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The Geography of Litter

An investigation into the sources, deposition, transfer dynamics, impact, and regional variations of anthropogenic waste debris in England

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The Geography of Litter

An investigation into the sources, deposition, transfer dynamics, impact, and regional variations of anthropogenic waste debris in England

Randa Lindsey Kachef

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A thesis submitted to the Department of Geography of King's College London for

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Declaration

I, Randa Lindsey Kachef, confirm that the work presented in this thesis is my own and all references are cited accordingly.

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Abstract

Understanding litter and littering is not as straightforward as one may assume, as it is a complex social-environmental issue. Nuances relate to a wide range of factors (e.g., litter movements, litter types, mitigations), but despite complexities, research and policy has historically approached the issue through behavioural intervention; reduce litter by addressing littering. Limited research efforts focus on holistically understanding physical properties of litter, material composition and regional variation. This thesis investigates these intricacies, exploring and testing the subtleties of litter and littering dynamics with focus on urban, British settings. In collaboration with the Hubbub Foundation UK, and local governments in London, Manchester, Birmingham and Brighton, interdisciplinary methods from Human and Physical Geography were used to reveal insights that reframe litter and littering.

A quantitative sampling of litter typology in the study sites revealed that cigarette litter was pervasive, accounting for 78% of all surveyed items. Of non-cigarette litter, a proportional analysis identified chewing gum as most prevalent, alongside till receipts (8%); whilst hot-topic litter items such as plastic bottles (2.7%), coffee cups (1.5%) and plastic bags (0.7%) contributed marginally to the sample. Additionally, when considering litter by associated activities*,* a grouped analysis revealed 30% of non-cigarette litter was attributed to eating. Behavioural observations found 63% of non-cigarette littering is unintentional*,* half of which is characterised by individuals placing rubbish on bin-like structures or stacking it neatly next to full bins, designated as Polite Littering. Mapping GPS tagged litter indicated that there are many influences that allow litter to travel in a terrestrial environment.

The study found that litter can enter a site through a range of direct and indirect human-mediated pathways, providing proof of concept to discussions on inland-based contributions to marine plastics. Following on, material composition of commonly littered items was evaluated to develop the Litter Impact Index. The index quantified item-specific levels of impact and provided a robust tool for establishing ranges of impacts. Finally, repurposing litter typology, associated activities and impact values, a comparative analysis identified connections between litter and place. Unexpectedly, variations in litter abundance exist across each of the case-study cities, although overall composition remained somewhat similar.

Considering insights gained within this thesis, it is proposed that a series of structural adjustments that reduce the potential for items to become litter can have greater impact than wide-scale public campaigns. These include solutions like smart bin design and intuitive cleansing schedules that consider spatial, meteorological, and temporal variability. Additionally, reflecting on policy, particularly the development of the Extended Producer Responsibility for Packaging, the implementation of the Litter Impact Index is proposed as a novel framework to influence packaging design standards and target reduced circulation of the most abundant and detrimental items. The results of these studies highlight that the blight of litter is highly misunderstood, and sheds new light on litter sources, dispersal, transfer dynamics and associated impacts – establishing new avenues for evidence-led, simple, and sustainable methods to mitigation.

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Glossary of Acronyms

Acronym	Definition
4T	The Four Ts: Toxicity, Tenacity, Threat and Transportability
ANOSIM	Analysis of Similarity
BPA	Bisphenol A
BPS	Bisphenol S
BRI	Brighton
CBD	Central Business District
CE	Circular Economy
CP	Community parameters: richness (R), density (D), evenness (E), impact (M)
DDT	Dichlorodiphenyltrichloroethane
DEFRA	Department for Environment, Food & Rural Affairs
ECHA	European Chemicals Agency
EPRP	Extended Producer Responsibility for Packaging
GBP	British pound sterling
GLA	Greater London Area
H	Shannon Diversity Index
HS	High Street
KAB	Keep Australia Beautiful
KAB*	Keep America Beautiful - Imposed this acronym for clarity sake
KBT	Keep Britain Tidy
LBL	London Bridge, London
LEQSE	Local Environmental Quality Survey of England
LII	Litter Impact Index
LIV	Litter Impact Value
NGO	Non-Government Organisation
nMDS	Non-metric Multidimensional Scaling Model
NSB	New Street, Birmingham
OXM	Oxford Street, Manchester
PP	Precautionary Principle
PPE	Personal protective equipment
PPP	Polluter Pays Principle
Q	Shannon Equitability Index
REACH	Research, Evaluation, Authorisation and Restriction of Chemicals
RSPCA	Royal Society for the Prevention of Cruelty to Animals
SHS	Sutton High Street, Sutton
SIMPER	Similarity Percentage Analysis
Tx	Toxicity indicator score
Te	Tenacity indicator score
Th	Threat indicator score
Tr	Transportability indicator score
UK	United Kingdom
USA	United States of America
USD	United States of America Dollars

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Chapter 1: Introduction and Research Aims

1.1. Motivation and context

This thesis is an exploration in the physical properties of a growing threat to society and the environment; the presence of manufactured anthropogenic debris outside of waste management systems. The advent of disposable packaging has led to an increase of persistent waste accumulating in nature (Roper and Parker, 2006); a large portion of which is believed to come from land-based human activities, specifically littering in public spaces (Lechthaler *et al.*, 2020). The presence of litter is ubiquitous (Rangel-Buitrago *et al.*, 2022), it can be found on the street outside your own home (Ballatore *et al.*, 2022), along motorways (Cowger *et al.*, 2022), in the middle of the ocean (Van Sebille, 2015) and even on remote uninhabited islands (Lavers and Bond, 2017).

The impacts of litter are many, and negative repercussions run deeper than simply being unsightly or unpleasant (Parker, Roper and Medway, 2015). Unfortunately, the presence of litter is associated with crime and anti-social behaviour (Braga and Bond, 2008), littered neighbourhoods have lower property values and draw less amenity income (Sherrington, Darrah and Hann, 2014). Litter can cause injuries (Campbell *et al.*, 2019), promote disease (Rodrigues *et al.*, 2019), and often leads to disruptive sewage blockages (Honingh *et al.*, 2020). Plastic litter in water can be toxic, and as they fragment, microplastics are increasingly found in the guts of animals and humans (Wright and Kelly, 2017). Ultimately, land-based litter contributes 80% of marine debris pollution, a long-term and ambiguous sink with global repercussions (European Commission, 2016).

The direct and indirect effects of litter on society and the environment are complex and widespread, illustrating the importance that this threat be taken seriously. Far too often, risks to health and the environment are identified only after repercussions become pervasive (as is the case in past use of asbestos (Harremoës *et al.*, 2001) and Dichlorodiphenyltrichloroethane (DDT) (Carson, 2002)), a fate that the encroachment of litter is steadily fulfilling.

A range of academic research on litter has explored a variety of litter reducing methods targeted at adjusting behaviour. Examples include the provision of rewards, shaming negative behaviour (Beck, 2001) the use of images of watching eyes (Bateson *et al.*, 2013), instructions on how to dispose of items (Cialdini, 2003) and designing more attractive waste bins (Geller, Brasted and Mann, 1979). These studies have all concluded with success in combatting litter. Yet, despite the implementation of these researched approaches to anti-littering campaigns, both by government and non-government organisations, the amount of litter in the environment continues to grow (Wever *et al.*, 2010). This thesis argues this discrepancy is due to a deep-rooted lack of understanding of the act of littering and litter itself, where past research has sought primarily to mitigate, rather than comprehending associated dynamic processes.

1.2. Research aims and objectives

As the range of items classified as litter are diverse, this study specifically focuses on macro-litter, meaning intact items that are large enough to be seen without aid. Prior research on litter often focuses on items made of plastic, as a result much of the literature used to inform these studies may be specific to plastic litter items, however the objective of this thesis is to address all litter items, regardless of their material composition.

The purpose of this research is to explore a range of attributes of litter. Specifically, this thesis seeks to identify qualities of the production and journey of litter from land to aquatic sinks. In considering the Lifecycle of Litter*,* illustrated in Figure 1.1, a clear path can be identified from consumption, deposition and terrestrial pathways to final marine resting places.

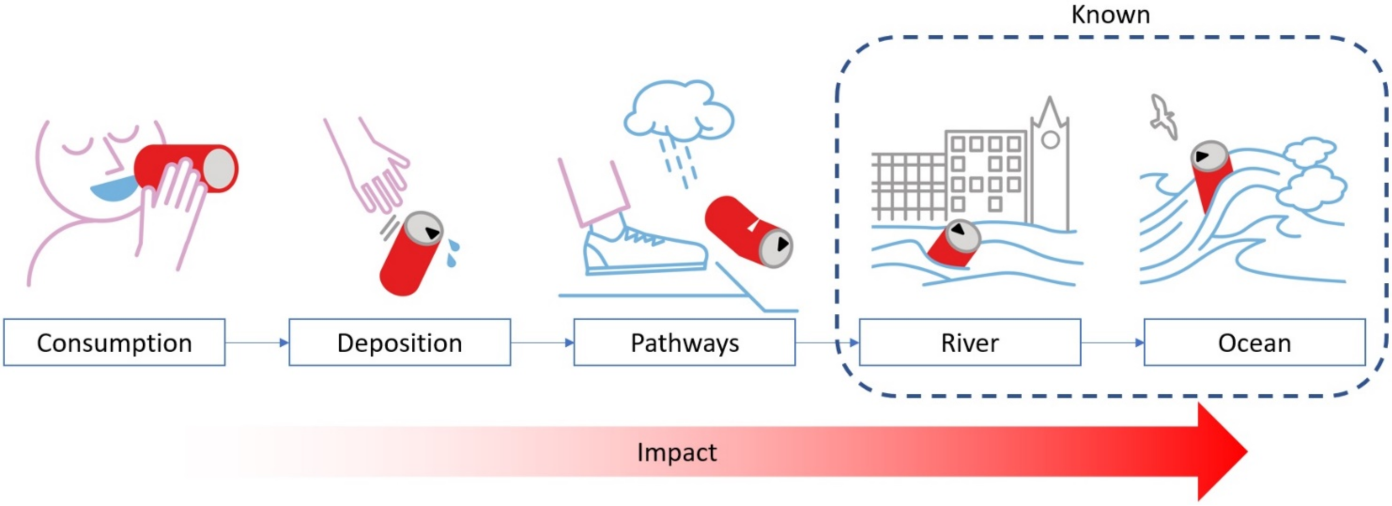

Figure 1.1 The Lifecycle of Litter. Illustrated stages of litter from consumption, deposition, pathways, through to rivers and finally the ocean.

Whether it be food wrappings, drink containers or cigarettes, mismanagement at consumption is generally accepted as the source of litter (Earll *et al.*, 2000; Seco Pon and Becherucci, 2012; Hahladakis, Iacovidou and Gerassimidou, 2020). Once the purpose of an item has been exhausted, deposition of the journey requires that item to be littered, whether it be through intentional or unintentional means. In pathways, items are subject to various forces that lead to the litter entering river systems, ultimately flowing to ocean. Throughout this journey there are negative associated Impacts, with magnifying ramifications along each step.

Collecting litter from river is difficult as litter exists not only on the surface but within the water column and riverbed (Morritt *et al.*, 2014; Schöneich-Argent *et al.*, 2019; Lechthaler *et al.*, 2020; Lorenzi *et al.*, 2020), and recollection efforts raise issues of safety and transport disruption (Winton *et al.*, 2020). Equally, intervention in the ocean is unclear as no one nation has responsibility (Leous and Parry, 2005). Meanwhile, under the stress of movement from consumption through to ocean, litter items are subject to fragmentation, rendering them increasingly more difficult to collect. As a result, land-based litter intervention is ideal (Carpenter and Wolverton, 2017) and to reduce the accrual impact within this journey, a distinct focus on consumption, deposition and pathways is required. Although the repercussions and dynamics of litter in marine environments (river and ocean) are well researched, there is little knowledge of land-based processes (consumption through pathways). These unknown areas will be the focus of this thesis.

Drawing from the core themes of Geography (i.e., human-environment interactions, location, place, discreet movement and region (Hill, 1989)), this thesis will present the results from five studies which pose the following research questions:

1. What consumption activities generate litter?
    - An understanding of the most common litter generating activities can inform mitigation efforts by targeting peak litter production times and locations.
2. How is litter deposited?
    - By examining methods of littering, assumptions can be made on the intention associated with the act.
3. How does land-based litter move?
    - Much public emphasis lies in the repercussions of land-based litter, aquatic accumulation, with little attention to the methods of transport from deposition to sinks.
4. Do all litter types have equal impact?
    - Litter surveys lead to observations on the diversity of items that are littered. An analysis of the material composition of litter can identify which items have greater adverse effects, ultimately informing producers on how to mitigate the impact of their products.
5. Is there a connection between litter and place?
    - Although the composition of urban locations are unique, anti-littering initiatives rarely take into consideration the differences in patrons and use of space. By comparing litter compositions between various test sites, regional patterns as to the nature of litter generation can be established.

To explore these questions, a variety of studies were conducted. The results from these shed new light on the study of litter, open avenues for further research and propose alternative means in approaching the issue of litter.

1.3. Thesis outline

Ultimately, The Geography of Litter is a series of focused exercises tailored to set a baseline understanding of the social and physical attributes of litter and littering. Each exploratory study has its own unique objective, and chapters can be read independently or in sequence for an overarching understanding a range of factors that contribute to litter in urban spaces across England. As such, thesis is composed of 9 chapters featuring five studies targeted to answer proposed research questions. Specific aims of each chapter fit into various section of the Lifecycle of Litter and are as follows:

Chapter 2: Literature review

The literature review highlights the gravity of the current state of litter and littering, presenting data on its pervasive and hazardous nature. As the blight of litter continues to grow, the review calls into question the effectiveness of popular passive mitigation methods such as behaviour changing techniques, while successful direct structural solutions are inherently disregarded. Gaps in knowledge are identified pertaining to sources of litter, methods of littering, forces in litter transport, uneven impact of items and locations of litter generation.

Chapter 3: Study Sites and Data Use

This chapter provides details on data accessibility, partnerships, describes study sites and outlines how collected data are used in tandem with, and tie into other chapters.

Chapter 4: Litter Source Dynamics: Litter as evidence of *consumption* trends

Detailed litter surveys were conducted in four English cities; South London, Manchester, Birmingham and Central London. Employing a method of behavioural archaeology, items are recategorized by their source activity to examine waste generating consumption trends.

Chapter 5: Litter Deposit Methods: Is *litter* the product of *littering*?

To examine methods of litter creation, covert observations of waste disposal behaviours are conducted in five English locations; South London, Manchester, Birmingham, Central London and Brighton. The analysis focuses on categorising observations by method of disposal, using these categories to draw conclusions on littering intent.

Chapter 6: Transfer Dynamics of Litter: Introduction to new *vectors* of terrestrial litter

This study attempts to provide proof of concept of the contribution of land-based urban litter to aquatic environments. Through a geospatial analysis of GPS tagged litter during a popular riverside event in West London, the influence of foot traffic on dispersal of land-based litter is examined.

Chapter 7: Material Composition of Litter: Toxicity, tenacity, threat and transportability

A reflection on the diverse array of items that are collectively referred to as litter leads to the creation of the Litter Impact Index. In scoring the material composition of individual items by indicators of toxicity, tenacity, threat and transportability (referred to as 4T), the index establishes a quantitative framework to determine the level of adverse effects posed by various litter types.

Chapter 8: Regional Variations in Litter: The connection between litter and place

Surveys from Chapter 4 are repurposed in a comparative analysis of litter profiles of the four study sites. Study sites are grouped by use type, to explore trends between the purpose of a place and the litter that it accumulates. Additionally, Litter Impact Scores from Chapter 7 are integrated into site profiles, weighing comparisons by the level of harmful items present.

Chapter 9: Conclusion

The final chapter summarizes the objectives of, and lessons learnt in each of the studies presented in Chapters 4 through 8. It concludes with a reflection on current litter policy, provides recommendations on the practical application of these findings and proposes avenues for future research.

1.4. Research innovation

The novelty of this thesis is to cast a magnifying glass on land-based litter, exploring litter as a process, taking into consideration facets of both human and physical influences.

Land-based litter has been the subject of academic research since the early 1970's, with two very distinct paths of inquiry, the social and environmental impact of litter and various methods of intervention to reduce litter and littering behaviour.

The study of litter impact is ongoing and increasingly stresses the negative effects that litter has on behaviour, crime, economy, health and the environment (Iacovidou *et al.*, 2020). Litter intervention has historically been researched within the social sciences and behavioural sectors, typically seeking to influence littering behaviour through individual change (Schultz *et al.*, 2013; Al-mosa, Parkinson and Rundle-Thiele, 2017). This research has been largely qualitative, often based on self-reported questionnaire data, and results have been inconsistent (evidenced in Chapter 2: Literature Review, section 2.9). Despite this, anti-littering campaigns across England have used these studies as the basis of planned interventions, with their effectiveness in question as the number of litter items in the environment continue to grow (Wever *et al.*, 2010).

Within the marine research sector, a quantitative approach has systematically been applied to understand abundance and identify sources of litter (Ryan, 2015, 2020; Rangel-Buitragoa *et al.*, 2019; Lechthaler *et al.*, 2020). In contrast, of the few quantitative studies on land-based litter, the primary focus has been on clean-up and descriptive categorization (Schultz *et al.*, 2013; DEFRA, 2020), with very little emphasis on accumulation rates or source identification. As a result, there is very little high resolution and exploratory research in the field.

Chapter 2: Literature Review

2.1. Introduction

Litter is a complex socio-environmental issue that, despite its prevalence and known impacts, continues to persist. Since identifying litter as a growing threat, policymakers, researchers, and social activists have devoted substantial energy towards reducing litter in the environment, establishing laws, mitigation strategies and organizing clean-up events. The flow of litter into the environment however remains unhindered, stipulating that there is a serious misunderstanding of how to effectively address the issue. The objective of this chapter is to provide the reader with a base knowledge of litter, providing context for upcoming analytical chapters and discussion. This is by no means an exhaustive review of the wide and abundant range of literature available.

To begin with, the word litter itself is a polyseme with several non-associated meanings that can lead to confusion (Lechthaler *et al.*, 2020). Not only does litter refer to waste that is improperly discarded by people, but the word is also used to describe the collective birth of multiple animals, the granules that are spread in a box for indoor pets to use when relieving themselves, straw bedding, a form of mid-18th century portable couch and the shedding of dead material from plants. As a result, there are several alternative ways that litter, in the desired meaning of this thesis, can be referred to. Synonyms include anthropogenic debris, discarded waste, anthropogenic litter. When plastics are the focus in litter discussion, it is often named as macroplastics, plastic litter, plastic debris, with those found within a marine environment dubbed marine litter or marine plastic (Lechthaler *et al.*, 2020).

It is surprising that such an enigmatic term is used to define a phenomenon as far-reaching as the blight of litter. Litter can be found in the most populous locations (DEFRA, 2020) strewn amidst ancient relics (Kissock, 2018; Shiong *et al.*, 2020) and in abundance on the beaches of the world's most remote uninhabited islands (Benton, 1995; Lavers and Bond, 2017). Litter is omnipresent in both aquatic and terrestrial spheres, it is found in outer space causing disruption to global communications systems (Reinstein, 1999) and can even be found on the moon (Whyte, 2019). The effects of litter extend beyond simply being unsightly, it is a drain on public funds, causes injury to both humans and animals and is a known contaminant to natural resources (Seco Pon and Becherucci, 2012; Sherrington, Darrah and Hann, 2014; Jones *et al.*, 2021).

In essence, litter is not only ambiguous but ubiquitous, with grave associated consequences that continue to come to light. Consequently, academic research and action groups have directed efforts to reducing litter by addressing littering, with a strong focus on influencing public behaviour (Wever *et al.*, 2010). This literature review will not only outline the prevalence and repercussions of litter but provide a summary of mitigation methods currently in practice, calling into question the value of these strategies.

2.2. What is litter?

Litter can be loosely defined as personal waste items present in a public space outside of proper waste receptacles (Geller, Witmer and Tuso, 1977; Al-Khatib *et al.*, 2009; Lechthaler *et al.*, 2020). The act associated with the generation of litter is littering and according to the Environmental Protection Act of 1990 is illegal in England (UK GOV, 1990); although enforcement does not apply to litter that is accidently dropped (DEFRA, 2018a).

> *"A person is guilty of an offence if he throws down, drops or otherwise deposits any litter in any place to which this section applies and leaves it."*
> *-Environmental Protection act 1990, Section 81 (1)*

Items that are considered litter are not defined in regulation and can encompass a wide range of materials such as plastic, glass, tin, paper etc. The collective term litter includes variations of both organic and inorganic materials, and the impact of the item is greatly influenced by the material composition. For example, orange peels are unsightly, promoting social misconduct and disease, however their organic nature means they will ultimately biodegrade (Ghinea *et al.*, 2019; Marsi *et al.*, 2019; Buxoo and Jeetah, 2020). This cannot be said for a plastic bottle, which has the same immediate social impact, but persists in the environment for centuries (Andriani *et al.*, 2020; Zhang *et al.*, 2021).

The main consistent quality of litter items is that their primary purpose has been exhausted and they are no longer considered of value. This is important to the argument of this thesis as when an item of value is dropped it is often recovered, either by the original owner or a new one. For example, when an individual finds a wallet on the ground it is typically collected, and either kept or taken to a nearby authority to be reclaimed by its owner, this is never done with an empty crisp packet or a cigarette end.

The reality is we live in an age of disposability, where the abundance of materials that are produced simply to be discarded is unprecedented (Meikle, 1995; Campbell, 2007; Thompson *et al.*, 2009; Zalasiewicz, Gabbott and Waters, 2019). Most of what we consume is wrapped in plastic and labelled with paper, creating unnecessary waste with every purchase; it is predicted that in England up to 7,000 tonnes of plastic packaging is littered every year (Iacovidou *et al.*, 2020). Littered fast food packaging, crisp packets, sweet wrappers and plastic bottles have steadily risen among the most littered items, plaguing streets and parks all across England (DEFRA, 2020). Modern comforts in availability and standards for food safety have inundated a growing population with items that are of no use once emptied of their contents (O'Brien, 2012; Zalasiewicz *et al.*, 2016; Plastics Europe, 2021). All too often obsolete items of a persistent nature are found where they don't belong, these are the items of interest to this study, rubbish that does not make it into proper waste management streams.

2.2.1. A brief history on disposable plastics

Originally developed in an effort to preserve natural resources, plastics have the unique ability to take on the qualities of any material, eradicating any limitations resource extraction once posed (Meikle, 1995). Practically anything that is used on a daily basis can, and most likely is, made of plastic; and in terms of durability, versatility, transportability, affordability and quality, plastic often outperforms the material it is meant to imitate (Meikle, 1995).

It was after World War 2, a time that initiated a 300% increase in the production of plastics in the United States (Ellen MacArthur Foundation, 2017; European Union, 2019; Campanale *et al.*, 2020), that single use plastics erupted on the market. These provided the public with disposable, versatile and light weight packaging, allowing for new standards in hygiene and convenience (Meikle, 1995; Thompson *et al.*, 2009; Lebreton and Andrady, 2019). The novelty, flexibility and endless supply of plastic soon resulted in the material becoming the norm in product packaging and production, accounting for a third of global plastic production (Thompson *et al.*, 2009).

Since the 1950s, both plastic use and production have increased exponentially (Zalasiewicz, Gabbott and Waters, 2019; Campanale *et al.*, 2020), up to twenty-fold, and continues to do so; predictions indicate their use will double in the coming two decades (Ellen MacArthur Foundation, 2017; European Union, 2019). Since their introduction, plastics have proven to be versatile, cost efficient, and vital in innovation (Zalasiewicz *et al.*, 2016; European Union, 2019). With over 350 million tonnes of plastic produced yearly (figure valid in 2017), plastic is the third most manufactured material, surpassed only by steel and concrete (European Union, 2019; Zalasiewicz, Gabbott and Waters, 2019).

Manufactured as a by-product of the petroleum refining process, plastic production accounts for 8% of annual fossil-fuel extraction (Thompson *et al.*, 2009; Lebreton and Andrady, 2019). Plastics do not biodegrade, they are however subject to abiotic weathering processes such as wind, sunlight and mechanical forces which cause fragmentation (Allen *et al.*, 1994; Lambert, Sinclair and Boxall, 2014; Ioakeimidis *et al.*, 2016; Weinstein, Crocker and Gray, 2016; Waring, Harris and Mitchell, 2018; Napper and Thompson, 2019; Chamas *et al.*, 2020; Zhang *et al.*, 2021). Plastic pieces larger than 5mm are referred to as macroplastics (Patil *et al.*, 2022), pieces equal to, or smaller than, 5mm labelled microplastics (Zhang and Xu, 2022), and fragments sized under 1000nm cited as nanoplastics (Cai *et al.*, 2021; Zaki and Aris, 2022). Microplastics starting at 200nm in diameter are known to cross the biological barrier (da Costa *et al.*, 2016; Mitrano, Wick and Nowack, 2021; Yee *et al.*, 2021) with recent studies finding particles as large as .05mm in human blood (Leslie *et al.*, 2022).

Although recent research on plastic has proven that they pose a variety of threats to people and the environment (Vethaak and Leslie, 2016), it is important to note that the invention and widespread use of plastics has likely played an important part in the flourishing of the human race over the past half century.

Plastic use has revolutionised the medical field (Odent, 2011). Plastic based peripheral intravenous catheters were first introduced by Massa in the 1950's, reducing injury by providing a malleable and versatile alternative to feather quills and metal needles (Rivera *et al.*, 2005; Lambert, Sinclair and Boxall, 2014). Every year, across the globe, approximately 16,000 million single use plastic syringes are used (Janagi, Shah and Maheshwari, 2015). It is through the availability and low cost of single use needles as well as post sterilization instrument packaging that countless lives have been saved and the potential for cross contamination and infection has been eradicated (Dempsey and Thirucote, 1988; Rivera *et al.*, 2005; Odent, 2011; Zalasiewicz *et al.*, 2016). More recently, the widespread use of personal protective equipment (PPE) in hazardous environments, particularly single use face masks, has directly led to the mitigation of the spread of the 2020 COVID 19 pandemic (Ammendolia *et al.*, 2021; Voegel and Wachsman, 2021).

Further to medical use, the introduction of plastic wrapping on food items has not only reduced potential for cross-contamination and bacterial infection, but maintains freshness by keeping moisture out and limiting oxidation, effectively reducing food waste (Zalasiewicz *et al.*, 2016; Iacovidou and Gerassimidou, 2018; Plastics Europe, 2021). Bottled water is clean and easily transportable (Zalasiewicz *et al.*, 2016), providing aid around the world, particularly to victims in the wake of natural hazards such as earthquakes, tsunamis, landslides and volcanic eruptions; where local water resources are often contaminated. Essentially, plastics save countless lives.

The problem with plastic items though is their abundance and tenacity (Rathje and Murphy, 2001; Zalasiewicz, Gabbott and Waters, 2019), particularly in non-critical uses. In the case of vital plastic based medical equipment, strict hazardous waste legislations and standards ensure collection and proper disposal (Goddu, Duvvuri and Bakki, 2007; Tudor *et al.*, 2008). In most countries, including England, clinical waste is either incinerated or rendered inert through other forms of thermal or chemical treatments (Tudor *et al.*, 2008; Janagi, Shah and Maheshwari, 2015); ensuring that medical waste does not end up in the environment.

Today, the market has developed standards and assumptions as to the convenience of on-the-go and disposable items, often resulting in superfluous use (O'Brien, 2012). This debris is so efficient at protecting, wrapping and carrying purchased goods that it is accumulating in landfills and in the environment, persistence being its primary trait (Rathje and Murphy, 2001; da Costa *et al.*, 2016; Waters *et al.*, 2016).

Plastic was originally marketed as a means to save the world; its ability to mimic natural resources such as wood, ivory and other limited materials, provided supply whilst alleviating stressors posed by environmental extraction (Meikle, 1995; Thompson *et al.*, 2009). This is ironic as not only do images of wildlife mistaking plastic products as food flood the media (McKenzie, 2019), but the public has been desensitised to its presence (Roper and Parker, 2008; De Veer *et al.*, 2022), illustrating how well plastic does indeed mimic and blend in to nature.

2.3. Where does littering occur?

The presence of litter is so pervasive that the public has become immune to its presence (Roper and Parker, 2008; De Veer *et al.*, 2022) and it is often omitted from view through overexposure and repetition. Due to its widespread presence and varied methods of entering an environment, it is difficult to accurately identify the source of litter (Lechthaler *et al.*, 2020) although it is predicted that 1.2 – 2% of waste generated in public spaces is littered (Jambeck *et al.*, 2015; Kawecki and Nowack, 2019).

Regular litter surveys in England have consistently found greater levels of litter in densely populated, urban, retail, commercial and industrial areas; while sparsely populated, rural and domestic areas remained comparatively litter free (DEFRA, 2020). In these surveys the deprivation of an area is also found to be influential to the amount of litter present, where a significant correlation ($p < .001$) was found between higher litter counts and increased levels of deprivation (DEFRA, 2020).

In terms of the litter found in aquatic environments, sources include not only land-based littering and sewage discharge (80%), but fishing and freighting activities as well (20%) (e.g. European Commission, 2016; Lechthaler et al., 2020; Mehlhart and Blepp, 2012; Morritt et al., 2014).

2.4. Where does litter accumulate?

Although the aesthetic impact of litter has been a topic of discussion for nearly half a century, it is only recently that the long-term accumulation of litter in the environment has come to light. Where litter was once forgotten after disposal, it is becoming increasingly apparent that what gets littered will persist in the environment for hundreds of years.

There are two types of litter sinks, temporary and permanent (Lechthaler *et al.*, 2020). Temporary sinks include aquatic environments such as riverbeds and lake and ocean surface waters as well as riparian zones such as river floodplains and shorelines (Lechthaler *et al.*, 2020; Zhang *et al.*, 2021). Permanent sinks include deep sea and terrestrial zones (Barnes *et al.*, 2009; Thompson *et al.*, 2009; Lechthaler *et al.*, 2020; Zhang *et al.*, 2021).

2.4.1. Coastal sinks

Recreational waste on beaches is predicted to be the largest contributor to coastal litter, accounting for up to 70% (Ocean Conservancy, 2020; Rangel-Buitragoa *et al.*, 2020). Sewage related debris is another source of land-based litter to coastal environments (Storrier and McGlashan, 2006; Lebreton and Andrady, 2019). Litter that is directly deposited into sewage systems through littering, surface run-off or originates from the home often cannot be processed out (Lechthaler *et al.*, 2020), causes blockages (Honingh *et al.*, 2020; van Emmerik and Schwarz, 2020) and experiences overflow, ultimately being dumped along coastal zones and washing back onto the beach (Williams and Simmons, 1996; Surfers Against Sewage, 2014).

The Marine Conservation Society (MCS) conducts yearly Beach Litter Reports, where they count, categorise, and analyse the nature of litter found on beaches around the United Kingdom (UK). Overall, it is projected that there has been a 140% increase in litter on beaches since 1994 (Surfers Against Sewage, 2014) with as many as 385 litter items found per 100 metres of beach (Marine Conservation Society, 2021).

2.4.2. Terrestrial sinks

Despite a public focus on marine plastics, litter inputs to terrestrial environments are estimated to exceed those in oceans by a factor of 40 (Kawecki and Nowack, 2019; Patrizi, Gambosi and Zanzotto, 2021). Permanent terrestrial sinks include weathered and interred litter items (Lebreton and Andrady, 2019; Lechthaler *et al.*, 2020; Mitrano, Wick and Nowack, 2021) the grinding of agricultural films into soils, (Kawecki and Nowack, 2019; Lechthaler *et al.*, 2020), and floodplain deposits (Hoffmann and Reicherter, 2014; Schwarz *et al.*, 2019). The terrestrial intrusion of litter result in stratigraphic layers of plastics and other man-made materials, known as Technofossils (Zalasiewicz *et al.*, 2014, 2016; Waters *et al.*, 2016; Zalasiewicz, Gabbott and Waters, 2019) that are specifically indicative of the Anthropocene (Harden, 2014; Hoffmann and Reicherter, 2014; Mitrano, Wick and Nowack, 2021). Terrestrial sinks of litter is an under-researched topic and it is theorised that the extent of intrusion is severely underestimated (Xu *et al.*, 2020).

2.4.3. Ocean sinks

Once littered on land, waste is subject to transportive forces (e.g., wind and rain), working its way around the environment, entering storm drains or collecting in various inlets (Honingh *et al.*, 2020; Lechthaler *et al.*, 2020; Schirinzi *et al.*, 2020; Roebroek *et al.*, 2021; Zhang *et al.*, 2021; Cowger *et al.*, 2022), contributing to an estimated 80% of marine plastic volumes (European Commission, 2016; Winton *et al.*, 2020). In-land contributions to marine waste are considered to originate anywhere between 50-200km from coastal areas (Van Sebille, England and Froyland, 2012; Jambeck *et al.*, 2015; Schwarz *et al.*, 2019).

Recently, the remote beaches of Henderson Island, part of the Pitcairn Island group, was discovered to be inundated with litter (Lavers and Bond, 2017; Monteiro, do Sul and Costa, 2018). Despite being uninhabited, researchers discovered up to 40 million individual pieces of plastic, and predict up to 26 new items per metre of beach accumulate daily (Lavers and Bond, 2017); supporting research that litter moves all over the world (Van Sebille, 2015; Zhang *et al.*, 2021).

It is estimated that 0.2% of global plastic production enters the ocean each year (Wilcox, Hardesty and Law, 2020), which in 2010 equated to approximately 12 million tons (Jambeck *et al.*, 2015; Geyer, Jambeck and Law, 2017; Brooks, Wang and Jambeck, 2018; Wilcox, Hardesty and Law, 2020; Huang *et al.*, 2021). Under the transport influence of the tides (van Sebille *et al.*, 2020), this litter accumulates in the centre of each ocean, globally forming 5 major gyres (Kershaw *et al.*, 2011; Cressey, 2016; Zhang *et al.*, 2021). The largest of the gyres, the Great Pacific Garbage Patch covers approximately 1.3 million square miles (Milman, 2016) and is estimated to contain anywhere from 1.1 to 3.6 trillion pieces of plastic, consisting of both microplastics as well as larger items in various stages of fragmentation (Lebreton *et al.*, 2018). As plastic production increases, it is expected that by 2050 there will be more plastic than fish in the ocean (Ellen MacArthur Foundation, 2017).

The European Commission lists litter from sewer overflow and storm water drains as one of the top contributors of land-based litter to the marine environment (Jambeck *et al.*, 2015; European Commission, 2016; Ryan, 2020). The remaining 20% of marine litter is predicted to stem from fishing activates (Cressey, 2016; Lechthaler *et al.*, 2020), although estimating exact sources and proportions have proven to be difficult.

2.4.4. Comments on litter accumulation

It is apparent that the presence of litter is pervasive and ubiquitous. In some form or another, it can be found in every sphere and surface of the planet, often far removed from where it originated. Dispersal mechanisms of litter in aquatic environments are well known, where capacity for long-distance travel is dependent on factors such as weight and buoyancy of the litter as well as force of flow (Fazey and Ryan, 2016; Liro *et al.*, 2020; Tramoy *et al.*, 2020; van Sebille *et al.*, 2020; Weideman, Perold and Ryan, 2020; Delorme *et al.*, 2021; Garello *et al.*, 2021; Maclean *et al.*, 2021; Ryan and Perold, 2021). Little is known on the physical processes that dictate rate and quantity of litter transport through land-based environments to the aquatic sphere (Lechthaler *et al.*, 2020; Roebroek *et al.*, 2021; Cowger *et al.*, 2022).

2.5. Known impacts of litter

One may assume that the main repercussion of litter is that it is unsightly, but it is in fact the visual representation of environmental and social degradation with complex impacts (Keep Britain Tidy, 2013; Parker, Roper and Medway, 2015). Litter cleansing and secondary effects are costly drainers to public budgets (Sherrington, Darrah and Hann, 2014) and the presence of litter is known to have a positive effect to further accumulation (Finnie, 1973; Powers, Osborne and Anderson, 1973; Crump, Nunes and Crossman, 1977; Krauss, Freedman and Whitcup, 1978). Litter can cause injury to both animals and humans, and it has a negative impact on the perception of a community, promoting criminal activity (Braga and Bond, 2008; Keizer, Lindenberg and Steg, 2008). The toxic effects of litter to natural resources such as water are of increasing concern (Slaughter *et al.*, 2011; Wright and Kelly, 2017) and the extent of known risks associated with litter continues to grow.

2.5.1. The cost of litter

It is estimated that 30 million tonnes of litter is collected in the streets of England each year (Keep Britain Tidy, 2013) with annual street cleansing efforts costing taxpayers just under £700 million (DEFRA, 2020). Litter clean-up takes place in city centres as well as along motorways and along transport lines; the cost of chewing gum clean-up is over £200 million and keeping Network Rail clear of litter is estimated at over £2 million (Keep Britain Tidy, 2017). These figures include only direct costs of litter clean-up, including manual litter picking in streets, parks and other public areas (Keep Britain Tidy, 2013). Secondary costs of litter vary greatly based on their impact, for example, the £2 million associated with litter collection on Network Rail property does not include the additional £500,000 in costs regarding delays and associated damage (Sherrington, Darrah and Hann, 2014).

Other secondary costs include the devaluation of property in littered areas (approximately £1 billion), care costs due to the impact on mental health (approximately £526 million) as well as the impact of reduced tourism to cities (approximately £702 million - £7.6 billion) and beaches (approximately £521 million - £1.1 billion) that exhibit high instances of litter (Sherrington, Darrah and Hann, 2014).

2.5.2. Litter breeds litter

Early research has found a 2-5 time increase to likelihood of littering in an environment that is already littered (Finnie, 1973; Powers, Osborne and Anderson, 1973; Crump, Nunes and Crossman, 1977; Geller, Witmer and Tuso, 1977; Krauss, Freedman and Whitcup, 1978; Huffman *et al.*, 1995), often implying that the most effective means of reducing litter in an area is to keep it litter free (Reiter and Samuel, 1980; Huffman *et al.*, 1995). One study interviewing children found they admitted they were 27% more likely to litter in areas that were already dirty (Al-Khatib, 2008). Other studies have found that although litter rates are inconsistent throughout an urban setting, there is always a strong correlation between likelihood to litter and presence of litter (Krauss, Freedman and Whitcup, 1978). Interestingly, one study found that a single piece of litter in a clean environment discouraged littering (Geller, Winett and Everett, 1982), however when the amount of litter increased so did littering behaviour (Hansmann and Scholz, 2003). This promotional effect of litter in an environment on littering behaviour is popularly referred to as litter breeds litter.

2.5.3. Influence of litter on anti-social behaviour

Litter is often considered the first sign of social decay (Keep Britain Tidy, 2013) and its presence has a negative impact on the perception of a community (Parker, Roper and Medway, 2015). The behavioural insight that Wilson and Kelling gained from their work titled *Broken Windows* (1982) made headlines when employed by New York City Mayor Rudy Giuliani in combating crime (Walker, 1984; Dixon, 1998). By increasing the visibility of the police, the perception of safety increased, resulting in a 50% reduction in felony crime as well as a 66% drop in murders from 1990-1997 (Dixon, 1998).

The original *Broken Windows* study examined the effect of increased foot patrol in high crime areas of New Jersey and led to the discovery that in terms of safety, perception is equally if not more valuable, than fact (Wilson and Kelling, 1982). As the namesake implies, the study began from an observation that once a single window was broken in a building, all the windows in that building would soon be broken (Wilson and Kelling, 1982). The implication was that by not repairing the initial broken window, and as it posed no extra cost or consequence, further vandalism was considered acceptable. This observation led to the theory that, if an area is perceived to be cared for, it will ultimately be cared for.

The dissolution of socially acceptable behaviour towards uncared for items is referred to as untended behaviour (Wilson and Kelling, 1982). In a study crafted to observe this behaviour, Wilson and Kelling placed two abandoned cars, without licence plates, in New York and California. Within a few hours, the New York car had begun to be dismantled, experiencing random destruction from people of all demographics (Wilson and Kelling, 1982). The car in California remained untouched for a week, until the authors intervened and damaged the car with a sledgehammer (Wilson and Kelling, 1982). Within the hour, destruction on the California car ensued, ultimately seeing the car turned over by the end of the day (Wilson and Kelling, 1982). Again, the representation of being untended acted as a catalyst for the breakdown of socially acceptable behaviour, where typically law-abiding citizens were observed to engage in the vandalism (Wilson and Kelling, 1982).

Developing further on this theory, Keizer et al (2008) questioned whether this applied to other socially unacceptable behaviour; mainly littering and graffiti. The study found that the act of observing criminal activity caused the amount of litter and graffiti in a site to double (Keizer, Lindenberg and Steg, 2008). Inversely, Braga and Bond (2008) tested whether the opposite could be true, if the presence of litter had a positive effect on criminal activity. The study in Massachusetts found a 19.8% drop in crime within areas that had recently been cleaned of litter (Braga and Bond, 2008). Crime induced by litter has an associated cost due to legal and incarceration fees as well as an increase in home and car insurance. Based on the studies in Massachusetts it is estimated that 4.6% of crime in England is directly attributed to the presence of litter, thus accounting for about £3.48 billion annually (Sherrington, Darrah and Hann, 2014). Ultimately, research shows that litter is a catalyst to the unravelling of social norms and cooperative behaviour, promoting crime and anti-social tendencies.

2.5.4. Litter related injuries and threat to health

Injuries caused by littered glass are a threat at beaches and children's playgrounds, and are prevalent in both developing and developed countries (Armstrong and Molyneux, 1992; Al-Khatib, 2008; Campbell, de Heer and Kinslow, 2014). A British study at the Royal Liverpool Children's Hospital found that 5% of all injuries within a 5-month window stemmed from broken glass, 45% of which occurred either in the street or in play areas, and most frequently included broken bottles (Armstrong and Molyneux, 1992). Similar studies in Pennsylvania, USA have also found a high number of child injuries caused by littered glass in public areas (Baker, Selbst and Lanuti, 1990). Surveys of children aged 5 or older in Palestine's Nablus district, found that 58.3% reported serious injuries related to litter (Al-Khatib, 2008). In England, road traffic accidents caused by litter in motorways are estimated to cause between £7.8 million and £51 million in damages, and about £8 million in car and bike tyre punctures (Sherrington, Darrah and Hann, 2014). Water that collects in or on litter items are breeding grounds for mosquitos and lend to the proliferation of mosquito transmitted viruses such as malaria (Njeru, 2006) and zika (Chan *et al.*, 2016).

Humans are not the only victims, injuries are common among both domestic and wild animals. In a survey, 95% of veterinarians reported having to treat an animal due to an injury resulting from interaction with litter, and the RSPCA receives over 7,000 calls about animal injures a year due to litter (RSPCA, 2022). Additionally, the impact of litter on marine wildlife has been discussed (section 2.5.6. Litter and marine life, page 53).

A portion of microplastics in the environment are generated from litter (Barnes *et al.*, 2009; da Costa *et al.*, 2016; Jiang *et al.*, 2020; Cai *et al.*, 2021; Huang *et al.*, 2021; Mitrano, Wick and Nowack, 2021; Zhang and Xu, 2022). Plastics are ingested by humans through inhalation, skin contact and food and beverage consumption (Wright and Kelly, 2017; Fournier *et al.*, 2021). Microplastics have been found in human stool (Schwabl *et al.*, 2019) and fragments as large as 0.05mm are known to cross from ingestion pathways into the bloodstream (Thompson *et al.*, 2009; Yee *et al.*, 2021; Leslie *et al.*, 2022; Zaki and Aris, 2022; Zhang and Xu, 2022). Due to their hydrophobic surfaces, plastics promote harmful microbial pathogen communities (Rodrigues *et al.*, 2019; Amaral-Zettler, Zettler and Mincer, 2020; Fournier *et al.*, 2021). These loads are transferred to humans when ingested, and pose a threat to life that is of increasing concern (Vethaak and Leslie, 2016; Wright and Kelly, 2017; Barboza *et al.*, 2018; Waring, Harris and Mitchell, 2018; European Union, 2019; Jiang *et al.*, 2020; Mohamed Nor *et al.*, 2021; Yee *et al.*, 2021).

2.5.5. Impact of litter to water quality

Marine water samples taken in 2004 exhibit high amount of microplastics (diameter < 5mm), up to 6 times more plastic than plankton (European Commission, 2016). Plastic surfaces act as collectors of heavy metals and toxic chemicals, accumulating loads from substances they interact with (Wright and Kelly, 2017), which are easily dispersed after entering an aquatic environment. Organic waste found in water, such as paper, food and faeces, promote contamination through bacterial cultures (Casadio *et al.*, 2010; Phillips *et al.*, 2012; Rangel-Buitragoa *et al.*, 2020) and reduce oxygen levels during decomposition (Faris and Hart, 1994).

2.5.5.1. Cigarette ends and water contamination

Cigarettes have been suggested to be the most commonly littered items in the world, accounting for up to 40% of litter in the US (Curtis *et al.*, 2014; Keep America Beautiful, 2021) and 66% of litter in England (DEFRA, 2020). It is estimated that 4.5 trillion used cigarette ends are littered every year (Novotny and Zhao, 1999; Torkashvand *et al.*, 2021) and in British beach surveys the MCS found 43 cigarette ends on every 100 metres of beach (Marine Conservation Society, 2019).

The cigarette end, including both a filter and a small amount of tobacco, are packed with chemicals that they filter from the rest of the burning cigarette (Novotny and Zhao, 1999; Green, Putschew and Nehls, 2014; Lima *et al.*, 2021; Torkashvand *et al.*, 2021). Developed as a marketing tool to frame cigarettes as safe (Pollay and Dewhirst, 2002; Novotny *et al.*, 2009; Curtis *et al.*, 2014), filters are made of cellulose acetate and like all plastics do not biodegrade in the environment, simply fragmenting into smaller more easily consumed pieces (Novotny and Zhao, 1999; Curtis *et al.*, 2014; Bonanomi *et al.*, 2020; Belzagui *et al.*, 2021; Torkashvand *et al.*, 2021). In reality, the use of filters on cigarettes has no known reductions to health risks associated with smoking (US Department of Health and Human Services, 2014; Curtis *et al.*, 2017; Hoek *et al.*, 2020).

Figure 2.1 Cigarette ends accumulating in a puddle on New Street, Birmingham. Smoked cigarette ends contain over 4000 chemicals that quickly leach into water, contaminating supplies. Photo credit: Randa L. Kachef, 2016.

These smoked filters include significant amounts of alkaloids, nicotine, and a variety of 4000 other chemicals, 50 of which are known to have carcinogenic properties (Slaughter *et al.*, 2011; Bonanomi *et al.*, 2020; Lima *et al.*, 2021). Not only are cigarette ends ingested by wildlife and fish (Faris and Hart, 1994; Cooper *et al.*, 2004; Santos *et al.*, 2005; Slaughter *et al.*, 2011), but the chemicals in a cigarette end take only an hour to leach into water (Figure 2.1), exposing fish species and invertebrates to toxic chemicals (Moriwaki, Kitajima and Katahira, 2009; Slaughter *et al.*, 2011; Green, Putschew and Nehls, 2014; Booth, Gribben and Parkinson, 2015). Research on the detrimental effects of cigarette end leachate in aquatic environments is ongoing, with many results highlighting the extreme threat it poses to humans, animals and the environment, particularly as it enters public drinking water reserves (Green, Putschew and Nehls, 2014; Rebischung *et al.*, 2018; Belzagui *et al.*, 2021; Green, Tongue and Boots, 2021; Lima *et al.*, 2021; Santos-Echeandía *et al.*, 2021; Torkashvand *et al.*, 2021).

2.5.6. Litter and marine life

Sewage and litter that enter aquatic environments block sunlight and as organic items decompose, they deplete oxygen and cause marine life to suffocate (Faris and Hart, 1994; Storrier and McGlashan, 2006). Fish and aquatic birds often become entangled in litter, which can cause death through restricted mobility (Lambert, Sinclair and Boxall, 2014; Ryan, 2018; van Emmerik and Schwarz, 2020) Litter is frequently mistaken for food, where larger persistent items remain in digestive tracts causing starvation (Faris and Hart, 1994; Storrier and McGlashan, 2006; Cressey, 2016; Markic *et al.*, 2020) and act as vessels of concentrated toxicity (Lebreton and Andrady, 2019). A third of the fish consumed in Britain (i.e., cod, haddock and mackerel) caught in the English Channel have plastics in their system (Lusher, Mchugh and Thompson, 2013) causing a real threat to human health through the food chain (Wright and Kelly, 2017; Waring, Harris and Mitchell, 2018; Cox *et al.*, 2019; Lebreton and Andrady, 2019; Schwabl *et al.*, 2019; Mitrano, Wick and Nowack, 2021).

