Rocky shoreline protocols miss microplastics in marine debris surveys (Fogo Island, Newfoundland and Labrador)

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ABSTRACT

Most anthropogenic marine debris shoreline studies are conducted on sandy shores, rather than rocky coastlines. We amended a standardized protocol for monitoring marine debris on a high-loading beach composed of small rocks and cobbles in Newfoundland, Canada. Our protocol had two parts: we conducted stratified sampling to a depth of ~20cm below the surface of the rocks (standing survey), and surveyed accumulation of items on the surface of rocks every other day (loading survey). We found the vast majority of smaller items were below the surface. Only 17.2% of debris were microplastics (< 5 mm). Types of anthropogenic debris differed significantly between the standing survey and the loading survey. We found no relationship between either wind direction or wind speed,

and distributions of debris. This study allows for a better understanding of marine debris detection along rocky coasts, and the limitations of protocols for studying them.

KEYWORDS

marine debris, plastic, rocky beach, shoreline survey, method, Newfoundland

INTRODUCTION

Anthropogenic marine debris has been observed on shorelines, in oceans, inland seas, and freshwater waterways for decades (Gregory, 1983; Pruter, 1987; Ryan 2015). Most of this marine debris is plastic (Debrot et al., 1999; Eriksson et al., 2013; Madzena and Lasiak, 1997; Rochman et al., 2015; Nagelkerken et al., 2001; Slip and Burton, 1991; Thiel et al., 2013). While there are many techniques and technologies for quantifying and characterizing anthropogenic marine debris in the marine environment, one of the least expensive methods is the shoreline survey, where debris is collected and quantified using transects, tracks, or entire beaches ("clean ups") (Rees and Pond, 1995; Ryan et al., 2009; Hidalgo-Ruz et al., 2012; Opfer et al., 2012; Lippiat et al., 2013). National organizations, such as the *National Oceanic and Atmospheric Administration* (*NOAA*) in the United States (Opfer et al., 2012) and the European Union (EU) Technical Subgroup on Marine Litter (EU-TSML 2013), among others (Rees and Pond 1995), have created protocols for shoreline studies in response to calls for the standardization of methods and techniques within marine debris research (Thompson et al., 2004; Löder and Gerdts., 2015; Hidalgo-Ruz et al., 2012; Rochman et al., 2015). However, despite the exponential increase of shoreline studies in the past decade, almost none focus on rocky or cobble shores, including the two national standardized techniques. Thus standardized protocols for shoreline marine debris studies are not developed for the rocky and icy shores that characterize locations such as Newfoundland, Canada, or indeed, much of the coastline found in high latitudes.

In a literature review of shoreline surveys conducted by Thiel et al (2013), of thirty-nine studies conducted between 1987 and 2012, only three included rocky shores (Vauk and Schrey, 1987; Slip and Burton, 1991; Nakashima et al., 2011). Of these, Vauk and Schrey (1987) do not mention their collection protocol at all. Slip and Burton (1991) state on pg. 250 that, "the rocky nature of much of the coastline precluded sampling of items smaller than 10 mm in length. Searches for small items, particularly plastic industrial pellets and polystyrene beads, were made on small areas of sandy beach". Nakashima et al. (2011) use aerial photographs taken by a digital camera attached to a helium balloon to estimate anthropogenic items larger than 10 cm x 10 cm, the maximum resolution of the camera. Thiel et al. (2013) sampled a rocky shoreline, but focused only on the high tide line (wrack line) which often includes seaweed that entangles debris. These methods avoid sampling for microplastics by focusing only in sandy or wrack line areas or with a camera whose resolution is unable to detect them. This means that debris under 5 mm in size is likely to be grossly under-represented in these collections. The inability to detect mircoplastics under 5 mm in size is an issue given that Eriksen et al. (2014) carried out trawl surveys and found that microplastics accounted for over ninety percent of plastic marine debris in the water column. What proportion of beach debris is microplastics is unknown, but it is more than likely under-sampled on rocky shorelines.

Studies on rocky shores are crucial for understanding marine debris trends. First, some geographical areas, such as Canada's far north, which are characterized by rocky and cobble shores, contain sensitive ecological areas that need to be monitored. Secondly, rocky shores include environmental dynamics important for understanding larger trends of marine plastics and their ability to be detected using current scientific protocols. Anthropogenic marine debris from the shore or sea has been shown to move from the shoreline and back into the sea by waves, run off, or winds (Nagaelkerken et al., 2001), but this may be reduced on rocky shores if plastics are caught in rocks, giving plastics a longer life on shore in rocky areas compared to sandy beaches (Eriksson et al., 2013). Complicating quantification even further, on rocky shores debris that is buried (in rocks or sand) can be later exhumed by wind and wave power (Kusui and Noda, 2003; Thompson et al., 2004; Smith and Markic, 2013). Williams and Tudor (2001a,b) found that while objects larger than surrounding cobbles were likely to work their way up to the surface, smaller items stayed buried, potentially skewing data designed to record shoreline debris as an indicator of overall marine debris in an area. Moreover, several studies suggest that rocky shores may serve as "grinding mills" that batter larger marine debris and accelerate the creation of microplastics (<5 mm) from macroplastics (>5 mm), which are then pulled back into the ocean (Debrot et al., 1999; Eriksson and Burton, 2003). Beach characteristics are thus important factors in determining how anthropogenic marine debris, and particularly plastics, circulate in environments and potentially confound quantitative studies of rocky areas.

