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LITTER DISTRIBUTION ON THE UK'S BEACHES: A DECOMPOSITION OF THE GINI COEFFICIENT

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Abstract
This study proposes a metric that builds upon the Lorenz curve and the Gini coefficient to measure litter distribution on beaches. We address not only the degree of litter distribution but also the causes in relation to litter abundance as well as to a wide range of geographic and climatic factors. We analyze a beach survey dataset that contains 10,262 records of litter counts for 1,803 beaches in the UK from 2000 to 2016. We found that litter distribution varies by litter type, with plastic and pottery being the least and most concentrated on beaches, respectively. A certain degree of litter distribution is due equally to litter abundance on both small and large beaches regardless of litter types. We also found location and seasonality have relatively larger effects on the overall distribution of beach litter while the effects of climatic conditions are negligible.

Keywords
beach litter, Lorenz curve, Gini coefficient, UK

Paper type: Full paper

1 INTRODUCTION

Beach tourism is historically important, particularly for island countries that lure not only local recreationalists but also an influx of international travelers. The British seaside, in particular, was the very definition of a holiday for Britons since the mid-19th century until the 1960s, when it was superseded by cheap air travel and the Mediterranean sunshine (Zuelow, 2015). Of the 2306 visitors surveyed by Tudor and Williams (2006) on the coast of Wales, 67% rated a beach as important to their holiday, with only two percent showing a lukewarm response. The attractiveness of beaches lies at their cleanliness, which is highly valued by tourists, and thus determines the success of local economies that depend on beach tourism (Ballance, Ryan, & Turpie, 2000). Balance et al.'s (2000) study showed that almost half the respondents from the Cape Metropolitan Region, South Africa, were willing to spend seven times the average trip cost to visit clean beaches, whereas up to 97% of the value of these beaches could be lost by a drop in standards of cleanliness. Loomis and Santiago (2013) reckoned that in [where] increasing beach water clarity and eradicating beach litter would generate an economic value of $34−74 and $77−131 per visitor day, respectively.

Nevertheless, beaches are among the easiest to be polluted because they are common resources and geographically open, subjected to garbage from shipping and waves, dumping, to various human activities (Briassoulis, 2002). According to the Marine Conservation Society (MCS, 2017), the UK's beaches are littered with 11 broad categories of garbage, ranging from the ubiquitous plastic to the rarely seen feces, and as many as some 100 specified types from various sources. Particularly in developing countries, such as Indonesia and Brazil, urbanization and the escalating tourism demand are exacerbating the pollution of anthropogenic marine debris (AMD) (Bravo et al., 2009; Gabrielides et al., 1991; Gregory, 1999; Madzena & Lasiak, 1997; Willoughby, Sangkoyo, & Lakaseru, 1997). Not only can human activities, such as tourism, lead to the increased abundance of beach litter, they also increase the varieties of litter items (Madzena & Lasiak, 1997). Araujo and Costa (2007) conclude that large amounts of solid wastes on beaches, although not immediately presenting health risks for beach users and marine biota, can significantly deteriorate the aesthetic of the coastal environment, thereby jeopardizing potential tourist activities.

Tackling beach pollution requires to measure litter abundance and map its distribution in the first place. Considerable attention has been drawn to profile beach litter in countries like

Brazil, Indonesia, and Australia, particularly regarding counting and weighting litter items. Previous research on marine pollution has overwhelmingly focused on flagging prevailing litter items, such as plastic, paper and wood, on sporadically surveyed beaches. Such a case study approach to investigating one beach, or a group of few, obscured a holistic understanding of the distribution of beach litter at the macro-level. Specifically, not only were a limited number of beaches analyzed in previous studies, but the focuses of these studies were on how litter was distributed within a single beach rather than across beaches. Also, previous research only dealt with one or two time intervals in longitudinal surveys, ending up with a snapshot, instead of a fuller picture, of litter distribution over time. We aim to bridge these gaps by not only measuring litter distribution on a vast population of beaches but also tracking the changes of litter distribution over time. We also aim to investigate a number of geographic and climatic factors that may affect litter distribution and contamination.

2 LITERATURE REVIEW

2.1 Abundance and Composition of Beach Litter

Research on beach litter, along with marine pollution, starts with profiling the abundance and composition of litter accumulated on beaches. Sources of beach litter can be attributed either to garbage discarded by beach users or to industrial and household refuse washed off onto beaches (Willoughby, 1986). Among the most abundant beach litter is various forms of plastic, which makes up a staggering proportion of 50%–90% of total litter counts (Corbin & Singh, 1993; Widmer & Hennemann, 2010), a rate almost unanimously reported in studies conducted in a wide range of coastal regions (Corbin & Singh, 1993; Eriksson et al., 2013; Oigman-Pszczol & Creed, 2007; Vauk & Schrey, 1987; Widmer & Hennemann, 2010). According to Oigman-Pszczol and Creed (2007), plastic, besides being left over on beaches, was the most abundant submerged marine debris observed. Not only is plastic pollution ubiquitous on beaches, it was also reported undergoing a gradual increase over time in some longitudinal studies that traced the change of litter accumulation on beaches (Williams & Tudor, 2001). Williams and Tudor (2001) concluded that the abundance of plastic found on beaches is mirrored in an inexorable rise in the use of plastics by society.

Other frequently recorded litter included paper and wood, along with a dozen others (Corbin & Singh, 1993; Martinez-Ribes et al., 2007; Oigman-Pszczol & Creed, 2007). In Oigman-

Pszczol and Creed's (2007) study, of nearly 16,000 litter items collected on beaches in Brazil, paper, i.e., cigarette butts discarded by visitors, displaced plastic to be the most abundant litter item. Martinez-Ribes et al. (2007) also found that cigarette butts (46%) were the most abundant item by count in peak tourism seasons, while plastic (67%) was predominant in wintertime, which was primarily related to personal hygiene/medical items. Corbin and Singh's (1993) survey of two islands in the Caribbean region revealed that driftwood was most common in Dominica (35.9% by count and 59.3% by weight) while plastic was most abundance in St. Lucia (51.3% by count and 38.6% by weight). On a beach in Eastern Australia, Smith and Markic (2013) found that monofilament, mainly resulting from recreational fishing activities, is the most common litter item found on local reefs. Willoughby et al. (1997) documented that new and rarely seen litter items, such as light bulbs, tins, fishing gear and glass bottles, emerged on beaches in Jakarta in the late 1990s, when urbanization and social developments were accelerating in Indonesia.

2.2 Distribution and Concentration of Beach Litter

The distribution of beach litter is associated with various factors, including beach morphology, location, climate and weather conditions as well as the intensity of human activities (Eriksson et al., 2013; Golik, 1997; Santos, Friedrich, & Sul, 2009; Silva-Cavalcanti et al., 2009; Smith & Markic, 2013; Thornton & Jackson, 1998). Santos et al. (2009) found that river-dominated and stable beaches had more debris than unstable, erosional beaches. Madzena and Lasiak (1997) found that litter distribution measured by both weight and count was significantly different among areas-within-shores. Santos et al. (2009) found that the southward of the dominant littoral drift in Bahia along Costa do Dendê led to threefold higher debris densities (9.1 items/m) than the densities observed north of Salvador City. Willoughby et al.'s (1997) analysis of nearly 34,000 litter items in Jakarta revealed that litter levels almost doubled on the inshore islands, and were five times higher on the offshore islands due to their adjacency to populous urban centers. However, Benton's (1995) study about two island in South Pacific Ocean found that the remote beach, thousands of miles away from industrial centers, had similar litter density as beaches adjacent to urban areas.