Persistent buoyant litter is colonised by larvae and barnacles and transported by the tides across the globe, leading to the proliferation of invasive species (Barnes *et al.*, 2009; Thushari and Senevirathna, 2020).

2.5.7. Comments on impacts of litter

The impact of litter is not only widespread, but presents long-term and grave threats to the economy, environment and human health. Unlike unseen contaminants such as those in water and air, litter items can be easily identified and removed before the full gravity of their impact can be achieved. Despite this, litter is rarely considered when addressing global issues and the topic continues to be undervalued.

2.6. Who litters?

One could argue that global population growth is responsible for the increase in litter (Rathje, 1996; Schultz, 2002; Nelms *et al.*, 2020), yet as public awareness of the repercussions of litter have also risen considerably (Schultz *et al.*, 2009) there appears to be a disconnect between litter awareness and litter behaviour. This disconnect can be observed in England, where self-reporting survey research found 20% of respondents admitted to littering (DEFRA, 2018b), but it is predicted that to achieve current accumulation rates, up to 63% of the population must litter (Keep Britain Tidy, 2013).

Although littering can be attributed to include blatant disregard, laziness and inebriation, it is frequently justified by blaming infrastructure failures such as lack of or full bins (Williams, Curnow and Streker, 1997; Beck, 2001; Campbell, 2007; Khawaja and Shah, 2013). Often, in settings such as cinemas, sports stadiums and other privately owned but publicly used spaces, littering is justified as there are systems dedicated to removing it (Baltes and Hayward, 1976; Beck, 2001; Arafat *et* *al.*, 2007; Campbell, 2007) Equally, littering dirty or smelly items, such as cigarette ends and food, is deemed acceptable due to the inconvenience they pose in carrying them long distances (Campbell, 2007; Al-Khatib, 2008; NSW EPA, 2013; Schultz *et al.*, 2013).

It is widely agreed that littering habits of an individual are determined by social norms and the presence of realistic penalties (Heberlein, 1972; Schultz, 2002; Hansmann and Scholz, 2003; Liu and Sibley, 2004; Arafat *et al.*, 2007; Campbell, 2007; Al-Khatib, 2008; Roper and Parker, 2008; Torgler, García-Valiñas and Macintyre, 2008; Luan Ong and Sovacool, 2012; Keizer and Schultz, 2018; Yew, 2020). As a result, to develop targeted anti-littering campaigns, many studies have attempted to profile those who litter (Bator, Bryan and Wesley Schultz, 2011). Studies have been conducted in the Middle East, Australia, South America, and North America, all with varied results.

2.6.1. Influence of gender on littering habits

Likelihood of littering based on gender has been recorded via both survey and observational analysis methods. Results are mixed, where some have found men are more likely to litter than women (Seed, 1970; Clark, Burgess and Hendee, 1972; Krauss, Freedman and Whitcup, 1978; Durdan, Reeder and Hecht, 1985; Al-Khatib *et al.*, 2009; Keep America Beautiful, 2009; Schultz *et al.*, 2013; Keep Britain Tidy, 2015) and others concluding there is no evidence that either gender has a higher tendency to litter than the other (Finnie, 1973; Williams, Curnow and Streker, 1997; Beck, 2001; Liu and Sibley, 2004; Rhodes, 2008; Schultz *et al.*, 2009; Al-mosa, Parkinson and Rundle-Thiele, 2017).

2.6.2. Influence of age on littering behaviour

The influence of age has also been recorded in littering surveys and observational studies. The results are varied and inconsistent. Some studies identify under 18s as having the highest littering rates (Seed, 1970; Heberlein, 1972; Finnie, 1973; Krauss, Freedman and Whitcup, 1978; Bator, Bryan and Wesley Schultz, 2011), others point the finger at the 18-30 demographic (Beck, 2001; Keep America Beautiful, 2009, 2016; Schultz *et al.*, 2009; Al-mosa, Parkinson and Rundle-Thiele, 2017) and some a threefold increase in littering to the 35-49 age group (Clark, Burgess and Hendee, 1972; Durdan, Reeder and Hecht, 1985). One Middle Eastern study found both the 12-14 year old and over 50 demographic were the most likely to litter (Arafat *et al.*, 2007) whilst the exact opposite was observed in an Australian study (Beck, 2001). Other studies have found no correlation between age and likelihood to litter (Williams, Curnow and Streker, 1997; Liu and Sibley, 2004; Rhodes, 2008).

2.6.3. Influence of socio-economic status and education on littering

Empirical data available on correlations between likelihood to litter and socio-economic status or education are either self-reported or assumed based on census-track data (Santos *et al.*, 2005; Rhodes, 2008; Al-Khatib *et al.*, 2009), as it is impossible to quantify these attributes through observation.

Self-reported studies in the Middle East found conflicting correlations between demographics and likelihood to litter, where 50% of those with lower education were *less* likely to litter, yet 50% of the those with lower socio-economic status were *more* likely to litter (Arafat *et al.*, 2007). Similar survey based studies in Australia report higher instances of littering among both the uneducated and unemployed (Beck, 2001)

Using census information in Brazil, it was found that beaches located in areas of lower education and income saw 1.6 more items littered per person than in popular beaches frequented by international tourists (Santos *et al.*, 2005; Watkins and ten Brink, 2017). In the USA, Rhodes compared neighbourhood litter surveys to census data, finding a correlation of -0.772 between number of observed litter items and levels of education and income (Rhodes, 2008). In England, annual *Litter Composition Analysis* reports by the Department for Environment, Food & Rural Affairs (DEFRA) found a threefold increase of levels of litter in deprived areas (DEFRA, 2020). The results in Brazil, USA and England could be the result of a higher likelihood to litter based on socioeconomic status or could just as well be the result of less cleansing resources dedicated to low-income areas.

As was noted in the *Broken Windows* study (section 2.5.3, page 47), citizens of all socio-economic statuses were observed vandalising the planted cars (Wilson and Kelling, 1982), which sets an argument against the influence of these factors in likelihood to litter.

Popular author David Sedaris made headlines in January of 2015 when he appeared on the Westminster Communities and Local Government panel to talk about his experience picking up litter in his home district of Horsham, West Sussex (Vidal, 2015; Young, 2015; 'Communities and Local Government Committee', 2015). Sedaris reports that he spends between 3- 8 hours a day collecting litter in the area. Although he rarely sees people littering, his intimate knowledge of the items littered paint a distinct profile of offenders. Sedaris says that the price point is noticeably low on littered items, where crisps packets, fast food, Mayfair cigarettes and Tesco bags dominate his collections, and nut packets or items from the nearby Waitrose are never found during his collection. When asked if he thought litter was a class issue, Sedaris proclaimed "well I'm not finding Opera tickets on the side of the road" ('Communities and Local Government Committee', 2015).

2.6.4. Influence of group size on littering behaviour

It was originally hypothesised that large groups would reduce an individual's likelihood of littering, however studies have found that the opposite is in fact true (Durdan, Reeder and Hecht, 1985; Wever, Gutter and Silvester, 2006; Al-mosa, Parkinson and Rundle-Thiele, 2017). In a 1985 study littering rates were observed by groups, finding groups of one or two to litter 40.7% of the time, groups of 3-5 exhibited a littering rate of 51.8%, and groups larger than 5 had a littering rate of 82.9% (Durdan, Reeder and Hecht, 1985). This is further supported with a recent study in London, where larger groups were also found to have higher littering rates (Keep Britain Tidy, 2015). These studies should however be evaluated with caution as large groups aren't frequently observed, and the sheer number of individual litterers outweighs the amount of litter deposited by large groups.

This phenomenon is thought to be attributed to the theory of *social loafing* (Fleishman, 1988; Schultz, 2002). Studies on *social loafing* hypothesise that as individuals enter a large group, the tendency towards pro-social and cooperative behaviour diminishes (Latané, Williams and Harkins, 1979). The logic is that in a group the outcome would not benefit the individual directly, therefore they are less concerned than if the task were attempted singlehandedly, where the glory of success can be solely enjoyed (Price, 1987; Karau and Williams, 1993; Williams, Karau and Bourgeois, 1993). Ultimately the mentality is one of equal distribution of responsibility, diluting the individuals need to be responsible (Latané, Williams and Harkins, 1979; Latané, 1981; Price, 1987; Karau and Williams, 1993, 1993; Williams, Karau and Bourgeois, 1993).

2.6.5. Are tourists more likely to litter?

Some studies have focused on comparing littering rates between locals and tourists. The reasoning here is that a sense of community is meant to reduce ones likelihood to litter (Grasmick, Bursik and Kinsey, 1991), and that a lack of knowledge about binning convention among tourists can be attributed to a higher rate of littering (Arafat *et al.*, 2007; Brown, Ham and Hughes, 2010).

Again, studies range in conclusions, where tourists are sometimes found to be the largest offenders (Gramann and Vander Step, 1987; Santos *et al.*, 2005; Brown, Ham and Hughes, 2010; Keep Britain Tidy, 2015; Watkins and ten Brink, 2017) to locals being identified as the perpetrators (McCool, 1995; Shiong *et al.*, 2020). Some studies highlight tourists as those most concerned with combatting litter in areas of beauty (Adam, 2021) and other studies have found no difference in rates of littering between tourists and residents (Campbell, de Heer and Kinslow, 2014).

Many times when tourists litter, it is due to lack of knowledge and is not done in an intentionally destructive way (Gramann and Vander Step, 1987). Providing tourist with information and education has a substantial effect on not only reducing littering rates but encouraging litter picking (Brown, Ham and Hughes, 2010). One of the anti-littering awareness tactics of Singapore is to post information about the fines attributed to littering in highly visible areas around the airport, predominantly when disembarking aeroplanes.

2.6.6. Regional and cultural influences on littering behaviour

Many regional studies on litter have taken place, primarily in the United States, the United Kingdom, Australia and the Middle East (Seed, 1970; Schultz, 2002; Arafat *et al.*, 2007; Campbell, 2007; Al-Khatib *et al.*, 2009; Keep America Beautiful, 2009; Khawaja and Shah, 2013; Reeve *et al.*, 2013; NSW EPA, 2016). None of these studies have resulted in consistent observations regarding demographics, behaviour and instances of littering between regions, highlighting that anti-littering approaches require a regional approach.

Globally, two examples are often referred to when researching cultural differences in littering behaviour; these are of Japan and Singapore. In the case of Japan, it is social norms and the fear of standing out that prohibit residents from littering, a mind-set that is instilled in early education, whereas in Singapore it is strict fines, public shaming and bodily harm that keep the streets clean (Luan Ong and Sovacool, 2012). These two examples illustrate two successful yet unattainable solutions to litter, specifically when attempting to mitigate the issue in England. Considering the amount of tourism, immigration and emigration from and to England, it is unrealistic to assume that early education could be effective, simply because the population will have had a varied past.

2.6.7. Comments on profiling litterers

If the data presented in this section have left the reader confused, it is because the results are confusing. Fundamental values of a person are dictated by social norms, where their attitude to environmental preservation are ingrained in their culture (and will be discussed in section 2.8.2 Social and cultural influences on behaviour, page 65) (Schultz, 2002; Liu and Sibley, 2004; Roper and Parker, 2008; Luan Ong and Sovacool, 2012; Havlíček and Morcinek, 2016). As the examples mentioned have all come from different locations, there is no single profile of 'most likely to litter' that can be universally applied. Unfortunately, when developing targeted anti-littering campaigns, variations in culture and geography are rarely considered, and results of littering profile studies are typically considered universal. As the research illustrates, understanding behaviour associated with litter is not a straightforward solution, and assumptions that are made in some parts of the world cannot be applied in others. Ultimately, most test sites have a unique littering profile, and each should be approached with a tailored campaign by first understanding those that patronise the site.

2.7. Litter legislation

The issue of litter is governed locally, with varying degrees of penalties associated with the act. For example, penalties in the US are dictated by state, where fines range from $25 to $30,000 USD and imprisonment can at times be enforced with sentences equalling anywhere from a week to 6 years (National Conference of State Legislatures, 2022). Due to Singapore's strict laws on littering, fines up to $5000

Singaporean Dollars can be issued, in conjunction with community service engineered to invoke public shame (Luan Ong and Sovacool, 2012). In England, the fine for littering is $150 and is rarely issued; with 56% of councils reporting less than one citation a week and 16% choosing not to enforce the law at all (Carrington, 2020).

2.7.1. Litter and the Precautionary Principle

Many litter items such as cigarette ends, medical waste and those containing even trace amounts of plastics are deemed among scientific communities as toxic and considered a hazard to both the environment and human health (Novotny and Zhao, 1999; Novotny *et al.*, 2009; Kawecki and Nowack, 2019; Foschi, D'Addato and Bonoli, 2021). According to the European Commission, when enough doubt has been cast as to the safety of a substance, the Precautionary Principle (PP) can be invoked, calling for a thorough risk assessment to make informed decisions on mitigative action (Haigh, 1994; European Union, 2019). Yet, according to the Research, Evaluation, Authorisation and Restriction of Chemicals (REACH) framework, the European Chemicals Agency (ECHA) classifies plastic based debris as low environmental concern (European Chemicals Agency, 2012; Lambert, Sinclair and Boxall, 2014). As a result, litter continues to prevail unhindered, particularly highly toxic items such as cigarettes and plastics.

2.7.2. The Polluter Pays Principle and litter

The Polluter Pays Principle (PPP) is yet another legislation designed to protect the environment and human health, by placing financial responsibility on the entities that generate pollution (Sykes, 1994; London School of Economics, 2018; Royal

Geographical Society, 2021). Yet, vague definitions of pollution and issues of identifying sources of pollution present obstacles in enforcement (Bleeker, 2009), particularly in the context of litter. Attempts at seeking high level litter reduction legislations have proposed the enforcement of the PPP towards producers of packaging (Pearce and Turner, 1992) and tobacco waste (Curtis *et al.*, 2014).

2.7.3. Packaging and packaging waste directives

Applying PPP to packaging has led the EU to adopt Extended Producer Responsibility (EPR) approach to mitigation (Cahill, Grimes and Wilson, 2011). The EPR shifts culpability away from the end user and towards producers, encouraging them to consider end of life of packaging materials (Iacovidou and Gerassimidou, 2018). As drink and food packaging account for large proportions of litter surveys in England (DEFRA, 2020), in 2019 DEFRA signalled intent to amend the UK Environment Bill to include the Extended Producer Responsibility for Packaging (EPRP), a legislation that would place the financial burden of litter collection on waste producers (DEFRA, 2021c). The legislation is currently under consultation and is expected to be enacted in 2023 (DEFRA, 2021b).

2.8. Behaviour theory

As legislation has yet to establish a long-term solution to reducing litter, academics have engaged in research on litter mitigation initiatives. Littering behaviour has been the focus of many studies and reduction through behaviour change and nudging has been proposed. Here I will outline the current understanding of risk perception, disposal culture, behaviour change theory and ‘nudging’.

2.8.1. Risk perception

Litter is not widely perceived as a risk to the individual, and as a result there is little motivation among the public to ensure that they do not litter. Having established that litter is among one of the most noticeable forms of social and environmental degradation, it is surprising that unlike invisible risks such as technology and air pollution, litter is often overlooked when discussing emerging threats.

It is theorised that past experiences dictate an individual’s risk perception which could ultimately influence their attitude towards littering. Embedded deep in the subconscious is a capacity for fast emotional thinking when weighing up the risks and benefits of an action (Kahnemen, 2011). This unique set of values, otherwise known as heuristics and biases (Tversky and Kahneman, 1973) are often not representative of actual risk (Slovic, 1987, 2000). Often, the perception of a risk is underestimated when ease and comfort are the benefits of engaging in that risk (Slovic, 2000). In terms of littering, far too often the discomfort of having to carry waste until a bin can be found results in a personal cost-benefit analysis where the outcome is that the individual chooses to litter (Campbell, 2007; Torgler, García-Valiñas and Macintyre, 2008; Khawaja and Shah, 2013; Castaldi, Cecere and Zoli, 2021).

The risks we face every day have evolved greatly and continue to do so (Beck, 1992). In the past, certain threats to society and the environment, such as obesity and carbon emissions, were not apparent but are now at the forefront of the risks people face every day. As a result, real risks go unnoticed as they are not at the forefront of laypeople’s thinking, and those individuals unknowingly engage in big picture risky behaviour because of a lack of knowledge of adverse effects (Slovic, Fischhoff and Lichtenstein, 1981; Kahan *et al.*, 2012).

The work of Paul Slovic has found that perception of risks is predictable, consistent among members of a particular group and that the term ‘risk’ means different things to different people (Slovic, 2000). In his book, *The Perception of Risk*, Slovic led an international study comparing the discrepancy between risk perceptions. He found that Hungarians perceived higher risk among common hazards such as home appliances and mushroom hunting, in comparison to the technological and chemical risks that dominated the fears of Americans (Slovic, 2000). These findings underline how societal factors shape individual perception (Slovic, Fischhoff and Lichtenstein, 1981)

The irony of environmental degradation is that humans are not only the primary driver, but also victims of the risk it poses (Dawson, 2021). By internalising the repercussions of littering in a way that can be felt, (e.g., social defamation, legal action, monetary loss (Khawaja and Shah, 2013), public health risk (Joshi, 2022)) a shift in perception of littering can accurately represent the impact is has to the individual. In turn, when faced with a situation where littering would be the simplest solution, the cost-benefit dialogue could switch to one that avoids littering, resulting in effective long-term mitigation.

2.8.2. Social and cultural influences on behaviour

Studies on the differences in perception between groups of people lead to evidence that values of an individual are dictated by local culture (Slovic, Fischhoff and Lichtenstein, 1981; Slovic, 2000; Schultz, 2002; Beck, 1992). In the context of litter, this can explain an individual's acceptance or intolerance of the act of littering, with the assumption that their fundamental beliefs are what drives that perception (Schultz, 2002; Liu and Sibley, 2004; Havlíček and Morcinek, 2016; Yew, 2020).

Mary Douglas was the first to propose Cultural Theory, to understand and explain variances between the values of people from different cultures (Douglas, 2013). Douglas sought to understand cultural differences in remote tribes, specifically in their rituals and consumption habits; and in doing so she established a theoretical framework believed to be universally applicable (Mamadouh, 1999; Douglas, 2007). Within a few years, Cultural Theory generated international debate amongst peers as others begin studying and publishing their works either in support or critique of the theory (Boholm, 1996).

Simply put, Cultural Theory is the study of individual risk perception based on the relationships between entities within a society and how those individuals perceive the environment (Douglas, 2013). It is measured in a Grid Group, which assume the following theoretical groups exist in all societies: Egalitarians, hierarchists, fatalists, individualists and although not officially accepted in the theory, those who are autonomous or often referred to as hermits (Douglas, 2007; Thompson, Ellis and Wildavsky, 2018). It is believed that each theoretical group and their way of life define their perception of acceptance of risk (Boholm, 1996). It is suggested that grid-group analysts can predict attitudes and behaviours towards any topic using information based on that person's ideal type (Mamadouh, 1999; Oltedal *et al.*, 2004).

Although some have discredited Cultural Theory, effectively debating against the assumption that all within a society fit within four box grid (Boholm, 1996); much research into the theory does lay the foundational understanding that the values that dictate perception and behaviour of the individual are influenced by cultural factors and surroundings (Slovic, Fischhoff and Lichtenstein, 1981; Sniehotta, 2009).

2.8.3. Behaviour change theory

Studies have attempted to use classic methods of both intentional and unintentional behaviour change to reduce litter in a variety of settings (discussed in upcoming section 2.9 Reducing litter through applied behaviour theory, page 68). Even now in England many current campaigns tailored to reduce littering and promote litter clean up are underway, however results are varied (Wever *et al.*, 2010), and it is apparent more research is needed to effectively tackle the issue.

Although it is sound to assume that fundamental behavioural traits are rooted in experience and local cultural values, the average intelligent person has the capacity for intentional behavioural change (Fishbein and Ajzen, 1977; Ajzen, 1991; Sniehotta, 2009). According to the Theory of Planned Behaviour, behaviour change is underpinned by intention and a perceived behaviour control, where level of intent dictates the result of the change (Ajzen, 1991; Sniehotta, 2009). This foundational research on planned behaviour has fuelled many studies on cognition models and has simultaneously garnered much criticism (Greve, 2001; Hardeman *et al.*, 2002; Ogden, 2003; Noar and Zimmerman, 2005). However, it is agreed that intent coupled with knowledge is necessary for long term behavioural change (Sheeran, 2002; Sniehotta, 2009). In the application of the theory, a knowledge of sources of behaviour (social, physical and psychological attributes) is required, insight that can only come from an understanding of littering offenders. In section 2.6 Who litters? I discussed the issues in identifying sources of behaviour, particularly that attempts to profile the litterer have been unsuccessful (Williams, Curnow and Streker, 1997).

2.8.4. Popularity of nudging

Nudging is a form of external influence tailored to result in unintentional and automatic behavioural change. This approach was first introduced to the public by Richard Thaler and Cass Sunstein in their 2008 book Nudge – Improving Decisions about Health, Wealth and Happiness. The concept that you can influence an individual to make the correct decision through gentle nudges (Thaler and Sunstein, 2008) has inspired many, including former UK Prime Ministers Tony Blair and David Cameron, who have employed nudge methods alongside Dr David Halpern, now CEO of the Behavioural Insights Team (Nester, 2014; Halpern, 2015). Although many nudge tactics have proven to be successful (Hansen and Jespersen, 2013), it is important to remember that the base of a good nudge is informed through research and statistics, and not simply a fun intervention (Halpern, 2015). Finally, much debate has drawn attention to the ability to use nudges for unethical reasons, and as a result a variety of frameworks have been proposed to ensure responsible nudge interventions by policy makers (Hansen and Jespersen, 2013).

2.9. Reducing litter through applied behaviour theory

Early research in litter reduction focused primarily on encouraging the clean-up of pre-existing litter. Though these studies have proved ineffective in long-term behaviour change, they have inspired further research in appropriate messaging, as well as the use of sanctions and the effects of watching eyes on promoting pro-social behaviour.

2.9.1. Providing incentives to clean litter

Litter research began in the early 1970’s with studies focused on encouraging others to collect already littered items. These early studies boasted that the use of rewards resulted in up to a 500% increase in litter pick up (Clark, Hendee and Burgess, 1972). The first to conduct such experiments were Burgess, Clark and Hendee in their 1971 study, An Experimental Analysis of Anti-Litter Procedures*.* The study tested the effectiveness of a variety of different pro-binning techniques on children during theatre screenings. The variables included a) to double the number of bins in the theatre b) to show an anti-littering film by Disney titled *Litterbug* c) to provide film goers with a litter bag with verbal instruction to use for litter d) to provide film goers with a litter bag complete with written instructions to use the bag for litter e) to provide film goers with a litter bag as well as a 10 cent (USD) incentive to return the bag full of litter f) to provide film goers with a litter bag and announce before the screening that a special movie ticket would be given for each bag of litter returned (Burgess, Clark and Hendee, 1971). The study revealed only a small increase in proper binning in variables a) b) c) and d) methods that did not provide rewards. The rewarding incentives, 10 cents or a free movie ticket, proved to be successful as 94%-95% of the litter in the theatre was returned in a bag (Burgess, Clark and Hendee, 1971).

To test the cost effectiveness of incentives and rewards, in 1977 a similar study was conducted in an amusement park, where the cost of providing incentives was compared to that of employing a litter cleansing team (Casey and Lloyd, 1977). The study found that not only was providing incentives to children more effective in litter clean up, it was two and a half times less expensive than employing maintenance staff (Casey and Lloyd, 1977).

Many more studies have further tested the effectiveness of rewards, where rewards are granted to promote picking (Clark, Hendee and Burgess, 1972; Powers, Osborne and Anderson, 1973; Chapman and Risley, 1974; LaHart and Bailey, 1975; Krauss, Freedman and Whitcup, 1978), as well as rewards for binning waste (Kohlenberg and Phillips, 1973). All studies concerning rewards conclude with positive results in eliminating litter from the environment.

It is apparent that the use of rewards is one that is effective, however the matter of the sustainability of this approach is questionable. Incentives require both the set up and reward of the activity, bearing an incremental cost over voluntary action, and more often than not, the positive actions stop when the incentives are exhausted (De Kort, McCalley and Midden, 2008). As the objective of rewards is to pick up already littered items, there are no indications that rewards influence long-term change in reducing littering behaviour. Although clean-up is important, tackling the issue at its source, ensuring that waste is properly disposed of, is a crucial factor in mitigating the issue (Milman, 2016).

2.9.2. Influencing behaviour with tailored messaging

Carefully crafted messages have been researched to identify effective ways to influence behaviour (Cialdini, 2003). Direct cues or instructions on how and where to dispose of litter have been found to be most effective in mitigating littering, over general “please don’t litter” messages (Geller, Witmer and Tuso, 1977; Durdan, Reeder and Hecht, 1985; Liu and Sibley, 2004; Brown, Ham and Hughes, 2010).

A study conducted in a grocery store found that flyers which encouraged smarter buying and disposal behaviour, increased recycling bottle returns by 25% (Geller, Farris and Post, 1973). The study noted the increase of flyer litter within the store, arguing that the success of the study was attributed more to information on incentives, and less so to promoting better decision making (Geller, Farris and Post, 1973). As a result, a follow up study tested the influence of messages printed on the flyers themselves (Geller, Witmer and Orebaugh, 1976). The instructions increased the likelihood of flyers being recycled and reduced litter by 50% (Geller, Witmer and Tuso, 1977). In the same line of inquiry, to reduce coffee cup littering in a cafeteria, messages were placed on cups highlighting their environmental impact (Wever, Gutter and Silvester, 2006). Although an immediate 4.5% reduction was observed, littering rates returned to, and surpassed, pre-trial rates once the labels were removed (Wever, Van Kuijk and Boks, 2008; Wever *et al.*, 2010).

Placement of messages has proven to have some significance. Research by Durdan et al (1985) found an 18% drop in litter when placing binning instructions directly on tables within a cafeteria (Durdan, Reeder and Hecht, 1985). This study effectively communicated with the public before they began their decision process on how to dispose of the waste they have just generated.

Comparative studies on the effectiveness of tone have explored the success of demanding and threatening messages to those designed to promote a sense of community. For example, Reich and Robertson (1979) compared the success of a threatening messaging, “don’t you dare litter” versus one tailored to community “help keep your pool clean” (Reich and Robertson, 1979). The results suggest that the threatening message had the opposite effect, promoting litter and that the message tailored to invoke a sense of community was slightly successful in reducing litter (Reich and Robertson, 1979). In contradiction, Reiter and Samuel’s (1980) comparison between a threatening message “Litter is Unlawful and Subject to a $10 Fine” and an encouraging one “Pitch In!” (Reiter and Samuel, 1980) found that messaging, regardless of the nature, was influential in reducing the amount of litter, indicating that the simple act of drawing attention to the issue is an effective mitigation strategy.

At times, messages that single out bad behaviour of an individual have a positive effect in promoting overall good behaviour. For example, a community speaking disapprovingly of the one neighbour who didn’t recycle, resulted in a 25% increase in neighbourhood recycling rates (Cialdini, 2003).

It is noted to avoid messaging that implies a particular undesirable behaviour is occurring, as it can acts as a promoter to engage in such behaviour (Durdan, Reeder and Hecht, 1985; Cialdini, 2003). This is exemplified by the theory of psychological reactance which suggests that in the interest of maintaining psychological freedom, some will react to aggressive messaging by doing the opposite of the intended outcome (Durdan, Reeder and Hecht, 1985).

2.9.3. Use of fines and penalties to reduce littering

Much of the early research on anti-littering tactics draws on gentle and rewarding tactics in combating litter issues, ignoring the fact that littering is in fact illegal (Grasmick, Bursik and Kinsey, 1991). Currently in England there is a £150 fine for littering, and it is considered a criminal offence (UK GOV, 1990). The flaw in fines is it requires very close monitoring in order to catch someone in the act of littering, and once littered it is impossible to trace the litter back to the source (Burgess, Clark and Hendee, 1971).

There is little data to support that the threat of fines has a positive effect on reducing littering (Schultz *et al.*, 2009). It is argued that threats of sanctions, although potentially successful in changing immediate behaviour, does not have a lasting effect and is limited to situations where the individual perceives the threat to be imminent (Sansone and Harackiewicz, 2000). The effectiveness of a threat is ultimately determined by whether the individual thinks they will be caught. A ‘can I get away with it’ mentality, where probability of fines or detection seem low, can result in an individual deciding that the risk is worth not having to hold on to litter items (Burgess, Clark and Hendee, 1971; Campbell, 2007; NSW EPA, 2013).

The use of fines as a litter deterrent is exemplified by the city state of Singapore, which enforces strict regulations and fines regarding litter. Public shaming work orders and fines up to $5,000 Singaporean Dollars are common consequences of chewing gum in public (Luan Ong and Sovacool, 2012), and offenders are regularly sentenced to canings for acts of vandalism such as graffiti (Charlton, 2015). Although the city is immaculate, many argue that this enforcement is overly strict and authoritarian (Wever, Gutter and Silvester, 2006; Yew, 2020).

2.9.4. Invoking shame and embarrassment

Research on the use of embarrassment or sanctions has been found to be effective in deterring criminal activity (Grasmick, Bursik and Kinsey, 1991) and in 1991 Grasmick, Bursik and Kinsey set out to see if associating embarrassment with littering could have an effect on behaviour. The seven-year study took place in Oklahoma and conducted baseline interviews on littering perceptions in 1982. Five years later in 1987 antilittering campaigns were implemented state-wide, two years later in 1989 interviews were conducted and compared to the baseline results. The results found that the level of guilt associated with littering rose by 30% and there was a 13% increase in the perception that littering would result in loss of respect from others in the community (Grasmick, Bursik and Kinsey, 1991).

Appealing to a community spirit is a form of shame and embarrassment, it is the threat that your peers will judge you or think differently of you if you engage in a particular behaviour (Grasmick, Bursik and Kinsey, 1991).

In many cases drawing attention to one person's bad behaviour within a community has incredibly positive results in collective behaviour. For example, in recycling campaigns Cialdini measured the effectiveness of ads that depicted neighbours gossiping about the household on the street that did not recycle, concluding in heightened instances of recycling within the community (Cialdini, 2003). More recently in England, the Behavioural Insights Team found that reminding individuals that their neighbours pay their taxes resulted in an increase of £20 million in taxes collected on time (Halpern, 2015).

2.9.5. Reducing litter with watching eyes

The phenomenon of the Watching Eyes Effect is one that has been widely studied. The theory dictates that, as people are more likely to act in socially acceptable ways when they know they are being watched, placing imagery of eyes will have the same effect on promoting pro-social behaviour (Bateson, Nettle D. and Roberts, 2006; Ernest-Jones, Nettle and Bateson, 2011; Keller and Pfattheicher, 2011; Francey and Bergmuller, 2012; Bateson *et al.*, 2013; Pfattheicher and Keller, 2015). This is impactful as it illustrates a perception where anti-social behaviour is acceptable only if there is no one to observe and judge those actions.

In application, some studies have found significance in watchful eyes reducing littering rates (Ernest-Jones et al., 2011), yet others have found no influence (Francey and Bergmuller, 2012; Bateson *et al.*, 2013). In 2015, Bateson et al studied whether placing watchful eyes on the littered items themselves would have any effect on proper binning (Bateson *et al.*, 2015). The study proved successful, reducing littering by two thirds when the item in question displayed an image of watchful and judging eyes (Bateson *et al.*, 2015). This study did find a large portion of the individuals observed kept the flyers on their person, not accounting for the final resting place of the flyer (Bateson *et al.*, 2015).

An extension of the watching effect was to study the effect of messaging that implies an area is being watched on pro-social behaviour. The study focused on bicycle theft, displaying a message of ‘Cycle Thieves, We Are Watching You’*,* and successfully reducing cycle theft by 62% (Nettle, Nott and Bateson, 2012). Ultimately, there is evidence that even gentle, and sometimes fabricated reminders are effective in altering behaviour (Bateson *et al.*, 2015) arguing that simple and unconscious cues are far more effective than complex ones (Francey and Bergmuller, 2012).

Interestingly a middle eastern study found 29.6% of children cited moral or religious beliefs as the primary motivator to not litter (Al-Khatib, 2008). Islam places an emphasis on cleanliness, and it is implied that the cleaning of public spaces is in fact a form of worship (Al-Khatib, 2008), and one could argue that the fear of a higher power witnessing anti-social acts is reminiscent of the concept behind the watching eyes effect.

Watchful eyes are however not a long-term solution, as eventually the effect of threatening cues wear off (Bateson *et al.*, 2015). It is a well-studied that individuals quickly become desensitised to stimuli not essential to survival, such as a repeated loud yet non-threatening noise (Sparks and Barclay, 2013; Dunn, 2017). To this effect,

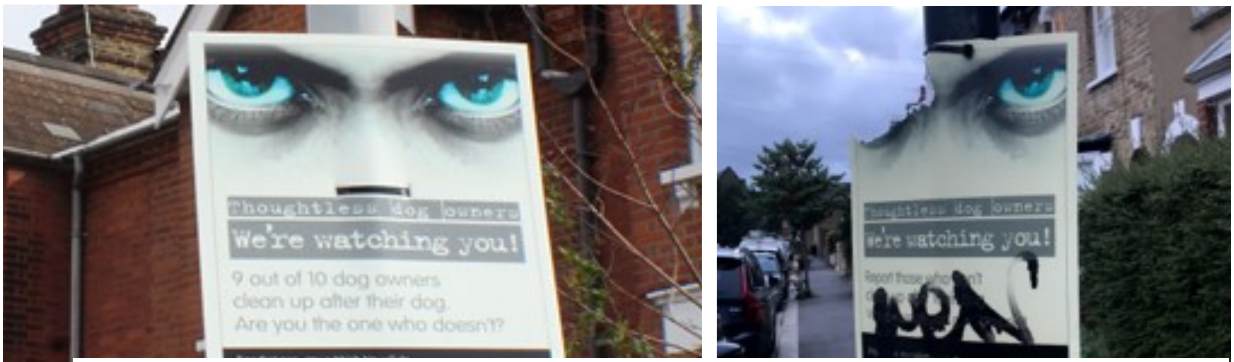

Figure 2.2 Using the image of watching eyes can lead to a decrease in anti-social behaviour. However, with over-exposure, the effects are known to wear off. These photos of a watching eyes campaign in South London illustrates how with time, the signs themselves can be vandalised. Photo credit: Randa L Kachef (2017).

the public is eventually desensitized to the threat of being observed invoked by watchful eyes, an idea that has been verified in the results of a 2013 study which found prolonged exposure to these images resulted in a decrease in effectiveness (Sparks and Barclay, 2013). With desensitization often comes disrespect, as is seen in Figure 2.2 which depicts vandalism of an anti-littering campaign in South London.

2.9.6. Comments on behavioural approaches to tackling litter

Having established that social norms and culture have a large influence on the acceptance of litter and littering behaviours, a focus on behaviour change to mitigate litter has negligible impact on multicultural and diverse publics. Ultimately, the effects of behaviour changing anti-littering campaigns are only known to be effective while present (Scott, 2004; Wever, Van Kuijk and Boks, 2008; Brown, Ham and Hughes, 2010), and the potential for desensitization is ever present.

Knowledge of the repercussions of littering have risen considerably since the 1950’s (Schultz *et al.*, 2009) yet the presence of litter in the environment continues to grow (DEFRA, 2020; Marine Conservation Society, 2021). If the assumption is that knowledge coupled with intent promotes behavioural change, then intent should be targeted, specifically by framing the repercussions of litter as a personal risk to the individual. In the following section, 2.10 Structural approaches to reducing litter, I present an argument to include a third dimension to behaviour change theory and how it pertains to litter. Coupled with knowledge and intent, the availability of means is crucial to reducing littering rates (Almosa, Parkinson and Rundle-Thiele, 2020); as without waste receptacles where can the public dispose of litter?

2.10. Structural approaches to reducing litter

Structural approaches refer to physical changes to spaces and products that have a reducing effect on littering. These include the placement and beautification of bins as well as intelligent packaging design.

2.10.1. Influence of bin placement

One of the most effective ways of combating litter is through the availability and attractiveness of bins, a way of providing the public means for disposal (Finnie, 1973; Geller, Brasted and Mann, 1979; Durdan, Reeder and Hecht, 1985; Cope *et al.*, 1993; Liu and Sibley, 2004; De Kort, McCalley and Midden, 2008; Keep America Beautiful, 2010; Schultz *et al.*, 2013). When placed in areas of contention, this approach is referred to as functionality matching, where the demand for means of disposal is met by an increase in waste collection capacity (Wever, Van Kuijk and Boks, 2008).

Lack of available bins is often to blame for litter and is sited as the second most prevalent factor leading to littering (Seed, 1970; Burgess, Clark and Hendee, 1971; Campbell, 2007; Al-Khatib, 2008) Testing the effects of adding bins to a site has been found to reduce littering by anywhere from 7%-17% (Finnie, 1973). In efforts to tackle cigarette end litter, a 9% reduction has been observed for each individual ashtray introduced to a test site (Cope *et al.*, 1993; Keep America Beautiful, 2010) and the integration of ashtrays to bin tops has been found to reduce cigarette end littering by 64% (Liu and Sibley, 2004). Interestingly, when discussing anti-littering approaches during collaborations in data collection for this thesis, the popular perception among local officials was that bins attract litter, and there have been several initiatives to remove bins from public spaces. In conversation, this approach is justified when litter is observed within the vicinity of a bin, particularly when the bin is full or overflowing (Seco Pon and Becherucci, 2012).

It is argued that by reducing the distance a person needs to travel to bin can have a reducing effect on littering, as a result distance to bin is a metric often recorded to understand motivation to dispose of waste correctly. In some studies, it has been found that being further from a bin increased likelihood to litter by 6% (Durdan, Reeder and Hecht, 1985) and in a London study littering rates were 50% when more than 5 metres from a bin (Keep Britain Tidy, 2015). By providing beach users with pocket ashtrays, one study found that completely eliminating the distance between the smoker and the bin reduced cigarette litter by 10-12% (Castaldi, Cecere and Zoli, 2021).

2.10.2. Promoting use through bin design and beautification

In an early study, regular bins in a shopping centre were replaced with bins that looked like birds, which increased average weekly weight of waste collected by 50% (Geller, Brasted and Mann, 1979). Fun bins, where messages such as ‘thank you’ can only be seen when an item is binned, have also been observed to increase waste collection by double (Cope *et al.*, 1993). Considering the potential for desensitization when novelty is the incentive for behaviour change, the long-term effectiveness of these initiatives could be questioned.

In comparative studies between methods of litter mitigation, it is argued that bin attractiveness and design alone is as effective as any carefully crafted messages (De

Kort, McCalley and Midden, 2008), and that effective bin placement can be successful as long as the end user's needs are considered (Keep America Beautiful, 2018).

2.10.3. Reducing littering through packaging design

A focus on redesigning packaging is the most consistent method of reducing targeted litter items. Intelligent packaging design (Lilley, Lofthouse and Bhamra, 2005) is a form of *technical* mitigation, reducing litter by removing the potential for the items to become litter. This is classically exemplified in the strategy of forced-functionality (Wever, Van Kuijk and Boks, 2008; Wever *et al.*, 2010). A notable example of this approach is the switch from pull-off tabs on beverage tins to those that stay attached (Wever *et al.*, 2010), seen in Figure 2.3. By creating a litter leash*,* fixing the tab to the tin, littering it becomes impossible (Wever *et al.*, 2010).

Figure 2.3 Packaging design is an effective structural method of reducing litter. An example of this is the redesign of the classic drink tin. Pull-off tin tabs were at one time the most littered item. By redesigning the tab to remain fixed to the tin, littering of tabs has effectively been eliminated. This is an example of product design that features a litter leash.[1]

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[1] Image taken from eBay. Available at https://i.ebayimg.com/images/g/8UgAAOSwPRteimOf/s-l640.jpg, accessed on 25/03/2022.

It is ultimately in the best interest of organisations that they take steps to reduce the littering of their products. In a British survey, 34% of respondents said that witnessing a littered brand makes them less likely to buy that brand (Keep Britain Tidy, 2013).

2.10.4. Comments on structural approaches to reducing litter

Availability of bins, bin placement and intelligent packaging are consistent and effective methods to mitigating litter. These are physical solutions that generate an automatic change in littering behaviour, a sustainable and long-term strategy. Despite the evidence of their success, there has been surprisingly little uptake of structural approaches by governing bodies and local action groups, which often choose low-cost quick fixes (Voulvoulis *et al.*, 2015).

2.11. Gap in knowledge

It is well established that litter has a far wider impact than simply being unsightly, and that the social, environmental and economic repercussions are many. Litter occurs in every area of both the inhabited and uninhabited world, and due to the persistent nature of plastic, is accumulating practically as quickly as it is being produced. Although the direct and indirect cost of litter is a drain on public funds and poses substantial threats to the environment and public health, legislations such as the Polluter Pays Principle have yet to address the issue with the gravity it deserves; particularly in addressing items of greatest concern for negative impact (addressed in Chapter 7).

Large gaps of knowledge exist on litter sources (addressed in Chapter 4), methods of deposition (addressed in Chapter 5), and locations (addressed in Chapter 8), while the forces (addressed in Chapter 6) of dispersal from land to sea are purely speculative. Despite this, litter mitigation research has persisted in addressing behaviour, which has failed in finding sustainable, long-term, and effective measures. Efforts to profile those who litter have proven unsuccessful, mostly due to regional and situational variations between studies. There is no evidence that behavioural approaches have continued effects when the external factors such as rewards, fines and messaging campaigns are removed (Crump, Nunes and Crossman, 1977; Scott, 2004; Wever, Van Kuijk and Boks, 2008; Brown, Ham and Hughes, 2010) and the application of behavioural change techniques is near impossible in multicultural and diverse settings as they require an understanding of the social, physical and psychological attributes of targeted individuals (Ajzen, 1991; Michie, van Stralen and West, 2011). Despite their success, there is very little public uptake of automatic and sustainable structural solutions to litter, meanwhile reports indicate the amount of litter in England continues to grow (DEFRA, 2020).

As this literature review highlights, from terminology through to mitigation, the topic of litter is inherently unclear. The generation of litter includes a myriad of complex subtleties that lead to misunderstandings and misapplications of methods to alleviate the ever-growing list of associated consequences. Evidence gathering is the foundation of academic research, where data collection and analysis lend clues to gain insight into various hypotheses. It is through this system that once anecdotal observations gain wider acceptance and validation among the scientific community.

Thanks to the rigorous process of peer review, it is rare that a vein of research can proliferate before the baseline and key understandings are set. This however is the case in the field of litter research, where the consistent approach to mitigation has been to address behaviour, yet never to fully understand litter itself.

Chapter 3: Study Sites and Data Use

3.1. Introduction

This thesis consists of 5 core chapters, each presenting the results of a unique study designed to shed new light on the topic of land-based litter in England. Each study features its own combination of study sites, methodologies, analyses and results. At the end of each chapter, these are summated in an overview and discussion, then rounded off in a lesson learnt. A synthesis of lessons learnt are accumulated and discussed in Chapter 9, which concludes with commentary on current policy and makes suggestions for future approaches.

Figure 3.1 on the following page illustrates the sources of data associated with Chapters 4 through 7, how they contribute to collated analysis in Chapter 8 and the final summation in Chapter 9.

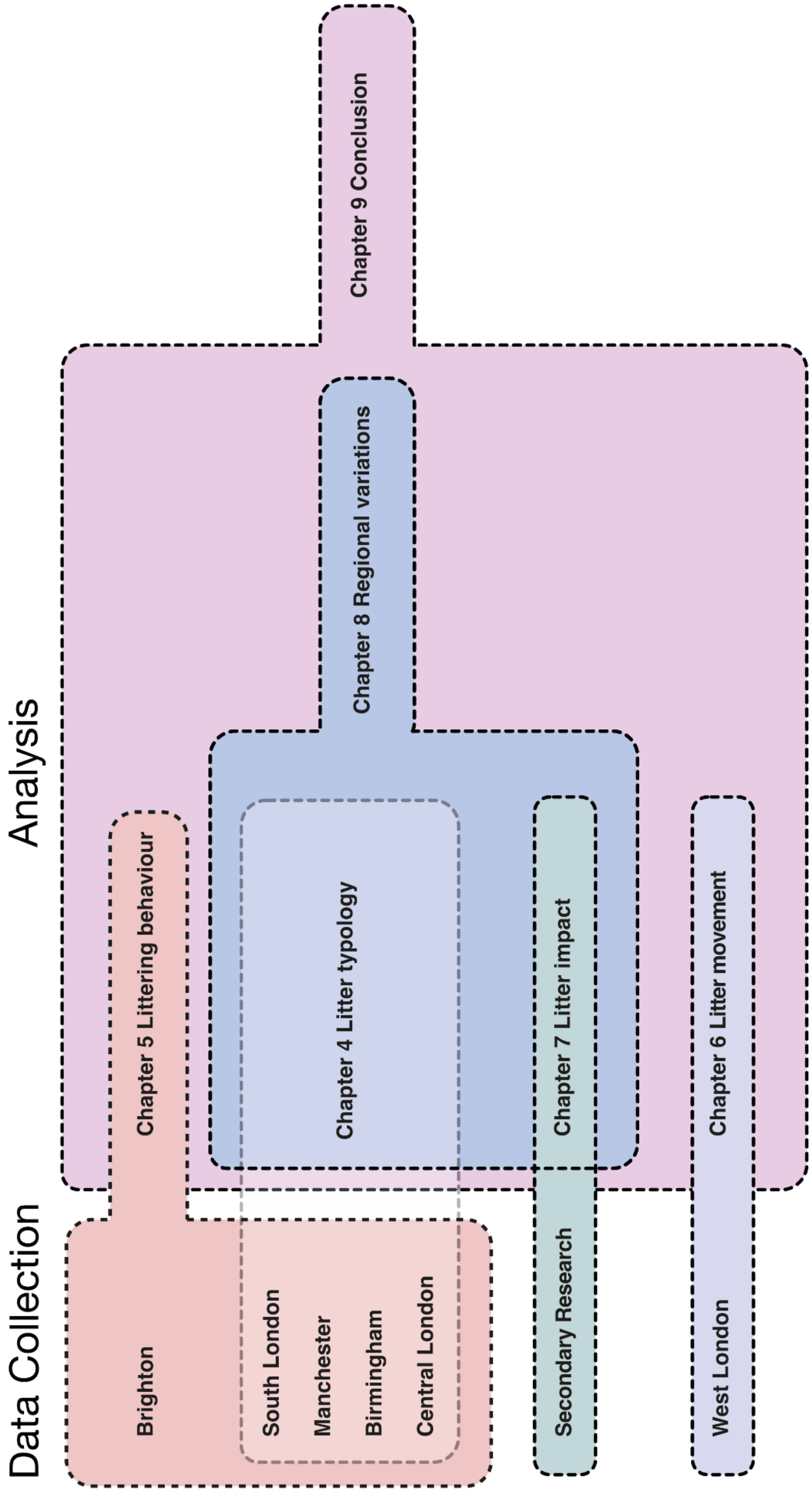
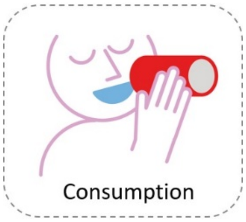


Figure 3.1 Structure of data use within individual chapters. Chapters 4 through 7 feature independent data analysis, which are repurposed towards a collated analysis in Chapter 8. Chapter 9 provides a synthesis of analytical chapters and includes a discussion on applications of insights gained.

3.2. Datasets and access

Three types of data were collected from select study sites and are openly available from the King's College London research data repository. Data are categorized by the steps they pertain to within the Lifecycle of Litter (Figure 1.1, page 26) and icons at the beginning of each chapter indicate which dataset is employed.



Litter typology Excel document and shapefiles

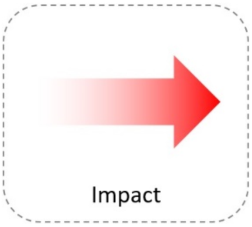
DOI 10.18742/19463102

Littering behaviour Excel document

DOI 10.18742/19467218

Litter movement Excel document and shapefiles

DOI 10.18742/19467332



Litter impact Excel document and figure

DOI 10.18742/19494617

3.3. Partnership information

Analyses in Chapters 4, 5, 6 and 8 were conducted on primary data. To collect the data, partnerships were established with English councils that were interested in reducing the amount of litter in their most problematic deposition areas. These relationships were executed and ultimately managed by The Hubbub Foundation UK (https://www.hubbub.org.uk/), however methodology and data collection were planned and implemented by the author. In return for partnership and cooperation, councils were offered detailed reports of analysis and insight upon conclusion of data collection exercises. Reports are available to the public on Hubbub's website. See Appendix A (page 372) for signed agreement between the author and The Hubbub Foundation UK for the use of collected data in this thesis.

