Southern Maine Coastal Marine Debris Accumulation Estimation Study

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Abstract

The ocean is facing a multitude of anthropogenic stressors that are happening simultaneously. Increasing ocean temperatures, ocean acidification, overexploitation of fisheries, and pollution can disturb natural processes, alter food webs, and impact economies. Marine debris is one of these pervasive stressors that can be found from the open ocean, along shorelines, and throughout the water column. This is a global problem that has zero boundaries. Marine debris can range from macro to micro size and consist of material that can float, sink, and break down. Marine debris can affect the smallest of marine organisms through microplastic ingestion to the largest organisms through fatal entanglement. By focusing on coastal beaches and partnering with NOAA's Marine Debris Monitoring and Assessment Project (MDMAP) a baseline for marine debris was created for the shoreline of Southern Maine. This location in the Gulf of Maine was chosen due to its high biodiversity, important commercial fisheries, a lucrative tourist destination, and limited marine debris data in this area. Four survey sites were created and surveyed three times each that followed MDMAP's Shoreline Survey Guide and entered into the MDMAP's public database. Along with these four sites, five existing Southern Maine MDMAP sites were utilized for quantitative statistical analysis using RStudio. Total debris accumulated, the most common type of marine debris found, and breakdown of marine debris type can be shown from this analysis. Differences between marine debris in the sites and between newer and older time periods of marine debris collection can be seen from this study. This Southern Maine coastal marine debris accumulation and estimation study provides a baseline for the current state of marine debris and helps to assess current and new mitigation strategies to conserve an important marine ecosystem.

Keywords
Coastal pollution, macro debris, micro debris, anthropogenic threats, beach pollution, Gulf of Maine, marine ecosystem

Introduction

The ocean is facing many anthropogenic stressors including climate change, overexploitation of fisheries, and pollution (Tuuri & Leterme, 2023). Changes in oceanic conditions induced by these stressors can disturb natural processes, alter food webs, and impact economies. The ocean regulates climate and weather, contributes $32 trillion in ocean economy, and provides carbon cycling (Tuuri & Leterme, 2023). We need a healthy ocean to survive, and marine debris is now widely recognized as a major threat to marine biodiversity and marine environments (Tahir et al., 2019; Willis et al., 2017). This is a wide scale problem with no boundaries found along coast lines, open ocean, and throughout the water column. Marine debris is accumulating in five large areas in the ocean called garbage patches. The largest garbage patch is in the North Pacific Gyre, known as the Great Pacific Garbage Patch, and is estimated to be three times the size of France (Leal Filho et al., 2021). The North Atlantic Garbage Patch is the largest in the Atlantic Ocean, with about 200,000 pieces of debris found per square kilometer (Leal Filho et al., 2021).

Marine debris consists of persistent, manufactured, or processed material that is discarded, abandoned, and disposed of in marine environments (Willis et al., 2017). This debris can be categorized into land and ocean-based debris, depending on their likely source (Blickley et al., 2016). Ocean-based debris includes buoys, fishing line, nylon rope, nets, and lobster rubber bands. Land-based debris includes cigarettes, straws, fireworks, personal care products, food wrappers, clothing, bottles, and plastic bags. Identifying or indicating this land or ocean based marine debris source can be difficult since items can be moved and carried far from the point of origination (Uhrin et al., 2022). One of the most common materials found in marine debris is plastic and comprises 60-80% of the total debris accumulated (Morét-Ferguson et al., 2010). The longevity of plastics, that they break down into smaller pieces of plastic, and that they can float and be carried in water makes them a trans-boundary pollutant (Alagarsamy et al., 2014). Smaller pieces of plastic are called microplastics and are less than 5mm, can be primary products such as microbeads, or come from degraded and broken pieces of larger plastics (Tuuri & Leterme, 2023).

All types of marine debris can affect marine ecosystems, food webs, and humans. Plastic debris affects all trophic levels from zooplankton to whales (Vegter et al., 2014). Microplastics in marine habitats and in marine organisms have a potential threat to human health because of high consumption of marine foods by humans (Nawab et al., 2023). Disregarded fishing gear called ghost gear can continue to trap, entangle, and kill sea turtles, whales, sharks, seals, birds, fish, and lobsters. Marine debris has affected at least 690 species by entanglement and ingestion and 17% of these species are listed as threatened or near-threatened (Tahir et al., 2019). Current vulnerable coastal marine environments such as mangroves, estuaries, marshes, sea grass beds, and coral reefs can be further damaged from marine debris and hinder critical processes that they provide. These ecosystems are breeding grounds and nurseries that increase biodiversity, sequester carbon, and they help reduce coastal erosion.

Marine debris is a major environmental concern and the increase of plastic use in society mirrors the increase in marine debris (Vegter et al., 2014). In order to mitigate the problem of marine debris, current baseline data must be documented. By quantifying the types and amounts of marine debris found in coastal Southern Maine a baseline for marine debris accumulation and estimation was created. Standardized beach cleaning surveys were conducted and followed the guidelines provided by NOAA's Marine Debris Monitoring and Assessment Project (MDMAP). This is a citizen science project and the data collected contributes to MDMAP's comprehensive public dataset and to larger scientific studies that offers a means for authentic scientific practice (Haywood et al., 2015). Nine sites from Southern Maine were used from MDMAP for quantitative statistical analysis that include four sites from 2023 and five existing sites that include 2016 and 2018. The geographic area that surveys were conducted in is part of the Gulf of Maine and is one of the world's most productive marine ecosystems (Chase et al., 2001). With guidance from NOAA's MDMAP Coordinator, this location was chosen due to the limited data available for this area. The Gulf of Maine is a critical marine environment for fisheries, a popular and lucrative tourist destination, and a biodiverse ecosystem. This Southern Maine coastal marine debris accumulation and estimation study helps to provide a baseline for the current state of marine debris and helps to assess current and new mitigation strategies to conserve an important ecosystem.

