense public parking lot for the beach. Nicholas Canyon Beach was first opened to the public on July 1, 1973 (Los Angeles County Department of Beaches & Harbors). Additional government bodies controlling Malibu Beaches are the California Department of Parks and Recreation, California Coastal Commission, Department of Beaches and Harbors, Los Angeles County Fire Department, Lifeguard Service, and the Mountains Recreation and Conservation Authority (“Malibu Beaches”).

Figure 3: Zuma Beach (Image by Zuma Beach Website)

According to Los Angeles County Department of Beaches and Harbors, Zuma Beach is popular amongst locals and tourists alike due to its plentiful amenities such as restrooms and volleyball nets as well as being the largest beach park in Malibu. Zuma Beach has 105 acres (42.492 ha) of property with 1.8 miles of beach frontage (backshore to nearshore) (figure 3). There are eight parking lots with an estimate of 2000 parking spaces including disabled spaces. Further, this beach is popular for its ocean activities such as surfing. Surfers and swimmers must be cautious due to periodic dangerous rip currents and rough waters. Zuma Beach is a great location to watch the winter migration of grey whales. (Los Angeles County Department of Beaches & Harbors). There is mechanical raking at Zuma Beach to control trash accumulation as well as the presence of trash cans at each entry. Zuma Beach's surrounding area is dominated by residential areas, commercial recreation, and institutional buildings (Malibu High School and Cabrillo Elementary School), which shows the dense urban center and popularity of locals living nearby the coast (Figure 5). The land cover of Zuma Beach is characterized by medium and high intensity development landward of the backshore in addition to the backdrop of the Santa Monica Mountains (Figure 6).

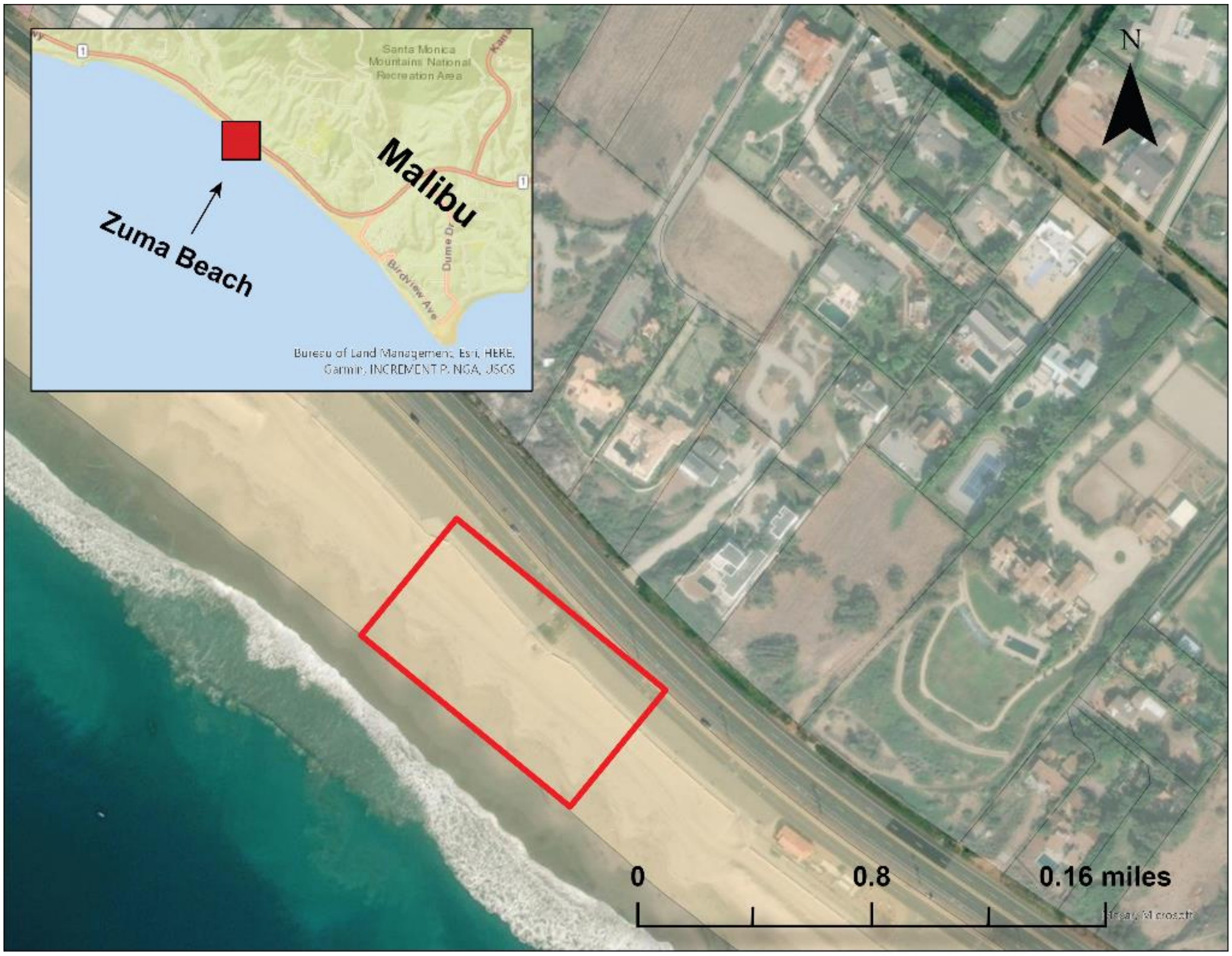

Figure 4: Reference map and the boundary of the 100-meter study area at Zuma Beach.

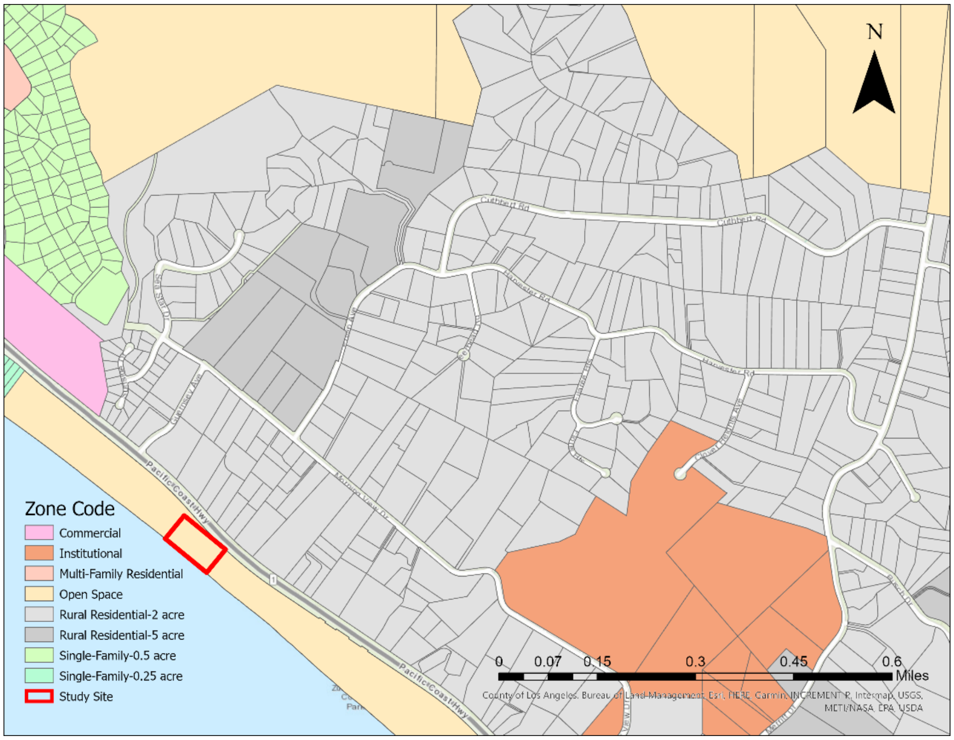

Figure 5: Zoning land use of surrounding area at Zuma Beach.

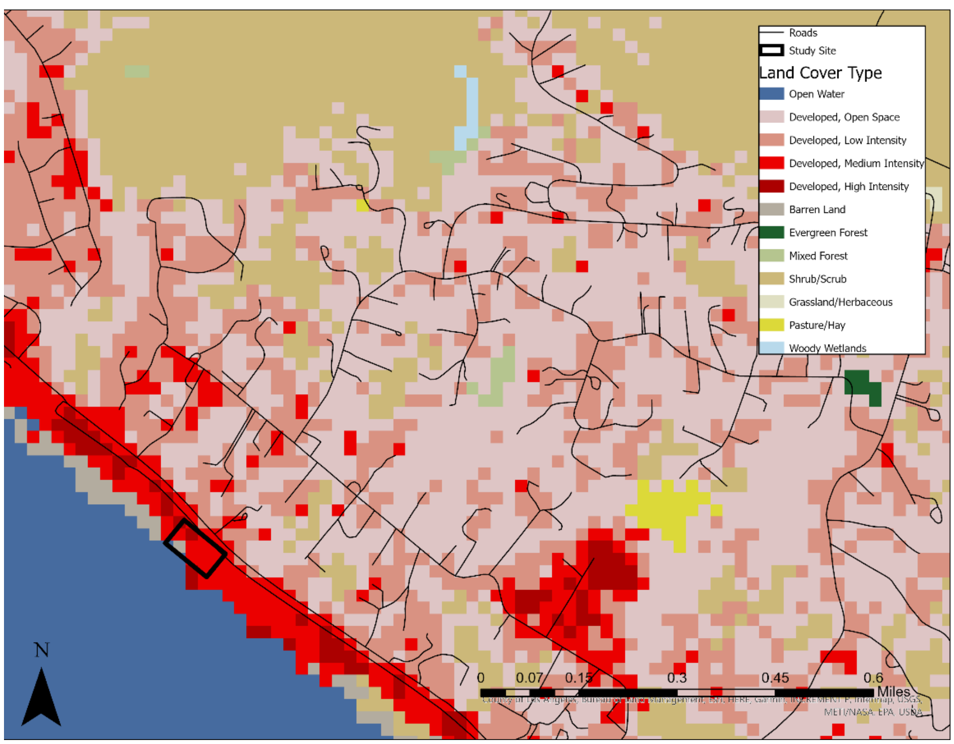

Figure 6: Land cover of surrounding area at Zuma Beach.

Figure 7: Nicholas Canyon Beach (Image by author)

According to Los Angeles County Department of Beaches and Harbors, Nicholas Canyon is reported as less crowded compared to the other Malibu Beaches. Nicholas Canyon has 23 acres (9.30777 ha) of property with an estimate of close to a mile of beach frontage (backshore to nearshore) (figure 7). Nicholas Canyon Beach has different topographic features compared to Zuma Beach due to this beach being at the base of a 22 m bluff. There is a parking lot with an estimate of 151 parking spaces located on the bluff, along with chemical toilets. There are two entryways to get to the beach, which are to go down the stairs at the south end of the beach or hike on the bluff trail to the concrete bluff-top Nicholas Canyon Road that leads down to the beach (Scholl 2009). The start of the concrete bluff-top road as well as the restroom facility nearby have been heavily eroded due to the process of upper bluff erosion, which is influenced by rainfall and thresholds of grain collapse related to unstable coastal sediments (figure 8). Also, trash cans are only accessible atop of the stairs and in the parking lot area. Also, there is no mechanical raking at Nicholas Canyon Beach. Nicholas

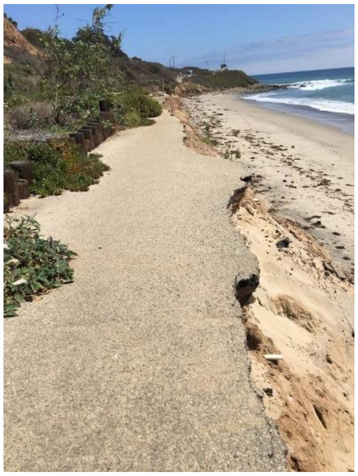

Figure 8: Erosion of Nicholas Canyon Road. (Image by Author)

Canyon Beach is great for ocean activities such as surfing. In addition, the Wishtoyo Foundation's Chumash Village is located on a 4-acre site at Nicholas Canyon Beach. The Chumash Village is available to the public by appointment, and it offers guided tours and presentations based on the daily living of Chumash people using models of Chumash homes, tools, canoes, ceremonies, and celebrations. The foundation also hosts beach clean-ups nearby at the local beaches (Los Angeles County Department of Beaches & Harbors). Furthermore, Nicholas Canyon Beach’s surrounding area is dominated by residential areas and commercial recreation (Figure 10). Additionally, the land cover of Nicholas Canyon Beach is characterized by medium intensity development with the backdrop of the Santa Monica mountains (Figure 11).

