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Marine debris in five national parks in Alaska

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ABSTRACT

Marine debris is a management issue with ecological and recreational impacts for agencies, especially on remote beaches not accessible by road. This project was implemented to remove and document marine debris from five coastal National Park Service units in Alaska. Approximately 80 km of coastline were cleaned with over 10,000 kg of debris collected. Marine debris was found at all 28 beaches surveyed. Hard plastics were found on every beach and foam was found at every beach except one. Rope/netting was the next most commonly found category, present at 23 beaches. Overall, plastic contributed to 60% of the total weight of debris. Rope/netting (14.6%) was a greater proportion of the weight from all beaches than foam (13.3%). Non-ferrous metal contributed the smallest amount of debris by weight (1.7%). The work forms a reference condition dataset of debris surveyed in the Western Arctic and the Gulf of Alaska within one season.

1. Introduction

The remote, relatively pristine coastline of Alaska has a surprisingly high accumulation of marine debris. Ocean currents and vessel activity result in large deposits of debris on Alaska's beaches (Howell et al., 2012). Currents bring in debris from other regions including Russia, Japan and China (Derraik, 2002; Coe and Rogers, 2011). Marine debris has continued to rise in recent years, and is likely to continue an upward trajectory with the increase in population, visitation and exploration in Alaska (Alaska Marine Stewardship Foundation, 2014).

There are numerous descriptive reports on marine debris in Alaska by agencies and foundations, but these are often challenging to locate and offer little discussion or conclusions (e.g., Cook, 1988; King, 2008; Marine Conservation Alliance Foundation, 2008; Carswell et al., 2011; Maselko and Johnson, 2011). Peer reviewed literature on marine debris in Alaska is limited and primarily focuses on plastics and fishing debris (e.g., Shaw, 1977; Pichel et al., 2012; Davis and Murphy, 2015). In spite of the shortage of data, efforts have been underway to clean the Alaskan coastline. Local and federal governmental agencies and non-profit organizations have been conducting targeted marine debris removal efforts in Alaska for several years. Additionally, a significant influx of debris resulting from the 2011 tsunami in Japan raised awareness and funding for debris removal in Alaska as debris from the tsunami event started washing up on the coast (Marine Conservation Alliance Foundation, 2012; Barnea et al., 2014).

In 2013, the National Oceanic and Atmospheric Administration (NOAA) sponsored a workshop in Anchorage, Alaska, to prioritize marine debris response efforts. The prioritization effort relied on a 2012 State of Alaska aerial imaging effort to map the density and distribution of marine debris across the Gulf of Alaska. The workshop identified high priority areas needing to be cleaned based on a combination of debris density, land access, feasibility of debris removal, natural and cultural resources threatened and economic impact. Several of the high priority areas were in Alaska's national parks.

The National Park Service (NPS) in Alaska, recognizing the high degree of visitor use and the wilderness designation of much of the NPS managed coastline, has been conducting marine debris surveys since 2009. Specifically, Kenai Fjords National Park (KEFJ) partnered with the Resurrection Bay Conservation Alliance to clean beaches with in KEFJ annually. Katmai National Park (KATM) and the Alaska Sealife Center (ASLC) partnered in 2013 to conduct an initial clean-up of the park's most visited coastal site. However, the NPS recognized that a larger coordinated effort, in conjunction with efforts already underway by NOAA, would be more effective at addressing an increased area of debris removal.

The main goal of this project was to remove as much marine debris as possible from five coastal National Park Service units in Alaska.

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Documentation of debris collection was a secondary goal and beaches were not chosen randomly, but for management concern, logistics and access. Debris was documented in broad categories with debris weights collected per beach to enable categorization by composition and sources to ultimately strategize how to prevent debris entry into the system. The documentation facilitated assessment of differences in accumulation within the parks and between two regions: the Gulf of Alaska and the Western Arctic.

2. Methods

2.1. Sampling locations

Marine debris collection occurred within five National Park Service units between May 21 and July 22, 2015. The park units were Kenai Fjords National Park (KEFJ), Wrangell-St. Elias National Park and Preserve (WRST), Katmai National Park and Preserve (KATM), Bering Land Bridge National Preserve (BELA) and Cape Krusenstern National Monument (CAKR) (Fig.1). Beaches were not randomly selected, but were chosen by the project lead at the park (Table 1, Fig. 2). The combined coastline in National Park land in Alaska is 3640 miles with 2104 miles of coastline associated with the parks in this publication. Much of this land is extremely remote and therefore very difficult to access. It would not have been possible to access all sites of a random design were used for beach selection. Beaches therefore were chosen based on multiple factors. Some of those factors included debris accumulation zones, but other factors included feasibility of boat or plans access, cost of access and ability to safely move crew on and off sire and housing/camping options for cleanups that lasted more than one day. The park based project leads chose beaches based on known accumulation zones, management concerns, accessibility and cost of access.

For this study, a beach was defined as a continuous stretch of shoreline. A beach was continuous if it could be walked in its entirety at high tide and was separated from other sample areas by at least 1 km. Some beaches were too long to be sampled in one day, so they were sampled in segments. Segments within a beach were aggregated.

2.2. Debris collection

For each beach, surveyors walked the beach and collected all debris >10 mm long from the waterline inshore to the highest strandline on the upper shore. Partially buried or debris lodged in logs and rocks was excluded if it was unsafe or time prohibitive to remove, but in general, <5% of total debris remained on a cleaned beach. The surveyors walked in an organized pattern to ensure that the entire deposition area was surveyed and debris was removed. This pattern varied by park and beach width. Survey teams were comprised of two to 12 persons. The survey teams weighed the debris according to six categories: plastic, rubber, non-ferrous metal, rope/netting, foam and 'other' (Table 2). Glass, ferrous metals and processed lumber were not collected since their impacts are considered relatively innocuous.