Methods

Site Selection

To account for Southern Maine's environmental coastal variations, high tourist numbers during the summer, and year-round resident population, four study sites were chosen to represent shorelines for this region. The four sites are: Site 1 Kinney Shores Saco, Site 2 The Creek Ocean Park, Site 3 Weymouth Ave Ocean Park, and Site 4 Old Orchard Beach South of Pier. These four sites are illustrated in Figure 5. Survey sites were chosen according to the criteria of the NOAA Marine Debris Monitoring and Assessment Project Shoreline Survey Guide. Each site had clear and direct access, 100 meters of continuous shoreline parallel to the water, and marked with a permanent landmark at the beginning and end for easy identification (Burgess et al., 2021). A Shoreline Site Characterization Form was filled out for each site that recorded the start and end coordinates, direction when facing the water, nearest river, stream, or inlet, and site remoteness. To record site selections into the MDMAP database an account was requested and granted.

Site 1 Kinney Shores Beach Saco

Kinney Shores is part of Saco, has year-round residents, and is a popular tourist beach. The primary substrate is sand and the land back barrier is primarily dunes. Goosefare Brook is the nearest stream to this site and runs alongside it. This is an intertidal creek that empties into Saco Bay in the Gulf of Maine. This area has strong currents, constant sand movement, changing sandbars, and erosion. Residents that I spoke with said that they regularly clean the beach themselves, but no formal municipal beach cleanings are conducted. Trashcans are located on every boardwalk but were off the beach because high tide water marks are right up to the dunes. Signs at the beginning of the boardwalk state fireworks are prohibited, dogs to be leashed April 1st - September 30th, a marine mammal hotline number for reporting, and no further rules were posted. Part of the 100m site is an endangered Piping Plover nesting area and part of the dunes are roped off for protection. They are monitored by the Maine Department of Inland Fisheries and Wildlife and Saco volunteers. Aerial view with coordinates can be seen in Figure 1.

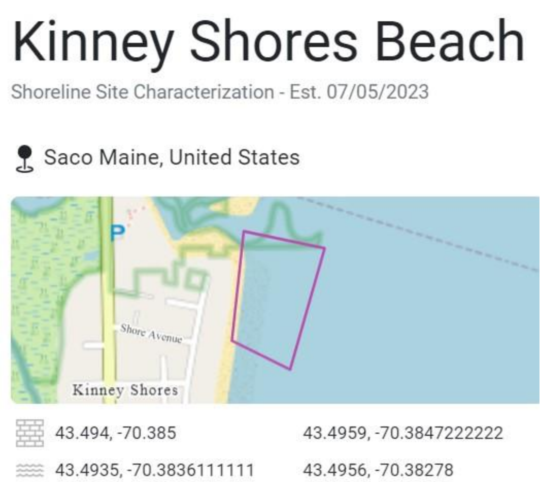

Figure 1. Kinney Shores Beach Coordinates. Map Credit (*MDMAP,* n.d.).

Site 2 The Creek Ocean Park

Ocean Park is part of Old Orchard Beach and is a popular tourist and residential beach. The primary substrate is sand and the land back barrier is primarily dunes. A beach cleaning vehicle is used for raking the sand in the morning that starts in May and ends after Labor Day. Trashcans are located on the beach at every boardwalk with signs stating carry out all trash, no smoking on beach, no public drinking, fireworks are prohibited, and hours when dogs are allowed. One boardwalk on Shore Rd was the exception and did not have a trashcan present. Goosefare Brook is right alongside this survey site and it is a tidal creek that empties into Saco Bay in the Gulf of Maine. There are strong currents coming in and out with the tides in this area, which causes constant sand movement, growing sand areas, sandbars, and erosion. Aerial view with coordinates can be seen in Figure 2.

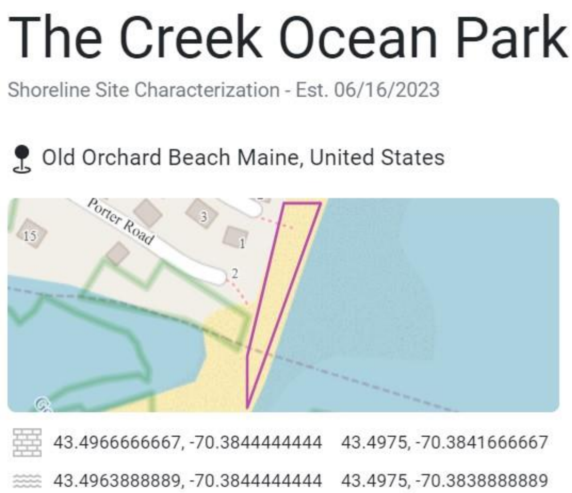

Figure 2. The Creek Ocean Park Coordinates. Map Credit (*MDMAP,* n.d.).

Site 3 Weymouth Ave Ocean Park

Ocean Park is part of Old Orchard Beach and is a popular tourist and residential beach. The primary substrate is sand and the land back barrier is primarily dunes. A beach cleaning vehicle is used for raking the sand in the morning that starts in May and ends after Labor Day. Trashcans are located on the beach at every boardwalk with signs stating carry out all trash, no smoking on beach, no public drinking, fireworks are prohibited, and hours when dogs are allowed. Part of the 100 meter area is an endangered piping plover nesting area and a portion of the dunes are roped off. This area is monitored by the Maine Department of Inland Fisheries and Wildlife. Goosefare Brook is 0.24 km from this survey site and it is a tidal creek that empties into Saco Bay in the Gulf of Maine. Aerial view with coordinates can be seen in Figure 3.