A fast growing litter concentration is largely due to increased population and urbanization in beach-adjacent areas, which is exacerbated by inadequate disposal practices and cleanups (Araújo & Costa, 2007; Gregory, 1999; Widmer & Hennemann, 2010; Willoughby et al., 1997). Araújo and Costa (2007) found that plastic contamination was associated with urban origin, mainly related to household activities and hospital wastes. Compared to urbanized beaches (located in residential areas outside main nucleus), urban beaches (located in main nucleus of municipalities) had higher densities of waste deposition and lower abundance of organic, domestic and other miscellaneous waste (Ariza et al., 2008). Since rivers draining populous areas are the major source of debris, Santos et al. (2009) showed that areas south of the major regional embayments (Camamu and Todos os Santos) become the preferential accumulation sites. Contamination of this sort is more evident in developing countries. Willoughby et al. (1997) found that Jakarta was the source of most of the litter, such as polystyrene blocks, plastic bags and discarded footwear, which made up 80% of the items. Widmer and Hennemann (2010) found that nearly 95% of litter items collected on the beaches of Florianópolis in Brazil were due to the fact that half of the Brazilian population live within 200 km of the coast and generate large amounts of garbage.

Certain litter items, such as cigarette butts, plastic cups, and drinking straws, are closely related to tourism and recreation uses, and their distributions vary greatly by the intensity of tourist and recreational activities (Ariza et al., 2008; Madzena & Lasiak, 1997; Martinez-Ribes et al., 2007; Oigman-Pszczol & Creed, 2007; Silva et al., 2008; Smith & Markic, 2013). Martinez-Ribes et al. (2007) found that beach users were the main source of summer debris such as cigarette butts, while low tourist season (wintertime) litter, such as plastics pertinent to personal hygiene/medical items, was primarily ascribed to drainage and outfall system. Beaches frequented by tourists and recreationists tend to have more establishment of hospitality businesses, which in turn generated more litter. In particular, the seasonality of tourist activities affects both the abundance and composition of beach litter (Martinez-Ribes et al., 2007; Silva et al., 2008; Thornton & Jackson 1998). Martinez-Ribes et al. (2007) found that litter abundance in summer was double that in low seasons and showed a heterogeneous nature associated with beach use. Silva et al. (2008) also found that the amount of flag litter items depended on the intense use of beaches, especially during summer weekends and sociocultural events.

By examining litter deposition on beaches in the Firth of Forth, Scotland, Storrier et al. (2007) highlighted the influence of climatic conditions and tidal patterns on the abundance of beach litter. Eriksson et al. (2013) concluded that onshore winds, storms and tides are pivotal in affecting the accumulation of beach litter through changing beach topography and composition. Also evident is the time-lag effects of winds and tides that may last for up to one week and thus can continue to affect the distribution of beach litter. Due to the influence of wind or wave processes, Thornton and Jackson's (1998) study in Cliffwood Beach, New Jersey found that the wind-dominated upper profile of the beach was deposited with small lightweight debris while the wave-dominated lower profile with heavier debris. Extreme weather such as storms, as Smith and Markic (2013) put, can not only intensify wind and wave into adjacent waterways but also introduce debris from adjacent subtidal habitats, leading to higher litter accumulation. A lot of studies concluded that tidal inundation is a primary mechanism not only for transporting debris onto beaches but also for removing it from beaches (Eriksson et al., 2013; Smith & Markic, 2013; Vauk & Schrey, 1987).

2.3 Measurement of Litter Abundance and Distribution on Beaches

Thornton and Jackson (1998) suggested a comprehensive classification of beach litter based on type, function, degree of fragmentation, length, weight, and location on the beach profile. Smith et al. (2013) argued that a challenge is not only to allocate the "lost" debris to various possible pathways, but also to differentiate between, and quantify, the input sources which include: "new" items arriving by floating; items sourced from adjacent subtidal habitats; items delivered by wind and by runoff from adjacent terrestrial areas; and items retained within the system through a cyclical process of burial, exhumation and further transportation. In order to trace the origins of beach litter, many studies distinguished between what is called anthropogenic marine debris (AMD) (Bravo et al., 2009; Oigman-Pszczol & Creed, 2007; Schulz et al., 2013) and organic litter for the rest of others. These classifications not only help to quantify beach abundance but also to investigate the sources of litter, thereby tackling the marine pollution more efficiently.

Quantitative measures of litter abundance and distribution include count, weight, size, to density. Count and weight are used to measure the prevalence of litter items. In particular, litter count is predominant not only in various beach surveys but also in scientific research that aimed to portray the contamination of beaches (MCS, 2017; Smith & Markic, 2013; Willoughby et al., 1997). Due to the vast dispersion of some litter items between count and weight in measuring prevalence, weight is used as a complementary measure (Corbin & Singh, 1993; Madzena & Lasiak, 1997). In Madzena & Lasiak's (1997) study for instance, plastic made up the largest proportion by count (83%) but much less so by weight (47%), while wood was more abundant by weight but much less so by count. Size is used to screen litter items because certain small litter is discarded in beach surveys due to its less visibility and less impact on the environment (MCS, 2017). Litter density is also widely used and cross-compared, which though requires sophisticated separation of a beach into small equally-sized parcels and the information of the size of a beach under investigation (Bravo et al., 2009; Oigman-Pszczol & Creed, 2007).

2.4 Research Gaps

Williams and Tudor (2001) argued that no standard methodology currently existed in the measurement of beach litter. Simmons and Williams 1993 concluded that the literature is replete with measurements/analyses, amongst others, of transects orthogonal to a beach. Existing methodologies include: (1a) cross-sectional studies of a single beach, focusing on the morphology of individual beaches; (1b) cross-sectional studies of more than one beaches to draw comparisons, which is a quite dominant methodology; (2a) longitudinal study of a single beach or a limited number of beaches (months in a given and several years, such as consecutive five years; or two intervals) to study the change of climate or urbanization (Williams & Tudor, 2001); (2b) longitudinal study of a population of beaches in an area is lacking.

Besides methodological limitations, the measures in the literature aimed at profiling litter items on a single beach or a handful of beaches. These measures failed to uncover how certain levels of litter is distributed or concentrated across a population of beaches in an area, and whether the degree of distribution changes over time. These limitations not only lie with the measures themselves but also lie at the cross-sectional and case study research designs in previous studies. Single and sporadic beach surveys that covered limited, and normally inconsistent, time intervals render mapping the distribution of litter items at the macro level impossible; nor did they allow to track the evolution of litter distribution over time. Previous studies also attempted to drew association between litter distribution and a range of factors, such as morphology or weather conditions, in order to understand the effects of these factors on litter distribution. These associations, nevertheless, were restricted to individual beaches, and thus shed little light on what affects litter distribution across beaches.

3 MODELS

3.1 Measures of Litter Distribution: Lorenz Curve and Gini Coefficient

The Lorenz curve was developed to measure income distribution, together with the Gini coefficient, to quantify income inequality. Both the Lorenz curve and the Gini coefficient delineate the distribution of income by factoring in both a population of individuals in a society and the proportion of total income each individual possesses. Despite being developed in economics, the Lorenz curve has been widely applied in various contexts, including measuring the concentration of market shares and fecundity of plants, to name a few (Bikker & Haaf, 2002; Damgaard & Weiner, 2000). For instance, the Lorenz curve was used to measure biodiversity, specifically related to species richness and evenness, because evenness is a key factor in preserving the functional stability of an ecosystem (Wittebolle et al., 2009). The Gini coefficient was used to quantify education attainment inequality (Thomas, Wang, & Fan, 2001), the productivity of university research output and publication (Halffman & Leydesdorff, 2010), health inequality (Asada, 2005), and the inequality of social network participation (Mierlo, 2016).