3.4. Study sites

Data were collected from six sites in England (Figure 3.2). Objectives, methods and outcome varied between sites. Sites and data collected are as follows: South London (littering behaviour, litter typology), Manchester (littering behaviour, litter typology), Birmingham (littering behaviour, litter typology), Central London (littering behaviour, litter typology), Brighton (littering behaviour) and West London (litter movement).

Figure 3.2 Map of England depicting the six study sites where data on litter and littering were collected for this thesis: South London, Manchester, Birmingham, Central London, Brighton, and West London.

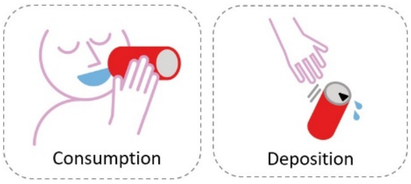
Due to the nature of the partnership, study sites and types of data collected were at the discretion of participating local councils. Prior to each study, local councils established their desired outcomes of the collaboration, resulting in the co-development of methods used for this work. Conversations with councils in South London, Manchester, Birmingham and Central London revealed objectives to target a specific problematic area. As a result, these councils agreed to both behavioural (Chapter 5:) and typology (Chapter 4:) analysis where data collection exercises would occur in tandem and were restricted to a single road of their choosing. The objectives in Brighton however varied as participation in the study fed into a wider communications campaign. Conversations revealed their main objective was to gain behavioural (Chapter 5:) insight to inform the communications campaign, leading to an agreement that behavioural data would be collected in several key problematic locations within the study centre. Finally, the study in West London differed entirely from prior locations as it was presented to the local council as an opportunity to be involved in an innovative pilot study (Chapter 6:).

Where single roads were analysed (South London, Manchester, Birmingham and Central London) these were divided into continuous sectors and further divided into subsectors. Subsectors were considered individual data sampling units, an important variable in the regional comparison analysis in Chapter 8:. This method was chosen as it was the most viable option to obtain a raster style dataset, where subsectors could be considered pixels in their own right.

Sectors and subsectors were drawn in QGIS on the Google Satellite Hybrid basemap, with the coordinate reference system set to WGS 84 (geocentric), authority ID EPSG:27700. The use of satellite imagery allowed for accurate placement of subsector boundaries. Simplicity is however a vital quality in map presentation, and the use of satellite imagery can at times result in crowded, unclear and pixelated images. With this in mind, all maps pertaining to study sites and sectors are presented in a simplified basemap titled Voyager, developed and distributed by CARTO (Giraldo, 2017). To achieve optimal representation, the symbology of Voyager was slightly altered in the following ways: Brightness set to -166, saturation set to 1 and contrast set to 50. The resulting basemap is not only clear, but accentuates road placement, allowing for an accurate representation of the urban centrality of study sites.

Due to the complexity of subsectors, greater simplicity was required in their representation. Thus subsector maps feature a smoother greyscale basemap titled Positron, provided by Geoapify (Geoapify, 2022). Public spaces in the real world are complex, contain a myriad of irregular shapes and oblique angles, and the use of a simplified basemaps does however raise an issue of accurate representation. As a result, subsectors drawn to precision on satellite imagery may appear unprecise when presented in a simplified environment. Please take note of this when reviewing the following maps as there may appear to be some discrepancies but rest assured that the utmost care was applied in maintaining integrity and accuracy.

3.4.1. South London, Sutton High Street



The borough of Sutton is London’s 9th largest metropolitan area, and Sutton High Street (SHS) is the primary local destination for leisurely activities, shopping and restaurants (Mayor of London, 2020). This street is pedestrian through its width, features benches and foliage throughout and has an open food market in the centre. There are no transport links on Sutton High Street, yet the main Sutton train station is located just south of the study site. Sutton council spends £4 million a year in litter cleanup costs throughout the borough (Local Government Association, 2016). The following images in Figure 3.3 depict the data collection site[2].

Figure 3.3 Images of study site on Sutton High Street. The street is mostly pedestrian and features trees and benches throughout. In the centre is an open food market which can be seen in the bottom photo.

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[2] *Google Maps Street View* (May, 2021). Available at https://www.google.co.uk/maps, accessed on 05/04/2022.

3.4.1.1. South London sectors

The full study site is 10,717 sq/metres and excludes any areas designated for automobile use (Figure 3.4). This site was divided into 4 sectors with median size of 2,679 sq/metres (Table 3.1). These sectors were used to define behaviour observation data collection boundaries.

Table 3.1 Total and individual sector areas in square metres of South London study site. Full study site equalled 10, 717 square metres.

	Area (sq. m)
Total site	**10,717.07**
Sector 1	*2791.05*
Sector 2	*2902.13*
Sector 3	*2527.12*
Sector 4	*2496.77*

Figure 3.4 Map of location of South London study site and individual sectors within.

3.4.1.2. South London subsectors

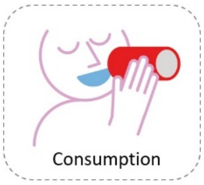
Sectors were further divided into 37 subsectors with a median size of 298.3 sq/metres (Table 3.2), illustrated in Figure 3.5 below. These subsectors were used to define litter typology data collection boundaries.

Table 3.2 Number of subsectors and median size in South London study site. The 4 sectors were divided into a total of 37 subsectors with a median size of 298.3 square metres.

Sector	Number of Subsectors	Median Size (sq. m)
1	12	*232.59*
2	9	*322.46*
3	7	*361.02*
4	9	*277.42*

Figure 3.5 Map of South London site with subsector division along Sutton High Street. Separate colours distinguish in which sector each belong.

3.4.2. Manchester, Oxford Road



Oxford Road is the most important economic area in Manchester, and is the centre of the Manchester Central Business District (Deloitte, 2019). The businesses in the area employ 70,000 highly skilled workers, and the road is host to a major train station (Deloitte, 2019). The site is characterised by a narrow pedestrian area on either side of a busy road lined with bus stops (Figure 3.6). On the southwestern tip of the study site is Manchester Metropolitan University, and even further south (off map, Figure 3.7) are Saint Mary's Hospital and Manchester University campuses which are patronized by up to 75,000 students (Deloitte, 2019).

Figure 3.6 Images of study site on Oxford Road, Manchester. The site is located in the Manchester Central Business District and is characterised by narrow pedestrian areas on either side of a busy road. The site is home to multiple business offices, university campuses, a hospital and features many points of transport. Photo credit Randa L Kachef (2016).

3.4.2.1. Manchester sectors

The full study site is 3,458 sq/metres and excludes any areas designated for automobile use (Figure 3.7). This site was divided into 4 sectors with median size of 864 sq/metres (Table 3.3). These sectors were used to define behaviour observation data collection boundaries.

Table 3.3 Total and individual sector areas in square metres of Manchester study site. Full study site equalled 3,458 square metres.

	Area (sq. m)
Total site	**3458.16**
Sector 5	*750.48*
Sector 6	*794.17*
Sector 7	*1224.47*
Sector 8	*689.04*

3.7 Map of location of er study site and individual thin.

3.4.2.2. Manchester subsectors

Sectors were further subdivided into 24 subsectors with a median size of 144.09 sq/metres (Table 3.4), illustrated in Figure 3.8 below. These subsectors were used to define litter typology data collection boundaries.

Table 3.4 Number of subsectors and median size in Manchester study site. The 4 sectors were divided into a total of 24 subsectors with a median size of 144.09 square metres.

Sector	Number of Subsectors	Median Size (sq. m)
5	6	*125.08*
6	6	*132.36*
7	6	*204.08*
8	6	*114.84*

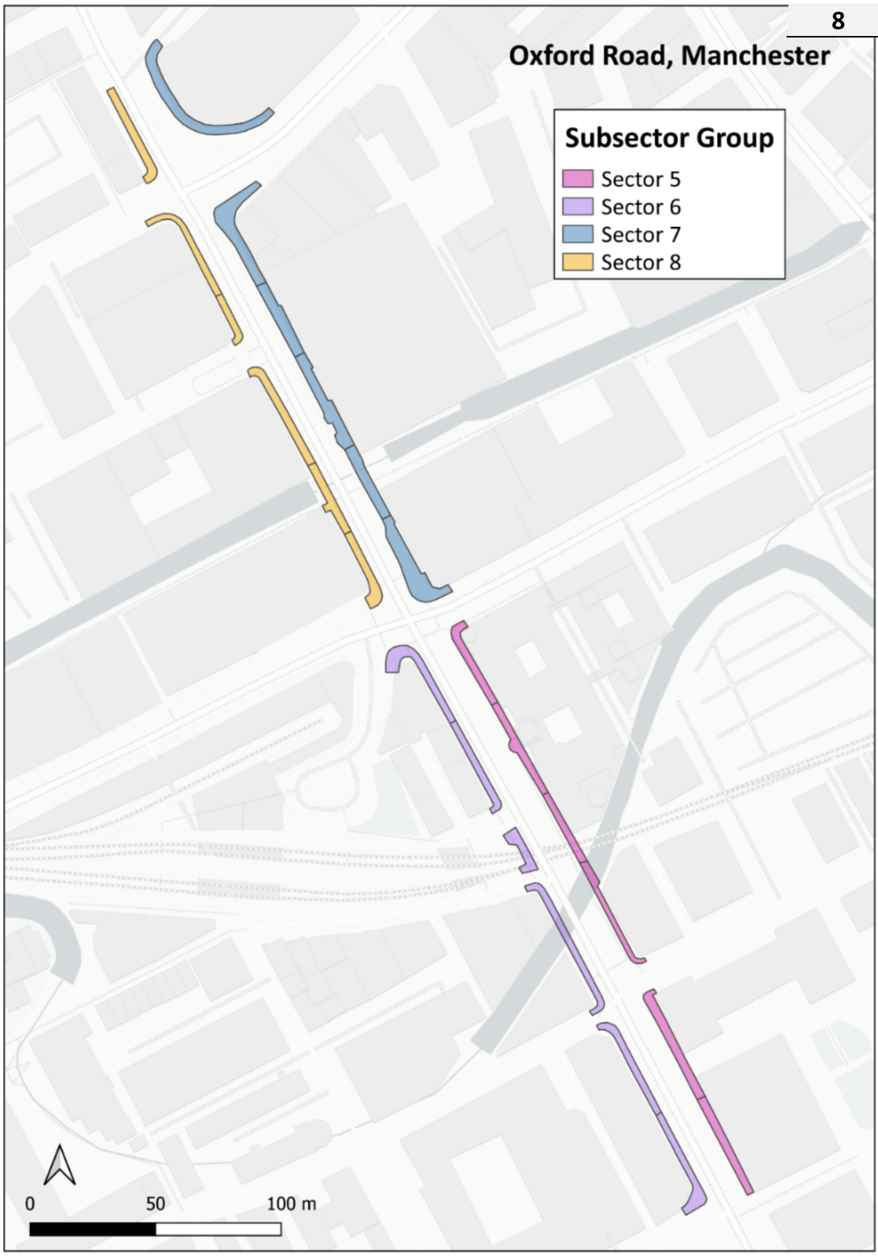


Figure 3.8 Map of Manchester site with subsector division along Oxford Road. Separate colours distinguish in which sector each belong.

3.4.3. Birmingham, New Street

Consumption Deposition

New Street is the most prominent High Street in Birmingham and is highly driven by leisurely activities, shopping and restaurants. New Street is primarily a pedestrian area, features benches, tables and foliage throughout, and hosts an average of 32,000 shoppers daily (Birmingham BID, 2017). There are no transport links on New Street, however a major train station is a short walk away (Birmingham BID, 2017). The following images in Figure 3.9 depict data collection site[3].

Figure 3.9 Images of study site on New Street. The street is predominantly pedestrian, features trees and benches throughout and is the primary shopping district in Birmingham.

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[3] *Google Maps Street View* (April, 2019). Available at https://www.google.co.uk/maps, accessed on 05/04/2022.

3.4.3.1. Birmingham sectors

The full study area is 5,155 sq/metres and excludes any areas designated for automobile use (Figure 3.10). This site was divided into 2 sectors with a median size of 2,578 sq/metres (Table 3.5). These sectors were used to define behaviour observation data collection boundaries.

Table 3.5 Total and individual sector areas in square metres of Birmingham study site. Full study site equalled 5,155 square metres.

	Area (sq. m)
Total site	**5155.13**
Sector 9	*2840.32*
Sector 10	*2314.81*

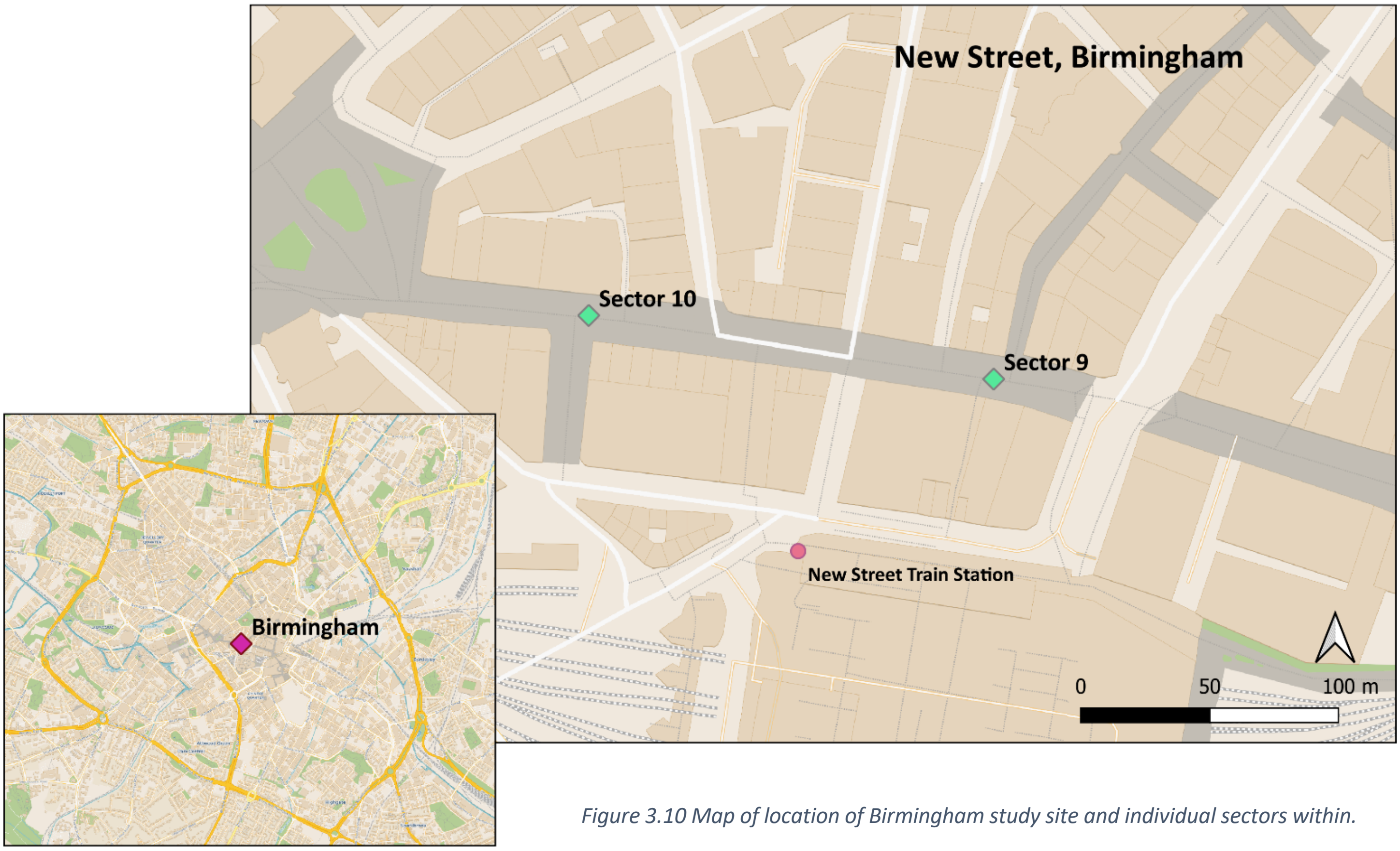


Figure 3.10 Map of location of Birmingham study site and individual sectors within.

3.4.3.2. Birmingham subsectors

Sectors were further subdivided into 28 subsectors with a median size of 186.02 sq/metres (Table 3.6), illustrated in Figure 3.11 below. These subsectors were used to define litter typology data collection boundaries.

Table 3.6 Number of subsectors and median size in Birmingham study site. The 2 sectors were divided into a total of 28 subsectors with a median size of 186.02 square metres.

Sector	Number of Subsectors	Median Size (sq. m)
9	12	*199.37*
10	16	*172.67*

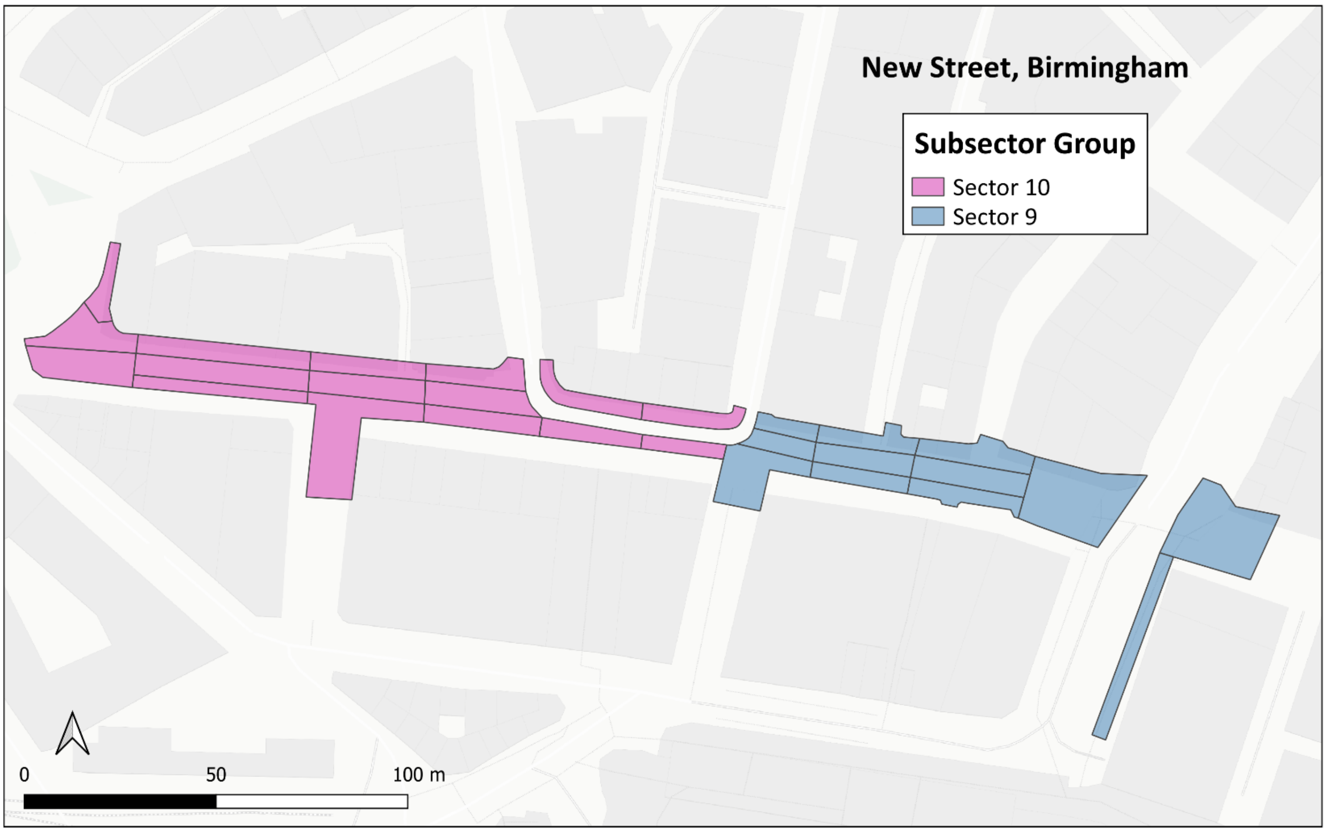
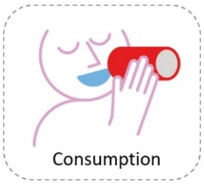


Figure 3.11 Map of Birmingham site with subsector division along New Street. Separate colours distinguish in which sector each belong.

3.4.4. Central London, London Bridge



The study site is located on the southern end of London Bridge at the junction of Tooley Street and is part of the London Central Business District (London Bridge BID, 2021). The site is adjacent to London Bridge train and tube stations, which lead to 350,000 people commuting through the site daily (London Bridge BID, 2021). Opposite to the site is Borough Market, a popular destination for lunch. The site is characterised by wide pedestrian areas on either side of two major intersecting roads. Located just south of the site (off map, Figure 3.13) are King's College London Guy's Campus and Hospital. The following images in Figure 3.12 depict data collection site[4].

Figure 3.12 Images of study site at London Bridge. Located at the intersection of Tooley Street, the site is adjacent to many points of transport into the London Central Business District.

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[4] *Google Maps Street View* (December, 2020). Available at https://www.google.co.uk/maps, accessed on 05/04/2022.

3.4.4.1. Central London sectors

The full test area is 3,034 sq/metres and excludes any areas designated for automobile use (Figure 3.13). This site was divided into 4 sectors with a median size of 758 sq/metres (Table 3.7). These sectors were used to define behaviour observation data collection boundaries.

Table 3.7 Total and individual sector areas in square metres of Central London study site. Full study site equalled 3,034.02 square metres.

	Area (sq. m)
Total site	**3034.02**
Sector 11	*323.49*
Sector 12	*676.40*
Sector 13	*1027.73*
Sector 14	*1006.40*

Figure 3.13 Map of location of Central London study site and individual sectors within.

3.4.4.2. Central London subsectors

Sectors were further subdivided into 42 subsectors with a median size of 80.24 sq/metres (Table 3.8), illustrated in (Figure 3.14) below. These subsectors were used to define litter typology data collection boundaries.

Table 3.8 Number of subsectors and median size in Central London study site. The 4 sectors were divided into a total of 42 subsectors with a median size of 80.24 square metres.

Sector	Number of Subsectors	Median Size (sq. m)
11	5	*64.70*
12	13	*52.03*
13	17	*60.45*
14	7	*143.77*

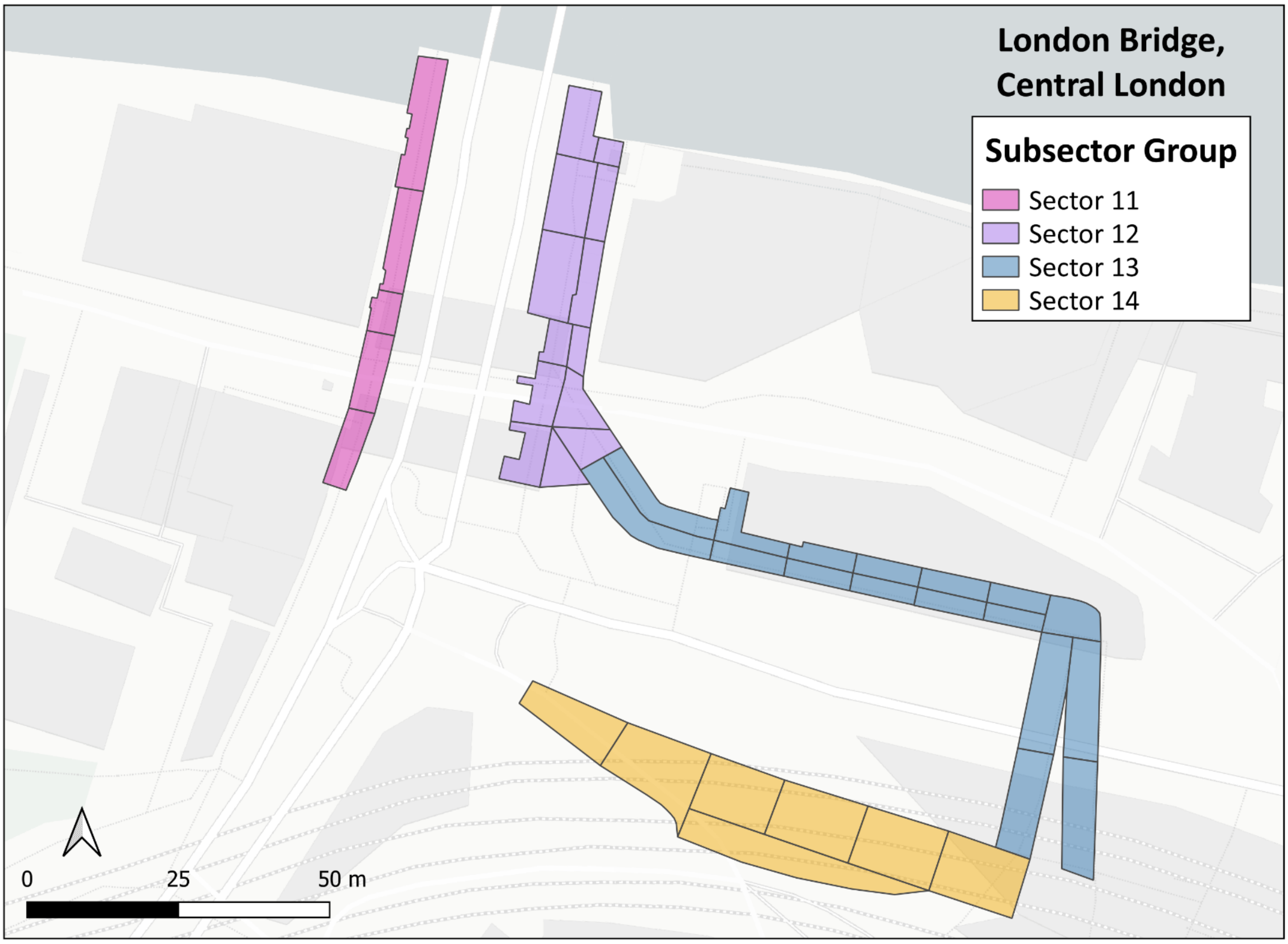

Figure 3.14 Map of Central London site with subsector division along New Street. Separate colours distinguish in which sector each belong.

3.4.5. Brighton and Hove

Deposition

Located an hour train ride south of London, Brighton is not only a vibrant and unique city, but with over 900 bars (My Brighton and Hove, 2006), it is a popular seaside and party destination for weekend travellers (Brighton & Hove City Council, 2021; Visit Brighton, 2022). There are just over 260,000 residents in Brighton (Brighton & Hove City Council, 2021), of which approximately 17,000 are students attending University of Brighton (University of Brighton, 2021). Each year the city hosts the UK’s largest Pride festival that attracts up to half a million visitors from all over the country (Brighton and Hove Pride, 2022). The following images in Figure 3.15 depict data collection sites [5].

Figure 3.15 Images of the data collection locations in Brighton and Hove. In order from top to bottom: Brighton train station, Jubilee square, New Road, Pavilion Gardens, Old Steine bus stop and Brighton Beach and pier.

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[5] *Google Maps Street View* (October, 2020). Available at https://www.google.co.uk/maps, accessed on 05/04/2022. Final photo of Brighton beach and pier credit to Randa L. Kachef (2017).


LIFEGUARD
SWIM BETWEEN

3.4.5.1. Brighton observation sites

This location varies from previous study sites as the partnership agreement did not include typology analysis, and focus was exclusively on behavioural observation analysis. As a result, the methodology was adjusted to include five targeted problematic sites around the city, as opposed to dividing a singular road into sectors and subsectors. Observation locations are: Brighton train station, Jubilee Square, New Road, Pavilion Gardens, Old Steine bus stop, and Brighton Beach (Figure 3.16).

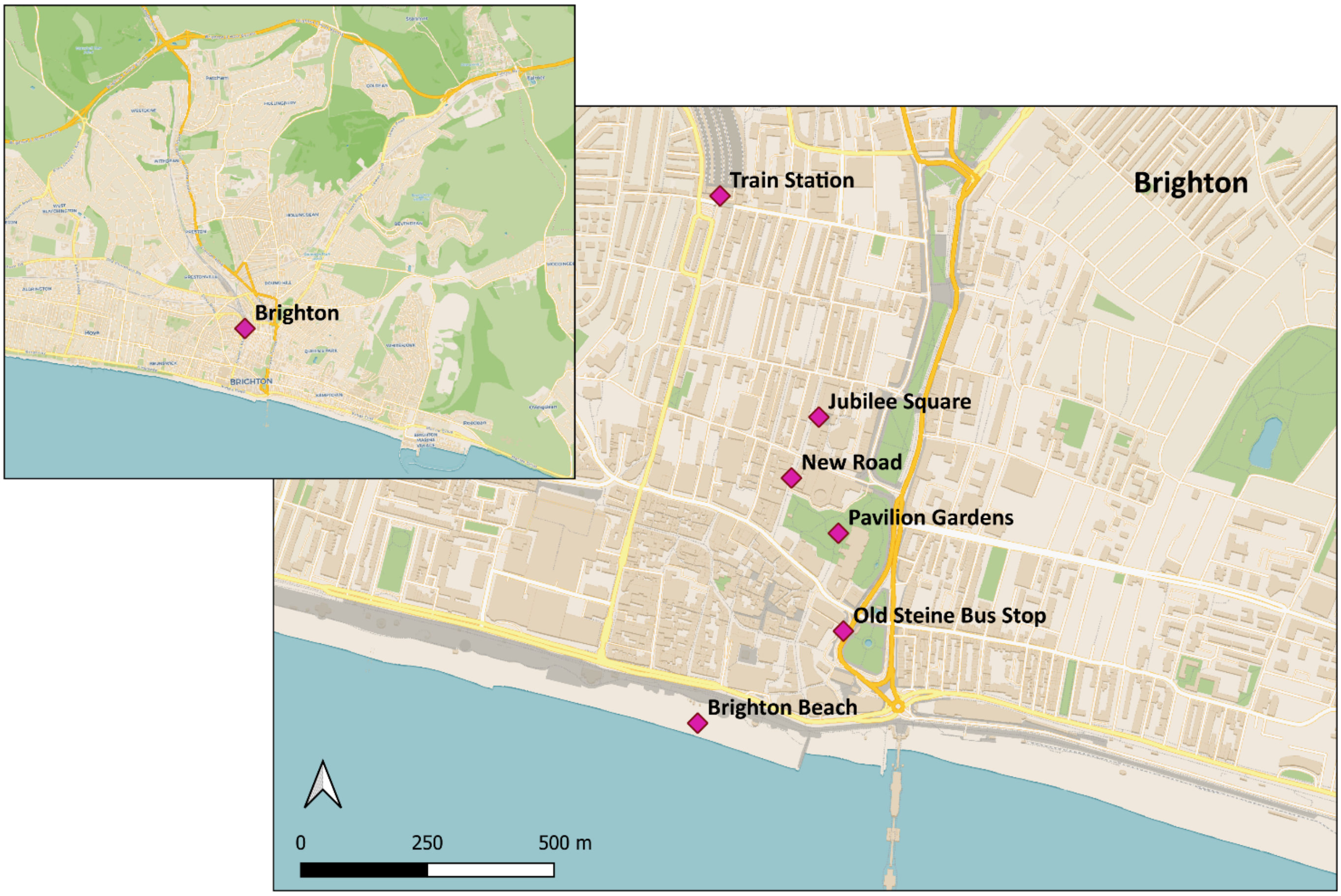

Figure 3.16 Map of observation data collection sites in Brighton and Hove: Brighton train station, Jubilee Square, New Road, Pavilion Gardens, Old Steine bus stop and Brighton Beach.

3.4.6. West London, Putney

The study conducted in West London is focused on litter transfer dynamics and is entirely unique in purpose and analysis from the previous sites. Putney is a largely domestic area located to the west of Central London (Figure 3.18) and features facilities for leisure activities such as shopping and dining (Putney BID, 2021; Wandsworth Council, 2021). Putney's riverside location not only allows locals and visitors to enjoy the banks of the Thames (Wandsworth Council, 2021), but the reduced tidal pull makes it an ideal entry point for water sport. Consequently, over 20 rowing clubs are located along the slipway of the Putney Embankment (Figure 3.17[6]) (Putney Exchange, 2017).

Figure 3.17 Image of West London study site, area between Putney Embankment and slipway.

Figure 3.18 Map of West London study site located at Putney Bridge, Putney

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[6] *Google Maps Street View* (September, 2020). Available at https://www.google.co.uk/maps, accessed on 05/04/2022.

Chapter 4: Litter Source Dynamics: Litter as evidence of consumption trends

4.1. Introduction

Humans are known to engage with an abundant and varied amount of materials on a daily basis and there are strong connections between human behaviour and these items; how individuals interact with, the function they fulfil and the activities that produce these items are as unique as the materials themselves (Reid, Schiffer and Rathje, 1975; Binford, 1981; O'Brien, 2012; Schiffer, 2016; Walker and Skibo, 2017). As these materials play a vital role in human evolution, artifact-based insights are commonly accepted as evidence, often leading to significant archaeological insight (Reid, Schiffer and Rathje, 1975; Zalasiewicz *et al.*, 2014; Schiffer, 2016). It is through this understanding of the connection between people and their debris that material evidence can be pieced together to understand past behaviour and culture (Binford, 1981; Schiffer, 1985).

The study of material objects as an indicator of behaviour is referred to as behavioural archaeology (Reid, Schiffer and Rathje, 1975) and has often been proposed as one the most significant advancements in the field (Yu, Schmader and Enloe, 2015; Walker and Skibo, 2017). By identifying the source associated with material debris, such as activity and purpose, inferences on behaviour can be made, an approach that can be applied in understanding both the past and the present

(Reid, Schiffer and Rathje, 1975; Schiffer, 1975, 1999, 2016; Rathje, 1996; Rathje and Murphy, 2001).

As the study of artifact-based archaeology highlights (e.g., discarded stone tools and pottery in understanding pre-historic human migration), the act of littering is as old as mankind itself (Murdock, 1945; Rathje and Murphy, 2001; O'Brien, 2012; Foley and Lahr, 2015). In fact, there is evidence of haphazardly discarded anthropogenic produced debris dating as far back as 2.4 million years (Foley and Lahr, 2015). In these traditional nomadic settings, refuse items were discarded the moment they were considered to no longer be of use, resulting in a scenario where humans moved away from their waste and were unaware of the possibility for accumulation (Rathje and Murphy, 2001). It was only with the advent of permanent settlements that waste began to pile up, bringing with it a new understanding and need for waste management systems (Rathje and Murphy, 2001).

Where litter of the past was exclusively made of organic materials, the nature of littered items has significantly changed since the invention and widespread use of plastics (Rathje and Murphy, 2001; Havlíček and Morcinek, 2016; Waters *et al.*, 2016; Zalasiewicz *et al.*, 2016). Plastics were first introduced to the public market in the early 1950s and their use and production has increased significantly; currently ranked as the third most manufactured material in the world (Zalasiewicz *et al.*, 2016; European Union, 2019; Zalasiewicz, Gabbott and Waters, 2019; Campanale *et al.*, 2020). The popularity of plastic is predominantly due to two factors, their resistance to decay and their ease of production (Rathje and Murphy, 2001; Zalasiewicz *et al.*, 2016; Zalasiewicz, Gabbott and Waters, 2019). The tenacious and abundant qualities of plastic make it an ideal material in the wrapping and distribution of products; as a result, plastics are often produced solely to be discarded after a single use (Meikle, 1995; Campbell, 2007; Zalasiewicz *et al.*, 2016). Never before have items been produced and discarded with such abundance as is currently being witnessed (Meikle, 1995; Zalasiewicz, Gabbott and Waters, 2019), and as they are designed to resist decay, much of modern litter is assumed to remain in the environment indefinitely.

In geology, organic markers such as fossils are commonly used as indicators of time, particularly in the study of sediment and ice core sampling. The advent of material production by humans has led to the first instances of Technofossils, where their composition is unique from traditional fossilized remains as they contain combined and processed materials (Zalasiewicz *et al.*, 2014). As a result, Technofossils are increasingly used as geological time markers of the current proposed Anthropocene, in the same way that fossil zones act as markers in the Geological Time Scale (Zalasiewicz *et al.*, 2014; Waters *et al.*, 2016). As widespread plastic production and use is a modern occurrence, the distribution and accumulation of plastic derived litter items in the environment act as a stratigraphic marker that is uniquely indicative of the current century (Hoffmann and Reicherter, 2014; Waters *et al.*, 2016; Zalasiewicz *et al.*, 2016; Brandon, Jones and Ohman, 2019; Campanale *et al.*, 2020). Technofossils and plastic deposits provide an opportunity for highly accurate modern geologic dating; from simple procedures such as noting the sell by date on littered food packaging, or complex applications such as to distinguish between modern and historic flood events by examining plastic based sediment distribution (Rathje, 1996; Hoffmann and Reicherter, 2014; Zalasiewicz *et al.*, 2014).

Modern litter does however present threats to societal, human and environmental wellbeing (described in Chapter 2: 2.5 Known impacts of litter, page 45). In England, 95% the public consider a litter free environment to be a priority, and efforts are made on a government and community level to mitigate the issue (Campbell, 2007; DEFRA, 2010, 2017, 2019; Keep Britain Tidy, 2013). Despite these efforts, litter in England continues to accumulate, with recent surveys reporting litter in 95% of monitored sites (DEFRA, 2020). How is it possible that a nation which values public cleanliness continues to exhibit behaviour that contradicts those values? As litter is a product of human activity, this study proposes that a behavioural archaeology approach could lead to new insight in this paradox; examining the evidence, litter, to understand the mysterious behaviour, littering.

A handful of recent studies have used material analysis as evidence to better understand the source dynamics of litter (Rathje, 1996; Carpenter and Wolverton, 2017; Rangel-Buitragoa *et al.*, 2020; Ryan, 2020). For example, to understand littering on the beaches of Kenya, Ryan (2020) examined the language on drink bottle labels to identify whether they originated from domestic or international sources. The study discovered that 20% of the bottles found were of Southeastern Asian origin, illustrating that a portion of litter input was from the sea, having traveled across the Indian Ocean before settling on east African shores (Ryan, 2020).

Carpenter and Wolverton (2017) applied the principles of behavioural archaeology to plastics found along a creek in Texas, with an objective to identify if the litter present in select sites were generated locally or if input had originated elsewhere. By focusing on the function and transportability of littered items, they were able to deduce which items were a product of local littering behaviour and which were accumulating from other locations. This study found that litter input sources were different between sites along the creek, some stemming from on-site littering behaviour and others were entering sites via fluvial or aeolian processes (Carpenter and Wolverton, 2017). Ultimately, this study allowed for tailored and effective mitigative measures of environmental control, either addressing behaviour issues or implementing physical barriers where appropriate (Carpenter and Wolverton, 2017).

On the western Chilean coast, Rangel-Buitrago et al (2020) created profiles of litter on five beaches determining magnitude and concentration to set a baseline for future mitigative measures. Each year, Chilean beaches welcome millions of visitors from around the world (Rangel-Buitragoa *et al.*, 2020). Not only is the environmental and aesthetic integrity of beaches paramount to the tourism industry, but proximity to the ocean implies that litter deposited on beaches are a direct source of plastic intrusion to marine environments (Poeta *et al.*, 2016; Rangel-Buitragoa *et al.*, 2020; Nazerdeylami, Majidi and Movaghar, 2021). In their analysis, this study reclassified litter items by the activities that would generate them, such as recreational activities, sewer overflow, direct dumping, fishing and so on. It was concluded that recreational beach activities dominated the sample of litter, illustrating that litter was being generated locally (Rangel-Buitragoa *et al.*, 2020).

The examples in Kenya, Texas and Chile effectively employ artifact-led analysis methods to determine source dynamics of litter in public spaces; however, each study is set in a riparian zone. Due to the transport abilities of water, proximity to fluvial processes increase the opportunity for litter consumption sources to exist off-site, as is the case in Kenya and Texas, often pointing the finger of blame to 'others'. Never have these approaches been applied to a land-based setting, where litter generation is predominantly local.

Since 2001, in collaboration with DEFRA, KBT conduct a yearly composition analysis of litter in England (DEFRA, 2020). The report describes the most frequently littered items and brands, employs a grading system to site cleanliness and conducts a correlation analysis between litter frequency and levels of communal deprivation (DEFRA, 2020). This report allows for a thorough snapshot of the state of litter in England; although, does little to provide insight as to its sources.

Question: What consumption activities generate litter?

Hypothesis: Applying typology analysis to littered items found in highly littered English streets, an understanding as to source activities will emerge. This knowledge can in turn fuel alternative approaches to tackling litter in an urban setting.

4.2. Methodology

Littering is a behaviour that is widely considered socially unacceptable, as a result self-reported and survey generated analysis on the topic are often vulnerable to bias (Rathje, 1996; Campbell, 2007; Carpenter and Wolverton, 2017). In the context of stigmatized behaviour, a discrepancy is far too often apparent between how individuals behave and what they admit to doing (Cote, McCullough and Reilly, 1985; Pieters, 1989; Rathje, 1996; Mervis, 2012).

A behavioural archaeology framework is a widely accepted way of predicting human behaviour (Reid, Schiffer and Rathje, 1975; Schiffer, 1975, 2016; Rathje and Murphy, 2001; Carpenter and Wolverton, 2017). Thus, a typology analysis of litter presents a clear advantage in developing accurate insight in littering behaviour (Carpenter and Wolverton, 2017). As a result, this study surveys litter items found in four sites and employs an artifact-led approach of analysis to identify consumption activities that generate litter.

4.2.1. Study sites

Litter counts were conducted in four sites located in the three largest cities in England; London, Manchester and Birmingham. The sites were chosen by local participating councils who identified their most problematic areas in terms of littering. According to land type indices, all study sites were categorised as areas of high intensity of use (DEFRA, 2019) and were located centrally in their respective areas.

Study sites included: Sutton High Street, South London (SHS); Oxford Street, Manchester (OXM); New Street, Birmingham (NSB); London Bridge, Central London (LBL) (Figure 4.1). Full descriptions of the study sites can be found in Chapter 3: 3.4 Study sites (page 88).

Figure 4.1 Map of study sites in source analysis geared to understanding consumption activities that generate litter.

4.2.2. Research design

Prior to data collection sessions, sample sites were canvassed, and an inventory of present litter was taken. This inventory was used to inform templated data collection forms and ensure that as many litter types as possible were included, whilst being cognisant that for ease of reporting the form should fit on a single page. This was done with the intention of reducing the portion of data in the sample classified as 'other'. During these canvassing sessions, each sample site was divided in sectors, allowing for multiple individuals to act as counters, simultaneously collecting data while eliminating any potential for duplicate counts. Sites varied in size and the number of sectors depended on number of counters available to conduct the survey simultaneously. Additional requirements for sectors were that they could each be surveyed in their entirety within a similar and reasonable timeframe, approximately 30 minutes. Full site and sector sizes are described in Chapter 3: 3.4 Study sites (page 88).

To ensure consistency across all counters, prior to data collection sessions, each counter was walked through the extent of their sector and trained in litter identification. In training exercises, data collection forms were reviewed to guarantee counters were familiar with and understood the meaning of each litter typology. Observers were often local to each study site (i.e., observers in London did not collect data in Manchester etc), therefore emphasis on comprehension of, and consistency in data collection methods was paramount.

Counters were provided with data collection forms that included 32 different litter typologies (defined in Table 4.2, page 119), allowing for a high-resolution tally method of data collection (see Appendix B, page 373 for template). Typologies were borrowed from previous studies (e.g. DEFRA, 2020; Keep America Beautiful, 2021; Keep Britain Tidy, 2018) allowing both consistency within the field of research and comparative analysis if desired. Additionally, counters were provided with detailed maps of their designated counting areas which included notes on physical markers such as lamp posts and changes in pavement tiles to aid in identifying area boundaries. As the health and safety of counters was of the upmost concern, instructions were to never count littered items located on a roadway and to only count litter items present in pedestrian designated areas.

Depending on the number of sectors in the study site, 2 to 4 counters collected data simultaneously. During data collection sessions, counters were instructed to systematically canvas the entirety of their sector, tallying each item of litter encountered in their data collection form. Each sector took no more than 30 minutes to canvass in its entirety. To remain within research budgets, each site was counted on 4 separate occasions.

Prior to litter survey sessions, counters had engaged in behaviour observation data collection (analysed in Chapter 5:). Observation sessions lasted two hours, during which time planning partners within local councils were instructed to request cleansing crews avoid study sites. This was done to allow for litter items to accumulate and to eliminate any external influences on littering behaviour.

Upon conclusion of each data collection exercise, counters reconvened and discussed any anomalies or insights they may have encountered during the session. These observations were submitted as additional notes alongside the templated litter count forms. See Appendix D (page 375) for full list of notes and comments from counters.

4.2.3. Analysis

Analysis was conducted on litter counts that included all littered items within the study site. A quadratic or transect method was not employed and data represents total litter present in each sector.

Data were analysed to generate proportional values of all individual items found, and then again with items pooled by activity source. Proportions were calculated by dividing the number of observed items by the sample total. As cigarette ends accounted for 78.8% of the sample, proportions were calculated with, as well as without, cigarette end counts.

Source categories were established by assuming the activity that generated litter types and include: Smoking, chewing gum, drinking, eating, transport, shopping and entertainment and other. Due to the large proportion of cigarette ends in the sample they were identified as their own activity, and not included in the smoking activity sample. Activity categorizations with items are defined in Table 4.4 (page 122).

4.3. Results

4.3.1. Sampling dates and litter counts

In total, 16 separate counting exercises produced a detailed typology of 26,209 individual items of litter. Table 4.1 describes data collection dates and litter counts[7].

Table 4.1 Number of litter items observed in each site during separate counting sessions. A total of 26,209 items were recorded and separated into 32 typologies during the 16 counting sessions.

Site	**Date**	**Time**	***N***
SHS	04-Mar-16	13:00	*2,830*
SHS	05-Mar-16	18:00	*2,775*
SHS	11-Mar-16	13:00	*2,869*
SHS	12-Mar-16	18:00	*3,306*
OXM	19-May-16	13:00	*1,657*
OXM	20-May-16	18:00	*1,486*
OXM	25-May-16	13:00	*1,303*
OXM	27-May-16	18:00	*1,629*
NSB	03-Jun-16	13:00	*897*
NSB	04-Jun-16	18:00	*1,140*
NSB	10-Jun-16	13:00	*1,309*
NSB	11-Jun-16	18:00	*1,558*
LBL	06-Apr-17	13:00	*966*
LBL	08-Apr-17	18:00	*833*
LBL	20-Apr-17	13:00	*747*
LBL	22-Apr-17	18:00	*904*
Total			**26,209**

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[7] Due to construction, a small portion of OXM (sector 7, subsector 45) on 25 May, 2016 was inaccessible and therefore not counted.

4.3.2. Individual litter items

Cigarette ends were the single most counted litter item (Table 4.2), accounting for 78.8% (20,640) of the total sample (26,209). A separate litter composition analysis of England estimates cigarette end litter proportion at 66% (DEFRA, 2020).

Table 4.2 Description of counts by litter typology and source activity. Cigarette ends accounted for 78.75% of the sample.

Item	**Activity**	***N***	**%**
Cigarette end	Cigarettes	*20640*	78.75%
Cigarette packs, cellophane wrapping and foil paper	Smoking	*323*	1.23%
Cigarette rolling papers, unsmoked filters	Smoking	*103*	0.39%
Lighters and matches	Smoking	*77*	0.29%
Gum - 3D	Gum	*561*	2.14%
Plastic bottle	Drinking	*149*	0.57%
Tin or aluminium drink can	Drinking	*106*	0.40%
Paper cup	Drinking	*92*	0.35%
Hot drink and insulating wraps	Drinking	*86*	0.33%
Other drink	Drinking	*58*	0.22%
Glass bottle	Drinking	*54*	0.21%
Sweet wrappers and bags	Eating	*470*	1.79%
Tissues and napkins	Eating	*376*	1.43%
Food	Eating	*185*	0.71%
Takeaway boxes: card, plastic, aluminium etc	Eating	*160*	0.61%
Cellophane wrapping - food	Eating	*128*	0.49%
Sandwich packs or wrap	Eating	*93*	0.35%
Utensils	Eating	*89*	0.34%
Crisp packets	Eating	*85*	0.32%
Paper bags	Eating	*44*	0.17%
Polystyrene food boxes or trays	Eating	*42*	0.16%
Train and bus tickets	Transport	*155*	0.59%
Till receipts	Shopping Entertainment	*468*	1.79%
Flyers and leaflets	Shopping Entertainment	*374*	1.43%
Cash point receipts	Shopping Entertainment	*272*	1.04%
Cardboard box	Shopping Entertainment	*52*	0.20%
Newspapers and magazines	Shopping Entertainment	*50*	0.19%
Plastic bags	Shopping Entertainment	*39*	0.15%
General litter (other)	Other Unsure	*702*	2.68%
Unsure	Other Unsure	*86*	0.33%
Bagged litter	Other Unsure	*72*	0.27%
Textiles	Other Unsure	*18*	0.07%
Total		**26209**	

Due to the small proportions of non-cigarette litter, Table 4.3 illustrates the sample with cigarette end litter omitted (N=5569).