To measure the length of the beach sampled, a track line was recorded using a Global Positioning System (GPS). The line measured depended on the geography of the beach: the berm line, wrack line, approximate vegetation line or beach centerline (Table 1). Beach length in kilometers (km) was used as a metric to standardize all sites; however, beach width varied widely within and between sites. While the additional measure of beach width would have provided area surveyed for

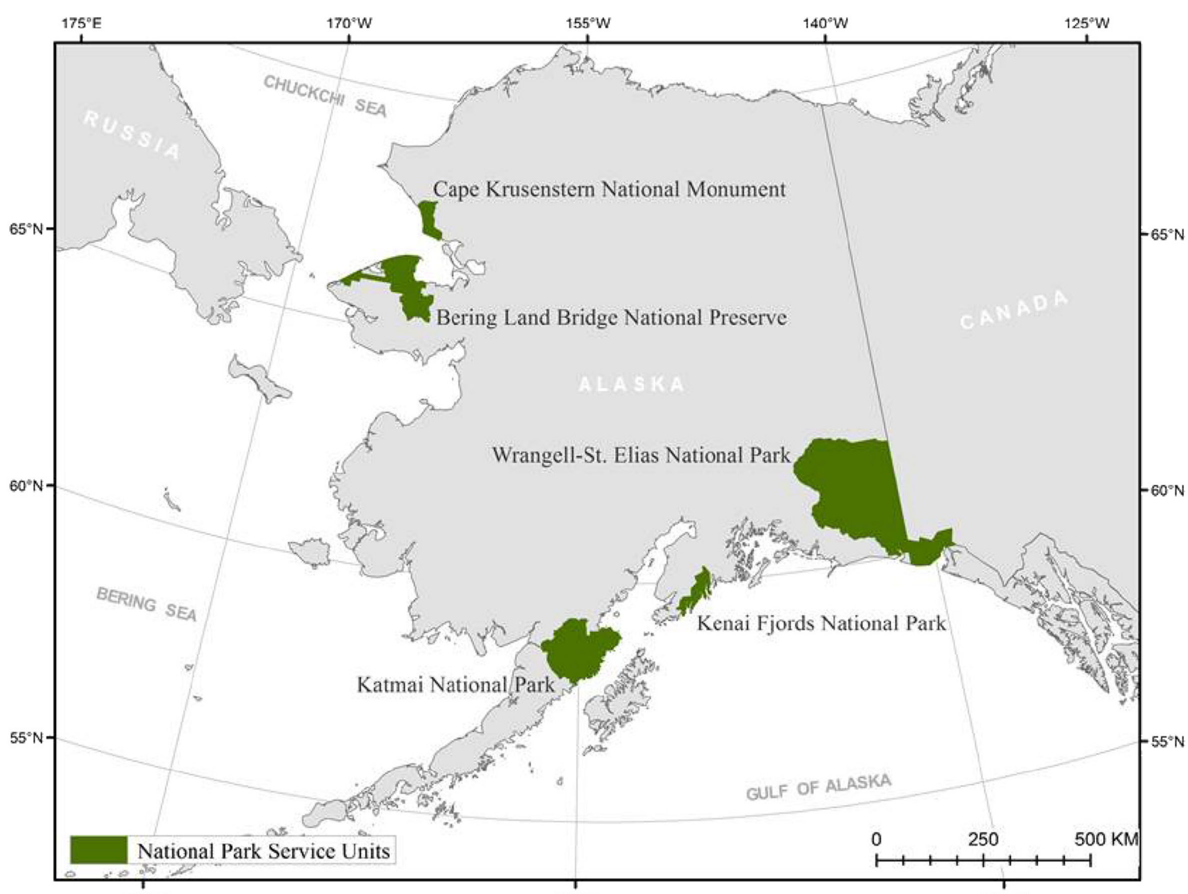

Fig. 1. Locations of five National Park Service units participating in marine debris collections.

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Table 1
A list of the beaches surveyed with start and end position, survey lines and total debris (kg). Survey line abbreviations follow: approximate vegetation line (V), wet-dry line (WD), berm line (B), wrack line (W) and beach center line (BC).

