MARINE DEBRIS - MONITORING AND ASSESSMENT PROGRAM AT GREATER FARALLONES NATIONAL MARINE SANCTUARY: JULY 2012 THROUGH JUNE 2017.

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Office of National Marine Sanctuaries
John Armor, Director

Report Authors:

Kate Bimrose[1], Kirsten Lindquist[1] Jan Roletto[2]

[1]Greater Farallones Association
[2]Greater Farallones National Marine Sanctuary

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Cover Photo:
Marine Debris survey volunteer on Limantour Beach.
Credit: Kate Bimrose

About the Marine Sanctuaries Conservation Series

The Office of National Marine Sanctuaries, part of the National Oceanic and Atmospheric Administration, serves as the trustee for a system of underwater parks encompassing more than 620,000 square miles of ocean and Great Lakes waters. The 13 national marine sanctuaries and two marine national monuments within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migration corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique or endangered species and are important to America's cultural heritage. Sites range in size from less than one square mile to more than 582,000 square miles and serve as natural classrooms, cherished recreational spots, and are home to valuable commercial industries.

Because of considerable differences in settings, resources, and threats, each marine sanctuary has a tailored management plan. Conservation, education, research, monitoring and enforcement programs vary accordingly. The integration of these programs is fundamental to marine protected area management. The Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the sanctuary system. Topics of published reports vary substantially and may include descriptions of educational programs, discussions on resource management issues, and results of scientific research and monitoring projects. The series facilitates integration of natural sciences, socioeconomic and cultural sciences, education, and policy development to accomplish the diverse needs of NOAA's resource protection mandate. All publications are available on the Office of National Marine Sanctuaries website (http://www.sanctuaries.noaa.gov).

Disclaimer

Report Availability

Electronic copies of this report may be downloaded from the Office of National Marine Sanctuaries website at http://sanctuaries.noaa.gov.

Contact

Kate Bimrose, Marine Debris Program Coordinator, Greater Farallones Association, 991 Marine Drive, San Francisco, CA, 94129, (415) 970-5245, kbimrose@farallones.org.

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Introduction

The pollution of our coasts and oceans by man-made debris is one of the fastest growing threats to our global marine system. Marine debris is defined as any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of in the marine environment (Marine Debris Act of 2012). Marine debris is a pervasive global problem that impacts marine life, damages habitat, impedes navigation, and affects our economy. From 1997 to 2010, total input of debris into the world's ocean grew from roughly 6.4 million tons/year to as much as 12.7 million tons/year (Inniss et al. 2017). Whether transported through streams, storm drains, mismanaged waste and wastewater, or directly from shipping and fishing activity, beach goers, and at-sea waste disposal, the pollution of our marine environment is ever increasing (Derraik 2002 and NOAA 2016).

The Government of Japan estimates that the 2011 9.0-magnitude Tohoku earthquake and subsequent tsunami washed roughly 5 million tons of debris into the Pacific Ocean, of which an estimated 1.5 million tons remained floating months and even years after the tragic event (NOAA Marine Debris Program, 2015a). This event increased attention to the global issue of marine debris, and prompted national and international collaboration to assess its quantity, location, and movement.

In 2012, the NOAA Marine Debris Program (MDP) initiated the Marine Debris Monitoring and Assessment Project (MDMAP) to collect a rigorous dataset of marine debris deposition along United States shores. The program engages citizen scientists to utilize standardized marine debris shoreline protocol for conducting two types of beach surveys, standing stock and accumulation, every four weeks. The main objectives for all surveys include: 1) estimate the quantity of debris at local and regional levels according to land use or other parameters; 2) determine types and concentration of debris present by material category; 3) examine the spatial distribution and variability of debris, and; 4) investigate temporal trends in debris type and concentration (Lippiatt et al. 2013). MDMAP survey data are entered into a NOAA managed online database (https://mdmap.orr.noaa.gov/login), which serves as a centralized resource for data sharing and analysis amongst program partners and the public.

At the program's inception Greater Farallones National Marine Sanctuary (GFNMS), in partnership with Greater Farallones Association, joined the MDMAP initiative as part of a wider network of participating government, academic, and non-profit partners. GFNMS is part of NOAA's national marine sanctuary system. The system consists of fourteen marine protected areas encompassing more than 600,000 square miles of marine and Great Lakes waters. GFNMS protects the wildlife, habitats, and cultural resources of 3,295 square miles off the northern and central California coast, spanning over 300 miles of coastal shoreline. The waters within GFNMS encompass a nationally significant marine ecosystem that provide breeding and feeding grounds for at least twenty-five endangered or threatened species; thirty-six marine mammal species; over a quartermillion breeding seabirds; and one of the most significant white shark populations on the planet (GFNMS, 2017). The area is also significant for recreational visitors and local economies. In 2011 an estimated 3.2 million person-days (number of days/visitor recreational activity) of recreation were spent in GFNMS (Leeworthy et al. 2015). Of the 20 recreational activities surveyed, excluding fishing, a total of $86.25 million dollars of spending were added to the local economy during this time. From 2010 through 2012, the GFNMS recreational fishing industry added roughly 200 jobs and an additional $10.3 million in income to local economies (Leeworthy and Schwarzmann 2015). The need to protect biological diversity and vulnerable habitats within GFNMS alongside preservation of critical tourism and fishing industries, highlights an ongoing demand for monitoring and assessment of GFNMS resources. Participation in MDMAP provided a critical component to this knowledge, allowing GFNMS to collect baseline information about the types and frequency of marine debris on sanctuary shores.

From July 2012 through June 2017, GFNMS participation in MDMAP included management of four standing stock survey sites. In June 2015, two accumulation survey sites were added. This report details the development and implementation of GFNMS-managed MDMAP survey sites and analyzes all survey data from July 2012 through June 2017 to provide insight into, and characterize, the marine debris problem along the north central California coast. We analyzed debris composition, product type (consumer, smoking, and fishing related products), and the most frequently recorded items for all six survey sites. We assessed how the movement of ocean water during seasonal currents, El Niño Southern Oscillation events, and short-term storm events may influence the amount of debris deposition and retention on beaches. Finally, we analyzed how debris from source and point-source origins can connect debris on beaches to specific locations, industries, and demographics. Understanding the type, composition, depositional patterns, and sources of marine debris is valuable for determining debris production, movement, and related impacts. The sanctuary will use this information to inform debris prevention and reduction management policies that will protect GFNMS species and habitats while ensuring safe recreational and commercial use of this special marine ecosystem.

Methods

GFNMS participation in MDMAP included execution of two survey types. Standing stock surveys determine debris density (# of items per m^2), and accumulation surveys determine debris flux (# of items per unit area, per time). Data were collected at standing stock sites from July 2012 through June 2017, and at accumulation sites from June 2015 through June 2017. Each survey site was established using MDMAP selection criteria: 1) year-round beach access and space to accommodate a 100 m long site; 2) sand or pebble substrate; 3) away from management zones (e.g. endangered species conservation zones, enclosures, restoration areas); 4) no disruptions to nearshore circulation such as breakwaters or jetties; 5) no regular monthly clean-up activities, and; 6) manager/land owner permission (Lippiatt et al. 2013). Survey site selection was also informed by GFNMS local knowledge and historical deposition patterns derived from 25 years of data collected as part of the GFNMS Beach Watch program. All six sites were located on north central California coast beaches within Marin, San Francisco and San Mateo counties, and managed by national or state park partners (Figure 1).

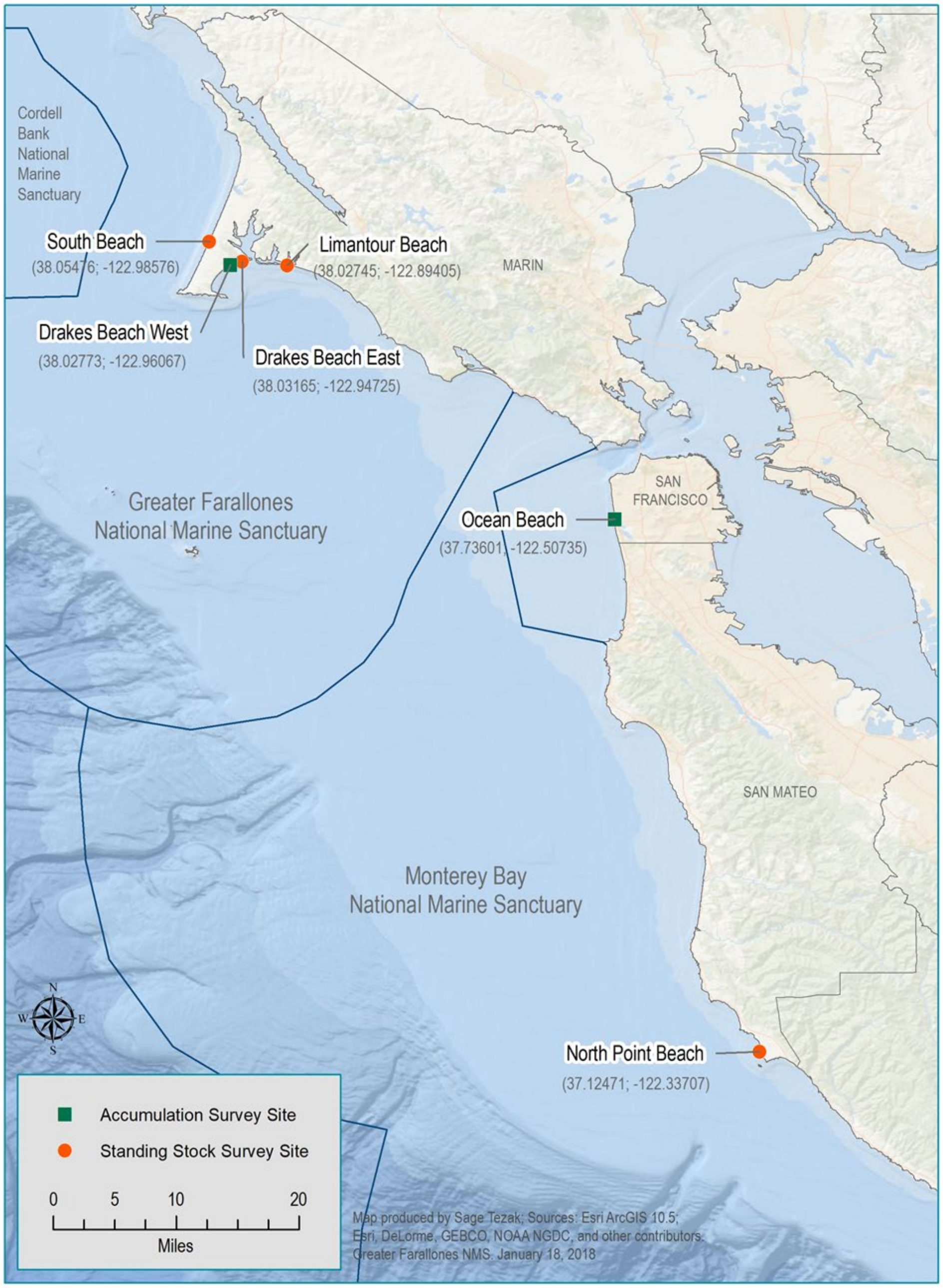


Figure 1. Location of GFNMS managed MDMAP standing stock and accumulation survey sites with latitude and longitude coordinates demarcating landward corner of each site.

Each standing stock and accumulation site was 100 m long, parallel to the water's edge, with two landward corners located where the primary substrate changed or at the first barrier (i.e. vegetation line, dunes), and two corners positioned along the water's edge. Width, from the two landward corners to the water's edge, was determined by tide height, which varied according to amount of beach exposed during daily tides. In order to survey the greatest width of beach, all surveys were conducted at low tide. Survey sites were sampled every 28 days, plus or minus three days, using MDMAP protocol and approved GFNMS survey sheets (Appendix A).

During each survey, beach characteristics were recorded to help determine influencing factors in debris source and/or deposition. These include the date, time, season, and weather, both current and recent storm activity (i.e. precipitation occurring within the previous seven days), as well as presence of debris at the back barrier located behind the two landward corners. Surveyors then tallied all man-made debris $\geq$ 2.5 cm within the survey area. All debris items were recorded under six major categories: plastic, wood, glass, cloth/fabric, metal, and rubber. Each of the six categories included sub-categories for more specific characterization of debris type (Table 1). Items that fell within a major category but not within a specified sub-category were identified under the "other" section of each major category. For example, plastic beach toys were recorded under the plastic "other" subcategory. Debris items were captured as "unclassified" when they did not fall within one of the six major debris categories, such as leather, wax, or when the surveyor was unsure of material type. For reoccurring items that were not included in the original sub-categories, we added a "custom item" sub-category, to better characterize the presence of specific items unique to the area. Plastic shotgun shells/wads and plastic debris from oyster farming activities such as mesh bags and oyster rack separator tubes,

Table 1. Six major debris categories and sub-categories along with examples of "Unclassified" items and "Other" items within each major category. *Represents sanctuary established custom debris items.

Category	Sub-categories
Plastic	Hard, foam and film fragments, bags, balloons, beverage bottles, bottle/container caps, buoys and floats, cigar tips, cigarette lighter, cigarettes, cups, fishing lures/line, food wrapper, other jugs or containers, oyster farm debris*, personal care products, rope/net pieces, utensils, shotgun wads*, six-pack rings, straws, other (e.g. toy, pen)
Wood	Cardboard cartons, lumber/building material, paper and cardboard, paper bags, other (e.g. cork, toothpick)
Glass	Beverage bottles, jars, glass fragments, other (e.g. picture frame)
Cloth/ Fabric	Clothing and shoes, fabric pieces, gloves, rope/nylon, towels/rags, other (e.g. seat belt, curtains)
Metal	Aerosol cans, aluminum/tin cans, metal fragments, other (e.g. bottle caps)
Rubber	Flip flops, gloves, balloons, rubber fragments, other (e.g. rubber bands)
Unclassified	Wax, leather, items of unknown material type

were identified as custom items for GFNMS survey sites in 2015. On occasions prior to 2015 when custom items were observed and recorded in the notes section of survey sheets these items were retroactively inserted in the plastic "other" category and indicated as a "custom item" in the NOAA online database. These data were included in the analysis of this report unless otherwise specified. It is important to note that custom items were not properly recorded prior to 2015 and thus data during these years is likely an underestimate

All debris items ≥ 2.5 cm, partially or completely within the survey area, were tallied. At least 50% of an item had to be present in order to be recorded as an identifiable item. When less than 50% of the item was present, the item was tallied as a single fragment. For example, 50% or more of a plastic beverage bottle was characterized as a beverage bottle, while less than 50% of a beverage bottle was recorded as a hard plastic fragment. Items composed of multiple material types were recorded under the category and sub-category of the most abundant material. For example, a piece of wooden building material with metal nails was tallied under the lumber category. For items 30 cm (1 ft) and larger, additional data were collected including material type, width, and length along with photo documentation.

Before data entry into the MDMAP online database all survey entries underwent a quality control process to verify accuracy, and all hard copy survey sheets were kept in-house at GFNMS. Site-specific features for each survey location were detailed on Characterization Forms (Table 2). An example of the Characterization Form can be found at https://marinedebris.noaa.gov/mdmap-protocol-documents-and-field-datasheets or on pages 57 and 58 in NOAA's *Marine Debris Monitoring and Assessment: Recommendations for Monitoring Debris Trends in the Marine Environment* (Lippiatt et al. 2013). After the verification process, data from survey sheets were entered into NOAA's online database available at https://mdmap.orr.noaa.gov/login.

Standing Stock Surveys

Standing stock survey sites were established using all MDMAP selection criteria. Additional criteria required sites to be established in remote areas with very low or no public use and away from outflows such as drainage pipes, rivers, or streams. Standing stock surveys measured debris concentration (# of items/m^2) and persistence through the recording, but not removal, of debris. This displayed changes in debris concentration between surveys and reflected the long-term balance between debris inputs and removal (Lippiatt et al. 2013). Items were removed during standing stock surveys only if they posed a human health or safety threat. Standing stock sites were surveyed by sampling and recording all man-made items within four randomly selected five-meter wide transects, perpendicular to the shoreline. Beginning in June, 2015 GFNMS surveyors documented smaller man-made debris items between 5 mm and 2.5 cm (mesodebris)

Table 2. A subset of physical and geographical features depicted in the Characterization Form for all six survey sites. PRNS = Point Reyes National Seashore; GGNRA = Golden Gate National Recreation Area; ANSP = Año Nuevo State Park

Beach Name	**Average Width (m)** (back of beach to water)	**Tidal Range (m)** (vertical range)	**Tidal Distance (m)** (from low- to high-tide line)	**Back of shoreline** (substrate change or first barrier)	**Aspect** (direction when viewing the ocean)	**Nearest town distance (km)**	**Nearest water body (km)**
South Beach, PRNS	32	2.4	40	vegetated dunes and cliffs	NW	20	3.5
Drakes Beach West, PRNS	43.5	2.1	40	vegetated dunes followed by parking lot	SE	11	3
Drakes Beach East, PRNS	66.5	2.1	40	dunes followed by marsh	SE	12	0.4
Limantour Beach, PRNS	47.7	2.1	40	European beach grass and dunes	S	10	0.5
Ocean Beach, GGNRA	32.9	1.8	30	steep ridge and parking lot	W	0	10
North Point Beach, ANSP	35.4	1.8	40	vegetated dunes	NW	17	8

at standing stock sites. These items were noted on the hard copy datasheets but not a component of NOAA survey protocol and therefore not entered into the NOAA online database. Instead GFNMS kept in-house records at the sanctuary offices. From June 2015 through June 2017 a total of 1,905 pieces of mesodebris were recorded across the four standing stock survey sites. During this time 4,785 pieces of debris ≥ 2.5 cm were recorded.