Table 4.3 Description of litter typology and source activity counts without cigarette ends (N=5,569). Due to the large proportion of cigarette ends, omission allows for a clearer view of litter composition.

Item	**Activity**	***N***	**%**
Cigarette packs, cellophane wrapping and foil paper	Smoking	*323*	5.80%
Cigarette rolling papers, unsmoked filters	Smoking	*103*	1.85%
Lighters and matches	Smoking	*77*	1.38%
Gum - 3D	Chewing Gum	*561*	10.07%
Plastic bottle	Drinking	*149*	2.68%
Tin or aluminium drink can	Drinking	*106*	1.90%
Paper cup	Drinking	*92*	1.65%
Hot drink and insulating wraps	Drinking	*86*	1.54%
Other drink	Drinking	*58*	1.04%
Glass bottle	Drinking	*54*	0.97%
Sweet wrappers and bags	Eating	*470*	8.44%
Tissues and napkins	Eating	*376*	6.75%
Food	Eating	*185*	3.32%
Takeaway boxes: card, plastic, aluminium etc	Eating	*160*	2.87%
Cellophane wrapping - food	Eating	*128*	2.30%
Sandwich packs or wrap	Eating	*93*	1.67%
Utensils	Eating	*89*	1.60%
Crisp packets	Eating	*85*	1.53%
Paper bags	Eating	*44*	0.79%
Polystyrene food boxes or trays	Eating	*42*	0.75%
Train and bus tickets	Transport	*155*	2.78%
Till receipts	Shopping Entertainment	*468*	8.40%
Flyers and leaflets	Shopping Entertainment	*374*	6.72%
Cash point receipts	Shopping Entertainment	*272*	4.88%
Cardboard box	Shopping Entertainment	*52*	0.93%
Newspapers and magazines	Shopping Entertainment	*50*	0.90%
Plastic bags	Shopping Entertainment	*39*	0.70%
General litter (other)	Other Unsure	*702*	12.61%
Unsure	Other Unsure	*86*	1.54%
Bagged litter	Other Unsure	*72*	1.29%
Textiles	Other Unsure	*18*	0.32%
Total		**5569**	

Despite efforts to generate a detailed litter typology inventory, the number of items categorised as other represented the largest portion of non-cigarette litter, at 12.61% (702) of the sample. The second most prevalent litter item was chewing gum, accounting for 10.07% (561). Other notable items that accounted for more than 5% of the sample were sweet wrappers (8.44%, 470), till receipts (8.40%, 468), tissues and napkins (6.75%, 376), flyers and leaflets (6.72%, 374) and cigarette packaging materials (5.80%, 323).

4.3.3. Activity source categorization

The sample was then pooled by activity source (Table 4.4). Eating was the primary source of litter in the sample, accounting for 30% (1672). Shopping and entertainment items were the second most observed activity source at 22.54% (1255) and items categorised as other accounted for 15.77% (878). Chewing gum was not pooled with any other item as chewing gum does not uniquely couple with any activity and can happen at any point of the day. Items such as clothing, hair ties and bagged litter were pooled in the other category as the activity source of those items is varied and cannot be assumed.

Table 4.4 Descriptions and counts of litter pooled by activity source. Eating (30%) was the primary source of litter, followed by shopping and entertainment (22.54%). Chewing gum was not pooled by activity and accounted for 10% of the sample.

Activity	Description of Items	N	%
Eating	Crisp packets, sweet wrappers, takeaway boxes (cardboard, plastic, aluminium, polystyrene), sandwich packs and wraps, napkins, tissues, paper bags, utensils, cellophane wrapping (non-cigarette) food items.	1672	30.02%
Shopping Entertainment	Cash point receipts, till receipts, flyers, leaflets, cardboard box, newspaper, magazines, plastic bags.	1255	22.54%
Other Unsure	Textiles, clothing, hair ties, bagged litter, other, unsure.	878	15.77%
Chewing Gum	Only three-dimensional chewing gum counted. Staining not included.	561	10.07%
Drinking	Plastic bottles, glass bottles, aluminium tins, paper cups, hot drink cups, hot drink insulating wraps, other drinks.	545	9.79%
Smoking	Cigarette packs, cigarette cellophane wrapping, cigarette foil paper, cigarette filters (unsmoked), rolling papers, matches, lighters.	503	9.03%
Transport	Train tickets, bus tickets.	155	2.78%

Chewing gum is a unique form of litter and the high volume of chewing gum in the sample is worth noting. Chewing gum is only recognised by the English Government as litter whilst it is in a three-dimensional form (i.e., it can be easily picked up) (DEFRA, 2019). Once a piece of chewing gum has been trodden on, it is then considered staining and local authorities are no longer responsible for removal during regular street cleaning (DEFRA, 2019). Trodden on chewing gum is tenacious and exceptionally difficult to remove; removal requires intensive steam cleansing methods at an average cost of £1.50 GBP per stain (Parliamentary Office of Science and Technology, 2003). As a result, chewing gum staining could potentially have been in the study site for many years, thus only three-dimensional chewing gum was counted in this study. It is predicted that 87% of the streets in England are stained with chewing gum, and studies have reported higher litter counts on streets that were stained with chewing gum (DEFRA, 2020, 2021a). Because of this, although not legally required, some local authorities choose to remove chewing gum staining at an estimated annual cost of £7 million GBP (Darrah *et al.*, 2021; DEFRA, 2021a).

4.4. Overview

In this study, smoked cigarette ends were the number one littered item, accounting for 78.8% (20,640) of the total sample (26,209). A smoked cigarette end is uniquely different from an unsmoked cigarette by identifying two characteristics. First, the tobacco has burnt away, all that remains is the filter and a small portion of the tobacco. Second, the filter has been smoked through and has a distinct yellowish colour and smoke odour. Depending on the state of the individual (relaxed, bored, anxious, busy etc) smoking an entire cigarette takes anywhere from 90 seconds to just under 9 minutes (Ashton and Watson, 1970; Hatsukami *et al.*, 1990) The presence of used cigarette ends in the test site ultimately indicate that an individual used the space to light and smoke a cigarette. The same could not be assumed if intact cigarettes or unsmoked filters were found.

Of the non-cigarette sample, chewing gum was the most littered item, where 561 (10.07%) pieces of chewing gum were counted. Only untrodden, three-dimensional pieces were counted. As all sites had high levels of foot traffic, it is safe to deduce that three-dimensional chewing gum litter had been littered relatively recently. Chewing gum is water resistant, highly malleable and made of a synthetic plastic based rubber that does not biodegrade (Parliamentary Office of Science and Technology, 2003). Given the persistent qualities of chewing gum, it can hypothetically be chewed for many hours, although a distinct chewing timeframe does not exist. One of the most important qualities of chewing gum is its ability to deliver flavour without consumption, often used to freshen breath or mimic the taste of something sweet. In consumer based taste testing, chewing gum flavour tends to diminish within 6 to 10 minutes of chewing (Gentile, 2016; Buxton, 2017). As chewing time is hypothetically indefinite, littered chewing gum indicate the chewer no longer had use for the gum. Perhaps the gum had lost its flavour, or the individual was about to begin an activity that made having gum in their mouth cumbersome, for example eating, smoking or engaging in a lengthy conversation. Either way, the littered chewed gum only differs from fresh chewing gum by the fact that it has been chewed, the qualities of persistence, water repellence and malleability remain.

Sweet wrappers accounted for 8.44% (470) of non-cigarette litter. These wrappers were unanimously empty, yet it was apparent that these litter items once held a trove of sweets. This is because food wrappings themselves are often more distinguishable than their contents; it is much easier to determine the flavour of a red sweet by reading the packet it was sold in than it is via a visual inspection of the sweet out of context. Essential details such as brand, type, flavour, ingredients and sell by date remain on the packaging long after they have been emptied. It is by examining the package and not what was inside that its original purpose can be identified.

This transition from function to burden explains the large proportion of litter attributed to eating (30.02% of all non-cigarette litter). Packaging is not only an essential component to maintaining freshness of foodstuffs and reducing the potential of bacterial contamination (Plastics Europe, 2021), but also displays all the information one would need to know about the product contained within. Yet, once the item inside has been removed, the packaging itself no longer serves any purpose and is often reduced to litter.

Entertainment litter items accounted for 22.54% of the total sample, where all items within the typology served outdated or perfunctory purposes. Items like till and cash point receipts serve intermittent purposes, to inform or keep a record of purchases and account balances. However, with the convenience of online banking, these physical records no longer have as high a personal value. The same is applied to newspapers, magazines, flyers and leaflets, where as soon as the information printed is read, the vessel of its delivery is no longer important.

At times, litter can even provide evidence on the spatial context of littering behaviour. It was apparent from observational feedback that lighter items were somewhat fluid within the study site and were often seen to travel. In observer comments (Appendix D, page 375) one counter in Sutton reported “litter consistently spotted rolling into other zones with slight breeze especially light plastic and tissues”. This is however not true of all litter. Due to its tenacious and sticky nature, the exact location of chewing gum littering is permanently marked. This is particularly true in the context of chewing gum staining, and the opportunity to explore this further is an exciting avenue in the study of litter.

4.5. Discussion

Society has a strong, complex and long-term relationship with waste materials and much can be learnt about behaviour from examining it (Reid, Schiffer and Rathje, 1975; Schiffer, 1975; Rathje and Murphy, 2001; O’Brien, 2012; Carpenter and Wolverton, 2017). Like ancient litter items, waste in public spaces can act as evidence of anthropogenic presence and provide clues as to the nature of activities taking place in their vicinity. By developing typologies and categorizing litter items by function, this study provides insight on the consumption activities that drive littering, a facet that would not normally be apparent in self-reported or survey driven analysis (Marshall, 1996; Rathje, 1996; Carpenter and Wolverton, 2017). The ability to deduct activities from litter is a testament to the significance of post-consumption analysis, facilitated by the ability for litter to maintain its identity long after it has been disposed of.

Despite this, current land-based litter surveys in England often employ a ranking system for cleanliness which ignores a wealth of potential information embedded as evidence of the activities that created them. By integrating litter typology analysis and associated activity sources, litter count exercises can be repurposed to understand consumption trends that lead to littering and provide clues on how to mitigate it.

A focus on litter source dynamics presents an opportunity for tailored waste management approaches (Earll *et al.*, 2000; Becherucci and Seco Pon, 2014), specifically by targeting the primary purpose of a shared space. For example, imagine a public space that is predominantly frequented by office workers for eating lunch. The source activity would become apparent based on the nature of food packaging litter found on site, such as takeaway containers and sandwich packs. To this effect, a focus on reducing food packaging waste can be established by providing bins directly next to tables or allowing patrons to return food packaging to the original vendor, as is the case in Japan (Edmond, 2017).

Concerning shopping and entertainment litter items, interventions targeted to reducing the number of potential litter items before their dispersal can prove successful. In targeting till and cash point receipts, a shift in convention, where one must request a receipt as opposed to being offered one (a traditional Nudge technique discussed in 2.8.4. Popularity of nudging, page 68), would reduce the number of receipt related litter. Similarly, stricter policy and restrictions in the public dispersal of flyers, leaflets, newspapers, and magazines present another opportunity to mitigate their presence as litter.

Knowledge of source dynamics can also be repurposed on a temporal scale. Seasonality of activities, days of the week and even times of the day can be targeted for maximum benefit. Take the above example of office workers eating their lunches. By establishing a timeline based on litter typology, street cleansing efforts can be augmented during peak activity times. More frequent litter picking during peak times will reduce the litter breeds litter effect, and regular emptying of bins eliminates issues associated with overflowing bins (as described in upcoming Chapter 5: Litter Deposit Methods: Is litter the product of littering?).

Currently, mitigative methods in England ignore the evidence associated with litter items and assume the intention and behaviour in littering is uniform. This study highlights that a detailed inventory of litter items can produce deeper knowledge of litter sources. Ultimately, this knowledge can be applied in targeted mitigative methods that have a higher potential for impact compared to the templated behavioural intervention strategy currently employed in England.

Later in this thesis, Chapter 8: Regional Variations in Litter: The connection between litter and place, presents a comparative analysis between the sites in this study to explore the effect on litter typology by primary use of a space.

4.5.1. Lesson learnt

Litter is evidence of the activities that created it

Litter items maintain distinct characteristics far after their primary use has been exhausted. These characteristics allow for assumptions on the activities that led to their fruition.

Chapter 5: Litter Deposit Methods: Is litter the product of littering?

5.1. Introduction

Throughout history humans have been littering, with evidence of discarding debris dating back as far as 2.4 million years (Foley and Lahr, 2015). This is apparent in the halls of every great archaeological museum, which showcase arrowheads, pottery, buttons, jewellery and other once valuable personal items that have been lost over time (*Garbage: The Archaeologist’s View of Trash*, 2011). These items are crucial in understanding human migration and civilisation trends (Rathje, 1996; *Garbage: The Archaeologist’s View of Trash*, 2011; O’Brien, 2012; Foley and Lahr, 2015; Campanale *et al.*, 2020), however unlike ancient times where personal waste was largely repurposed or made entirely of organic materials (Rathje and Murphy, 2001; Havlíček and Morcinek, 2016), the current market is increasingly saturated with single use items manufactured from persistent materials.

Discarded debris is a natural part of human evolution, causing settlements to not only grow in area but often piling so high that inhabitants were forced to build on top of debris, resulting in vertical growth (*Garbage: The Archaeologist’s View of Trash*, 2011). Despite this, an analysis to identify common historical trends and values among cultures, anthropologist George P. Murdock identified the inherent need for humans to strive to keep designated communal spaces clean (Murdock, 1945;

Havlíček and Morcinek, 2016); raising questions about the dichotomous nature of littering behaviour.

The advent of organised urban planning and established hierarchical governments have proved this inherent need for cleanliness, where growing populations, the development of urban areas and subsequent saturation of human and domestic waste were the inspiration for the first public waste management systems over 2,000 years ago (Rathje and Murphy, 2001; Havlíček and Morcinek, 2016). Interestingly, some have argued that solid waste management systems and government-led cleansing of public spaces has inadvertently led to furthering littering behaviour, as it is generally assumed that someone will clean up after you (Moore, 1995; Campbell, 2007; Luan Ong and Sovacool, 2012; NSW EPA, 2013).

Humans have been negatively impacting the environment for millions of years, (Schultz, 2002; Foley and Lahr, 2015) where the gravity of their influence is increasing exponentially (Waters *et al.*, 2016; Zalasiewicz *et al.*, 2016). As mentioned, ancient litter was not only biodegradable, but far less abundant than what is currently being observed in the environment today (Rathje and Murphy, 2001; Schultz, 2002; Campbell, 2007). For the first time in history, objects are manufactured with the sole purpose to be used once and discarded (Meikle, 1995; Campbell, 2007; Zalasiewicz *et al.*, 2016). Landfill sites are piling high around the world, often contaminating neighbouring areas (Rathje, 1989, 1996; Zalasiewicz, Gabbott and Waters, 2019; Tenodi *et al.*, 2020; Vaverková *et al.*, 2020), fragments of littered items are being found in the guts of wildlife (Chagnon *et al.*, 2018; Provencher *et al.*, 2018; Waring, Harris and Mitchell, 2018; Schwabl *et al.*, 2019; Mohamed Nor *et al.*, 2021), and large islands of rubbish continue to accumulate in every ocean on this planet (Lechthaler *et al.*, 2020; Miladinova *et al.*, 2020; Jones *et al.*, 2021; Lima *et al.*, 2021).

It is assumed that a growing global population has a part to play in this, where more people will undoubtedly create more waste (Rathje, 1996; Schultz, 2002; Nelms *et al.*, 2020). As littered items continue to pile up in public places, there is an ever increasing awareness of their presence (Schultz, 2002; Campbell, 2007; DEFRA, 2017; Ortiz Peñate, 2021), generating unprecedented international attention from the public, academia and policymakers (Luan Ong and Sovacool, 2012; Keep Britain Tidy, 2013; DEFRA, 2020). Unlike unseen environmental pollutants, such as air or water contamination, litter is a visual representation of environmental degradation; often referred to as the first sign of social and environmental decay (Ross and Mirowsky, 1999; Keep Britain Tidy, 2013; Parker, Roper and Medway, 2015). Yet, surprisingly the presence of litter in urban spaces in increasing (Campbell, 2007; Luan Ong and Sovacool, 2012; House of Commons, 2015; DEFRA, 2020). The rising numbers of littered items in the environment is in direct contradiction with increased social awareness; surveys across the globe indicate an increasing interest in environmental preservation, particularly in regards to litter prevention (Schultz, 2002; Campbell, 2007; DEFRA, 2020; Keep America Beautiful, 2021). Despite a universal aversion to litter, it is predicted that 62% of the UK population actively drops litter (Keep Britain Tidy, 2013), yet only 20% of the population will admit to it (DEFRA, 2018a). This raises questions on how rubbish continues to accumulate in public spaces.

Attitudes towards littering could be explained by regional variations in social norms (Schultz, 2002; Liu and Sibley, 2004; Roper and Parker, 2008; Al-Khatib *et al.*, 2009; Yew, 2020). It is widely accepted that attitudes towards cleanliness vary by culture, having been developed over long lengthy periods time (Roper and Parker, 2008; Havlíček and Morcinek, 2016). As a result, motivations towards maintaining clean public spaces vary greatly between regions (Schultz, 2002; Roper and Parker, 2008).

In Singaporean culture, responsibility of cleanliness is placed on the individual, driven primarily by the fear of consequence; specifically attributed to rigorous implementation of fines and shaming punishments (Luan Ong and Sovacool, 2012).

Littering is rare occurrence in Japan as cleanliness is historically deeply engrained in the culture, (Norbeck, 1952; Hanley, 1987; Luan Ong and Sovacool, 2012). Culture, education and public campaigns are key in reducing littering behaviour, where cleaning litter in public is seen as an honourable act and the enforcement of anti-littering laws are increasingly unnecessary (Luan Ong and Sovacool, 2012).

The United States of America (USA) struggles greatly with litter volumes (Jambeck *et al.*, 2015). Predictions estimate 50 billion individual pieces of litter can be found along roadways and motorways at any given time, equating to approximately 152 littered items per USA resident (Keep America Beautiful, 2021). The lack of motivation towards communal cleanliness can be explained by social loafing (Schultz, 2002). Loafing is characterised by an individual's lack of motivation to work towards a goal when engaged in a collective task; where the sum effort is lower than that of the individuals involved (Latané, Williams and Harkins, 1979).

Behavioural attitudes towards littering in Islamic countries found that religion was the primary motivation against littering, and fines (i.e., in Singapore) and awareness campaigns (i.e., in Japan) ranked low as behavioural influencers (Arafat *et al.*, 2007; Al-Khatib, 2008; Al-Khatib *et al.*, 2009). The teachings of Islam place great emphasis on cleanliness, to a degree that street cleansing is considered an act of worship (Arafat *et al.*, 2007; Al-Khatib *et al.*, 2009). As is highlighted in the examples of Singapore, Japan, USA and Palestine, social norms are highly connected with the investment a culture has in environmental preservation, and subsequently influences frequency of littering through different means (Schultz, 2002; Torgler, García-Valiñas and Macintyre, 2008).

Social norms are, however, known to fluctuate not only between, but within regions as well (Schultz, 2002). England is a culturally diverse country, although 80% of the population identifies itself as White British, 13.4% of the population (or 7.5 million people) were born outside the UK (Office for National Statistics, 2011; Home Office, 2021). Diversity in England also stems from tourism and emigration. In 2019 there were 145.1 million arrivals in the UK (Home Office, 2019) and permanent settlement was granted to just over 87,000 individuals from outside the European Economic Area (Home Office, 2019). Unlike Japan, where less than 2% of the population are of foreign origin (Strausz, 2019), and Palestine, where the predominant religion is Islam (Arafat *et al.*, 2007; Al-Khatib, 2008) the population of England is far less culturally uniform. To further complicate things, levels of ethnic diversity are not consistent across the country. For example, in the 2011 census the White British population in London was reported at 44.9%, yet is closer to 87% in the north west, where the largest city is Manchester. In culturally diverse settings such as this, personal norms have been found to have significantly higher impacts on environmental preservation than social norms (Hosta and Zabkar, 2021).

Due to the rich and culturally diverse population in England, efforts to understand social and cultural motivations for littering are complex, and research on profiling behaviours equally so (Campbell, 2007). For example, despite the increasing volumes of litter in England (DEFRA, 2020), littering is in fact a punishable act, incurring a fine from £50 to £150 (UK Statutory Instruments, 2019). However, unlike in Singapore, the threat of fines does little to deter littering behaviour (Campbell, 2007) where the public appears to employ a ‘can I get away with it’ mentality towards littering (Torgler, García-Valiñas and Macintyre, 2008). Generally, those who admit to littering in England find justification in their actions by either diverting blame to lack of adequate disposal resources in public spaces, or simply stating they did not care (Campbell, 2007).

Although motivation to maintain cleanliness is regional, it would seem motivation to litter is quite universal. Terms such as ‘herd mentality’, ‘drop in the bucket’ and ‘litter breeds litter’ all describe an internal littering justification monologue where, if an environment is already littered, or if others are engaging in littering behaviour, an individual act of littering is less impactful and therefore acceptable (Finnie, 1973; Crump, Nunes and Crossman, 1977; Geller, Witmer and Tuso, 1977; Reiter and Samuel, 1980; Wilson and Kelling, 1982; Cialdini and Reno, 1990; Huffman *et al.*, 1995; Schultz, 2002; Hansmann and Scholz, 2003; Liu and Sibley, 2004; Torgler, García-Valiñas and Macintyre, 2008, 2008; Al-Khatib *et al.*, 2009; Schultz *et al.*, 2013;

Al-mosa, Parkinson and Rundle-Thiele, 2017). Displacement of accountability has also been identified as an explanation for littering behaviour, where littering occurs simply because resources are established to clean public spaces (Baltes and Hayward, 1976; Beck, 2001; Campbell, 2007; Luan Ong and Sovacool, 2012; NSW EPA, 2013). Finally, lack of bins often justifies littering, particularly for items that are too bulky or soiled to carry any further (i.e., food scraps, cigarette ends etc) (Seed, 1970; Beck, 2001; Campbell, 2007; Al-Khatib, 2008; Al-Khatib *et al.*, 2009; NSW EPA, 2013).

Given that motivations for environmental preservation vary by region, and that the complexities of human behaviour render it difficult to predict (Ajzen, 1991; Farrokhi and Mahmoudi-Hamidabad, 2012), this study aims not to explain, but to observe waste disposal behaviours. To remain unbiased in this study, it was decided to observe behaviour covertly rather than to perform public surveys. Prescribed survey forms are far more likely to lead respondents through intention, and the opportunity for blind spots regarding outcomes that have not previously been considered is present (Rathje, 1996; Gavrilov, 2021). This is particularly true in the context of a socially unacceptable act such as littering, a phenomena that is referred to as social desirability bias (Arafat *et al.*, 2007; Roper and Parker, 2008), meaning that when faced with a question which may come across as an accusation, respondents are often untruthful through self-defence (Rathje, 1996; Arafat *et al.*, 2007; Campbell, 2007). In the case of litter and waste generation, there is often a large discrepancy between the behaviour an individual admits to and how they actually behave (Cote, McCullough and Reilly, 1985; Pieters, 1989; Rathje, 1996; Mervis, 2012).

Self-reporting surveys on littering behaviour in England are already executed on a regular basis. Often, these surveys have variable results. For example, a survey funded by Keep Britain Tidy in 2006 reported that 48% of the population admits to littering (Campbell, 2007), yet in 2010 Keep Britain Tidy published survey results stating 20% admitted to littering (DEFRA, 2018b) and again, a 2013 report quotes the figure at 28% (Keep Britain Tidy, 2013). Given that litter in England is on the rise (DEFRA, 2020), these numbers raise a variety of questions.

As an alternative to surveys, covert observation methods allow for an open mind, eliminating the influence of social desirability bias. In covert or unobstructed observation analysis, there is no interaction between the observers (the term that will be used from here forward in reference to those individuals recording the data for this study) and the observed (the public) (O'Connor *et al.*, 2010; Lindemann-Matthies, Bönigk and Benkowitz, 2012; Williams, 2015; Al-mosa, Parkinson and Rundle-Thiele, 2017); allowing for the public to act as they would without any external influences[8].

Through convenience sampling, this study explores trends in littering habits by performing a series of covert, unobstructed behaviour observation sessions in five English locations: South London, Manchester, Birmingham, Central London, and Brighton and Hove.

Question: How is litter deposited?

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[8] No interaction between observers and the observed led to this thesis not requiring an ethics approval for data collection.

Litter Deposit Methods: Is litter the product of littering?

Hypothesis: By examining methods of littering, assumptions can be made on the intention associated with the act.

5.2. Methodology

Data were collected through convenience sampling, where behaviour was recorded when within view of an observer. Although convenience sampling is considered the most accurate and accessible method of qualitative data collection, it is not without flaws. Convenience sampling is restricted by the observational abilities of the observer (Marshall, 1996) the richness of the data collected (Beck, 1993) and does not eliminate the potential for observational bias. Because of this, concerns of credibility and reliability are often raised when collecting qualitative data. To ensure data were collected in a reliable manner, a series of guidelines were considered, as outlined in “Qualitative Research: The Evaluation of Its Credibility, Fittingness, and Auditability” (Beck, 1993).

In convenience sampling, every observation is documented, thus the data are not considered a random sample, a metric that is required for a probability approach to data analysis (Marshall, 1996). Although random sampling is ideal in a situation where the aim of the study is to project results onto the population, the aim of this study is to explore the complexities of disposal behaviour: not the who, but the how in littering, thus adequate in this situation (Marshall, 1996; Williams, 2015).

Observing littering behaviour through convenience sampling is not a new science, and convention exists on how to collect and analyse the data. Published in 2015, *Analysing Public Disposal Behaviour: Observational Research* (Williams, 2015) sets the premise for research design and outlines complexities in the method. The methodology outlined in Williams’ report were the basis of this study, however as they mention, adjustments in methodology were required to tailor data collection to specific study sites.

5.2.1. Study sites

Observations were collected in five sites in England. The sites were chosen by local participating councils who identified their most problematic areas in terms of littering. According to land type indices, all study sites were categorised as an areas of high intensity of use (DEFRA, 2019) and were located centrally in their respective cities.

Study sites were: Sutton High Street, South London (SHS); Oxford Street, Manchester (OXM); New Street, Birmingham (NSB); London Bridge, Central London (LBL); and six locations Brighton[9] (BRI). Detailed descriptions of each study site can be found in Chapter 3 (3.4 Study sites, page 88) and are indicated in Figure 5.1.

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[9] Brighton train station, Old Steine bus stop, Brighton Beach, Pavilion Gardens, Jubilee Square and New Road.

Figure 5.1 Map depicting location of the five sites analysed in this study: South London, Manchester, Birmingham, Central London, and Brighton

5.2.2. Research design

Prior to data collection sessions, sample sites were canvassed, and behaviour observed without intention. This was done for two reasons, first to ensure all local aspects of littering were accounted for (and not assumed) in data collection forms. Second, as several observers were deployed simultaneously within each study site, to establish specific data collection *sectors* to reduce the risk of duplicate instances of reporting.

Each observer was trained prior to sampling and walked through the extent of their designated sector. During training, trial observations were conducted to guarantee accuracy across all observers. Training included exercises on age estimation, 5-metre distance estimation, a thorough explanation of littering methods included in data collection forms, as well as tips on collecting observational data, the importance of objectivity and health and safety regulations. Observers were often local to each study site (i.e., observers in London did not collect data in Manchester etc), therefore emphasis on comprehension of, and consistency in data collection methods was paramount.

Data were collected through a convenience sample (Marshall, 1996; Patton, 2014), meaning observations were recorded if they occurred within view of the observer.

Depending on the size of the study site, a team of between 2 to 4 observers collected data simultaneously. For each data collection session, observers were instructed to continuously canvass their sector for a period of two hours, remaining as discreet as possible and recording a series of metrics each time a littering or binning event was witnessed. Metrics were recorded on a templated form (Appendix C, page 374) that included: general demographics (estimate age and gender), distance to closest bin, method of disposal and, when possible, item disposed.

As the health and safety of observers was paramount, instructions were to remain on areas designated for pedestrian use and to never confront or approach an individual that was observed littering, since confrontation can at times lead to an aggressive response (Campbell, 2007).

Prior to the data collection sessions, regular street cleansing schedules were not interfered. However, to eliminate external behavioural influences, during observation sessions planning partners within local councils were instructed to request that cleansing crews avoid study sites. At each site data was collected on four separate occasions, where two sessions occurred during the day, 11:00-13:00 and the other two near the end of the day, 16:00-18:00.

Upon conclusion of each data collection exercise, observers reconvened and discussed any anomalies or insights they may have encountered during the session. These observations were submitted as additional notes alongside the templated observation forms. See Appendix D (page 375) for full list of comments from data collection sessions.

5.2.3. Analysis

Analysis was conducted using data collected via a convenience sampling of unobstructed waste disposal behaviours. Analysis was conducted on 1) frequency of littering, 2) disposal behaviour and distance to bin, 3) littering methods and 4) littering motivation. Data were analysed to generate simple graphs and proportional values were generated by dividing number of observations by the total sample. Further to this, as 71.1% of littering events occurred with the disposal of cigarette ends, proportions were reanalysed with cigarette end deposits omitted. Analysis was done for both the individual study sites as well as the cumulative sample (referred to as All Sites).

Although metrics such as gender and age were recorded, behaviour profiling was not the objective in this study and will not be emphasised in the analysis. There are two reasons for the omission of demographic data analysis. The first is because past research studies of this nature have been conducted across the globe and consistently generate conflicting or insignificant results (Beverage Industry Environment Council, 2001; Liu and Sibley, 2004; Schultz *et al.*, 2009; Wever *et al.*, 2010; Williams, 2015; Al-mosa, Parkinson and Rundle-Thiele, 2017). In fact, despite many efforts to profile those who litter, research is increasingly finding that there is more of a connection in how things are littered than in who litters (Beverage Industry Environment Council, 2001). The second is a matter of statistical significance. Convenience sampling is an example of non-probability sampling, meaning data can only be interpolated and not extrapolated (Farrokhi and Mahmoudi-Hamidabad, 2012). As a result, projections as to demographic predictors on littering behaviour will not be accurate. The use of non-parametric data does restrict available methods of analysis, however it presents opportunities for new insight in complex issues (Marshall, 1996).

Ultimately, the results of this analysis are to be considered an exploration into regional behaviour trends, and not representative of wider population behaviour.

5.3. Results

In all, 3,603 disposal observations were recorded over 192 discreet observational hours (Table 5.1).

Table 5.1 Data collection dates and number of observations collected for all 5 sites. A total of 192 hours were spent observing disposal behaviour resulting in a sample of 3,063 instances.

Site	Dates	Hours	Observations
SHS	04, 05, 11, 12 March 2016	24	485
OXM	19, 20, 25, 27 May 2016	32	768
NSB	03, 04, 10, 11 June 2016	16	263
LBL	06, 08, 20, 22 April 2017	32	512
BRI	28, 29 June and 01, 02 July 2017	84	1035
		192	**3063**

5.3.1. Littering frequency

Of the total disposal events (3,063), 37.3% (1,143) were littered and 62.7% (1,920) were binned. Binning was more frequent than littering in all but one site NSB (55.9% littered). Two sites experienced littering rates that were lower than the All Sites (37.3%) sample, SHS (22.7%) and LBL (22.5%); interestingly both these sites are located in the Greater London Area (GLA). Littering rates were highest in cigarette disposal, accounting for a 15.2% inflation in overall littering frequency across All Sites (15.2% = 37.3% - 22.1%). See Table 5.2 for detailed results.

Table 5.2 Proportions disposal events by instances of littering and binning for each site. Includes full sample proportions as well as instances pertaining solely to cigarettes and those that did not include cigarettes. Generally, more instances of binning were observed, although cigarettes were littered more often than not.

Site	*N*	Littered	Binned
SHS	***485***	**22.70%**	**77.30%**
Cigarettes	*228*	*35.10%*	*64.90%*
Non-Cigarettes	*257*	*11.70%*	*88.30%*
OXM	***768***	**45.10%**	**54.90%**
Cigarettes	*436*	*59.60%*	*40.40%*
Non-Cigarettes	*332*	*25.90%*	*74.10%*
NSB	***263***	**55.90%**	**44.10%**
Cigarettes	*141*	*61.70%*	*38.30%*
Non-Cigarettes	*122*	*49.20%*	*50.80%*
LBL	***512***	**22.50%**	**77.50%**
Cigarettes	*265*	*32.50%*	*67.50%*
Non-Cigarettes	*247*	*11.70%*	*88.30%*
BRI	***1035***	**41.10%**	**58.90%**
Cigarettes	*501*	*59.90%*	*40.10%*
Non-Cigarettes	*534*	*23.40%*	*76.60%*
All Sites	***3063***	**37.30%**	**62.70%**
Cigarettes	*1571*	*51.80%*	*48.20%*
Non-Cigarettes	*1492*	*22.10%*	*77.90%*

Cigarette disposal (1,571) accounted for 51.3% of the total sample (3,063), where 51.8% (813) were littered and 48.2% (758) were binned. Generally, cigarettes were more frequently littered than binned, however not all individual sites experienced this trend; binning of cigarettes was more prevalent in both GLA sites, SHS (64.9%) and LBL (67.5%).

Non-cigarette disposal accounted for 48.7% (1,492) of the total sample (3,063); where 22.1% were littered (330) and 77.9% were binned (1,162). Across all sites, non-cigarette items were binned more frequently than they were littered. Two sites experienced higher non-cigarette binning rates than All Sites (77.9%), they again were both GLA sites, SHS (88.3%) and LBL (88.3%).

5.3.2. Distance to bin

Past research has investigated proximity to bins as a metric when analysing littering behaviour, with the specific distance of 5 metres consistent amongst studies (Williams, Curnow and Streker, 1997; Williams, 2015; Keep America Beautiful, 2021). There are however mixed results, where studies in the USA report a reduction in littering while bins are nearby (Meeker, 1997; Keep America Beautiful, 2009), yet studies in Australia noticed little influence on behaviour (Beverage Industry Environment Council, 2001).

In this study, littering rates were 21.1% lower across All Sites when within 5 metres of a bin (21.1% = 52.2% - 31.2%). All sites experienced higher instances of littering with increased distance from a bin; although in the case of SHS and LBL, binning behaviour maintained the majority of documented events (where > 50% were binned when beyond 5 metres of a bin). See Table 5.3 for full results.

Across All Sites, cigarette littering was greatly influenced by proximity to bins, where littering events dropped by 27.1% (27.1% = 70.7% - 43.6%); as opposed to non-cigarette littering, which only saw a 13.2% reduction (13.2% = 31.6% - 18.4%).

Table 5.3 Instances of disposal behaviour in relation to distance from closest bin in each site. Includes full sample proportions as well as instances pertaining solely to cigarettes and those that did not include cigarettes. Generally, more instances of littering increased as distance from bin increased.

	Within 5 Metres			**Beyond 5 Metres**		
Site	***N***	**Binned**	**Littered**	***N***	**Binned**	**Littered**
SHS	***371***	**84.60%**	**15.40%**	***114***	**53.50%**	**46.50%**
Cigarettes	*161*	*77.00%*	*23.00%*	*67*	*35.80%*	*64.20%*
Non-Cigarettes	*210*	*90.50%*	*9.50%*	*47*	*78.70%*	*21.30%*
OXM	***571***	**61.30%**	**38.70%**	***197***	**36.50%**	**63.50%**
Cigarettes	*289*	*43.30%*	*56.70%*	*147*	*34.70%*	*65.30%*
Non-Cigarettes	*282*	*79.80%*	*20.20%*	*50*	*42.00%*	*58.00%*
NSB	***162***	**46.30%**	**53.70%**	***101***	**40.60%**	**59.40%**
Cigarettes	*91*	*42.90%*	*57.10%*	*50*	*30.00%*	*70.00%*
Non-Cigarettes	*71*	*50.70%*	*49.30%*	*51*	*51.00%*	*49.00%*
LBL	***384***	**82.80%**	**17.20%**	***128***	**61.70%**	**38.30%**
Cigarettes	*191*	*79.10%*	*20.90%*	*74*	*37.80%*	*62.20%*
Non-Cigarettes	*193*	*86.50%*	*13.50%*	*54*	*94.40%*	*5.60%*
BRI	***683***	**64.00%**	**36.00%**	***352***	**49.10%**	**50.90%**
Cigarettes	*368*	*49.20%*	*50.80%*	*133*	*15.00%*	*85.00%*
Non-Cigarettes	*315*	*81.30%*	*18.70%*	*219*	*69.90%*	*30.10%*
All Sites	***2171***	**68.80%**	**31.20%**	***892***	**47.80%**	**52.20%**
Cigarettes	*1100*	*56.40%*	*43.60%*	*471*	*29.30%*	*70.70%*
Non-Cigarettes	*1071*	*81.60%*	*18.40%*	*421*	*68.40%*	*31.60%*

5.3.3. Polite littering

During this exercise, an alarming trend in littering behaviour was observed, Polite Littering. British culture has long been known as one that values civility and politeness (Brown, Levinson and Levinson, 1987, 1987; Klein, 1989; Sifianou, 1999; Peltonen, 2003). Since the early eighteenth century, politeness has been considered a quality of the upper classes, and those who did not belong to the elite strove to emulate politeness as a way to augment their social standings (Klein, 2013) This tendency towards politeness continues in modern British national identity (Floyd *et al.*, 2018; Floyd, 2021). In observing littering behaviour for this study, a pattern of what can only be described as *Polite Littering* emerged.

Figure 5.2 Examples of Polite Littering: Bottle of prosecco placed on fuse box at LBL site (2017) and coffee cup placed on a fence (2019). Photo credit Randa L Kachef.

Polite Littering occurs when an individual is faced with the need to dispose of an item yet cannot find a bin. In lieu of flagrantly throwing it on the ground, many of those observed chose to place their rubbish on structures, such as ledges, fences (Figure 5.2), planting pots (Figure 5.3 Examples of Polite Littering: Coffee cup placed in planter at NSB site (2016) and tins wrapped in paper bags placed in bushes (2017). Photo credit Randa L Kachef.Figure 5.3), salt and grit bins and any other bin lookalike items nearby (Figure 5.4, page 151).

Figure 5.3 Examples of Polite Littering: Coffee cup placed in planter at NSB site (2016) and tins wrapped in paper bags placed in bushes (2017). Photo credit Randa L Kachef.

In this act of *Polite Littering*, the behaviour of the individual suggests that they are aware that littering in its traditional sense is frowned upon. Polite Litterers choose not to throw litter on the ground, yet are not prepared to commit to carrying the item home or at least until a bin can be found.

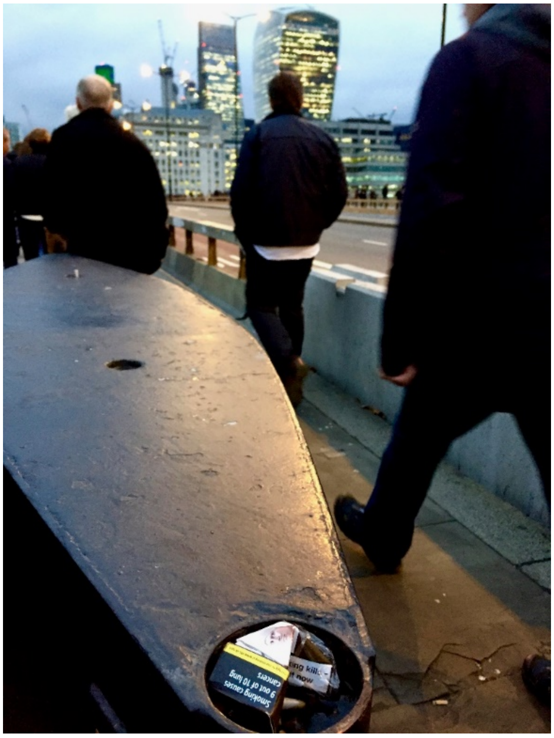

Figure 5.4 Examples of Polite Littering, in clockwise order from top left: Cigarette ends placed in decorative vent on Bush House façade (2022), cigarette packet placed in recession in terrorist barriers on London Bridge (LBL, 2017), cigarette ends in salt and grit bin at LBL site (2017), drink containers placed on top of non-functional coffee cup recycling bin (2017), takeaway box and food wrappings placed in broken light fixture at LBL site (2017). Photo credit Randa L Kachef.

5.3.4. Method of littering

A total of 1,143 littering events were recorded across All Sites. Nine different methods of littering were identified in the literature review and included in the templated data collection forms[10] (Table 5.4), these methods are defined in previous behavioural studies and borrowed for this study in the interest of consistency and comparison if desired (Williams, Curnow and Streker, 1997; Beverage Industry Environment Council, 2001; Campbell, 2007; Schultz *et al.*, 2009; Williams, 2015). These littering methods fall under three broad categories of intent: Intentional, Polite Littering and Unintentional.

Table 5.4 Descriptions of 9 different methods of littering: flagrant, shoot and miss, fell out of bin – noticed, drop – noticed, next to bin, in non-bin receptacle, left behind, fell out of bin – did not notice, drop - did not notice. Includes level of intent for each method: intentional, polite and unintentional.

Method	Description	Intent
Flagrant	Litter is thrown directly on the ground.	Intentional
Shoot and miss	Litter is thrown at the bin however does not enter the receptacle. In this instance the offender is aware of the miss and leaves littered items where they land.	Intentional
Fell out of bin, noticed	Individual attempts to bin their litter, however the item falls out of the bin as it is too full, or the opening is obstructed. In this instance the offender is aware that the litter has fallen and decides to leave it on the ground.	Intentional
Accidental drop, noticed	Litter item is dropped accidently however the individual is aware of the drop. In this instance the offender chooses not to collect their dropped item.	Intentional
Next to bin	When a bin is full or the opening obstructed, litter is neatly placed on the ground next to the bin.	Polite
In non bin receptacle	Litter is placed on or in a receptacle that is not intended for disposal. A non-bin receptable can be a ledge, hedge, fence, salt and grit bin, an uncovered lamp and so on. Individuals were often rather creative.	Polite
Left behind	Individual is seated at a table or bench, places litter items on table or bench and leaves items behind when they leave the location.	Polite
Fell out of bin, did not notice	Individual attempts to bin their litter, however the item falls out of the bin as it is too full, or the opening is obstructed. In this instance the offender is not aware that the litter has fallen.	Unintentional
Accidental drop, did not notice	Litter items are dropped without the individual being aware. This often happened while removing something from a pocket or bag causing another item to drop.	Unintentional

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[10] Although included on templated forms, two methods of littering (accidental drop, noticed and fell out of bin, noticed) were not recorded and thus omitted from the results.

Of the total sample (1,143), 70.2% (802) of littering events were flagrant, however cigarettes accounted for 87.3% (700) of these instances. The two most common littering methods of non-cigarettes were flagrant (30.9%, 102 items) and placed in a non-bin receptacle (25.8%, 85 items); a typical example of Polite Littering. See

Table 5.5 for full results.

Table 5.5 Proportions of littering observations in each site grouped by method of littering. Includes full sample proportions as well as instances pertaining solely to cigarettes and those that did not include cigarettes. Generally, cigarette ends accounted for the largest proportion of flagrant littering, while non-cigarette littering was typically done by placing items in non-bin receptacles.

Site	*N*	Flagrant	Shoot and miss	Next to bin	In non-bin receptacle	Left behind	Fell out of bin	Drop did not notice
SHS	***110***	**58.2%**	**2.7%**	**14.5%**	**5.5%**	**10.0%**	**6.4%**	**2.7%**
Cigarettes	*80*	*65.0%*	*1.3%*	*20.0%*	*1.3%*	*12.5%*	*0.0%*	*0.0%*
Non-Cigarettes	*30*	*40.0%*	*6.7%*	*0.0%*	*16.7%*	*3.3%*	*23.3%*	*10.0%*
OXM	***346***	**77.5%**	**2.9%**	**1.7%**	**4.9%**	**9.0%**	**0.0%**	**4.0%**
Cigarettes	*260*	*89.2%*	*1.9%*	*0.0%*	*0.4%*	*8.1%*	*0.0%*	*0.4%*
Non-Cigarettes	*86*	*41.9%*	*5.8%*	*7.0%*	*18.6%*	*11.6%*	*0.0%*	*15.1%*
NSB	***147***	**63.3%**	**6.1%**	**4.8%**	**5.4%**	**7.5%**	**4.8%**	**8.2%**
Cigarettes	*87*	*81.6%*	*4.6%*	*2.3%*	*1.1%*	*6.9%*	*2.3%*	*1.1%*
Non-Cigarettes	*60*	*36.7%*	*8.3%*	*8.3%*	*11.7%*	*8.3%*	*8.3%*	*18.3%*
LBL	***115***	**74.8%**	**5.2%**	**5.2%**	**7.8%**	**1.7%**	**0.0%**	**5.2%**
Cigarettes	*86*	*93.0%*	*1.2%*	*5.8%*	*0.0%*	*0.0%*	*0.0%*	*0.0%*
Non-Cigarettes	*29*	*20.7%*	*17.2%*	*3.4%*	*31.0%*	*6.9%*	*0.0%*	*20.7%*
BRI	***425***	**68.5%**	**1.2%**	**3.3%**	**12.7%**	**11.5%**	**0.5%**	**2.4%**
Cigarettes	*300*	*88.3%*	*0.7%*	*2.0%*	*2.0%*	*6.3%*	*0.0%*	*0.7%*
Non-Cigarettes	*125*	*20.8%*	*2.4%*	*6.4%*	*38.4%*	*24.0%*	*1.6%*	*6.4%*
All Sites	***1143***	**70.2%**	**2.9%**	**4.3%**	**8.2%**	**9.1%**	**1.4%**	**3.9%**
Cigarettes	*813*	*86.1%*	*1.6%*	*3.6%*	*1.1%*	*6.9%*	*0.2%*	*0.5%*
Non-Cigarettes	*330*	*30.9%*	*6.1%*	*6.1%*	*25.8%*	*14.5%*	*4.2%*	*12.4%*

5.3.5. Littering intent

Methods of littering were categorised by three forms of intent: Intentional, Polite and Unintentional (Table 5.4, page 152). In Table 5.6 on the following page, the sample is pooled by intent.

The most frequent littering intent across All Sites was Intentional, accounting for 74.5% (851) of littering events, followed by 21.6% (247) Polite events and finally, 3.9% (45) were considered Polite Littering. Although instances of Intentional littering maintain the majority in individual sites, proportions of Unintentional and Polite Littering fluctuate greatly from site to site.

Table 5.6 Proportions of littering observations in each site grouped by littering intent. Includes full sample proportions as well as instances pertaining solely to cigarettes and those that did not include cigarettes. Generally, intentional littering was the most common intent, however proportions are differently distributed by site and when cigarettes are omitted.

Site	*N*	Intentional	Polite	Unintentional
SHS	**110**	**60.9%**	**30.0%**	**9.1%**
Cigarettes	*80*	*66.3%*	*33.8%*	*0.0%*
Non-Cigarettes	*30*	*46.7%*	*20.0%*	*33.3%*
OXM	**346**	**80.3%**	**15.6%**	**4.0%**
Cigarettes	*260*	*91.2%*	*8.5%*	*0.4%*
Non-Cigarettes	*86*	*47.7%*	*37.2%*	*15.1%*
NSB	**147**	**69.4%**	**17.7%**	**12.9%**
Cigarettes	*87*	*86.2%*	*10.3%*	*3.4%*
Non-Cigarettes	*60*	*45.0%*	*28.3%*	*26.7%*
LBL	**115**	**80.0%**	**14.8%**	**5.2%**
Cigarettes	*86*	*94.2%*	*5.8%*	*0.0%*
Non-Cigarettes	*29*	*37.9%*	*41.4%*	*20.7%*
BRI	**425**	**69.6%**	**27.5%**	**2.8%**
Cigarettes	*300*	*89.0%*	*10.3%*	*0.7%*
Non-Cigarettes	*125*	*23.2%*	*68.8%*	*8.0%*
All Sites	**1143**	**73.1%**	**21.6%**	**5.3%**
Cigarettes	*813*	*87.7%*	*11.6%*	*0.7%*
Non-Cigarettes	*330*	*37.0%*	*46.4%*	*16.7%*

Intently littered cigarettes were the single most occurring event, accounting for 62.4% (713) of the total sample of littering events (1,143), maintaining the most frequent method of cigarette disposal among individual sites. Cigarettes were far less frequently littered via Polite (11.6%) or Unintentional (0.7%) means.