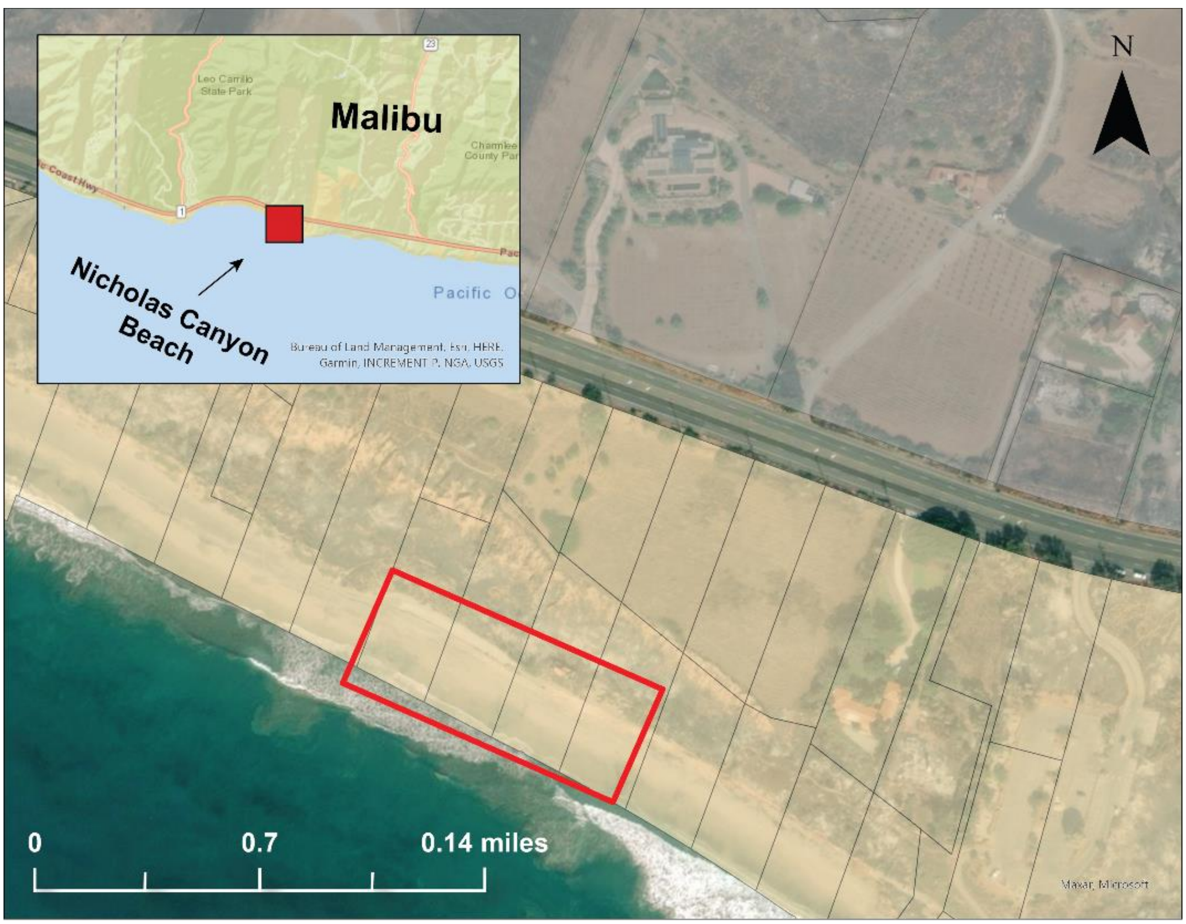

Figure 9: The boundary of the 100-meter study area at Nicholas Canyon Beach.

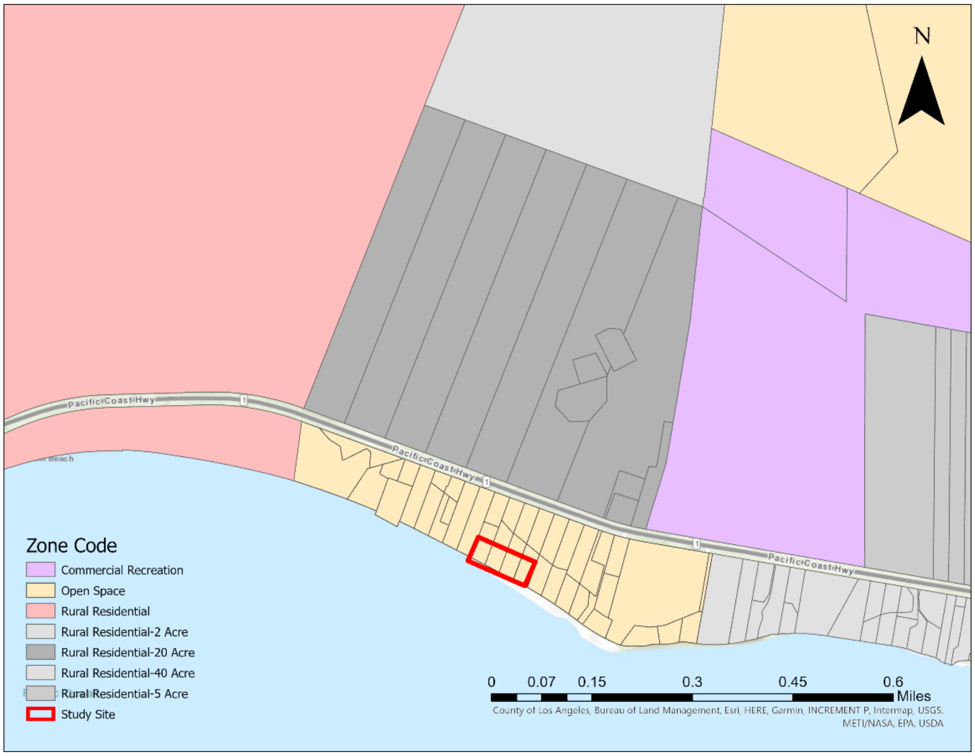

Figure 10: Zoning land use of surrounding area at Nicholas Canyon Beach.

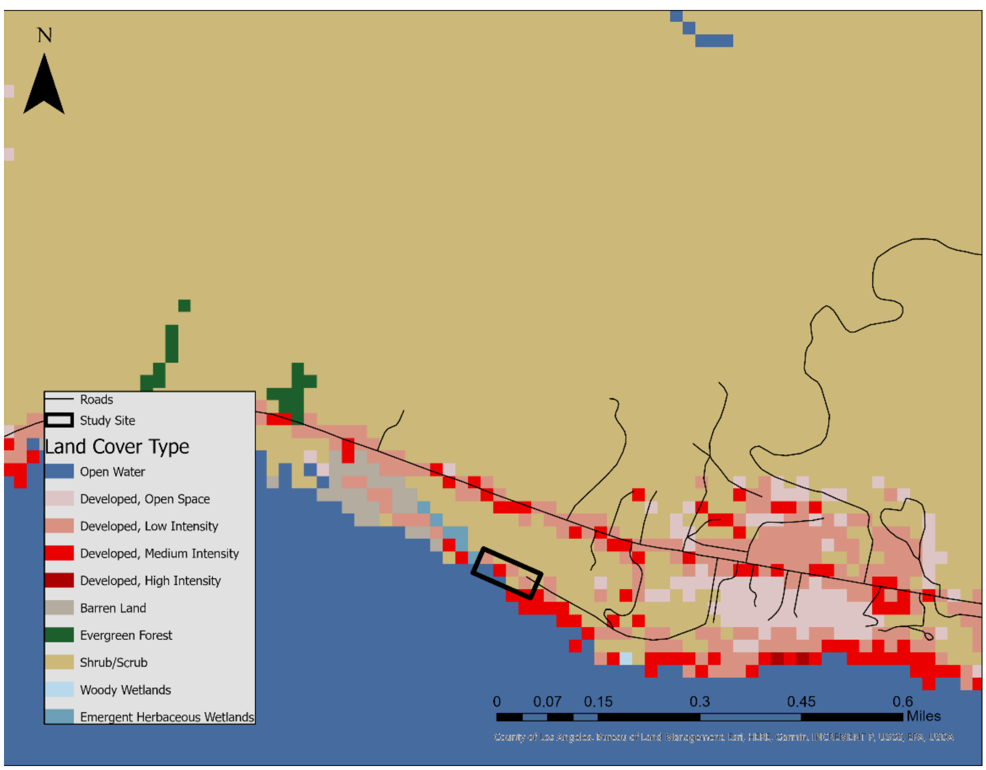

Figure 11: Land cover of surrounding area at Nicholas Canyon Beach.

Zuma Beach and Nicholas Canyon Beach were suitable study sites to understand the human-environment impact of beachgoers littering on public beaches. Zuma Beach had the highest number of visitors of all beaches within Los Angeles County beaches accounting for 5.5% of the entire Southern California beach visits (Dwight et al. 2007). The average visits to Zuma Beach were 7,060,397 from the mean annual beach visits from 2000 to 2004. In contrast, based on the same annual beach visits from 2000 to 2004, Nicholas Canyon Beach had the lowest average visits, which was 200,939 visitors. By selecting these two disparate beaches, based on population, this research provided insight into the impacts of population on beach waste.

Figure 12: Map of Nicholas Canyon and Zuma Beach.

3.2 Data and Sources

This study used a standing-stock survey at both study sites located at Nicholas Canyon Beach and Zuma Beach. The standing-stock survey's purpose was to collect data based on debris density and debris material type per transect (Lippiatt, Opfer, and Arthur 2013). This type of survey technique was adapted by the NOAA Marine Debris Monitoring and Assessment Project (MDMAP), which is a citizen science initiative. With citizen science, NOAA can guide the monitoring of marine debris for volunteers, organizations, and other researchers who share their findings on the NOAA monitoring database for beaches around the world.

A standing-stock survey was conducted once a week from September 2018 to October 2018 as well as from August 2020 to October 2020 within 3 hours of a low-tide for both beaches. The period surrounding low tide (lower low-tide and higher low-tide) was suitable for the survey because it showed the maximum width of both study sites (Lippiatt, Opfer, and Arthur 2013). Before arrival at the two 100-meter study sites, six random transects were selected using a random number table in correspondence with a transect location table, which amounted to 20 transects to choose from in a 100-meter site, with the exception of four transects assigned on the first survey in 2018.

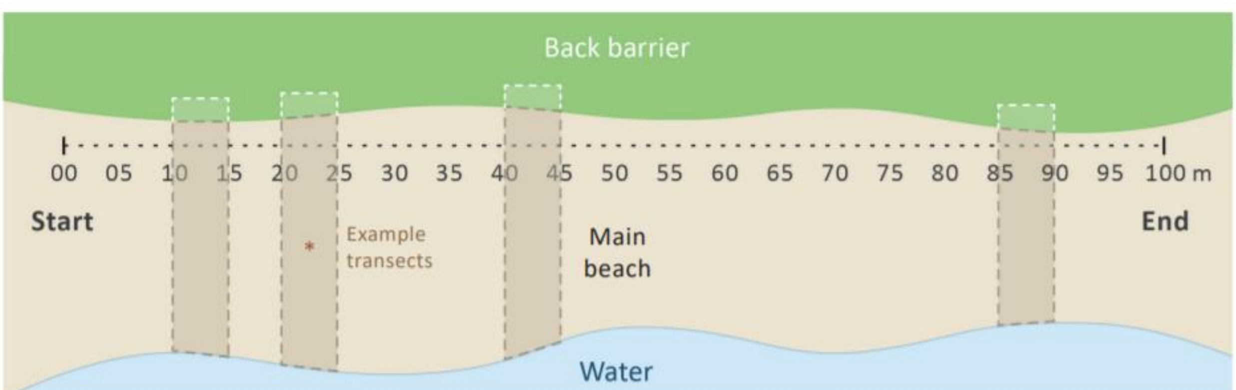

Figure 13: An example of 100-meter study site with four transects of a 5 meter-length. (Image by NOAA)

Following the methodology of Lippiatt, Opfer, and Arthur (2013), this study used the random number table technique for the first year of the beach survey in September and October of 2018 as well as August 2020. September and October 2018 were chosen because it was a suitable timeframe for the undergraduate senior project for fall semester 2018 and it was replicated for this study in 2020 with an additional month of August to include the summer season. In September and October of 2020, the same transects were used as in September and October of 2018. The random number table technique was used as a crucial attempt to remove any biases upon the visual representation of the shoreline. This avoided the tendency to choose areas of the beach that have a lot of debris and instead assign random transects to get an accurate representation of the 100-meter study site. The six assigned transects were 5 meters in length and provided 30% coverage of the 100-meter shoreline. The chosen transects started perpendicular from the water's edge to the back of the shoreline. The transects were marked with flags that corresponded to the measuring wheel laid out within the 100-meter study sites.