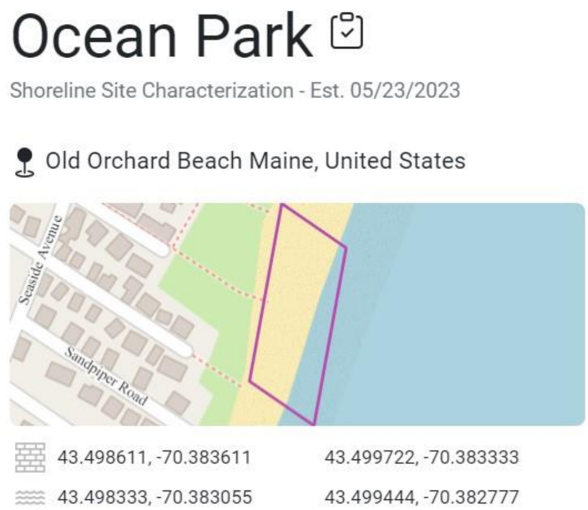

Figure 3. Weymouth Ave Ocean Park Coordinates. Map Credit (*MDMAP,* n.d.).

Site 4 Old Orchard Beach South of Pier

This area of Old Orchard Beach is considered "downtown" and is a vacation destination with a popular tourist and residential beach. There is a pier and amusement park in this area and every Thursday during the summer there is municipal fireworks display at this location. The primary substrate is sand and the land back barrier is primarily dunes. A beach cleaning vehicle is used for raking the sand in the morning that starts in May and ends after Labor Day. Trashcans are located on the beach at every boardwalk with signs stating carry out all trash, no smoking on beach, no public drinking, fireworks are prohibited, and hours when dogs are allowed. Goosefare Brook is 5.13 km from this survey site and it is a tidal creek that empties into Saco Bay in the Gulf of Maine. Aerial view with coordinates can be seen in Figure 4.

Figure 4. Old Orchard Beach South of Pier Coordinates. Map Credit (*MDMAP,* n.d.).

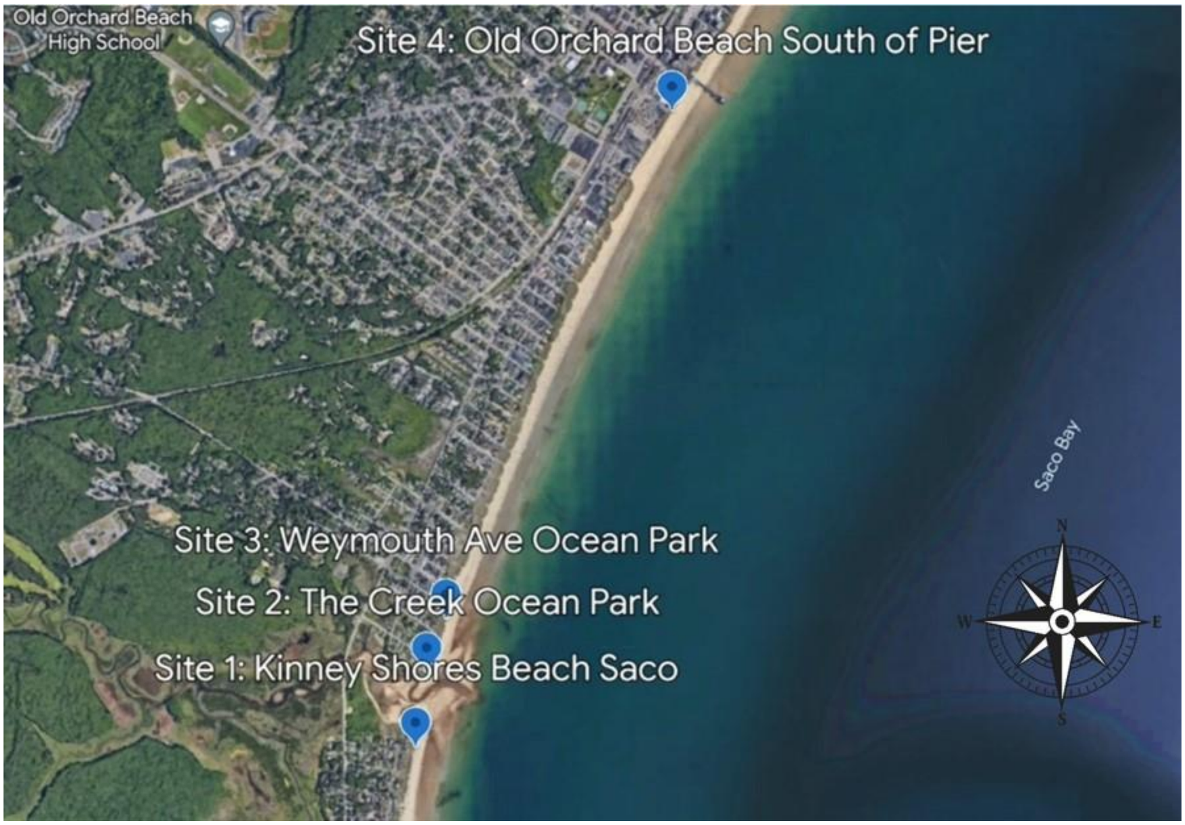

Figure 5. Aerial view of four chosen sites. Map Credit (*Google Earth,* n.d.).

Site Surveys

Weekly surveys were done at each of the four sites and conducted following the NOAA MDMAP Shoreline Survey Guide. A Survey Cover Sheet was filled out for each survey that recorded date, name of surveyors, total time to do survey, how many recreators on the beach, weather description, if trash cans were present, if drains were present within 100 meters of site, whether all debris was removed, and photo notes. Every survey site had four transects that were randomly selected to help eliminate observer bias. Each transect was five meters wide and started at the back barrier of the site to the water's edge as presented in Figure 6. These four transects are the areas where debris was collected, recorded, and removed.