The wide applicability of the Lorenz curve in measuring distribution lies at its statistical generality and parsimony that rely only on the number of subjects being known in a population and the proportion that each subject possesses with regard to a concerned attribute. Also, in all these cases where the Lorenz curve applies, it can be interpreted either as the extent to which total income, for instance, is concentrated on a few richest or as the degree to which total income is evenly distributed among all people. Such interpretational flexibility has profound implications that can be tailed to different contexts wherever the Lorenz curve can apply. For instance, when it comes to tackling market concentration, the Lorenz curve suggests governmental regulations target a few key market players in curbing monopoly; as far as income inequality is concerned, it suggests governmental resources or subsidies be channeled to the vast majority of low income households for the sake of social welfare and justice.

We apply the Lorenz curve to measure the distribution of beach litter. Instead of dealing with individual or a handful of sampled beaches as previous studies did, the Lorenz curve can address the shortcomings of existing metrics that are incapable of profiling a population of beaches in an area. The use of the Lorenz curve helps us look beyond sporadically surveyed beaches while evaluating litter distribution on a population of beaches.

3.2 Models of Lorenz Curve for Beach Litter Distribution

Suppose a population of beaches under investigation is N (*1, n*), x_i is the number of a type of litter discerned on beach i ($i = 1\Lambda\ n$). We index all N beaches in a non-decreasing order based on the amount of the litter count as $x_1 \le x_2 \le \Lambda \le x_n$, which represents the size of the beaches that is defined by litter counts. Worth noting is that the size of a beache in our study is not the geometric dimensions of the beach, but the scale of the beach that squares with the amount of litter that it amasses. The distribution of the litter on all N beaches is delineated by a polygon connecting all the points determined by (Damgaard & Weiner, 2000):

$$\left(h/n, L_h/L_n\right),$$

where $h = 0, 1, \ldots n$; and $L_0 = 0$, $L_h = \sum_{i=1}^{h} x_i$.

This polygon represents a geometrical presentation of the Lorenz curve, and the deviation of the edge of the polygon from the 45° diagonal that connects between (0, 0) and (1, 1) indicates the degree of the litter concentration. In other words, the 45° diagonal represents a perfectly even distribution of the litter across beaches, in which each individual beach has an identical proportion of the litter.

We use the Gini coefficient to quantify the degree to which the Lorenz curve defined above deviates from the 45° diagonal, namely to what extent the litter distribution diverges from the perfect even distribution. Arithmetically, the Gini coefficient is calculate as (Dagum, 1980; Damgaard & Weiner, 2000; Lambert & Aronson, 1993):

$$G = \frac{1}{2n^2\mu}\sum_i \sum_j \left|x_i - x_j\right|, \qquad (1)$$

where μ is the mean of litter counts on all beaches (*n*), representing the average size of the beaches defined by litter count, x_i and x_j are the counts of litter on beach i, j respectively. G denotes the Gini coefficient, which takes values from 0 to 1, indicating from the least concentration (i.e., perfectly even distribution) to the most concentration (i.e., perfectly uneven distribution) of the litter.

Despite being a prevailing metric to quantify the Lorenz curve, the Gini coefficient is insufficient to reveal all properties of the Lorenz curve because a group of Lorenz curves can substantially differ by shape from one another even though all can have an identical Gini coefficient. Therefore, researchers proposed and developed what is called the Lorenz asymmetry coefficient (LAC) as a supplement to the Gini coefficient (Damgaard & Weiner, 2000; Shumway & Koide, 1995; Weiner & Solbrig, 1984). The LAC aims to measure whether a certain degree of concentration defined by a specific Gini coefficient is, in our case for an illustration, due to very few largest beaches that contribute substantially to the total litter counts or to a great number of smallest beaches that contribute little to the total litter counts. According to Damgaard and Weiner (2000), the LAC is calculated as

$$S = F(\hat{\mu}) + L(\hat{\mu}), \qquad (2)$$

in which

$$\delta = \frac{\hat{\mu} - x_m}{x_{m+1} - x_m},$$

$$F(\hat{\mu}) = \frac{m + \delta}{n},$$

$$L(\hat{\mu}) = \frac{L_m + \delta x_{m+1}}{L_n},$$

where the functions F and L define the Lorenz curves, m is the number of the beaches with a size smaller than the mean μ, and S is the statistic of the LAC, taking values $S \in (0, \infty)$. The threshold value $S = 1$ indicates a perfect symmetry of the concentration, suggesting a certain degree of litter concentration is proportionally in line with the sizes of the beaches defined by litter counts. Whenever $S \neq 1$, the litter distribution is asymmetric, which can occur in two different ways: if $S < 1$, the asymmetry of the Lorenz curve is skewed to numerous smallest beaches; if $S > 1$, the asymmetry is skewed to very few largest beaches.

Besides examining the LAC to reveal the hidden property of the Lorenz curve, we decompose the Gini coefficient to detect whether a set of categorical variables that disaggregate a population of beaches can affect the overall distribution of beach litter. The decomposition analysis of the Gini coefficient thus further reveals the sources of the overall distribution that may or may not be related to a categorical variable. Following Mookherjee and Shorrocks's (1982) decomposing analysis, we disaggregate the population of beaches into a number of subgroups separated by a categorical variable. It follows that if N_k represents a subpopulation of beaches in subgroup k defined by the categorical variable, and this subgroup numbers $n_k$with mean μ_k, then the overall Gini coefficient in equation (1) can be decomposed as:

$$\begin{aligned} G &= \frac{1}{2n^2\mu}\sum_i \sum_j |x_i - x_j|, \\ &= \frac{1}{2n^2\mu}\sum_k \Big(\sum_{i\in N_k}\sum_{j\in N_k}|x_i - x_j| + \sum_{i\in N_k}\sum_{j\notin N_k}|x_i - x_j|\Big), \\ &= \sum_k \left(\frac{n_k}{n}\right)^2 \frac{\mu_k}{\mu} G_k + \frac{1}{2n^2\mu}\sum_k \sum_{i\in N_k}\sum_{j\notin N_k}|x_i - x_j|, \quad (3) \end{aligned}$$

where G_k is the within-group Gini coefficient for litter counts in subgroup k. By introducing a residual R, equation (3) can be generalized to any circumstances regardless of whether or not the ranges of litter counts in any subgroup k and in any other subgroup h overlap, then:

$$G = \sum_k v_k^2 \lambda_k G_k + \frac{1}{2}\sum_k \sum_h v_k v_h |\lambda_k - \lambda_h| + R, \quad (4)$$

where $v_k = n_k/n$ is the proportion of the population in subgroup k, and $\lambda_k = \mu_k/\mu$ is its mean of litter counts relative to that of the whole beach population.

Following Lambert and Aronson (1993), for a more straight interpretation of the sources of the overall Gini coefficient, we simplify equation (4) by replacing the first two components on the right side with $\sum a_k G_k$ and G_B, respectively:

$$G = \sum_k a_k G_k + G_B + R, \quad (5)$$

where a_k is the product of population share and litter account share commanded by subgroup k, G_k, as stated above, is the within-group Gini coefficient for subgroup k, G_B is the between-group Gini coefficient, defined as the one which would obtain if litter counts of all beaches in each subgroup were to be replaced by the mean of litter counts of that subgroup, and R is the residual (a residual of G after G_k and G_B being subtracted) which is zero if the ranges of litter counts in the subgroups k and h do not overlap.

Equation (5) spells out, exhaustively, the sources of G pertinent to the categorical variable. Since the definition of G_B eliminates the variations of litter counts within all subgroups, leaving G solely accounted for by the mean differences between all subgroups. Given G, the bigger the G_B, the larger the effect of the categorical variable on G. If G_B approaches zero, the effect of the categorical variable disappears. In this case, G is entirely attributed to within-group differences if all subgroups completely overlap, in which $G_B = 0$ and $R = 0$. This means that G remains invariant to the categorical variable in the decomposition, and the categorical variable thus has no effect on the overall distribution.