Of the All Sites sample, Polite Littering was the main means of disposal in non-cigarette related littering events (46.4%), with 37% Intentional (122), and 16.7% Unintentional (55). Polite Littering accounted for the highest proportion of non-cigarette disposal in LBL (41.4%) and BRI (68.8%), maintaining a strong presence in

OXM (37.2%) and NSB (28.3%). With the exception of SHS (33.3%) and NSB (26.7%) Unintentional means typically contributed marginally to littering methods.

5.4. Overview

Generally, items were more frequently binned (62.7%) than littered (37.3%), a proportion that was augmented when focusing on non-cigarette items, of which 77.9% were binned (22.1% littered). However, the proportion of cigarette ends that were littered (51.8%) to those binned (48.2%) was far closer and in favour of littering. This general trend of non-cigarette binning was consistent across all sites, however the proportions varied enough where at times the influence of littered cigarette ends resulted in closer margins, or even reversed trends in full site statistics. This information is consistent with global statistics that cigarettes are the most abundant and frequently littered item (Novotny *et al.*, 2009; Torkashvand *et al.*, 2021).

Being within 5 metres of a bin led to a 21.1% decrease in littering behaviour. As promising as this may seem, there was often an issue of lack of bins within the study sites (e.g., only 3 bins were present in the London Bridge, London (LBL) study site).

Cigarettes (813 littered) accounted for 71.1% of all recorded littering events (1,143) and were littered Intentionally 87.7% of the time. Polite Littering accounted for almost half (46.4%) of all documented non-cigarette related littering events. Coupled with Unintentional methods, 63% of observed non-cigarette littering was considered passive. This included instances where litter was placed on structures, in a non-bin receptacle or next to an overflowing bin.

Unintentional and Polite Littering pose a variety of issues. Often, wind, rain, gravity, or foot traffic displaces neatly placed items from their original location, causing them to end up on the ground, thus turning the item into what is traditionally seen as litter. Once on the ground, litter acts as a green light to others to litter, as documented in the litter breeds litter effect (Powers, Osborne and Anderson, 1973; Geller, Witmer and Tuso, 1977; Reiter and Samuel, 1980).

5.5. Discussion

Due to complex social and cultural influences, predicting littering behaviour has resulted in little success in informing anti-littering interventions. By covertly observing public waste disposal, this study chose to investigate how litter is deposited, as opposed to traditional approaches that aim to discover who is depositing litter. In doing so, a series of peculiar waste disposal behaviours were documented.

Cigarette ends are considered the most commonly littered item in the world, where an estimate 4.95 trillion (equating to 1.2 million tons) are improperly disposed of every year (Kurmus and Mohajerani, 2021; Santos-Echeandía *et al.*, 2021). Observers repeatedly reported that due to the small size of cigarette ends it was difficult to observe this behaviour, often finding freshly littered cigarettes nearby without having witnessed the event. On several occasions a curious behaviour was reported during post-observation discussions. Observers often witnessed an individual bin an item, such as a drink container, then immediately litter a cigarette. Binning the first item clearly demonstrates that the understanding of proper binning responsibility is present, however littering the cigarette implies that there is a disconnect as to the fact that it is litter. Cigarettes aren't widely considered litter and the act of littering them is part of the smoking ritual (Rath *et al.*, 2012; Castaldi, Cecere and Zoli, 2021).

Observers also reported that cigarettes were often thrown directly down sewers. In doing this, the individual immediately eliminates the physical representation of their littering act, in essence absolving them of the act by removing the evidence. However, this habit allows for cigarette litter to have maximum negative impact. First, entering the sewer eliminates any potential for the cigarette end to be collected and disposed of through regular street cleansing efforts. Second, environmental contamination by cigarette ends is of rising concern; they are known to leach heavy metals, microplastics, nicotine, and thousands of toxic chemicals into aquatic environments (Register, 2000; Novotny *et al.*, 2009; Slaughter *et al.*, 2011; Green, Putschew and Nehls, 2014; Santos-Echeandía *et al.*, 2021). By depositing the cigarette end directly into a sewer, the individual is guaranteeing it will ultimately enter drinking water reserves.

The lack of bins in test sites was an unexpected factor in this study. When asked about bins during informal conversations, local council partners generally cited two reasons for this. First, acts of terrorism have been known to have involved bins as a way to conceal explosive devises, thus bins have historically been removed from high traffic areas, specifically intersections of public transport. Second, there appears to be a common agreement among councils that bins attract more litter than they collect, which has initiated a movement to remove them from public spaces. I have yet to find evidence of this and in fact, research consistently indicates that bins have a reducing effect on the amount of litter in a site (Finnie, 1973; Durdan, Reeder and Hecht, 1985; Cope *et al.*, 1993; Liu and Sibley, 2004; De Kort, McCalley and Midden, 2008; Schultz *et al.*, 2013; Becherucci and Seco Pon, 2014). Often when bins become full, the overflowing rubbish accumulates in their vicinity. This creates a disorderly and dirty scene (Seco Pon and Becherucci, 2012), which is likely reason for the perception that bins attract litter (as illustrated in Figure 5.5).

Figure 5.5 Image of overflowing bin causing litter despite good intention by those disposing of items.

Lack of bins appear to be one of the driving forces for Polite Littering, which accounted for 21.6% of all observed littering events. During post-session debriefs, several observers reported witnessing an individual searching for a bin, finally choosing to place their litter on a ledge in an act of Polite Littering. A Google search of “what is littering” emphasises that the common understanding of littering involves items being thrown carelessly and looking untidy. The Oxford English Dictionary defines litter with terms such as “disorderly”, “strewn”, “scattered about” and “untidy” (Oxford English Dictionary, 2021). The Cambridge Dictionary describes litter as “small pieces of rubbish that have been left lying on the ground in public places”, and the act of littering “to spread across an area or place untidily” or “to drop rubbish on the ground in a public place” (Cambridge Dictionary, 2021). Even the legal definition of littering in England describes littering as someone who “throws down” and “drops” items (UK GOV, 1990). By placing items neatly on structures, or tidily next to a bin, the act of Polite Littering does not fit into conventional descriptions of littering. In essence, Polite Litterers may believe their behaviour absolves themselves of environmental responsibility as it is not flagrant or untidy. As a result, Polite

Litterers are not aware that this behaviour is equally as impactful as simply throwing their litter on the ground. This insight is alarming as without the understanding that they are in fact littering, Polite Litterers are immune to anti-littering campaigns.

In post data collection sessions, several observers noted that litter items would often appear on non-bin receptacles without their witnessing the event. Given this feedback I believe many acts of Polite Littering were missed.

5.5.1. Accidental littering

Accidental instances of littering accounted for 12.4% of non-cigarette littering (referred to as ‘drop did not notice’ in analysis). Accidental littering is difficult to observe, and I suspect it is more prevalent than has been documented in this study. Accidental littering can occur under a number of scenarios (e.g., carrying too many items, pulling something out of a pocket etc.), yet is done without the individual being aware. English law does not suggest imposing fixed penalties to those who drop litter accidently (DEFRA, 2018a), resulting in the potential for a grey area in enforcement. The presence of accidentally generated litter does however have an equally promotional effect on littering as intentionally discarded items.

Smart packaging design is a potential to mitigate the issue of accidental littering. For example, original aluminium drink tins had a detachable tab to open, often causing them to be littered; littering of aluminium tabs was effectively eliminated by altering the design where the tab remained attached to the tin after it is opened, an approach that is referred to as a litter leash (illustrated in Figure 2.3, page 80) (Wever *et al.*, 2010).

5.5.2. Missed mitigation opportunities

By assuming conventional littering behaviour is the primary source of litter, low cost, long term, and efficient structural solutions are often missed. Take Figure 5.6 of a littered scene in South London. A street cleanser would report levels of litter in this area as high, and city councillors would in turn assume that action against littering would need to be taken, however would this be the most appropriate method of mitigation?

Figure 5.6 Litter strewn in the vicinity of a bin in a beautiful park setting. This appears to be the work of littering park patrons, however upon closer inspection the influence of wildlife have an effect on litter dispersal. Photo credit Randa L Kachef (2018).

During the Brighton data collection exercises, I was asked to provide demographic insight on those littering, to inform the council on how to tailor future anti-littering campaigns. During observation sessions, there were many bins available in the gardens and on the beach, yet litter was often found within their immediate vicinity. I was perplexed by this, and spent time observing bins with surrounding litter, such as the one pictured in Figure 5.7 (left side). It soon became clear that seagulls were taking binned items out of the bin and pulling them apart in search for food, in essence creating litter. Due to its seaside location, seagulls are a common sighting in

Brighton, so much so that their likeness adorns the official uniforms of the Brighton & Hove Albion Football Club.

This observation highlighted that the litter issues in Brighton were not simply a matter of behaviour, but one of bin design as well. Since reporting this to Brighton, public bins have been replaced with animal proof bins (Figure 5.7, right side).

Figure 5.7 Example of structural methods of litter mitigation when faced with vermin dispersal. Bin without top in Brighton (left, 2017) and new animal proof bins (right, 2019). Photo credit: Randa L Kachef.

It should be noted that the updated bins in Brighton effectively reduced the amount of litter generated by gulls as well as the influence on littering behaviour caused by the presence of litter. The bins however do not address any litter generated by people in the first instance, and have the potential to increase littering behaviour due to the design requiring the public touch the lid to access the bin, an undesirable feature to those who may perceive it as dirty.

Although not documented in this study, I speculate that the red fox (*Vulpes vulpes*) also has a substantial influence in litter dispersal and most likely the culprit of the disarray in the South London littered scene in Figure 5.6 (page 160). Known as an urban exploiter the red fox has increasingly been found to favour densely populated areas due to the increased availability to household food waste (Harris and Rayner, 1986; Harris and Trewhella, 1988; Scott *et al.*, 2014; DeCandia *et al.*, 2019; Handler, Lonsdorf and Ardia, 2020). Red foxes are nocturnal, choosing to scavenge for food and mate under the cover of darkness, however sightings have occurred during the day (Scott *et al.*, 2014). Few city dwellers in London can say they have escaped scattering of rubbish caused by the urban red fox when failing to secure lids on household bins; an issue that certainly occurs in public open top bins left unemptied overnight. Equally, there is potential for rats and the grey squirrel to generate similar scenes of littering.

This issue of vermin dispersal, where wildlife is responsible for litter in public spaces, can be addressed with small proactive structural changes. Further to the bin design solution illustrated in Brighton, bin emptying schedules can be tailored for fluctuations in patronage. By scheduling frequent street cleansings in high times of foot traffic (i.e., summer, weekends, during public events etc) and emptying bins at dusk, the opportunity to reduce littering issues caused by vermin, unsecure or overflowing bins significantly increase. In eliminating vermin dispersal, any subsequent promotion of littering by humans through the litter breeds litter effect is eradicated.

When items inadvertently become litter, as in the case of Unintentional and Polite Littering, the offender is completely unaware of the promotional effect they have on future littering behaviour. In the case of accidental littering (e.g., dropped reusable face masks), and vermin dispersal (e.g., seagulls removing rubbish from open top bins), investigation is the most powerful means of understanding and addressing the root cause of a local littering issues.

These examples of alternative methods of litter generation illustrate that behavioural intervention is not the most effective means of mitigation. By engaging in this form of littering (i.e., unintentional, polite, accidental etc), an individual is not aware of their responsibility in generating litter. In turn, campaigns geared to change littering behaviour often miss their mark, not effectively communicating to unintentional and Polite Litterers. This undermining of anti-littering campaigns results in wasted efforts and misuse of funds intended to promote environmentally conscious behaviour. Unfortunately, when anti-littering campaigns aren't successful, motivation to invest in them wane, resulting in funding cuts (Parker, Roper and Medway, 2015).

Attempting to approach littering through mitigation can have unintended consequences in terms of posing a significant risk to the environment, not only though continued input, but government led street cleansing efforts divert public funds away from other essential services. I suggest that in lieu of continued behavioural interventions, three alternative methods to litter mitigation be considered. First a rebranding or expansion of the terms litter and littering is crucial and must include both intentional and unintentional acts. Second, as the abundance of litter-able items has a direct relationship with unintentional littering, smarter product design must be implemented on a policy level, effectively redirecting environmental responsibility from the consumer/individual to the producer. Finally, structural changes to bin design and street maintenance schedules have the potential for permanent reduction of litter caused by vermin dispersal and subsequent promotion of public littering behaviour.

These three steps have a potential for permanent reductions in the abundance of litter found in an urban environment, particularly in a socially and culturally diverse setting such as England.

5.5.3. Lesson learnt

Litter and littering do not go hand in hand

Behaviour towards and deposition of litter is complex and varies regionally. The presence of litter does not always equate to littering.

Chapter 6: Transfer Dynamics of Litter: Introduction to new vectors of terrestrial litter

6.1. Introduction

Ancient Egypt is long credited as one of the most influential civilisations in history, progressing cultural developments that have led to the advent of modern complex societies (Yevjevich, 1992; Wilkinson, 2007; Vianello, 2015a). Ancient Egypt would never have come to fruition without freshwater resources carried by the Nile River, a life source that allowed for permanent settlement, and has rightfully earned the accolade of one of the Cradles of Civilization (Yevjevich, 1992; Wilkinson, 2007; Vianello, 2015a; Macklin and Lewin, 2020). In fact, rivers can be found at the heart of many great cities, where access to waterways has historically acted as the catalyst for strategic colonization (Everard and Moggridge, 2012; Cengiz, 2013; Phong, 2015; Vianello, 2015a). Unfortunately, the same cities that depend on rivers habitually exploit the resources they provide, leading to long term degradation, depletion, and contamination of freshwater reserves.

Originally, river settlements developed due to accessibility to fresh water for both human consumption and agricultural purposes; flooding of rivers provide nutrients to flood plains through sediment deposition which promotes successful cultivation (Phong, 2015; Vianello, 2015a, 2015b; Knoll, Lubken and Schott, 2017). Prior to the invention of the combustible engine, ships were the most efficient mode of travel, thus rivers and coastlines were essential to trade and transport, facilitating both economic and population growth (Vianello, 2015b; Knoll, Lubken and Schott, 2017). Rivers also provided access to inland settlements, acting as trade routes for domestic distribution of goods both for export and import (Knoll, Lubken and Schott, 2017).

In modern cities, rivers are a source of recreation and green space to urban dwellers and tourists, while simultaneously cooling surrounding areas and providing habitats for wildlife (Francis and Hoggart, 2009; Hathway and Sharples, 2012; Cengiz, 2013). Although still used in the trade of goods, today, rivers also supply public drinking water and act as a means for wastewater disposal in an urban setting (Findlay and Taylor, 2006; Even *et al.*, 2007; Glińska-Lewczuk *et al.*, 2016).

As advantageous as proximity of settlements to rivers can be to humans, the same cannot be said for the rivers. Humans have a long history of negatively affecting the environment (Schultz, 2002; Foley and Lahr, 2015), and precious resources such as waterways are no exception to this trend (Findlay and Taylor, 2006; Everard and Moggridge, 2012; Cengiz, 2013; Glińska-Lewczuk *et al.*, 2016).

As mentioned, rivers act both as a means to dispose of wastewater as well as a source of drinking water; a paradox that is addressed through the filtration and sanitation of water in both output (wastewater) and uptake (drinking water) systems (Field and Struzeski Jr, 1972; Long, Hulsey and Hoehn, 1999; Qasim, 2017; Crini and Lichtfouse, 2019). Although, in theory, this system is designed to maintain a balance, it is not without its flaws, and the integrity of urban rivers around the world is steadily declining (Findlay and Taylor, 2006; Everard and Moggridge, 2012; Glińska-Lewczuk *et al.*, 2016). Urban development and population growth impose three distinct stressors on local rivers: degradation of water quality, depletion of water quantity and a sink for macro-pollution waste.

Examples of this abusive relationship between humans and rivers can be seen in the biologically dead rivers of São Paulo Brazil, where the dumping of untreated wastewater straight into the Tietê and Pinheiros rivers has led to severe contamination of drinking water supplies (Harding, 1992; Groppo *et al.*, 2008; Barbosa Merg, 2019); and in the over extraction of the mighty Colorado River in Southwestern USA, which has depleted it to mere trickle by the time it reaches the Gulf of California (Woodhouse, Gray and Meko, 2006; Rajagopalan *et al.*, 2009; Summit, 2013; Brusca *et al.*, 2017). The stories of the dead rivers of São Paulo and over extraction in the Colorado River are examples of identifiable sources of water resource stressors. The contribution of the final stressor, macro-pollution, is unique as there is little research on the factors that lead to their contribution.

Macro-pollution is commonly referred to as litter. Litter differs from dissolvable contaminants, such as chemical contamination, as it can be easily seen. The nature of litter varies greatly, from discarded food packaging to cigarette ends, but one common quality remains amongst litter items, that their primary use has been exhausted (as discussed and evidenced in Chapter 4: Litter Source Dynamics). Litter is generally agreed to be a product of human activity and humans are considered the primary contributor of river litter (Liro *et al.*, 2020). Little is known about the quantities of litter currently residing in river environments, estimations on the global yearly input of terrestrial litter to rivers range from 0.8 million tonnes (Ryberg *et al.*, 2019) to 4.2 million tonnes (Lechthaler *et al.*, 2020). Despite discrepancies in contribution estimates, experts unanimously agree that the frequency of land-based litter is directly related to the quantity of litter that enters a river environment (Mehlhart and Blepp, 2012; Best, 2019; van Emmerik and Schwarz, 2020).

The presence of litter in river systems poses a variety of threats to its health and the wellbeing of the ecosystems that reside within and depend on it. The most obvious of these repercussions is the potential for wildlife entanglement, causing restricted mobility to fish, waterfowl and other aquatic fauna, resulting in grave injury or death (Lambert, Sinclair and Boxall, 2014; van Emmerik and Schwarz, 2020). Wildlife is also prone to the ingestion of litter, where undigestible items remain in their guts and lead to injury or death (Wilcox, Van Sebille and Hardesty, 2015).

Litter in rivers are often colonized by organisms such as barnacles, mollusks and aquatic based larvae (Barnes, 2002; Lambert, Sinclair and Boxall, 2014; Weideman *et al.*, 2020). As persistent and lightweight items are easily transported, colonized litter acts as a vessel for long distance travel, more than doubling the distribution of these organisms, ultimately leading to the proliferation of invasive species (Barnes, 2002). Within the water column, submerged items accumulate on the riverbed, blocking sunlight and smothering aquatic fauna (Storrier and McGlashan, 2006).

Larger littered items in rivers are known to cause damage to boats (Honingh *et al.*, 2020; van Emmerik and Schwarz, 2020) and their presence deteriorates the aesthetics of rivers, having a negative impact on tourism (van Emmerik and Schwarz, 2020). Litter is known to clog urban sewage and drainage systems, not only resulting in costly repairs, but augmenting the risk of flooding (Honingh *et al.*, 2020; van Emmerik and Schwarz, 2020).

Littered items that have toxic components are known to leach chemicals into water, contaminating drinking water resources (Novotny *et al.*, 2009; van Emmerik and Schwarz, 2020; Santos-Echeandía *et al.*, 2021). Through flow action, abrasion and attrition, persistent plastic-based litter items are subject to wear and tear, ultimately fragmenting into micro-pieces (< 5 mm), known as microplastics (Lambert, Sinclair and Boxall, 2014; European Commission, 2016; van Emmerik and Schwarz, 2020). Microplastic ingestion is an emerging risk to human health and generating increased research and attention (European Union, 2019). It is becoming abundantly clear that the issue of litter is a threat to the wellbeing of urban rivers and the cities that depend on them.

London is a thriving international city that can trace its success to its strategic location along the tidal river Thames (Francis and Hoggart, 2009; Zahedieh, 2010). However it too is guilty of mismanaging the waters that birthed it, where half a century ago the portion of the Thames that runs through Central London, much like the rivers of São Paulo, was declared a dead river (Francis and Hoggart, 2009; McConville *et al.*, 2020). Through mitigative techniques, primarily restricting the direct dumping of industrial waste into the Thames, the river has experienced a regeneration and is currently considered one of the cleanest rivers in Europe, supporting over 120 different species of fish (Francis and Hoggart, 2009; McConville *et al.*, 2020; Rowley *et al.*, 2020). This regeneration however does not account for macro-waste contamination, where speculation is that litter quantities are steadily increasing (Port of London Authority, 2015; Rowley *et al.*, 2020).

Every year, the Port of London Authority collects approximately 300 tonnes of litter from the Thames (Port of London Authority, 2015) and non-profit organizations such as Thames 21 collect tens of thousands of litter items from the foreshore every month (McConville *et al.*, 2020). These numbers only account for surface water litter loads, and research has found that depending on weight and material, litter items can be found not only on the surface but suspended within the water column as well as settled in the riverbed (Morritt *et al.*, 2014; van Emmerik and Schwarz, 2020).

Although little is known about how litter is deposited into rivers, a look at the composition of littered items can lead to clues as to their origin (Carpenter and Wolverton, 2017; Treilles *et al.*, 2021). Inventories of collected items hint that up to one quarter of litter found in the Thames is deposited directly from households via sewage systems, consisting primarily of items such as wet wipes and sanitary products (Morritt *et al.*, 2014; McConville *et al.*, 2020). This is consistent with general estimates of wastewater contribution of river litter loads across the globe (Lechthaler *et al.*, 2020), and is the result of untreated sewer overflow into rivers during intense periods of rainfall (McCoy *et al.*, 2020; Roebroek *et al.*, 2021; Treilles *et al.*, 2021). In addition to household wastewater contribution, cigarette ends are often observed being littered directly into sewage drains, increasing their potential for river intrusion and subsequent water contamination (as observed in *Chapter 5: Litter Deposit Methods*).

Litter inventories have identified that 47% of the litter in the Thames consists of drink bottles and take-away food containers (Port of London Authority, 2015), items that are too large to be transported via sewage systems and don’t typically originate from in-home activities (Schirinzi *et al.*, 2020). These are items that are typically consumed on-the-go or in public spaces, and as there are laws against direct dumping of waste into the Thames, this raises the question as to how they are entering the river.

There is some speculation on the factors that cause terrestrial litter to enter rivers, these include wind and rain; where ease of transport is dependent on item weight, base material, terrain incline and percentage of impervious (Lambert, Sinclair and Boxall, 2014; Lebreton *et al.*, 2017; Honingh *et al.*, 2020; Lechthaler *et al.*, 2020; Schirinzi *et al.*, 2020; Roebroek *et al.*, 2021; Cowger *et al.*, 2022). Quantification of the influence of these terrestrial vectors on land-based litter, as well as their overall contribution to river litter loads, has not yet been attempted (Roebroek *et al.*, 2021).

In observational studies outlined in Chapter 5: Litter Deposit Methods, observer comments brought up the potential for a third geomorphic agent in terrestrial transfer dynamics. Along with wind and rain, a theory developed that humans, through foot traffic, kicking and sweeping of surfaces, can act as a method for litter dispersal.

Through mining, agriculture, riparian erosional defences and habitat development, humans are now considered the most influential force in changing landscapes (Hooke, 2000; Church, 2010; Harden, 2014; Cendrero *et al.*, 2020). Although these are examples of mass movement, spanning continents, research has identified the impact of footsteps on vegetation, particle suspension, soil compaction and erosion, sand dune formation, and more significant to this research, sediment displacement (Valentine and Dolan, 1979; Whitecotton *et al.*, 2000; Gomes, Freihaut and Bahnfleth, 2007; Wilkinson and McElroy, 2007; Barale, 2015). If humans and foot traffic can be categorised as geomorphic agents of equal or greater influence in transfer dynamics of natural surface materials, they surely should be considered in the displacement of anthropogenic produced materials such a litter.

This study initiates the exploration of the influence of foot traffic in litter dispersal and the subsequent contribution to river litter loads. To achieve this, a trial study was conducted by placing GPS tracked litter items in a high footfall event along the banks of the river Thames in West London, UK.

Question: How does land-based litter move?

Hypothesis: Although meteorological influence is highly sited as the major influencer of litter movement, no value has yet been established to the influence human activity has as a vector for litter transport.

6.2. Methodology

To illustrate the effects of footfall on litter transport, partners in this study chose to conduct this survey during a high footfall public event that takes place yearly on the banks of the Thames in Putney, West London.

6.2.1. Study site

The event was the Oxford vs Cambridge Boat Race, held on Sunday 2nd April, 2017 from 16:30 to 18:00. In 2017 the Boat Race was attended by over 250,000 spectators congregated along the south bank of the Thames from the start line at Putney Bridge and west through to the finish line at Chiswick Bridge (ARUP Group, 2017). The event attracts large crowds not only to view the race, but equally to attend entertainment events and frequent food and drink stands along the banks of the Thames. By choosing a popular riverside event with defined borders, this test site allowed for the trackers to be under the influence of high footfall within a controlled space.

The study site extended along the southern bank of the Thames for a length of 1 km northwest of Putney Bridge (Figure 6.1).

Figure 6.1 Map depicting the location of study site within the Greater London Area, highlighting the proximity to the river Thames.

The site includes three different riverside environments, where the south eastern portion features a tall concrete embankment, followed by a concrete slipway with a gradual slope allowing transport of rowboats into the river, followed by another embankment and finally the northern portion remains untouched with a natural vegetation covered slope (as illustrated in Figure 6.2).

Figure 6.2 Map of Putney study site highlighting the different riverside environments: embankment, slipway, and slope.

6.2.2. Materials

For this study, plastic bottles were equipped with GPS trackers, the standard for tracking studies of similar nature (Tramoy *et al.*, 2020; Newbould, 2021). It was important to ensure the housing was not only representative of existing items of litter, but were also watertight, buoyant, opaque, and robust. Based on these criteria it was decided drink bottles with large labels that wrap entirely around the bottle would best hide the GPS components housed inside (Figure 6.3). To this effect, Lucozade bottles were chosen as their labels offered full coverage of the bottle and have consistently been identified as the number one littered brand of small plastic bottle, accounting for 17% of bottle litter in England (DEFRA, 2020).

Figure 6.3 Photo of completed GPS transmitters in plastic bottles. Lucozade bottles were chosen to house GPS units as not only do they feature full coverage labels, concealing contents, but they account for a large portion of bottle litter in England.

Completed bottles, including GPS units and batteries weighed approximately 147g. Once deposited, the GPS units transmitted their coordinates at pre-programmed intervals within a 5-metre accuracy and included an accelerometer. See Appendix E (page 377) for detailed instructions on build process and Appendix F (page 380) for data collection and formatting process.

6.2.3. Research Design

Ten bottles were deposited during the Oxford vs Cambridge boat race. The bottles were distributed at relatively equal intervals within a distance of approximately 1 km northwest of Putney Bridge (Figure 6.1, page 173), which was the start line of the race as well as the most south-easterly boundary of the event.

The designated test site was surveyed initially for areas with items of litter that had already been deposited. When an existing item of litter was identified, it was replaced by one of the bottles fitted with a GPS tracker. The item of existing litter was then collected and placed in an appropriate bin, effectively removing one item (often more) from the environment while simultaneously depositing one. This process was executed with discretion as to not draw attention to the bottles equipped with trackers.

Before distributing the bottles, an initial command was sent to all bottles to begin reporting their GPS coordinates at a 10-minute interval. As each bottle was deposited, a photo was taken of its location and the current time and bottle number was noted.

In an effort to mitigate any environmental impact the study may have, the site was visited 27 hours after bottles were released. For bottles that had lost signal, the last known location was visited. As the primary purpose of bottles that had lost signal was exhausted, visiting the last known location allowed for the recollection of GPS units and ensured that as few bottles as possible remained in the environment. Bottles that remained active were avoided and left to continue their journey.

During this site visit the paths of bottles that had left the test site were also visited. This was done to ground proof their journey and gain insight on how or why they may have come to those locations.

6.2.4. Analysis

The data collection process was considered complete when all trackers had stopped sending location data. Once all signals had ceased, a CSV file was downloaded with data from all bottles. See Appendix F (page 380) for detailed instructions on the data collection and formatting process.

6.2.4.1. Import to QGIS

The CSV was imported into QGIS using the Add Delimited Text Layer function which generated a shapefile assigning data from the Latitude column to the Y axis and the Longitude column to the X axis. This created a single shapefile with points in the location of every data point received from all GPS units. A separate shapefile was then generated for each bottle. All maps presented in results are set to the WGS 84 EPSG:27700 coordinate reference system and feature the Positron basemap provided by Geoapify (Geoapify, 2022).

6.2.4.2. Deposit and end locations

To illustrate the specific deposit and end locations of each bottle, the first and last data points in each bottle shapefile were selected in the attribute table and saved as separate layers. Once isolated, a 5-metre buffer was applied to both the first and last location layers. This was done to account for the 5-metre accuracy stated in the GPS manufacturer's specifications.

Once layers were generated for deposit location, the distance from Putney Bridge and the distance between each deposit site was calculated.

Distance from Putney Bridge was calculated using the Join by Lines (hub lines) tool, which is a QGIS built in function of Vector analysis. To run the tool, first a layer titled PutneyBridge was created which included one point at the Bridge and was assigned an ID value of 1. In a single layer containing all deposit sites (AllDep), a column was created titled HubID and each row was also assigned a value of 1. In executing the Join by Lines (hub lines) tool, Hub layer was set to PutneyBridge, Hub ID field set to the ID column with the 1 value, Spoke layer set to AllDep, Spoke ID field set to HubID and Create geodesic lines was deselected. In the attribute table of the resulting layer, titled DistToPut, a new column was generated and the $length function in the field calculator was used to calculate the distance from Putney Bridge to each deposit location.

Distance between each deposit location was calculated using the Geodesic Measurement Layer tool within the QGIS Shape Tools plugin (Hamilton, 2022). First, the QGIS built in Points to Path tool was executed on the AllDep layer, ensuring that the Order field followed the shortest distance between each point. This resulted in a line layer connecting all deposit locations and was named AllDepPath. The Geodesic Measurement Layer tool was then executed using the AllDepPath layer, Measure total length rather than each line segment was deselected and units were set to metres. This generated a layer illustrating the distance between each deposit location.

6.2.4.3. Bottle travel paths

Simplifying the Data

The precision of GPS coordinates are dependent on the number of mobile towers available for triangulation (Lee *et al.*, 2016) and at times a GPS unit will report slight changes in coordinates despite remaining static. To account for this, the data were simplified to eliminate sequential points that were present within a 5-metre area[11].

To simplify the data, the QGIS Shape Tools plugin (Hamilton, 2022) was used. Within the plugin, the Geodesic Point Decimate function was applied to each bottle dataset. In execution, Point order field was set to the Time column and Point grouping field was set to the Date column. Both options to Preserve final point and Remove points that are less than the minimum distance were selected and Minimum Distance between points was set to 5 metres. Remaining time field settings were left blank. This generated simplified datasets which resulted in cleaner visual representation and reduced the effects of GPS jitter.

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[11] In line with defined location accuracy in manufacturer specifications.

Illustrating Paths

To illustrate the path of each bottle, the simplified datasets were run through the Points to Path function. In execution, Order field was set to the Time column and Group field was set to the Date column, ensuring the resulting path maintained the sequential order.

Once a simplified path layer was created for each bottle, the distance of each path was calculated in the Attribute Table. This resulted in distance travelled for each day active and was collated in Excel to calculate the total distance travelled.

6.2.4.4. Standard deviational ellipse

Standard deviational ellipses are a tool often used to illustrate the spatial trend among point data (Yuill, 1971; ESRI, 2009). In executing an ellipse, the mean location of points in the data set is determined and the standard deviation of each point to the mean is then calculated (Yuill, 1971; ESRI, 2009). The resulting shapefile, which is represented in a singular oval shape, generates three metrics which can then be used to describe the dataset; mean point location (ellipse centre), concentration (area of ellipse) and distribution (eccentricity of ellipse) (Yuill, 1971).

To compare the difference between instances of high and low footfall, an ellipse was executed not only for the full dataset of each bottle, but also for each day the GPS tracker remained active. Bottle data were subdivided by selecting all points within each Date in the Attribute Table, exporting the selected data and saving each subset as a new shapefile. Note that the data used in ellipse analysis was the full point dataset and not the simplified layers created in section 6.2.4.3. Bottle travel paths.

Ellipses were generated using The QGIS Standard Deviational Ellipse Plugin (Tveite, 2018). In execution, no weighting was applied, Method used was Yuill and Corrections were set to sqrt(2).

Mean Point Location

To analyse mean travel distance, the difference between the ellipse centre and actual deposition location was measured. To do this, the resulting meanx and meany coordinates were collected from attribute tables of each completed ellipses and used to create a new point shapefile called EllipseCentre. A second shapefile, called ActualDepo, was generated with the locations of deposition. Unique IDs were assigned in both shapefiles to allow the system to match corresponding ellipse centres and actual deposit points. The Join by Lines (hub lines) tool was used to measure the distance between corresponding points and distance between the ellipse centre to each deposit location was calculated in the resulting layer attribute table.

Concentration

Two values were calculated to analyse point concentration, both the size of the ellipse and the percent of data points within the ellipse (Yuill, 1971). Size of each ellipse was calculated in individual attribute tables by creating a new column for Area and executing the $area function in the field calculator. Percent of coverage was calculated in QGIS using the Count points in polygon tool for each ellipse, this information was then imported into Excel and divided by the total points in the corresponding layer.

Distribution

Eccentricity of the ellipse is a visualisation of the distribution of points, where high values represent a linear distribution and lower values represent a circular pattern (Yuill, 1971). The orientation of the ellipse represents the direction of the point distribution and is measured in degrees from north (Yuill, 1971; ESRI, 2009). Both eccentricity and orientation values are automatically calculated when generating the ellipse, were collected from individual attribute tables and exported to Excel.

6.3. Results

Nine bottles were distributed prior to the Oxford vs Cambridge boat race on April 2nd, 2017, which began at 16:30 and reported an attendance of 250,000 people (ARUP Group, 2017). Although 10 bottles had been prepared for this study, Bottle 8 was damaged in transit to the test site. All deposited bottles replaced already littered items, and in each event the litter was collected and binned. Efforts were made to photograph deposits before and after the switch, however the need for discrepancy at times made this impossible. See Table 6.1 for full details.

Table 6.1 General description of data collected from the ten GPS bottles. Includes information for each bottle on deposit time, distance of deposition from Putney Bridge, time and date of last signal, number of minutes active and total distance travelled while active. No data is available for Bottle 8 as it was damaged in transit.

Bottle	Time Deposited	Distance to Putney Bridge (m)	Last Signal Date	Last Signal Time	Active Minutes	Distance Travelled (m)[12]
1	14:10:00	125.08	03/04/2017	13:09:00	1379	929.53
2	14:15:00	273.43	04/04/2017	21:21:00	3306	1213.80
3	14:20:00	445.06	02/04/2017	18:45:00	265	188.18
4	14:24:00	604.94	02/04/2017	18:45:00	261	80.12
5	15:15:00	674.94	03/04/2017	02:05:00	650	61.72
6	14:39:00	808.69	03/04/2017	15:43:00	1504	233.18
7	15:35:00	460.69	02/04/2017	18:55:00	200	117.49
8	NA	NA	NA	NA	NA	NA
9	14:51:00	1036.58	02/04/2017	21:55:00	424	3732.96
10	15:05:00	1203.56	05/04/2017	00:06:00	3421	11071.53

Weather information during active dates was sourced from the Met Office (Table 6.2). Weather was clear and wind was low for the first two days of data collection. As a result, any movement on these days is more likely to be attributed to anthropogenic and not meteorological forces.

Table 6.2 Weather while GPS bottles were active. Conditions were generally calm with low wind speeds, clear skies and free of precipitation.

Date	Conditions	Average Temperature (c)	Average Relative Humidity	Average Wind Speed (km/h)
Day 1: 02/04/2017	Clear	12	66%	8
Day 2: 03/04/2017	Clear	11	69%	8
Day 3: 04/04/2017	Light rain AM, mostly clear	12	80%	12.8

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[12] Distance calculated from simplified path dataset.

From the results, ellipses were constructed for both the full dataset as well as for each day the bottle remained active. In instances where it was apparent external forces (e.g., street cleansing efforts) were responsible for bottle movement, ellipses were not reported in the results. All ellipses omitted from results can be reviewed in Appendix G (page 382). Results of the ellipse analysis are described in Table 6.3 and will be visualised in detail in upcoming section 6.3.3. Detailed bottle movement descriptions.

Table 6.3 Full set of results from ellipse analysis conducted on GPS data of each bottle, including ellipses on full paths as well as paths divided by days active.

	Distance btw Deposition and Mean Point (m)	**Minus 5-metre accuracy**	**Ellipse Area (sq m)**	**Concentration**	**Eccentricity**	**Orientation (degrees from north)**
Bottle 1	42.85	37.85	14221.96	84.78%	0.97346	9.02
Day 1	*9.36*	*4.36*	*297.45*	*85.00%*	*0.49472*	*59.99*
Day 2	*82.25*	*77.25*	*22715.36*	*73.08%*	*0.97146*	*9.80*
Bottle 2	12.38	7.38	330.56	78.31%	0.64365	120.82
Day 1	*12.01*	*7.01*	*331.78*	*77.59%*	*0.89872*	*156.89*
Day 2	*14.18*	*9.18*	*414.12*	*69.32%*	*0.58650*	*171.30*
Day 3	*10.02*	*5.02*	*69.56*	*62.79%*	*0.57627*	*113.36*
Bottle 3	10.39	5.39	377.48	66.67%	0.72793	139.13
Bottle 4	1.24	0.00	91.36	65.38%	0.86688	76.66
Bottle 5	6.44	1.44	34.19	77.27%	0.81565	112.18
Day 1	*5.60*	*0.60*	*41.83*	*73.58%*	*0.73519*	*141.58*
Day 2	*6.56*	*1.56*	*0.00*	*100.00%*	*0.00000*	*0.00*
Bottle 6	5.24	0.24	41.89	58.90%	0.46018	110.07
Day 1	*4.95*	*0.00*	*43.79*	*60.00%*	*0.74469*	*170.91*
Day 2	*5.68*	*0.68*	*34.77*	*55.56%*	*0.72589*	*3.67*
Bottle 7	8.24	3.24	151.63	76.19%	0.77700	166.34
Bottle 9	867.01	862.01	612156.07	92.86%	0.99682	90.71
Bottle 10	505.54	500.54	2746219.48	73.68%	0.80833	117.49
Day 1	*1.62*	*0.00*	*58.76*	*66.04%*	*0.66543*	*30.90*
Day 2	*300.32*	*295.32*	*416705.23*	*77.14%*	*0.97527*	*166.69*
Part Day 2	*6.99*	*1.99*	*30.87*	*71.43%*	*0.77188*	*29.46*

6.3.1. Deposit locations

Figure 6.4 illustrates deposit locations of each bottle as well as the distance between each. Efforts were made to deposit trackers in regular intervals within the study site. The bottles were deposited an average of 136.12 metres apart. The total distance between Putney Bridge and Bottle 10 was 1.2 km and the distance between Bottle 1 and 10 was 1.09 km. All distances are accurate within 5 metres. Bottle 1, 2, 3, 5 and 6 were deposited within the two embankment zones, Bottles 7 and 4 were deposited along the slipway, and Bottle 9 and 10 in the slope zone (as defined in Figure 6.2, page 174).

Figure 6.4 Deposit locations of GPS tagged bottles within study site. Bottles were deposited an average interval of 136 metres apart, spanning a distance of 1.2km from Putney Bridge.

6.3.2. Recollection efforts

On April 3rd, the day following the bottle launch, the site was visited at 17:30, a time of low tide (UK Hydrographic Office, 2017). This was done to retrieve any bottles that had lost signal. The last known locations of Bottle 3, 4, 5, 6 and 7 were visited. Bottle 6 was retrieved from the base of the Embankment on the Thames foreshore and upon inspection found to have broken (Figure 6.23, page 200). Bottle 3, 4, 5 and 7 were not found. The locations of active bottles were avoided. During this visit, the path of Bottle 1 was investigated to identify the places it had travelled.

6.3.3. Detailed bottle movement descriptions

6.3.3.1. Bottle 1

Figure 6.6 Photo of deposit location of Bottle 1. Bottle 1 was placed in the location of a McDonald's paper cup that had been previously littered along the embankment fence. Photo credit Randa L Kachef.

Bottle 1 was deposited at 14:10 in the location of this paper cup along the Embankment (Figure 6.6) and the final signal was received at 13:09 on day 2. A total of 46 location points were collected by Bottle 1, of which 10 were removed in data simplification. Bottle 1 stayed close to the deposition site for the duration of day 1 until 9:05 on day 2 when it is assumed to have been collected by street cleansers. Once collected, the bottle moved to St Mary's Church at 10:05 and then to the Putney Exchange shopping centre at 10:36, where it remained until the signal was lost at 13:09 (illustrated in Figure 6.5).

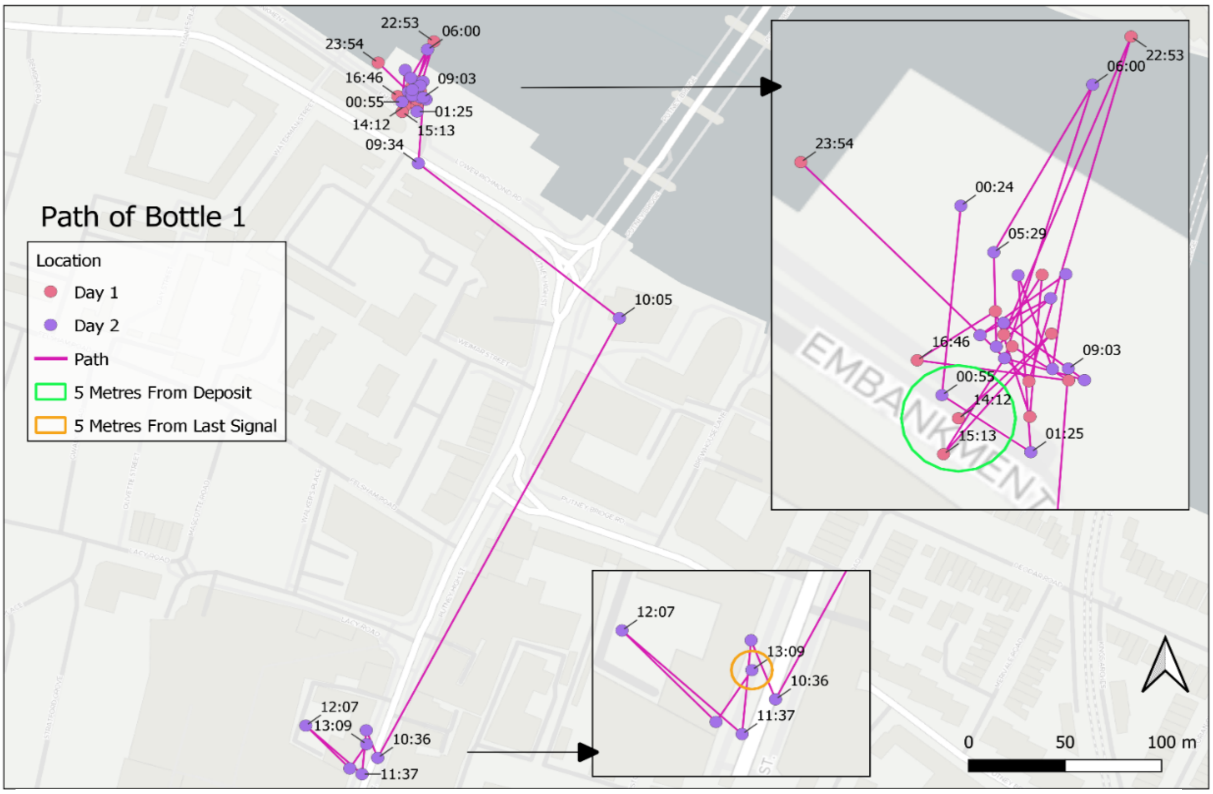


Figure 6.5 Map of total path of Bottle 1. Bottle was deposited at 14:10 and the final signal was received the following day at 13:09. During that time the bottle travelled a distance of 929.53 metres.

Ellipse analysis of Bottle 1

It is assumed that the main influence on day 2 was deliberate and only movement on day 1 will be reported in the results, remaining ellipse can be viewed in Appendix G, page 382.

Table 6.4 Results of ellipse analysis conducted on Bottle 1, including ellipses on full path as well individual paths for day 1 and 2.

	Distance btw Deposition and Mean Point (m)	Minus 5-metre accuracy	Ellipse Area (sq m)	Concentration	Eccentricity	Orientation (degrees from north)
Bottle 1	42.85	37.85	14221.96	84.78%	0.97346	9.02
Day 1	*9.36*	*4.36*	*297.45*	*85.00%*	*0.49472*	*59.99*
Day 2	*82.25*	*77.25*	*22715.36*	*73.08%*	*0.97146*	*9.80*

The ellipse analysis for day 1 found a 9.36 metre distance from deposition point. As this is greater than the 5-metre accuracy of the units, it is assumed that the bottle travelled a minimum of 4.36 metres in a north-eastern direction (59.99 degrees from north). The points were fairly concentrated (85%), and the low eccentricity value indicates a tight circular cluster, as illustrated in Figure 6.7.

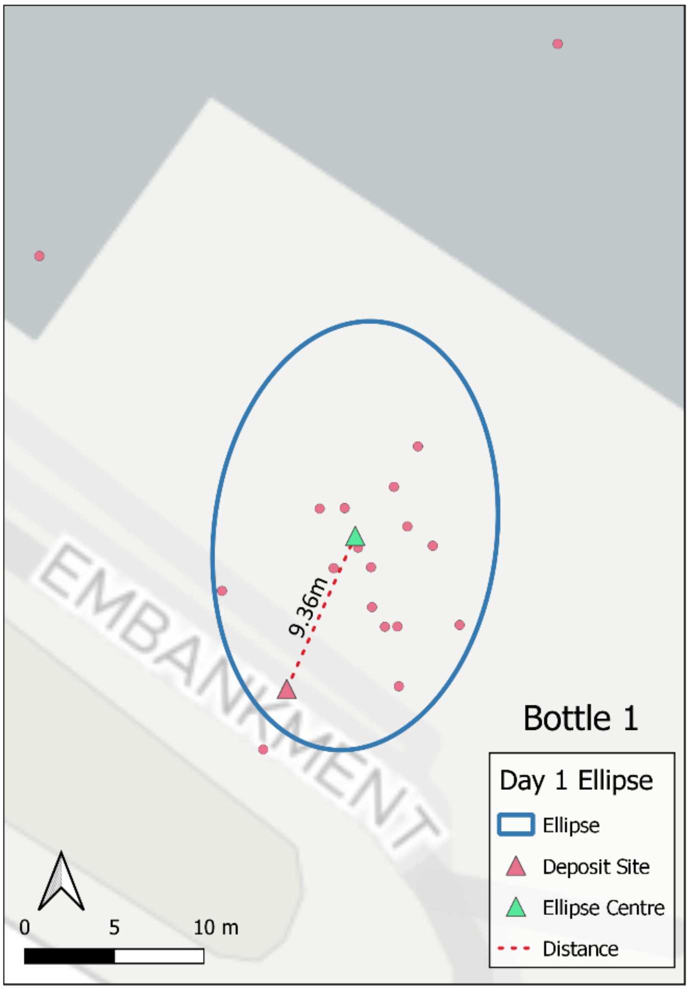


Figure 6.7 Ellipse analysis of first day Bottle 1 was active. Analysis suggests the bottle moved 4.36 metres in a north-eastern direction.

6.3.3.2. Bottle 2

Bottle 2 was deposited at 14:14 near a tree approximately 12 metres from the Embankment (illustrated in Figure 6.8) and the final signal was received at 21:21 on day 3. A total of 189 location points were collected by Bottle 2, of which 91 were removed in data simplification. Bottle 2 remained within the vicinity of the deposit site throughout all 3 days of active signal, as illustrated in Figure 6.9.

Figure 6.8 Photo of deposit location of Bottle 2. Bottle 2 was placed next to a tree approximately 12 metres from the embankment. Photo credit Randa L Kachef.