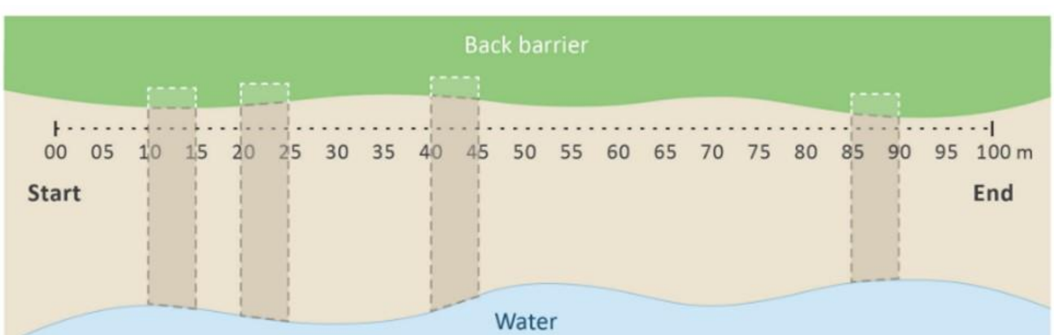

Figure 6. Visualization of 100m survey site with four random 5m transects.
Diagram Credit (Burgess et al., 2021).

Weekly Accumulation

Weekly surveys took place once every 7 days (+/- 3 days) for a total of three beach surveys per site. The surveys were completed in three consecutive weeks for each site as illustrated in Table 1. A total of 12 beach surveys were done from May 2023 to August 2023. For every survey, a Transect Survey Form was completed following the NOAA MDMAP Shoreline Survey Guide. This form recorded the start of the transect, beach width, slope of the beach, back barrier, and recorded the type and number of debris removed. Only debris larger than 2.5cm were recorded according to NOAA's guidelines and debris smaller than 2.5cm was included in the note section. All debris that could be seen with the naked eye was removed including any debris partially buried in the sand. Each survey consisted of two participants that searched for debris. All site survey data was collected by the same two surveyors who were trained by MDMAP's video tutorials and Shoreline Survey Guide to ensure consistency. Surveys were completed at low tide and either in the morning or at night to ensure little to no interference by beachgoers. Completed transect debris removal surveys were entered into the MDMAP database.

Table 1. Summary of completed surveys for four chosen sites.

Site	Date Survey 1	Date Survey 2	Date Survey 3
Site 1	07/05/2023	07/10/2023	07/20/2023
Site 2	06/16/2023	06/22/2023	06/24/2023
Site 3	05/23/2023	05/30/2023	06/06/2023
Site 4	07/24/2023	07/28/2023	08/04/2023

Marine Debris Categories

Marine debris items were classified according to the seven pre-defined types: plastic, metal, glass, rubber, processed lumber, fabric, and others. These main types of debris were further broken down into subtypes that can be seen in Table 2. Plastic fragments consisted of film, foam, and hard. Single-use consisted of plastic bags, beverage bottles, caps, cups, food wrappers, straws, utensils, and six-pack rings. Tobacco products had cigar tips, cigarettes, and disposable lighters. Fisheries consisted of buoys and floats, lures and lines, and rope and nets. Metals were listed as metal fragments, aerosol cans, and aluminum cans. Glass consisted of glass fragments, beverage bottles, and jars. Rubber consisted of rubber fragments, balloons, flip flops, gloves, and tires. Processed lumber contained cardboard cartons, lumber and building, paper and cardboard, and paper bags. Fabric consisted of fabric fragments, clothing and shoes, face masks, gloves (non-rubber), ropes and nets, and towels and rags. The number of items were recorded and whether the items were found on the main beach or back barrier. Collecting and sorting marine debris was conducted according to the NOAA MDMAP Shoreline Survey Guide. Pictures were taken of debris collected from each survey site's transects and included a 12inch ruler in the background for size reference, as can be seen in Figure 7.

	PLASTIC	main beach	back barrier
FRAGMENTS	Film		
	Foam		
	Hard		
SINGLE-USE	Bags		
	Beverage bottles		
	Bottle or container caps		
	Cups *(incl. polystyrene/foam)*		
	Food wrappers		
	Other jugs & containers		
	Straws		
	Utensils		
	Six-pack rings		
TOBACCO	Cigar tips		
	Cigarettes		
	Disposable lighters		
FISHERIES	Buoys & floats		
	Lures & line		
	Rope & nets		
OTHER	Balloons *(mylar)*		
	Personal care products		
	Shotgun shells & wads		
	Other plastic		

CUSTOM	main beach	back barrier

OTHER	main beach	back barrier

METAL	main beach	back barrier
Metal fragments		
Aerosol cans		
Aluminum/tin cans		
Other metal		

GLASS	main beach	back barrier
Glass fragments		
Beverage bottles		
Jars		
Other glass		

RUBBER	main beach	back barrier
Rubber fragments		
Balloons *(latex)*		
Flip flops		
Gloves *(rubber & latex)*		
Tires		
Other rubber		

PROCESSED WOOD	main beach	back barrier
Cardboard cartons		
Lumber & building		
Paper & cardboard		
Paper bags		
Other processed wood		

FABRIC	main beach	back barrier
Fabric fragments		
Clothing & shoes		
Face masks		
Gloves *(non-rubber)*		
Rope & nets *(natural fiber)*		
Towels & rags		
Other fabric		

Table 2. Marine debris categories and subtypes.
Table Credit MDMAP Transect Survey Form (Burgess et al., 2021).

Figure 7. Photo of marine debris from Site 2 transect 10 on 6/22/23.
Photo Credit Melissa Pratt.