3.3 Data Description

The data were from Beachwatch survey conducted by the Marine Conservation Society (MCS), the UK's leading marine environment protection and not-for-profit organization. Beachwatch is the largest volunteer beach cleaning and litter survey initiated in 1992 in the UK, which contains a total of 10,262 records (surveys) for 1,803 distinct beaches (distinct beach-year) across the coast and offshore islands of the UK from 2000 to 2016. Since the unit of analysis was the number of beaches rather than that of beach surveys, for a beach surveyed more than once in a given year, we selected the survey with the maximum total litter counts as the measure of litter concentration on that beach. From the perspective of Beachwatch that aims solely at cleaning up the UK's beaches, a multiple-surveyed beach indicates that the beach itself tends to accumulate more litter than those surveyed once. Beaches are less frequently surveyed because they tend to amass less litter, and if they were surveyed more frequently, litter abundance would fail. Since each survey reduces litter on a beach, choosing the survey that records the maximum total litter counts not only reflects the high, and true, accumulation of litter on the beach, but also reconciles with those beaches surveyed only once in the analysis.

Table 1. UK's beaches classified in various subgroups (2000–2016)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Location	**75**	**102**	**260**	**295**	**322**	**433**	**455**	**452**	**500**	**533**	**492**	**448**	**419**	**384**	**389**	**424**	**480**
Channel Islands	3	5	55	36	39	42	38	40	37	36	33	25	20	28	22	20	17
North East England	7	9	25	19	27	37	42	48	51	48	46	44	48	32	44	37	38
North West England	3	7	8	16	21	16	20	18	16	31	18	13	18	11	16	20	22
Northern Ireland plus Republic of Ireland	4	4	8	13	3	14	9	7	12	21	11	24	12	9	5	7	5
Scotland	12	25	52	58	55	99	84	63	70	76	81	56	81	64	58	100	161
South East England	13	22	46	65	79	97	125	132	133	123	124	126	112	116	109	108	112
South West England	19	15	36	63	61	90	95	100	113	109	103	91	65	78	85	71	85
Wales	14	15	30	25	37	38	42	44	68	89	76	69	63	46	50	61	40
Season	**75**	**102**	**260**	**295**	**322**	**433**	**455**	**452**	**500**	**533**	**492**	**448**	**419**	**384**	**389**	**424**	**480**
Spring	9	19	20	22	29	46	48	50	55	59	71	54	114	39	34	34	59
Summer	10	14	6	24	14	34	37	40	44	39	38	41	33	32	33	29	53
Autumn	50	48	212	228	250	307	330	331	372	389	363	317	236	284	290	340	348
Winter	6	21	22	21	29	46	40	31	29	46	20	36	36	29	32	21	20
Wind direction	**NA**	**NA**	**NA**	**NA**	**NA**	**433**	**455**	**452**	**500**	**533**	**492**	**448**	**419**	**384**	**389**	**424**	**480**
Onshore	NA	NA	NA	NA	NA	130	149	171	171	198	202	224	175	160	125	142	164
Offshore	NA	NA	NA	NA	NA	61	97	126	115	123	120	99	104	77	109	99	133
Other	NA	NA	NA	NA	NA	242	209	155	214	212	170	125	140	147	155	183	183
Wind strength	**NA**	**NA**	**NA**	**NA**	**NA**	**433**	**455**	**452**	**500**	**533**	**492**	**448**	**419**	**384**	**389**	**424**	**480**
Light	NA	NA	NA	NA	NA	181	289	309	351	357	258	195	226	209	264	251	302
Strong	NA	NA	NA	NA	NA	67	56	73	61	80	126	184	102	83	41	75	71
Other	NA	NA	NA	NA	NA	185	110	70	88	96	108	69	91	92	84	98	107
Tide Strength	**NA**	**NA**	**NA**	**NA**	**NA**	**433**	**455**	**452**	**500**	**533**	**492**	**448**	**419**	**384**	**389**	**424**	**480**
Calm	NA	NA	NA	NA	NA	133	193	210	268	292	180	131	176	159	213	206	243
Moderate	NA	NA	NA	NA	NA	134	149	167	155	152	191	176	139	122	106	119	118
Rough	NA	NA	NA	NA	NA	21	23	27	26	23	47	83	28	36	17	24	27
Other	NA	NA	NA	NA	NA	145	90	48	51	66	74	58	76	67	53	75	92
Tide height	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**448**	**419**	**384**	**389**	**424**	**480**
High	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	22	28	37	18	28	52
Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	426	391	347	371	396	428

Notes: NA = Data are not available.

Table 1 shows the number of distinct beaches surveyed each year in the period 2000–2016 disaggregated on six categorical variables recorded in Beachwatch, namely location, season, wind direction, wind strength, tide strength and height. Table 1 shows that the number of beaches was not evenly distributed across these categories. Northern Ireland (plus the Republic of Ireland) had the fewest beaches being surveyed; Autumn was the season when beaches were overwhelmingly being surveyed; beaches surveyed at the time of onshore winds outnumbered those surveyed in offshore winds; beaches surveyed in light winds were three to four times more than those surveyed in strong winds; beaches survey in calm and moderate tides far outnumbered those in rough tides; and beaches surveyed with the occurrence of high tides were far fewer than those without.

Table 2 shows that there are 10 major litter types counted and collected annually in Beachwatch for each beach, namely (1) plastic/polystyrene, (2) rubber, (3) cloth, (4) paper/cardboard, (5) wood (machined), (6) metal, (7) glass (8) pottery/ceramics, (9) sanitary, and (10) medical. We discarded feces in the analysis due to its negligible counts on a yearly basis, which though is aggregated to the total litter counts (all litter). Of the 363,011 litter items counted on yearly average for the period 2000–2016, a whopping number of 258,443 was plastic, or making up 71.2% of the total litter counts. Other frequently counted litter types on yearly average included sanitary (20,917), metal (20,250), and paper (19,350), while medical (620) was among the least abundant litter.

Table 2. Counts of litter types on the UK's beaches (2000–2016)

Year	*N*	Plastic/ polystyrene	Rubber	Cloth	Paper/ cardboard	Wood (machined)	Metal	Glass	Pottery/ ceramics	Sanitary	Medical	All litter
2000	75	60'833	961	1'541	7'706	3'072	3'477	2'191	340	5'283	109	85'513
2001	102	74'135	1'507	2'397	7'558	3'824	6'748	5'783	969	8'533	169	111'624
2002	260	187'441	4'482	5'668	18'165	8'229	16'486	11'872	1'916	13'513	385	268'157
2003	295	226'912	5'454	8'666	22'813	14'565	22'043	13'270	2'138	1'322	368	341'278
2004	322	251'073	5'556	6'870	12'111	9'626	18'928	10'609	1'689	21'673	427	338'562
2005	433	321'487	7'928	12'894	20'581	14'050	24'876	14'072	1'985	30'916	700	449'489
2006	455	327'865	9'554	16'877	23'516	9'867	27'432	14'942	2'718	43'382	754	476'907
2007	452	340'582	10'253	16'154	24'964	11'786	24'656	17'883	2'782	29'308	870	479'241
2008	500	401'813	10'516	19'236	21'402	12'071	26'088	21'689	2'912	29'492	1'035	546'255
2009	533	348'281	8'043	10'473	24'454	10'550	27'704	15'661	2'242	22'824	785	471'695
2010	492	332'533	7'558	9'863	18'183	8'481	25'204	14'583	3'440	26'622	858	448'147
2011	448	254'992	7'902	8'544	16'253	8'271	22'355	16'747	2'669	18'172	636	357'431
2012	419	247'300	6'312	9'632	19'406	9'150	20'684	18'435	2'077	17'547	746	352'198
2013	384	238'040	5'861	7'446	19'036	7'031	18'490	11'289	1'510	15'747	678	325'855
2014	389	259'392	7'457	9'252	22'047	8'376	20'126	14'808	1'996	19'470	716	364'674
2015	424	236'112	6'229	10'165	18'078	7'516	20'712	21'785	3'023	21'813	680	347'093
2016	480	284'748	5'121	6'713	32'674	6'486	18'234	18'201	2'709	29'977	627	407'070
Mean		**258'443**	**6'511**	**9'552**	**19'350**	**8'997**	**20'250**	**14'342**	**2'183**	**20'917**	**620**	**363'011**

Notes: *N* is the number of distinct beaches surveyed on a yearly basis.