Figure 14: Ground level of Nicholas Canyon Beach (A); 5-meter length transect at Nicholas Canyon Beach with blue flag (B).

Figure 15: Ground level of Zuma Beach (A); 5-meter length transect at Zuma Beach with pink flag (B).

Global Positioning System (GPS) coordinates were recorded in decimal degree format at two locations within the transect; the first point was at the water's edge, which was the mark of the low tide and then at the back of the shoreline for the second point. The GPS coordinates were useful for NOAA to keep track of change on the shoreline over time throughout the study. In addition, ancillary data were recorded, which included the time, season, date the last survey was conducted, weather conditions for that current day, description of recent storms that may have occurred, the number of individuals who have helped throughout the survey, and the length of each transect from water's edge to the back of the shoreline. The standing-stock survey debris datasheet tallied the solid waste found in each of the six transects for both study sites, categorized as plastics, metal, glass, rubber, processed lumber, cloth/fabric, and unclassifiable items (Ryan et al. 2009; Rees and Pond 1995). Within these major categories, there were subcategories to specify the items tallied. The debris items that were tallied followed the NOAA protocol for items to be at least 2.5 cm in size (macro-debris) based on the longest dimension. This guideline was important because waste that was smaller than 2.5 cm would be difficult to tally due to the lack of visibility. Furthermore, it was required to tally individual pieces when the original item was broken into pieces to understand debris impact on the shoreline and to improve the efficiency of beach cleanups. If the material type was non-recognizable, it was listed in the section of other/non-classifiable. In addition, the standing-stock survey protocol does not allow the removal of the macro-debris found in the randomly chosen transects. The survey was completed once the twelve transects in total were finished for that day at both study sites. Furthermore, the survey results were uploaded on the NOAA MDMAP database to share both study sites with others who were interested in solid waste found in southern California beaches. Other standing-stock surveys were submitted on the NOAA MDMAP database for the beaches across Malibu City. The organization called Heal the Bay conducted the standing-stock survey in consecutive months from June 2012 to May 2014 at Carbon Beach. In addition, a NOAA MDMAP personnel conducted the survey at Zuma Beach on September 6, 2016. The data from these two beach surveys were used for comparison in the discussion section based on debris density and type in Malibu City as well as comparing other regions around the world.

3.3 Measurements

This study used a t-test to compare differences between the two study sites based on debris type and occurrence. The independent samples t-test is used when there are two groups in the sample that are independent from each other to compare their means to find a significant difference between them. The average numbers of the total debris count were used for an independent samples t-test across both months, September only, and October only in 2018 for both beaches. Additionally, an independent samples t-test was used for the average numbers of the total debris count for August only, September only, October only, and across the three months in 2020 for both beaches. The paired samples t-test is used when one group is measured twice to compare their means. This test is appropriate when comparing the years of one group to determine if there are significant changes (Nishishiba, Jones, and Kraner 2014). A paired samples t-test was conducted for Nicholas Canyon Beach and Zuma Beach based on the means of the total debris count for 2018 and 2020.

This study used additional statistical test a two-way ANOVA (Factorial ANOVA). The two-way ANOVA requires two categorical variables and one dependent variable to analyze how the mean changes for the dependent. The two-way ANOVA is a useful analysis to understand the interaction between the two categorical variables on the dependent variable. The two-way ANOVA was used to test whether the two independent variables of beach location and the seven major categories have an influence on the averages of the total debris count. The post-hoc tests are based on a pair-wise comparison of the groups (Bevans 2021). When the two-way ANOVA results are statistically significant ($p < 0.05$), it is required to do post hoc tests to determine which independent groups are significantly different. The post-hoc test used for the analysis was Tukey's HSD (honestly significant difference) to test which groups were significantly different from one another based on the major categories and beach location. The raw data of the debris count were whole numbers. The whole numbers obtained for the total debris were used to find the averages for both beaches.

3.4 Analysis

The standing-stock assessment survey was used to gather raw data from Zuma and Nicholas Canyon Beach. This shoreline technique was chosen to measure the debris load over time at both study sites. The standing-stock survey technique was beneficial within a two-month time frame in 2018 and a three-month time frame in 2020 to gather raw data and conduct an analysis of the temporal variation of debris load. It assessed the long-term aspect of the balance between the input of debris (land and ocean-based) and removal of debris (by burial, degradation, export) (Lippiatt, Opfer, and Arthur 2013).

The data gathered from both study sites showed a spatial trend between Zuma (more populated) and Nicholas Canyon Beach (less populated). An independent samples t-test and a paired samples t-test were used to determine if there were significant differences in total debris accumulation for both beaches. In addition, a two-way ANOVA to determine the significant difference of mean debris counts based on two grouping variables of beach location and the seven material types. Additionally, the Tukey HSD was used to do the pair-wise comparisons of the groups to determine a significant difference among several groups for the two-way ANOVA. In addition, temporal trends were observed on a weekly basis that assessed the natural flux of deposition and removal of debris at both beaches over time. This is important to observe how the debris load changed at a temporal scale regarding beachgoers visits in different months. Furthermore, the types of litter found at both beaches were compared to find the predominant litter type at each to assess the potential differences in drivers for debris deposition. Additionally, the total debris concentration was calculated per transect (# of items/m^2) as well as the average across all six transect concentrations to get a survey-level concentration for Nicholas Canyon and Zuma Beach to compare with other studies in the discussion section.

Chapter 4: Results

4.1 Independent Samples T-Test for Debris in 2018 and 2020

Generally, Zuma Beach had the highest average total debris count (6.8) compared to Nicholas Canyon Beach for both months combined in 2018 (Table 1). Zuma Beach had a higher average debris count (8) compared to Nicholas Canyon Beach in September (Table 1). In contrast, Nicholas Canyon Beach had a higher average total debris count (6.1) than Zuma Beach in October (Table 1). Zuma Beach had the highest average debris count across the months of August (10.9), September (11.7), and October (12.3) compared to Nicholas Canyon in 2020 (Table 1). Across all months in 2020, Zuma Beach's average debris were twice more than Nicholas Canyon Beach (Table 1).

Table 1: Descriptive statistics of debris count for Zuma Beach versus Nicholas Canyon, 2018 and 2020.

	Mean	Standard Deviation	Sample Variance
Zuma Beach, Debris (All months, 2018)	6.89	5.27	27.80
Zuma Beach, Debris (September 2018)	8.00	5.96	35.60
Zuma Beach, Debris (October 2018)	5.41	3.94	15.53
Nicholas, Canyon, Debris (All Months, 2018)	4.28	4.95	24.50
Nicholas Canyon, Debris (September 2018)	2.87	3.38	11.45
Nicholas Canyon, Debris (October 2018)	6.16	6.14	37.78
Zuma Beach, Debris (All months, 2020)	11.58	4.73	22.41
Zuma Beach, Debris (August 2020)	10.94	4.05	16.40
Zuma Beach, Debris (September 2020)	11.72	4.02	16.21
Zuma Beach, Debris (October 2020)	12.33	6.63	44.06
Nicholas, Canyon, Debris (All Months, 2020)	5.95	4.37	19.10
Nicholas Canyon, Debris (August 2020)	6.50	5.54	30.73
Nicholas Canyon, Debris (September 2020)	5.27	3.61	13.03
Nicholas Canyon, Debris (October 2020)	6.16	3.56	12.69

Average debris count across all months was significantly higher for Zuma Beach (6.89) than Nicholas Canyon (4.28) in 2018 (t=1.907, df=54, p=0.06). Average total debris for September only was also significantly higher at Zuma Beach (8.00) compared to Nicholas Canyon (2.87) (t=2.988, df=24, p=0.006). Conversely, no significant difference in debris count was found in October between these two locations. Average total debris count for Zuma Beach (11.553) was also significantly higher than Nicholas Canyon Beach (5.872) in 2020 (t=6.008, df=91, p=0.00). This pattern persisted for all individual months. Zuma Beach had the lowest average in August (10.82) compared to Nicholas Canyon Beach in September 2020 (4.94).

4.2 Paired Samples T-Test for Debris in Zuma Beach Between 2018 and 2020

Zuma Beach's average debris nearly doubled in 2020 compared to 2018 for all months combined (Table 1). Average debris count for Zuma Beach were significantly higher in 2020 versus 2018 for both months (t=-3.649, df=26, p-value=0.001), September only (t=-2.322, df=14, p=0.03), and October only (t=-2.95, df=10, p=0.01). The highest average debris count occurred in October 2020, whereas the highest average occurred in September 2018 for the individual years.

4.3 Paired Samples T-Test for Debris in Nicholas Canyon Beach Between 2018 and 2020

Nicholas Canyon Beach's average debris were similar in 2020 (5.57) compared to 2018 (4.28) for all months combined (Table 1). Average total debris for September only was significantly higher in 2020 versus 2018 (t=-2.294, df=14, p=0.03). Conversely, no significant difference in debris count was found in October and all months combined between these two years.

4.4 Two-Way ANOVA Between Major Categories and Beaches

Of the major litter categories, plastic had the highest average total debris count compared to metal, glass, rubber, processed lumber, cloth/fabric, and unclassified (Table 2). Processed lumber followed as the second highest compared to the other material types.

Table 2: Descriptive statistics regarding the major categories of plastic, metal, glass, rubber, processed lumber, cloth/fabric, and unclassified based on total debris count.

	Mean	Standard Deviation	Sample Variance
Plastic	32	17.31	299.84
Metal	1.84	1.61	2.61
Glass	0.03	0.19	0.03
Rubber	0.26	0.53	0.28
Processed Lumber	8.28	7.39	54.62
Cloth/Fabric	1.92	1.64	2.71
Unclassified	0.19	0.56	0.32

The analysis showed a statistically-significant difference in average debris count by both material type ($f(6)= 91.223$, $p<0.00$) and beach location (Nicholas Canyon and Zuma) ($f(1)=16.681$, $p < 0.00$). A Tukey post-hoc test revealed that the plastic material type resulted in higher amounts of debris on average than metal (30.1 debris), glass (31.9), rubber (31.7), processed lumber (23.8), cloth/fabric (30.0), and unclassified (31.8) material types (Table 3). Similarly, the processed lumber material type resulted in higher amounts of debris on average than metal (6.30), glass (8.11), rubber (7.88), cloth/fabric (6.23), and unclassified material type (7.96) (Table 3). The Malibu Beaches were also significant, with Zuma Beach resulting in a higher amount of debris on average of 3.76 debris over Nicholas Canyon Beach (Table 3).

Table 3: Tukey's honestly significant difference (HSD) results to find the significance between the major categories and between Nicholas Canyon and Zuma Beach.