Accumulation Surveys

Accumulation sites were also established using MDMAP selection criteria, but did not require any specific distance from outflows or human access points. Accumulation surveys determined the rate of debris deposition, i.e. flux (# of items per m^2 per unit time), by recording and removing all debris from the entire site. This displayed debris accumulation within each site from one survey to the next. Two accumulation survey sites, Drakes Beach West and Ocean Beach, were established in June 2015. Location of the Drakes Beach West survey site was roughly one mile from the Drakes Beach East site in order to avoid impact or influence on data between the two locations (Figure 1). During each survey the entire 100 m site was sampled and all man-made items ≥ 2.5 cm were recorded, removed unless too large for manual removal, and recycled whenever possible. Documentation of smaller mesodebris items were not recorded during accumulation surveys due to the amount of time required and potential likelihood of overlooking items. We analyzed debris flux (# items/m^2/time) for all accumulation surveys at both sites.

Results

Survey data from July 2012 through June 2017 was analyzed to provide insight into the composition, abundance, movement, and sources of marine debris present at each of the six survey sites. From July 2012 through June 2017, 280 marine debris surveys were conducted, documenting 24,926 items ≥ 2.5 cm. The 59 standing stock surveys at South Beach documented 1,668 items at an average of 0.0577 items/m^2 (0.1628 standard deviation). Sixty surveys at Drakes Beach East documented 4,357 items at an average of 0.0558 items/m^2 (.0558 standard deviation). At Limantour Beach 63 surveys documented 1,867 items with an average of 0.0329 items/m^2 (0.0353 standard deviation), and at North Point Beach 53 surveys documented 1,959 items at an average of 0.0646 items/m^2 (0.1694 standard deviation) (Figures 2 through 5). Debris concentration per survey for each of the standing stock sites ranged from 0.0329 items/m^2 to 0.0646 items/m^2 (Figure 6). From June 2015 through June 2017, 22 accumulation surveys were conducted at Drakes Beach West documenting 7,511 items at 0.0028 items/m^2/time (0.0023 standard deviation) (Figure 7). During this time 23 surveys were conducted at Ocean Beach documenting 7,564 items at 0.0036 items/m^2/time (0.0032 standard deviation) (Figure 8). Mean flux at accumulation sites ranged between 0.0028 – 0.0036 items/m^2/time (Figure 9). North Point Beach had the highest debris concentration per survey for the standing stock sites, and Ocean Beach had the highest debris flux for the accumulation sites.

Debris Composition

Of all debris counts for both survey types, per site per survey, over 90% of total items recorded were plastic (Appendix B). The majority of the plastic items were hard plastic fragments. Of the non-fragment plastic items at each site, the most abundant were consumer related products, ranging between 41% - 64% at each of the survey sites. Examples of these items include food wrappers, beverage bottles, bottle caps and straws (Figure 10). The highest abundance of fishing related products, including fishing line, lures, and buoys, were at South Beach (19%), while both accumulation sites had the

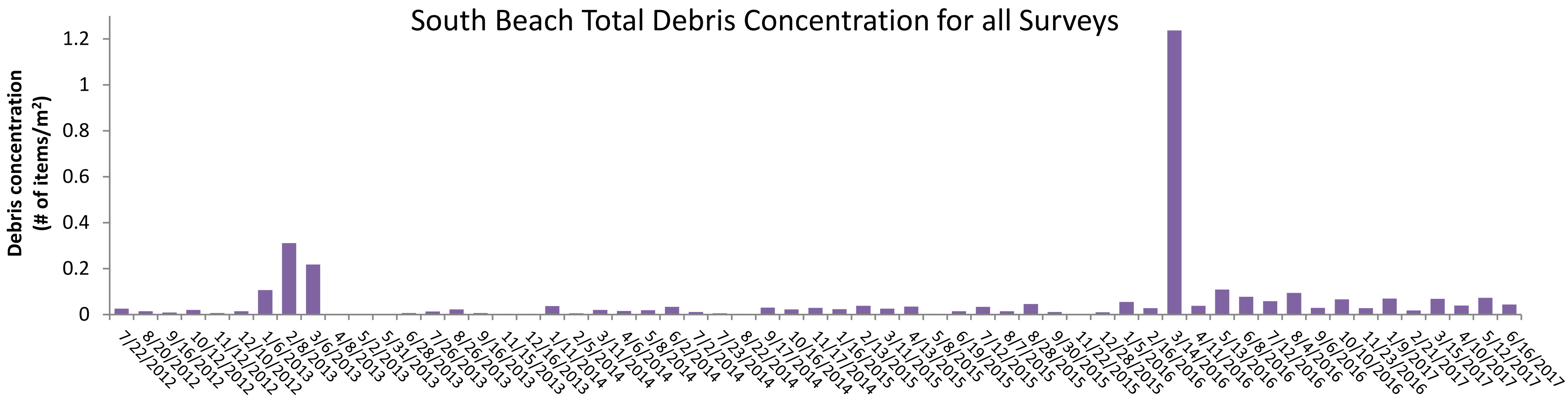


Figure 2. Total debris concentration per survey at South Beach standing stock site, July 2012 through June 2017.

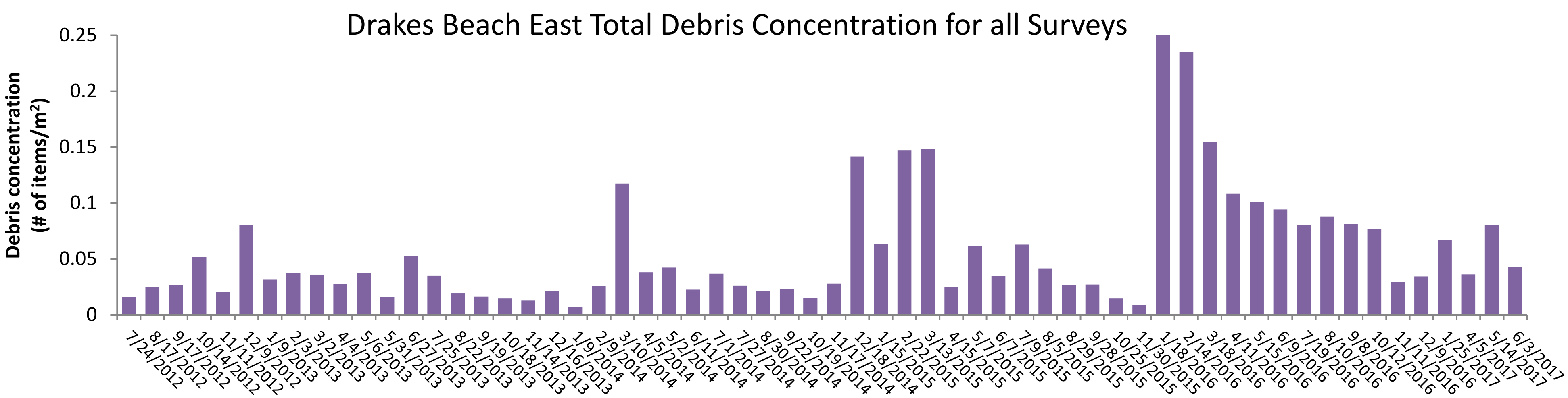


Figure 3. Total debris concentration per survey at Drakes Beach East standing stock site, July 2012 through June 2017.

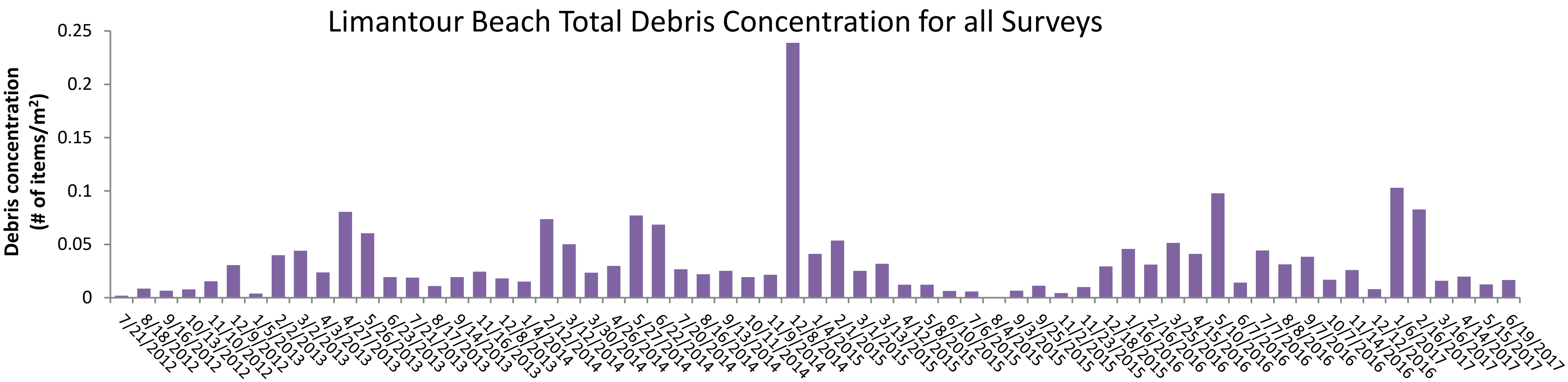


Figure 4. Total debris conservation per survey at Limantour Beach standing stock site, July 2012 through June 2017.

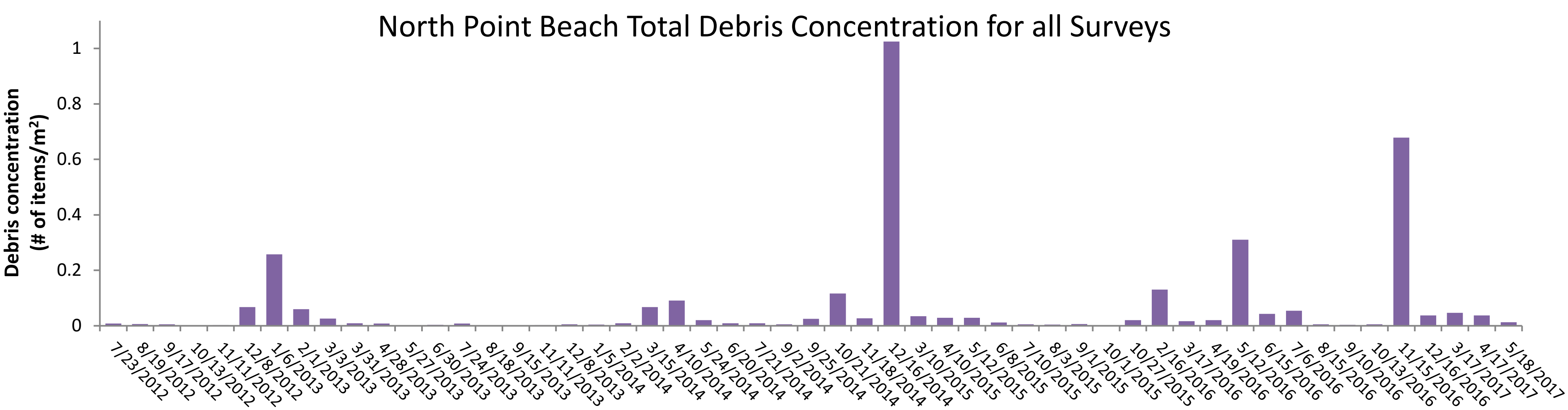


Figure 5. Total debris concentration per survey at North Point Beach standing stock site, July 2012 through July 2017.

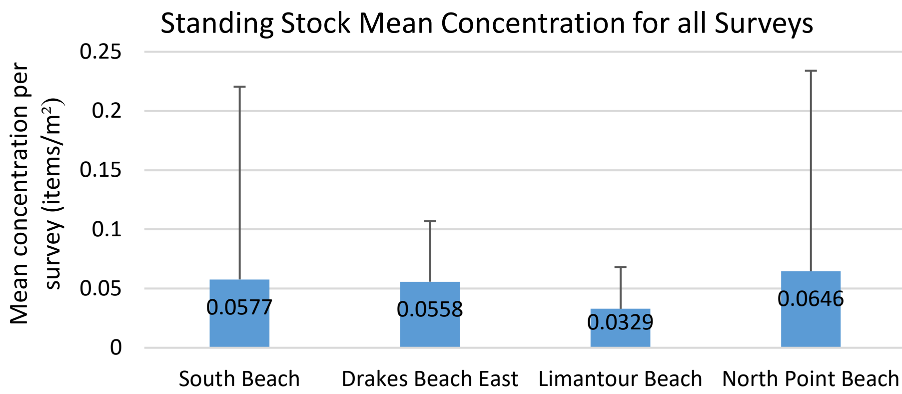


Figure 6. Standing stock site mean concentration per survey for all surveys, July 2012 through June 2017.

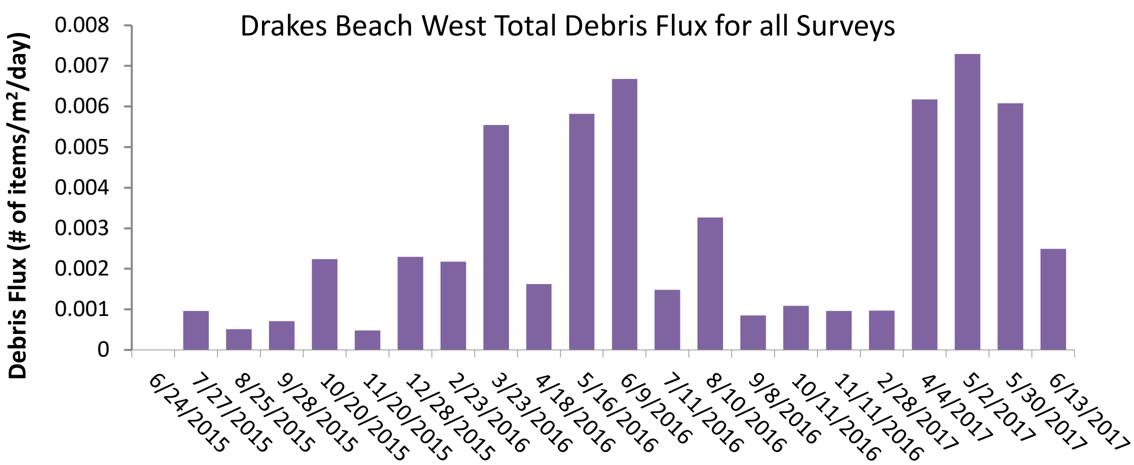


Figure 7. Total debris flux at Drakes Beach West accumulation site, June 2015 through June 2017.

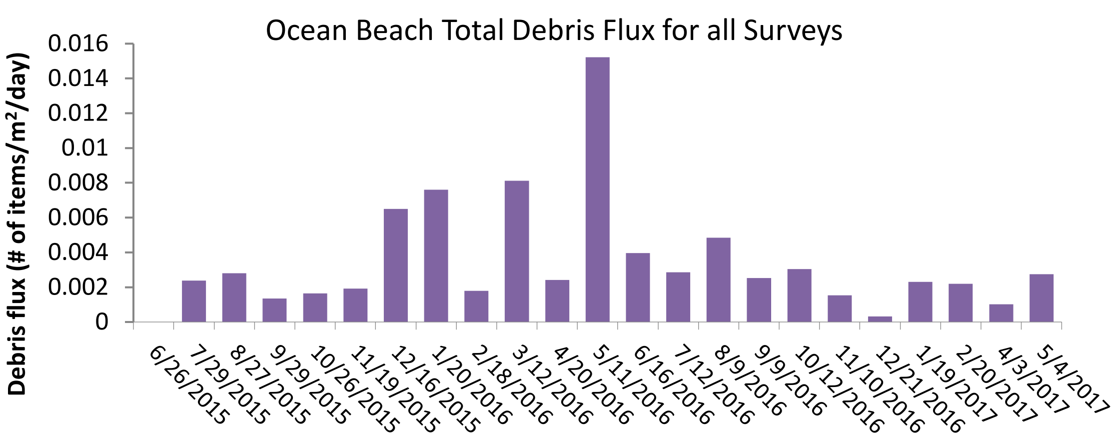


Figure 8. Total debris flux at Ocean Beach accumulation site, June 2015 through June 2017.

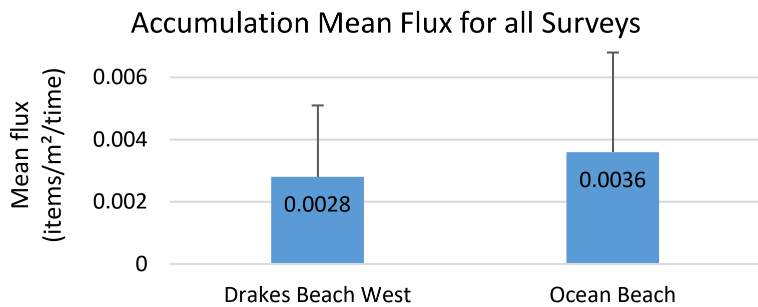


Figure 9. Accumulation site mean flux for all surveys, June 2015 through July 2017.