4 RESULTS AND DISCUSSION

We first present the results of the overall Gini coefficients (equation (1)) to examine the degree of litter concentration on the UK's beaches. Second, we present the LACs (equation (2)) for the overall Gini coefficients, which provide complementary information for detecting the asymmetry of the Lorenz curves. Finally, we decompose the overall Gini coefficients (equation (5)) by disaggregating all beaches into subgroups based on the six categorical variables. This decomposition analysis allows us to evaluate whether and to what extent these variables affect the aggregate distribution of beach litter. Wolfram Mathematica (v. 11.2) was used to calculate all the Gini coefficients, the LACs, and perform the decomposition analysis.

4.1 Lorenz Curves and Gini Coefficients of Beach Litter

Table 3 reports the overall Gini coefficients of the 10 litter types, along with total litter, on the UK's beaches from 2000 to 2016. Figure 1 further shows the changes of the Gini coefficients over time. Plastic was among the least concentrated litter type, with the Gini coefficients hovering over the mean $G = .544$ for the period of 2000−2016. In other words, plastic was the most evenly distributed litter type, most visible on all beaches. We found that the means of the Gini coefficients as well as their changes for all litter were much similar to those of plastic, suggesting that total litter concentration resembles that of plastic, and is actually driven by plastic. The reason is that plastic is the most dominant litter on the beaches by count, which renders the concentration of total litter very close to that of plastic. Since plastic is the least concentrated, so is total litter.

Metal ($G = .612$) and rubber ($G = .650$) took the second and third places respectively in less degree of concentration, which also showed quite stable and small variations in the Gini coefficients over time, followed by cloth and wood. Paper and medical showed mediate concentration, and their Gini coefficients also hovered around the mean, indicating that their concentration changes very little over time. Sanitary and glass were quite concentrated, indicated by their relatively higher Gini coefficients. While glass had smaller Gini coefficients on average than sanitary, Figure 1 shows that glass became more concentrated than sanitary as its Gini coefficients kept rising over time, which surpassed that of sanitary in 2011. Pottery/ceramics was the most concentrated litter, with the highest Gini coefficients standing at $G = .868$ on average.

Table 3. Gini coefficients of beach litter

Year	*N*	Plastic/ polystyrene	Rubber	Cloth	Paper/ cardboard	Wood (machined)	Metal	Glass	Pottery/ ceramics	Sanitary	Medical	All litter
2000	75	.561	.712	.689	.885	.791	.548	.725	.814	.767	.768	.538
2001	102	.542	.676	.722	.877	.805	.648	.830	.894	.826	.764	.548
2002	260	.543	.648	.675	.778	.678	.635	.801	.893	.831	.777	.525
2003	295	.492	.594	.690	.703	.770	.610	.746	.879	.887	.775	.487
2004	322	.524	.613	.695	.738	.690	.605	.718	.859	.863	.798	.501
2005	433	.561	.646	.699	.735	.712	.609	.765	.876	.893	.781	.546
2006	455	.533	.676	.690	.730	.623	.622	.751	.886	.887	.720	.522
2007	452	.574	.689	.664	.754	.663	.612	.800	.897	.874	.723	.550
2008	500	.562	.634	.676	.769	.664	.611	.806	.852	.831	.747	.535
2009	533	.565	.657	.692	.737	.714	.635	.773	.879	.829	.734	.543
2010	492	.546	.645	.690	.717	.682	.616	.778	.887	.826	.741	.526
2011	448	.518	.666	.712	.706	.664	.638	.832	.899	.795	.709	.501
2012	419	.509	.610	.715	.682	.659	.572	.813	.834	.759	.724	.486
2013	384	.542	.637	.680	.764	.676	.615	.785	.834	.770	.740	.519
2014	389	.543	.645	.681	.719	.680	.585	.821	.844	.760	.708	.513
2015	424	.560	.636	.758	.750	.702	.646	.870	.874	.803	.708	.541
2016	480	.578	.660	.691	.804	.725	.599	.872	.848	.804	.747	.558
Mean		**.544**	**.650**	**.695**	**.756**	**.700**	**.612**	**.793**	**.868**	**.824**	**.745**	**.526**