Tukey HSD	Difference	Tukey HSD p-value
Beaches		
Zuma Beach -Nicholas Canyon Beach	**3.76**	**0.00**
Material Type		
Plastic-metal	**30.15**	**0.00**
Plastic-glass	**31.96**	**0.00**
Plastic-rubber	**31.73**	**0.00**
Plastic-processed lumber	**23.84**	**0.00**
Plastic-cloth/fabric	**30.07**	**0.00**
Plastic-unclassified	**31.80**	**0.00**
Metal-glass	1.80	0.96
Metal-rubber	1.57	0.98
Metal-processed lumber	**6.30**	**0.02**
Metal-cloth/fabric	0.07	1.00
Metal-unclassified	1.65	0.97
Glass-rubber	0.23	0.99
Glass-processed lumber	**8.11**	**0.00**
Glass-cloth/fabric	1.88	0.95
Glass-unclassified	0.15	1.00
Rubber-processed lumber	**7.88**	**0.00**
Rubber-cloth fabric	1.65	0.97
Rubber-unclassified	0.07	1.00
Processed lumber-cloth/fabric	**6.23**	**0.02**
Processed lumber-unclassified	**7.96**	**0.00**
Cloth/fabric-unclassified	1.73	0.97

4.5 Predominant Litter for 2018 Sample

Nicholas Canyon Beach had a total of 120 macrodebris items and Zuma Beach had a total of 193 macrodebris items, which were classified into 47 categories and 7 major groups. In 2018, Zuma Beach and Nicholas Canyon Beach both had plastic as the predominant type of litter, which accounted for 69% and 73%, respectively. Furthermore, processed lumber was the second most abundant group at Zuma Beach (20%), followed by cloth/fabric (5%), metal (3%), unclassified (1%), rubber (1%), and glass (1%) (Figure 16). In contrast, Nicholas Canyon Beach had similar percentages amongst processed lumber (9%) and metal (8%), followed by cloth/fabric (6%), unclassified (3%), rubber (1%) and an absence of glass (Figure 16). In general, the plastic category type had the highest number of subcategories in the following order of food wrappers, hard plastic fragments, bottle caps, and cigarettes at Zuma Beach compared to

Nicholas Canyon Beach, which had polystyrene cups as the dominant subcategory type with low amounts in the other subcategories. Furthermore, the processed lumber category type had the highest debris in the paper and cardboard subcategory at Zuma Beach, which was made up predominantly of napkins compared to Nicholas Canyon, which consisted of only lumber building materials.

Figure 16: Summed debris counts across the transects by material type (plastic, metal, glass, rubber, processed lumber, cloth/fabric, and other/unclassified) in 2018 at Zuma Beach and Nicholas Canyon Beach.

The types of plastics were divided into three different categories, which were consumer products, smoking products, and fishing-related products for the various survey dates. Consumer products included food wrappers, plastic beverage bottles, bottle/container caps, bags, cups, plastic utensils, straws, and personal care products. Also, smoking products greater than 2.5 cm included cigar tips, cigarettes, and disposable cigarette lighters. Also, fishing-related products included plastic rope/net, buoys and floats, and fishing lures and line. Specifically, the primary type of plastic debris that was dominant at Zuma Beach was plastic consumer products followed by plastic-smoking products (Figure 17). Similarly, Nicholas Canyon had plastic consumer products as the dominant type followed by plastic fishing-related products (Figure 17). The plastic smoking products had cigarettes as the dominant subcategory type at Zuma Beach compared to none being present at Nicholas Canyon Beach. Additionally, there was one item found for the plastic rope/small net pieces that accounted for plastic fishing-related debris being present at Nicholas Canyon Beach but none at Zuma Beach.

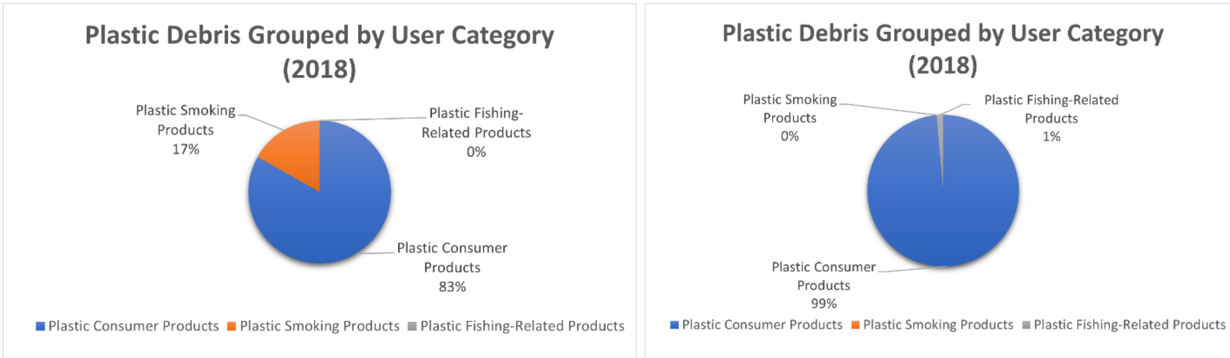

Figure 17: Plastic debris concentrations for the transects by user category at Zuma Beach (left) and Nicholas Canyon Beach (right).

4.6 Predominant Litter for 2020 Sample

There was an increase in the amount of litter for Nicholas Canyon (286 items) and Zuma Beach (556 items) in 2020. 2020 followed a similar pattern to 2018 due to plastic being the predominant material type followed by processed lumber (figure 18). Zuma Beach persisted in high amounts of plastic food wrappers, likewise Nicholas Canyon persisted in high amounts of polystyrene cups. Napkins was the dominant subcategory within the processed lumber category as well.

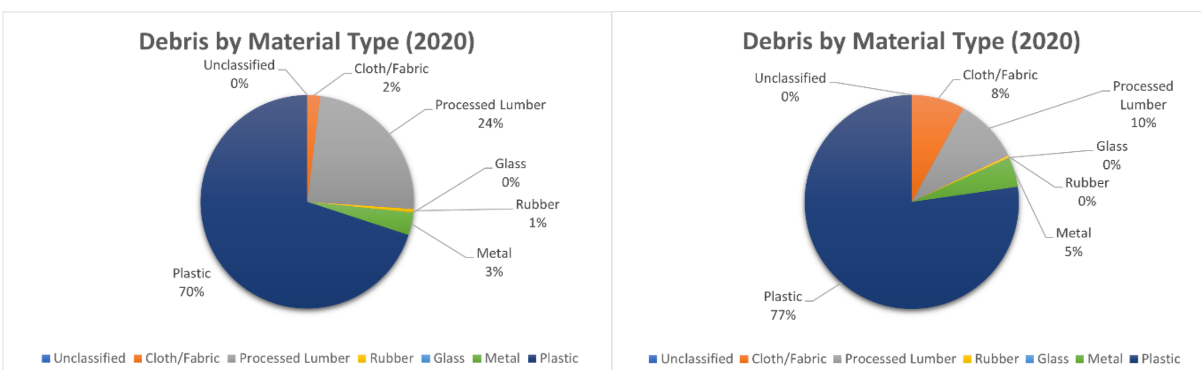

Figure 18: Summed debris counts across the transects by material type (plastic, metal, glass, rubber, processed lumber, cloth/fabric, and other/unclassified) in 2020 at Zuma Beach (left) and Nicholas Canyon (right).

Zuma Beach and Nicholas Canyon Beach had plastic consumer products as the dominant type followed by smoking products, predominantly cigarettes (figure 19). Fishing-related products (1 item) were found only at Zuma Beach in 2020.

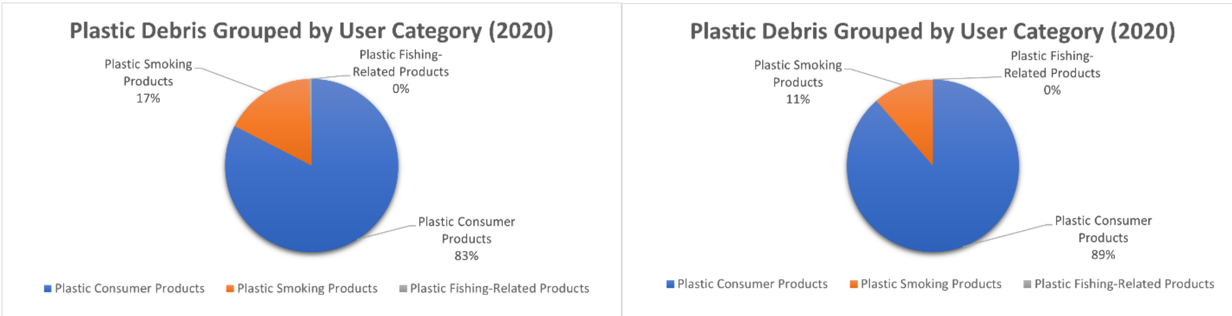

Figure 19: Plastic debris concentrations for the transects by user category at Zuma Beach (left) and Nicholas Canyon (right).

4.7 Temporal Trends for 2018 Sample

The weekly trend of debris at Zuma Beach was constant with it being considerably higher on 9/26/2018 and lower on 10/10/2018 (Figure 20). In contrast, the weekly trend at Nicholas Canyon Beach had an increase in debris.

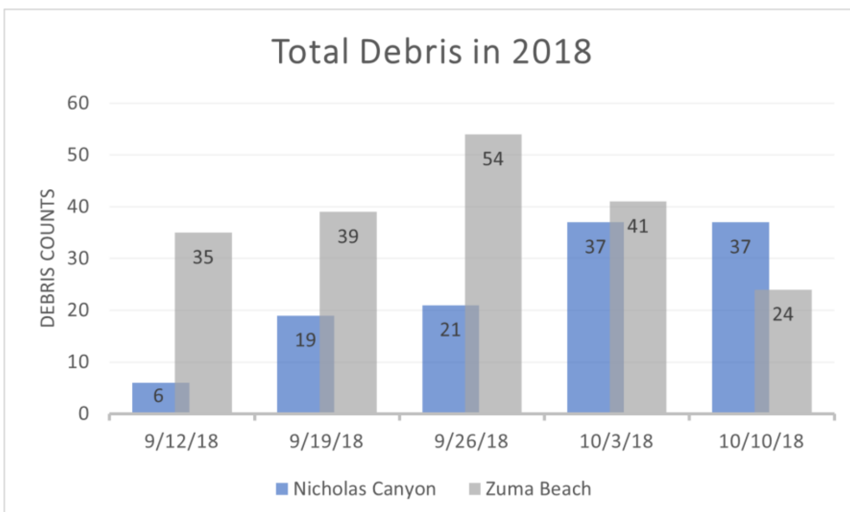

Figure 20: Total debris counts for all transects combined at Zuma Beach and Nicholas Canyon Beach in 2018.

The transects that were randomly chosen at Nicholas Canyon Beach provided an in-depth look at debris removal and deposition on specific sections of the shorelines. For example, transect 8 reoccurred twice from 9/19/18, with a decrease of debris on 10/3/18 (Figure 21). There was a higher accumulation of debris at the start of the study site from transect 1 to 8 (0 to 40 meters) as the debris count declined to the end of the study site from transect 11 to 20 (50 to 100 meters). However, this general trend was not noted in 10/10/18. In addition, transect 5 had the highest number of debris with 23 reported from all transects (Figure 21). Similarly, Zuma Beach had a higher accumulation of debris at the start of the study site from transect 1 to transect 11 (0 to 55 meters) as the debris count decreased from transect 12 to 20 (55 to 100 meters), except for 10/10/18 which had similar amounts of debris throughout the study site (Figure 23). Transect 11 had the highest amount of debris with 21 reported from all transects.

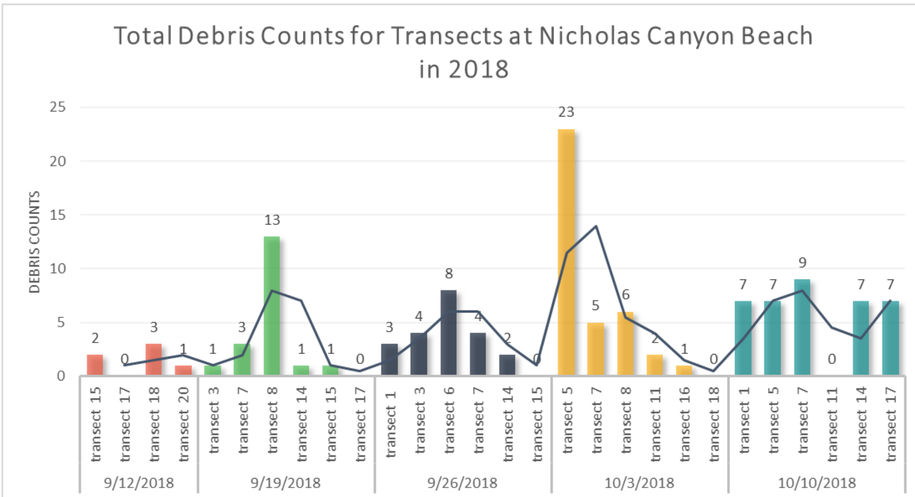

Figure 21: Total debris counts for transects from 9/12/18 – 10/10/18 at Nicholas Canyon Beach.