Park	Beach	Start latitude	Start longitude	End latitude	End longitude	Survey line	Beach length (km)	Total debris (kg)	Debris density (kg/km)	Debris load (kg/km/h)
KEFJ	PAGU-1	59.675	−150.093	59.679	−150.106	V	0.89	6.82	0.01	2.19
KEFJ	NWES-1	59.711	−149.924	59.73	−149.926	V	2.53	206.82	0.08	2.52
KEFJ	THUN-1	59.578	−150.213	59.576	−150.215	WD	0.35	483.64	1.39	53.45
KEFJ	THUN-2	59.573	−150.213	59.574	−150.214	B	0.14	237.73	1.76	121.44
KEFJ	TARO-1	59.623	−150.14	59.624	−150.141	V	0.07	105.45	1.57	196.74
KEFJ	TARO-2	59.62	−150.139	59.607	−150.121	W	1.83	291.36	0.16	0.00
KEFJ	TARO-3	59.621	−150.162	59.619	−150.157	W	0.39	35.00	89.74	17.95
KEFJ	TARO-4	59.624	−150.147	59.62	−150.165	V	1.22	207.27	169.48	8.69
KEFJ	THUN-3	59.581	−150.174	59.579	−150.173	W	0.28	90.00	319.15	79.79
KEFJ	THUN-4	59.576	−150.185	59.574	−150.185	W	0.29	11.82	41.47	49.76
KEFJ	THUN-5	59.581	−150.202	59.58	−150.21	BC	0.45	57.27	126.43	84.29
KEFJ	BLAC-1	59.506	−150.245	59.507	−150.247	W	0.14	583.18	4195.55	171.25
KEFJ	TARO-5	59.588	−150.113	59.589	−150.119	V	0.33	24.55	73.49	24.50
WRST	YAKU-1	59.703	−140.453	59.703	−140.453	V	0.19	401.36	2134.91	164.22
WRST	YAKU-2	59.696	−140.295	59.71	−140.226	B	4.26	1694.55	397.87	1.99
CAKR	CHUK-1	67.063	−163.308	67.084	−163.469	V	10.75	286.09	26.60	0.24
CAKR	CHUK-2	67.153	−163.74	67.123	−163.739	V	3.50	221.50	63.30	2.26
CAKR	CHUK-3	67.233	−163.753	67.302	−163.791	W	7.98	168.50	21.11	0.59
BELA	ESPE-1	66.594	−163.955	66.592	−163.885	V	3.19	76.00	23.86	0.66
BELA	ESPE-2	66.593	−163.965	66.587	−164.239	V	12.30	149.50	12.15	0.23
KATM	SWIK-1	58.609	−153.771	58.604	−153.765	BC	2.92	77.00	26.41	7.54
KATM	SWIK-2	58.612	−153.689	58.612	−153.689	BC	5.00	616.00	123.15	5.36
KATM	SUKO-1	58.857	−153.32	58.854	−153.309	BC	6.04	1036.10	171.54	2.69
KATM	SUKO-2	58.813	−153.369	58.848	−153.333	BC	0.73	302.10	416.12	31.68
KATM	KAGU-1	58.518	−153.923	58.574	−153.881	BC	6.98	1038.20	148.76	3.87
KATM	HALLO-1	58.403	−154.029	58.428	−154.061	BC	3.71	1086.20	292.54	6.74
KATM	HALLO-2	58.428	−154.061	58.435	−154.065	BC	0.85	202.90	239.55	64.17
KATM	HALLO-3	58.436	−154.072	58.457	−154.074	BC	2.45	707.73	288.75	4.40

data comparison, this extra metric was considered time- and manpower-prohibitive.

Two different metrics are presented to try to standardize the debris data and compare across the five parks: (a) debris density (kg/km) and (b) debris load (as defined by debris density per person-hour). With the limited time on these remote beaches, the focus was removing marine debris. Time spent sorting debris into categories and weighing the debris was excluded from the effort total. The metrics proposed in this study have been used and accepted in other peer-reviewed published work (Debris weight and/or composition based publications e.g., Dixon and Dixon 1981, Mio and Takehama 1988, Podolsky 1989, Hodge et al., 1993, Rees and Pond, 1995, Thornton and Jackson, 1998) and as standard reporting for government agencies (e.g., King 2008, Alaska Marine Stewardship Foundation, 2014).

Debris was collected in 50 gal heavy duty garbage bags. At the end of each beach or segment, all bags were weighed for each debris type collected. Weight was taken using a 100 lb spring scale, accurate to 1 lb or a 55 kg spring scale, accurate to 0.5 kg. For weighing large debris items a tripod was made out of driftwood. If the whole item was too heavy for the scale, the item was broken down into parts for weighing. Debris originally weighed in pounds was converted to kilograms for analysis. The total weight of each bag included the weight of the debris and the garbage bag. For heavy items, a tripod was utilized.

2.3. Data analysis

2.3.1. Statistics

Statistical analysis was conducted using Systat (Richmond, CA). Due to the small sample sizes in CAKR, BELA and WRST, the parks were combined into two regions for statistical analysis. BELA ($n = 2$) and CAKR ($n = 3$) were joined as the Western Arctic region. WRST ($n = 2$), KEFJ ($n = 13$) and KATM ($n = 8$) were joined as the Gulf of Alaska region. To control for the effect of effort, debris density per person-hour was calculated and is referred to as debris load (kg/km h^{-1}) for the remainder of the paper. A Mann-Whitney *U* Test was used to compare the average debris load by type and overall between the two regions. Significance was set at $p < 0.05$.

2.3.2. Geospatial data processing

To determine beach length, a track line was recorded with either a Trimble GeoExplorer 7 (Sunnyvale, CA) series unit (KEFJ, WRST) or a Trimble Juno 3 unit (BELA, CAKR). In KATM, a Trimble GeoExplorer 7 unit was used in Kaguyak and Swikshak Bays and a Garmin GPS 72 (Lenexa, KS) unit was used in Sukoi Bay. No tracks were recorded for Hallo Bay beaches, therefore beach lengths were recreated based on points taken by the survey crews using a Garmin GPS unit and Google Earth imagery. All track lines were segmented to account for beach shape and therefore total beach length was not a straight line.

3. Results

Marine debris was found at all 28 beaches surveyed. Hard plastics were found on every beach. Foam was found at every beach except one. Rope/netting was the next most commonly found category, present at 23 out of 28 beaches. Non-ferrous metal was found at 19 out of 28 beaches, and rubber was found at 18 beaches. The 'other' category was the least common, and was collected at 14 out of 28 beaches. Overall the dominant marine debris, hard plastic, contributed to 60% of the total weight of debris while non-ferrous metal contributed only 1.7% by weight. At all beaches, rope/netting (14.6%) was a greater proportion of the weight than foam (13.3%).