Based on these concerns, we amended a sandy shore protocol for monitoring marine debris on a high-loading rocky beach on Fogo Island in Newfoundland, Canada, that contained a variety of sizes of rocks (from cobble to stone). This protocol is adapted from sandy shoreline transect surveys recommended by the National Oceanic and Atmospheric Administration (NOAA) (Opfer et al., 2012). It specifically mirrors NOAA's recommended shoreline method that uses quadrats along transects to focus on meso and microplastics (Opfer et al., 2012; Lippiat et al., 2013). The NOAA guidelines for plastic class sizes that we follow categorize macroplastics as those over 25 mm in size, mesoplastics as particles between 5 and 25 mm, and microplastics as those less than 5 mm in their largest dimension (Lippiat et al., 2013). It diverges from the NOAA protocol by sampling below-surface debris through sampling layers of rock, rather than digging and sieving sand. Sampling depth is carried out through layered strata, because, unlike digging sand, digging rocks and cobbles would dislodge much debris and cause it to be lost in deeper crevices and hence go unrecorded. We then also looked at anthropogenic debris loading onto the rocky shoreline using quadrats on the surface of the rocks without sampling below the surface.

Our amended protocol assess whether the types and amounts of debris detected on the surface of rocky beaches is different from those detected at varying beach depths. We wanted to see whether we could detect microplastics below the beach surface, since we predict that microplastic do accumulate on rocky beaches by slipping between rocks, despite other studies that have been unable to detect them (Slip and Burton 1991; Nakashima et al. 2011). We anticipate that our method will find around 70% of anthropogenic debris are plastics, following the global average calculated by Theil et al. across a variety of media (2013). We also anticipate that while the sizes of plastics would likely diverge from shoreline studies on sandy beaches, microplastics under 5 mm in size would make up a significant portion of retrieved plastic, as when sandy shoreline studies that record size classes have found the majority of plastics by number are in meso and micro categories (Browne et al. 2010; Heo et al. 2013; Jayssiri et al. 2013; Laglbauer et al. 2014). Finally, we hypothesized that wind speed and direction would correlate to the amount and types of plastics collected, as we anticipated that rocky shores may entrap smaller plastics while larger ones would be more available for the wind to dislodge and redistribute, and that plastics would be deposited on days with higher winds that blew debris from elsewhere.

Study area

Fogo Island (237 km^2) is located off the northeast coast (49° 39′ N, 54° 11′ W) of the main island of Newfoundland in the province of Newfoundland & Labrador, Canada, and has a terrain similar to many areas in high latitudes that are characterized by rocky shores. The island is home to approximately 2,400 residents (2011 Census Canada) scattered amongst 11 communities (which are amalgamated into one island-wide municipality for administrative purposes). The main economic activities are fishing and tourism, both of which are seasonal activities, and both of which produce marine plastic debris.

We surveyed a single small (~ 200 m^2) beach we call Half House Beach on the north side of Fogo Island (49° 43′ 25.47″ N, 54° 11′ 21.42″ W) in the community of Barr'd Islands (Fig. 1). The beach is a rocky/cobble beach and faces into a small bay that opens onto open ocean. The prevailing current influencing this beach is the Labrador Current, a cold water current that flows southward along the coast of Labrador (Ma et al., 2015) from the Arctic and is stronger in fall and weaker in spring (Wu et al., 2012). The inshore Labrador Current, which has slightly different seasonality, is the main current to which the study beach is exposed and is driven mainly by wind patterns and water density (Wang et al., 2015). Although our study beach is in a fairly deep (~800 m), sheltered bay, the dominant flow of water which might carry debris would be from the north and west (Ma et al., 2015). Thus, we predict that most marine debris will accumulate when winds are from the north. As such, the type of shoreline, type of likely debris (fishing and consumer waste), and origins of water are characteristic of many rocky shorelines in the northern part of the northern hemisphere.

METHODS

Rocky Beach Protocol Sampling Field Work

To develop an appropriate protocol for marine debris sampling on the rocky shorelines found throughout Newfoundland, we adapted the methods used to collect samples of anthropogenic debris down to 1 mm in size from sandy beaches recommended by NOAA. The NOAA protocol, published for a general audience (Opfer et al., 2012), along with a more detailed companion document (Lippiat et al., 2013), includes both an accumulation survey method to track the flux of large marine debris loading onto entire beaches that focuses on macroplastics and a standing stock survey using quadrats and transects to estimate the amount of smaller sized plastic debris (meso- and microplastics) on a shoreline by extrapolating a smaller, detailed set of samples. As we are chiefly concerned with the phenomena of small debris falling between rocks or being swept back into the ocean, we adapted the quadrat method for both standing and loading studies. Following this adapted NOAA protocol, we randomly selected two sets of 1 x 1m quadrats on the high tide line (wrack line); on the back beach above the high tide line, and below the high tide line (Lippiat et al., 2013: 16-17), for a total of six quadrats. One set of quadrats was used for a standing stock survey that sampled layers of rocks, and the other for an accumulation survey that investigated plastics loading onto the surface of the rocky shore. The small dimensions of our beach (20 m x 5-10 m) were such that we could not fit more sets of three quadrats, as described in Lippiatt et al. (2013), for either the standing stock or accumulation survey. Thus, we had one set of three quadrats for each of the two survey types described below. As this was an exploratory study, we surveyed a single, high-loading beach (Fig. 1).

Standing stock survey

Both NOAA and the European Union Technical Subgroup for Marine Litter protocols require the top 2 cm (NOAA) or 5 cm (EU-TSML 2013) of sand within a quadrat to be sampled. Because our beach was made of large rocks and cobbles, instead of sand/pebbles for which these other protocols were developed, we adapted our protocol as follows. We sampled each 1 x 1 m quadrat (one quadrat each below the wrack line, at the wrack line and at the back beach) to a depth of ~20 cm since the gaps between rocks and cobbles will result in smaller pieces of debris being trapped below the surface. To assess marine debris accumulation at different depth intervals below the surface of the beach, we first picked all visible anthropogenic debris from the surface of the rocks, shoveled a single layer (~5 cm) from the quadrat, placed the shoveled items into a large tray, and then hand-picked all debris from the tray. We repeated this process a total of four times. We also randomly sampled 10 rocks from each of the four layers to average the rock sizes per layer.