Figure 22: Color-coded transects represented for various dates in 2018 at Nicholas Canyon Beach. (Left side of image was the start of the study site; Right side was the end of the study site).

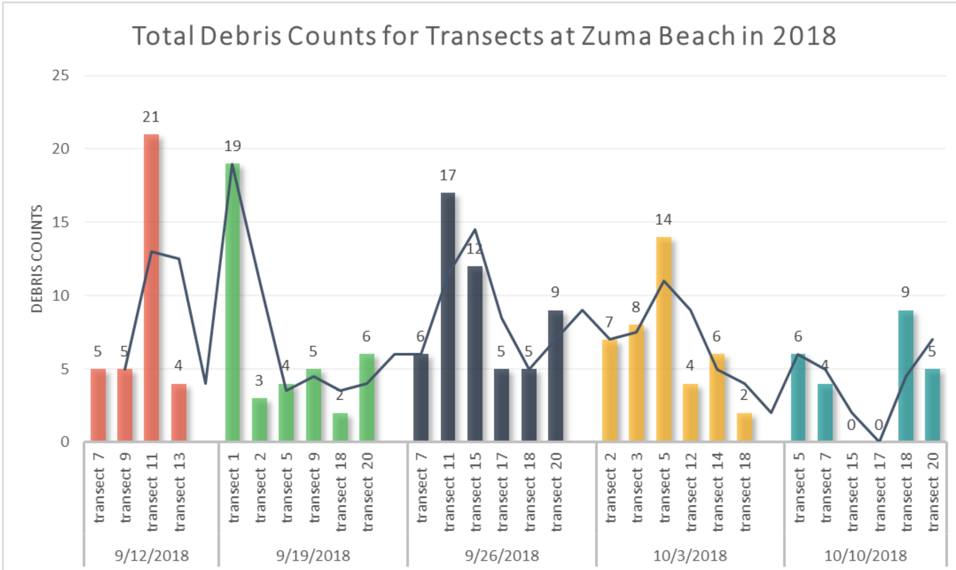

Figure 23: Total debris counts for transects from 9/12/18 – 10/10/18 at Zuma Beach.

Figure 24: Color-coded transects represented for various dates in 2018 at Zuma Beach. (Left side of image was the start of the study site; Right side was the end of the study site).

4.8 Temporal Trends for 2020 Sample

Zuma Beach had the highest number of debris on 10/8/20 with the second highest load of debris on 9/10/20. There was a slight increase in debris in the summer months with a decline in the fall months (September/October) except for the last survey date in October (Figure 25). In addition, Nicholas Canyon Beach had the highest number of debris on 8/17/20 with a considerable decrease the following weeks with a slight increase at the end of September.

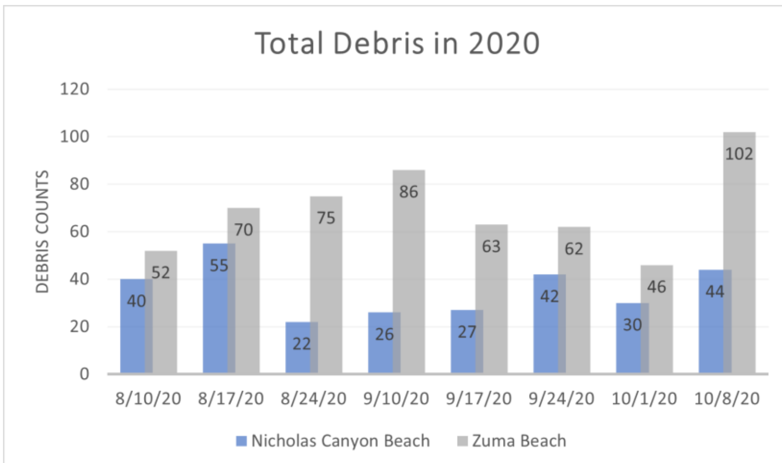

Figure 25: Total debris counts for all transects combined at Zuma Beach and Nicholas Canyon Beach in 2020.

The debris load's fluctuation was evident across the 100-meter study site at Zuma Beach. Due to mechanical raking at Zuma Beach, this would apply to the trash left behind from the mechanical raking and its efficiency in trash removal. In 2020, the highest accumulation of debris were distributed throughout the study site from 0-55 m (transect 1-11) as well as from 65 to 100 m (transect 14-20) (Figure 26). Zuma Beach had the highest amount of trash recorded on 10/8/2020 on transect 18 and transect 17, which was the farthest end of the study site next to an entrance (Figure 26). In addition, there are transects that have the similar amounts of debris on various weeks. For example, transect 13 reoccurred four times from 8/10 to 9/10, with counts ranging from 12 to 16 pieces of trash. Also, transect 11 had an increase of trash on 9/10 following a reduction on 9/24 owing to possible causes of mechanical raking with less visits by beachgoers.

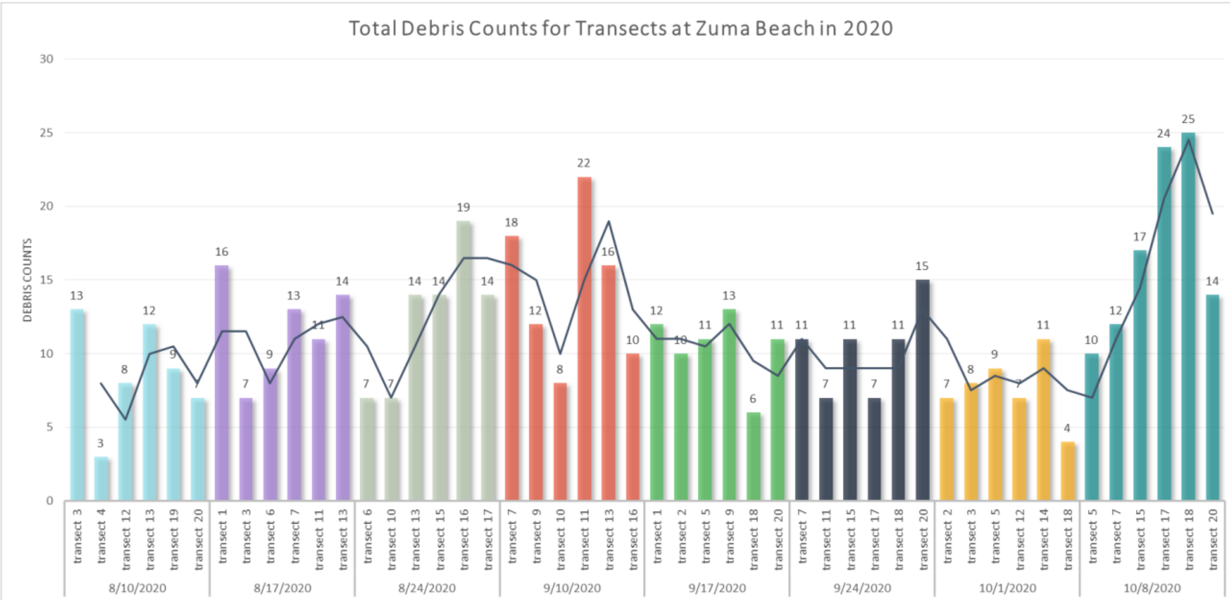

Figure 26: Total debris counts for transects from 8/10/20 – 10/8/20 at Zuma Beach.

Figure 27: Color-coded transects represented for various dates in 2020 at Zuma Beach. (Left side of image was the start of the study site; Right side was the end of the study site).

Contrarily, Nicholas Canyon Beach does not have mechanical raking and no trashcans found on the shoreline for easy accessibility. The debris removal and deposition would be based on natural causes of tidal waves and currents as well as human factors of beachgoers leaving behind and picking up trash. Specifically, between 30-35 meters (transect 7) tend to have the highest accumulation of trash across the various survey dates except for debris being the same amount on transect 17 (80-85 m) at the last survey date (Figure 28). In addition, Nicholas Canyon had the highest amount of trash at transect 7 on 8/17/20 owing to the possible cause of transect 7 being located near a storm drain (figure 29). Furthermore, debris removal was significant when it was reduced three times the debris count for transect 7 on 8/17 to 9/17.

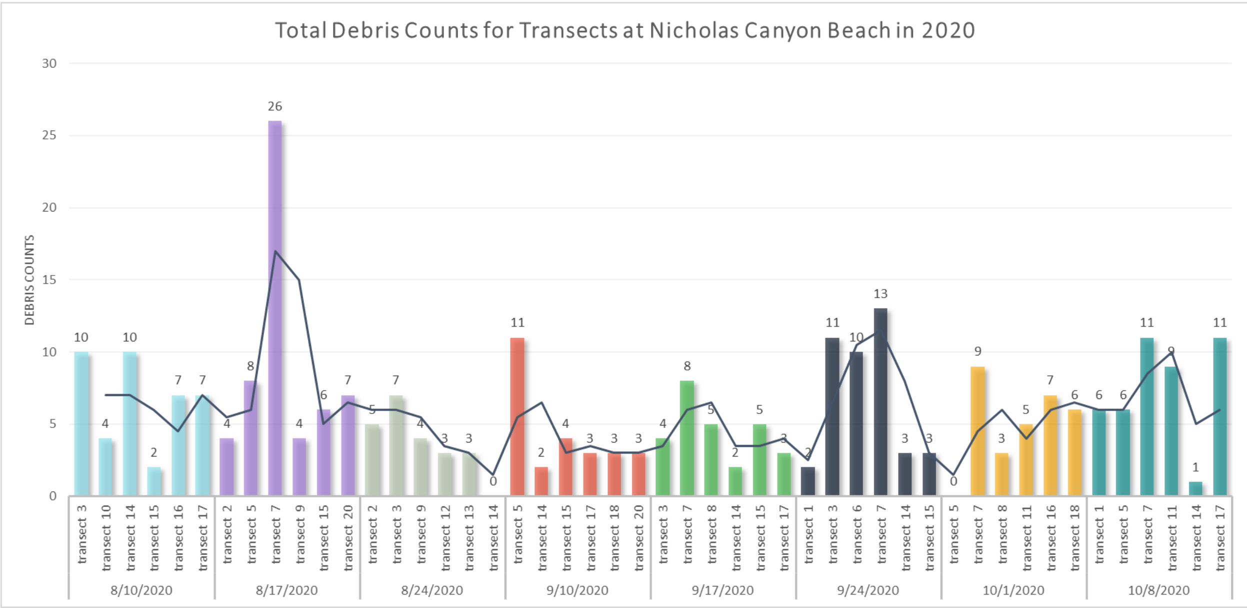

Figure 28: Total debris counts for transects from 8/10/20 – 10/8/20 at Nicholas Canyon Beach.