Debris density, a measure of debris weight per km of beach surveyed, varied widely within and between the parks: 7.7 to 4195.6 kg/km (Fig. 3). Both the maximum and the minimum debris density were found on beaches in KEFJ (Table 1). WRST had the highest debris density with all beaches combined for the park (Table 12). KATM had the highest total debris collected but also surveyed the greatest beach length, therefore had lower debris density than KEFJ and WRST (Table 1). Overall, as parks, BELA and CAKR had the lowest debris density, 14.6 and 30.6 kg/km, respectively (Table 1).

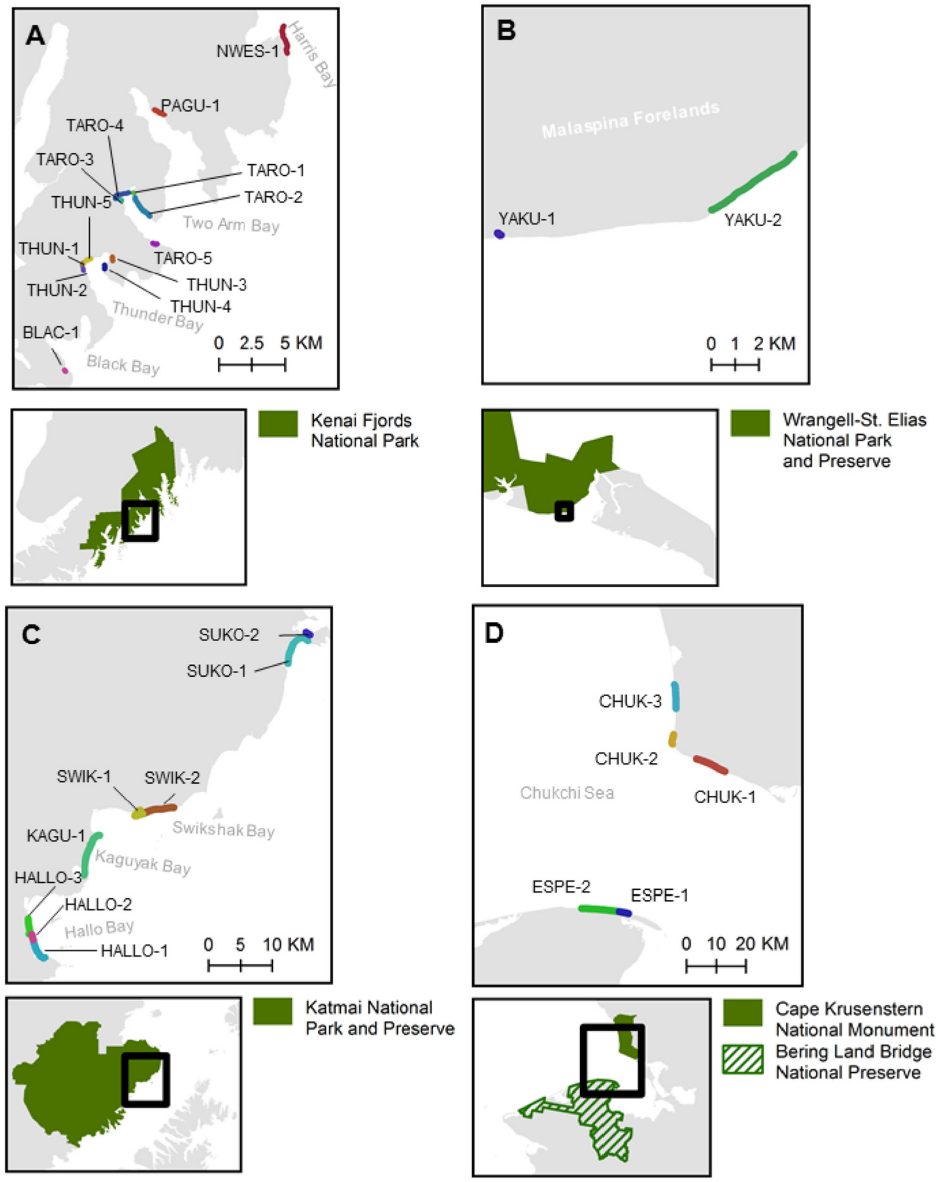

Fig. 2. Locations of beaches within the five national parks surveyed from May 21–July 22. A) Kenai Fjords National Park, B) Wrangell-St. Elias National Park, C) Katmai National Park, D) Cape Krusenstern National Monument and Bering Land Bridge National Preserve. Beaches are designated by thick, colored lines and labeled with their names. Inset maps show the survey area within the extent of the park unit.

Table 2
The six debris categories used during the five Parks Marine Debris Survey.

Category	Items
Plastic	Bottles, jugs, caps, wrappers, bags, cigarettes, disposable lighters, 6 pack rings, cups, utensils, straws, crates, fragments of plastic, fiberglass, vinyl, Igloo coolers, floats and buoys. As time allowed, large hard plastic floats and buoys were weighed separately.
Rubber	Fragments, shoe soles, boat fenders, tires, snow machine treads
Non-ferrous Metal	Beverage cans, aerosol cans, scrap metal, building materials, aluminum boat parts
Rope/netting[a]	Rope, line, trawls, seines, gill nets and drift nets made from any material
Foam[a]	All styrofoam pieces, foam floats, packaging materials, flip-flops, PFD's
Other	Anything that didn't fit into the other 5 categories. See the 'Other' description for each park for a list of what was found. This includes cloth, shoes of mixed materials and large equipment of mixed materials.