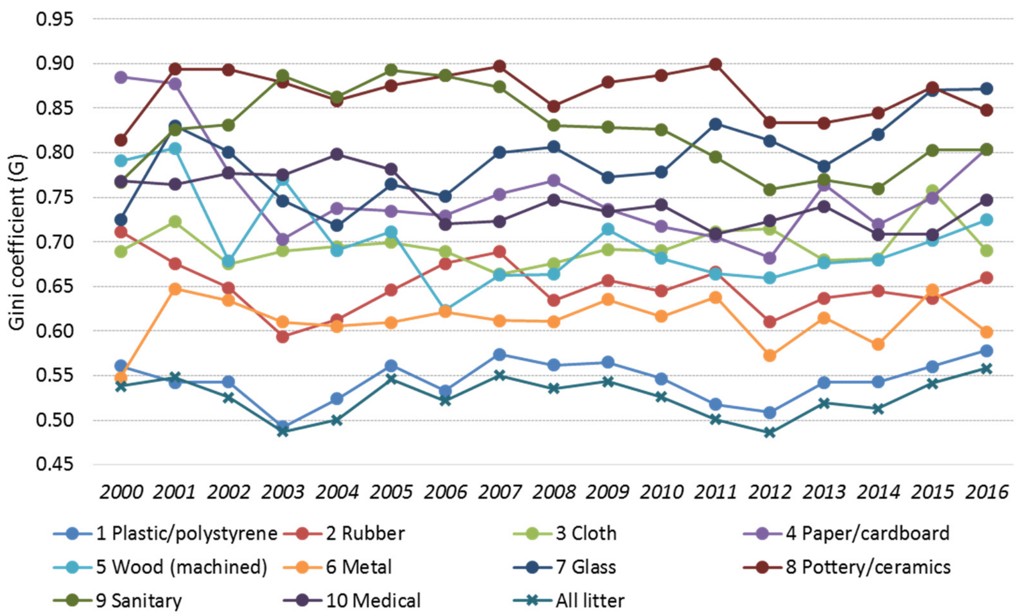


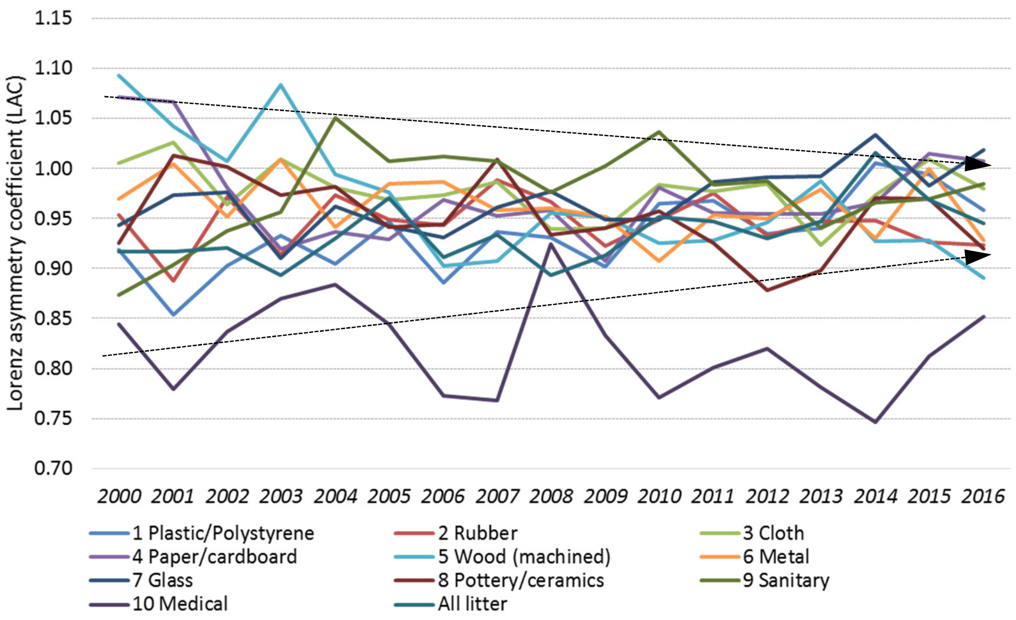
Figure 1. Gini coefficients of beach litter

4.2 Asymmetries of Gini Coefficients of Beach Litter

Table 4 reports the LACs for measuring the asymmetry of litter concentration. Except for medical which had a relatively smaller $S = .820$, the LACs of other nine litter types had were close to, but slightly below, one, indicating that their corresponding Lorenz curves are slightly asymmetric towards smallest beaches. This means that a certain degree of litter concentration is due to the relatively larger number of smallest beaches that amassed very little litter relative to the population's total litter counts. This distribution pattern is most evident for medical ($S = .820$), being the lowest. Only in some years did we find the concentration of some litter types slightly asymmetric towards few largest beaches as they had LACs larger than one, such as wood between 2000 and 2003 and sanitary between 2004 and 2010 except 2008.

Table 4. Lorenz asymmetry coefficients (LAC) of beach litter

Year	*N*	Plastic/ polystyrene	Rubber	Cloth	Paper/ cardboard	Wood (machined)	Metal	Glass	Pottery/ ceramics	Sanitary	Medical	All litter
2000	75	.919	.953	1.005	1.072	1.093	.970	.943	.925	.874	.844	.917
2001	102	.854	.888	1.026	1.066	1.042	1.004	.973	1.013	.903	.779	.917
2002	260	.902	.971	.964	.981	1.007	.952	.976	1.002	.937	.837	.921
2003	295	.933	.914	1.009	.919	1.084	1.009	.911	.973	.956	.870	.893
2004	322	.904	.973	.981	.937	.994	.941	.962	.982	1.051	.884	.930
2005	433	.947	.949	.969	.929	.976	.985	.942	.941	1.007	.844	.971
2006	455	.885	.943	.973	.969	.903	.987	.931	.944	1.012	.773	.911
2007	452	.937	.989	.986	.952	.907	.959	.961	1.009	1.007	.768	.934
2008	500	.931	.966	.939	.958	.956	.960	.977	.934	.976	.924	.893
2009	533	.902	.922	.940	.908	.952	.951	.949	.941	1.002	.833	.913
2010	492	.965	.949	.983	.981	.926	.907	.949	.958	1.036	.771	.951
2011	448	.968	.975	.977	.955	.928	.953	.987	.925	.983	.801	.947
2012	419	.935	.933	.985	.954	.946	.950	.991	.878	.987	.820	.930
2013	384	.940	.947	.923	.954	.987	.979	.992	.898	.941	.782	.947
2014	389	1.005	.948	.974	.966	.927	.930	1.034	.971	.966	.746	1.016
2015	424	.994	.926	1.009	1.015	.929	1.000	.983	.970	.969	.812	.969
2016	480	.959	.923	.980	1.008	.891	.928	1.018	.920	.985	.852	.945
Mean		**.934**	**.945**	**.978**	**.972**	**.967**	**.963**	**.969**	**.952**	**.976**	**.820**	**.936**



Notes: The two arrows indicate that the LACs seem to converge over time.

Figure 2. Lorenz asymmetry coefficients (LAC)

Figure 2 shows the variations of the LACs over time. Clearly, medical had a set of smallest LACs for the period 2000 to 2016, all below .900 except for that in 2008. Worth noting is the LACs of other nine litter types and of all litter that seemed to converge at an $S = .950$ over time. There used to be substantial variations in the LACs by litter types in 2000, and these variations gradually waned except for medical. For instance, with medical being excluded as an anomaly, the largest variation ($\Delta S = .219$) in 2000 was detected between wood ($S = 1.093$) and sanitary ($S = .874$), which shrunk to almost the half ($\Delta S = .127$) in 2016 detected between glass ($S = 1.018$) and wood ($S = .891$). Despite the Gini coefficients varying noticeably by litter types over time, their corresponding LACs tended to converge, which would have been more evident if a longer period of data was available.

4.3 Decomposition of Gini Coefficients of Beach Litter

Tables 5 shows the decomposition of the overall Gini coefficients of all litter on the six categorical variables to investigate their contribution to the overall Gini coefficients and thus the distribution of all beach litter[1]. Figure 3 further juxtaposes the 18 graphs that delineate the changes of G_k, G_B and R across the six categorical variables to visualize their respective contribution to the overall Gini coefficients of the 10 litter types[2]. As the overlap of the distribution between groups is concerned, we found that seasonality was associated with the smallest R in the decomposition of the overall Gini coefficient compared to the other five categorical variables. In other words, there is a less overlap of Gini coefficients between different seasons, suggesting that the distribution of beach litter varies more across seasons. While the data for tide height were not available until 2010, the results showed that there was also an extremely small overlap of Gini coefficients between groups, suggesting that tide height also has a significant effect on the distribution of beach litter. When it comes to location, not only was R the largest for almost all litter types among the six categorical variables, but there was also quite a large divergence of R across litter types. These results suggest that location has the smallest impact on the overall distribution of beach litter, namely the litter distribution is invariant across the eight regions.

When location was used to disaggregate the beaches, we found that the overall Gini

[1] For the decomposition results for each of the 10 litter types, please see Tables 1−18 in the appendix.
[2] For a better and detailed view of each of the 18 individual graphs, please see Figures 1−18 in the appendix.