Accumulation survey

We conducted accumulation surveys every second day from 22 July 2015 to 28 August 2015 to avoid underestimating loading quantities and to ensure our technique could account for the full range of the types of marine debris occurring at Half House Beach over time. For the three quadrats used in the accumulation survey (wrack line, back beach, and below the high tide line) we collected all anthropogenic marine debris from the surface; we did not investigate debris that fell between the rocks since our sampling method would have disturbed the beach topography, affecting subsequent accumulation and giving us unreliable results. This is a deviation from the standard beach surveys (Lippiat et al., 2013), but as discussed above, it is necessary for rocky/cobble beaches. When compared to our standing stock survey, this accumulation survey will give us insights into how much debris is missed in a survey that only considers the surface of rocky shores. In accordance with NOAA protocols, we sampled during lowest tide, which occurred between 11:00 AM and 12:00 PM over the course of the study. We noted the time of high tide closest to our survey. The average maximum wind speed, average wind direction, and maximum temperature from the previous two days were obtained from Environment Canada's nearest weather station (Twillingate, WMO ID: 71402). During each survey, we removed all surface debris from the accumulation quadrats. There was one 4-day gap from August 8 to August 11 where we did not collect any samples, resulting in a total of 19 days of monitored accumulation.

Lab work

Once in the laboratory, we analyzed samples for marine debris type, size, and quantity. We filled the sample bags with water and poured the contents through a 0.335 mm sieve to capture any unseen or hard-to-remove plastics from the bags. Then we visually identified the marine debris items using the classification scheme in NOAA's marine debris shoreline field guide developed by Opfer et al. (2012) that includes categories for plastic, metal, glass, rubber, processed lumber, cloth/fabric, and other/unclassifiable. We used a hand lens and dissecting and compound microscopes as necessary to discriminate natural materials from anthropogenic items. We then measured three orthogonal dimensions (length, width, height) for each anthropogenic marine debris item and each rock sample using digital calipers to approximate the volume.

Data analysis

To analyze the samples, we quantified debris items by type and relative volume of each item for the 3 “standing stock” quadrats separately from the accumulation survey quadrats. We also summed total count by date. We could not assess count of debris items by volume of sediment, since the volume of irregularly shaped beach rocks is much harder to measure than that of sand, and does not mean the same thing in terms of density calculations (Lippiatt et al., 2013). We assessed whether loading (i.e., total count) was correlated to the average of the previous two days’ weather events (maximum wind speed, wind direction and maximum temperature) using a Spearman correlation analysis. Since data were non-normal we did not use a Peason’s correlation analysis. The correlation analysis excluded data from the first (22 July) day of sampling to assess how recent weather events might influence accumulation of anthropogenic marine debris over a two-day period. We also tested whether total volume and average volume of items accumulated over two days was related to weather events.

RESULTS

Standing stock survey

Rock size in each layer of the beach was highly variable (Table 1). Most of the debris found during the standing stock survey across all layers was either glass (75.7%) or plastic (17.9%) with very small quantities of other materials (lumber, metal, rubber, cloth; Fig. 2a). Glass was mostly accumulated below the wrack line, while plastic was more evenly distributed across the three beach areas. The distribution of glass in the depth layers was also quite different from plastic; most glass particles were found in the deeper layers only, while plastic particles were more evenly distributed throughout (Fig. 2b). The majority of debris by volume was found at the surface (73-99.9%) but the majority of items by count (86-99%) was found below the surface at all three sampling locations, meaning that smaller items were more plentiful below the surface (below the wrack line, at the wrack line, and back beach; Table 2; Fig. 3). The smallest particles (< 1 cm^3) were found in deeper depths of the quadrat below the wrack line; these were mainly small glass particles. Particle size below the surface had an average volume of ~ 5.3×10^{-5} to 0.042 cm^3, although there was considerable variation in particle size (Table 2).

Accumulation survey

On the initial sampling day for the accumulation survey, we collected 98 anthropogenic waste items of varying kinds. Subsequent sampling every other day yielded between 1 and 56 items per day (mean = 9.4 ± 12.9). Over the course of the entire accumulation study we collected a total of 258 items. The debris collected varied by type, but was dominated by plastic (82%). Number of items, total volume per day and average volume per day also varied through time (Fig. 4). The majority of the items (67%) collected were less than 1 cm^3 in volume; of these 16% of items collected qualify as microplastics (< 5 mm in the largest dimension, following NOAA classifications).

When relating number and volume of items loaded to weather parameters averaged over the previous two days (temperature, maximum wind speed, wind direction), only temperature was significantly negatively correlated to total volume (Spearman's rho = -0.539, p = 0.00275, n = 17) and average volume (Spearman's rho = -0.635, p = 0.00074, n = 17) of debris accumulated. None of the weather variables were significantly correlated to total number of items at alpha = 0.05, nor were wind parameters significantly to total or average volume of items at alpha = 0.05.

DISCUSSION

Anthropogenic debris distribution

The main purpose of this study was to discern if marine plastics are disappearing between rocks on rocky shores and thus whether data are confounded when using protocols designed for sandy beaches. In our standing stock survey we found that plastics and other anthropogenic debris such as glass indeed exist at a depth of ~20 cm below the surface of rocky shores. Glass was found at the deepest levels, while plastics were distributed evenly throughout the strata, though with greatest density in the first ~5cm. The vast majority (85-99%) of smaller items were below the surface. This suggests that smaller items are driven between rocks, and denser items such as glass are interred there, particularly below the wrack line where the tide rolls.