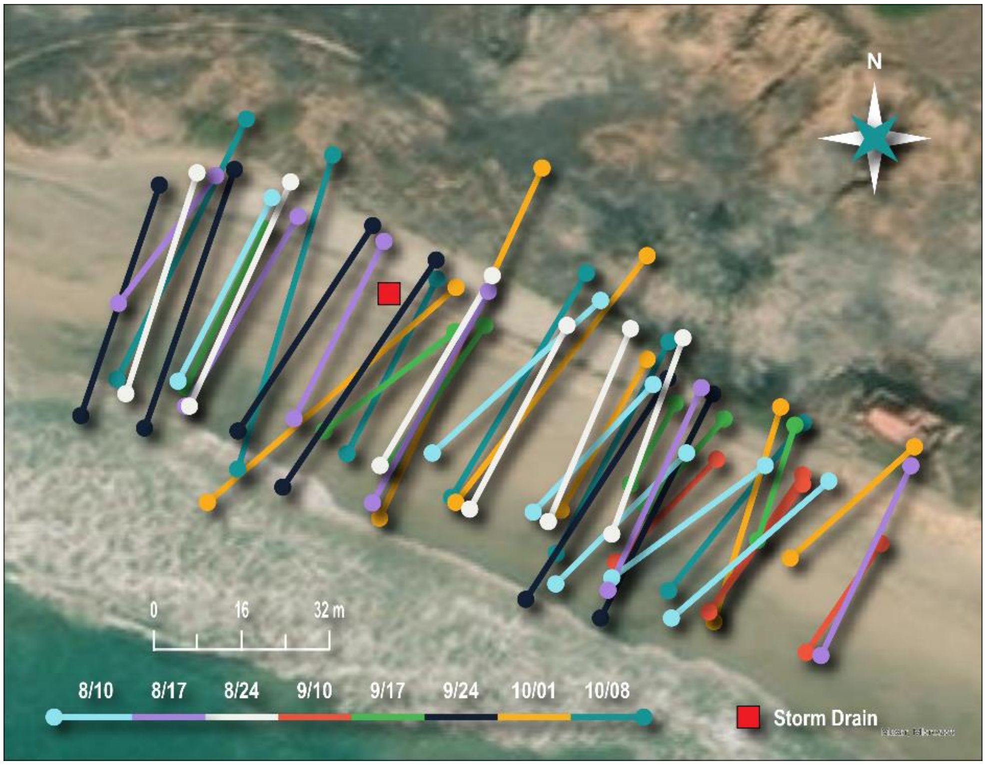

Figure 29: Color-coded transects represented for various dates in 2020 at Nicholas Canyon Beach. (Left side of image was the start of the study site; Right side was the end of the study site).

4.9 Summary

Nicholas Canyon Beach and Zuma Beach both varied in debris load in 2018 and 2020 with it being significantly higher at Zuma Beach due to its popularity, a wider variety of debris sources, and the amenities offered by the beach. Additionally, Zuma Beach's debris load nearly tripled in 2020 versus 2018, whereas Nicholas Canyon Beach's debris load doubled from 2018 to 2020. Furthermore, the findings showed both beaches had plastic as the predominant litter type in 2018 and 2020. The statistical analysis supported the abundance of plastic followed by processed lumber with it being significantly different compared to the other major material types signifying the grave concern of plastic pollution in the coastal and marine environment. The seasonal trend was observed in 2018, showing that Zuma Beach had a decline of debris in the fall season, whereas Nicholas Canyon Beach had an increase of debris in the fall season. In 2020, the seasonal trend accounted for the summer and fall season showing that there were high amounts of debris occurring in the summer months leading to a decline of debris towards the fall. In addition, the individual transects for both beaches shared a general pattern of most of the debris being found near storm drains and beach entrances. Lastly, the two beaches in Malibu, California had a total of 1,155 items.

Chapter 5: Discussion

This study addressed solid waste contamination at two southern California beaches. It was hypothesized that the spatiotemporal analysis would show a higher amount of solid waste at Zuma Beach compared to Nicholas Canyon Beach. The standing-stock assessment survey was used to gather raw data from these beaches. In addition, inferential statistics (t-test) were used to find the significant difference between both beaches based on the average count of debris load as well as the significant difference between 2018 and 2020. Additionally, an ANOVA statistical analysis was done to find the significant difference by both major material type and beach location. Furthermore, the predominant type of litter was compared to assess the potential differences in drivers for debris deposition. The temporal trends were observed on a weekly basis to assess the natural flux of debris deposition and removal. The hypothesis was partially supported by the results as the last day of fieldwork contradicted the general trend of Zuma Beach's higher count of debris compared to Nicholas Canyon Beach in 2018 compared to the hypothesis being supported in 2020. Also, the hypothesis was partially supported between both years with Nicholas Canyon Beach being significantly different for one month compared to the statistical significance across all months at Zuma Beach. Also, the hypothesis was supported between the different major material types being significantly different as well as the beach location.

5.1 Inferential Statistics for Debris

There was a significant difference between Zuma and Nicholas Canyon Beach based on the average total debris count for all months combined in 2018 and 2020 due to the possible higher number of visitors at Zuma Beach compared to Nicholas Canyon. The popularity of Zuma Beach brings in more visitors that may lack awareness of trash being disposed properly in nearby trashcans. In return, the main source of debris found on the coastline of these two beaches may be contributed to by public littering by beachgoers. A study by Nelm et al. (2017) concluded most litter items found on the beach of interest came from beach users, including bottle caps, cigarette stubs, and plastic. A factor that had been commonly reported by other studies claimed that the widest beach was often the most polluted (Araujo and Costa 2007). Zuma beach's width is wider than Nicholas Canyon by 40 meters, which may be a possible explanation for the difference being significant between both beaches.

The hypothesis was also supported accounting for the individual months in 2020 and supported only for September in 2018. Contrarily, the month of September showed considerable difference in debris compared to October of 2018. The fall season began on September 22, 2018, so beach visitors were less likely to visit due to cooler weather (the last survey date in October was in the low 70's) and the return of families to the school year. It was likely there was a decrease in visitor attendance in October compared to September that may be related to the difference between the two months. Furthermore, Zuma Beach has mechanical raking compared to Nicholas Canyon Beach, which may have contributed to the debris load decreasing at Zuma in October due to the lack of visitors. The contrast between the two months could also be related to two weeks of data recorded in October compared to three weeks of data in September, despite the significance found in October 2020.

The hypothesis for this study was based on there being a significant difference in debris load count between 2018 and 2020 for Zuma Beach and Nicholas Canyon Beach. The results concluded there was a significant difference found for the debris load count in comparison with the years. The debris found in 2020 were three times more than the debris load in 2018 for Zuma Beach. Contrarily, this study can reject with 97% certainty the null hypothesis for September except for both months combined and October only for Nicholas Canyon Beach. This may be related to the increase in popularity resulting from the pandemic during the summer and beginning of fall 2020. The beach closures were lifted in May 2020, which allowed beachgoers to visit the beaches for recreational use and on site there were large crowds observed since it was an outdoor space in the summer. This is important to consider due to beach goers being a source for polluting the beaches.

Upon further analysis, the hypothesis was also supported by both material type and beach location, which claim that the beach location and the major material type have a relationship to average debris counts. The results concluded plastic along with processed lumber was significant above all other types due to possible land-based origins of beachgoers littering and nearby sewers. A study found that the main reasons people litter on beaches is an absence of respect for the environment, lack of effort, and lack of education (Keenan 2008), which may be linked to the littering of napkins and plastic packaging products. Also, plastic litter are likely to be transported by the longshore-current off the Malibu coast and deposited on the coast of Malibu Beaches, similar to the findings of another study (Nakashima et al. 2011). In addition, the analysis showed that there was a significant difference between Nicholas Canyon and Zuma Beach for the two-way ANOVA analysis. Both beaches have a different level of pollution with Zuma Beach being the higher level. This may be related to beach popularity, access and proximity to the greater southern California area, and beach characteristics.

5.2 Predominant Litter

Zuma and Nicholas Canyon Beach both had plastic as the predominant litter type in 2018 and 2020. Similarly, numerous studies elsewhere found plastic as the top pollutant (Santos et al. 2005; Araujo and Costa 2007; Kusui and Noda 2003; Debrot, Tiel, and Bradshaw 1999; Topcu et al. 2013). The most abundant type of plastic was polystyrene plastic (foamed) for Nicholas Canyon Beach in 2018 and 2020, which was broken pieces of disposable polystyrene cups (figure 30). This finding supports other results from beaches beyond southern California owing to the popularity of polystyrene being used as food/drink containers by beachgoers, as well as easily carried by the wind, sewers, and ocean currents (Araujo and Costa 2007; Kusui and Noda 2003). By contrast, Zuma Beach had food wrappers as the most abundant form of litter in 2018 and 2020 (figure 31). Possible reason food wrappers were prominent at Zuma Beach may be the popularity and frequent picnics, whereas Nicholas Canyon Beach had a sewer that may have contributed to the polystyrene foam as well as by beachgoers that littered polystyrene packaging and remained in the environment breaking down over time accumulating into higher amounts. Similar results (notably food wrappers and plastic bags) were found by Purba et al. (2018) in Savu Sean Marine National Park, Indonesia. In addition, Zuma Beach had plastic smoking products (cigarettes) as the second leading plastic type for both years, whereas Nicholas Canyon had smoking products which appear on site only for 2020, which may be related to the summer months attracting beachgoers visiting less popular beaches to remain socially distanced during the pandemic. Cigarette stubs have been reported globally as a common problem on beaches (Widmer and Reis 2010), with one study showing that beaches in the Mediterranean found cigarette butts as the dominant type of litter (Topcu et al. 2013). Additionally, Zuma and Nicholas Canyon Beach both had processed lumber as the second leading dominant material type, which consisted of paper and cardboard at Zuma Beach for both years and Nicholas Canyon in 2020, whereas lumber/building material was recorded only at Nicholas Canyon in 2018. Processed lumber was the second highest due to beachgoers carrying napkins and toilet paper for accessible clean-up, as well as cardboard food take-outs and packaging being used for picnics. There may have been an increase in picnics occurring at Nicholas Canyon in 2020. Comparably, a study by Laglbauer et al. (2014) reported that paper was the second most abundant group reported for the six beaches along the Slovenian coast.

Figure 30: Polystyrene foam found at Nicholas Canyon Beach.

Figure 31: Food wrapper packaging at Zuma Beach.

5.3 Potential Drivers of Debris Deposition

The difference in debris sources is important to acknowledge because the local factors associated with Zuma and Nicholas Canyon Beach differ based on the physical beach characteristics and the surrounding neighborhood. The presence of an eroded coastal bluff at Nicholas Canyon contributed to additional pollutants on the shoreline. The damage was evident by the metal material, such as the pipes, rods, and sheet metals that were loosely attached to a paved road on the bluff. The bluff is vulnerable to increased damage as also from rain, waves, wind, and earthquakes. The vulnerability is evident from the thunderstorm that occurred in October 2018, where construction material became loose and was exposed on the shoreline the following week.

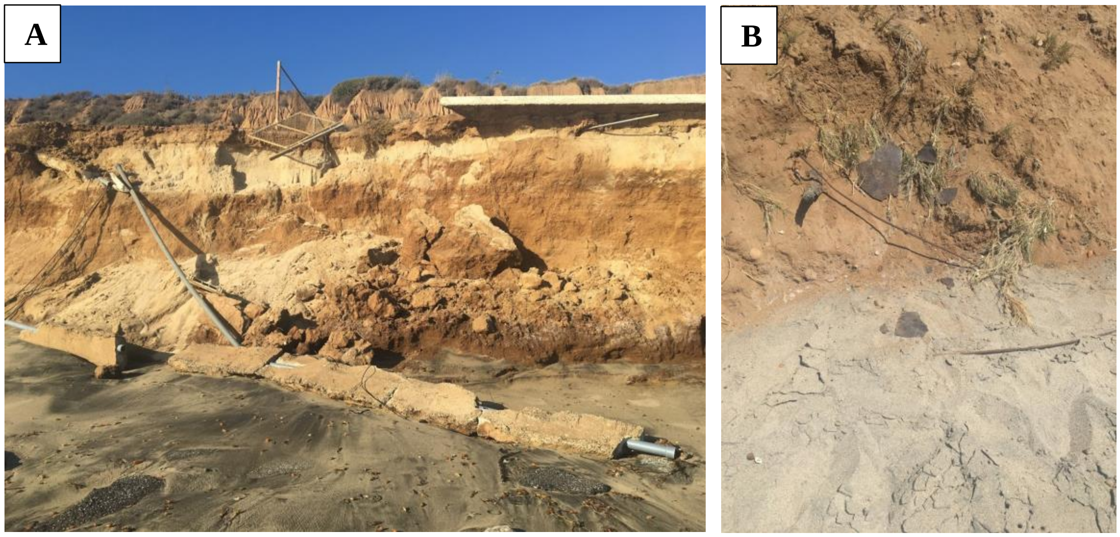

Figure 32: Nicholas Canyon Road evidence of erosion with pipes falling (A) and metal sheets and smaller rods (B). (Image by Author)

In 2020, the presence of eroded construction material was seen on the study site, which provides evidence that the eroded pavement on the bluff needs to be fixed by the city because the contaminants will likely continue polluting the coastal and marine environment (figure 32). In addition, the surrounding area between Nicholas Canyon Beach and Zuma Beach are different due to Zuma being more developed than Nicholas Canyon with beach amenities (snack shops, showers, and restrooms on the backshore, etc.) present. Additionally, near Zuma Beach there is a middle school, residences and a commercial area (figure 33). The high development at Zuma Beach attracts tourists to attend Zuma Beach as well as families that live nearby that may be a possible explanation of debris coming from land-based sources such as beachgoers littering. By contrast, Nicholas Canyon Beach is less developed with a small residential area on the north side of Pacific Coast Highway and limited housing along the bluff top along the highway (figure 33).