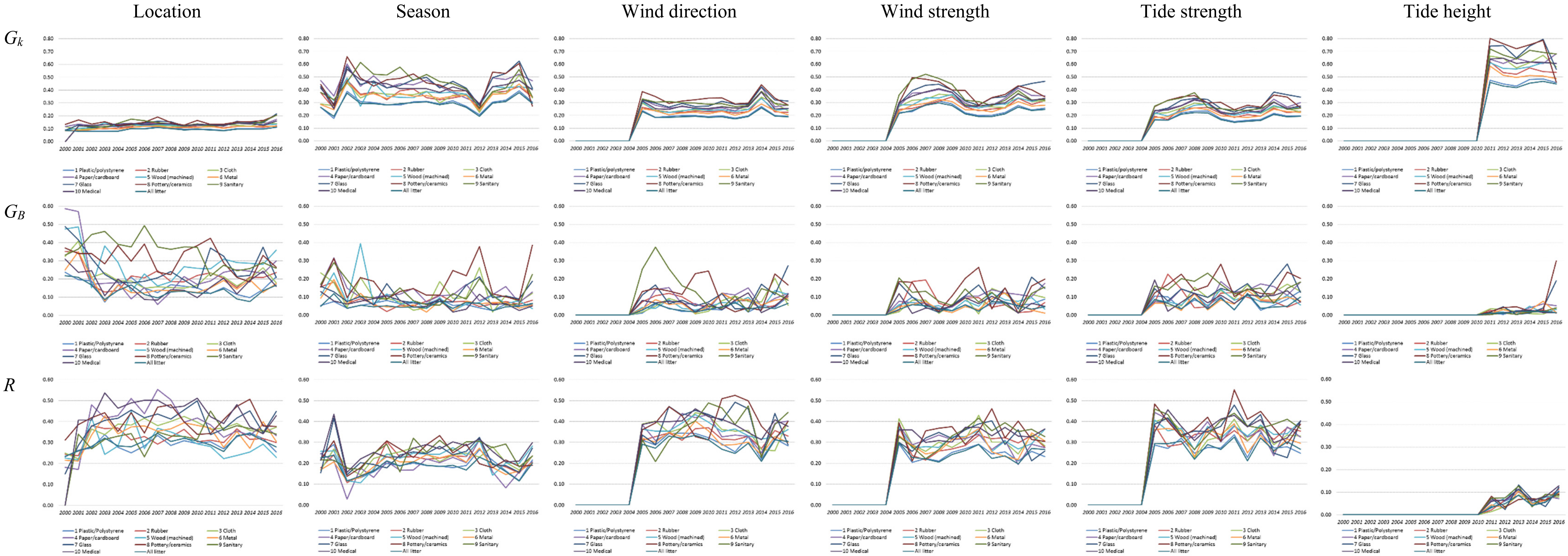
coefficients were substantially accounted for by G_B and by a higher R for all litter types. On the other hand, G_k based on location was not only among the lowest but also showed the smallest variations across litter types, suggesting that all 10 types of litter are quite evenly distributed in each of the eight regions ($G_k \approx .096$). Despite having a higher R for locations, G_B accounted for large proportions of the overall Gini coefficients, and these proportions varied significant across litter types. As for seasonality, the lowest R indicates that seasonality plays a pivotal role in affecting litter distribution; the highest G_k indicates that the overall Gini coefficients are primarily accounted for by high concentration of litter on beaches that are surveyed in different seasons. These results were compelling to suggest that litter distribution in each of the four seasons is uneven in their own right with little overlap between groups, which confirmed the effect of seasonality on the overall distribution of beach litter.

We found that the remaining three categorical variables pertinent to climate and weather, namely wind direction, wind strength, and tide strength, ended up with similar patterns with regard to G_k, G_B, and R. The patterns of the three components of the overall Gini coefficient, though, are drastically different from those associated with location and seasonality. For the three climate- and weather-related categorical variables, the overall Gini coefficients were accounted for by relatively high G_k and R. These results indicate that the effects of various weather conditions have no substantial effect on the overall litter distribution, evidenced by higher R yet lower G_B. On the other hand, the distribution of beach litter under each of the weather conditions is quite uneven, evidenced by higher G_k. For tide height in particular, we found that G_k made up almost all the overall Gini coefficients during 2010–2016, for which data were available, suggesting that tide height has a substantially strong effect on the overall litter distribution, and the distribution under each tide height condition is uneven.

Table 5. Decomposition of the overall Gini coefficients of beach litter (All litter)

Year	*N*	Location			Season			Wind direction			Wind strength			Tide strength			Tide height		
		G_k	G_B	R	G_k	G_B	R	G_k	G_B	R	G_k	G_B	R	G_k	G_B	R	G_k	G_B	R
2000	75	.085	.219	.234	.263	.049	.226												
2001	102	.080	.209	.259	.193	.117	.238												
2002	260	.078	.167	.281	.373	.038	.115												
2003	295	.078	.087	.322	.295	.054	.139												
2004	322	.080	.137	.283	.292	.046	.162												
2005	433	.100	.167	.280	.282	.052	.212	.229	.026	.291	.215	.032	.299	.165	.087	.295			
2006	455	.099	.115	.308	.292	.043	.187	.184	.065	.273	.237	.057	.228	.163	.065	.294			
2007	452	.109	.097	.344	.300	.044	.206	.184	.035	.331	.279	.051	.220	.210	.034	.307			
2008	500	.101	.129	.306	.305	.040	.190	.189	.025	.321	.297	.032	.206	.222	.094	.219			
2009	533	.091	.132	.320	.284	.076	.184	.192	.017	.335	.278	.024	.242	.220	.034	.289			
2010	492	.095	.123	.308	.299	.037	.190	.184	.030	.312	.211	.055	.261	.167	.094	.266			
2011	448	.091	.122	.288	.262	.070	.168	.189	.045	.267	.190	.022	.289	.146	.030	.325	.457	.010	.033
2012	419	.083	.145	.258	.193	.065	.229	.171	.068	.247	.191	.073	.223	.155	.120	.212	.428	.009	.049
2013	384	.097	.090	.333	.295	.023	.201	.190	.033	.296	.212	.072	.236	.161	.037	.321	.416	.017	.086
2014	389	.096	.076	.342	.308	.045	.160	.258	.045	.210	.266	.050	.197	.208	.044	.261	.452	.020	.041
2015	424	.097	.135	.310	.378	.049	.115	.194	.035	.312	.238	.032	.271	.190	.049	.303	.467	.020	.054
2016	480	.114	.166	.278	.294	.064	.200	.189	.064	.305	.247	.045	.266	.192	.099	.267	.445	.012	.101

Notes: G_k = Within-group Gini coefficients, G_B = Between-group Gini coefficients, and R = Residual.



Notes: G_k = Within-group Gini coefficients, G_B = Between-group Gini coefficients, and R = Residual.

Figure 3. Decomposition of the overall Gini coefficient of beach litter by type

5 CONCLUSION

We proposed an application of the Lorenz curve and the Gini coefficient to measure litter distribution on the UK's beaches. Both are widely-used metrics in economics for measuring income and wealth distribution yet were barely touched in the literature pertinent to litter distribution and marine pollution. This study deviates from conventional beach litter measurement that focused on single or a handful of beaches with a case study approach, while looks at litter distribution on a population of beaches at the macro level. This methodology allows us to look beyond the effect of the morphology of individual beaches to examine the extent to which a certain degree of litter pollution is distributed across all beaches in a vast area. Using a decompose analysis of the Gini coefficients, we further examined the effects of various factors, such as location, seasonality, climate and weather conditions, that may affect litter distribution on the beaches.

We found that there were clear and stationary stratifications in the Gini coefficients by litter type, indicating that the degree of litter concentration varies by litter type, with plastic and pottery/ceramics being the least and most concentrated, respectively. On the other hand, the LACs of all litter types except medical tended to converge towards symmetric, suggesting that certain degrees of litter concentration correlate, in proportion, to the size of the beaches. That said, a certain degree of litter concentration is attributed equally to the accumulation of litter from both small and large beaches defined by litter counts, regardless of the types of litter. In particular, plastic remains the least concentrated litter and its concentration is due to a great number of smallest beaches that accumulated very little amounts of litter relative to the total litter amassed on all beaches. In addition, the concentration pattern of plastic largely drives that of total litter on the UK's beaches.