[a] Most fishing nets, lines and foam are forms of plastic but have separated for the purpose of this study.

3.1. Kenai Fjords National Park

Within KEFJ, debris density varied greatly between beaches (Fig. 3). Four beaches had densities >1000 kg/km, but all of the other beaches had densities <320 kg/km. Hard plastic made up the majority of debris found in KEFJ (61%), with foam and rope/netting making up the majority of the rest of the debris (Fig. 4).

3.2. Wrangell-St. Elias National Park and Preserve

Two beaches in WRST were surveyed (Fig. 2). One was a short beach with high debris accumulation and the other was a long stretch of wide beach with small areas of high debris accumulation dispersed throughout. The short beach had more plastic and foam proportionally (401 kg/0.19 km) than the longer beach (1694 kg/4.26 km). The longer beach had a more even distribution of types of debris, but foam and hard plastic still dominated. WRST had the greatest amount of foam in any park, both by weight and proportionally (555.0 kg, 26%, Fig. 4). WRST

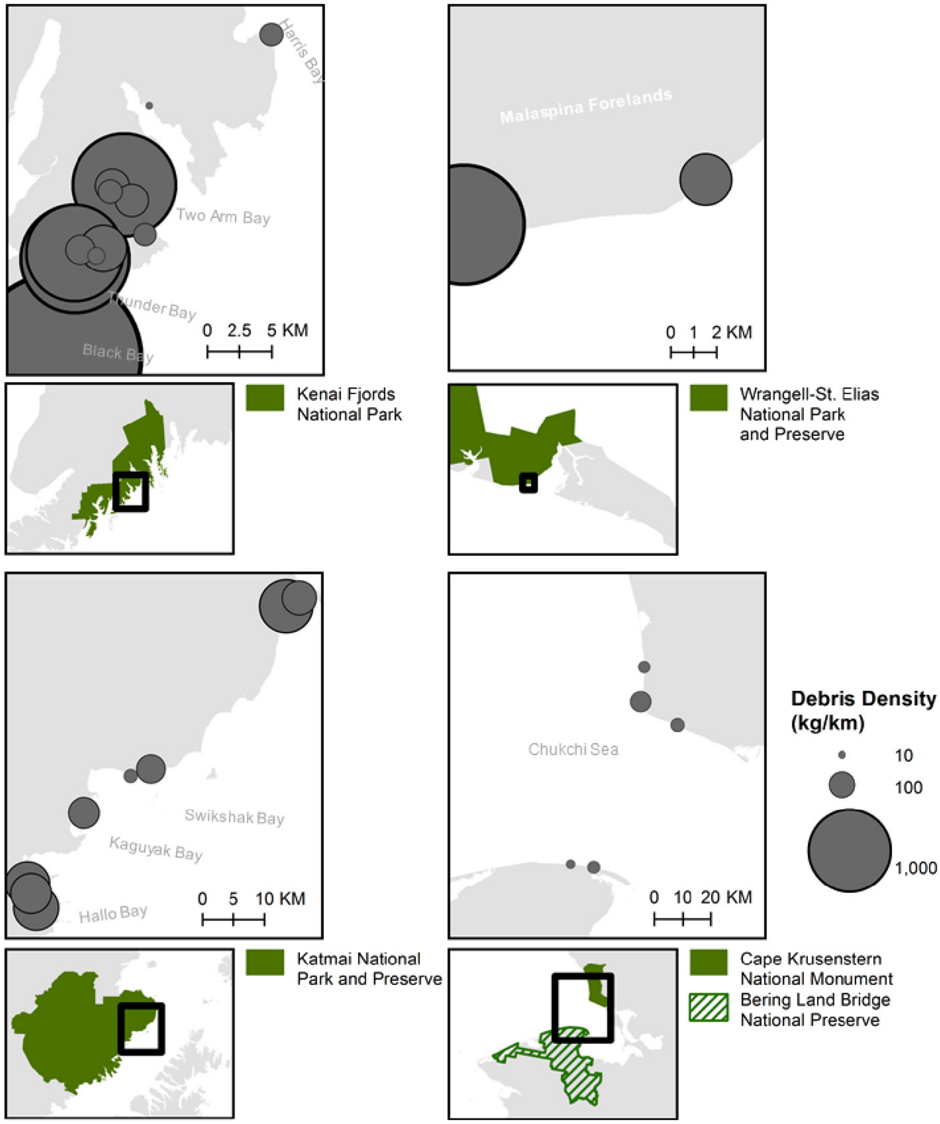

Fig. 3. Total debris density (kg/km of beach) estimates of marine debris collected in five Alaska National Park units. Density is represented by proportionally sized grey circles per beach.