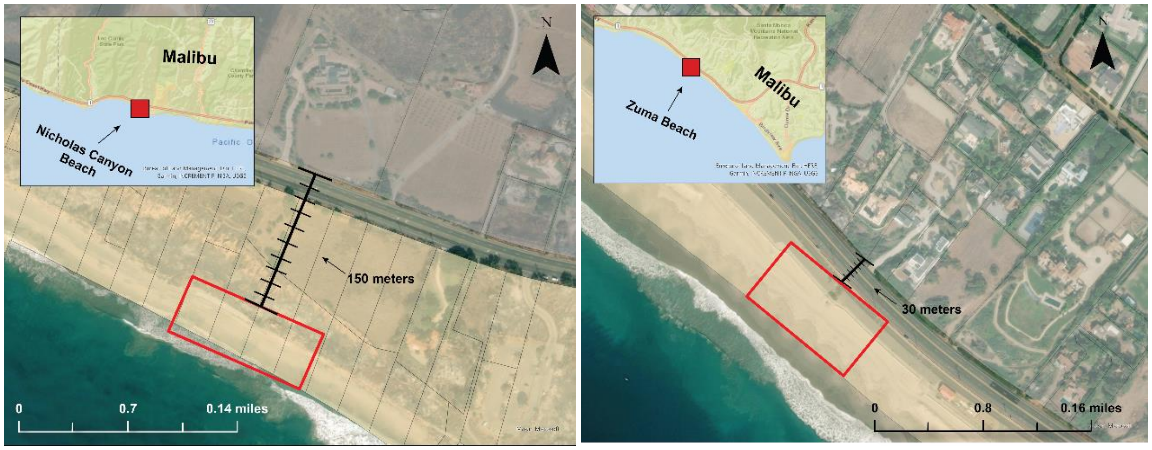

Figure 33: A) Distance in meters to residential area at Nicholas Canyon Beach B) Distance in meters to residential area at Zuma Beach, which is comparatively closer at Zuma compared to Nicholas Canyon Beach.

Figure 34: Secluded Nicholas Canyon Beach (Image by California Beaches website)

Nicholas Canyon Beach is more secluded as a pocket beach separated by small rocky headlands (figure 34), which may also explain the possible sources of litter at Nicholas Canyon Beach may be attributed by ocean-based sources such as debris being transported by the nearshore current, possible sources by the northern beaches (Leo Carrillo Beach etc.) or the Channel Islands. Also, land-based sources such as litter by beachgoers that prefer a less popular beach. Fishing is a popular recreational activity downcoast at Malibu Pier, so fishing debris may be attributed to fishing upcoast or from the Channel Islands.

Ocean-based debris were evident across the shoreline at Zuma and Nicholas Canyon Beach due to concentrated macro-debris (items >2.5 cm) found on the high tide mark. Zuma Beach had litter from marine-based sources (currents and tides) in 2020 due to the lack of removal of debris at the high tide line from the mechanical raking at the last survey date, which was not evident on the study site in 2018. The presence of mechanical raking at Zuma Beach reduces the amount of debris load on the shoreline, which contributes to an increase in beach debris if not properly maintained. Likewise, Nicholas Canyon had litter items found on the wrack line (a zone where organic material is deposited at high tide) due to the items being entangled within the seaweed in both years. This was evident in 2018 as well, due to identification of fishing-related debris at the site such as a crab cage. Fishing-related debris is disposed into the ocean by maritime activities such as commercial fishing, recreational fisheries, and shipping (Nelms et al. 2017; Purba et al. 2018). Similarly, a study by Scisciolo et al. (2016) proposed that marine debris found on the wrack-lines (high-tide mark) close to the waterfront on the beaches came from marine-based origins (transported by oceanic currents). A possible explanation for litter deposited on the high tide line at Zuma and Nicholas Canyon Beach may be influenced by the California Current and the nearby longshore-current transporting debris due to a combination of high tides and distant storm surges (figure 35). A study found that the North Pacific Gyre played a critical role in the distribution of debris on the shorelines of the Hawaiian beaches (Corcoran, Biesinger, and Grifi 2009).

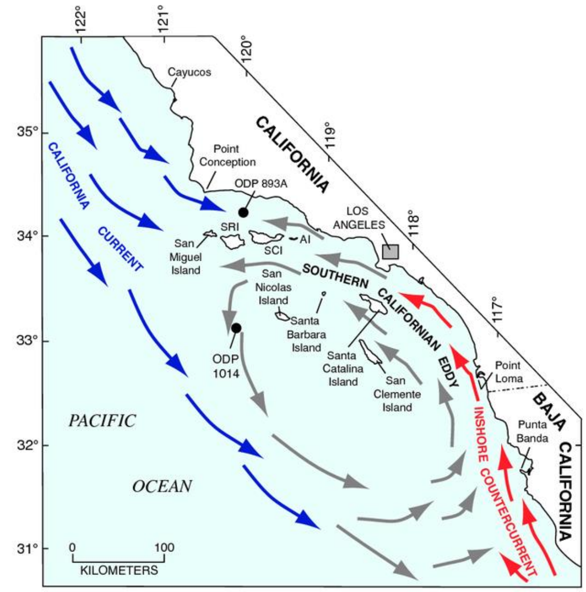

Figure 35: Possible marine debris transportation via the California Current (Map by Muhs, Groves, and Schumann 2014).

Land-based sources such as beachgoers and nearby storm drain outlets contributed the litter across the shoreline for both beaches (figure 27; 29). Littering by beach goers was evident across both beaches in both years as evidenced by the abundance of plastic polystyrene cups, bottle caps, plastic pieces, food wrappers, napkins, and cigarette butts commonly found on the upper zones (nearby beach entrances) of the transects. It is important to place trashcans nearby beach entrances to reduce beach debris. Many studies found that the anthropogenic marine debris densities were highest on the upper zones of the beach (backshore) compared to the lower zones of the beach (berm and foreshore) (Bravo et al. 2009; Silva Iniguez and Fischer 2003; Jackson, Cerrato, and Elliot 1997; Cunningham and Wilson 2003; Claereboudt 2004). This type of distribution pattern suggests local sources are to blame, due to the upper zones of the beach being more highly frequented by beach goers (Bravo et al. 2009). Additionally, both study sites have a beach outlet pipe that had fragments of debris around the storm drain source (figure 36). Additional sources of debris come from inland sources where debris are carried away to the coasts by rivers, wind, drainage systems or human activity (Corcoran, Biesinger, and Grifi 2009;

Araujo and Costa 2007; Barnes et al. 2009). Another study found through the comparison of 20 beaches on the Cadiz coast of Spain, the litter items found on the beach sites originated from either industrial/commercial waste transported onshore or by domestic/recreational sources (Williams et al. 2016).

Figure 36: A) Storm drain at Nicholas Canyon Beach B) Flowing storm drain at Zuma Beach.

5.4 Temporal Trend

Zuma beach showed an expected trend of debris declining in the fall associated with cooler temperatures and a return to school in 2018 and 2020. The decline of litter observed in October was apparent at Zuma Beach in 2018 due to weather conditions towards the end of the summer season as well as schools beginning in fall despite the highest amount of litter occurring the last week of September. Similarly, another study found that the public beaches of the Catalan coast in Girona, Spain, had a decline of small-sized debris in September because of unfavorable weather conditions toward the transition to fall related to the influence of cold Atlantic based air masses dominating the region (Ariza, Jimenez, and Sarda 2008). Additionally, the mechanical raking at Zuma led to further reduction of litter in October. Conversely, the increase on the last survey date in October 2020 at Zuma Beach may be attributed to an absence of mechanical raking.

Ariza, Jimenez, and Sarda (2008) also speculated that the mechanical cleaning procedures were insufficient at picking up the debris on the beaches of Spain during the peak season. Debris left behind on very busy days by the mechanical raking was an observed problem at Zuma Beach. For example, the removal of debris during the third week of September, which had high temperatures in the 80s, when the beach was overcrowded, was insufficient based on the increase of debris the following week of September 26, 2018, which had a high temperature as well (table 4). High temperatures have an influence to attract beach goers to visit beaches for recreation activities such as swimming and picnicking in the nice weather. By contrast, Nicholas Canyon had an increase in debris during fall 2018 and 2020 associated with other factors such as tidal wave action and current influence, which was not observed at Zuma in 2018 due to the mechanical raking removing debris but observed on the last survey date in 2020. A similar study found that solid waste buried under the sand during the dry season became exposed by the stronger waves and tidal action (Araujo and Costa 2007). At the study site in 2018, Nicholas Canyon's physical characteristics were altered each week by the tides, which was not evident in 2020. For example, one week there was a high concentration of seaweed that accumulated onshore (wave height: 0.78 ft; lower low tide). The following week the seaweed disappeared, and gravel dominated across the shoreline because of nearshore gravel bars migrating onshore (wave height: 2.78 ft; lower low tide). Additionally, the force of the wave may have deposited marine debris from the nearshore current on the last survey date at Zuma Beach (wave height 4.55 ft.) during lower high tide in 2020 (table 4). This is evidence of the strength of the waves and their ability to push a variety of anthropogenic and natural debris to shore. Tidal inundation, wave height, and approach has a significant role in the removal and transportation of macro litter onto the beach. Similarly, a study on the Mediterranean Coast of the Black Sea found higher litter concentrations in autumn due to factors such as intense rain, high waves, and strong northern winds that push surface currents to the coast (Topcu et al. 2013). Storm activity was evident for both Nicholas Canyon and Zuma Beach. Storm activity occurred before and after sampling on October 3rd, 2018, which may be associated with storms occurring at sea due to the low pressure (rainy weather) being off the coast, thus higher waves were evident (figure 37). Tides were higher than the usual low tides with stronger winds (wave height 2.78 ft: lower low tide), which was the highest recorded during the study period of 2018 (table 4). By contrast, rain did not occur in 2020 until later in the fall season.

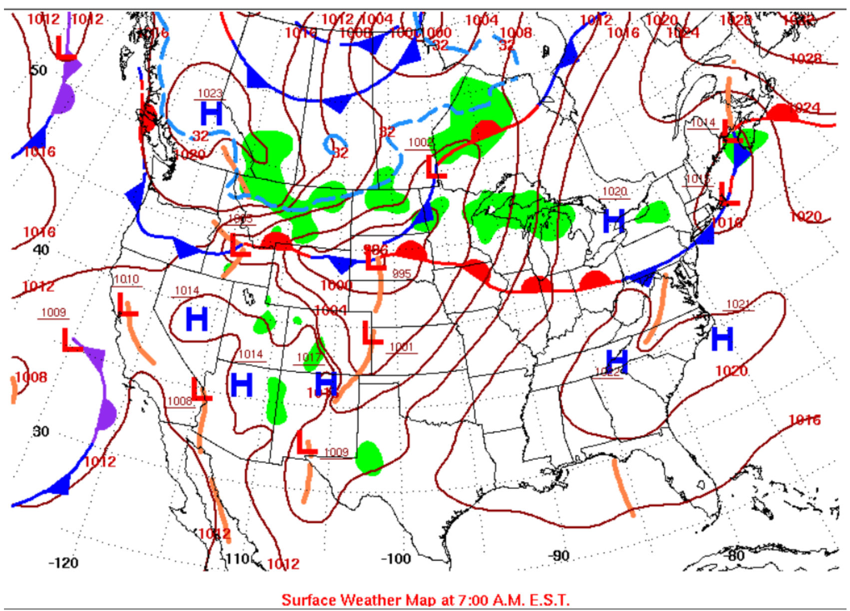

Figure 37: Daily weather map obtained by NOAA for October 3rd, 2018.