The main difference between our standing stock and accumulation surveys is the dominance of glass (75.7%) in the standing stock survey that surveyed interred items deep into the rock layers, and the dominance of plastics (82%) in the accumulation survey that only sampled new items arriving on the surface of the shore every second day. The glass particles in the standing stock survey were mostly found below the surface (small pieces of glass slipped easily between rocks and cobbles), and we did not sample below the beach surface in the loading survey. The distribution in time and space of glass versus plastics indicates that the glass at Half House Beach has been there for some time, or came during a unique event, as new glass is not being deposited on the shore while plastics are. It may also indicate that plastics do not become interred in the rocks over long periods the way that glass may, or that our modified protocol failed to detect microplastics interred below the surface. While some studies have found more plastics on sandy shores (Moore et al. 2001; Thiel et al. 2013), boulder shores (Podolsky 1989), and in mangroves (Smith 2012) compared to rocky shores, we argue that studies may be missing anthropogenic debris, particularly meso and microplastics, deeper in the rock strata.

Distribution of anthropogenic debris between the back beach, wrack line, and below the wrack line did not vary greatly. However, the wrack line (the high tide line) had a smaller volume of debris below the surface (0.09%) than the other two locations (23 and 27%). Given that we do not have replicate sample quadrats of each location, we cannot conduct statistical tests, but this pattern does suggest that either debris goes below the surface over time, or that organic debris at the wrack line keeps anthropogenic debris at the surface.

Size classes of marine plastics

The breakdown of plastic size classes in the standing survey were 11.5% macro, 71.3% meso, and 17.2% microplastics. While the majority (67%) of the items collected in the standing stock survey that sampled ~20 cm into the rocks were smaller than 1 cm^3, only 17% were small enough to be considered microplastics less than 5 mm in the longest dimension. Some of the small debris (9%) was fishing gear and line, which are thin but long and thus are not technically microplastics because they are longer than 5 mm in one dimension.

Our figures for microplastics are low in comparison to existing studies in the literature. While shoreline studies are becoming increasingly common, a review study by Browne et al. (2011) found that only 9% of studies recorded the number of plastics in articulated size classes. Of these studies, many use different ranges for each size category. In comparison these studies, our percentage of microplastics under 5 mm (17.2%) are much lower than those reported by Browne et al. (2010) in the Tamar Estuary, UK, where 65% of marine plastics were microplastics. For studies with size classes that overlap ours, even our figure of 71.3%

mesoplastics (5-25mm) is out of line with figures reported by Heo et al. (2013) in the China Sea, where over 95% of shoreline plastics were in the 2-10 mm range, as well as figures reported by Jayasiri et al. (2013) from India, where 41.85% of shoreline plastics were microplastics between 1-5 mm, and 75% were under 20 mm. Moreover, while a shoreline study in nearby Nova Scotia, Canada, used very different methods on shoreline sediments to monitor microplastics, they consistently found between 20 and 80 microfibers in samples (Mathalon and Hill 2014). As we found no microfibers, we can assume these very small microplastics are eluding our analysis (likely), are not being interred in any way on rocky shorelines (less likely), or are not present in Newfoundland waters (extremely unlikely). We can further assume that our count of microplastics is low as 93% of plastics on the surface of oceans globally are microplastics (Eriksen et al., 2014), though we cannot tell what proportion gets deposited on beaches.

For these reasons, do not think our proportion of microplastics on Half House Beach is representative of the amount of microplastics in the local environment, and that we are missing a significant number of these small plastic items in our data collection. It is likely many of the micropastics sink even deeper between the rocks and cobbles and/or are not collected in the adapted protocol, and thus new protocols and/or technologies will have to be developed to capture microplastics on rocky beaches. The high variation in rock size, both across location on the beach, and at different depth layers (Table 1) illustrates that the beach has many cracks and crevices where smaller particles can become trapped and hence not visible.

Despite the limitation in sampling microplastics, our adapted protocol does allow us to describe trends in items that are usually overlooked in shoreline clean ups that tend to concentrate on macrodebris larger than 10 cm, and is the first of its kind that samples plastics smaller than 10 cm from areas on rocky shores above and below the wrack line (Nakashima et al., 2011). In our standing survey, we found a very low percentage of anthropogenic debris by volume is found below the surface (Table 2), but a large percentage by count, meaning that some small debris is certainly below the visible surface. Thus, we conclude that restricting rocky shoreline surveys to the surface omit a high number of small particles, including but not limited to meso and microplastics.

Plastics versus other forms of anthropogenic debris

In both the standing survey and accumulation survey there was a high amount of plastic although it was the second-most abundant material behind (environmentally benign) glass in the standing stock survey. As 82% of the items in the accumulation study were plastic, but only 17.9% of items in the standing survey were plastic, plastics may be loading onto shorelines from the ocean, then being swept back out without being interred in the rocks, or that the glass on the shoreline has been interred for a long period of time before plastics became the more common form of anthropogenic debris in the area. In both studies, there was a substantial proportion of debris that was fishing gear and line (9% in the standing survey and 60.5% in the accumulation survey), which further characterizes the temporality of anthropogenic debris types on Half House Beach.