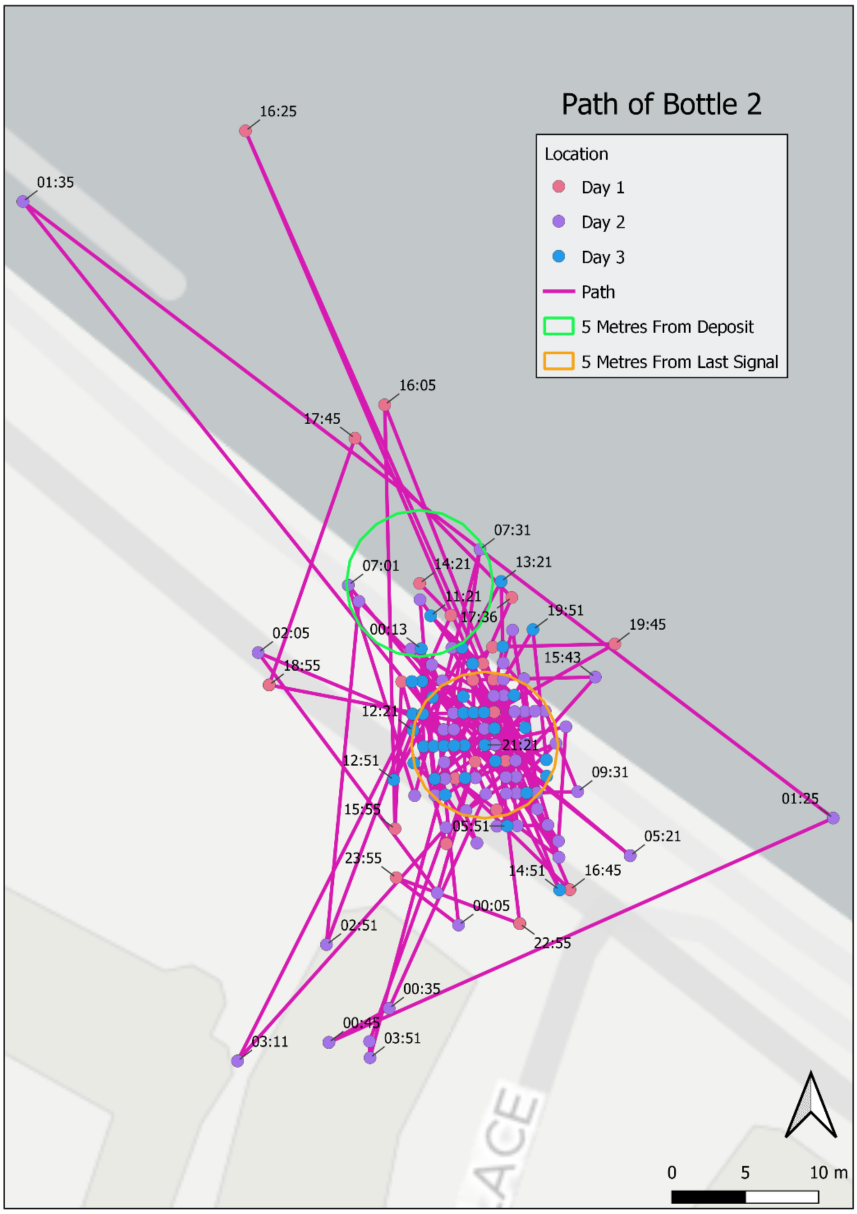


Figure 6.9 Map of total path of Bottle 2. Bottle was deposited at 14:15 and the final signal was received two days later at 21:21.

Ellipse analysis of Bottle 2

As there were no dramatic changes in acceleration, it is assumed that all movement within the three days of active signal were influenced by foot traffic.

Table 6.5 Results of ellipse analysis conducted on Bottle 2, including ellipses on full path as well individual paths for day 1, 2 and 3.

	Distance btw Deposition and Mean Point (m)	Minus 5-metre accuracy	Ellipse Area (sq m)	Concentration	Eccentricity	Orientation (degrees from north)
Bottle 2	12.38	7.38	330.56	78.31%	0.64365	120.82
Day 1	*12.01*	*7.01*	*331.78*	*77.59%*	*0.89872*	*156.89*
Day 2	*14.18*	*9.18*	*414.12*	*69.32%*	*0.58650*	*171.30*
Day 3	*10.02*	*5.02*	*69.56*	*62.79%*	*0.57627*	*113.36*

Full dataset ellipse

There was a 12.38 metre distance between the deposition point and the ellipse constructed from the entire dataset. As this is greater than the 5-metre accuracy of the units, it is assumed that the bottle travelled a minimum of 7.38 metres in a south eastern direction (120.82 degrees from north). Concentration of points around the total mean was moderately high (78.31%) and the low eccentricity (0.64365) implied a circular pattern (illustrated in Figure 6.10).

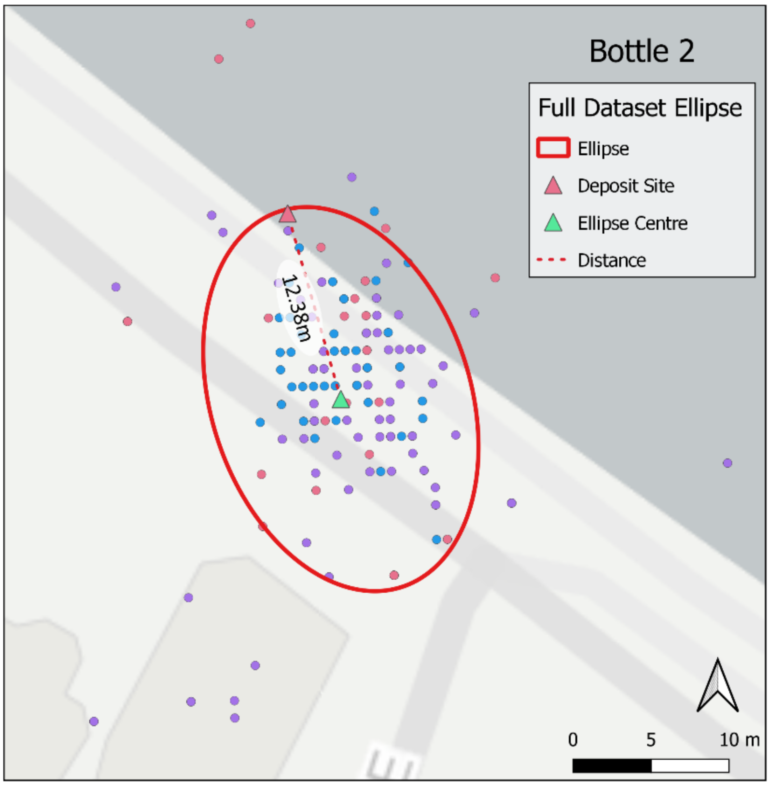


Figure 6.10 Ellipse analysis of full dataset collected while Bottle 2 was active. Analysis suggests the bottle moved 7.38 metres in a south eastern direction.

Individual day ellipse

To explore any changes in movement between active days, each day was analysed individually, and the resulting ellipses were overlayed in a singular image (Figure 6.11).

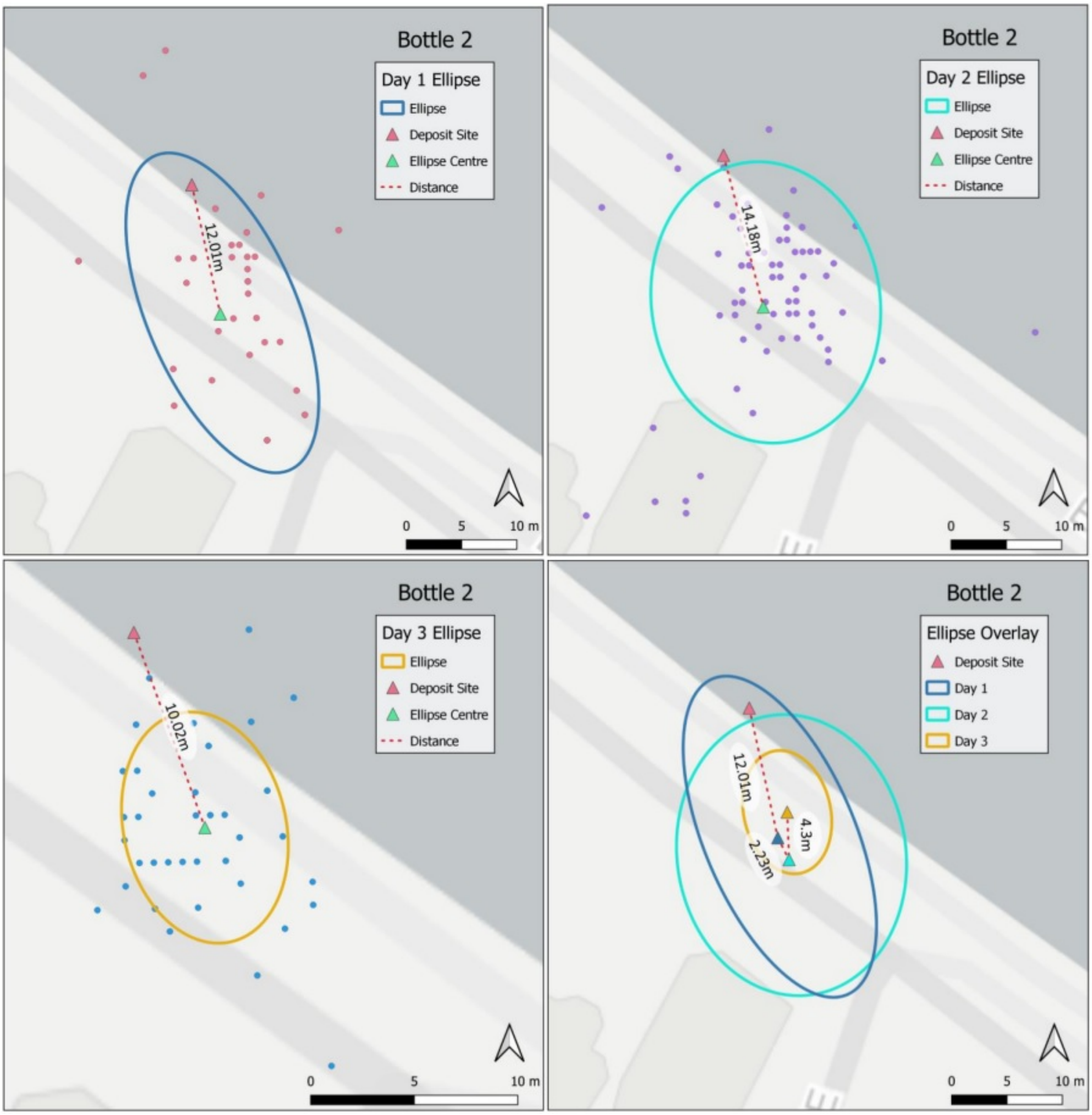


Figure 6.11 Ellipse analysis of each day Bottle 2 was active and overlay of all three ellipses. Overlay suggests the bottle experienced greatest movement on day 1 (12.01 metres in a south-east direction) with significantly lower movement on day 2 (2.2 metres in a south-east direction) and day 3 (4.3 metres north).

Day 1 experienced the most dramatic movement of 7.01 metres, with a moderately high concentration (77.59%) in a linear pattern (.89872) towards the southeast (156.89 degrees from north). On day 2, the ellipse centre moved 2.23 metres south, and the dramatic reduction in eccentricity (0.58650) imply that the movement had less direction. Finally, day 3 resulted in the smallest (69.56 sq m) and most circular pattern (0.57627). The overlay of all three ellipses illustrates a steady reduction in movement and distribution throughout all three days.

6.3.3.3. Bottle 3

Bottle 3 was deposited at 14:17 in the place of a water bottle on the edge of the Embankment (Figure 6.12), and the last signal was received at 18:45 the same day. A total of 27 location points were collected by Bottle 3, of which 7 were removed in data simplification.

Figure 6.12 Photo of deposit location of Bottle 3. Bottle 3 was placed in the location of a water bottle that had been previously littered along the embankment fence. Photo credit Randa L Kachef.

While active, Bottle 3 remained within the vicinity of the deposit site. A visual inspection of the path in Figure 6.13 leads to the assumption that Bottle 3 may have been collected by street cleansers at around 17:45, however as there were no obvious increases in acceleration this is simply speculation.

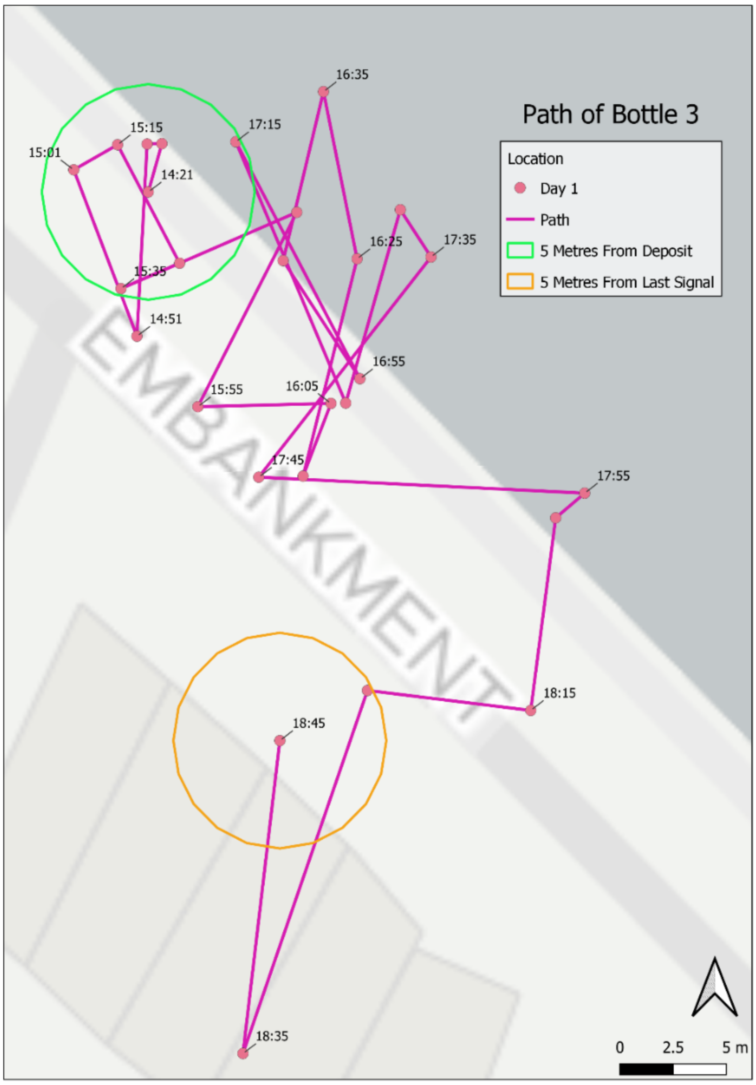


Figure 6.13 Map of total path of Bottle 3. Bottle was deposited at 14:20 and the final signal was received the same day at 18:45. During that time the bottle travelled a distance of 188 metres.

Ellipse analysis of Bottle 3

Table 6.6 Results of ellipse analysis conducted on Bottle 3 which was active for 265 minutes.

	Distance btw Deposition and Mean Point (m)	Minus 5-metre accuracy	Ellipse Area (sq m)	Concentration	Eccentricity	Orientation (degrees from north)
Bottle 3	10.39	5.39	377.48	66.67%	0.72793	139.13

As the distance between deposition and the ellipse centre was greater than the 5-metre accuracy, it is assumed the bottle travelled a minimum of 5.39 m (Figure 6.14). The pattern was fairly distributed with a high ellipse area (377.48 sq m) paired with a low concentration (66.67%). Eccentricity (0.72793) implied a fairly linear spread in a south-eastern direction (139.18 degrees from north).

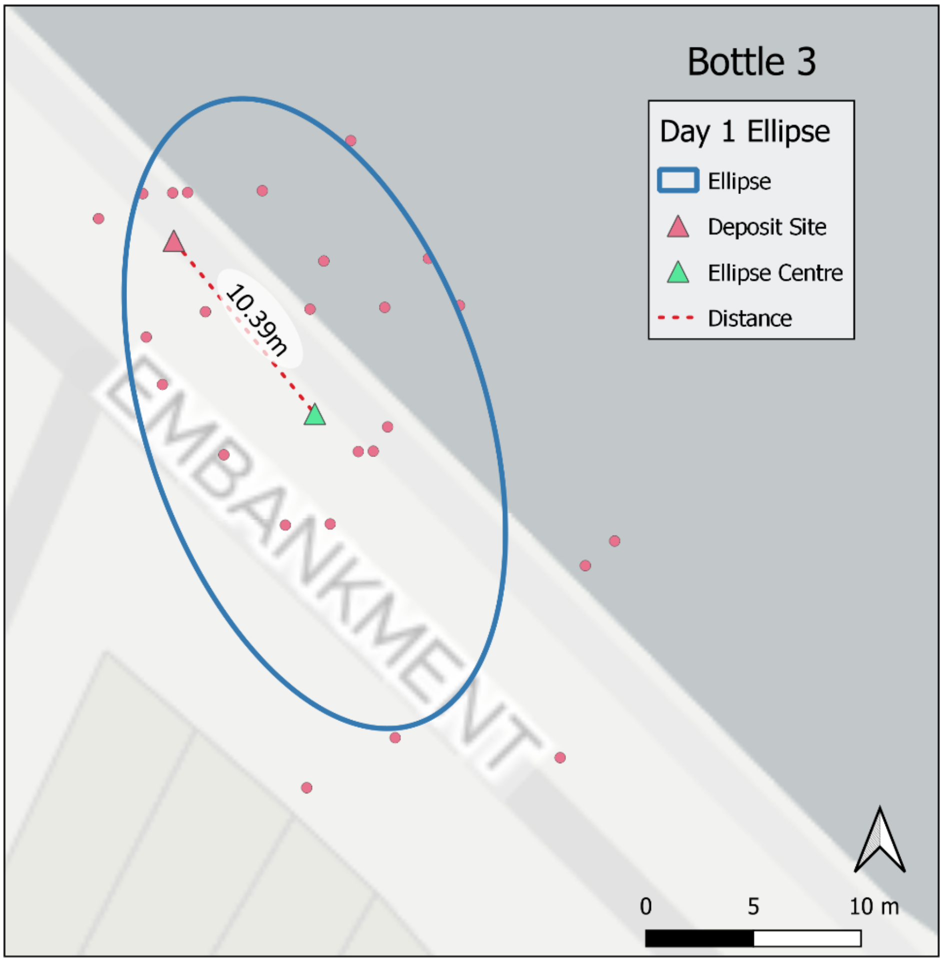


Figure 6.14 Ellipse analysis of full path of Bottle 3. Analysis suggests the bottle moved 10.39 metres in a south-eastern direction.

6.3.3.4. Bottle 4

Bottle 4 was the first bottle to be deposited near the rowboat slipway, which is characterised by a gentle slope towards the river (Figure 6.15). It was deposited in the location of a water bottle at 14:24 and remained active until 18:45 the same day. A total of 26 location points were collected by Bottle 4, of which 16 were removed in data simplification. While active, Bottle 4 remained within vicinity of the deposit site illustrated in Figure 6.16.

Figure 6.15 Photo of deposit location of Bottle 4. Bottle 4 was placed in the location of a plastic bottle (seen on left) that had been previously littered along the slipway. Photo credit Randa L Kachef.

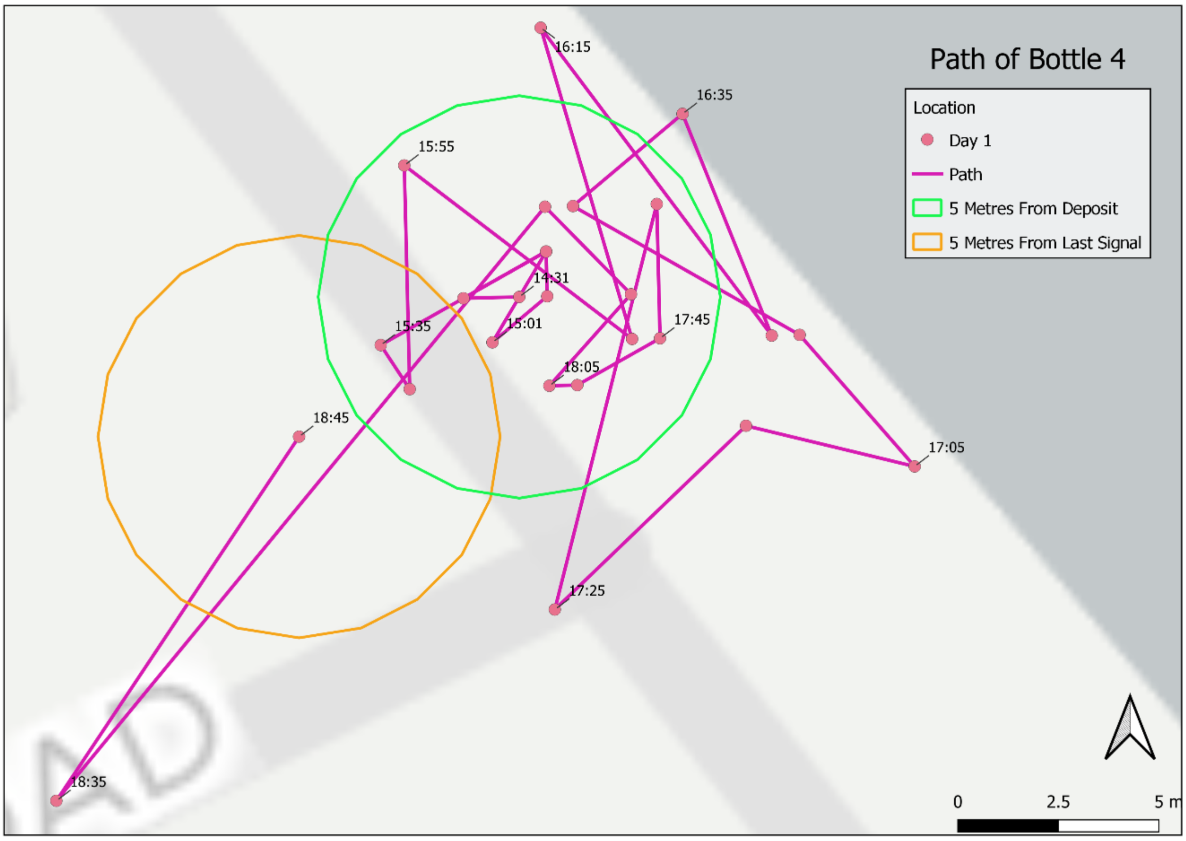


Figure 6.16 Map of total path of Bottle 4. Bottle was deposited at 14:24 and the final signal was received the same day at 18:45.

Ellipse analysis of Bottle 4

Table 6.7 Results of ellipse analysis conducted on Bottle 4 which was active for 261 minutes,

	Distance btw Deposition and Mean Point (m)	Minus 5-metre accuracy	Ellipse Area (sq m)	Concentration	Eccentricity	Orientation (degrees from north)
Bottle 4	1.24	0.00	91.36	65.38%	0.86688	76.66

The distance between the deposit site and the ellipse centre was marginal in a north-eastern direction and given the 5-metre threshold of accuracy, I cannot assume there was any movement. This raises questions as a visual inspection of the path illustrated in Figure 6.16 above implies some movement towards the south-west, with a return to the original deposition location. The ellipse was small (91.36 sq m) with a low concentration (65.38%) and a fairly linear distribution (0.8668) towards the northeast (76.66 degrees from north) as illustrated in Figure 6.17.

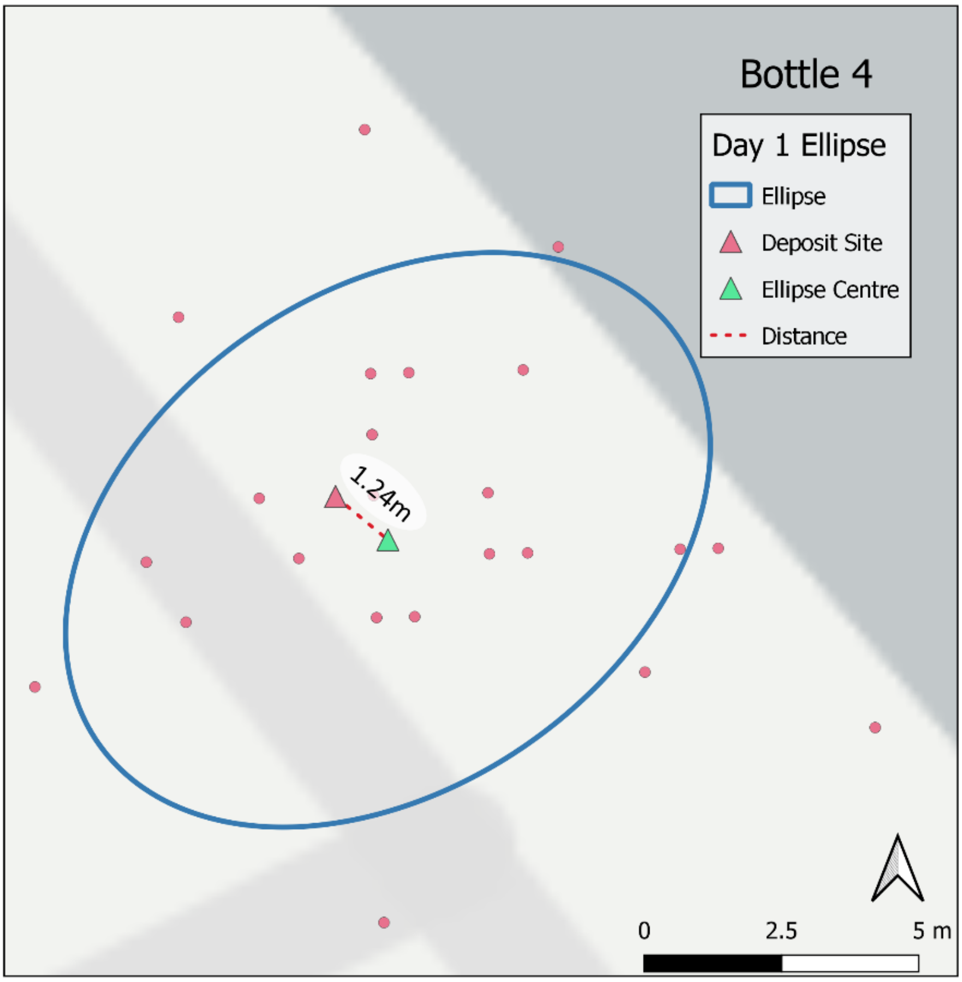


Figure 6.17 Ellipse analysis of Bottle 4 which suggests there was no movement.

6.3.3.5. Bottle 5

Bottle 5 was deposited at 14:39 in an act of *Polite Littering* (as described in *Chapter 5*) on a park bench on the opposite side of the footpath from the river (Figure 6.18). It remained active until day 2 at 02:05 and broadcast 66 location points, of which 55 were removed through data simplification. The reason for the large proportion of data removed during simplification is that all location data received after 18:25 on day 1 remained in the same location (Figure 6.19). It is unclear if this was a result of damage to the unit or could be proof of location accuracy in static units.

Figure 6.18 Photo of deposit location of Bottle 5. Bottle 5 was left on a park bench in an act of Polite Littering on the opposite side of the footpath from the river. Photo credit Randa L Kachef.

Figure 6.19 Map of total path of Bottle 5. Bottle 5 was deposited at 15:15 and the final signal was received the following day at 02:05. During that time the bottle travelled a distance of 61 metres.

Ellipse analysis of Bottle 5

As there was no movement reported on day 2, an ellipse could not be generated. The measurement for day 2 included in the *Distance btw Deposition and Mean Point (m)* was calculated from the static location of the bottle on day 2.

Table 6.8 Results of ellipse analysis conducted on Bottle 5, including ellipses on full path as well individual paths for day 1 and 2.

	Distance btw Deposition and Mean Point (m)	Ellipse Area (sq m)	Concentration	Eccentricity	Orientation (degrees from north)
Bottle 5	6.44	34.19	77.27%	0.81565	112.18
Day 1	*5.60*	*41.83*	*73.58%*	*0.73519*	*141.58*
Day 2	*6.56*	*0.00*	*100.00%*	*0.00000*	*0.00*

The inclusion of the static points from day 2 were influential on the ellipse analysis and can be observed when comparing the data of the full ellipse to that of the day 1 ellipse. It is apparent that the static data elongated the ellipse (eccentricity) while simultaneously increasing the concentration and reducing the ellipse area.

On day 1 the bottle travelled 5.6 metres in a north easterly direction, crossing the footpath and resting in the bushes along the river edge (Figure 6.20).

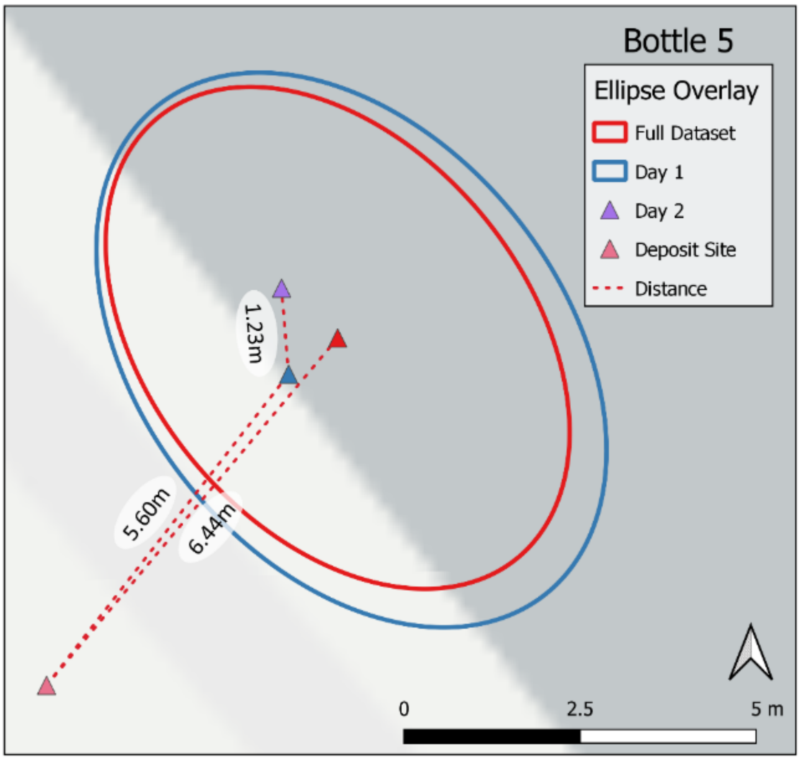
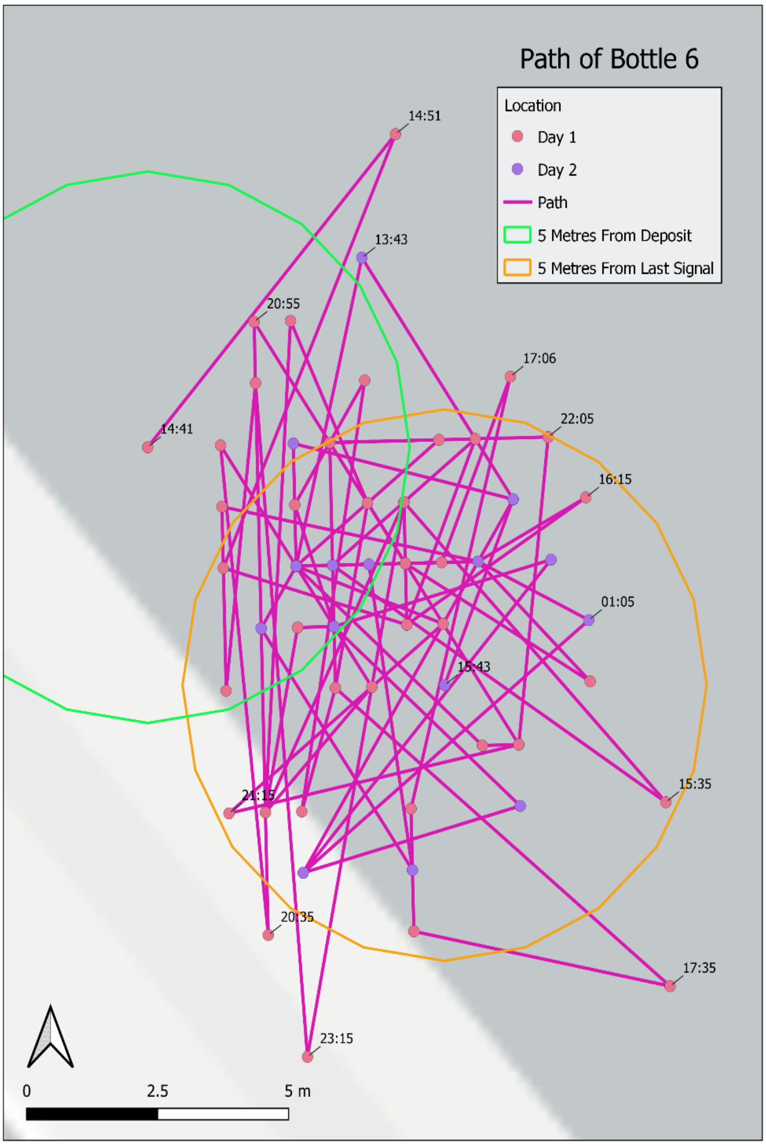


Figure 6.20 Overlay of ellipse analysis Bottle 5 including full dataset and data from day 1. The bottle moved approximately 6 metres in towards the northeast, crossing the footpath and resting in the bushes along the river edge.

6.3.3.6. Bottle 6

Bottle 6 was deposited at 14:35 in the place of an orange Lucozade bottle along the embankment (seen on left in Figure 6.21), the final signal was received at 15:43 on day 2.

Figure 6.21 Photo of deposit location of Bottle 6. Bottle 6 was placed in the location of a Lucozade bottle that had been previously littered along the embankment fence. Photo credit Randa L Kachef.



A total of 73 location points were collected by Bottle 6, of which 37 were removed in data simplification. While active, Bottle 6 remained within vicinity of the deposit site (Figure 6.22).

Figure 6.22 Map of total path of Bottle 6. Bottle was deposited at 14:39 and the final signal was received the following day at 15:43. During that time the bottle travelled a distance of 233 metres.

The final signal from Bottle 6 was received at 15:43, shortly after the lowest tide point (0.2 m, as illustrated in Figure 6.32, page 207) at 14:50 (UK Hydrographic Office, 2017). During the recollection efforts on day 2, the last known location of Bottle 6 was visited at 17:40 and was found on the foreshore just below where the final signal had been reported. Upon inspection, Bottle 6 appears to have been damaged, presumably during the fall from the Embankment to the foreshore. If this bottle had not been collected it could have remained on the foreshore until high tide (5.5 m) at 20:01 (UK Hydrographic Office, 2017), at which point it would have been swept away in the Thames. It is important to note the area where Bottle 6 was found was particularly littered, items that could very well have ended up in the Thames (Figure 6.23).

Figure 6.23 Photo of Bottle 6 during site visit on following day. Bottle 6 was found along the Thames foreshore during low tide, over 5 metres south of where it had been deposited.

Ellipse analysis of Bottle 6

Table 6.9 Results of ellipse analysis conducted on Bottle 6, including ellipses on full path as well individual paths for day 1 and 2.

	Distance btw Deposition and Mean Point (m)	Minus 5-metre accuracy	Ellipse Area (sq m)	Concentration	Eccentricity	Orientation (degrees from north)
Bottle 6	5.24	0.24	41.89	58.90%	0.46018	110.07
Day 1	*4.95*	*0.00*	*43.79*	*60.00%*	*0.74469*	*170.91*
Day 2	*5.68*	*0.68*	*34.77*	*55.56%*	*0.72589*	*3.67*

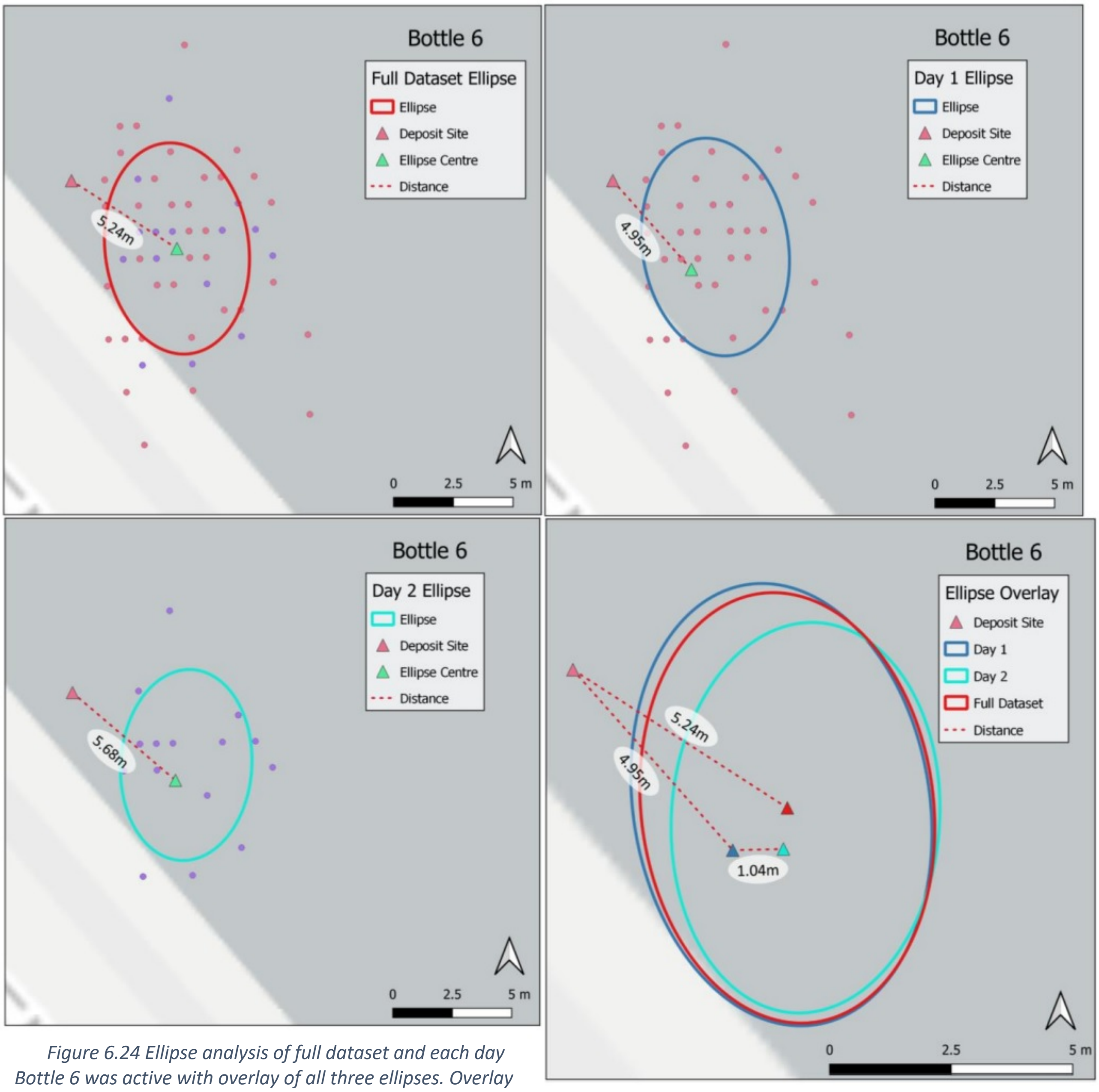


Figure 6.24 Ellipse analysis of full dataset and each day Bottle 6 was active with overlay of all three ellipses. Overlay suggests the bottle experienced greatest movement on day 1 (5 metres in a south-east direction) with significantly lower movement on day 2 (1 metre east).

According to the ellipse (Figure 6.24), the distance travelled by bottle 6 was minimal. Different orientations between day 1 and 2 led to a highly linear pattern on individual days, yet a tighter circular distribution when evaluating the full dataset. Small ellipse areas with low concentration indicate a wide spread of points, which is apparent in visual inspection of the path map (Figure 6.22, page 199).

6.3.3.7. Bottle 7

Bottle 7 was deposited at 15:29 along a barrier that had been set up approximately 16 metres inland from the Embankment (Figure 6.25) and relatively close to Bottle 3. Bottle 7 remained active until 18:55 the same day, in that time a total of 21 location points were collected, 7 of which were removed in data simplification.

Figure 6.25 Photo of deposit location of Bottle 7. Bottle 7 was placed in the location of two tins that had been previously littered along a crowd barrier approximately 16 metres inland. Photo credit Randa L Kachef.

While active, Bottle 7 remained within vicinity of the deposit site. A visual inspection of the path in Figure 6.26 illustrates a close proximity between the deposit site and final destination in a southwestern direction.

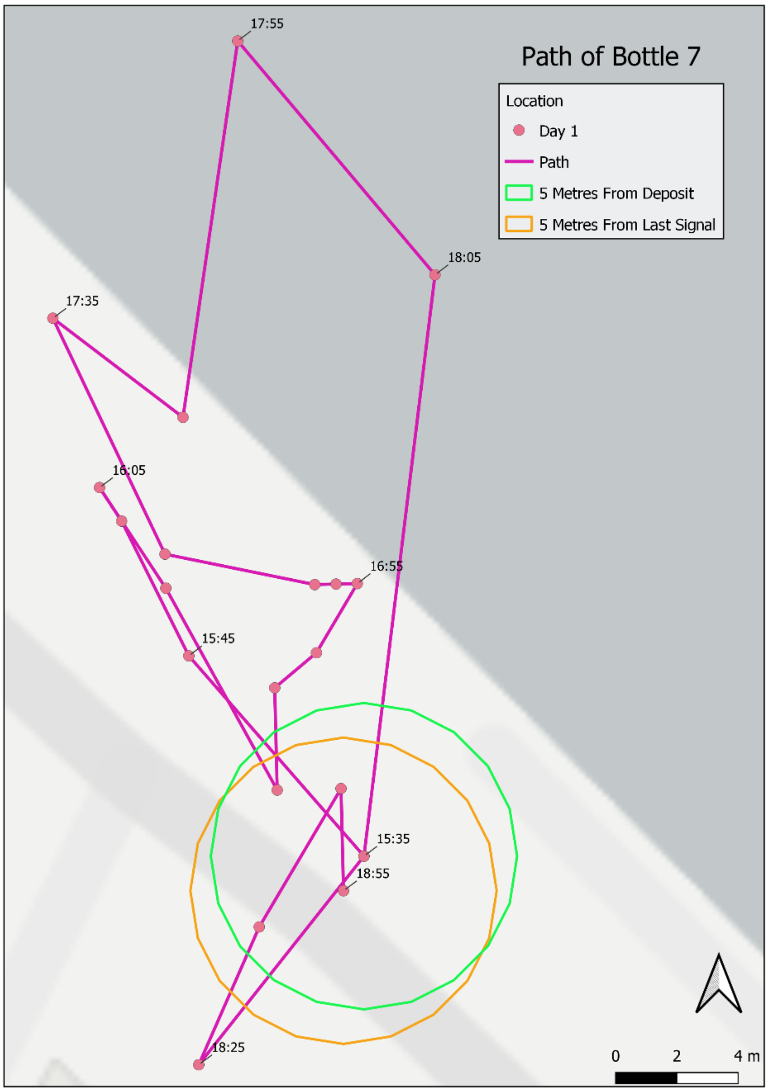


Figure 6.26 Map of total path of Bottle 7. Bottle was deposited at 15:35 and the final signal was received the same day at 18:55 within the 5-metre buffer around deposit site.

Ellipse analysis of Bottle 7

Although a visual inspection of the path of Bottle 7 implies a final destination within 5 metres to the southwest, the ellipse however tells a different story.

Table 6.10 Results of ellipse analysis conducted on Bottle 7 having been active for 200 minutes.

	Distance btw Deposition and Mean Point (m)	Minus 5-metre accuracy	Ellipse Area (sq m)	Concentration	Eccentricity	Orientation (degrees from north)
Bottle 7	8.24	3.24	151.63	76.19%	0.77700	166.34

From the distance between the ellipse centre and the deposit site, there appears to be a minimum movement of 3.24 metres in a relatively linear pattern (0.777) towards the southeast (166.34 degrees from north) as illustrated in Figure 6.27.

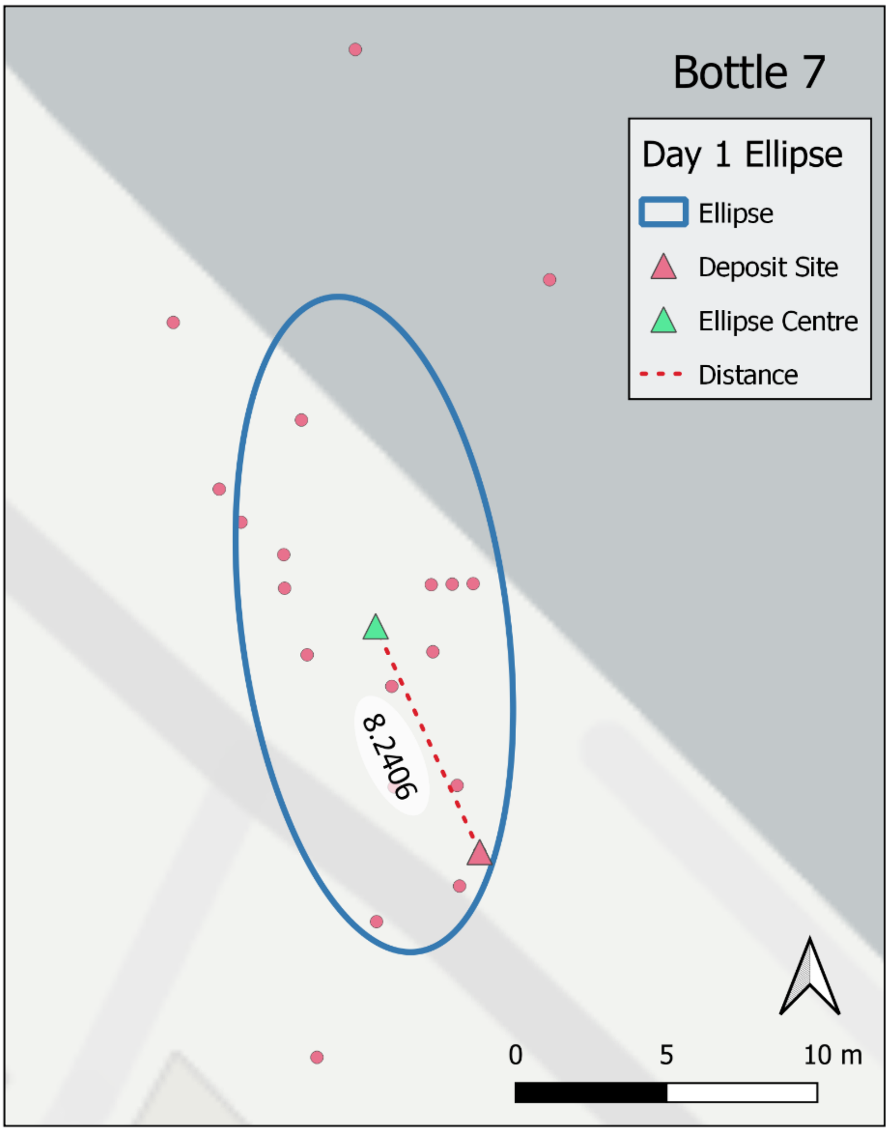


Figure 6.27 Ellipse analysis of Bottle 7 while active. Analysis suggests the bottle moved 8 metres in a south-eastern direction.

6.3.3.8. Bottle 9

Figure 6.29 Photo of deposit location of Bottle 9 on the foreshore where other litter was observed. Photo credit Randa L Kachef.

Bottle 9 was deposited at 14:48 on the Thames foreshore during low tide (Figure 6.29). Bottle 9 remained active until 21:55 that day, in that time 42 location points were collected, 10 of which were removed through data simplification. Bottle 9 was apparently collected within an hour of deposit and quickly moved south towards Putney Bridge and then east, arriving to Essex Court (Essex Ct, Station Rd, SW13 0ER) at 18:45 were it remained until the signal was lost (Figure 6.28). On this journey, the accelerometer logged a top speed of 43.5 km/hr. As it is assumed to have been under the influence of an individual, the ellipse of Bottle 9 will not be reported in these results but can be viewed in Appendix G (page 382).