Statistical Analysis

To add geographic range and historical data to this debris study in Southern Maine, five additional existing sites were used from MDMAP database. Freddy Beach in Biddeford was surveyed in 2018 and had a total of six surveys. The following sites were surveyed in 2016 and had a total of one survey each: Drakes Island Beach Wells, Goochs Beach Kennebunk, Ogunquit Beach, and Old Orchard Beach North of the Pier. This provides nine total survey sites for the statistical analysis and is presented in Figure 8. Quantitative statistical analysis was conducted using RStudio with the following packages: tidyverse, ggplot2, GGally, and dplyr. The data from the nine Southern Maine sites was exported from NOAA's MDMAP database into an Excel spreadsheet. The raw data was cleaned to ensure no redundancies and read into R. For 2023 site surveys the data columns of back barrier and main beach collection were merged to use for 2023 comparison only. Years prior to 2021 in MDMAP the back barrier collection was not recorded yet. Analysis for the years 2016, 2018, and 2023 includes data collection for the main beach only to prevent any inflation of marine debris.

Figure 8. MDMAP view of all nine survey sites in Southern Maine
Map Credit (*MDMAP,* n.d.).

T-tests were run to see if there was a statistical difference between 2023 data and data prior to 2018. The t-test is a statistical hypothesis that takes samples from both groups to determine if there is a significant difference between the means of the two groups (Awan, 2023). T-tests were done between two-year groups and ANOVA tests were used to compare three or more-year groups. One-way ANOVA tests were run with the independent variable of year being tested in the model.

Box plots were created for individual variables or for variables by group (Kabacoff, n.d.). This visualizes standard deviations and distributions of all data, sites, all debris, and type of debris breakdown. A box plot was created to depict the total debris distribution per site collection, total debris distribution per site collection in 2023, total debris distribution per year, and total plastic distributions per year. A stacked bar chart was created to show the total number of debris for each of the nine sites and indicated how much of each type of debris was found including plastic, glass, rubber, processed wood, cloth, metal, and other. A histogram was used to visualize the distribution of one or several variables (Holtz, n.d.). Eight histograms were created to show the frequency of one variable including total debris items, total cloth items, total glass items, total plastic items, total rubber items, total processed lumber items, total metal items, and total other items from the cumulative nine sites. This was to show an overview of the distributions.

Results

In 2023 from May to August a total of twelve beach cleaning surveys were conducted at four sites in Southern Maine. These surveys were entered into NOAA's MDMAP database for public use. These twelve beach cleaning surveys recorded and removed a total of 1,346 marine debris items from the Gulf of Maine shoreline. The items were larger than 2.5cm and included collection from the back barrier and main beach area. The most prevalent type of debris collected from all sites was plastic except at Site 4 Old Orchard Beach South of the Pier, where the most prevalent type of debris collected was processed lumber. Debris composition was similar among Sites 1, 2, and 3. Site 4 Old Orchard Beach South of the Pier had the highest total accumulation, followed by Site 2 The Creek Ocean Park, and Site 3 Weymouth Ave Ocean Park had the least amount of total marine debris accumulation as shown in Figure 9.

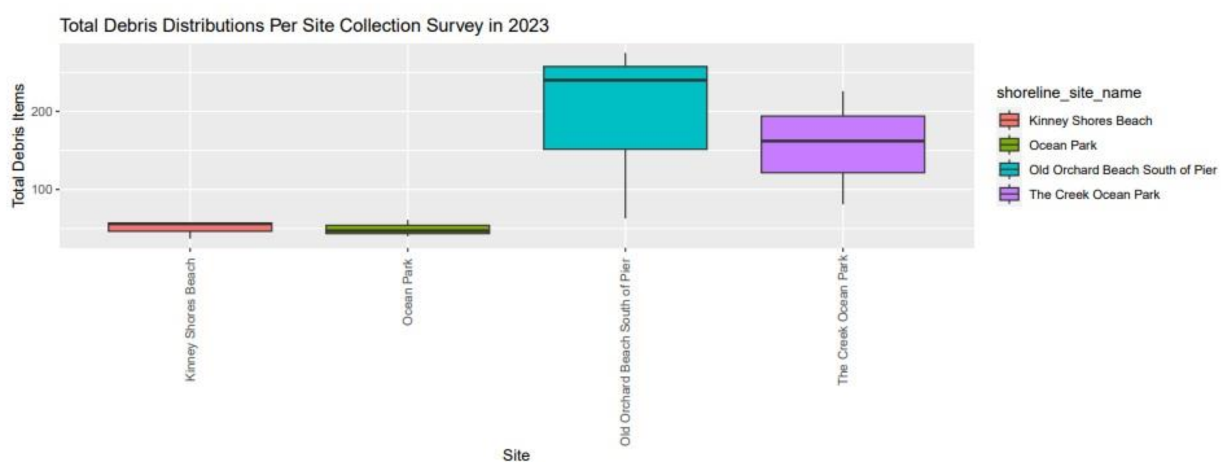

Figure 9. Boxplot of Total Debris Distributions Per Site in 2023
Created by Melissa Pratt Using RStudio.

In 2018 from February to March a total of six beach cleaning surveys were conducted at Freddy Beach in Biddeford, Maine. The most prevalent type of debris collected from this site was plastic with it being 91% of the debris found. In September of 2016 a total of four beach cleaning surveys were conducted with one each at Drakes Island Beach Wells, Goochs Beach Kennebunk, Ogunquit Beach, and Old Orchard Beach North of the Pier. The most prevalent type of debris collected from all 2016 sites was plastic and represented more than 70% of the debris found. Debris composition was similar among Goochs Beach Kennebunk, Ogunquit Beach, and Old Orchard Beach North of the Pier with processed lumber being the second most marine debris type found. At Drakes Island Beach Wells, the second most marine debris type found was cloth fabric.

A total of nine sites in Southern Maine were analyzed and the total debris breakdown for each of the sites included the seven pre-defined types: plastic, metal, glass, rubber, processed lumber, fabric, and others. This can be seen in Figure 10. All nine sites except Old Orchard Beach South of the Pier had predominantly plastic marine debris items. The seven histograms shown in Figure 11 show the frequency of one variable from all the nine sites.