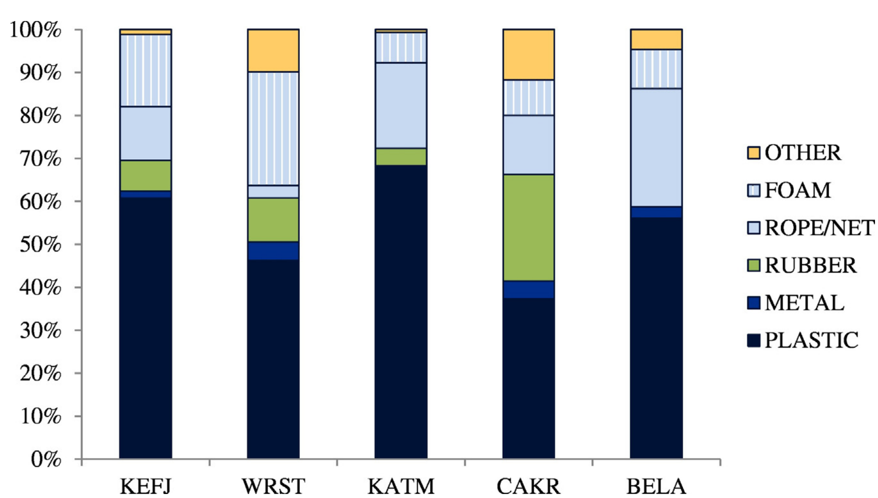

Fig. 4. Types of debris found at five Alaska National Park units in 2015 as a proportion of total debris collected. Park names are abbreviated as follows: KEFJ–Kenai Fjords National Park, WRST–Wrangell-St. Elias National Park and Preserve, KATM–Katmai National Park and Preserve, CAKR–Cape Krusenstern National Monument and BELA–Bering Land Bridge National Park.

had a high proportion of 'other' by weight (10%). Several heavy conglomerates of inseparable rope, wire and rubber and an abandoned ATV contributed to this value.

3.3. Katmai National Park and Preserve

The surveyed beaches in KATM had similar densities of debris. Six out of eight beaches had debris densities between 100 and 300 kg/km. As a park, KATM, had the highest total debris weight along with the most non-float hard plastic and the most rope/netting by weight. Proportionally, very little metal (0.2%), rubber (4.0%) and 'other' (0.7%) were found in KATM (Fig. 4). Hard plastic represented 68% of the debris found in KATM.

3.4. Bering Land Bridge National Preserve

BELA had both the lowest overall debris collected and the lowest debris density (Fig. 3). No rubber was found. Hard plastic and rope/netting made up the two most commonly found categories. BELA had the highest proportion of rope/netting by weight (27%) (Fig. 4).

3.5. Cape Krusenstern National Monument

The second lowest amount and second lowest debris density were found in CAKR. CAKR had the smallest proportion of plastic (38%), the highest proportion of rubber (25%) and the highest proportion of 'other' (12%; Fig. 4).

3.6. Regional comparison

As previously mentioned, two regions were designated for comparisons: the Gulf of Alaska and the Western Arctic. Between the two regions, debris collection volume was divided by overall effort to determine a debris load (kg/km h^{-1}). Debris load was significantly different ($U = 113.0$, $p = 0.001$, $df = 1$) (Table 3) between the regions. The Gulf of Alaska parks had a significantly higher debris load on average than the Western Arctic parks. Plastic ($U = 115.0$, $p = 0.001$, $df = 1$) and foam ($U = 110.0$, $p = 0.002$, $df = 1$) were also found in significantly higher loads in the Gulf of Alaska parks than in the Western Arctic parks. All of the other categories were not significantly different between the two regions.

4. Discussion

A substantial marine debris response effort was undertaken with the aim to remove as much marine debris as possible from five relatively remote coastal National Park Service units in Alaska. Approximately 80 km of coastline were cleaned with over 10,000 kg of debris collected. Marine debris was found on every beach surveyed supporting the pervasiveness of coastal marine debris in Alaska (Alaska Marine Stewardship Foundation, 2014).

Plastic debris was the most common coastal debris in the study and was found on every beach surveyed. Derraik (2002) conducted a worldwide review of marine debris literature and found marine debris was primarily plastics (60–80%). Not surprisingly foam was the second most abundant type of debris. The Marine Conservation Alliance Foundation (2012) noted large amounts of Styrofoam on Alaskan shores. Davis and Murphy (2015), although not the focus of their study, also noted large pieces of foam in Alaskan waters.

4.1. Kenai Fjords National Park

Marine debris cleanups have been conducted in KEFJ for the past several years (National Park Service, unpublished data). These efforts have shown similar debris volume from year to year. The amount of foam collected from KEFJ beaches in 2014 is almost equal to the amount of foam collected for this study by weight, supporting the Pallister and Gaudet (2011) theory of debris accumulation being an annual event driven by winter storms on Gulf of Alaska beaches. In the case of KEFJ, and possibly other beaches in Alaska, previous cleanup efforts are unlikely to prevent the future accumulation of debris, but more data is needed to support this postulation.

4.2. Wrangell-St. Elias National Park and Preserve

The two selected beaches in WRST had the highest amount of foam and high accumulation of plastic. This is different than would be expected from Cook (1988), who noted that little debris was found in WRST, although a measure of debris was not documented in the study. WRST is the one park where there was an apparent increase in debris load from previous surveys (National Park Service, unpublished data). This was similarly noted by Maselko and Johnson (2011).

4.3. Katmai National Park and Preserve

The KATM Hallo Bay collections in the study were similar to collections conducted in 2013 in Hallo Bay (Alaska Marine Stewardship Foundation, 2014). Beach location within the bay was not defined in the report for the 2013 survey but was close to the combines Hallo-1 and Hallo-2 sections. Regardless, the amount collected from Hallo Bay in 2013 and this study in 2015 both resulted in approximately 2000 kg of debris. With the replacement of debris after previous cleanup efforts, this project, similar to KEFJ, further supports the theory of annual accumulation of debris by Pallister and Gaudet (2011), previously mentioned. The annual accumulation of debris could suggest the debris bank in the North Pacific Gyre feeds the Alaskan coastline via winter storms. It is unknown what the rate of marine debris accumulation is for these beaches. Regardless, this would mean that although we conduct annual debris removal for a one year resolution, the debris issue is much larger than local cleanup efforts can resolve.