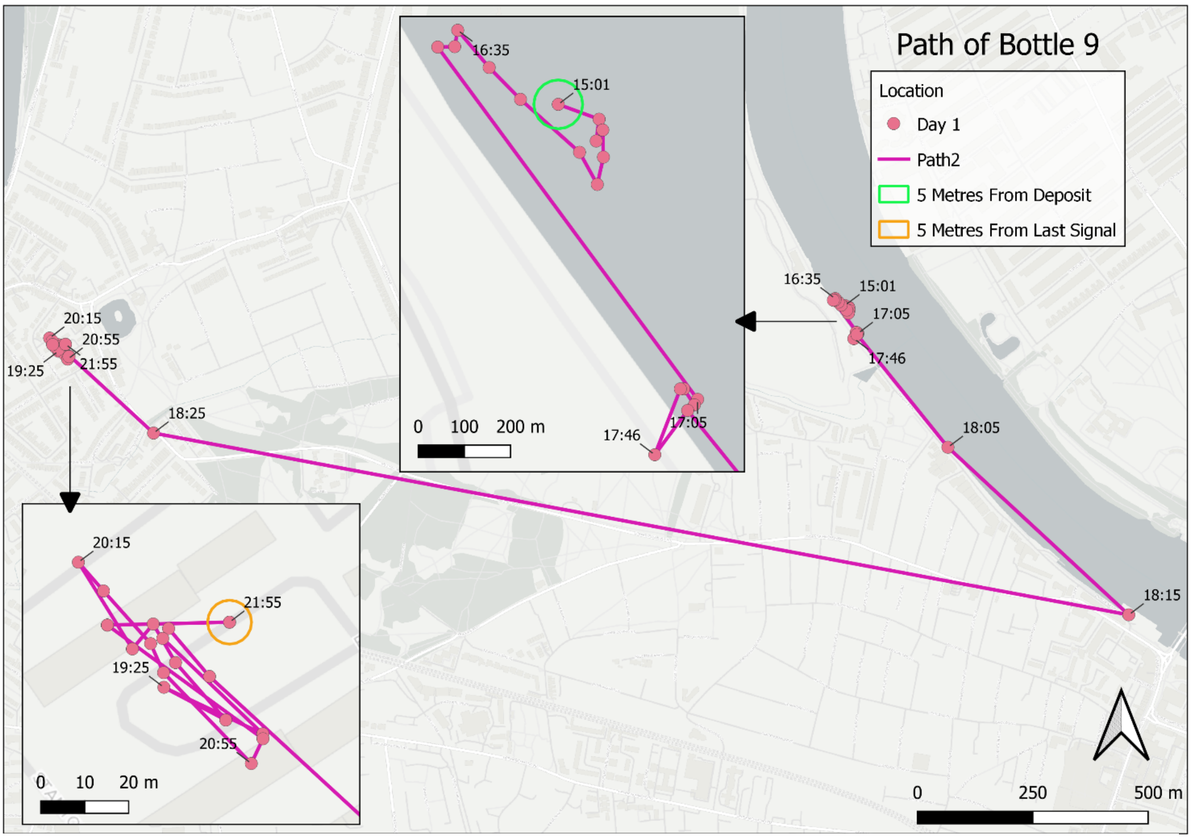


Figure 6.28 Map of total path of Bottle 9 which was displaced quickly after it was deposited at 14:51. The bottle travelled south then 3km north east to a residential area in postal code SW13 0ER.

6.3.3.9. Bottle 10 - HELP

Bottle 10 was deposited at 15:05 on the opposite side of the footpath from the river, in an area that was being used to picnic (Figure 6.31). Bottle 10 was the longest running unit and remained active until 00:06 on April 5th (day 4). In that time Bottle 10 collected 133 location points, of which 62 were removed in data simplification. Bottle 10 moved east from the deposit site towards the river until 12:43 on day 2 where it was picked up by the ebb tide (outward) and carried to the opposite side of the Thames. From then on Bottle 10 followed the ebb and drain tides of the river until it lost signal (Figure 6.30).

Figure 6.31 Photo of deposit location of Bottle 10. Bottle 10 was placed in the location of a glass beer bottle that had been previously littered on the opposite side of the footpath from the river. Photo credit Randa L Kachef.

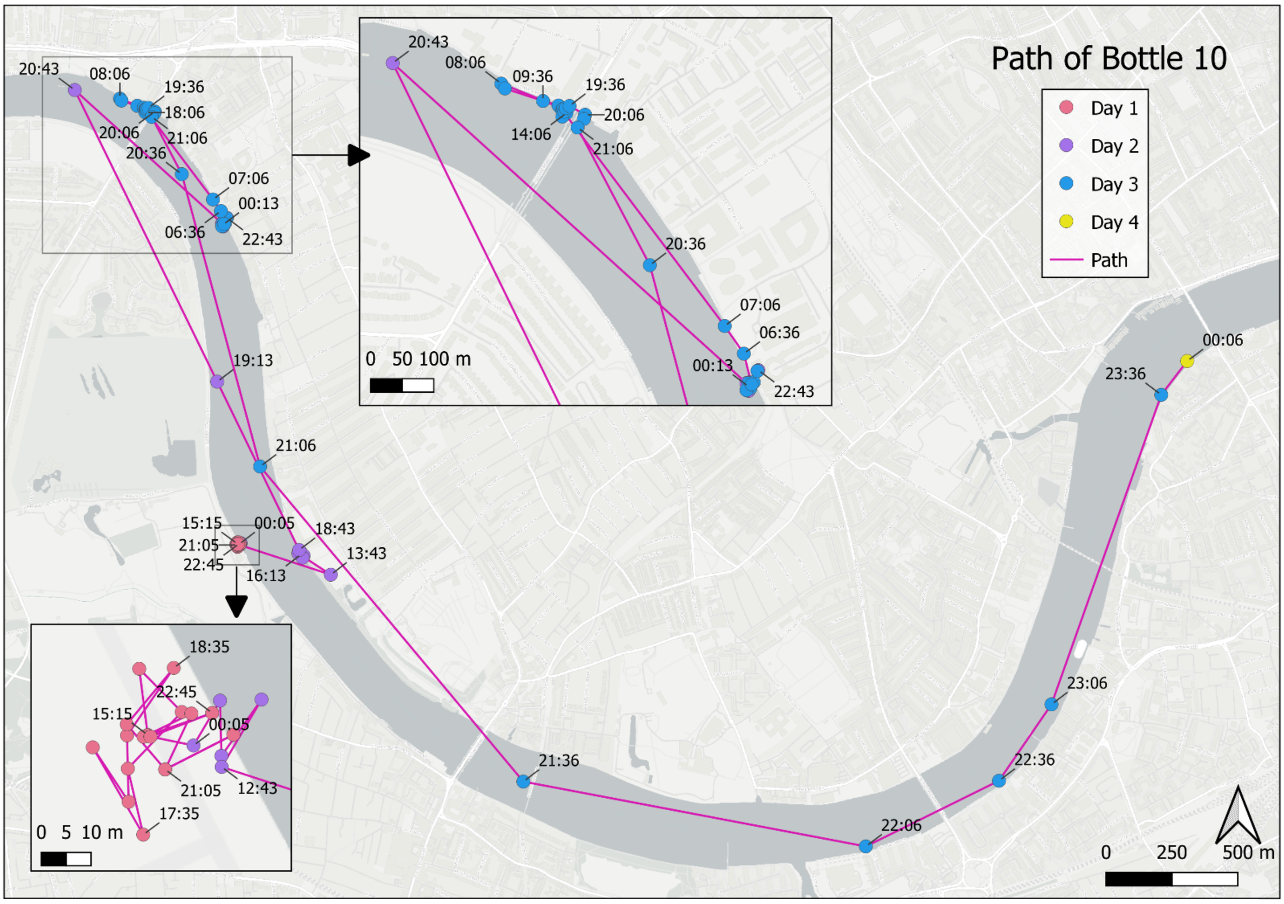


Figure 6.30 Map of total path of Bottle 10. Bottle was deposited at 15:05 and the final signal was received three days later at 00:06. During that time the bottle travelled a distance of 11 km.

Figure 6.32 illustrates the tidal height of the Thames from deposit time to last signal on April 5th, 2017. Peaks indicate high tide, which is followed by an easterly flow (ebb), dips represent low tide which is followed by a westerly flow (drain).

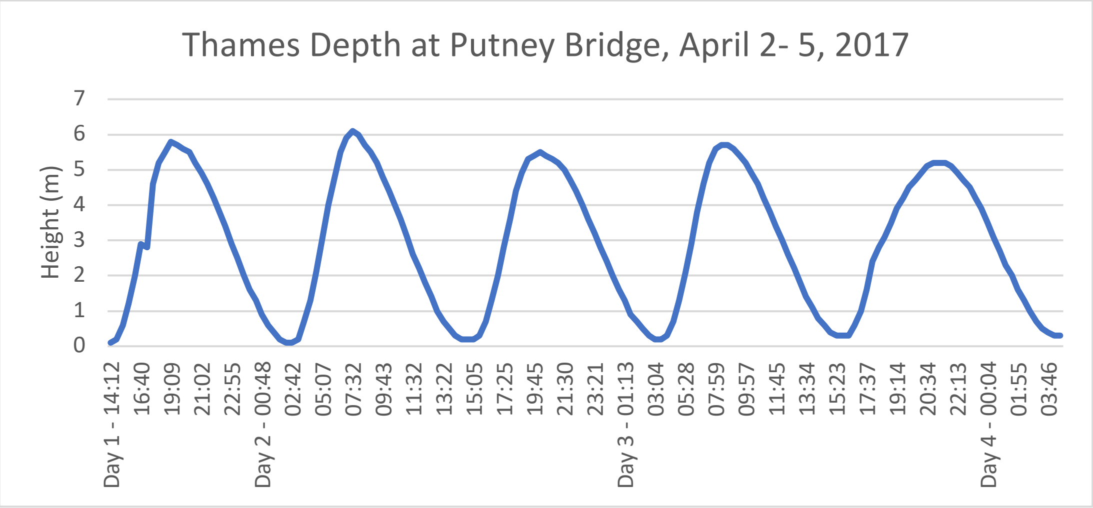


Figure 6.32 Tide times of the river Thames while Bottle 10 was active. Path of bottle once it entered the river follows flow of tide.

Ellipse analysis of Bottle 10

Ellipses were generated for the full dataset, days 1 and 2 as well as a subset of day 2 which only includes locations of the bottle prior to it being picked up by the Thames at 12:43. As this analysis is interested in bottle movement while on land, only ellipses for day 1 and part of day 2 will be presented. Remaining ellipses are available in Appendix G (page 382).

Table 6.11 Results of ellipse analysis conducted on Bottle 10, including ellipses on full path as well individual paths for day 1 and 2, as well as a partial dataset from day 2 before the bottle entered the river.

	Distance btw Deposition and Mean Point (m)	Minus 5-metre accuracy	Ellipse Area (sq m)	Concentration	Eccentricity	Orientation (degrees from north)
Bottle 10	505.54	500.54	2746219.48	73.68%	0.80833	117.49
Day 1	*1.62*	*0.00*	*58.76*	*66.04%*	*0.66543*	*30.90*
Day 2	*300.32*	*295.32*	*416705.23*	*77.14%*	*0.97527*	*166.69*
Part Day 2	*6.99*	*1.99*	*30.87*	*71.43%*	*0.77188*	*29.46*

The ellipse centre on day 1 was only marginally removed from the deposit site (1.62 m) and well under the 5-metre accuracy. The ellipse area (51.76 sq m) and concentration (66.04%) indicate a largely distributed circular pattern (0.66543) towards the northeast (30.90 degrees from north). The ellipse of partial data from day 2 was not only smaller (30.87 sq m), but more concentrated (71.43%) and portrayed a slightly more linear pattern (0.77188) in a similar direction as day 1 (29.46 degrees from north), as illustrated in Figure 6.33 below. It is important to note that although the movement on day 2 seems more extreme (6.99 m from deposit site), a visual inspection of the bottle path Figure 6.30 (page 206), illustrates that many points later in day 1 began to overlap with earlier points on day 2.

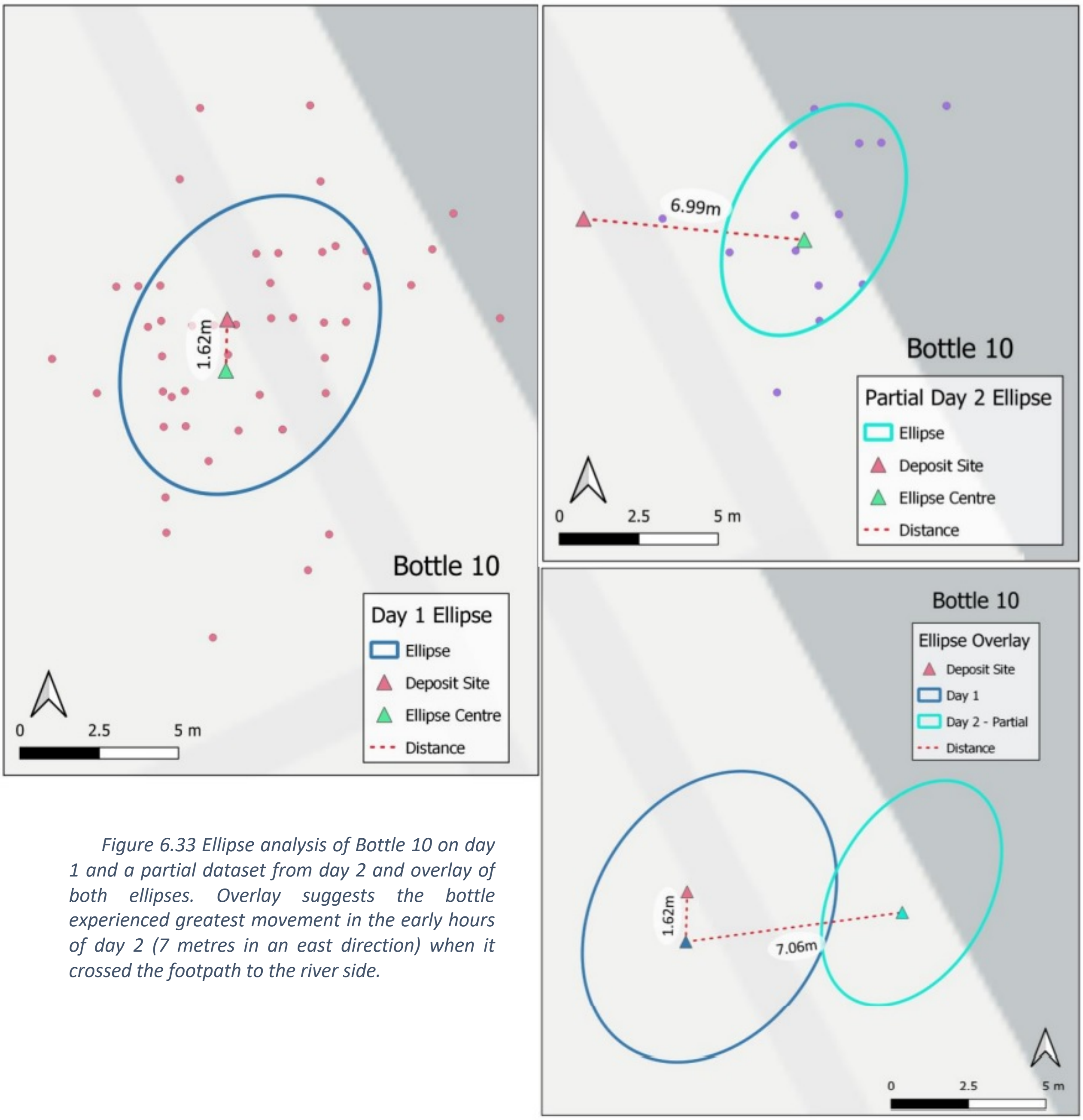


Figure 6.33 Ellipse analysis of Bottle 10 on day 1 and a partial dataset from day 2 and overlay of both ellipses. Overlay suggests the bottle experienced greatest movement in the early hours of day 2 (7 metres in an east direction) when it crossed the footpath to the river side.

6.4. Overview

This study was designed to begin a conversation on the indirect influence of humans on litter transport. Calm weather conditions during the study indicate that items were not under the influence of typically sited methods of transport (i.e., wind, rain and surface runoff), but exposed primarily to foot traffic. Many limitations and sources of error can be identified in this study. To name a few, the site and bottles were subject to an infinite number of external influences, only a small number of bottles were deployed and the hardware itself was questionable in accuracy. Despite these limitations, some insight was generated that can lend itself to future research.

Extra cleansing staff on the day of the event led to Bottle 3, 4, 7 and 9 being collected within a few hours of deposition. Bottle 1 and 5 initially evaded cleansing efforts but were collected early the following day.

The ellipses constructed on Bottle 2 over the three days suggest potential influence of footfall as litter transport (Figure 6.34). The decreasing size and eccentricity throughout the active period mimic the decrease in foot traffic that occurred from the event on day 1 to the patronage experienced on standard non-event days.

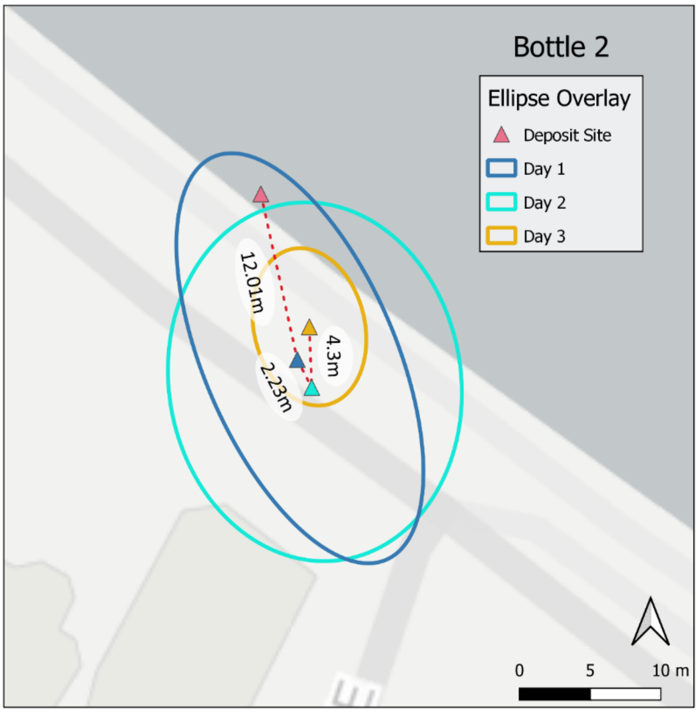


Figure 6.34 Ellipse overlay of all three days Bottle 2 was active. Analysis suggests further and more linear movement on days of high footfall.

The ellipses of Bottle 6 and 10 (Figure 6.35) on calm weather days (which both travelled to the Thames foreshore), hint at the ability for non-meteorological forces to cause litter to inadvertently enter the Thames.

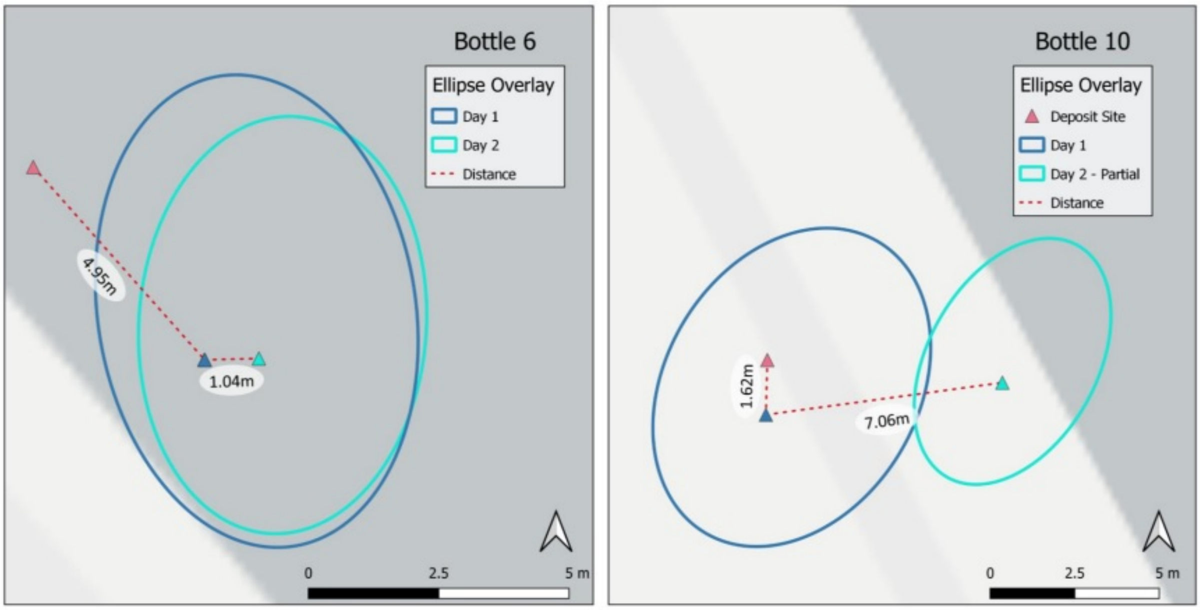


Figure 6.35 Ellipse overlay of Bottle 6 and 10 which travelled to Thames foreshore despite lack of forces such as wind and rain which are typically attributed to terrestrial litter transport.

Note that locations where bottles 6 and 10 were deposited were very different. Bottle 6 was left along the embankment which featured a railing with a large gap at ground level, where bottle 10 was left in the bushes on the inland side of a footpath, opposite from a gradual slope covered in thick brush towards the river.

Improvements to this study could include higher quality GPS hardware, better padding within the bottles to reduce potential of damage, improved battery life, a higher number of deployed bottles, the use of a wide range of sites with various features and topographies and deployment during various meteorological conditions.

6.5. Discussion

Litter has a high potential for transport through aquatic environment, rivers and oceans are repeatedly found to not only contain, but displace large quantities of litter (Tramoy *et al.*, 2020; van Sebille *et al.*, 2020; Al-Zawaidah, Ravazzolo and Friedrich, 2021; Delorme *et al.*, 2021; European Commission, 2022). Rivers act as a pathway for litter from land to the ocean (Crosti *et al.*, 2018; Castro-Jiménez *et al.*, 2019; Delorme *et al.*, 2021), accumulating debris from inland sources as far as 200 km from the coast (Van Sebille, England and Froyland, 2012; Schmidt, Krauth and Wagner, 2017). It is estimated over 4 million tonnes of plastic is transported via rivers every year (Jambeck *et al.*, 2015; Schirinzi *et al.*, 2020), accounting for 80% of the waste found in the ocean (European Commission, 2016; Winton *et al.*, 2020). Due to the transport potential, it is no surprise that water flow causes large-scale global distribution of litter (Garello *et al.*, 2021).

Pathways of litter from land to rivers are far more complex, and exact data on land-based transport methods and levels of contribution is often left to speculation (European Commission, 2016). Facilitating factors of land-based transport are theorised to include the weight and material composition of the item, the incline of the terrain and meteorological forces such as wind and rain (Lambert, Sinclair and Boxall, 2014; Fazey and Ryan, 2016; Lebreton *et al.*, 2017; Honingh *et al.*, 2020; Lechthaler *et al.*, 2020; Schirinzi *et al.*, 2020; Roebroek *et al.*, 2021; Cowger *et al.*, 2022). There is however growing evidence of the influence of human dispersal (Cowger *et al.*, 2022) as this study suggests.

The concept of foot traffic as a contributor to land-based litter transport is unique to this study, and the theory raises implications on wider public accountability. If the act of displacement through kicking is a vector for marine intrusion, any individual that engages in this behaviour (intentionally or not) is to some degree complicit in the consequences that ensue. From this standpoint, liability not only falls on the litterer, but responsibility can be transferred to those who aid in displacement and potentially to those who do not collect items they interact with in public.

In considering the contribution of land-based litter to aquatic environments, implementation of physical barriers has a high potential for reduction. Embankments and bridges in London feature fences to protect the public from falling in the river, yet the design of these fences often have ground level gaps large enough for litter to pass under. This is of course to allow for surface runoff to enter the river, however, there are ways to instal barriers at ground level that stop litter while not hindering the flow of water.

In the following chapter (Chapter 7: Material Composition of Litter) the concept of litter transportability will be discussed, introducing the characteristics which facilitate a litter item’s ease of transfer within the environment. In the context of this study, to contain litter regionally and reduce in-land contribution to marine plastics, designs that minimise transportability of litter items is highly recommended. Additionally, the placement of physical barriers in areas where litter has the potential to enter rivers (e.g., a small ledge along embankment walls) is a structural and sustainable approach to stemming the flow of land-based litter to the ocean.

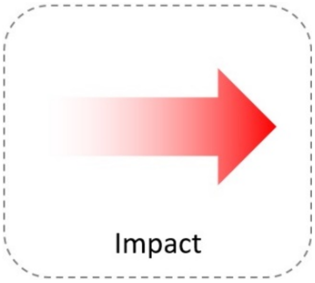
Ultimately, this study highlights that litter is not simply deposited; it flows. Litter is not restricted by boarders or confined to any singular environment, it travels long distances and can do so within, and between various systems.

6.5.1. Lesson learnt

Litter can enter a site by means other than littering

After deposition, there are multiple forces at play in the pathways of litter throughout an environment.

Chapter 7: Material Composition of Litter: Toxicity, tenacity, threat and transportability



7.1. Introduction

We live on a dynamic planet, where landscapes constantly change under natural forces of erosion and accumulation (Summerfield, 2014). Geographic features formed by tectonic movement (Endogenic processes), such as continents, oceans, ocean islands and mountains, take tens of millions of years to form (Summerfield, 2014), changing so unperceivably that until the late 1960's their presence was widely believed to be permanent (Dickinson, 1971; Laudan, 1978). Dramatic landscape change (Exogenic processes) can however be observed along coasts, in the bends and meanders of rivers and in the sand dunes of vast deserts (Summerfield, 2014). Simply put, the size and resilience of materials that make up the landscape dictate the temporal and spatial scale of change (Summerfield, 2014; Huggett, 2016); where the forces required to move a mountain made of boulders are far greater than those that transport sand along a beach. Material composition is one of the main factors in how these landscapes behave in the environment (Scheidegger, 2012; Summerfield, 2014; Huggett, 2016).

The influence of material composition is universal and can be applied to any field. For example, in ecology, consider the dispersal patterns of winged seeds by wind versus those encapsulated in burs clinging to the pelts of animals; or in the field of engineering, the integrity of a home made of brick versus one made of plywood.

Material composition plays an integral role to both impact and fate of the items in question.

Research and policy action on littering has however largely ignored the influence of material composition, where the term litter encompasses a wide variety of items. In fact, the UK legal definition of littering is when a person “throws down, drops or otherwise deposits any litter” (UK GOV, 1990, Section 81 (1)), offering no definition of what items constitute litter. Legally, any item can be litter, this includes a dropped wallet, a bit of lettuce from a sandwich or even a cigarette end. These items share no similarities in terms of value, biodegradability, or method of littering. The one thing that connects these items is that they are no longer possessed and exist in an environment where no single individual has direct responsibility for them.

Litter in public spaces has an adverse effect on the environment, society, human health and can have both a local and a global influence. I argue that not all litter is made equal, and that the material composition of individual items has a direct influence on their level of impact; particularly in terms of toxic loads, tenacious nature, the threat they pose to public health and their ability to be transported.

Consider the toxic nature of two litter items, cigarette ends and nut shells. Cigarette ends are saturated with chemicals which are easily leached into surface water (Slaughter *et al.*, 2011; Booth, Gribben and Parkinson, 2015). As several trillion are littered every year, they are considered the number one littered item in the world (Bonanomi *et al.*, 2020). Yet in a study of several Saudi Arabian parks, pistachio nut shells were the most littered item, accounting for a third of litter; cigarette ends didn’t even appear on the list of top 5 littered items (Al-mosa, Parkinson and Rundle-

Thiele, 2017). Nut shell litter has been associated with human activity for thousands of years and the consumption of pistachios is synonymous with social and leisure activities in Islamic culture (Casas-Agustench, Salas-Huetos and Salas-Salvadó, 2011; Salas-Salvadó, Casas-Agustench and Salas-Huetos, 2011). Smoking and snacking are often promoted in social situations and even provide relief for cravings, stress or boredom (King, 1971; Jiwa, Krejany and Kanjo, 2021). The difference is that nut shells are inert, often even used as fertilizers, yet the risk posed by the toxic load of cigarette ends is of such gravity that European regulation has classed them as hazardous waste (Rebischung *et al.*, 2018). The toxicity of these two items is polarized, however under UK legislation, the penalty for littering either is equal.

Littering is a human habit that can be traced back millions of years (Rathje, 1996; Foley and Lahr, 2015). Modern litter is however unique as it is increasingly made from tenacious materials, unlike historic items which were entirely derived from organic and biodegradable sources (Rathje and Murphy, 2001; Havlíček and Morcinek, 2016). The tenacious nature of modern litter, particularly those made of plastic, leads to items accumulating in the environment; it is theorized that a single plastic carrier bag requires anywhere from 400-1,000 years of exposure to the elements for it to completely fragment into microplastics (Bell and Cave, 2011; Andriani *et al.*, 2020). Although this process eliminates the plastic bag, plastics do not biodegrade, and the fragmented microplastics will remain in the environment, further breaking down into smaller pieces (Zhang *et al.*, 2021). Paper bags, which serve an identical purpose to those made of plastic, do not exhibit the same persistent qualities. Research on the tenacity of paper products mixed in soil has found a 39% reduction of mass in 5 months (Line, 1995), and when shredded prior to application, a 100% degradation in a year (Ghimire *et al.*, 2020). The tenacious nature of these interchangeable litter items is clearly incomparable.

The presence of litter in public spaces is a threat to public wellbeing and can cause injury to both humans and animals. Broken glass bottles on roadways are responsible for up to 10% of car and bicycle tyre punctures (Sherrington, Darrah and Hann, 2014), increasing the likelihood of accidents and injury. Children are often injured by broken glass in streets and playgrounds (Forsyth and Davidson, 2010). In UK hospitals, litter accounted for 45% of glass related injuries over a period of 5 months (Armstrong and Molyneux, 1992). In Palestine, 58% of children interviewed had at one time been injured from littered glass (Al-Khatib, 2008), and in USA interviews, 34% reported the same (Makary, 1998). In both Palestine and USA, approximately half of the incidents were of a severity where they required professional medical care (Makary, 1998; Al-Khatib, 2008). On beaches, where it is common to walk barefoot, glass is one of the most commonly surveyed forms of litter and the threat of injury due to littered glass is considered to be of great concern (Hidalgo-Ruz *et al.*, 2018; Campbell *et al.*, 2019; Nelson Rangel-Buitragoa, 2019; Maleki and Soria, 2020; Rangel-Buitragoa *et al.*, 2020). But it isn't just humans that are at risk, the Royal Society for the Prevention of Cruelty to Animals (RSPCA) warns of issues of wildlife entrapment and injuries due to glass litter (RSPCA, 2022), and 95% of veterinarians report having treated a domestic pet injured by litter (Clean up Britain, 2016). Most recent litter counts in the UK report that 87% of littered glass bottles surveyed were for alcoholic consumption (DEFRA, 2020). Alternatively, aluminium drink containers are equally as effective as glass in delivering alcoholic beverages, but in contrast, they cannot be smashed into sharp fragments (Forsyth and Davidson, 2010) and pose fewer physical threats to humans or animals. The use of aluminium is in fact recommended as a safer vessel for carbonated and pressurized drinks (Kuhn *et al.*, 2004). The opposing threats to bodily harm that glass and aluminium litter pose are poles apart, despite both items serving identical purposes.

Lightweight litter items are highly transportable (Wilson and J. Randall, 2005). Due to their buoyancy and weight, plastic bottles are able to travel long distances, often swept into waterways and intruding marine environments (Rech *et al.*, 2014; Jambeck *et al.*, 2015; Crosti *et al.*, 2018). Surveys of litter on the beaches of Kenya found 20% of plastic bottles had travelled across the Indian Ocean, originating from Southeast Asia (Ryan, 2020). In researching marine and riverine transfer dynamics of litter, plastic bottles are often used to house GPS trackers (Tramoya *et al.*, 2020), as was illustrated in Chapter 6: Transfer Dynamics of Litter. However, not all plastic items behave this way. For example, chewing gum is mostly composed of a synthetic plastic that leads to its elastic and persistent qualities (Parliamentary Office of Science and Technology, 2003; Martinetti *et al.*, 2014; Konar *et al.*, 2016; Palabiyik *et al.*, 2020). Chewing gum is however very sticky, and when littered will remain in the exact spot it was dropped unless removed using intense and costly cleansing techniques (Parliamentary Office of Science and Technology, 2003). In the UK, plastic bottles represent nearly a quarter of litter by volume (DEFRA, 2020) and in Chapter 4: Litter Source Dynamics, chewing gum was found to be the second most non-cigarette littered item, accounting for 10% of the sample. The transportability of these plastic based, frequently littered items is dramatically different, one being inherently mobile and the other persistently static.

As illustrated in the examples above, the toxicity of cigarette ends against that of pistachio shells, the tenacity of plastic bags contrary to that of paper bags, the threat of harm posed by glass compared to that of aluminium and the transportability of plastic bottles differing from chewing gum, there are dramatic differences between the characteristics of litter items that often serve identical purposes. In each case, the material composition of the litter dictates their potential impact. These litter items vary greatly and do not have equal weighting within the categories of toxicity, tenacity, threat and transportability (4T).

Despite being a diverse accumulation of items that behave in different ways, litter is clustered into one overarching collective noun. To understand litter dynamics and subsequent impact, an investigation in material composition and resulting characteristics of individual items is required. One way to evaluate distinct characteristics is to compartmentalise litter within an index.

Indexes can be used in quantitative analysis as a method of creating a single measurement collated from a series of characteristics, referred to as indicators (Diamantopoulos and Winklhofer, 2001). The indicators included in an index are separate variables that, when combined, characterise a greater measurement, referred to as the value (Diamantopoulos and Winklhofer, 2001). The use of indices allows for a robust analysis that accounts for a wide range of component characteristics (Diamantopoulos and Winklhofer, 2001). In the case of this study, I am interested in indexing the independent indicators that lead to the negative repercussions associated with litter.

The upcoming chapter will establish, validate, and examine an index built to determine the level of harm individual items of litter can inflict. Based on research on the negative repercussions of litter, indicators analysed will be toxicity, tenacity, threat and transportability, referred to as The Four T’s (4T). The index will produce a Litter Impact Value for frequently littered items.

Question: Do all litter types have equal impact?

Hypothesis: An analysis of the material composition of individual litter items will reveal that not all litter has equal impact and identify which have greater associated adverse effects.

7.2. Descriptors of the Four Ts

7.2.1. Toxicity

The category of toxicity refers to the toxic, chemical or microorganism load of an individual litter item. Characteristics of toxic litter do not include physical harm, and scores are dependent on the indirect adverse effects posed by the item on health and the environment.

Toxic and chemical loads can come directly from the litter item itself, as is seen in the case of cigarette ends (Rebischung *et al.*, 2018), adhesives and paints (Wright and Kelly, 2017). Toxicity can also stem from litter items acting as accumulators and magnifiers of chemical loads. This is the case for hydrophobic materials such as plastic, which attract and harbour pollutants and heavy metals they interact with (Wright and Kelly, 2017). Finally, harmful bacteria and microorganisms can be found in, and proliferate on, litter items such as food, faeces, sanitary and medical waste (Rangel-Buitragoa *et al.*, 2020).

7.2.2. Tenacity

The category of tenacity is measured by the residence times of litter items in the environment. Tenacity scores are specifically determined by litter behaviour when exposed to elements such as sunlight, oxidation, bacterial decomposition and chemical and mechanical action (Lambert, Sinclair and Boxall, 2014). Residence times of litter items are not to be confused with those of waste in landfill, as research has found that the preservation qualities of landfill significantly reduce degradation rates (Rathje and Murphy, 2001).

For the purpose of this litter index, the tenacity of an item ends once the item no longer represents its original form. This is an important detail in the discussion of the tenacity of plastic derived items, as although they are known to fragment (Lambert, Sinclair and Boxall, 2014), the resulting microplastics themselves will persist in the environment (Zhang *et al.*, 2021).

7.2.3. Threat

The category of threat focuses on the potential for litter to cause physical harm, either towards humans or animals. Physical harm can be inflicted directly by injury, or indirectly through the behavioural influence of litter.

Severe injury from litter is caused by interaction with sharp items such as broken glass and syringes, and affect humans (Campbell *et al.*, 2019) as well as domestic animals and wildlife (RSPCA, 2022). There are also high rates of death and injury associated with animal and wildlife becoming entangled in litter items (Godley *et al.*, 1998; Thiel *et al.*, 2018; RSPCA, 2022).

The presence of litter has a promotional effect on negative behaviour (Wilson and Kelling, 1982). As a result, neighborhoods with high numbers of litter present in their streets typically have increased instances of crime (Keizer, Lindenberg and Steg, 2008; Sherrington, Darrah and Hann, 2014) posing an indirect threat to physical wellbeing. Thus, the presence of seemingly inert litter items have the potential for physical harm.

7.2.4. Transportability

The category of transportability focuses on the potential distances an item of litter can travel. Transportability is important in impact value as it determines the spatial range of associated adverse effects. In the case of highly transportable litter, when littering behaviour is not addressed correctly locally, the negative implications can be experienced globally. The same concept can be observed in issues such as air pollution and climate change, where national borders do not constrain repercussions, and a collective effort is required for mitigation.

Items made up entirely of soft and light plastics are highly transportable in water (Roebroek *et al.*, 2021). Half of the plastics produced globally have densities that are lesser than that of water, and are easily carried along the surface of rivers and oceans under the influence of wind, tides and waves (Lechthaler *et al.*, 2020). This does not ignore the distance potential of denser plastics, where items found within the water column are known to travel further than their buoyant counterparts (Ryan and Perold, 2021).

Items characterised with a higher surface to volume ration, such as packaging films and foils, are easily transported by wind (Lechthaler *et al.*, 2020). Paper items are, however, an exception (Roebroek *et al.*, 2021) as any interaction with water or moisture immediately changes their weight and consistency.

7.3. Methodology

Indexing is a common method in quantitative research that summates a series of characteristics to achieve a composite metric (Diamantopoulos and Winklhofer, 2001). In creating an index, a scoring system is established for each indicator, applied to each item within a data set and combined to generate a final value (Diamantopoulos and Winklhofer, 2001).

Although indexes are a useful method of establishing a collated value to a wide variety of items, there is no standard in their construction and no methods of establishing significance in their validation (Diamantopoulos and Winklhofer, 2001). It is generally advised to do the best you can do (Bagozzi, 1994) and results should be read with the knowledge that they are at the discretion of the author, influenced by their expertise in the field and thus presents a degree of subjectivity.

7.3.1. Building the index

As index structures are highly influenced by the context of the study, there is very little literature describing how to build one (Diamantopoulos and Winklhofer, 2001). General guidelines are outlined by Diamantopoulos and Winklhofer (2001), and with input from Crossman (2020), the following steps were taken to build the Litter Impact Index: 1) select items to be measured in the index, 2) designate a desired value outcome, 3) identify indicators that contribute to the value, 4) establish a scoring system, 5) execute the index and validate the outcome.

7.3.2. Index items

The first step in creating an index is to select the items that you wish to measure (Diamantopoulos and Winklhofer, 2001; Crossman, 2020). In the case of this study, the objective is to measure values for common littered items. Litter items were sourced from the UK Department for Environment, Food & Rural Affairs (DEFRA) “2020 Litter Composition Analysis”, the litter survey in Chapter 4: Litter Source Dynamics and supplemented with previously unaccounted for and recently observed litter items.

7.3.3. Index value

Next, the desired outcome of the index must be determined (Crossman, 2020). This is done by examining the relationship between the items in question (Crossman, 2020) and identifying what links them together in the context of your study. The idea of establishing a litter index came to mind whilst researching the topic of litter in the initial stages of drafting the literature review of this thesis. On the 25th of August

2015, there was a collective outcry across media outlets in England and Wales over a woman who was fined £75 for littering a leaf of lettuce in a McDonald's drive-through (Briant, 2015; Glanfield, 2015; Hartley and Smith, 2015; ITV News, 2015; Wales News Agency, 2015; Willis, 2015). The arguments set out by news outlets of the trivial nature of littering lettuce caused me to reflect on the meaning of litter and how it encompasses such a wide range of items. It soon became clear to me that although litter items have varying degrees of negative impact, they continue to be litter just the same. Thus, in the case of this study, the index value that will be analysed is the negative impact associated with discreet litter items.

7.3.4. Index indicators

Once items and desired value have been established, the next step is to identify which indicators contribute to the index value (Diamantopoulos and Winklhofer, 2001). Indicators were determined through extensive research on litter and the characteristics that lead to their associated impact. In selecting indicators, it is vital to ensure that indicators are the cause of the index value, and not caused *by* the value (MacCallum and Browne, 1993).

Chosen indicators for this index are litter characteristics that I believe influence their level of negative impact. Indicators in the index are, toxicity, tenacity, threat and transportability, collectively referred to as 4T.

7.3.5. Index scoring system

Having identified the index indicators, a scoring system for each indicator must be established (Diamantopoulos and Winklhofer, 2001; Crossman, 2020). The determined scoring system is the result of an extensive review of the qualities that lend themselves to each indicator.

As this is the first attempt to construct a holistic litter impact index, I decided to air on the side of simplicity and repeatability when deriving the scoring system. An index of this nature could certainly utilise the input of a wide range of experts to research and refine scores to a greater degree. As time and resources were limited, scores were determined given a broad 4-point scale ranging from 0-3, however As the toxic potential of cigarette ends and receipts were considered exceptionally severe it was decided that they deserved a category above other commonly littered items, as a result it was awarded a 5-point scale from 0-4.

7.3.6. Research item characteristics

Upon finalising the index framework (i.e., items, value, indicators, and scores), the index can now be executed. To execute the index, research was conducted on the material composition and resulting characteristics of each item. Research included a literature review and my unique knowledge in the field of litter analysis. The material composition for each item was classified to reflect indicator score parameters, this led to the Indicator Score Guide (Appendix H, page 385). Score values were then assigned based on attributes displayed in the indicator score guide.

7.3.7. Weighted values and scaling

It was decided that although all four indicators are a measurement of negative impact, the level of risk associated with each is not equal. For example, the risk of an item having a toxic effect far outweighs the impacts of transportability. As a result, a weighting system was applied to each indicator, placing emphasis on indicators with higher levels of associated risk. These were chosen given their potential to generate whole numbers in the final scaled value and are not without an element of subjectivity themselves. The weighting values for each indicator are, toxicity: 5, tenacity: 2, threat: 2 and transportability: 1.

Once applied, the final weighted values for each item could fall within a scale of 0-35. Given that familiar numbering systems are far easier for the public to understand, particularly when visualised in a continuous scale diagram (Izard and Dehaene, 2008; Gilmore, Attridge and Inglis, 2011; Gebuis and Reynvoet, 2012), the weighted values were further adjusted to fit within a 100-point measurement. To achieve this, weighted scores were multiplied by a factor of 2.86 resulting in the Scaled Value.

The final scaled Litter Impact Value (LIV) was calculated using the following equation; where Tx is the assigned *toxicity* indicator score, Te is the assigned *tenacity* indicator score, Th is the assigned *threat* indicator score and Tr is the assigned *transportability* indicator score

$$LIV = \big((Tx \times 5) + (Te \times 2) + (Th \times 2) + Tr\big) \times 2.857143$$

7.3.8. Validate index

Finally, it is important to validate the completed index (Diamantopoulos and Winklhofer, 2001; Crossman, 2020). There is no standard in index validation techniques, so it was chosen to review the value outcome of each item and use prior knowledge to decide if the value reflects what is known of that item (Crossman, 2020).

7.4. Results

7.4.1. Indicator scores

Whenever an item can be categorised in multiple score descriptions, the higher value was applied to the index.

7.4.1.1. Toxicity

Table 7.1 Index scoring framework for litter items within toxicity indicator. Includes quality descriptors as well as examples and is scored from 0-4.

Toxicity	Description	Examples
0	No known toxins	Uncoated aluminium and metal, glass, rubber, uncoated paper, rubber
1	Microorganism and bacterial source	Food, faeces, used tissue, sanitary waste, medical waste
2	Trace toxic amplifiers	Part plastic, plastic coated paper
3	Complete toxic amplifier	Plastic items
4	Toxic contribution	Cigarette end, thermal paper, chemically contaminated

Toxicity scores (Table 7.1) are dictated both by the load originating from the litter item as well as the propensity for that item to collect and magnify toxic components.

Items of no known toxins (score 0) include materials of organic origin that are not classified as food, such as paper, uncoated aluminium, glass, rubber and paper items that are not coated in plastic.

Food, faeces, used tissues, and sanitary and medical waste are items that promote bacterial cultures (Sherrington, Darrah and Hann, 2014) and can harbour microorganisms from their source, as is highlighted in the potential viral load of a used syringe (Carico *et al.*, 2020) or the tissue of a person who is unwell (Gholami *et al.*, 2020; Jafari *et al.*, 2021). The toxic potential of bacterial and viral loads is dependent on the source and includes a degree of uncertainty, however it was decided to air on the side of caution and assume that these loads were fairly inert and not life threatening. These items merit a score of 1.

Due to the hydrophobic surface qualities of plastic, they are known to attract pesticides, heavy metals and other hazardous chemicals they interact with in the environment (Wright and Kelly, 2017). Items with plastic are considered toxic amplifiers and not direct contributors of toxicity. Part-plastic and plastic-coated items[13] score 2 and items made entirely of plastic score 3.

Two items of litter were considered to pose exceptional toxicity and were designated a score of 4, these were cigarette ends and thermal paper products. This value would also be applied to chemically contaminated items which were not found during litter typology surveys.

The smoked cigarette end, including both a filter and a small amount of tobacco, are full of the chemicals that they filter from the rest of the burning cigarette (Slaughter *et al.*, 2011). These ends include significant amounts of alkaloids, nicotine and a variety of 4000 other chemicals, 50 of which are known to have carcinogenic properties (Register, 2000; Slaughter *et al.*, 2011; Rebischung *et al.*, 2018). It takes only one hour for the chemicals in a cigarette end to leach into water, exposing fish species and invertebrates to toxic chemicals (Moriwaki, Kitajima and Katahira, 2009;

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[13] Full description of plastic-coated items available under subsection 7.4.1.2. Tenacity, page 231.

Slaughter *et al.*, 2011) as well as contaminating urban water reserves designated for human consumption (Casadio *et al.*, 2010; Green, Putschew and Nehls, 2014).

Thermal papers, such as those used in producing cash point and till receipts, contain high levels of Bisphenol A (BPA) and Bisphenol S (BPS) (Porras, Heinälä and Santonen, 2014; Lv *et al.*, 2017; Ndaw *et al.*, 2018; Fang *et al.*, 2020; Frankowski *et al.*, 2020). Exposure to BPA and BPS have notable impacts to human health, particularly as endocrine disruptors that can have long term repercussions to reproductive health (Fang *et al.*, 2020; Frankowski *et al.*, 2020; Edaes and de Souza, 2022). It has been noted that these chemicals can be transferred to humans simply by touching receipts made of thermal papers (Lv *et al.*, 2017; Ndaw *et al.*, 2018) and their use in products is widely contested (Edaes and de Souza, 2022).

As toxicity is the most impactful indicator, the scores were weighted by a factor of 5.

7.4.1.2. Tenacity

Table 7.2 Index scoring framework for litter items within tenacity indicator. Includes quality descriptors as well as examples and is scored from 0-3.

Tenacity	Description	Examples
0	Biodegradable	Uncoated paper, faeces, wood
1	Organic subject to weathering	Glass, aluminium, foil, rubber, textiles, metal bottle tops
2	Trace persistent tenacity	Part plastic, plastic-coated items, sanitary waste
3	Complete persistent tenacity	Plastic items

Tenacity scores (Table 7.2) are dictated by the degradation rates of litter items specifically when under the influence of elements such as sunlight, oxidation, microorganisms and chemical and mechanical action. Degradation rates were established through a literature review on the presumed materials of litter items included in the index. Tenacity of an item concludes once its original form is no longer distinguishable.

The least tenacious of litter items include fully organic and biodegradable items such as uncoated paper, faeces and wood, and are awarded a null score.

Not all items derived of organic materials biodegrade and instead are subject to a slow process of weathering. A score of 1 is awarded to these items, and include glass (Melcher, Wiesinger and Schreiner, 2010), uncoated aluminium (Wood, 2006) and other metal derived items. Also included in this score are rubber or latex items which begin to degrade within a few weeks when exposed to the elements (Burchette, 1989). Biodegradation is aided by fungus, enzymes, bacteria (Stevenson, Stallwood and Hart, 2008), temperature (Somers *et al.*, 2000), UV exposure (Burchette, 1989; Somers *et al.*, 2000), soil and water (Burchette, 1989). These items include condoms

(Bó *et al.*, 2011), surgical gloves (Wilkinson and Beck, 1996; Hiemstra *et al.*, 2021), balloons (Burchette, 1989), and hair ties (Chen, 2014). Textiles have been bundled in this score as although their material composition varies greatly from item to item, they have not previously been recorded in past litter surveys as a persistent issue.