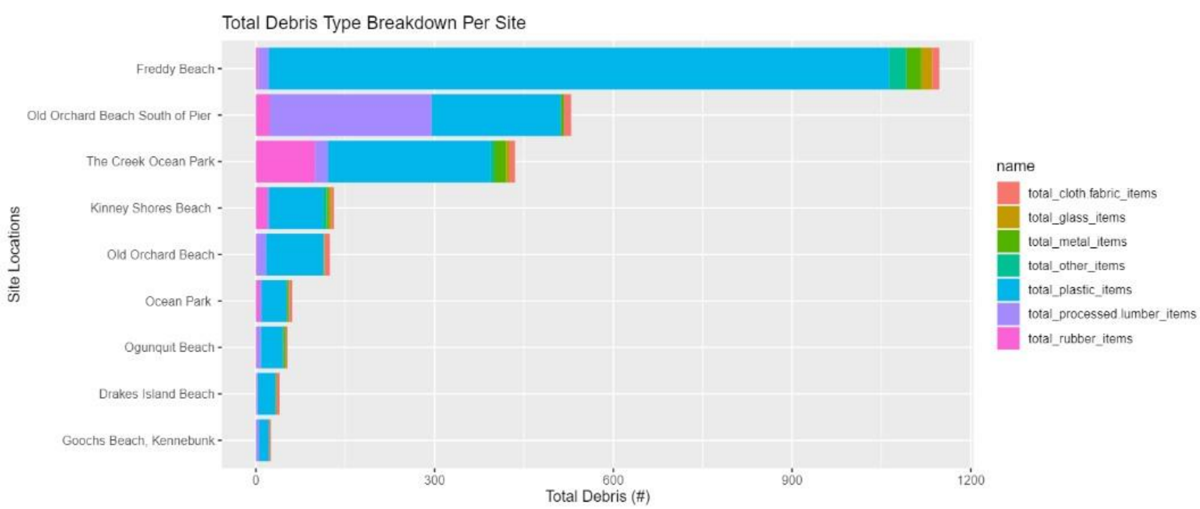

Figure 10. Stacked Bar Chart Total Debris Type Breakdown Per Site
Created by Melissa Pratt Using RStudio.

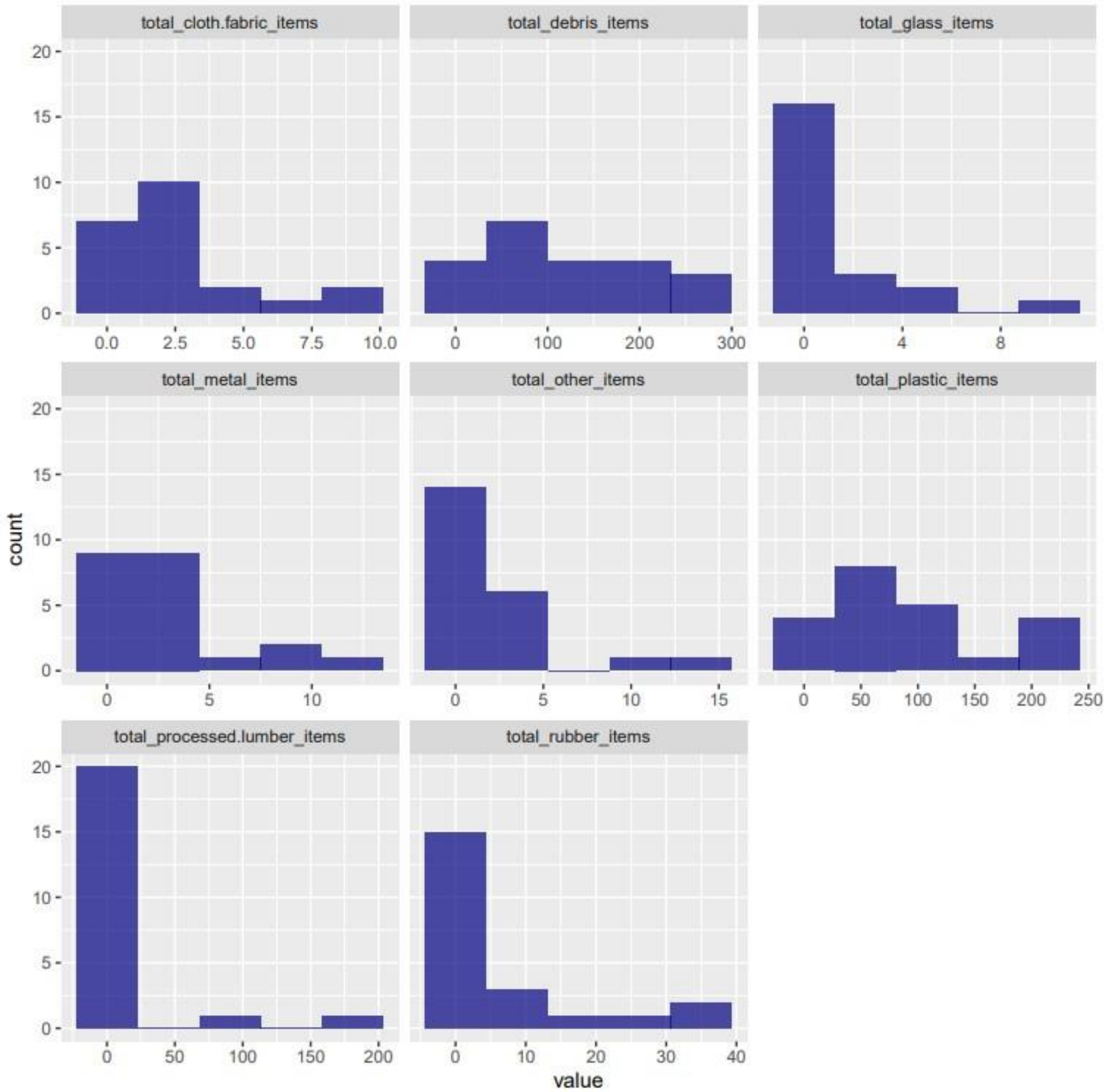

Figure 11. Histograms Showing Frequency of Each Variable from All Nine Sites
Created by Melissa Pratt Using RStudio