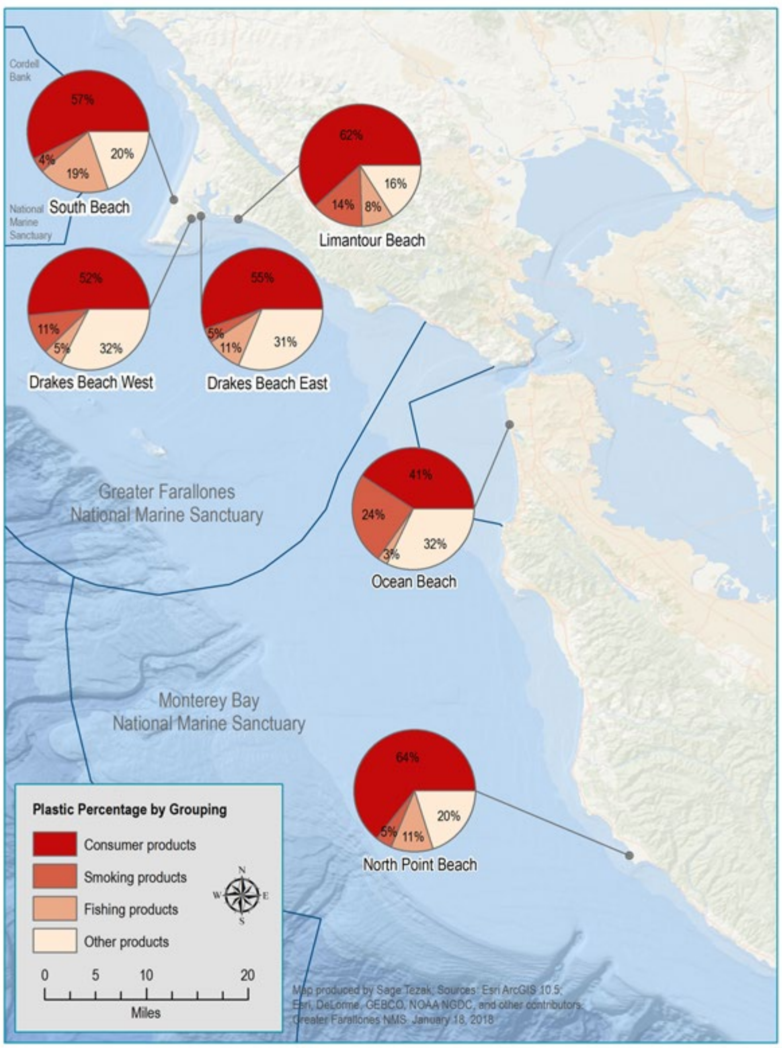


Figure 10. Percentage of non-fragment plastic debris groupings for each survey site from July 2012 through June 2017. Consumer products include: food wrappers, plastic beverage bottles, other jugs/containers, bottle/container caps, 6-pack rings, bags, cups, plastic utensils, straws, balloons, and personal care products. Smoking products include: cigarettes, cigarette lighters, and cigars tips. Fishing products include: plastic rope/net, buoys/floats, fishing lures, and fishing line. Other products include: shotgun shells/wads, oyster farm debris, and other plastics. *Shotgun shell/wad and oyster farm debris data are underestimated for July 2012 through May 2015 at standing stock sites.

lowest mean flux of these products. The highest abundance of smoking related products were at Ocean Beach (24%). The abundance of “other” products including shotgun shells/wads and oyster farm debris were highest at Drakes Beach West (32%), Drakes Beach East (31%), and Ocean Beach (32%). (Figure 9). Of the top ten most abundant non-fragment plastic items found at all survey sites bottle caps, straws, shotgun shells/wads, and rope were present at all six sites. Food wrappers and beverage bottles were among the top ten most common items at five out of six survey sites. Items such as cups, bags, buoys/floats were among the top ten at only one site (Figure 11).

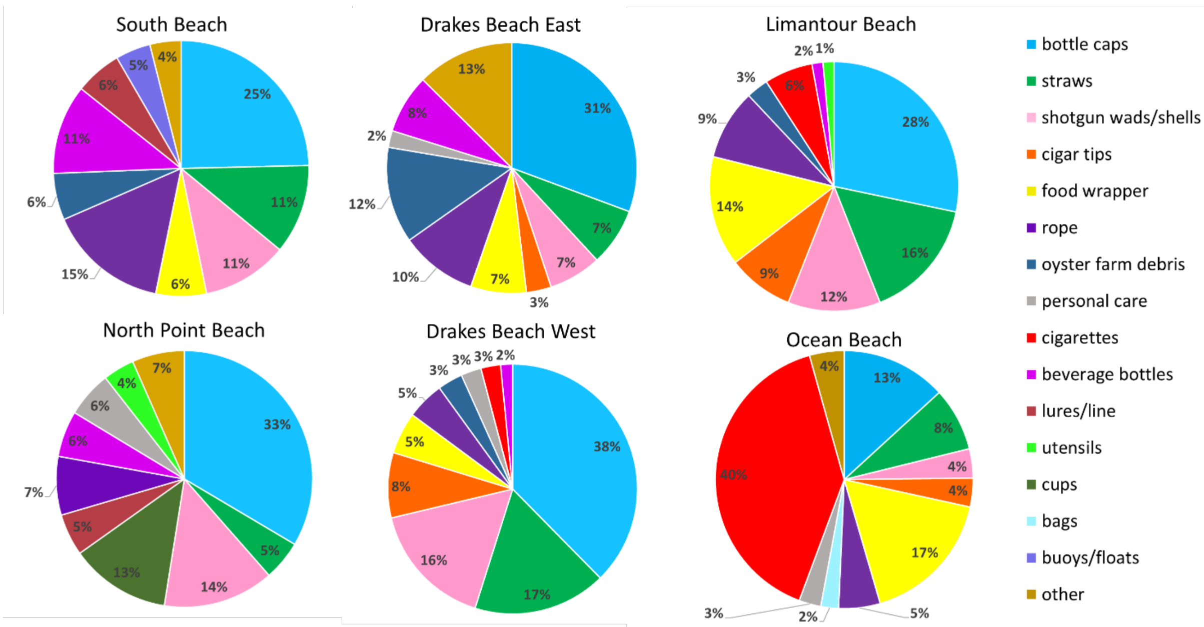


Figure 11. Top ten most common plastic sub-categories, not including plastic fragments, relative abundance over all surveys, for all survey sites July 2012 through June 2017.* Shotgun shell/wad debris data are underestimated for July 2012 through May 2015 at standing stock sites.

Non-plastic items were recorded less frequently; therefore we report only the top five non-plastic items with the highest mean concentration or flux, per site per survey (Figure 12). Lumber and other building materials represented the highest abundance of non-plastic items for all sites, except for Ocean Beach. This site was dominated by paper/cardboard debris including a high increase in the abundance of cardboard byproducts from spent fireworks after the fourth of July holiday (Figure 13). Glass fragments had high abundance at all sites except Ocean Beach, which had a high abundance of unbroken glass beverage bottles. Rubber items, specifically rubber bands used for wrapping newspapers, were present at all sites except at Drakes Beach East and Ocean Beach. Aluminum cans were the least common of the top five non-plastic items, and only present at Drakes Beach East. It is important to note that concentration or flux of these non-plastic items represent a much smaller portion of overall debris items recorded at each survey.

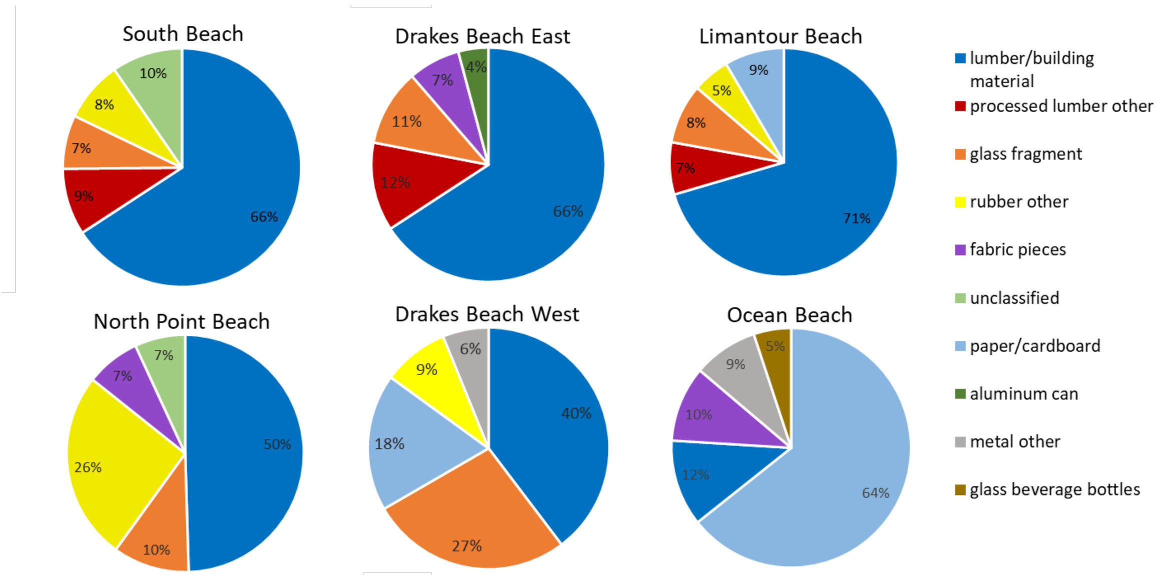


Figure 12. Top five most common non-plastic sub-categories, relative abundance over all surveys, for all survey dates from July 2012 through June 2017.

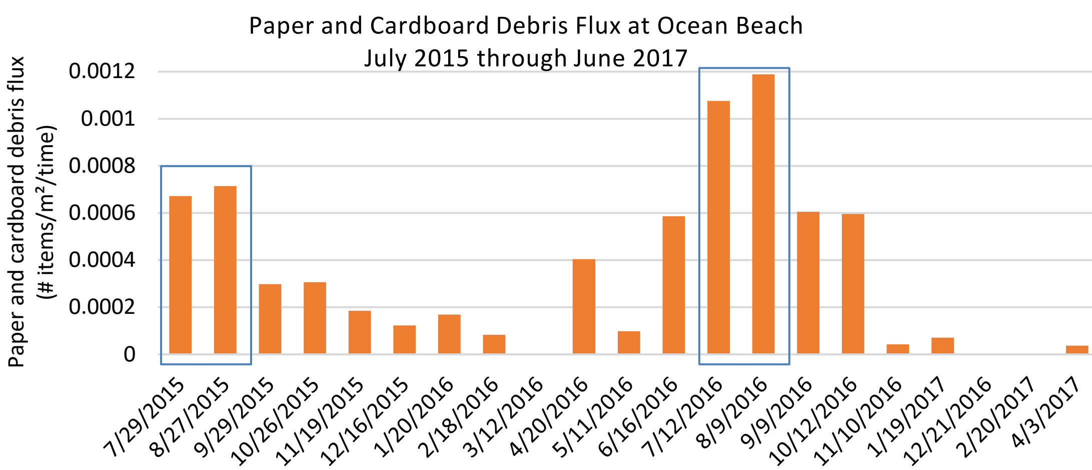
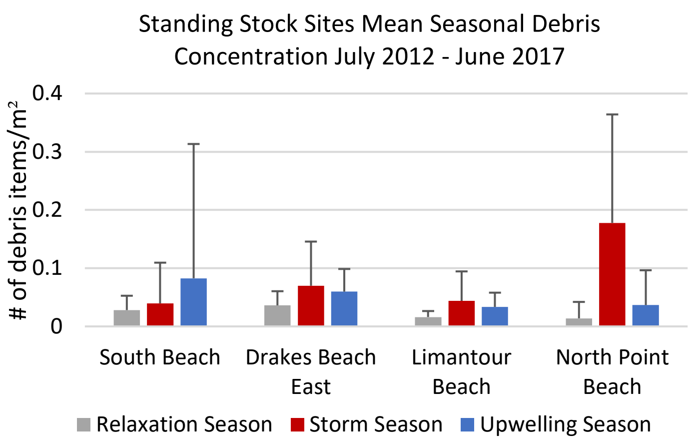


Figure 13. Paper and cardboard debris flux on Ocean Beach noting an increase in debris due to firework packaging and casings, during the months of July and August as indicated by the blue boxes.

Seasonal Oceanographic Influences on Deposition and Retention

To investigate seasonal variation and its influence on debris concentration at beaches we looked at debris deposition patterns during three oceanographic seasons: the upwelling season (March through July), the relaxation season (August through October), and the storm season (November through February). For standing stock sites, where debris is left in place, there was higher concentration of debris deposition and retention per survey during the upwelling ($0.0335/m^2 - 0.0827/m^2$) and storm seasons ($0.0396/m^2 - 0.178/m^2$). The relaxation season had consistently lower concentrations of debris deposition or retention ($0.01389/m^2 - 0.03617/m^2$) (Figure 14a). On December 16, 2014 a total of 436 plastic items were recorded at North Point Beach, for a plastic debris concentration of $1.0227/m^2$ compared to $0.0048/m^2$ for all other debris categories on that date. We considered this large increase an anomaly and reviewed the site's mean debris concentration value without data from this survey (Figure 14b). When this survey was omitted, mean debris concentration at North Point Beach during the storm season dropped from $0.1777/m^2$ to $0.1070/m^2$ per survey. This indicates that, outside of this anomalous survey, North Point Beach had a consistent pattern of debris deposition and retention comparable to the other standing stock sites during the storm season.



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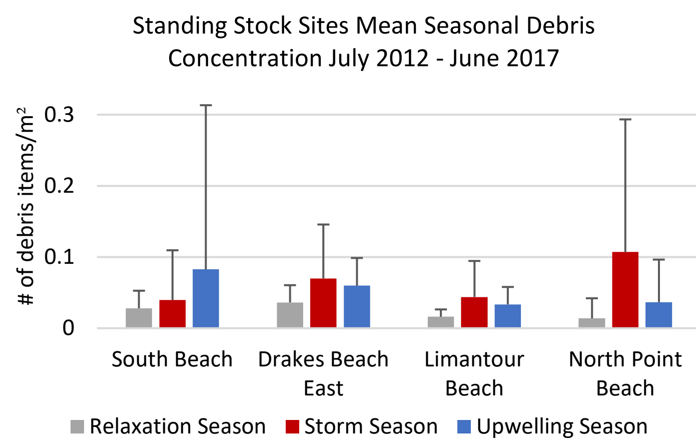

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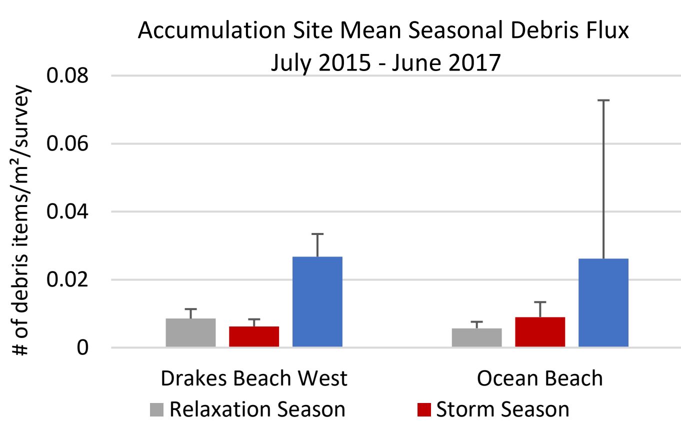


14c

Figure 14. Mean seasonal concentration of all debris items per survey for standing stock sites (14a), for standing stock sites omitting December 2014 North Point Beach survey (14b), and seasonal flux of all debris items for accumulation sites (14c).

Data from all accumulation sites were also examined for patterns in seasonal debris flux (Figures 14c). Both Drakes Beach West (0.0267/m^2/time) and Ocean Beach (0.0262/ m^2/time) had considerably higher debris flux during the upwelling season. The high abundance coincides with summer months when tourists and vacationers frequent these heavily recreated sites as seen by the increase in debris flux at Ocean Beach in July and August (Figure 13). Drakes Beach West had a lower flux during the storm season (0.0062/m^2/time) and Ocean Beach had a lower flux during the relaxation season (0.0057/m^2/time).

El Niño-Southern Oscillation Events

Variability along the California coast is affected by El Niño Southern Oscillation (ENSO) events, characterized by El Niño (warm) and La Niña (cold) episodes. We examined standing stock data for connections between debris concentration and ENSO events using NOAA National Weather Service Climate Prediction Center sea surface temperature data from July 2012 through June 2017. From September 2015 through February 2016 a strong El Niño occurred, and from September through November 2016 a weak La Niña occurred (Figure 15). For each standing stock site we calculated average monthly debris concentration for all surveys and compared it to the average monthly debris concentration during the El Niño (red) and La Niña (blue) events (Figure 16). Although no obvious patterns were apparent, data showed that only Drakes Beach East had an increase in debris load above the mean monthly concentration (0.0556/m^2) during both the El Niño (0.1082/m^2) and La Niña (0.0625/m^2) events. North Point Beach showed an increase in mean debris concentration during the La Niña event, from 0.0646/m^2 to 0.2293/m^2, per survey. For South Beach and Limantour Beach, debris concentrations were lower than the monthly mean concentration during both the El Niño and La Niña events. South Beach debris concentration dropped from the monthly average of 0.0577/m^2 to 0.0210/m^2 during the El Niño event, and to 0.0412/m^2 during the La Niña event. Limantour Beach debris concentration dropped from the monthly mean of 0.0329/m^2 to 0.0219/m^2 during the El Niño event, and to 0.0271/m^2 during the La Niña event. Of the four standing stock sites both of these locations had the lowest debris concentrations during the El Niño event.