The unique high levels of glass in deeper strata and the high amount of loading plastics that are made of fishing gear and line are both characteristic of the activities around Fogo Island. Within global trends were an average of 71.7% of shoreline plastic are plastic (Theil et al. 2013), a handful of sandy shoreline locations have distinct non-plastic anthropogenic material signatures, such as Somerset and the Irish Sea, UK, which have 40% and 37% metal, respectively (Williams and Simmons 1997); Cuzios, Brazil, which had 50.6% paper (Oigman-

Pszczol and Creed (2007); the South China sea, which had 33.7% wood (Zhou et al. 2001); and Baja California, Mexico, which had 31.8% glass (Silva-Iñiguez and Fischer 2003). Fogo Island in Newfoundland joins these unique places that deviate from the global average of types of anthropogenic debris via unusually high loads of glass below the surface of the shoreline, and fishing gear loading onto the shoreline.

Effects of wind and weather on debris loading

We sampled debris on Half House Beach every second day throughout the summer. However, when we tested if weather events over the previous two days played a significant role in the amount of debris accumulated over the two day interval, only temperature was significant with a significantly higher total and average volume of items when weather was colder. This is counter to our expectation that days with high wind, especially wind from the north, would yield more debris. It is possible that some of the debris we found is landward in origin. We are unable to think of a reason why temperature would be correlated and we feel this is a spurious correlation that is not linked to any causality. The prevailing current comes from a remotely populated part of Canada, and the beach is close to a road and village and some debris may not be oceanic in origin. However, many items showed signs of oceanic weathering which suggests a substantial marine input of debris on this beach.

CONCLUSION

Our survey represents the first sampling of a rocky beach at multiple depths, and over time. We found that plastics and glass dominated debris, and existed at depths of ~20 cm below the surface of the rocky shore, where particles were smaller but more plentiful by count than on the surface of the ground. We did not find that wind speed and direction had any correlation on the distribution of marine debris either horizontally or vertically. Our technical protocol captured a variety of debris by size, type, and location, but sampled far below the number of anticipated microplastics. While the adapted protocol describes many trends in anthropogenic debris, including new information about the dominance of glass and plastics in debris types overall, the distribution of plastics and glass across rock strata, and the lack of correlation between wind and plastics loading, it was unable to procure small microplastics that other literature has demonstrated exists in marine environments. We strongly recommend that future work develop and validate protocols and techniques to better sample microplastics on rocky beaches, including the possibility of using passive samplers to capture small marine debris that would otherwise fall between rocks and cobbles or be swept back into the ocean.

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FIGURE CAPTIONS

Figure 1. Lower map: the study area at Half House Beach (boxed) on Fogo Island, Newfoundland, Canada. Top map shows the location of Fogo Island in relation to eastern North America.

Figure 2. Debris count (number of items) by material type as collected during a single day (standing survey) on Half House Beach, Fogo Island, Newfoundland, Canada. **a.** Data in each bar is dived by location on the beach. **b.** Glass and plastic data only. Data in each bar is grouped by depth layers. Depth layer 1 represents the surface of the beach and 8 is the deepest layer. Even numbers represent shoveled samples, and odd numbers represent where we picked debris from the exposed surface. See also Table 2 for a description of the depth layers.

Figure 3. Data from the standing survey showing percentage of items by count and volume found below the surface (up to 20 cm depth) of 1 x 1 m quadrats below the wrack line, at the wrack line and at the back beach. Percentage by volume at the wrack line is less than 1% and thus is not visible on the graph.

Figure 4. Box plot of volume of all items collected per sampling day (in cubic cm) collected between 22 July and 28 August, 2015. Mean is indicated by solid line. Boxes represent 1.5 interquartile distances and whiskers represent 95% confidence limit. Note that for visualization purposes, the y-axis is scaled. Number of items found each day are listed along the top of the graph.

TABLES

Table 1. Rock size (in cm^3) within 4 depth layers sampled on Half House Beach at three locations along the beach in the standing survey. Values are mean (± standard deviation) from 10 randomly sampled rocks in a 1 m^2 quadrat.

Location	**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**
Below wrack line	173.1 (135.2)	316.9 (357.9)	29.4 (35.0)	--
Wrack line	309.3 (242.3)	114.9 (52.7)	124.0 (172.8)	48.7 (39.2)
Back beach	243.1 (231.4)	206.1 (141.0)	200.6 (137.7)	245.2 (233.1)

Table 2. Number of items and volume of marine debris (in cm^3) at 8 depth layers in three 1 x 1 m quadrats on Half House Beach, sampled on a single day (standing survey). Values are mean (± standard deviation) volume of all particles sampled in that layer. For each depth layer, the exposed surface was first sampled by picking (P) all visible debris, then the layer was sampled by shoveling (S) an approximately 5 cm deep layer of rocks onto a tray and then picking out pieces of debris, and finally by immersing rocks in water to float any microplastics. A comparison of the total amount of debris (by count and volume) at the surface is included at the bottom of the table (see also Fig. 2). The percentage indicates what percent of debris at each location (below wrack line, wrack line, back beach) is below the surface.

Depth Layer	**Below wrack line**		**Wrack line**		**Back beach**	
	count	**volume (cm^3)**	**count**	**volume**	**count**	**volume**
1S	17	0095(0.387)	17	22.5 (92.9)	22	0.194 (0.497)
1P	112	5.3 x 10^{-5} (0.0003)	49	0.003 (0.007)	9	0.002 (0.003)
2S	16	0.0004 (0.001)	9	0.002 (0.002)	18	0.042 (0.128)
2P	26	0.0002 (0.001)	23	0.002 (0.004)	19	0.001 (0.003)
3S	13	0.0003(0.0004)	16	0.001 (0.002)	21	0.001 (0.003)
3P	864	0.0003 (0.0.0004)	22	0.002 (0.003)	18	0.003 (0.006)
4S	41	0.0004(0.0005)	8	0.003 (0.003)	28	0.023 (0.110)
4P	1,115	0.0002 (0.0002)	35	0.002 (0.002)	19	0.001 (0.002)
Total	**2204**	**2.099**	**179**	**383.429**	**154**	**5.847**
Total below surface	**2187 (99%)**	**0.474 (23%)**	**162 (90%)**	**0.336 (0.08%)**	**132 (86%)**	**1.572 (27%)**