The surveyed years of 2023, 2018, and 2016 represent the nine total sites surveyed in Southern Maine. Total marine debris distribution per year with the highest total items was in 2018 shown in Figure 12. The year 2018 is only represented by Freddy Beach in Biddeford, which led to comparing the mean of Freddy Beach 115.6818 to the mean of all other sites 87.375 shown in Figure 13. On average there is 14% more debris at Freddy Beach than all other sites: (116-87)/(116+87) = 0.1428571

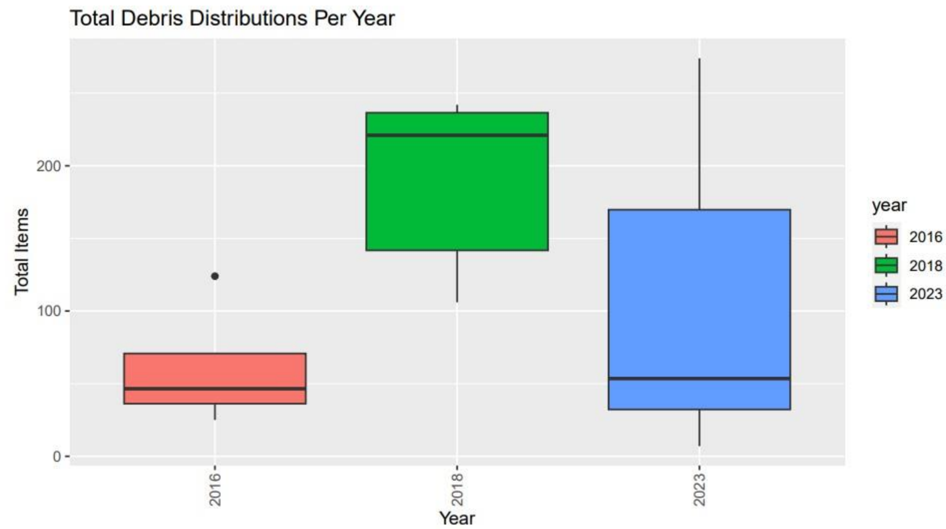

Figure 12. Boxplot of Total Debris Distributions Per Year
Created by Melissa Pratt Using RStudio.

Figure 13. Boxplot of Total Debris Distributions at Freddy Beach vs All Other Sites
Created by Melissa Pratt Using RStudio.

Discussion

Plastics were the predominant type of marine debris found in Southern Maine. Plastic marine debris is a growing and common problem that represents by far the most litter found on beaches (Alkalay et al., 2007; Law et al., 2010; Mishra et al., 2023). Eight of the nine sites in Southern Maine illustrated this global dire problem. Amounts of debris in strandlines can vary among beaches and, from time to time, on the same beach (Browne et al., 2015). This was seen in the nine surveyed sites and even with the variation amount; the type of marine debris, plastics, remained the most common type found.

Of all nine sites surveyed in Southern Maine, Freddy Beach in Biddeford had the highest total amount of marine debris and the highest amount of plastics. Freddy Beach is located at the mouth of the Saco River. This river starts in New Hampshire's White Mountains and meanders 136 miles to Maine, where it empties into the Gulf of Maine (Saco River Watershed, 2023). Large rivers are a major source of plastic waste and every year between 1.15 and 2.41 million tons enter the oceans (Chassignet et al., 2021; Zocco et al., 2023). The Saco River may be a contributing source of high amounts of plastic and other debris found at Freddy Beach.

Old Orchard Beach South of the Pier had the second highest total amount of marine debris, with the most common type of marine debris being processed lumber. This area has a high concentration of tourists, takeout restaurants, and novelty stores. In coastal areas around the world, human coastal activities were found to be a dominant source of beach waste (Kong et al., 2023). Old Orchard Beach has a year-round population of 9,000 residents but in the summer the population can jump up to 75,000 (Old Orchard Beach, 2023). OOB South of the Pier is the location of seasonal weekly firework displays. These surveys found an excessive amount of fireworks debris on the main beach and was also seen washing out to shore as shown in Figure 14 and 15. The town of OOB was contacted and a high amount of fireworks debris was reported. The following week this site was sampled after the fireworks display and only three pieces of fireworks debris were found. It is unclear if it was a rare occasion that high amounts of fireworks debris were left on the beach or if this is common practice and was only addressed because of this study's complaint. Firework debris was broken down into two marine debris types: processed lumber and plastics, which explains why this site had the highest amount of processed lumber. This sampling may have been an outlier since it was only surveyed three times during the peak tourist season and two of the surveys were directly after firework displays.


From left to right Figure 14. Total fireworks debris collected at Old Orchard Beach South of the Pier on 7/28/2023.

Figure 15. Fireworks debris at Old Orchard Beach South of the Pier's shoreline on 7/28/2023.