Storm Events

In addition to ENSO events, individual storm events can also impact debris deposition. Factors such as wind speed, rainfall, and storm surge can increase the amount and movement of debris entering waterways and landing on beaches (NOAA Marine Debris Program, 2015b). To examine this we assessed NOAA's National Centers for Environmental Information Storm Events Database for Marin, San Francisco, and San Mateo counties from July 2012 through June 2017. For all counties combined, the

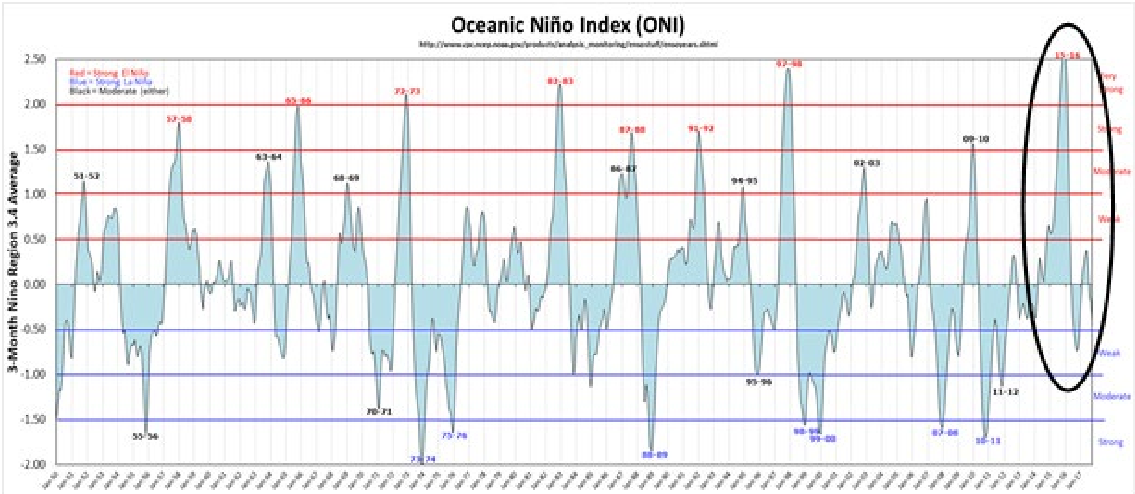


Figure 15. Three-month average of sea surface temperature recorded for region 3.4 (5ºN - 5ºS, 120º - 170ºW) during the study period July 2012 through June 2017. From September 2015 through February 2016, the NOAA Climate Prediction Center buoy data measured a very strong El Niño event and from September through November 2016, buoy data measured a weak La Niña event. El Niño and La Niña events are circled.

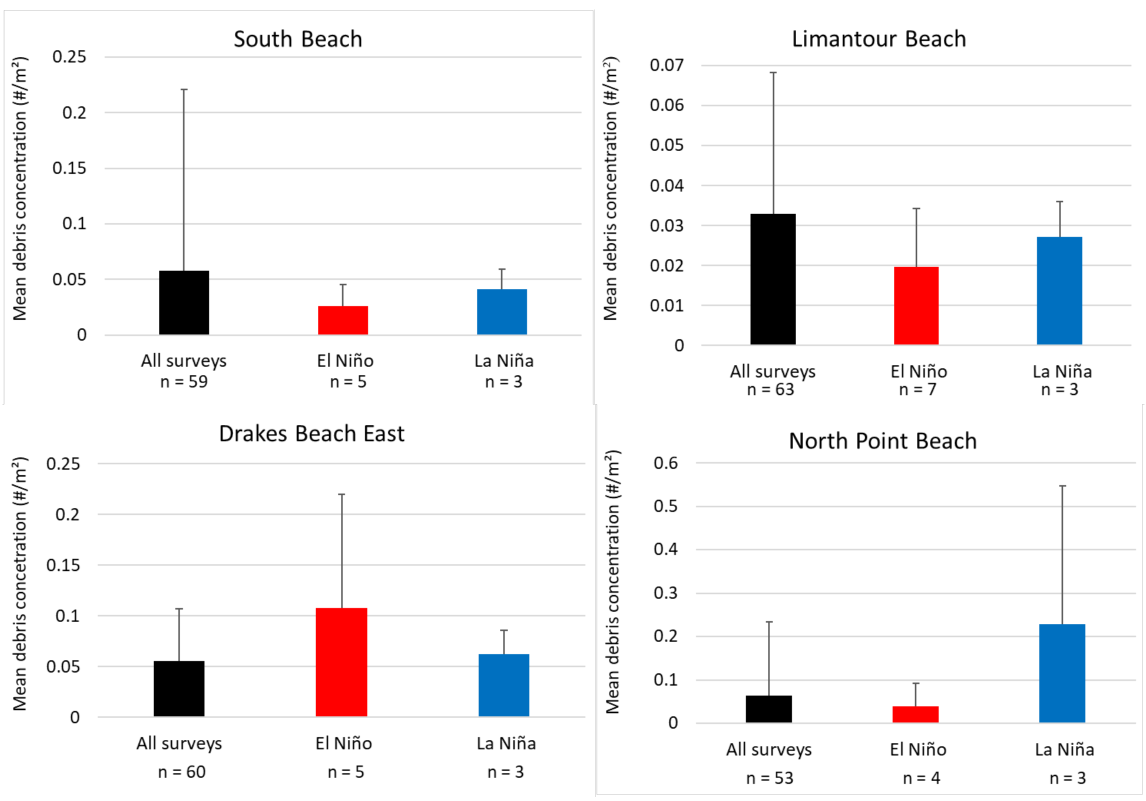


Figure 16. Mean debris concentration at standing stock sites for all surveys July 2012 through June 2017 (black), during the strong El Niño event, September 2015 through February 2016 (red), and the weak La Niña event, September through November 2016 (blue).

database reported 98 occurrences of at least one of the following storm characteristics during this time period: high surf, high wind, coastal flood, debris flow, storm surge/tide, and heavy rain. The high number of instances can be attributed to multiple storm characteristics, for example high surf, high wind and heavy rain, occurring in multiple counties during one single storm event. From July 2012 through June 2017, all 98 events occurred over the course of twelve months including: November 2012, December 2012, March 2013, February 2014, December 2014, February 2015, December 2015, January 2016, October 2016, January 2017, February 2017, and March 2017. Storm event definitions are available in Table 3 and all storm event dates and occurrences are listed at www.ncdc.noaa.gov/stormevents/. We analyzed survey data in each of these 12 months, plus an additional month following the event to account for potential lag time for debris to travel to survey sites.

Table 3. National Weather Service Storm Weather Preparation document definitions for storm events data characterization (NWS, 2016).

Storm Event	Definition
High Surf	Large waves breaking on or near shore, resulting from swell spawned by a distant storm or from strong onshore winds, causing a fatality, injury or damage.
High Wind	Sustained non-convective winds of 35 knots (40 mph) or greater lasting for 1 hour or longer, or gusts of 50 knots (58 mph) or greater for any duration (or otherwise locally/regionally defined).
Coastal Flood	Flooding of coastal areas due to the vertical rise above normal water level caused by strong, persistent onshore wind, high astronomical tide, and/or low atmospheric pressure, resulting in damage, erosion, flooding, fatalities, or injuries. Coastal areas are defined as those portions of coastal land zones (coastal county/parish) adjacent to the waters, bays, and estuaries of the oceans.
Debris Flow	A combination of water, soil, rock and other material that forms on the sides of hill slopes and moves rapidly downhill. Large boulders, trees, and massive amounts of sediment can be carried in a debris flow.
Storm Surge/Tide	The vertical rise above normal water level associated with a storm of tropical origin (e.g., hurricane, typhoon, tropical storm, or subtropical storm), caused by any combination of strong, persistent onshore wind, high astronomical tide and low atmospheric pressure, resulting in damage, erosion, flooding, fatalities, or injuries. Note: Coastal flooding not associated with a typhoon, hurricane, tropical storm or subtropical storm should be reported under the Coastal Flood event
Heavy Rain	Unusually large amount of rain which does not cause a Flash Flood or Flood event, but causes damage, e.g., roof collapse or other human/economic impact.

We analyzed the total mean debris concentration per survey for standing stock sites and the mean flux for accumulation sites across all months and compared it to the mean debris concentration per survey (standing stock sites) or mean flux (accumulation sites) during storm event months. All standing stock sites except for South Beach had an

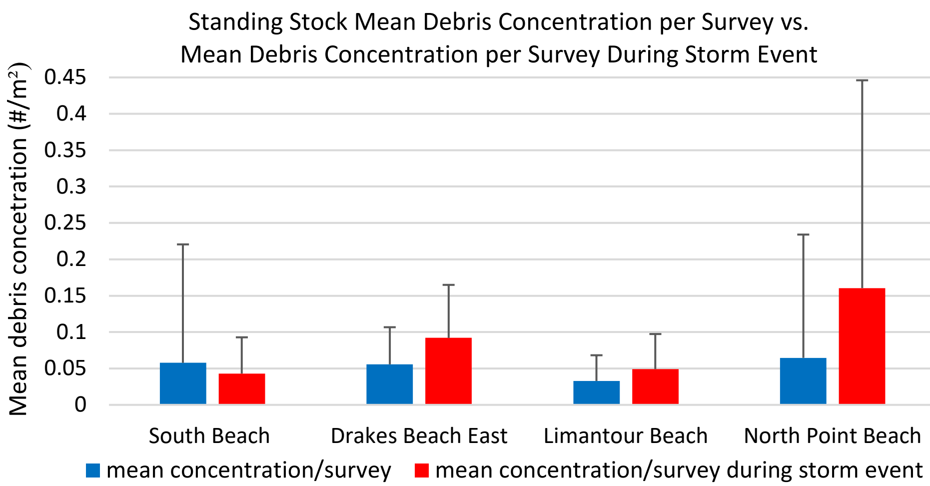


Figure 17. Standing stock sites mean debris concentration per survey (blue) compared to the mean debris concentration during and one month following a storm event (red).

increase in debris concentration per survey during storm event months when compared to the mean debris concentration per survey for all months (Figure 17). During storm event months mean concentration increased from $0.0556/m^2$ to $0.0920/m^2$ at Drakes Beach East, from $0.0329/m^2$ to $0.0491/m^2$ at Limantour Beach, and from $0.0646/m^2$ to $0.1605/m^2$ at North Point Beach. Mean debris concentration decreased at South Beach during storm event months from $0.0577/m^2$ to $0.0431/m^2$. Mean debris flux for both of the accumulation sites slightly decreased during storm events when compared to mean debris flux for all months, with Drakes Beach West decreasing from $0.081/m^2/time$ to $0.0065/m^2/time$ and Ocean Beach decreasing from $0.0125/m^2/time$ to $0.0059/m^2/time$ (Figure 18).

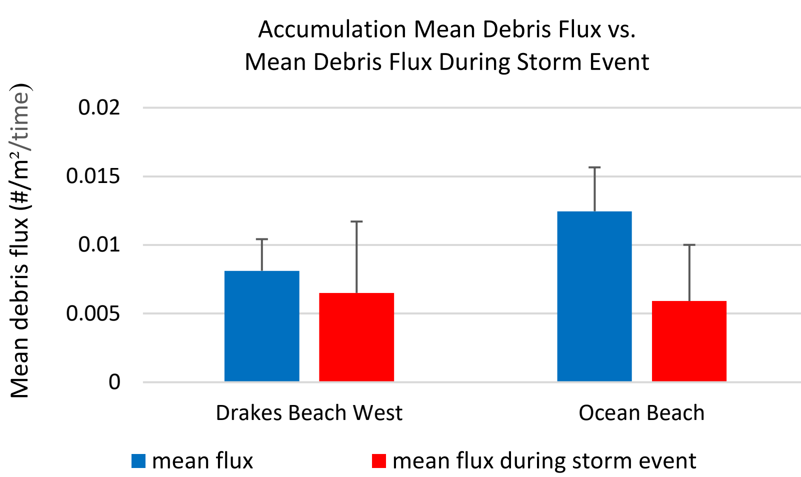


Figure 18. Accumulation sites mean debris flux (blue) compared to the mean debris flux during and one month following a storm event (red).

Sources

In addition to composition, seasonal currents, and weather patterns, factors that determine debris origin also help characterize the local marine debris problem. Marine debris is often identified as either ocean-based or land-based depending on where items are released into the marine system. Studies suggest that roughly 80% of marine debris originates from land-based sources (UNEP, 2005). These sources include direct input by beach users, items traveled by wind, currents, natural outflows such as rivers, streams, and bays, as well as built systems such as municipal landfills, industrial facilities, and culverts, storm drain and sewage pipe outflows (Martinez-Ribes et al. 2007, UNEP, 2005). All debris categories (metal, paper, plastic, glass, cloth, and wood) can derive from land-based sources. Ocean-based sources are associated with large cargo ships, recreational and commercial fishing boats, military fleets and research vessels, cruise ships, and offshore installations such as aquaculture, wind farms, and oil and gas platforms (Martinez-Ribes et al. 2007, UNEP, 2005). Examples of ocean-based debris are more often connected to the metal and plastic debris categories including metal traps and lures, and plastic fishing line, rope and buoys.

Of the non-fragment items we compared plastic debris count from land-based versus ocean-based sources at each of the six survey sites. We targeted fishing related items (e.g. fishing lures/line, plastic rope/net, and buoys/floats) as indicators of ocean-based debris, and smoking (e.g. cigarettes, cigarette lighters, and cigars tips) and consumer products (e.g. food wrappers, plastic beverage bottles, other jugs/containers, bottle/container caps, 6-pack rings, bags, cups, plastic utensils, straws, balloons, and personal care products), as indicators of land-based debris. Items indicated as "other" were omitted from comparison as they included both land-based (shotgun shells/wads) and ocean-based (oyster farm debris) debris.

All six sites had considerably more land-based than ocean-based debris (Figure 19). Although Drakes Beach East had the highest count of ocean-based debris compared to all other sites, this number represented only 14% of the total count. Despite a much smaller count, ocean-based debris at South Beach represented 19% of the total count. Ocean-based debris at Limantour Beach represented 11% of the total count, and 14% of the total count at North Point Beach. For the accumulation sites ocean-based debris represented only 6.4% of the total count at Drakes Beach West and only 6.6% of the total count at Ocean Beach.

Shotgun shells/wads

One pathway for land-based debris, specifically shotgun shells/wads, to reach coastal beaches is through the San Francisco Bay delta. Although not identified in Marine Debris Program survey sheets, shotgun shells/wads were identified as a GFNMS custom item because of their regular occurrence at all six survey sites, and added to the GFNMS survey sheets in 2015. These items were included under the plastic "other" category when analyzing data for patterns and trends. On occasions prior to 2015 when shotgun shells/wads were observed and recorded in the notes section of survey sheets these items were retroactively inserted in the plastic “other” category and indicated as a “custom item” in the NOAA online database. It is important to note that shotgun wads were not properly recorded prior to 2015. Data during these years is likely an underestimate.

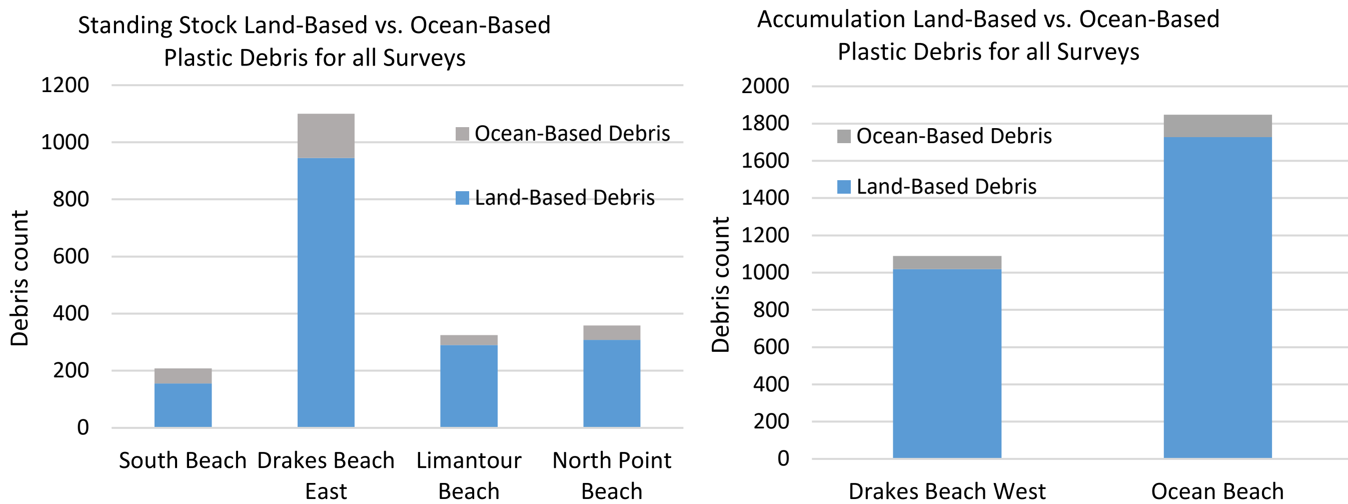


Figure 19. Mean plastic debris count for ocean-based debris (fishing lures/line, plastic rope/net, and buoys/floats) vs. land-based debris (cigarettes, cigarette lighters, cigar tips, food wrappers, plastic beverage bottles, other jugs/containers, bottle/container caps, 6-pack rings, bags, cups, plastic utensils, straws, balloons, and personal care products) for all plots. Note that there are assumptions on what signifies land-based vs ocean-based debris.