Table 4: Weather and tide level information for Malibu City.

Date	Day of the week	Weather (Daytime Temperature)	Tide Level	Wave Height (ft)
9/12/18	Wednesday	81	Lower low tide	0.64
9/19/18	Wednesday	81	Lower low tide	2.60
9/26/18	Wednesday	81	Lower low tide	0.74
10/3/18	Wednesday	79	Lower low tide	2.78
10/10/18	Wednesday	72	Lower low tide	-0.03
8/10/20	Monday	77	Higher low tide	1.81
8/17/20	Monday	88	Higher low tide	1.99
8/24/20	Monday	79	Higher low tide	1.44
9/10/20	Thursday	79	Higher low tide	1.47
9/17/20	Thursday	91	Higher low tide	0.60
9/24/20	Thursday	88	Lower low tide	3.05
10/1/20	Thursday	99	Higher low tide	0.92
10/8/20	Thursday	77	Lower high tide	4.55

The fluctuation of debris across the transects throughout the selected months was evident in 2018 and 2020. Nicholas Canyon had a high accumulation of debris found between transects 5-8 throughout the various survey dates in 2018 and 2020. These transects are located by a sewer at the site and a beach entrance with no trashcans available (figure 29). Similarly, Zuma Beach's high accumulation of debris were found by a sewer outlet (transect 11) as well as near a lifeguard tower (transect 1) and beach entrances throughout the site (figure 27). The lifeguard tower was later removed after returning to the same study site in 2020, which may have influenced the concentration of debris being mainly near the lifeguard tower due to being a suitable spot, the use of tower as shade, and an identifier spot if others are lost. The general trends for Nicholas Canyon and Zuma Beach were different from another study done at Tamandare Beach, Brazil. Araujo and Costa (2007) found that the highest amount of beach debris was located at the most northern and southern ends of the beach, compared to the lowest amount of beach debris in the middle of the study area.

5.5 Comparison of Debris Densities

Nicholas Canyon and Zuma Beach's debris density were measured by the number of debris items/per meter squared (Bravo et al. 2009; Schmuck et al. 2017; Scisciolo et al. 2016; Laglbauer et al. 2014). In the years 2018 and 2020, Nicholas Canyon Beach had a mean density of macro-debris (>2.5cm) of 0.028 ± 0.031 and 0.042 ± 0.032 items/m^2 (mean ± SD) respectively. Similarly, this study found that for Zuma Beach the mean density of macro-debris (>2.5cm) was 0.023 ± 0.018 in 2018 and 0.043 ± 0.017 in 2020. In total, the two beaches in Malibu, California had a mean density of macro-debris of 0.036 ± 0.026 items/m^2, accounting for a total of 1,155 items. In comparison with other studies globally, the macro-debris concentrations on Malibu Beaches were lower than on the beaches in the Pacific Basin region of Japan (Kusui and Noda 2003), Northern Taiwan (Kuo and Huang 2014), and South Korea (Lee et al. 2013) except for the South China Sea (Zhou et al. 2011) as well as being lower than the other beaches located in other basins of Slovenia (Laglbauer et al. 2014), Turkey (Terzi and Seyhan 2017), Russia (Kusui and Noda 2003), Brazil (Oigman-Pszczol and Creed 2007) and Tasmania (Slavin, Grage, and Campbell 2012) (Table 5). Similarly, the total number of macro debris items reported in this study were lower than those reported on South Korean (Lee et al. 2013), Japanese (Kusui and Noda 2003), Northern Taiwanese (Kuo and Huang 2014), and South China Sea (Zhou et al. 2011) beaches found in the Pacific-Basin Region, as well as, Slovenia (Laglbauer et al. 2014), Brazil (Oigman-Pszczol and Creed 2007), and Turkey (Terzi and Seyhan 2017) (Table 5). The low debris concentrations and total item count in Malibu compared to the other studies may be associated with the number of surveyed beaches, popularity of the beaches, and period of study. Conversely, comparing the beaches in the other basins, the total number of items on Malibu Beaches were nearly two times more than the debris count on Russian beaches (Kusui and Noda 2003), but similar in comparison to Tasmanian beaches (Slavin, Grage, and Campbell 2012) despite the lower number of beaches surveyed for this study (Table 5). A possible explanation may be associated with an influx of tourists visiting Malibu Beaches in Los Angeles County compared to Russia and Tasmania. Generally, the beaches found in the Pacific-Basin Region had higher amounts of debris by total number of items/m^2 compared to the other basins, which may be attributed to the North Pacific and South Pacific Gyre that may transport debris on the shorelines of other countries as well as these beaches being popular tourist destinations.

Table 5: Macro debris litter densities and total number of items in this study and other regions of the world.

	Total number of items/m2	**Number of Surveyed Beaches**	**Average Densities (items/m2)**	**References**
Pacific-Basin Region				
California, USA	1,155	2	0.03	This Study
Japan	32,212	18	3.41	Kusui and Noda (2003)
Northern Taiwan	9,319	6	0.149	Kuo and Huang (2014)
South Korea	8,205	6	1.0	Lee et al. (2013)
South China Sea	37,500	9	0.01	Zhou et al. (2011)
Other Basins				
Brazil	15,832	10	0.13	Oigman-Pszczol and Creed (2007)
Russia	679	8	0.21	Kusui and Noda (2003)
Slovenia	5,840	6	1.25	Laglbauer et al. (2014)
Tasmania	1,010	9	0.28	Slavin, Grage, and Campbell (2012)
South-eastern Black Sea Coast, Tukey	5,690	9	0.16	Terzi and Seyhan (2017)

The only previous quantification of debris on the Malibu City shoreline was from data collected by a non-profit organization called Heal the Bay (Orrala 2012) as well as by a NOAA personnel (Lippiatt 2016) (Table 6). The data of their study sites was obtained by the NOAA MDMAP database and used for comparison between the different beaches in Malibu City. Heal the Bay conducted the standing-stock survey in consecutive months from June 2012 to May 2014, which provided an overall pattern of debris load across various seasons throughout the years at Carbon Beach, Malibu, CA (Orrala 2012). Furthermore, a NOAA personnel conducted a beach survey at Zuma Beach one time in September 2016 (Lippiatt 2016). The survey-level debris concentration was highest at Carbon Beach (0.06) compared to NOAA's study site at

Zuma Beach (0.05), Nicholas Canyon Beach (0.04) and Zuma Beach (0.04) (Table 6). Additionally, plastic debris was prevalent among the Malibu Beaches across the years from 2012 to 2020 despite the different number of surveys per beach and years. Moreover, processed lumber, which consisted of napkins for the study sites, were the second dominant type of litter left behind by beachgoers across the other study sites. The estimates of the total debris count provided by the MDMAP database differed across the selected Malibu Beaches due to the number of surveys, period of study, characteristics of beach property, and popularity of the beaches by locals and tourists.

Table 6: Comparison of total debris counts for material type and survey-level concentration for the study sites across Malibu City obtained by the NOAA MDMAP database.

Debris Type	Heal the Bay	NOAA MDMAP	Present Study	Present Study
	Carbon Beach 2012-2014 (All Seasons)	Zuma Beach 2016 (September)	Zuma Beach 2018/2020 (Aug, Sep., Oct.)	Nicholas Canyon 2018/2020 (Aug., Sep., Oct.)
No. of Standing-Stock Surveys	22	1	13	13
Plastic	438	21	523	309
Metal	10	1	25	23
Glass	6	0	1	0
Rubber	0	0	5	2
Processed Lumber	77	4	173	39
Cloth/Fabric	2	0	20	30
Unclassified	2	0	2	3
Total Debris	535	26	749	406
Survey-Level Debris Concentraton	0.06	0.05	0.04	0.04

5.6 Limitations and Future Research

The limitations that have arisen for this thesis are related to data issues, small sample size, and timeliness. Specifically, all the dates had six transects except for September 12, 2018, when only four transects were surveyed. It would be useful to conduct an accumulation survey at both beaches where the 100-meter study site is covered instead of the limited number of transects. Furthermore, future research can extend the 100-meter sampling design to increase the data collection from both beaches. Ultimately, this could help to find potential hot spots of debris found along the coast as well as increasing the number of beaches to include all the beaches in Los Angeles County for comparison with the Orange County beaches (Moore et al. 2001). Furthermore, the study began on September 12, 2018 to October 10, 2018 at the beginning of the fall season compared to sampling across three months in 2020. It would have been preferred to begin during the summertime in 2018 to gather raw debris data and compare the fluctuation of debris from the summer to fall seasons. The limitations of timeliness for future research can show the fluctuations of debris concentration and type throughout different seasons of the year for both beaches. Furthermore, data issues related to GPS points for the chosen transects have arisen by the meter wheel that was used to mark the start and end point of the study site being altered by a few meters every week. For example, upon walking along the shoreline of Zuma Beach, the meter wheel got twisted and loose from the wind and other factors to alter the meters for each transect. The limitations of GPS points for the transects can be improved using a measuring wheel that is firm and not bendable, so it would not be altered throughout the shoreline by a variety of factors. Also, a setup of a permanent temporary benchmark (elevation reference in surveying) on the backshore of the beach is useful to have an accurate representation of the shoreline. However, the consistency of the same study site was the goal for both beaches to be an accurate representation of the section of shoreline that was chosen. In addition, both beaches chosen are public beaches owned by Los Angeles County. However, Zuma Beach has mechanical raking to pick up the debris whereas Nicholas Canyon Beach does not have consistent cleaning service, which affected debris concentration.

The temporal results that were related to the concentration of debris from both beaches are not generalized to other beaches globally due to the difference in clean-up managements, urban proximity, and the impact of visitors. Also, there is evidence from the literature that the difference between sources of debris among beaches makes comparison difficult. However, the generalization of plastic being the predominant litter type found at both beaches may apply to beaches globally because the consumption of plastic is used by society on a large scale. The next logical steps for the evolution of this research would be to analyze the concentration of microplastics found at Zuma and Nicholas Canyon Beach. The high volume of plastic found for both beaches raises a concern about the decomposition and persistence of fragments which are 2.5 cm, thus raising broader concerns for impacts on human health and marine ecosystems.

Chapter 6: Conclusions

The grave concern of marine debris winding up in the coastal and marine ecosystem highlights the grim trend that marine debris is a major environmental problem moving forward especially as the COVID pandemic have allowed more single-use plastic usage and plastic bag usage. The city of Malibu has created public policies of eliminating single-use plastic, plastic bags, and polystyrene foam to mitigate the problems of marine debris. Additional aids in educational workshops, signage postings on the beaches, and the presence of trash cans in proximity may help mitigate the problem of litter found on our valuable coastal and marine ecosystems.

Figure 38: New signage posted throughout Los Angeles County Beaches in September 2020.

Litter on beaches is harmful to marine fauna, human health, and the quality of the coastal ecosystem. The finding of plastics as the main debris provides a major concern for society as these concentrations increase each year globally. Plastic production worldwide had increased from 225 to 311 million tons per year between 2004 and 2014 (Hengstmann et al. 2017) and will continue to have significant negative impacts. Malibu Beaches had a lower amount of beach debris compared to other coastal regions around the world owing to vigilant plastic policies, increased signage, and educating the public (figure 38).

As plastics continue to degrade, forming microplastics, and circulate in the ocean gyres, they will continue to pollute our marine systems and wash ashore on coastlines globally. Only through policy changes which limit plastic usage and continued education which teach people about the impacts of litter will significant changes in debris concentration occur. One potential strategy is to encourage the “leave no trace” education concept used heavily in natural parks conservation for educating park and trail users. If the pollution of our marine systems does not stop soon, the oceans globally would be suffocated with plastics and other litter that is transported to the oceans and eventually collapse the food chain, impacting human health directly. The coastal environment and oceans need to be conserved so that ecosystems can balance themselves to their natural state. This will create more ecosystems for all living species on Earth for centuries to come.

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