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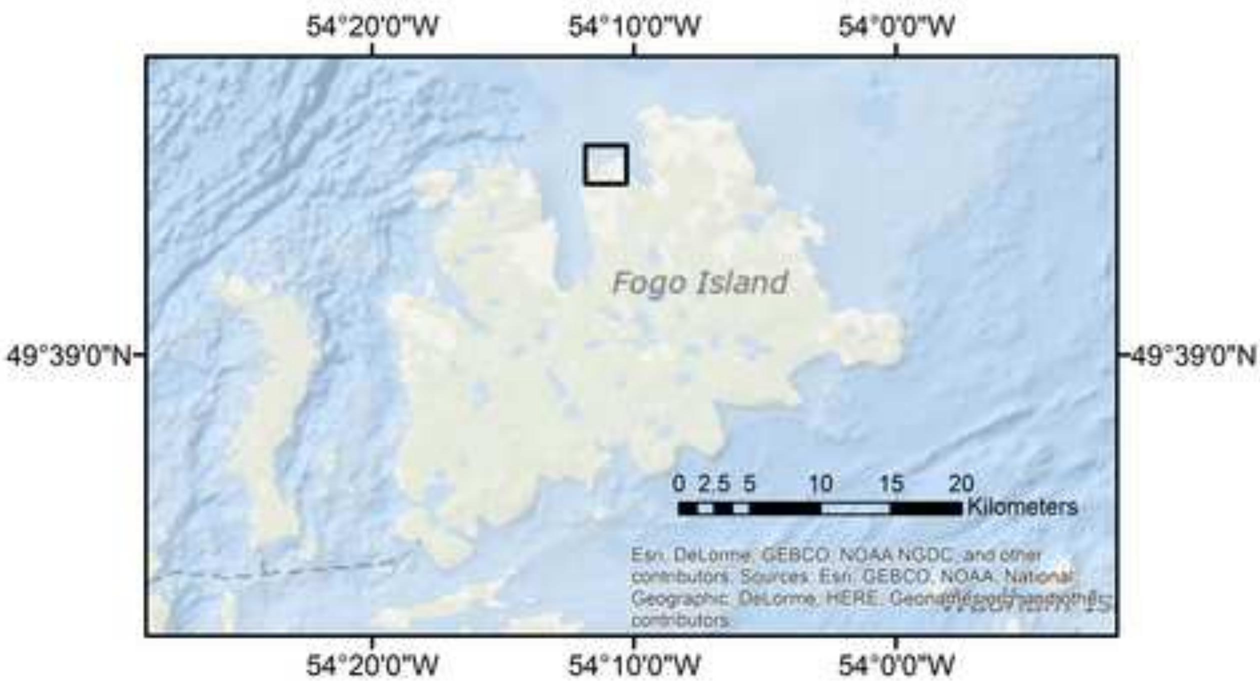

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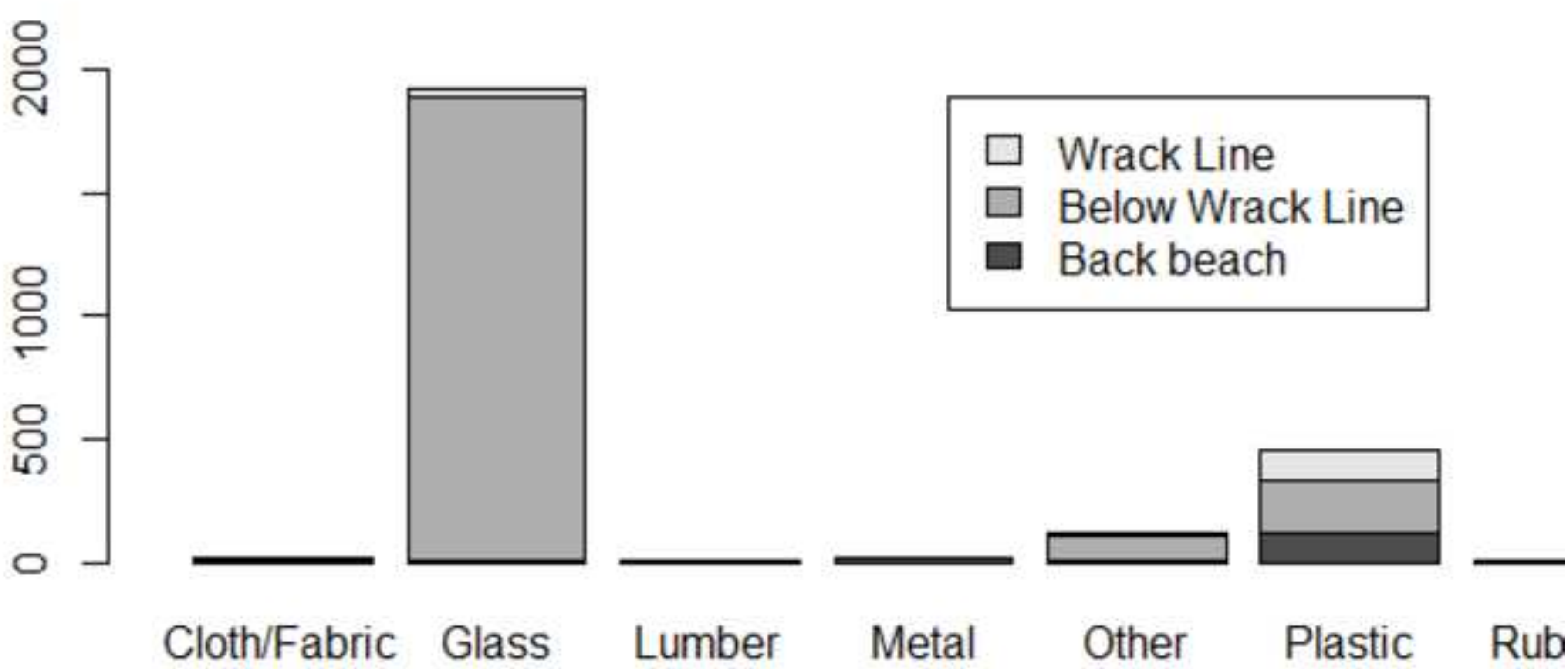