Shotgun shells/wads are spent primarily during California’s waterfowl hunting season, generally from October through January, at year-round shooting ranges and state and federally managed hunting reserves within the bay and delta. The location of these reserves and ranges along shorelines and near outflows facilitate the travel of shotgun shells/wads to beaches (Figure 20). We assessed monthly shotgun shell/wad deposition per survey for all six survey sites from June 2015 through June 2017 for both standing stock and accumulation survey sites. For standing stock sites the highest concentration occurred in November, followed by May, January, and February, and the lowest concentration occurred in December followed by October, April, and September (Figure 21). Accumulation sites consistently had higher relative abundance of shotgun shells/wads than standing stock sites, with the highest flux occurring in March followed by February, December, and June. The lowest relative abundance occurred in November followed by September, July, and May (Figure 22).

For all years of the project, July 2012 through June 2017, North Point Beach had the highest shotgun shell/wad concentration per survey (0.00033/m^2) for the standing stock sites. (Figure 23a). For accumulations sites, from June 2015 through July 2017, Drakes

Beach West had a higher abundance of shotgun shells/wads than Ocean Beach, including significantly high deposition events in April ($0.0318/m^2$/time) and May 2017 ($0.0473/m^2$/time) (Figure 23b). When surveys from these two months are removed, the mean flux at Drakes Beach West was lowered considerably from $0.00675/m^2$/time to $0.00360/m^2$/time (Figure 23c).

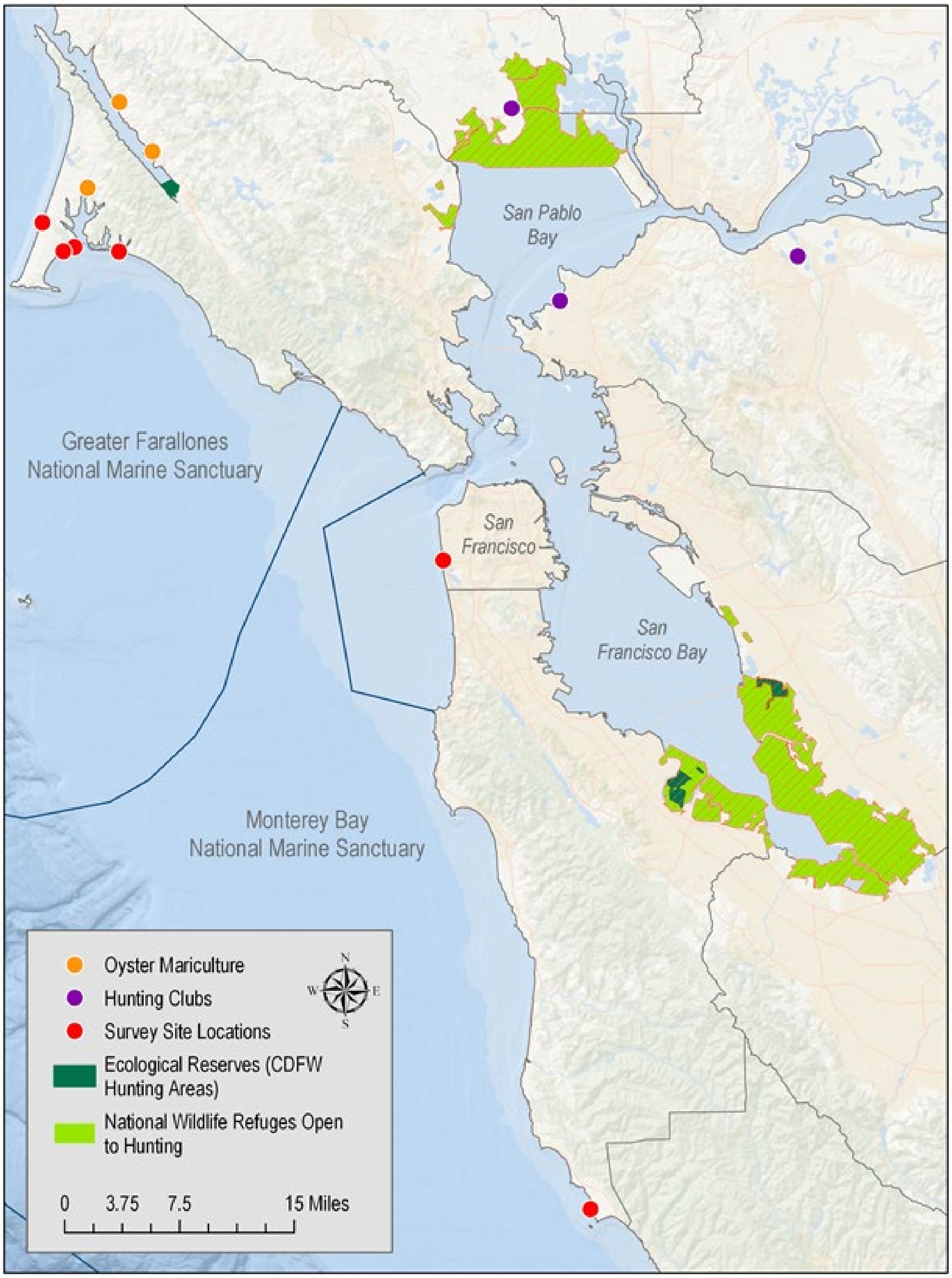


Figure 20. Location of oyster mariculture farms (closed and currently operating), public hunting clubs, and state and federally managed hunting reserves near the study region during the project period.

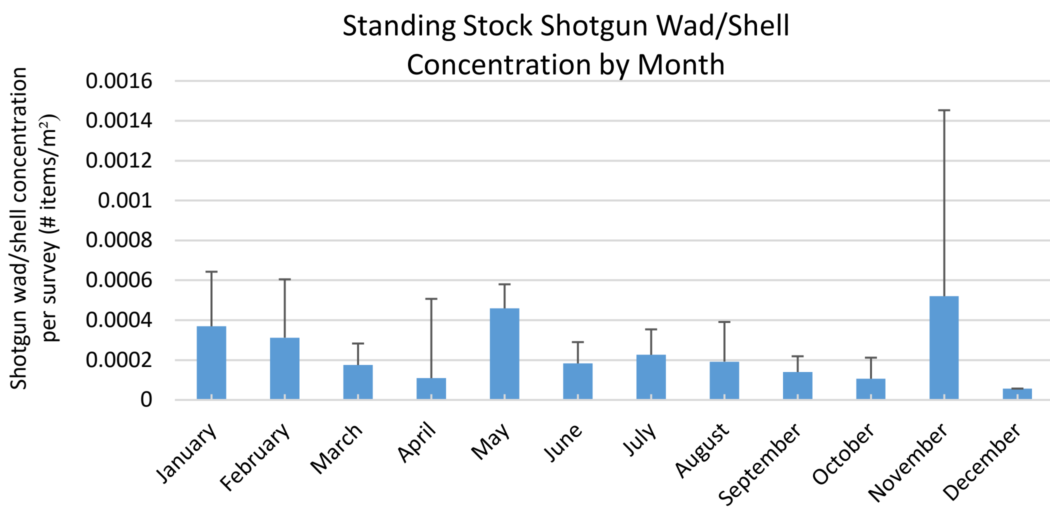


Figure 21. Monthly mean concentration of shotgun shells/wads per survey for all standing stock sites, June 2015 through June 2017.

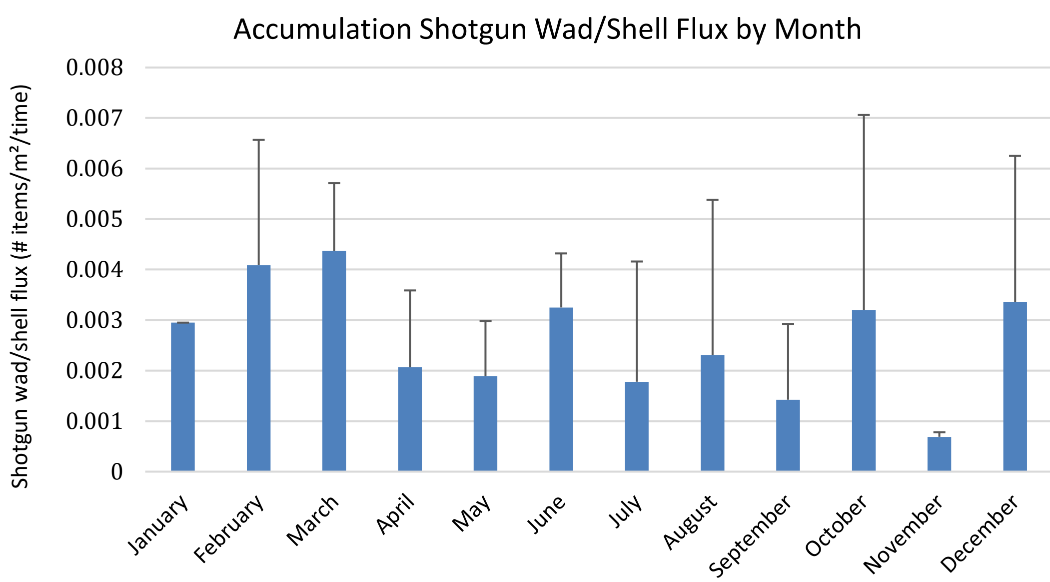
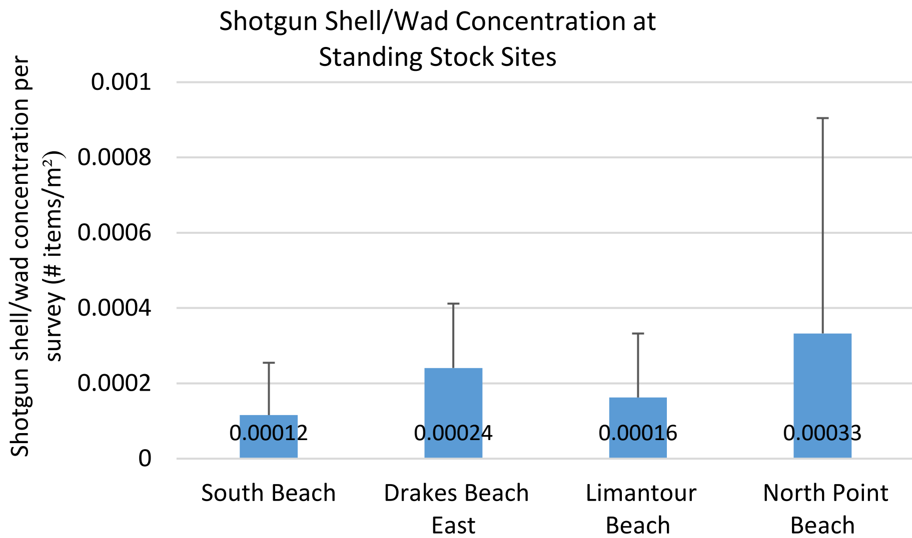


Figure 22. Monthly relative abundance of shotgun shells/wads for all accumulation sites, June 2015 through June 2017.



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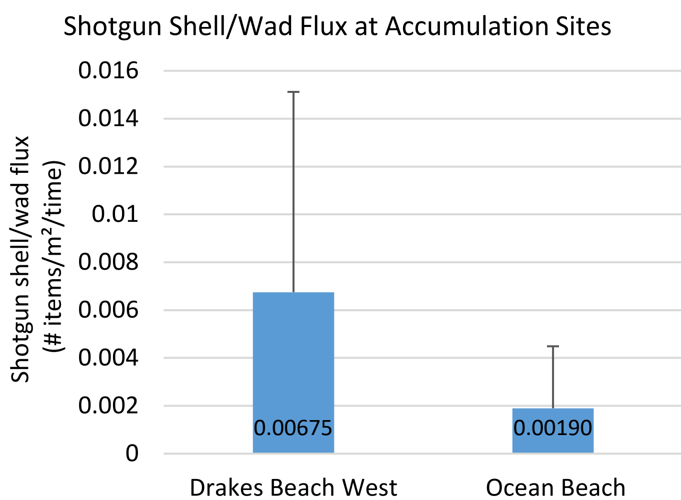

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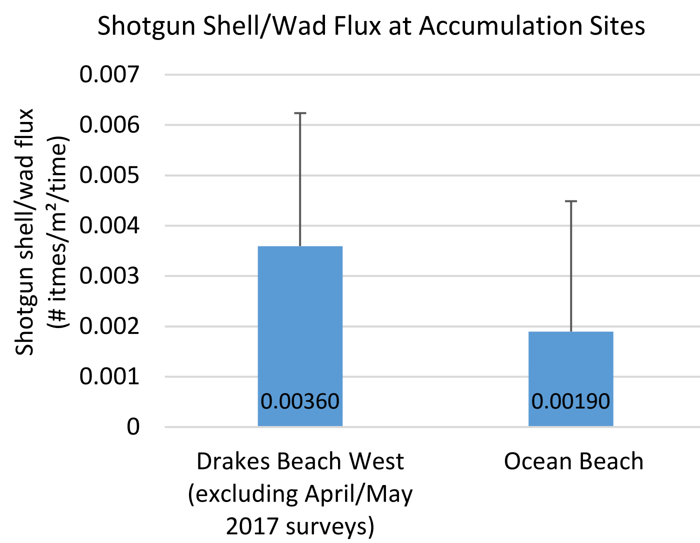


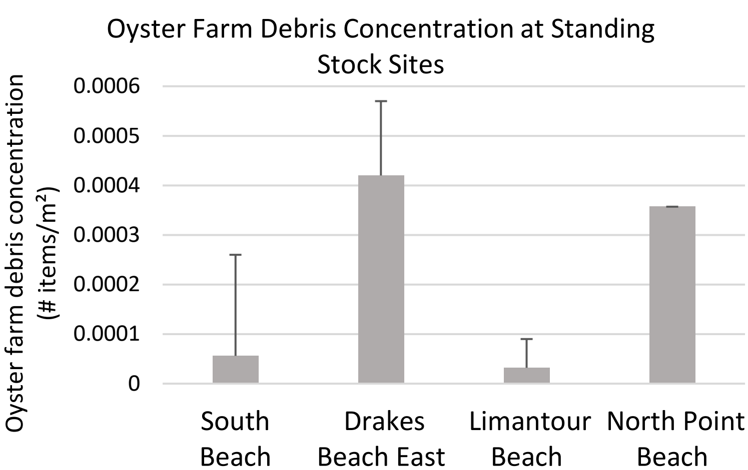
23c

Figure 23. Mean concentration of shotgun shells/wads across all surveys from July 2012 through June 2017 at standing stock sites (23a), mean flux at accumulation sites June 2015 through June 2017 (23b), mean flux at accumulation sites June 2015 through June 2017, excluding data from April and May 2017 surveys at Drakes Beach West (23c). *Shotgun shell/wad data are underestimated for July 2012 through May 2015 at standing stock sites (23a).

Oyster Farm Debris

Another custom debris item with an identifiable point source is oyster farm debris, characterized by mesh bags and plastic tubes used to separate oyster racks. This custom item was also incorporated into GFNMS survey sheets in 2015. Similar to shotgun shells/wads, prior to 2015 when oyster farm debris were observed and recorded in the notes section of survey sheets these items were retroactively inserted in the plastic "other" category and indicated as a "custom item" in the NOAA online database. Unless specified, these data were also included in the analysis described in this report, although it is important to note that not all oyster farm debris were properly recorded at sites prior to 2015. Data collected during these years are likely underestimated.

Oyster mariculture is located in Marin County within Tomales Bay (Hog Island Oyster Company and Tomales Bay Oyster Company), and occurred at Drakes Estero (Drakes Bay Oyster Company), until operations closed in December 2014. Oyster farm debris flux at Drakes Beach West was 0.00139/m^2/time and oyster farm debris concentration at Drakes Beach East was 0.00042/m^2 per survey. Both of these sites were located closest to the former Drakes Bay Oyster Company, and had the highest abundances of oyster farm debris for their respective survey types (Figure 24). Understanding that the Drakes Beach West accumulation site was established in June 2015, we analyzed only Drakes Beach East for changes in oyster farm debris prior and preceding Drakes Bay Oyster Company closure in December 2014. Volunteers conducting surveys at Drakes Beach East were familiar with oyster farm debris and kept accurate records for this custom item from July 2012 through June 2017. Data show that the concentration of oyster farm debris at Drakes Beach East before the closure was 0.0005 items/m^2 per survey, and after closure concentration dropped to 0.0003 items/m^2 per survey, a 37.5% decrease (Figure 25).



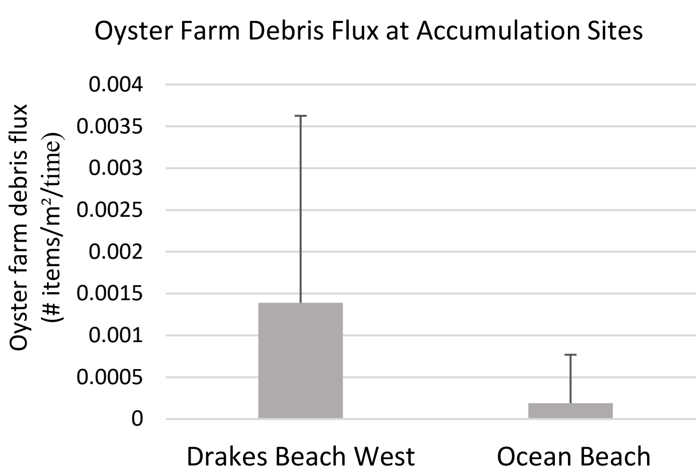


Figure 24. Mean concentration of oyster farm debris per survey for each standing stock site from July 2012 through June 2017 (left), and mean flux for each accumulation site from June 2015 through June 2017 (right). *Oyster farm debris data recorded from July 212 through May 2015 are underestimated for standing stock sites except Drakes Beach East.