Photos Credit Melissa Pratt

The Creek Ocean Park had the third highest total amount of marine debris. This site is located at the mouth of Goosefare Brook, which is an eight-mile-long stream that is an important watershed for Old Orchard Beach and Saco (City of Saco, n.d.). Goosefare Brook flows through two towns and can pick up pollutants and debris, which can alter the ecology of the watershed and transfer debris into the ocean. This site was the only location that did not have a trashcan present at every boardwalk within the 100m surveyed area. It was noted that this site had a trashcan in the past and when the town was contacted to request the trashcan back, there was no response. Trash was being placed by locals and returning tourists where the trashcan had previously been located. Indicating that if the trashcan was present, it would have been used to reduce the marine debris found at this site. This beach has high erosive areas where beach morphology from waves, currents, tides, and winds drastically changes its' appearance on a day-to-day basis (Slovinsky, 2005). Sand-buried marine debris is a major sink on beaches, and tides not only transport the debris to land but also carry it away (Smith & Markic, 2013). Due to its location at the mouth of a stream and the lack of adequate trash receptacles, this may be why this site has the third highest amount of total marine debris. Even according to this ranking, the extreme erosion and morphology of this beach should be taken into account when considering that the total accumulation of marine debris is likely to be largely underestimated.

Site 3 Weymouth Ave Ocean Park had the least amount of total debris from sites surveyed in 2023. This location is not directly along a stream or river, with the closest stream being Goosefare Brook 0.24 km away. Every boardwalk within the 100m transect surveyed had a trashcan present. This site had sections of back barrier dunes roped off to protect endangered piping plover nests. Roped off areas were created and monitored by the Maine Department of Inland Fisheries and Wildlife. Although this is still a popular summer beach, it is not as highly populated as Old Orchard Beach South of the Pier. The combination of not being at the mouth of a stream or river, multiple trashcans present, lower levels of coastal human activities, and steady monitoring by Maine Department of Inland Fisheries and Wildlife could be the reason for the lower amounts of marine debris found. It is important to note that this site was surveyed primarily in May and early June before the peak of the tourist season, which could also explain the lower levels of marine debris recorded.

Mitigation

Three of the four sites surveyed in 2023 are in Old Orchard Beach. This town had clear signage at the beginning of every boardwalk informing the public to carry out all trash, no smoking on beach, and no public drinking. Also, at every boardwalk a trashcan was present, except for one boardwalk located at Site 2 The Creek Ocean Park. Site 4 Old Orchard Beach South of the Pier accompanied the trashcans with bottle recycle bins. Old Orchard Beach has taken beneficial approaches to mitigating marine debris with signage educating the public, supplying trashcans, emptying trashcans daily, beach cleaning vehicle rakers in the summer, and hiring additional staff during the summer to help clean high tourist areas. Current mitigation strategies in OOB are effective and could be used as a model for other Southern Maine towns, however there is still need for improvement. Simple remedies such as ensuring trashcans are present at every boardwalk with a separate bottle recycle bin, trashcans present throughout the year, trashcans regularly emptied throughout the year, and mandatory firework clean up directly after display would help decrease the marine debris found at these sites. Municipal regulations requiring takeout restaurants to use sustainable plates, napkins, utensils, and straws would be beneficial since these were the products found at Old Orchard Beach South of the Pier. These regulations could go as far as banning the use of Styrofoam, plastic straws, plastic bags, and other single use plastic items. These efforts would reduce the amount of plastics and other marine debris from ever reaching the ocean.

Debris mitigation is not only the responsibility of coastal towns and cities. Inland locations with proximity to lakes, rivers, streams, and watersheds are sources of pollution that can transfer debris from land to sea. The Saco River is a prime example that spans multiple states; yet coastal areas like Freddy Beach at the mouth of the river see the consequences of land sourced marine debris. If the marine debris is not picked up and properly recycled it can be carried away to other places by wind, tides, currents, and storms. There is a rapid loss of marine debris from beach surfaces from the time it is deposited (Smith & Markic, 2013).

Both prevention and cleanup aspects must be considered when addressing the problem of marine debris (Alagarsamy et al., 2014). Removing marine debris through organized public cleanups helps to educate the community, spread awareness, create engagement, and instantly reduces the amount of debris in the environment. Marine debris cleanups don't only have to be on the beach to be effective; they can be in marshes, along rivers, at lakes, and at other inland locations. They are an inexpensive and accessible way to mitigate the problem of marine debris. Another beneficial option is engaging in citizen science projects like NOAA's Marine Debris Monitoring and Assessment Project. Simultaneously removing marine debris from the environment and recording important data into a public database helps fill research gaps, quantifies information for further research, and provides opportunities to examine large-scale impacts of marine debris (Rochman et al., 2016).

Conclusion

This short-term local study has provided an important baseline for marine debris in Southern Maine. This quantitative study accurately provides an assessment to inform the public, policymakers, and non-governmental organizations about the scope of this environmental problem. The absence of adequate marine debris monitoring data creates barriers to addressing marine debris solutions (Ambrose et al., 2019). By following NOAA's MDMAP Shoreline Survey Guide, this study helped reduce that barrier by contributing new data to MDMAP's public database. In order to incorporate future projections a standardized long-term debris monitoring study would need to be conducted (Blickley et al., 2016). This is feasible by following the same MDMAP Shoreline Survey Guide, surveying the same nine sites in Southern Maine, and conducting multi-year sampling. A large-scale and long-term study would improve the comparability, repeatability and increase the value of this monitoring effort (Uhrin et al., 2022).

Appendix

Appendix A

The Marine Debris Monitoring and Assessment Project's data can be found at: https://mdmap.orr.noaa.gov/References

To find the data collected and used for this Southern Maine marine debris study enter "Maine" into the search bar. All nine sites used in this study are available to view and each site has an export option where all raw data can be downloaded.

Appendix B

Data analysis was conducted with RStudio and the code for this can publicly be viewed at GitHub:
https://github.com/mpratt02/maine-coastal-debris

Appendix C

Set of Guidelines from the Journal Conservation Biology Followed:
https://conbio.onlinelibrary.wiley.com/pb-assets/assets/15231739/Author%20Style%20Guide%20feb2019-1551741575403.pdf

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