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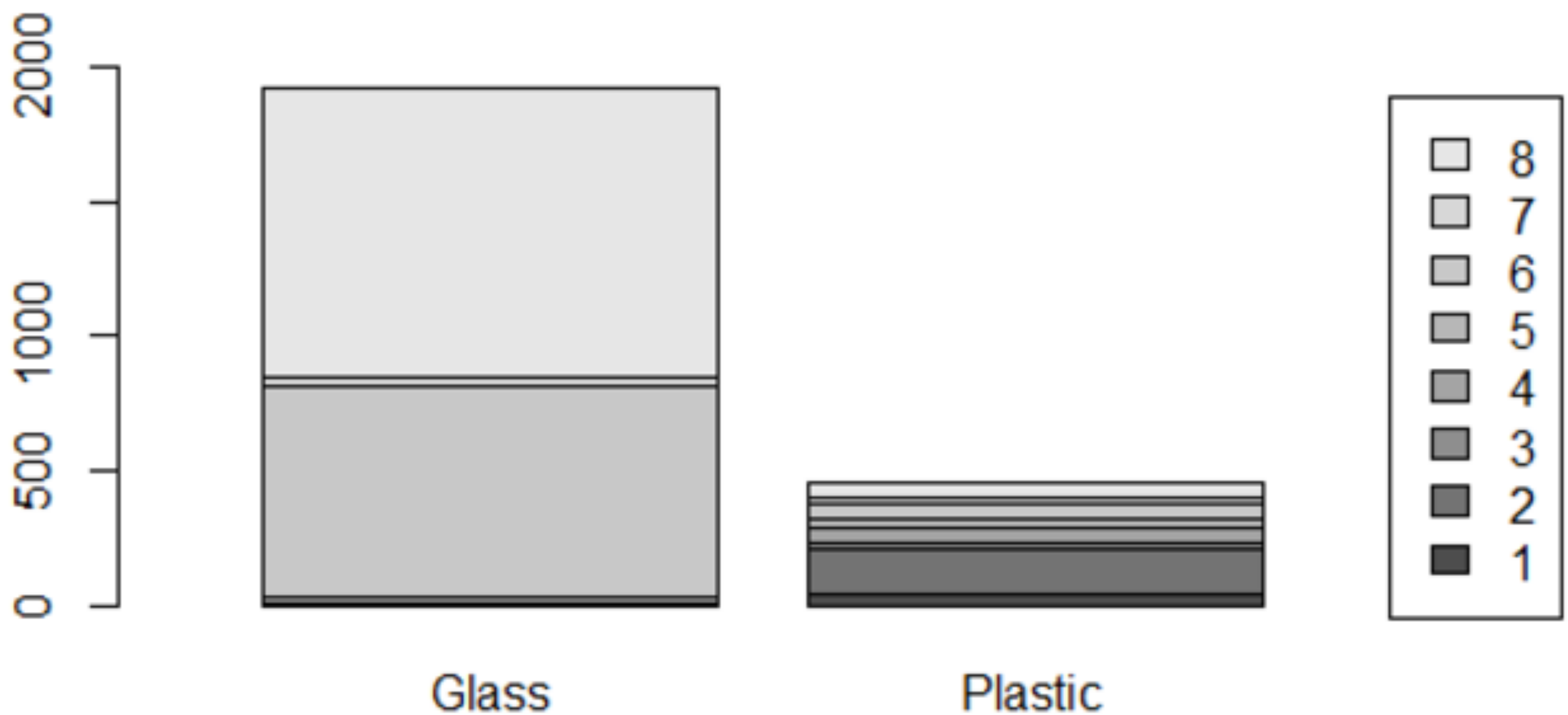