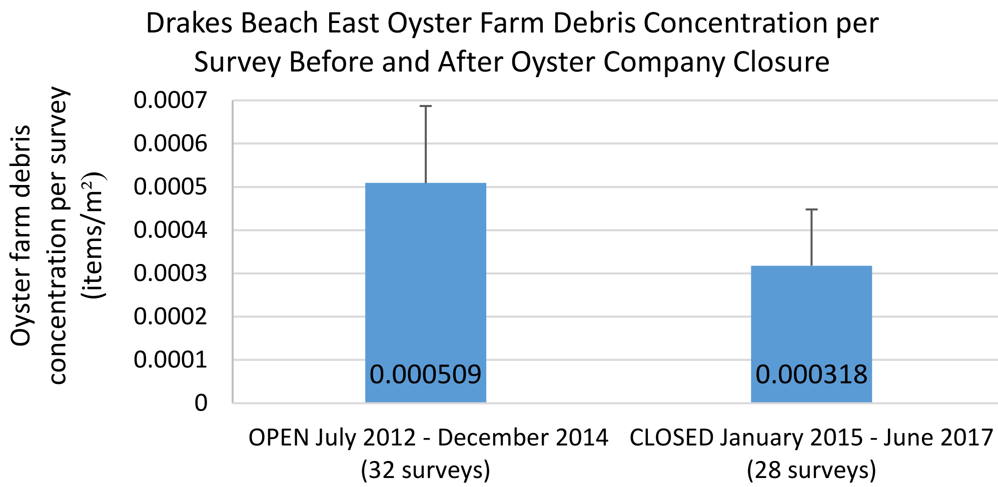


Figure 25. Mean concentration of oyster farm debris per survey at Drakes Beach East before (July 2012 through December 2014) and after (January 2015 through June 2017) the closure of Drakes Bay Oyster Company.

Discussion

Data analyzed in this report characterizes the abundance of debris types including most commonly found items, and custom items unique to this area. Data was also analyzed to determine if seasonal ocean currents, long-term ENSO events, and short-term storm events influenced the transport, frequency, and intensity of marine debris deposition on beaches. Potential debris source and point source contributors also provided insight into the local marine debris problem. We analyzed Drakes Estero as a potential point source for oyster farm debris on beaches, and San Francisco Bay and delta as a potential point source for shotgun shell/wad debris on beaches. Identifying interactions between debris type and composition, seasonal currents, long and short-term weather patterns, and debris source contributions at each of the six survey sites is critical for determining the scope of the local marine debris problem and developing removal, reduction, and prevention strategies to address it.

Varying site characteristics (i.e. accumulation sites are located without regard to high humans use or proximity to outflows) and protocol methods (i.e. debris is left in place at standing stock sites) are two additional components that influenced debris deposition and retention on beaches and shaped the narrative of the local marine debris problem. Standing stock survey data illustrated the concentration of debris items ($\#/m^2$) per survey and, because debris was not removed, best displayed changes in debris abundance. This can provide insight into debris degradation and persistence (burial and decomposition). Being that GFNMS standing stock sites were located away from heavy recreational use and outflows, there was less direct debris deposition from beach users, rivers, streams, and culverts. Studies show that the distance from beach sites to constructed outflow systems can be a proxy for local waste treatment effectiveness as beach sites in closer proximity to these systems can see increases in debris (Ribic et al. 2012). Distance from outflows can therefore reduce the amount of land-based debris at these sites compared to accumulation sites, and may account for the higher relative abundance of ocean-based debris (e.g. fishing related products) at sites like South Beach, Drakes Beach East, and North Point Beach. Accumulation survey data captured debris accumulation rates, or flux, to compare how much debris amassed from one survey to the next. Because these sites were established without required distance from recreational use or outflows, these data can assess short-term changes in debris flux from both land-based and ocean-based sources, as well as large-scale debris events, and trends in storms or weather patterns.

Debris Composition

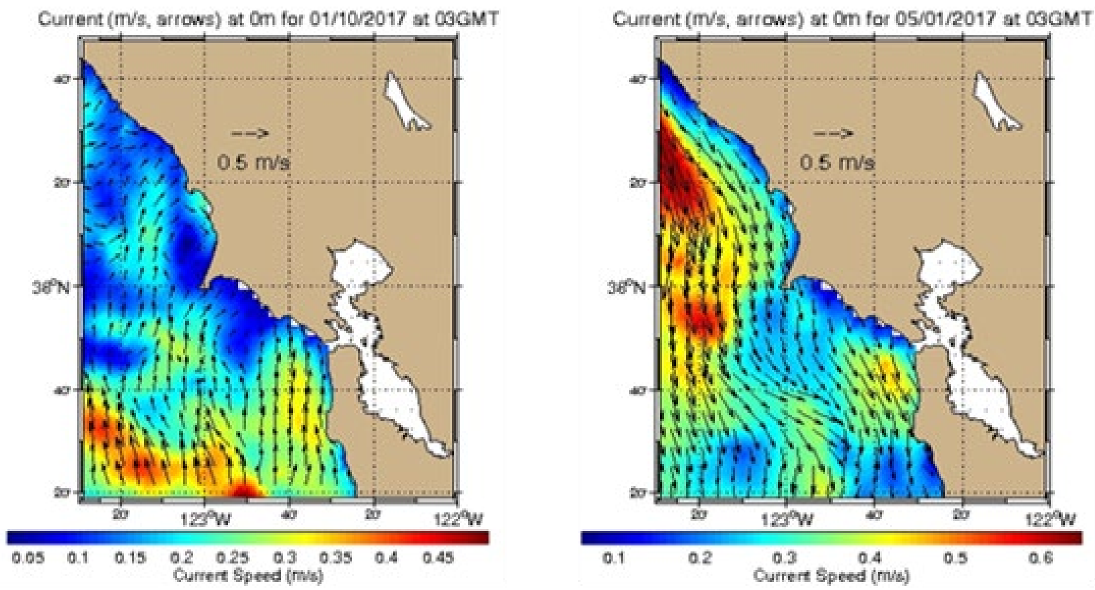
When we analyzed the types of marine debris present at each beach it is not surprising that plastic items were most dominant, specifically hard plastic fragments (Appendix B). Analysis of plastic debris sub-categories showed that, although the presence of plastic beverage bottles was marginal, bottle caps had the highest occurrence at five of the six sites (Figure 11). This is likely attributed to the high consumption of disposable single-use water bottles, whereby the plastic bottle is discarded or moved off the beach by waves/wind and the smaller more durable caps are dropped and buried. Another thought to consider is the California Redemption Value (CRV) that allows consumers to redeem their bottles for $0.05 or $0.10, depending on size. In some cases, states with existing container deposit legislature such as this can reduce beverage bottle litter on coasts by as much as 40% compared to states without such legislature (Schuyler et al. 2018). In cities like San Francisco where people often collect discarded bottles and sift through open trash bins for recyclables to redeem, the CRV may account for the large discrepancy between beverage bottles and beverage caps on beaches.

Of all non-plastic items recorded, lumber had the highest density (Figure 12). This is likely due to the buoyancy of wood and the ease of transport during high tides, surf, and wind events. Lumber also made up the majority of all debris items ≥ 30 cm, as many of these items included 2x4 building materials and large pilings and posts.

The absence of debris on beaches also tells an important story. For example, the absence of plastic bags could be an indicator of effective policy resulting from the San Francisco plastic bag ban in 2007. Similarly changes in product packaging can help reduce the amount of certain debris categories and sub-categories on beaches. The use of cardboard boxes as a replacement for six-pack rings is likely one reason why only four six-pack rings were recorded across all 280 surveys from July 2012 through June 2017.

Seasonal Oceanographic Influences on Deposition and Retention

Ocean water along the western United States is characterized by interactions between the northerly California current (0-300 m deep) and the southerly Davidson current that lies beneath it (Lynn and Simpson 1987, Marchesiello et al. 2003, Garcia-Reyes and Largier 2012). Processes within, and transition between, these currents is characterized by the ocean's upwelling (March through July), relaxation (August through October) and storm (November through February) seasons (Figure 26).



26a **26b**

Figure 26. Examples of the storm season displaying northward movement of the Davidson Current from January 2017 (26a), and upwelling season displaying southward movement of the California current from May 2017 (26b), along the north central California coast. Maps from COPS 2017.

Dominance of the California current during the upwelling season moves cold, nutrient rich waters from the ocean floor to its surface, mixing the water column and bringing sand normally scoured during the storm season, back onto beaches. This can bring debris from the seafloor or suspended in the water column up on to beaches, creating an increase in debris concentration/flux as seen at South Beach, Drakes Beach West, and Ocean Beach. However, some coastal areas along central California are characterized by upwelling shadows where the retention of warmer surface water acts as a barrier for mixing (Graham and Largier 1997). In these areas upwelling is reduced and a pattern of higher than normal surface temperature is observed. Often these places are contained within a curved coastline downstream from capes or headlands. Drakes Bay, where Drakes Beach West, Drakes Beach East, and Limantour Beach are located, is identified as one such upwelling shadow (Wing et al. 1998, (Figure 27).

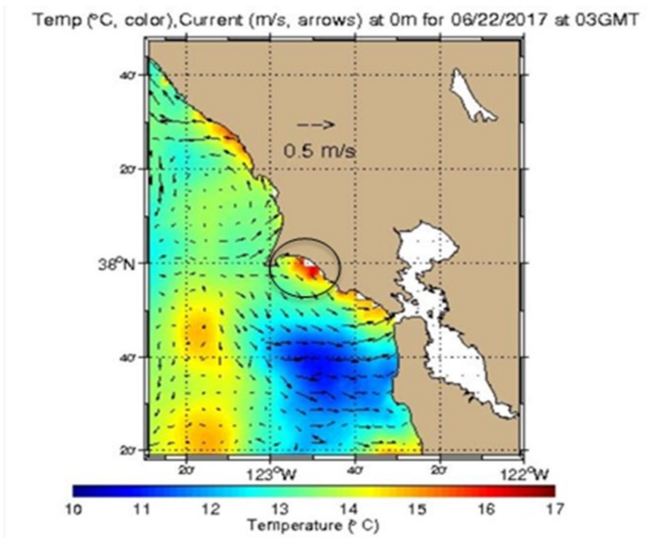


Figure 27. Location of upwelling shadow as indicated by anomalously warm water (red) in Drakes Bay (circled). Map source: http://west.rssoffice.com/ca_roms?variable=temp

The curved shape of the bay and protection from winds and waves provided by the Point Reyes headlands create circulation within the bay that retain coastal waters, sometimes even moving in a counterclockwise direction (Figure 28). In these cases runoff from Drakes Estero may transport debris west as it enters the bay and move items towards the Drakes Beach East and West sites rather than easterly towards Limantour Beach. This can explain why the standing stock site at Drakes Beach East had a higher concentration of debris than Limantour Beach despite their locations at the base of Drakes Estero. Although Point Reyes National Seashore receives over 2.5 million visitors annually and each of the sites within the park have year round access with comparable recreational use, it seems debris abundance and frequency is influenced by oceanographic processes of seasonal currents and upwelling shadows rather than recreational patterns (PRNS 2018).

Figure 28. Counterclockwise circulation within Drakes Bay with red dots representing Drakes Beach West, Drakes Beach East, and Limantour Beach (left to right), and orange dot representing the former Drakes Bay Oyster Company. Map source: http://www.cencoos.org/data/hfradar/rtv.

As the upwelling season transitions ocean conditions stabilize, the water column stratifies, and the relaxation season begins (Garcia-Reyes and Largier 2012). This likely reduces the amount of debris deposited on beaches from the ocean, as demonstrated at all standing stock sites (Figure 14). However this time also coincides with late summer when weather along the north central coast is often best, bringing increased numbers of people to the beach on nice days. This may account for an increased debris flux at Drakes Beach West during the relaxation season. In these cases it may be worthwhile to indicate the condition of debris (i.e. fragility, fading of color, and/or presence of barnacles) during the relaxation season in order to determine if items derive from the ocean or directly from beach users.

In November the storm season begins and currents shift as the weakened California Current moves offshore and is replaced by the southerly Davidson Current. This directional shift is demonstrated by an event that occurred on Tuesday October 16th, 2012 when a 72 ft. Oracle Team USA catamaran capsized in San Francisco Bay, broke apart, and was carried out the Golden Gate Bridge by the current moments after the wreck (Kleinbaum 2012). On December 12, 2012 marine debris survey volunteers discovered a piece of the broken catamaran on South Beach in Point Reyes, roughly 25 miles north of the crash site.

Using San Francisco Bay as a debris source would suggest an increase in debris concentration for the survey sites north of the bay during the storm season when ocean water moves northerly. Although this is true for Limantour and Drakes Beach East, it is not the case for South Beach and Drakes Beach West where debris abundance is highest during the upwelling season (Figure 14). South Beach is positioned along the Point Reyes peninsula and part of the Point Reyes Great Beach, which faces northwest, is considerably sloped against a back barrier of dunes and vegetation, and is the most exposed of all six sites to the open ocean. At the southern end of the peninsula is the Point Reyes headlands which sits perpendicular to the Great Beach, and separates Drakes Bay from the Pacific Ocean. This is likely why debris concentration was highest during the upwelling season when winds are predominately from the northwest and debris, whether floating or resurfaced from the ocean floor, is intercepted at South Beach as it travels south along the California current. The reverse may be true during the storm season when southerly winds, facilitating the northerly current, can be blocked by the Point Reyes headlands. This, along with the beach’s northwest aspect can reduce the frequency of debris deposition on South Beach. Moreover, storm season months are characterized by extreme high and low tides, and increased rain, wind, and storm events that may move debris off of both South Beach and Drakes Beach West and redeposit it into the ocean.

The interaction between the geographical and physical dynamics of North Point Beach during the storm season lend insight into why this site had a higher debris concentration compared to all other standing stock sites. Each storm season North Point Beach is heavily scoured, exposing partially buried rocks that are normally covered during the upwelling and relaxation seasons when beaches have more sand (Figure 29). When rocks were exposed, surveyors also observed partially buried and worn plastic fragments in between these rocks, suggesting the debris was also exposed rather than newly deposited. Throughout this process of burial (upwelling and relaxation seasons) and resurfacing (storm season), plastic items break apart and create smaller pieces but remain on the beach tucked between rocks. This is exemplified by the North Point Beach survey conducted in December 2014 which documented 436 items, 206 of which were plastic fragments, and greatly increased the mean debris concentration per survey at this site (Figure 14).

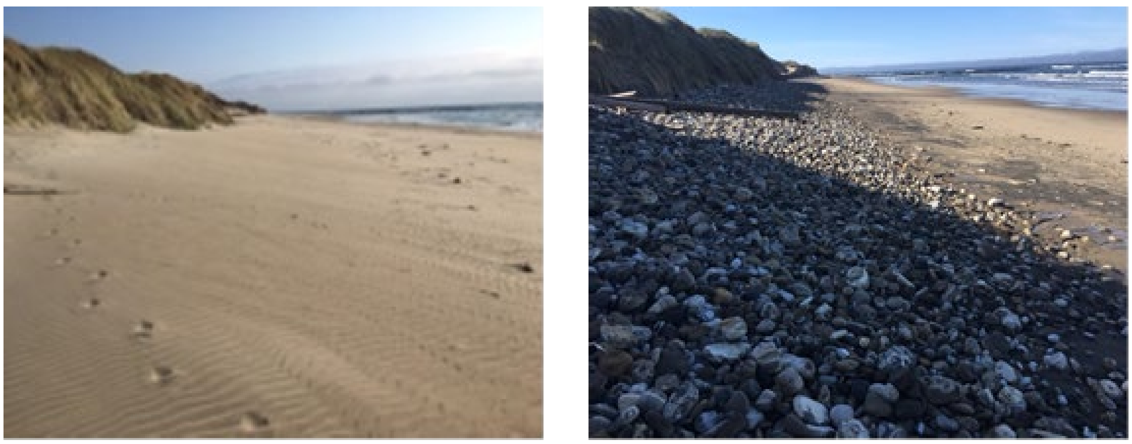


Figure 29. Photo of North Point Beach standing stock site, demonstrating annual beach deposition in March 2017 (left) and exposed rock due to scoring in December 2016 (right). Photo credit: Kate Bimrose

El Niño-Southern Oscillation and Storm Events

Oceanic seasons are characterized by shifting currents and beach dynamics, but they also correlate with seasonal weather patterns. Just as winter storms often arrive during the storm season and warmer calmer weather characterizes the relaxation season, there are interannual and short-term storm events that can affect debris loads. We analyzed basin scale (ENSO) and local (storm events) weather patterns for their influence on debris loads at beaches.

Our study area was positioned at the southern reaches of El Niño conditions and the northern reaches of La Niña conditions making it difficult to directly correlate ENSO episodes with changes in debris loads (NOAA CPC 2017, Figure 30). Marine debris surveys conducted in Hawaii from 2000 through 2007 as part of the National Marine Debris Monitoring Program demonstrate that surveys conducted during an ENSO related La Niña event showed between 26% and 39% reduction in debris loads (Ribic et al. 2012). Here, the largest reduction in mean debris concentration occurred at South Beach, Limantour Beach and North Point Beach during the El Niño event. Only South Beach and Limantour Beach showed a decrease in debris during the La Niña event, while North Point Beach displayed significant increase in debris concentration during this time. This increase is due to a surge in debris items recorded during a November 2016 survey that included 238 plastic fragments and 704 mesodebris items. As described in the previous section, this upsurge may be more linked to geographical and physical dynamics during the storm season than factors relating to the ENSO event.