4.4. Bering Land Bridge National Preserve & Cape Krusenstern National Monument

The selected beaches in BELA and CAKR had the lowest amount of debris. There is no published literature on debris history for these beaches for comparison. It is possible that our survey produced an underestimate of the debris present in BELA and CAKR. Both areas have high levels of beach erosion and deposition, therefore the beach topography is quite variable (Manley and Lestak 2012). BELA has experienced erosion of approximately 0.26 m/year between 1980 and 2003, while CAKR has seen a net accretion of 0.16 m/year during that time period. The debris load is affected by similar processes and therefore may be highly variable between years. Foam and other debris were documented in the beach dunes and outwash areas beyond our collection

Table 3
Average debris load (density per person hour, kg/km h^{-1}) ± standard deviation by debris category for each study region. Gulf of Alaska includes KEFJ, KATM and WRST beaches. Western Arctic includes CAKR and BELA beaches. Significantly different densities per person hour are in bold ($p < 0.05$).

	Plastic (kg/km h^{-1})	Metal (kg/km h^{-1})	Rubber (kg/km h^{-1})	Rope/netting (kg/km h^{-1})	Foam (kg/km h^{-1})	Other (kg/km h^{-1})	Total (kg/km h^{-1})
Gulf of Alaska	**29.5 ± 37.8**	0.78 ± 1.55	2.39 ± 5.94	5.96 ± 14.5	**9.15 ± 15.6**	0.45 ± 1.57	**48.3 ± 60.8**
Western Arctic	**0.28 ± 0.17**	0.02 ± 0.02	0.23 ± 0.43	0.16 ± 0.18	**0.05 ± 0.04**	0.05 ± 0.08	**0.80 ± 0.84**

window. Additionally, many items were partially buried and therefore not collected during the study.

4.5. Local geography

The highest debris density was found in KEFJ which is primarily made of pocket beaches, followed by WRST where log jams, particularly on the shorter rocky beach, exposed directly to the Gulf of Alaska, led to extremely dense debris areas. KEFJ had several beaches with densities over 1000 kg/km. Three (THUN-1, THUN-2, BLAC-1) had debris deposited back into a lagoon/wooded area >100 m from shore. In contrast, the long sandy or gravelly beaches of KATM, CAKR and BELA were associated with lower densities of debris. KATM had back lagoons that likely accumulate debris, but were >100 m from shore and therefore were not included in the cleanup effort. KATM, CAKR and BELA had small aggregation areas within a beach (e.g. log jams at a creek mouth, areas near rocky headlands). The aggregations made little impact on total density when analyzed as a whole beach, because the density on the rest of the beach was minimal. Therefore our results suggest local geography and substrate of a beach likely has a strong effect on the amount and concentration of debris collected. Subsampling the beaches in smaller segments could have better identified aggregation areas, but documentation at a more refined level is time consuming, would have been at the cost of total beach surveyed, and was not the primary objective: removal.

It was noted that aggregation areas such as log jams were dominated by plastic and foam, while non-aggregated areas of beach had all types of debris. We speculate foam and plastic are more susceptible to deposition in beach driftwood and to wind transport on shore until trapped by beached driftwood creating a dense accumulation area, and that heavier items like metal, rubber, rope and netting are less likely to move once on shore. The Alaska Marine Stewardship Foundation (2014) found similar high accumulation zones with more plastic and foam.

Barnes et al. (2009) indicated that proximity to urban centers influences marine debris distribution. Based on our findings, this likely extends to human occupation in any form including small rural communities and permanent cabins. Plastic on Alaskan shores differs from the distribution of plastic debris proposed by Barnes et al. (2009) due to the lack of large urban areas near the beaches surveyed in this study; therefore we postulate that the major drivers for debris on the Alaskan coastline are likely broad scale winds and currents, but further investigation is need. In CAKR there are numerous seasonal fishing and hunting camps near the beach and there were high proportions of rubber (tires and snow machine treads) and 'other' (sneakers, cloth and broken down ATVs) on the beach. Similarly in WRST near a cabin there were items such as an old ATV and a large aluminum boat stern. In contrast, the fish camps in BELA are on bluffs above the beach and very little debris that could be attributed to local deposition (rubber, metal, 'other') was found. Large amounts of rubber and foam were found on one beach in KATM, even though human occupation in the area is low. This is likely due to the shipwreck of the FV *Northern Pride* in early 2015 that, although salvaged, resulted in fragments of the wreck remaining on the beach surveyed.

4.6. Region

The Gulf of Alaska and the Western Arctic are influenced by different pressures for debris. The Gulf of Alaska is exposed to ocean and coastal processes that include prevailing currents and storms. Alaska Coastal Current and winter storms bring debris from a central gyre to Gulf of Alaska coasts (Merrell, 1980; Johnson, 1989; Pallister and Gaudet, 2011; Howell et al., 2012). Water flow along Alaska's Northwest Arctic coasts come from a continuation of the North Pacific subarctic gyre in the Bering Sea Basin, through the Bering Strait (Stabeno and Reed, 1994). This water along with the outflow of the Yukon and Kuskokwim rivers are debris sources for the Northwest Arctic. The Northwest Arctic debris is documented to include small quantities of debris from Russia, Korea, Japan and China (Coe and Rogers, 2011). Although not documented by weight, there was a higher occurrence of Russian debris in the Western Arctic parks, although debris from Japan and Korea were also present, and a broader international presence (Argentina, China, Japan, Korea, Russia, Singapore and South Africa) in the Gulf of Alaska parks.