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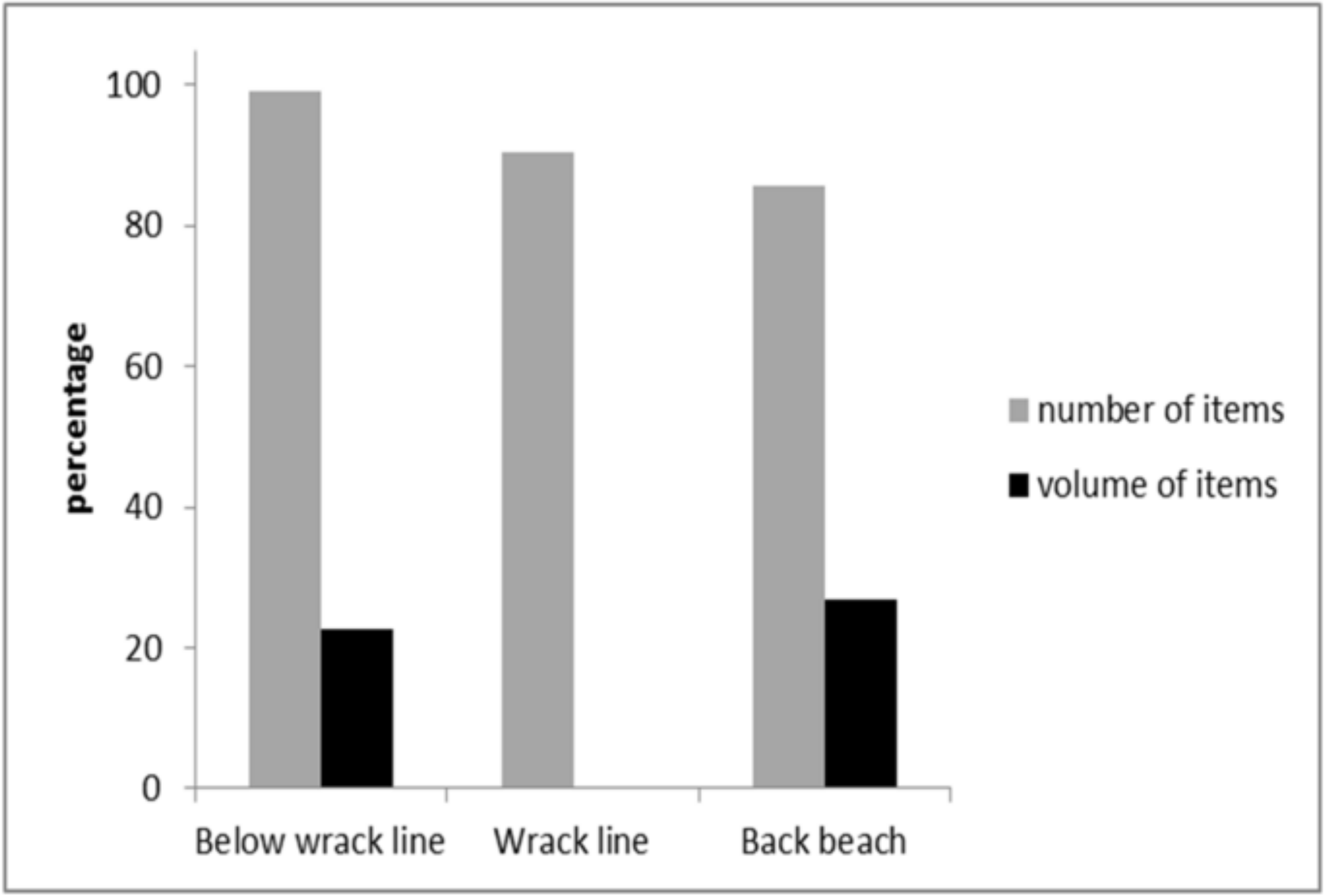

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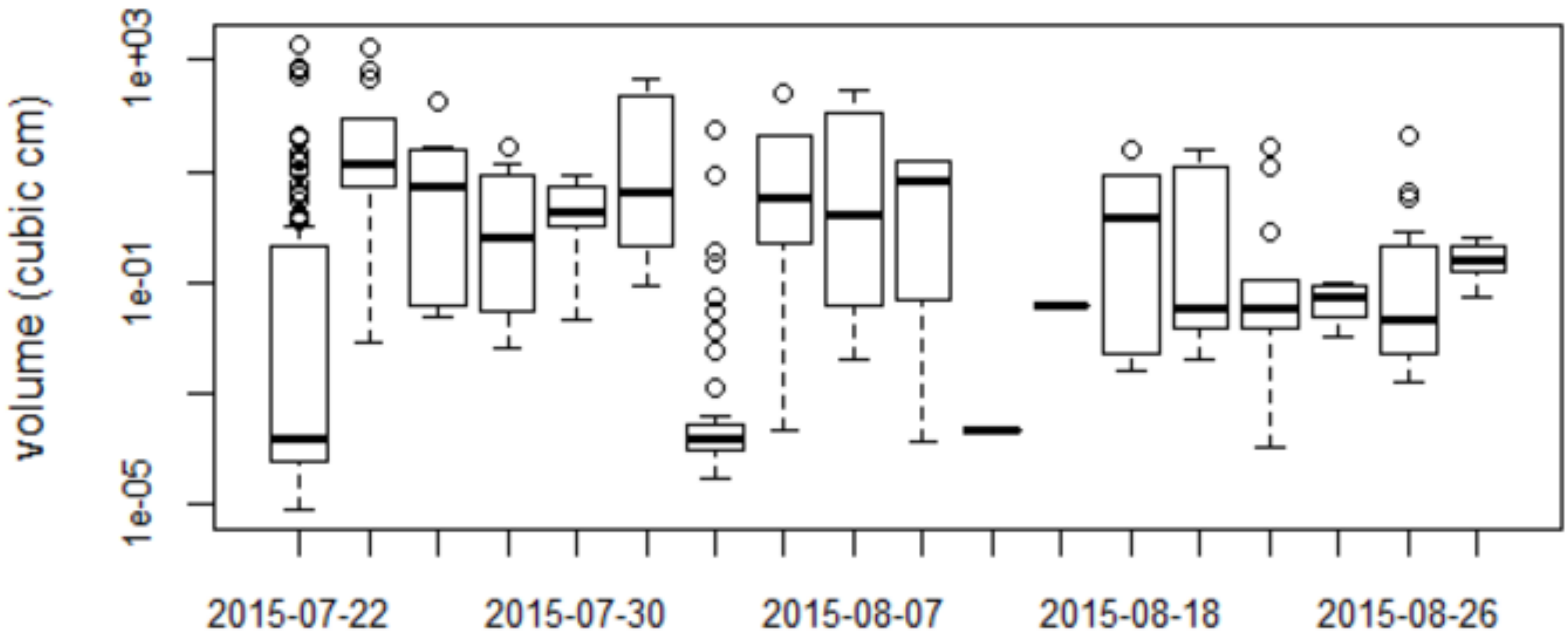

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