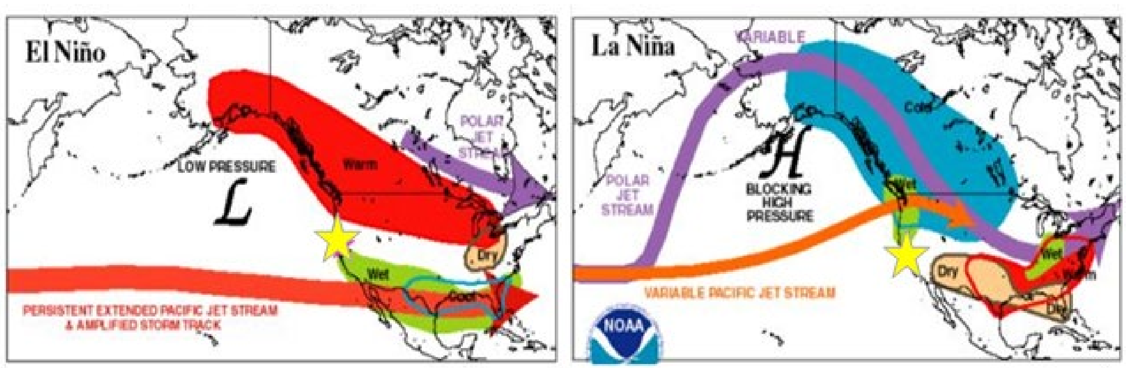


Figure 30. Star indicates GFNMS study region at the northern reaches of El Niño conditions and southern reaches of La Niña conditions. Source: NOAA CDC, 2005.

In addition to ENSO events, we assessed debris deposition patterns during, and one month following, 98 storm events in Marin, San Francisco, and San Mateo counties, over the course of 20 survey months. All survey sites except South Beach had a higher abundance of debris per survey during the storm event months when compared to the mean concentration per survey, or flux, for all months. Factors such as the northwest aspect, considerable slope, and overall low recreational use may attribute to the lower concentration of debris at South Beach during storm event months.

The varying physical and geographical characteristics between survey sites, and how they interact with currents and short and long-term storm events can help draw conclusions about the type, abundance, and/or frequency of debris deposition on beaches. Despite these conclusions, with only five years of data, and two years in the case of accumulation sites, it is difficult to determine exactly which factors most influence debris concentration/flux, and when. Additional data collection and monitoring are needed in order to definitively assess any correlations between debris concentration/flux on beaches and seasonal currents, El Niño/La Niña episodes, and storm events.

Sources

There is considerable difficulty in determining the origin of land vs. ocean-based debris when assessing data from standing stock and accumulation surveys. Because standing stock sites were established in remote areas away from built and natural outflows it is assumed these sites receive more ocean-based debris than accumulation sites which were adjacent to recreational use areas and/or outflows that likely bring more land-based debris to beaches. Data analysis at the Ocean Beach accumulation site and South Beach standing stock site demonstrate this thinking.

Ocean Beach is located five miles south of the mouth of San Francisco Bay, exposing the site to debris originating from the bay and delta as it exists under the Golden Gate Bridge. This site is also located within San Francisco, a major metropolis with a population over 800,000. Studies show that beaches within 40 km (~25 miles) of a population center with at least 250,000 people increases the magnitude of land-based debris generation (Ribic et al. 2012). The majority of debris items at Ocean Beach were plastic consumer and smoking based products such as cigarettes and food wrappers (Figure 10 and 11). Of the non-plastic items, Ocean Beach had the highest concentration of paper/cardboard items, dominated by paper and napkins. These debris are likely the result of beach picnics and/or easily transported by wind from nearby streets and receptacles (Figure 12). An increase in spent cardboard firework casings after the Fourth of July holiday also attributed to high concentrations of paper/cardboard items on Ocean Beach (Figure 13). Each of these items were considered indicators of land-based debris and tied directly to beach users. Thus, proximity to San Francisco Bay and position within the city of San Francisco can help explain why this site was dominated by land-based rather than ocean-based debris and why the mean flux was 22% higher than the other accumulation site at Drakes Beach West, which had less recreational use and was further from a large population center.

Of the standing stock sites South Beach had very low recreational use and was the most exposed to the open ocean. Data show that this site received that largest percentage of fishing related (i.e. ocean-based) debris compared to all other sites (Figure 10). This is further supported by data from the GFNMS monitoring program Beach Watch. Beach Watch data demonstrate that the bodies of Cassin's Auklets, a seabird that lives and dies entirely offshore, deposit at higher rates on South Beach than other beaches monitored through the program, including Drakes, Limantour, Ocean, and North Point beaches (K. Lindquist, pers. comm. Beach Watch 2018).

Despite these findings, items associated with typically land-based sources (e.g. water bottles, cigarettes) can derive from sea, and generally ocean-based items (e.g. fishing line, rope) can originate from land. Destruction caused by natural disasters such as the 2011 Japanese earthquake and tsunami, Superstorm Sandy in 2012, and recent hurricanes Maria and Florence create and transport debris to and from both land and ocean-based sources, further clouding the distinction between these two origins. For these reasons it is difficult to conclusively label certain items as solely land or ocean-based and may not be the most effective indicator of debris origin. Items analyzed in this report such as buoys, floats, and oyster farm debris are by and large exclusively used in the marine environment and may be the only few indicator items that characterize ocean-based debris. Improving the definition of land vs. ocean-based debris is important for accurately determining debris origin.

Shotgun Shells/Wads

We analyzed San Francisco Bay and delta as a source of debris to the open ocean, particularly for shotgun shells/wads at Ocean Beach. Beginning in the Sacramento and San Joaquin rivers, about half of California's runoff flows through the delta and into the bay and ocean. On average 15.8 million-acre feet (MAF) enter the ocean each year through San Francisco Bay. During wet years this number rises up to 29 MAF and during dry years can reduce as much as 6.4 MAF (The Delta Plan 2013). High winds and increased rainfall during wet years are thought to bring more debris through the watershed and into the ocean. Once this outflow exits the bay, the time of year and oceanic season may influence whether debris travels north or south along the coast.

Waterfowl hunting season in north central California generally runs from October through January during the oceanic storm season when the California current travels northerly. This may account for the low number of shotgun shells/wads on standing stock beaches in late summer and early fall before the hunting season begins. Considering the three months it took Oracle catamaran debris to reach South Beach, shotgun shells/wads leaving San Francisco Bay during the hunting season may take several months to reach survey sties in Point Reyes National Seashore. After the hunting season closes, higher densities of shotgun shell/wads during summer months may be connected to beach dynamics during the upwelling season when shotgun shells/wads on the bay or ocean floor can resurface and land on beaches as waters churn and sand is replenished.

Oyster Farm Debris

Drakes Estero was analyzed as a source of oyster farm debris, predominantly at Drakes Beach West, Drakes Beach East, and Limantour Beach within Drakes Bay. Although oyster farming occurs in Tomales Bay as well, the dimensions of the bay as a narrow estuarine basin cause unique interaction between bay and ocean water that reduce its likelihood as a major source for debris on beaches. During the summer months fresh water evaporation exceeds inputs from rain and runoff, causing a hypersalinity in Tomales Bay that impacts the density and mixing of bay waters. The occurrence of hypersalinity is an indicator of weak exchange between bay and ocean waters, so that the residence time of water in Tomales Bay lasts between 40-100 days (Largier.et al. 1997). In drought years, of which 2012 through 2015 had below average rainfall, the scarcity of fresh water elongates the hypersaline season, further reducing water exchange and increasing residence time, both of which lessen the likelihood of debris traveling out of the bay and to the open ocean. This corroborates our thinking that the former Drakes Bay Oyster Company acted as a point source for debris traveling downstream through the Estero and onto beaches.

In the case of oyster farm debris, Drakes Beach East (0.0004/m²) and Drakes Beach West (0.0014/m²) had the highest concentration of oyster farm debris across all six sites (Figure 24). Despite a 37.5% drop in oyster farm debris at Drake's Beach East after closure of Drakes Bay Oyster Company, debris was still recorded at this and other survey locations in Drakes Bay, likely due to the resuspension of oyster farm debris previously deposited by the oyster company (Figure 25). Even though Limantour Beach was also very close to the former oyster company, there were notably less instances of oyster farm debris recorded here when compared to other sites along Drakes Bay (Figure 24). This can be attributed to the often counterclockwise surface current within Drakes Bay, which can move oyster farm debris easterly away from Limantour Beach as items flow out of Drakes Estero (Figure 28).

Conclusion

MDMAP is a critical tool for sanctuary management to better understand the scope of the marine debris problem, the factors that contribute to debris concentrations on beaches, its potential sources, and mechanisms for addressing its impacts. Five years of data collection provided GFNMS with the tools and data needed to characterize the local marine debris problem. Using this data sanctuary outreach programs can better educate and message end users about the material types and products that most impact our beaches. Data can inform management to develop more effective seasonal and post-storm clean up strategies to target high deposition areas. Understanding when high deposition may occur will increase the effectiveness of limited clean up resources and expedite removal, thus reducing threats to sanctuary wildlife and habitats. With a better understanding of the origin of specific debris types, sanctuary management can target demographics and locations associated with those sources through improved outreach, volunteer, and stewardship programs.

On a broad scale MDMAP is critical for understanding regional and local baseline debris deposition and an important tool for sharing data amongst agency partners, beach managers, and coastal planners. The MDMAP program provides a central resource for collecting, sharing, and analyzing marine debris data locally, regionally, and globally. Information gathered and lessons learned through GFNMS participation in MDMAP can be applicable to other agencies and organizations monitoring marine debris, and can help improve the effectiveness of this and other debris monitoring programs. Continued beach monitoring through programs like MDMAP is vital to identifying long range changes in debris deposition and can help measure the effectiveness of policy and management changes related to the production, use, disposal, and removal of consumer products. MDMAP's standardized protocol, centralized database, and ease of data sharing is a critical component of the campaign against marine debris and provides scientists, managers and policy makers with the tools necessary to combat this important global issue.

Recommendations

Surveys conducted at standing stock sites from July 2012 through June 2017 and accumulation sites from June 2015 through June 2017, helped determine the scope and abundance of the marine debris problem along north central California. Here we offer recommendations to MDMAP protocol and methodology for improving the effectiveness of the survey process. Recommendations seek to strengthen protocol consistency to bolster data comparison across national programs, better define the scope and nature of the local marine debris issue, and provide management agencies additional tactics for reduction, prevention, and mitigation of marine debris on local beaches. Survey data analysis and recommendations can assist others in characterizing, tracking, and addressing their own local marine debris problem.

- Continue monthly surveys at all sites for at least ten years in order to monitor for reoccurring patterns and trends and better capture environmental and oceanographic influences on debris deposition. This will capture long-term variability, effects from severe storm or drought years, and can capture longer-term effects resulting from single event natural disasters.
- Include data on human use activities (i.e. swimming, fishing from shore, picnics, dogs on beach, permitted bon fires) and special events (sand castle building contest, dog day at the beach) to accompany survey data so trends in increased or decreased debris deposition can be correlated to human use and direct disposal of debris on beaches by recreational users.
- Increase the number of survey sites with set distances from high human-use beaches and/or near outflows (culverts, rivers). Locate new sites at places known to have higher likelihood of deposition from tides and currents, such as beaches on the south side of points or peninsulas, and also have equal numbers of standing stock and accumulation sites.
- Accumulation surveys are preferred by volunteers over standing stock surveys. If protocol for standing stock surveys could include debris removal there would be an increased support for and participation in standing stock surveys.
- New sites should have similar and comparable characteristics. For example, sites in different locations with similar aspects can be compared to one another to assess how debris deposition may be affected by directional exposure.
- Assess survey sites that are located within protected bays or estuaries to determine how upwelling shadows or runoff sources impact debris loads at different locations and times (e.g. after storm events).
- Where possible, increase sampling frequency to two-week intervals for standing stock sites to better capture storm events and calculate retention rates and densities.
- Develop a consistent definition to "recent storm activity" on survey sheets for both standing stock and accumulation sites. Definition may require Beaufort Wind Force scale, previous week's maximum wind speed, accumulated rainfall, and any other notable storm surges or unexpected tide heights.

- Add Beaufort Wind Force and wind direction under the "current weather" section of the survey sheets.
- Add other beach identifiers such as changes in the slope of the beach, presence of scoured, eroded or replenished sand, and location of wrack line within the site (e.g. waters edge, middle of beach, back barrier) to help determine how ocean and tidal dynamics affect beaches and debris deposition.
- Include in the data sheets when survey was conducted four days or less after favorable weekend weather, holiday (Memorial Day, Fourth of July, Labor Day) or prescribed event. In addition to organized clean ups such as Coastal Clean-up Day, GFNMS beach sties hold annual sandcastle building competitions on both Drakes Beach West and Ocean Beach. Events like these may affect debris loads on beaches. As a general assumption, four days or longer after an event is a reasonable amount of time for debris deposited during that event to be removed or pushed off the beach.
- Revise definition of fishing related debris to target items that may have come from a boat or a beach (e.g. buoys, traps), items that float versus those that may sink (e.g. lures with weight), various types of rope (e.g. weighted nylon line, polypropylene line, hemp or cloth rope). This will help to better define land-based vs ocean-based debris.
- Items with biota on them should have photos taken to help determine how long they have been in the environment and also for visual reference of potential invasive species. This may also help identify ocean-based vs. land-based debris origin.
- Reoccurring items recorded during standing stock surveys should include a process for tagging or marking the item along with making a note of the status (surface vs. buried), location (include GPS points), and date of the items each time it is recorded, pictures should also be taken of the item as visual comparisons can help determine beach dynamics and properly record debris persistence.
- Add more commonly seen items to sub-categories (e.g. plastic beach toys, plastic pens, pen caps, metal bottle caps, aluminum foil, napkins, grocery store paper bags, fast food paper bags).
- When defining locations for standing stock and accumulation surveys, make sure survey sites are at least one site length (100 m) apart so that survey area and potential removal of debris does not impact other survey sites.
- For standing stock surveys, add a section to record the presence of individual mesodebris (5 mm to 2.5 cm).
- Develop and provide outreach strategies for commonly found debris items such as bottle caps, straws, and shotgun shells/wads, which can be tied to certain products and product uses.
- Create prevention and reduction campaigns or policies around specific products to achieve the greatest success in reducing the amount of debris on our local beaches.
- Develop and provide outreach strategies for seasonal items, such as Mylar balloons in May and June when many students graduate. Targeted seasonal campaigns will strengthen the effectiveness and success of the outreach campaign.

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Appendix A

Blank GFNMS data sheet examples for standing stock and accumulation surveys. Sheets are modified from the original protocol developed by the NOAA Marine Debris Program.

Page 1 of GFNMS standing stock survey sheets.

Amended GFNMS Marine Debris Monitoring & Assessment SURVEY SHEET	NAME(S)		
	DATE		
BEACH NAME		LAST SURVEY DATE	
Latitude (N)		Longitude (W)	
WAYPOINT 001			
2nd CORNER			
3rd CORNER			
4th CORNER			
TIME Start End		SEASON	TIME OF LOW TIDE
RECENT STORM ACTIVITY		CURRENT WEATHER	

Tally for mesodebris 5mm – 2.5 cm								
Transect #								
Transect Meters								
Transect Width(m)								
Debris at back of shoreline?	YES NO		YES NO		YES NO		YES NO	
Plastic	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**
Hard fragment								
Foamed fragment								
Film fragment								
Bags								
Balloons								
Beverage bottles								
Bottle/ container caps								
Buoys and floats								
Cigar tips								
Cigarette lighter								
Cigarettes								

Page 2 of GFNMS standing stock survey sheets

Transect #								
Cups (includes foam)								
Fishing lures and line								
Food wrapper								
Other jugs or containers								
Oyster farm debris								
Personal care								
Plastic rope/ net pieces								
Plastic utensils								
Shotgun Shells/wads								
Six-pack rings								
Straws								
Other								
Metal	**Tally**	**Tot**	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**
Aerosol cans								
Aluminium/ tin cans								
Metal fragments								
Other								
Glass	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**
Beverage bottles								
Jars								
Glass fragments								
Other								
Rubber	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**
Flip flops								
Gloves								
Rubber fragments								
Other								

Page 3 of GFNMS standing stock survey sheets.

Transect #								
Lumber	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**
Cardboard cartons								
Lumber/ building matl.								
Paper and cardboard								
Paper bags								
Other								
Cloth/Fabric	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**
Clothing and shoes								
Fabric pieces								
Gloves								
Rope/net (non-nylon)								
Towels/rags								
Other								
Other/ Unclassifiable	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**	**Tally**	**Tot.**
Item #1								
Item #2								
Item #3								
Item #4								

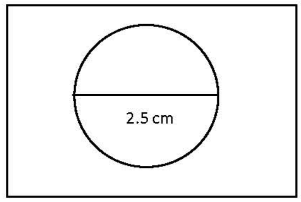
Large Debris Items ≥12 inches					
Item Type	**Status (buried etc…)**	**Approximate Length (m)**	**Approximate Width (m)**	**Transect number**	**Photo #**

NOTES

Page 1 of GFNMS accumulation survey sheets.