While the theoretical models and methodology of the Lorenz curve are indifferent in measuring income distribution and litter concentration, the interpretations are quite the opposite, so are the corresponding police implications. Instead of crediting a more even income distribution for the sake of egalitarianism, we credit a more uneven distribution (i.e., more concentrated) of beach litter, especially asymmetrically towards largest beaches, for eradicating litter pollution. A more concentrated and asymmetric ($S > 1$) distribution indicates that the litter concentration is attributed to very few largest beaches, and therefore flagging these key beaches and eradicating the litter on them accordingly becomes instrumental in reducing overall litter abundance. Yet a less concentrated and symmetric ($S = 1$) distribution entails cleaning up litter on almost all beaches before a substantial decrease of litter pollution can be foreseen, which though is difficult. Since the concentration pattern of plastic in our study exemplifies the latter scenario, eradicating plastic, a ubiquitous pollutant on beaches, becomes extremely challenging.

In the decomposition analysis of the overall Gini coefficient, we found that location, seasonality, and climate and weather were associated with distinct patterns of G_k, G_B, and R. Within-group Gini coefficient G_k decomposed on location was the smallest, residual R decomposed on season was the smallest, while between-group Gini coefficient G_B on weather conditions was relatively smaller. These results suggest that location and seasonality have large effects on the overall distribution of beach litter and, for location in particular, litter is most evenly distributed in each of the eight regions in the UK regardless of litter types. However, the decomposition analysis does not explain what affects litter abundance on individual beaches. Rather, it explains what affects the distribution of litter across the beaches, which can be independent of the accumulated litter items on beaches.

REFERENCES

Araújo, M. C., & Costa, M. (2007). An analysis of the riverine contribution to the solid wastes contamination of an isolated beach at the Brazilian Northeast. *Management of Environmental Quality: An International Journal*, *18*(1), 6–12.

Benton, T. G. (1995). From castaways to throwaways: Marine litter in the Pitcairn Islands. *Biological Journal of the Linnean Society*, *56*(1–2), 415–422.

Bikker, J., & Haaf, K. (2002). Measures of competition and concentration in the banking industry: A review of the literature. *Economic & Financial Modelling*, summer, 1–46.

Bravo, M., de los Ángeles Gallardo, M., Luna-Jorquera, G., Núñez, P., Vásquez, N., & Thiel, M. (2009). Anthropogenic debris on beaches in the SE Pacific (Chile): Results from a national survey supported by volunteers. *Marine Pollution Bulletin*, *58*(11), 1718–1726.

Briassoulis, H. (2002). Sustainable tourism and the question of the commons. *Annals of Tourism Research*, *29*(4), 1065–1085.

Corbin, C. J., & Singh, J. G. (1993). Marine debris contamination of beaches in St. Lucia and Dominica. *Marine Pollution Bulletin*, *26*(6), 325–328.

Cowell, F. A. (1980). On the Structure of Additive Inequality Measures. *Review of Economic Studies*, *47*(3), 521–531.

Damgaard, C., & Weiner, J. (2000). Describing inequality in plant size or fecundity. *Ecology*, *81*(4), 1139–1142.

Eriksson, C., Burton, H., Fitch, S., Schulz, M., & van den Hoff, J. (2013). Daily accumulation rates of marine debris on sub-Antarctic island beaches. *Marine Pollution Bulletin*, *66*(1), 199–208.

Gabrielides, G. P., Golik, A., Loizides, L., Marino, M. G., Bingel, F., & Torregrossa, M. V. (1991). Man-made garbage pollution on the Mediterranean coastline. *Marine Pollution Bulletin*, *23*(Supplement C), 437–441.

Gini, C. (1912). Variabilità e mutabilità. Reprinted in E. Pizetti & T. Salvemini (Eds). (1955). *Memorie di metodologica statistica*. Rome: Libreria Eredi Virgilio Veschi.

Golik, A. (1997). Debris in the Mediterranean Sea: Types, quantities, and behavior. In *Marine Debris* (pp. 7–14). New York, NY: Springer.

Lambert, P. J., & Aronson, J. R. (1993). Inequality Decomposition Analysis and the Gini Coefficient Revisited. *Economic Journal*, *103*(420), 1221–1227.

Lambert, P. J., & Decoster, A. (2005). *The Gini Coefficient Reveals More* (SSRN Scholarly Paper No. ID 809004). Rochester, NY: Social Science Research Network. Retrieved from https://papers.ssrn.com/abstract=809004

Madzena, A., & Lasiak, T. (1997). Spatial and temporal variations in beach litter on the Transkei coast of South Africa. *Marine Pollution Bulletin*, *34*(11), 900–907.

Marine Conservation Society (MCS, 2017). *Great British beach clean report 2017*. Retrieved from https://www.mcsuk.org/media/GBBC_2017_Report.pdf

Martinez-Ribes, L., Basterretxea, G., Palmer, M., & Tintoré, J. (2007). Origin and abundance of beach debris in the Balearic Islands. *Scientia Marina*, *71*(2), 305–314.

Mishra, P., & Parikh, A. (1992). Household Consumer Expenditure Inequalities in India: A Decomposition Analysis. *Review of Income and Wealth*, *38*(2), 225–236.

Mookherjee, D., & Shorrocks, A. (1982). A Decomposition Analysis of the Trend in UK Income Inequality. *Economic Journal*, *92*(368), 886–902.

Oigman-Pszczol, S. S., & Creed, J. C. (2007). Quantification and classification of marine litter on beaches along Armação dos Búzios, Rio de Janeiro, Brazil. *Journal of Coastal Research*, *23*(2), 421–428.

Santos, I. R., Friedrich, A. C., & Sul, J. A. I. do. (2009). Marine debris contamination along

undeveloped tropical beaches from northeast Brazil. *Environmental Monitoring and Assessment*, *148*(1–4), 455–462.
Schulz, M., Neumann, D., Fleet, D. M., & Matthies, M. (2013). A multi-criteria evaluation system for marine litter pollution based on statistical analyses of OSPAR beach litter monitoring time series. *Marine Environmental Research*, *92*(Supplement C), 61–70.
Shumway, D. L., & Koide, R. T. (1995). Size and reproductive inequality in Mycorrhizal and Nonmycorrhizal populations of Abutilon Theophrasti. *Journal of Ecology*, *83*(4), 613–620.
Silva, J. S., Barbosa, S. C. T., & Costa, M. F. (2008). Flag items as a tool for monitoring solid wastes from users on urban beaches. *Journal of Coastal Research*, 890–898.
Smith, S. D. A., & Markic, A. (2013). Estimates of Marine Debris Accumulation on Beaches Are Strongly Affected by the Temporal Scale of Sampling. *PLOS ONE*, *8*(12), 1–6.
Tudor, D. T., & Williams, A. T. (2006). A rationale for beach selection by the public on the coast of Wales, UK. *Area*, *38*(2), 153–164.
Vauk, G. J. M., & Schrey, E. (1987). Litter pollution from ships in the German Bight. *Marine Pollution Bulletin*, *18*(6), 316–319.
Weiner, J., & Solbrig, O. T. (1984). The meaning and measurement of size hierarchies in plant populations. *Oecologia*, *61*(3), 334–336.
Widmer, W. M., & Hennemann, M. C. (2010). Marine debris in the island of Santa Catarina, South Brazil: Spatial patterns, composition, and biological aspects. *Journal of Coastal Research*, 993–1000.
Williams, A. T., & Tudor, D. T. (2001). Temporal Trends in Litter Dynamics at a Pebble Pocket Beach. *Journal of Coastal Research*, *17*(1), 137–145.
Willoughby, N. G., Sangkoyo, H., & Lakaseru, B. O. (1997). Beach litter: An increasing and changing problem for Indonesia. *Marine Pollution Bulletin*, *34*(6), 469–478.
Zuelow, E. (2015). *A history of modern tourism*. Macmillan Education UK.