As sea ice duration decreases in the Arctic, the correlated increase in open water and lengthened time of action for primary debris transport vectors (wind and currents) may contribute to accumulation of more debris on Arctic beaches in the future. With climate change progressing steadily in the Arctic, sea ice has retreated by an average of 1.3% per year (Laxon et al., 2013) since the 1950's. In the summer months, the Arctic ice pack is now sufficiently far north to allow for passage of vessels via both the Northern Sea Route (above Siberia) and the Northwest Passage (through the Canadian Archipelago to Greenland). As a result, vessel traffic has increased dramatically through the Bering Straits (Arctic Council 2009). As sea ice duration continues to decrease in the Arctic, the correlated increase in open water may contribute to accumulation of more debris on Arctic beaches in the future. Moreover, the dramatic increase in vessel traffic is likely to contribute additional debris.

Only plastic and foam are significantly different between the two regions. Plastic and foam also are more likely to survive the gyre transport; where rubber (tires), metal (soda cans that fill with water), 'other' (ATV), rope/netting (fishing) are heavier and more likely to sink (Thiel et al., 2013). The source of heavier items like rubber, cans, rope and netting are therefore more likely from local users, which would support why quantities were close to equal between the two regions. Of note, there were more small foam floats, often called banana floats, in the Gulf of Alaska and more cylindrical floats in the Western Arctic. Alaska Marine Stewardship Foundation (2014) reports that banana floats are internationally derived and cylindrical floats are domestic to the US, suggesting a heavier external influence on the debris found in the Gulf of Alaska than the Western Arctic. This difference in floats may be partially explained by the significant fishing industry in the Bering Sea, which is home the largest fishery in the United States and directly upstream from the Western Arctic.

The Gulf of Alaska is already well exposed to vessel traffic. This includes fishing vessels, oil tankers, commercial shipping, ferries and tourism. The Western Arctic region exposure to vessel traffic in the Chukchi Sea has been primarily fishing operation but, as noted, vessel traffic is rapidly increasing in the Arctic (Arctic Council. 2009), with additional pressures from exposure to bulk carriers and tankers using the routes in the Bering Sea (Azzara et al. 2015). Removing marine debris deposited on shore is expensive and time consuming. Long term solutions must include education and engaging stakeholders at both land based sources and vessel-based sources of marine debris. Assuming that vessel traffic explains some of the difference between the two regions, marine debris composition and volume in the Western Arctic may come to more closely resemble that found in the Gulf of Alaska, as vessel traffic increases. Since vessel traffic into and through the Arctic is still low, engaging industries such as fishing, shipping and passenger vessels to adopt best practices to reduce marine debris is likely to have a greater effect on preventing marine debris deposition in the near term for Western Arctic shores.

4.7. Future surveys

Consistency in data collection is needed for comparative work with other debris collections. Length of beach is easy to measure with a simple GPS unit and allows for determination of beach length and cleanup effort, with little time investment mapping the entire beach. Debris collection by person-hour, effort, should be used with careful consideration for cleanup efforts. There are several challenges to using this approach as a metric for several reasons including different efficiencies based on access and training in accomplishing removal tasks; individual health and stability will affect efficacy; habitat type can significantly change the time necessary for removal efforts; tasks can differ from simple picking up of lightweight items to removals of larger items that might take multiple people to address changing removal efficacy; and fatigue over time. However, there are significant benefits in collecting this information in identifying and planning appropriately for future removal efforts, monitoring over time how removal rates change with respect to ongoing efforts and addressing beaching that have large clean up teams versus just a few individuals.

Beaches with easier access can facilitate larger survey teams which can overrepresent person-hour (cleaning a beach with 10 people versus 100 people) and can change the volume of debris collected disproportionately. Weight of debris items is appropriate for Alaska and comparable to other debris collections. Using broad categories for debris documentation is needed for large scale coastal removal efforts where miles of coastline cleaned is the priority, thus requiring minimal time for documentation. Regions with smaller beaches can use more fine scale debris categories that could be combined for more coarse comparisons. A stratified sampling design could be used to subsample debris on low density beaches to allow more focused time on hotspots, such as logjams, to facilitate maximum debris removal.

There are two questions that were not a focus of this study but could enhance future work. One is the documentation or tracking of debris sources to determine if the sources are local, regional, or transported in from other regions. The second question is the accrual of microplastics. The potential accumulation of microplastics in the Alaskan environment is poorly documented. Current studies of microplastics in sea ice indicate higher concentrations in the Arctic compared to the North Atlantic and North Pacific Gyre (Obbard et al. 2014). Microplastics concentrations in Arctic waters as a whole are on the same order of magnitude as the Oceanic gyres (Lusher et al. 2015). With plastics making up the largest volume of debris, getting a baseline on volume and prevalence of microplastics is needed.

Effects on marine life (entanglement, seabird ingestion) are well documented (e.g., Robards et al., 1995; Laist, 1997; Mallory et al., 2006; Raum-Suryan et al., 2009), but there is not much in the literature on effects to land based species of debris deposited well above the waterline. The survey team documented several large foam floats torn up by bears, plants growing through debris and moss growing on debris.

This study collected debris across a wide range of Alaska's coastline. Changing climate that leads to shifts in storms, beach erosion and changes in tidewater glaciers may shift the patterns of marine debris accumulation. Additionally, as exploration, vessel traffic and tourism continue to rise in Alaska, especially in the Western Arctic, debris deposition may increase. There needs to be a planned effort to repeat this work to track changes on, and impact to, the Alaskan coast.

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Appendix A. Supplementary data

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