GFNMS Marine Debris Monitoring & Assessment ACCUMULATION SURVEY SHEET	SCHOOL/ ORGANIZATION	# OF SURVEYORS
	DATE	TIME OF LOW TIDE

ALL ITEMS SHOULD BE THE DIAMETER OF OR LARGER THAN A STANDARD BOTTLE CAP



PLASTIC 2.5 cm (1 inch) – 30 cm (12 inches)		TOTAL
Hard Fragment		
Foamed Fragment		
Film Fragment		
Bags		
Balloons		
Beverage bottles		
Bottle/container caps		
Buoys and floats		
Cigar tips		
Cigarette lighter		
Cigarettes		
Cups (includes foam)		
Fishing lures/line		
Food Wrapper		
Other jugs/containers		
Oyster farm debris		
Personal care products		
Plastic rope/ net pieces		
Plastic utensils		
Shotgun shells		
Six-pack rings		
Straws		
Other		

Page 2 of GFNMS accumulation survey sheets

METAL		**TOTAL**
Aerosol cans		
Aluminum/tin cans		
Metal fragments		
Other		
GLASS		**TOTAL**
Beverage bottles unbroken		
Jars unbroken		
Glass fragments		
Other		
RUBBER		**TOTAL**
Flip flops		
Gloves		
Rubber fragments		
Other		
LUMBER		**TOTAL**
Cardboard cartons		
Lumber/building materials		
Paper bags		
Paper & cardboard		
Other		
CLOTH/ FABRIC		**TOTAL**
Clothing and shoes		
Fabric pieces		
Gloves		
Rope/net (non-nylon)		
Towels/rags		
Other		

Page 3 of GFNMS accumulation survey sheets.

OTHER/UNCLASSIFIABLE: Description and Size – Remember to take a photo!	PHOTO #
Item #1	
Item #2	
Item #3	
Item #4	
Item #5	

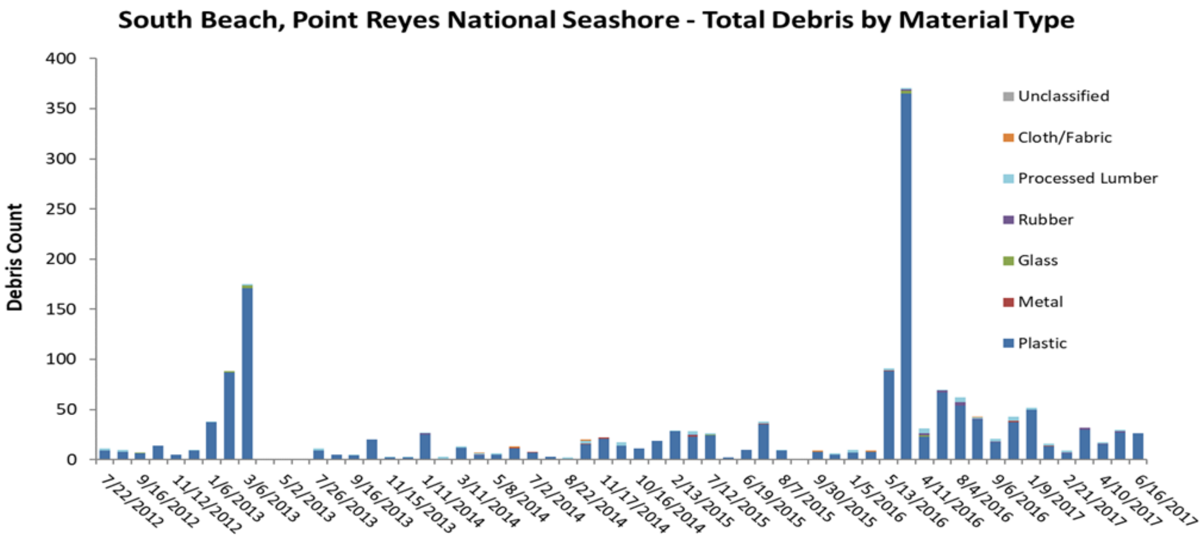
LARGE DEBRIS ITEMS (> 1 foot or ~ 0.3m)				
Item Category (Plastic – cloth – metal – rubber – lumber – glass – other)	**Status (buried, on surface etc…)**	**Approx. Length (m)**	**Approx. Width (m)**	**Photo #**

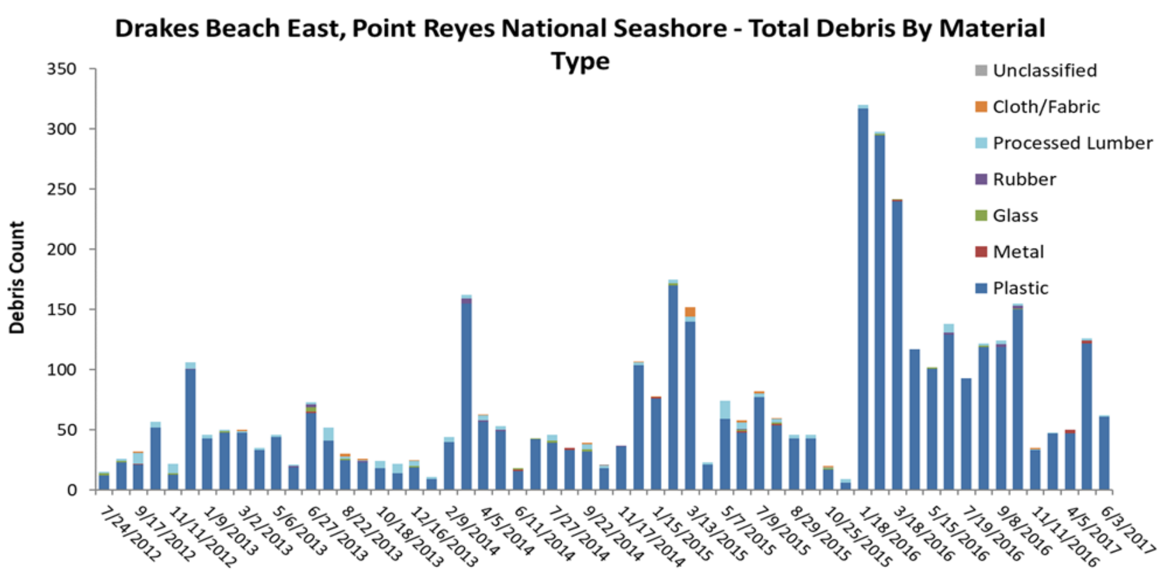
NOTES

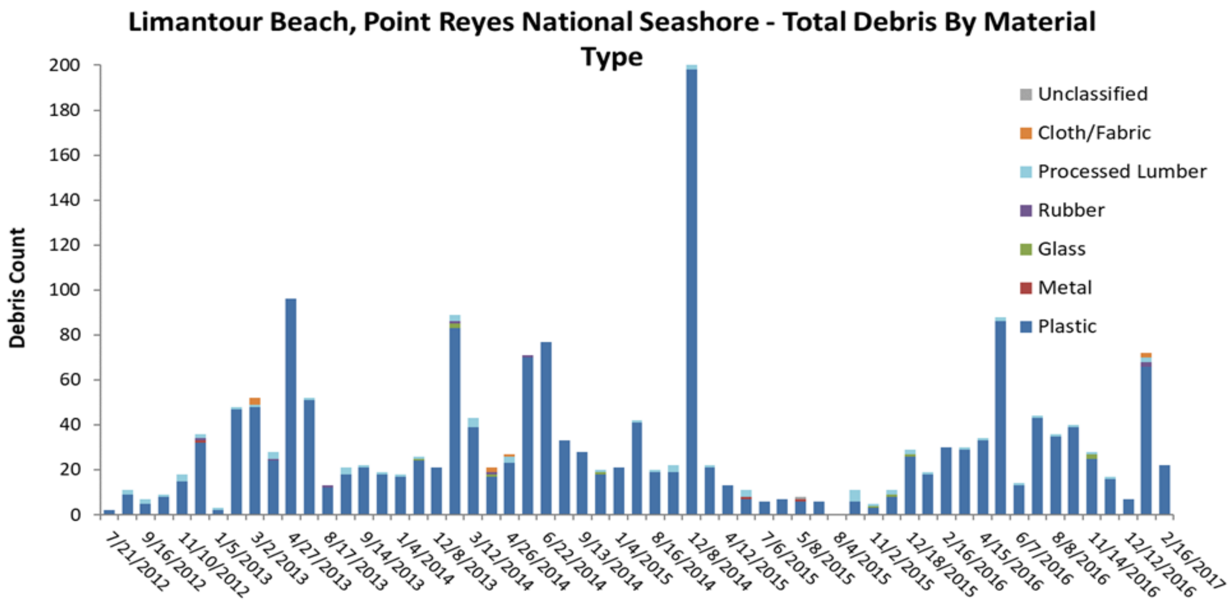
BEACH CHARACTERISTICS	
BEACH NAME	LAST SURVEY DATE
Latitude (N)	Longitude (W)
WAYPOINT 001	
WAYPOINT 002	
WAYPOINT 003	
WAYPOINT 004	
Width at North end	Width at South end
RECENT STORM ACTIVITY	SEASON
LARGE ITEMS? YES NO	DEBRIS BEHIND BACK BARRIER? YES NO
TIME of SURVEY Start End	
CURRENT WEATHER Precipitation: YES NO; Cloud Cover: Clear Partial Overcast/Fog; Wind: No wind Slight breeze Strong gust	

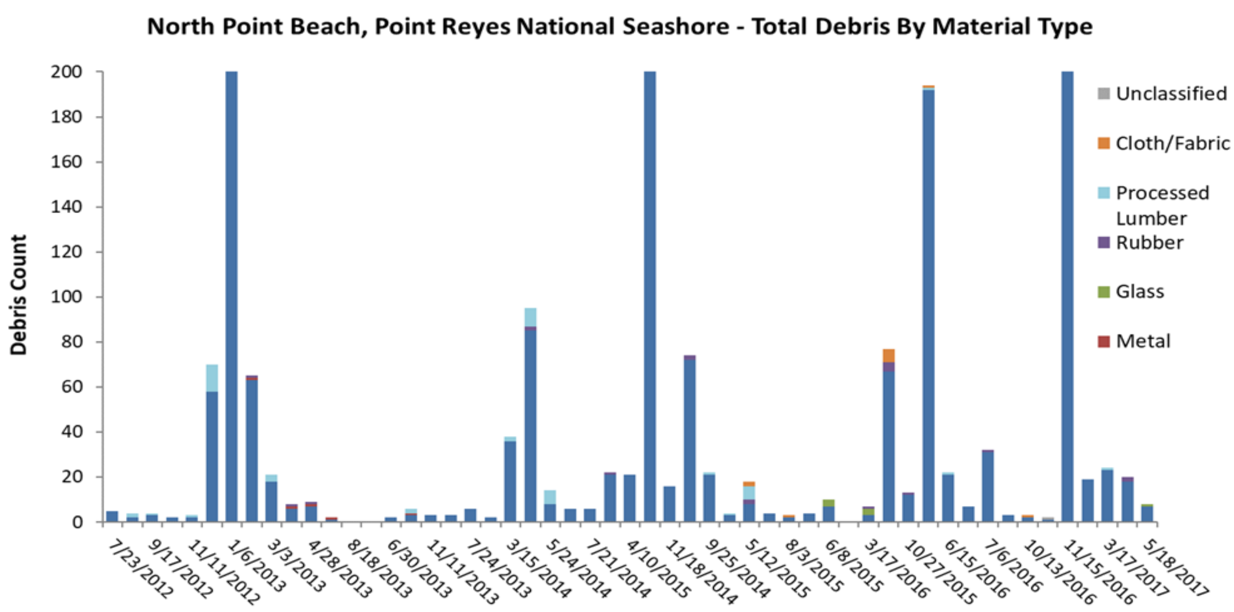
Appendix B

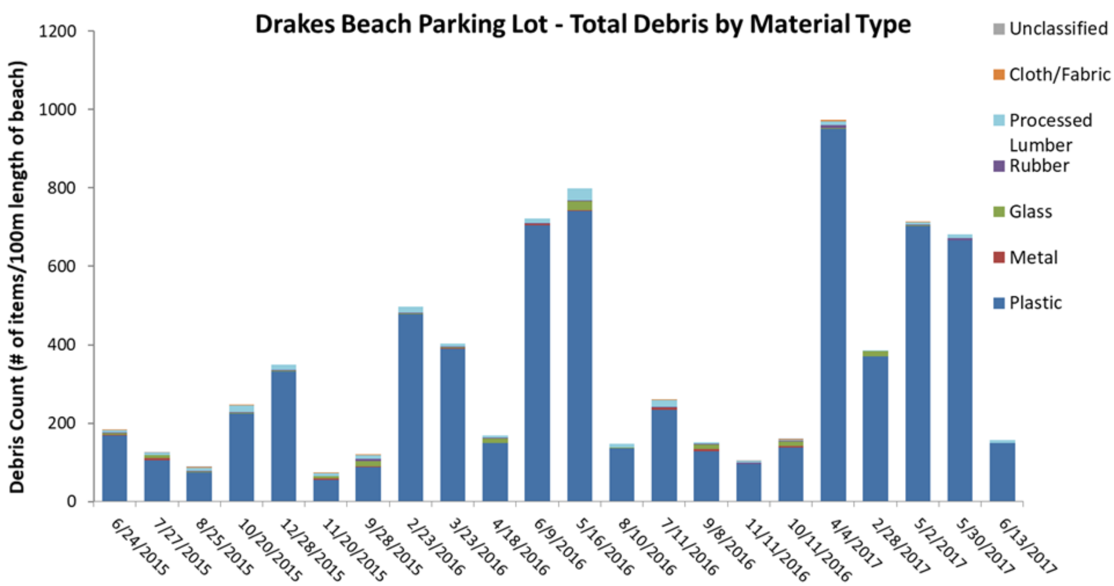
Debris types by count at each standing stock (South Beach, Drakes Beach East, Limantour Beach and North Point Beach) and accumulation (Drakes Beach West and Ocean Beach) survey site, July 2012 through June 2017.



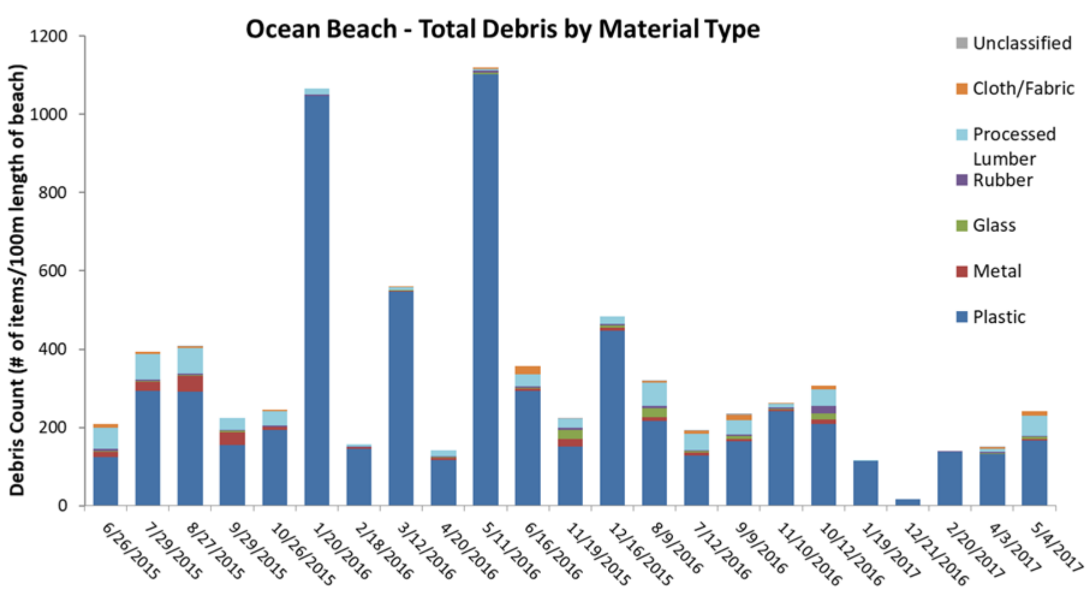



Limantour Beach, Point Reyes National Seashore - Total Debris By Material Type
Debris Count
Unclassified
Cloth/Fabric
Processed Lumber
Rubber
Glass
Metal
Plastic


North Point Beach, Point Reyes National Seashore - Total Debris By Material Type
Debris Count
Unclassified
Cloth/Fabric
Processed Lumber
Rubber
Glass
Metal



Drakes Beach Parking Lot - Total Debris by Material Type
Debris Count (# of items/100m length of beach)
0
200
400
600
800
1000
1200
Unclassified
Cloth/Fabric
Processed Lumber
Rubber
Glass
Metal
Plastic
6/24/2015
7/27/2015
8/25/2015
10/20/2015
12/28/2015
11/20/2015
9/28/2015
2/23/2016
3/23/2016
4/18/2016
6/9/2016
5/16/2016
8/10/2016
7/11/2016
9/8/2016
11/11/2016
10/11/2016
4/4/2017
2/28/2017
5/2/2017
5/30/2017
6/13/2017



Ocean Beach - Total Debris by Material Type
Debris Count (# of items/100m length of beach)
0
200
400
600
800
1000
1200
Unclassified
Cloth/Fabric
Processed Lumber
Rubber
Glass
Metal
Plastic
6/26/2015
7/29/2015
8/27/2015
9/29/2015
10/26/2015
1/20/2016
2/18/2016
3/12/2016
4/20/2016
5/11/2016
6/16/2016
11/19/2015
12/16/2015
8/9/2016
7/12/2016
9/9/2016
11/10/2016
10/12/2016
1/19/2017
12/21/2016
2/20/2017
4/3/2017
5/4/2017

NATIONAL MARINE
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