Items partially composed of plastic are categorised in mid-range tenacity and are designated a score of 2. The reasoning is that although their composition includes tenacious components, the vulnerable portions of these items are subject to degradation and the original form of the litter is quickly lost. An example being cigarette ends, where although the filter itself is composed of microplastic fibres, the paper that surrounds and binds the filter together quickly dissolves, and the original form of the cigarette is no longer distinguishable (Bonanomi *et al.*, 2020). This also includes plastic-coated paper items. Plastic-coatings are often applied to paper products to increase printability, service life (Morsy and El-Sherbiny, 2004; Pawde and Deshmukh Kalim, 2006) and to maintain integrity against humidity and liquids (Morsy and El-Sherbiny, 2004; Pawde and Deshmukh Kalim, 2006; Brinton *et al.*, 2019) particularly when the purpose is to contain liquids and foods. Plastic-coated paper is characterised by a smooth shiny finish (Pawde and Deshmukh Kalim, 2006), is thicker than conventional paper and more difficult to bend (Morsy and El-Sherbiny, 2004). Some plastic treated papers are obvious, such as food, gum, cigarette card and paper packaging, however others can be covert. Plastic coating can be found on paper cups (Foteinis, 2020; Ranjan, Joseph and Goel, 2021; Sandhu *et al.*, 2021), paper straws (Timshina *et al.*, 2021) and thermal papers such as till and cash point receipts (Campanale *et al.*, 2020; Ortiz Peñate, 2021). To reduce vulnerability to corrosion, plastic-coatings are applied to the inside of aluminium drink tins (Ortiz Peñate, 2021; Yousef *et al.*, 2021). Tampons and sanitary napkins also contain plastic components in order to maintain integrity when exposed to moisture (Borunda, 2019).

Plastic is not known to biodegrade and items made entirely of it take hundreds of years to fragment (Bell and Cave, 2011; Andriani *et al.*, 2020), resulting in the highest score (3) within the tenacity indicator. This includes single use face masks which are made of polypropylene (Hiemstra *et al.*, 2021).

Due to the mid-level risk posed by tenacity, scores were weighted by a factor of 2.

7.4.1.3. Threat

Table 7.3 Index scoring framework for litter items within threat indicator. Includes quality descriptors as well as examples and is scored from 0-3, although no items are considered to merit a null value.

Threat	Description	Examples
0	No harm	
1	Indirect bodily harm	Minimum value of all litter due to increased crime
2	Wildlife entanglement and harm	Yoke, hair tie, face mask, balloon, plastic bag, surgical glove, cigarette end, plastic utensil, polystyrene, plastic straw
3	Direct bodily harm	Glass, metal bottle top, syringe

Threat scores (Table 7.3) are dictated by an items ability to inflict bodily harm and can pose either a direct or indirect threat. The presence of any litter item, regardless of their material composition, are known to promote crime and anti-social behaviour (Wilson and Kelling, 1982; Keizer, Lindenberg and Steg, 2008; Sherrington, Darrah and Hann, 2014), thus all litter items have a minimum score of 1.

Items known to harm wildlife were designated a mid-range score of 2. Wildlife is known to become entangled in strap-like litter items such as yokes (industrial term for six pack ring straps), hair ties and face masks (Coleman and Wehle, 1984; Ryan, 2015; Hiemstra *et al.*, 2021) and can get caught inside balloons, plastic bags and surgical gloves (Wilcox *et al.*, 2016; Hiemstra *et al.*, 2021). When ingested, cigarette ends (Cooper *et al.*, 2004; Novotny *et al.*, 2011; Slaughter *et al.*, 2011), plastic utensils (Wilcox *et al.*, 2016) and fragmented plastic items such as polystyrene (Ryan, 2015) persist in the guts of wildlife and can result in serious health issues or even starvation (Ryan, 2015; Wilcox, Van Sebille and Hardesty, 2015). In 2015 a video of a turtle having a plastic straw removed from its nose generated millions of views (*The turtle with a straw in its nose: The story behind the viral video*, 2015), ultimately sparked a global movement to prohibit their use and transition to paper based straws (Gutierrez *et al.*, 2019; McKenzie, 2019; Timshina *et al.*, 2021).

Sharp litter items that frequently cause bodily harm score the highest (3) and include glass (Armstrong and Molyneux, 1992; Makary, 1998; Al-Khatib, 2008; Campbell *et al.*, 2019), metal bottle tops (Forsyth and Davidson, 2010; Williams *et al.*, 2013) and syringes (Forsyth and Davidson, 2010; Williams *et al.*, 2013; Carico *et al.*, 2020).

Due to the mid-level risk posed by threat, scores were weighted by a factor of 2.

7.4.1.4. Transportability

Table 7.4 Index scoring framework for litter items within transportability indicator. Includes quality descriptors as well as examples and is scored from 0-3.

Transportability	Description	Examples
0	No movement	Chewing gum, faeces, food, wood, textiles, metal bottle top, sanitary waste, rubber with low surface to volume ratio
1	Minimal movement	Glass and plastic, foil, part plastic, coated paper, and uncoated paper w/ low surface to volume ratio
2	Moderate movement	Plastic-coated and uncoated paper w/ high surface to volume ratio
3	Maximum movement	Plastic, part plastic, and foil w/ high surface to volume ratio, balloons

Transportability scores (Table 7.4) are dictated by the movement potential of a littered item. Litter items such as chewing gum, faeces and food are scored as no movement due to their consistency. Other items such as wood, textiles, metal, sanitary waste (i.e. diapers, tampons, sanitary towels etc) and most rubber items are considered to have no movement due to their weight and low surface to volume ratio, and are awarded a null score.

A score of minimal movement (1) is assigned to items with low surface to volume ratio that have the potential for movement due to foot traffic and other anthropogenic intervention. These include glass bottles and heavier plastic, foil, part plastic, plastic-coated paper and uncoated paper items.

The score for moderate movement (2) is awarded to plastic-coated and uncoated paper with high surface to volume ratios, as they have conditional transportability potential. Their lightweight nature lends itself well to be easily displaced by wind, however once these paper products come in contact with moisture, their transportability diminishes significantly (Roebroek *et al.*, 2021).

Maximum movement (3) is awarded to items composed of waterproof materials, such as plastic, part plastic and foils with high surface to volume ratio as they are easily transported by wind and water (Lechthaler *et al.*, 2020; Roebroek *et al.*, 2021). This score is also applied to balloons as they are highly transportable when inflated (Burchette, 1989).

Transportability is arguably the most subjective indicator and the most difficult to score. Some estimates were made in relation to surface to volume ratios of litter items and were based on observing these litter items under the influence of wind and foot traffic in the environment.

As transportability posed the lowest risk among the indicators, scores were weighted by a factor of 1.

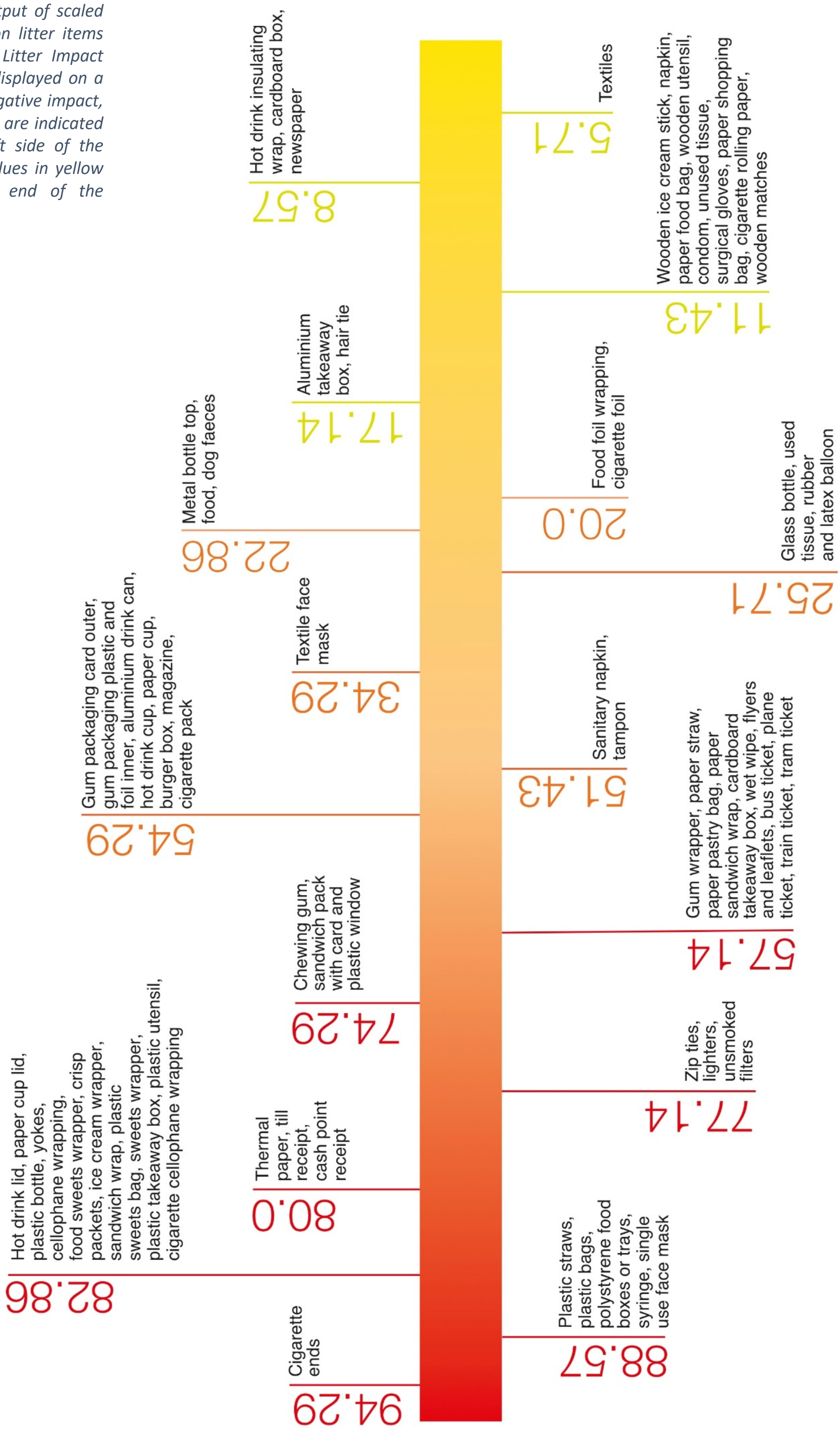
7.4.2. Indicator score guide

By collating the known characteristics of the index items, the Indicator Score Guide was built to categorise the items within indicator score metrics. These categories are plastic, part plastic, rubber, plastic-coated, uncoated paper, high surface to volume ratio and low surface to volume ratio. The Indicator Score Guide can be found in Appendix H, page 385.

7.4.3. Executed index

The index was executed and styled to fit on a single scale featured on the following page (Figure 7.1). Raw index calculations with breakdown of values for each indicator can be found in Appendix I, page 386.

Figure 7.1 Output of scaled values for common litter items according to the Litter Impact Index. Items are displayed on a sliding scale of negative impact, where high values are indicated in red on the left side of the figure and low values in yellow on the opposite end of the spectrum.



7.5. Overview

Due to their toxic loads, cigarette ends scored highest in the Litter Impact Index (94.29), followed closely by lightweight items made entirely of plastic (88.57). On the opposite end of the impact spectrum, heavier organic materials such as items made entirely of paper, rubber and wood dominated.

Often, items of similar purposes were positioned on polar ends of the index, having been scored both in plastic form and in an alternative material; for example utensils (82.86/11.43), straws (88.57/57.14), sandwich wrappings (82.86/57.14) and bags (88.57/11.43). Perhaps the most diverse litter items are those designated for drinking purposes; plastic bottles (82.86) amplify toxins and travel long distances; toxic components lurk in the protective films on paper cups and aluminium tins (54.29) and glass bottles (25.71) pose great threat of injury in their vicinity. Each of these items served an interchangeable purpose, yet the level of impact associated with their material composition were disparate.

Application of the index should always consider relationships between items that may have different scaled values. For example, the paper drink cup may have scored in the mid-range impact with 54.29, however these cups are rarely sold without high scoring plastic lids (82.86) and at times even higher scoring plastic straws (88.57). The same dichotomous impact is observed between ice cream wrappings (82.86), wood ice cream sticks (11.43) and the ice cream itself (food: 22.86); as well as cigarette rolling papers (11.43) and unsmoked filters (77.14), and a fair many other combination of related litter items.

7.6. Discussion

Litter is incredibly diverse and can range from inert items such as nut shells to highly toxic cigarette ends. Historically, cleanliness of public spaces is measured on a rating scale, with little interest on the purpose, source and composition of individual items. However, the material composition of litter items has a direct effect on the risk they pose to people and the environment. Despite this inequality in impact, litter is consistently referred to as a collective term and no distinction is made in either policy or mitigation research. As a result, the Litter Impact Index was constructed, which collates measures of toxicity, tenacity, threat and transportability, to establish a single value denoting level of harm associated with commonly littered items. This study is the first to add weighted values to individual items regarding their potential for negative impact. It should be noted that this index in not intended to disqualify accountability for littering items that score low, all litter breeds litter, no matter the impact score. The purpose of the Litter Impact Index is to inform targeted reduction efforts, product development and policy associated with packaging.

It is proposed among academics that the nature of a litter item often dictates the associated rate and method of littering (Williams, Curnow and Streker, 1997; Campbell, 2007; Wever *et al.*, 2010; NSW EPA, 2013). This is commonly observed in cigarette end litter, where they are more frequently discarded in flagrant and intentional ways (as observed in Chapter 5: Litter Deposit Methods) (Rath *et al.*, 2012). Given that a targeted approach can be more effective than a generalised message of please don’t litter (Durdan, Reeder and Hecht, 1985; Liu and Sibley, 2004;

Brown, Ham and Hughes, 2010), perhaps the Litter Impact Index can be repurposed to tailor mitigation efforts by specifically addressing items with a high impact value.

In European Union environmental policy, Polluter Pays Principle (PPP) has long dictated that accountability of pollutants in the environment is determined by its source (Sykes, 1994). In action, the PPP is applied to instances of poisonous and chemical contamination from sources such as factories and mining facilities (London School of Economics, 2018). Despite the negative effects of litter in the environment, the application of the PPP to litter is often overlooked. It is increasingly suggested that liability of littered items falls to the producers of common packaging items, and can be implemented in the form of taxes devoted to funding litter clean-up efforts (Regulatory Policy Committee, 2020; Darrah *et al.*, 2021). To this effect, in 2019 DEFRA proposed a reformation of the UK Environment Bill to include the Extended Producer Responsibility for Packaging (EPRP) (Regulatory Policy Committee, 2020; DEFRA, 2021c, 2021b). The objective of the EPRP is not only to efficiently implement a PPP taxation framework to packaging litter, but to motivate producers to develop smarter and less detrimental packaging design.

Of the 74 items included in the index, nearly half (49%) were single-use packaging for food and drink. Keeping in line with the EPRP objectives, the *Litter Impact Index* can inform producers on developing packaging design. By examining impact scores within individual indicators, negative characteristics of items can be targeted and reduced; effectively mitigating the impact of litter before it is littered. Equally, I suggest that the Litter Impact Index be integrated in the EPRP objectives, establishing proactive packaging regulations designed to mitigate the risks associated with litter.

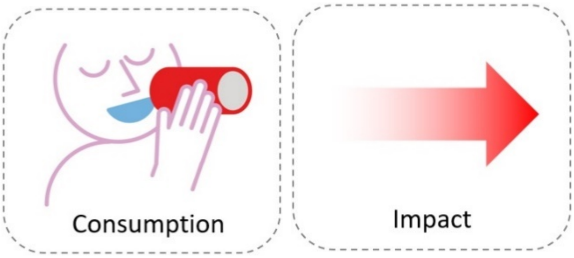
In the upcoming chapter, Chapter 8: Regional Variations in Litter: The connection between litter and place, litter impact values will be repurposed to examine regional variations between the four test sites where litter surveys were conducted.

7.6.1. Lesson learnt

Not all litter is created equal

Litter items have varying degrees of adverse effects and cannot be considered equally impactful.

Chapter 8: Regional Variations in Litter: The connection between litter and place



8.1. Introduction

Over half of the global population lives in an urban setting (The World Bank, 2022). By congregating in a specific area, dense populations are benefited with symbiotic support between various working parts of a city. Like an ecosystem, urban spaces provide a singular point where complex security, education, employment, transport and social networks are built. Designed to make life easier, the luxuries of living in an urban environment are plenty. No more are the days of hunting and gathering, the modern city allows convenient immediate access to anything you require; from individually wrapped meals, bottled drinks, a new item of clothing, to the deodorant you may have forgotten to apply this morning. There is, however, a fragile balance here, and the urban ecosystem is itself often vulnerable to stressors that threaten its wellbeing. One of these threats is the presence of anthropogenic debris, also known as litter (Schultz, 2002; Becherucci and Seco Pon, 2014).

Although the importance of the urban area is universal, the purpose and characteristics are unique to each. Variations in urban areas are seen between nations, where capital cities possess landmarks and an aesthetic that is often so iconic they can be identified by photographs alone. Take for example an image of the cobblestones of Paris with the Eiffel Tower peaking over uniform rows of Haussman style buildings constructed of light stone (Paccoud, 2016); or the broad endless streets of New York City, peppered with yellow taxis on the backdrop of towering skyscrapers gleaming in the sun. Urban areas can often vary immensely within a country, where many nations feature both old and new world cities, each serving their own unique purpose in national economy and society. England is a shining example of national variations, where urban areas have grown organically based on exclusive circumstances; such as industrial centres like Birmingham and Manchester which proliferated due to accessibility to raw industrial product for manufacturing purposes (Hopkins, 2002; King, 2012; Maw, 2018) and historic London, established by the Romans due to proximity to water for distribution of goods (Bateman and Milne, 1983; Milne, 1985; Franconi, 2013). Even within the capital of London, old and new meld as heritage structures such as the Tower of London and Tower Bridge are backdropped by the sleek modern high-rises of City of London. Despite these distinctive histories and catalysts for growth, the blight of litter is universal across English cities and specifically intense in city centres with retail and commercial purposes (DEFRA, 2020).

Litter can loosely be defined as personal items that are misplaced or intentionally disposed of in an improper manner (Geller, Brasted and Mann, 1979; Lechthaler *et al.*, 2020) and is commonly accepted to be the byproduct of littering, a human behaviour (Schultz *et al.*, 2013). While litter is omnipresent, it is found in every reach of the planet, from the busiest intersections to uninhabited remote islands in the middle of the Pacific, it poses a significant problem in public spaces (Luan Ong and Sovacool, 2012; House of Commons, 2015; Jambeck *et al.*, 2015; Geyer, Jambeck and Law, 2017; Kolodko and Read, 2018).

Litter is a generalized term that encompasses a wide array of items despite their complex and distinguishable variations. As this thesis explores, different activities produce different litter types (Chapter 4), not all litter items are discarded in the same manner (Chapter 5), litter is vulnerable to many forces of dispersal through the environment (Chapter 6) and the material composition of litter items determines the level of associated negative impact (Chapter 7).

Despite an unprecedented increase in awareness of the issues associated with litter, litter continues to exist in urban spaces (Luan Ong and Sovacool, 2012). This is apparent as anti-littering efforts, community clean-ups and regular litter cleansing are still an important aspect in public budgets (Schultz *et al.*, 2013; Local Government Association, 2016). For example, according to the English Local Government Association, the country spends up to £1 billion a year tackling litter and fly-tipping (Keep Britain Tidy, 2014; Local Government Association, 2016); whilst predicted annual litter picking costs in the US are over $11 billion USD (Schultz *et al.*, 2013).

Due to the systematic and continuous negative effects that litter poses, both locally and globally, it is vital that the cleanliness of urban spaces not only be standard (Luan Ong and Sovacool, 2012) but more importantly, are approached in a sustainable manner to avoid societal and environmental impacts as well as financial stress.

Orchestrated land-based litter management has existed for years. Management has however existed regionally, with legislation and social acceptance differing between nations, often further fragmented by locality. Internationally, criminalization is the most common force against littering. This differs greatly across the globe, where in Singapore the fine for littering can be as high as $5,000 SGD (roughly £2,500 GBP) and citations often include public shaming through Corrective Work Orders (Luan Ong and Sovacool, 2012). Inversely, the fine for littering in England is £150 (UK GOV, 1990) and as local authorities are not required to enforce littering laws (DEFRA, 2019), citations are rarely issued. A survey of penalties in 2018-19 found that 16% of councils had not issued a single littering fine, and 56% had issued less than one citation a week (Carrington, 2020). Despite the rarity of criminal enforcement, local councils throughout England spend substantial portions of ever diminishing budgets maintaining the cleanliness of public spaces through public bin maintenance, litter picking and mechanic street cleansing (Keep Britain Tidy, 2014; House of Commons, 2015; Local Government Association, 2016).

The public however appreciates clean streets, with widespread agreement that it deteriorates the aesthetic of public spaces (Schultz *et al.*, 2013; DEFRA, 2019). As a result community oriented anti-littering events and communication campaigns regularly take place in the England (e.g., Clean for the Queen and the Great British Spring Clean), to promote litter picking, and action groups such as Keep Britain Tidy conduct annual litter surveys and anti-littering communication campaigns (House of Commons, 2015). However, as littering in the streets of England persists (House of Commons, 2015), the long term effectiveness and sustainability of action groups and communication campaigns is in question (Wever *et al.*, 2010).

Academically, urban land-based litter and littering has mostly been researched within the social sciences and behavioural sectors, typically seeking to influence littering behaviour through individual change (Schultz *et al.*, 2013; Al-mosa, Parkinson and Rundle-Thiele, 2017). This research has been largely qualitative and often based on self-reported questionnaire data. In quantitative studies, litter counting has primarily focused on clean-up and descriptive categorization (Schultz *et al.*, 2013; DEFRA, 2020), with very little emphasis on accumulation rates and regional comparative analysis. There is very little high resolution or exploratory research in land-based litter.

Based on the understanding of littering in urban spaces and the lack of critical empirical evaluation of this, I sought to evaluate how different street types in different cities affect accumulation and litter type. Incorporating data from previous chapters of this thesis, this study is designed to explore differences in litter profiles between regions and further grouping study sites by their purpose within the urban structure. Litter profiles will be compared in four ways, individual typology, prevalence, source activity and impact. It is theorized that the function of a street can influence types of littering; and if litter generating activities within specific urban spaces can be predicted, a better understanding of targeted approaches can emerge.

Question: Is there a connection between litter and place?

Hypothesis: A comparison of litter compositions between test sites will identify regional patterns as to the nature of litter generation.

8.2. Methodology

8.2.1. Study sites

This study was conducted in four sites within England's three largest cities: two London sites, Central: London Bridge (LBL) and South: Sutton High Street (SHS), Birmingham New Street (NSB) and Manchester Oxford Road (OXM) (Figure 8.1).

Figure 8.1 Map depicting location of the four sites included in this study: South London, Manchester, Birmingham and Central London.

The four sites fit into two distinct urban spaces, the High Street (HS) and the Central Business District (CBD) and are all considered high intensity of use in government land type indices (DEFRA, 2020).

Both the HS (SHS and NSB) and the CBD (OXM and LBL) are centrally located and highly connected in terms of transport, but the two serve very different roles in the lives of those who patronize them. The HS is a socio-economic hub, providing communal outdoor space for socializing, as well as a destination for food, shopping and entertainment (Mayor of London, 2017). Whereas the distinguishing factor of a CBD is its role as host to corporate office spaces and headquarters; often attracting healthcare and higher education institutions, and is patronized by a large population of highly skilled workers (Greater London Authority, 2008; Deloitte, 2019). Detailed descriptions of all four sites can be found in Chapter 3: 3.4 Study sites (page 88).

8.2.2. Research design

This study includes litter data from Chapter 4: Litter Source Dynamics: Litter as evidence of consumption and Chapter 7: Material Composition of Litter: , and specific data collection frameworks can be found in those respective chapters. Data application however differs slightly in this chapter as litter typology counts and associated source activities from Chapter 4 are further divided by subsector and counting session. Detailed descriptions of subsectors can be found in Chapter 3: 3.4 Study sites (page 88), and sessions are defined by individual instances where counting exercises occurred.

In Chapter 7 it was concluded that not all litter items have equal ramifications and values from the Litter Impact Index (litter impact value, LIV) (Figure 7.1, page 238) are repurposed in this study as weighted values of impact between regions.

8.2.3. Analysis

Modelling approaches from community ecology were applied to surveyed litter items. Community parameters are generally considered indicative measurements of the strength and diversity of an ecosystem (Barrantes and Sandoval, 2009), and are used here in the context of understanding the structure and diversity of litter types within the study sites. These parameters not only include measurements of volume, a traditional approach to litter analysis, but analyse variety in types present and identifies dominant types within each site.

Litter items were recorded by typology (Chapter 4) within each subsector from 4 separate counting sessions. Subsectors by session were considered independent sampling units and, except for areas designated as roadways, were surveyed in their entirety.

A series of indices on typology were calculated for each sampling unit and are considered community parameters. Community parameters (CP) include, abundance (N, total count of litter items), richness (R, number of types of litter counted), density (D, abundance divided by subsector area), evenness (E, richness divided by abundance) and impact (M, mean LIV of counted items[14]). Due to the nature of the

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[14] In instances where typology categories included multiple litter items of different scores (e.g., cigarette packaging, bagged litter, other etc), the highest score was applied.

sampling units, the summary count of the data were assumed non-parametric and were not transformed for normality.

To measure the influence of sessions on community parameters, a one-way ANOVA was run for each in SigmaPlot 14.5, comparing means with the Tukey Test (Winer, 1962; Hinkle, Wiersma and Jurs, 1982; Zar, 1999; Becherucci and Seco Pon, 2014). As the size of subsectors were not consistent, abundance was not included in community parameter analysis, and analysis of density was considered as an appropriate indicator of levels of litter present. Once it was determined that sessions had no influence on the data, regional influences on community parameters (R, D, E and M) were analysed using a Kurskall-Wallis Test between cities (SHS, OXM, NSB and LBL). When significant differences were observed, a Dunn's method pairwise comparison procedure was employed to further investigate. The influence of street types (HS and CBD) on community parameters were analysed using, a Wilcoxon Test. In all comparison analysis, differences were considered statistically significant when $P<0.05$. Violin plots to represent community parameters by city and street type were built in R Studio using the ggplot2 (version 3.3.6) package.

Overall diversity by city and street type were calculated in Excel using the Shannon Diversity Index (H = sum of (-ln®)*E) then transformed for ease of comprehension to the Shannon Equitability Index (Q = H/ln®) (Allaby, 2014).

Data on litter typology and source activity were normalized by area and modelled in R Studio using the vegan (version 2.6-2) and cluster (version 2.1.3) software packages. An Analysis of similarity (ANOSIM) was run to test for similarities in litter composition among city and street type groupings (Clarke, 1993; Becherucci and

Seco Pon, 2014; RDocumentation, 2022a) and the Similarity Percentage analysis (SIMPER) procedure was employed to identify particular typologies and activity groupings that were responsible for these similarities (Clarke, 1993). Finally, A non-metric multidimensional scaling (nMDS) model was performed using Bray-Curtis distances to illustrate community structures within test sites (Anderson, 2001; Ho, 2008; Ebner, 2018).

8.3. Results

During four separate data collection sessions in each of the four sites, a total of 26,209 items of litter were counted[15] within 132 subsectors (Table 8.1).

Table 8.1 Number of litter items observed in each site during separate counting sessions. A total of 26,209 items were recorded and separated into 32 typologies during the 16 counting sessions.

Site	**Date**	**Time**	***N***
SHS	04-Mar-16	13:00	*2,830*
SHS	05-Mar-16	18:00	*2,775*
SHS	11-Mar-16	13:00	*2,869*
SHS	12-Mar-16	18:00	*3,306*
OXM	19-May-16	13:00	*1,657*
OXM	20-May-16	18:00	*1,486*
OXM	25-May-16	13:00	*1,303*
OXM	27-May-16	18:00	*1,629*
NSB	03-Jun-16	13:00	*897*
NSB	04-Jun-16	18:00	*1,140*
NSB	10-Jun-16	13:00	*1,309*
NSB	11-Jun-16	18:00	*1,558*
LBL	06-Apr-17	13:00	*966*
LBL	08-Apr-17	18:00	*833*
LBL	20-Apr-17	13:00	*747*
LBL	22-Apr-17	18:00	*904*
Total			**26,209**

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[15] Note that due to construction, a small portion of OXM (sector 7, subsector 45) on 25 May, 2016 (session 3) was inaccessible and therefore not counted.

Litter items were categorized into 32 typologies and 8 source activities. Source activities are defined in Table 4.4 (page 122). Table 8.2 on the following page includes a full breakdown of the dataset by site.

Table 8.2 Detailed breakdown of total and site-specific litter. Includes raw numbers as well as proportions of site total.

Item	Activity	Total	%	SHS	%	OXM	%	NSB	%	LBL	%
Cigarette end	Cigarettes	20640	78.75%	9919	84.20%	4279	70.44%	4063	82.85%	2379	68.96%
Cigarette packs, cellophane wrapping and foil paper	Smoking	323	1.23%	53	0.45%	88	1.45%	115	2.35%	67	1.94%
Cigarette rolling papers, unsmoked filters	Smoking	103	0.39%	30	0.25%	34	0.56%	0	0.00%	39	1.13%
Lighters and matches	Smoking	77	0.29%	34	0.29%	15	0.25%	2	0.04%	26	0.75%
Gum - 3D	Gum	561	2.14%	215	1.83%	129	2.12%	52	1.06%	165	4.78%
Plastic bottle	Drinking	149	0.57%	36	0.31%	52	0.86%	25	0.51%	36	1.04%
Tin or aluminium drink can	Drinking	106	0.40%	21	0.18%	42	0.69%	12	0.24%	31	0.90%
Paper cup	Drinking	92	0.35%	40	0.34%	25	0.41%	20	0.41%	7	0.20%
Hot drink and insulating wraps	Drinking	86	0.33%	21	0.18%	31	0.51%	4	0.08%	30	0.87%
Glass bottle	Drinking	54	0.21%	7	0.06%	31	0.51%	4	0.08%	12	0.35%
Other drink	Drinking	58	0.22%	7	0.06%	3	0.05%	33	0.67%	15	0.43%
Crisp packets	Eating	85	0.32%	17	0.14%	45	0.74%	8	0.16%	15	0.43%
Sweet wrappers and bags	Eating	470	1.79%	200	1.70%	108	1.78%	67	1.37%	95	2.75%
Takeaway boxes: card, plastic, aluminium etc	Eating	160	0.61%	43	0.37%	86	1.42%	19	0.39%	12	0.35%
Polystyrene food boxes or trays	Eating	42	0.16%	10	0.08%	12	0.20%	5	0.10%	15	0.43%
Sandwich packs or wrap	Eating	93	0.35%	11	0.09%	40	0.66%	23	0.47%	19	0.55%
Tissues and napkins	Eating	376	1.43%	159	1.35%	80	1.32%	54	1.10%	83	2.41%
Paper bags	Eating	44	0.17%	10	0.08%	17	0.28%	3	0.06%	14	0.41%
Utensils	Eating	89	0.34%	16	0.14%	12	0.20%	29	0.59%	32	0.93%
Food	Eating	185	0.71%	23	0.20%	79	1.30%	41	0.84%	42	1.22%
Cellophane wrapping - food	Eating	128	0.49%	42	0.36%	28	0.46%	8	0.16%	50	1.45%
Train and bus tickets	Transport	155	0.59%	6	0.05%	117	1.93%	11	0.22%	21	0.61%
Cash point receipts	Shopping Entertainment	272	1.04%	93	0.79%	39	0.64%	120	2.45%	20	0.58%
Till receipts	Shopping Entertainment	468	1.79%	276	2.34%	74	1.22%	69	1.41%	49	1.42%
Flyers and leaflets	Shopping Entertainment	374	1.43%	55	0.47%	212	3.49%	45	0.92%	62	1.80%
Cardboard box	Shopping Entertainment	52	0.20%	19	0.16%	22	0.36%	3	0.06%	8	0.23%
Newspapers and magazines	Shopping Entertainment	50	0.19%	4	0.03%	25	0.41%	3	0.06%	18	0.52%
Plastic bags	Shopping Entertainment	39	0.15%	5	0.04%	27	0.44%	2	0.04%	5	0.14%
Textiles	Other Unsure	18	0.07%	4	0.03%	3	0.05%	4	0.08%	7	0.20%
General litter (other)	Other Unsure	702	2.68%	363	3.08%	247	4.07%	44	0.90%	48	1.39%
Unsure	Other Unsure	86	0.33%	6	0.05%	41	0.67%	11	0.22%	28	0.81%
Bagged litter	Other Unsure	72	0.27%	35	0.30%	32	0.53%	5	0.10%	0	0.00%
Total		**26209**		**11780**	**44.95%**	**6075**	**23.18%**	**4904**	**18.71%**	**3450**	**13.16%**

8.3.1. Influence of sessions

The influence of sessions on community parameters (CP) has been considered inconsequential in similar studies (Becherucci and Seco Pon, 2014). In this study, a one-way ANOVA on the influence of sessions on CP (Table 8.3), identified differences in richness (P=<0.001), yet none by density (P=0.051), evenness (P=0.489), or impact (P=0.515). Given the similarity in richness medians and evidence from prior research, I chose to discount the influence of sessions.

Table 8.3 Kruskal-Wallis One Way ANOVA on ranks to determine influence of sessions on community parameters. Significant differences were observed in richness parameter however differences were insignificant by density, evenness and impact.

Influence of *sessions* on *richness*, P=<0.001

Session	N	Median	25%	75%
1	131	5	3	7
2	131	6	4	8
3	130	5	3	7
4	131	6	4	9

Influence of *sessions* on *density*, P=0.051

Session	N	Median	25%	75%
1	131	0.253	0.15	0.514
2	131	0.263	0.149	0.449
3	130	0.284	0.158	0.442
4	131	0.35	0.214	0.51

Influence of *sessions* on *evenness*, P=0.489

Session	N	Median	25%	75%
1	131	0.13	0.0833	0.222
2	131	0.156	0.0909	0.278
3	130	0.139	0.0727	0.238
4	131	0.14	0.08	0.225

Influence of *sessions* on *impact*, P=0.515

Session	N	Median	25%	75%
1	131	89.289	84.606	91.786
2	131	88.575	82.057	91.492
3	130	88.927	84.82	91.981
4	131	88.761	83.854	91.432

8.3.2. Community parameters

8.3.2.1. Richness

Richness is a measurement of number of species within a dataset, a high richness score indicates a community with many species present. In this study, individual litter types are considered individual species. A violin plot of richness by city (Figure 8.2) shows a wider spread towards higher values in OXM, otherwise no patterns are immediately apparent.

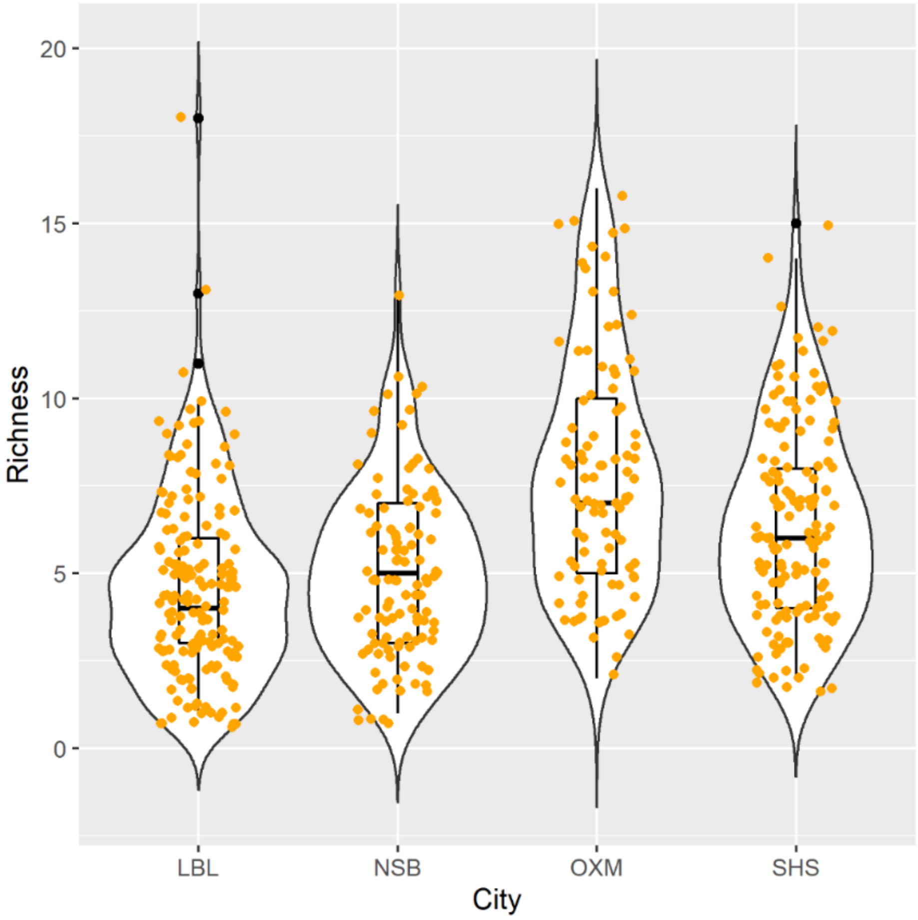


Figure 8.2 Violin plot of richness by city shows no distinguishable patterns in data. Overall shape of violin represents the distribution of data. Dots represent actual data points. Box and whisker plots within violin represent interquartile intervals.

When pooled by street type (Figure 8.3) richness shows concentrated data towards lower values in HS and a wider spread in CBD towards higher values.

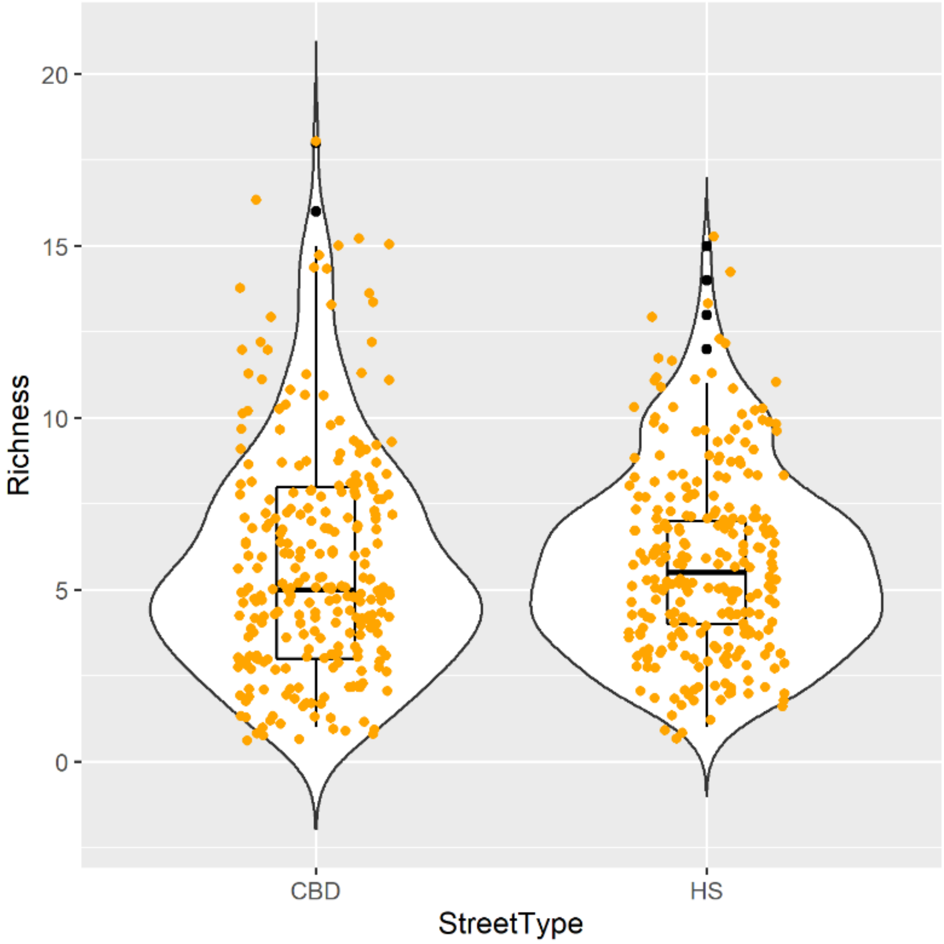


Figure 8.3 Violin plot of richness by street type implies concentrated low richness values in HS while CBD features a wider spread towards higher values. Overall shape of violin represents the distribution of data. Dots represent actual data points. Box and whisker plots within violin represent interquartile intervals.

8.3.2.2. Density

Density is the number of litter items counted per square metre and does not consider the size of individual litter items. As sampling units did not have equal areas, density is considered a more accurate measurement than abundance. Violin plot of density by city (Figure 8.4) shows clear similarity in length and number of outliers between SHS and NSB (HS sites) and OXM and LBL (CBD sites). CBD sites appear to have a wider spread towards higher densities of litter.

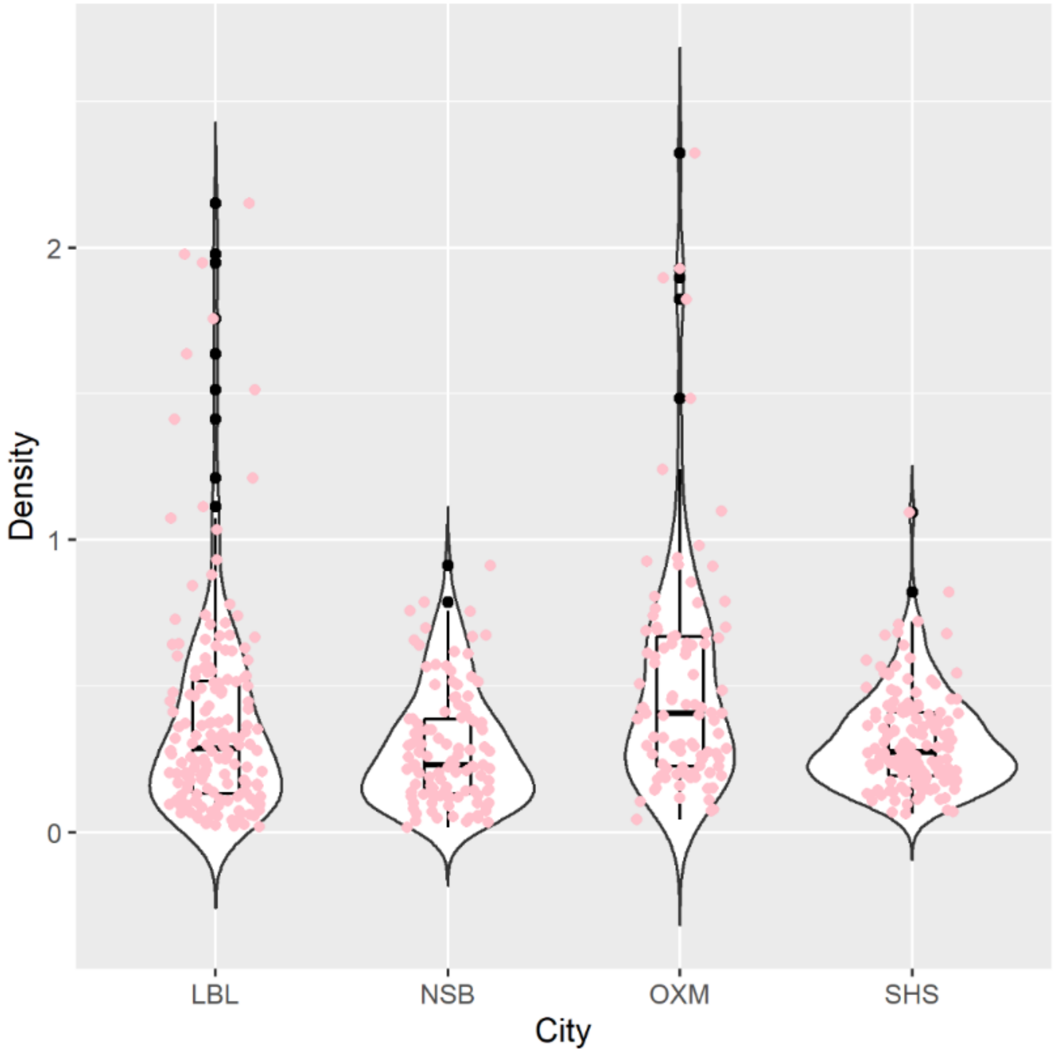


Figure 8.4 Violin plot of density by city shows a pattern of similarity in spread between LBL and OXM and between NSB and SHS. Overall shape of violin represents the distribution of data. Dots represent actual data points. Box and whisker plots within violin represent interquartile intervals.

This is further supported when the data are pooled by street type (Figure 8.5). HS display concentrated data towards low densities while CBD has a wider spread with many outliers towards higher densities.

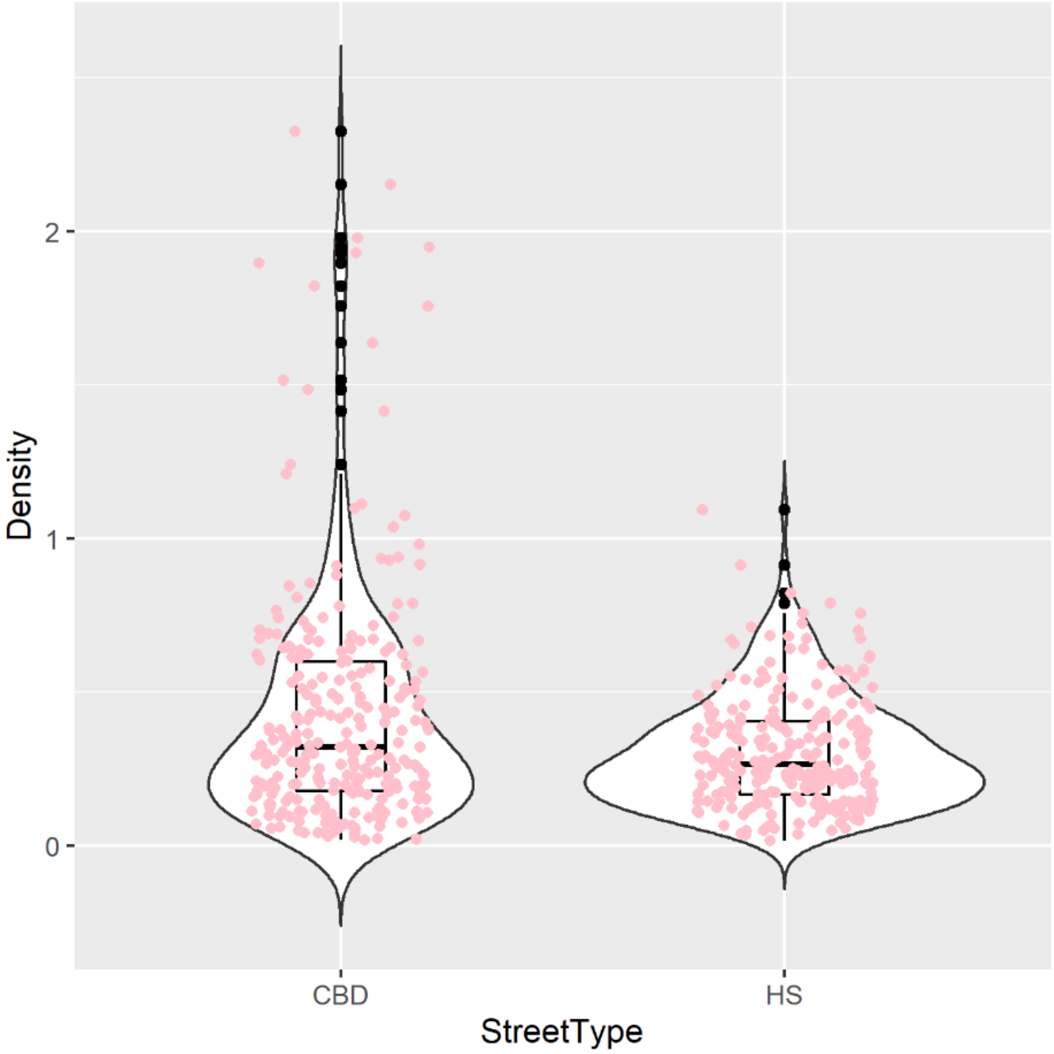


Figure 8.5 Violin plot of density by street type implies consistently lower densities in HS while CBD features a wider spread towards higher densities. Overall shape of violin represents the distribution of data. Dots represent actual data points. Box and whisker plots within violin represent interquartile intervals.

8.3.2.3. Evenness

Evenness is a single value that describes level of balance between species in a given space. It is measured on a scale of 0-100, where a score of 100 represents an equally distributed number of species and 0 denoting a sample that is heavily in favour of a dominant species. Violin plot of evenness by city (Figure 8.6) shows more instances of equal distribution within LBL, while SHS was concentrated much closer towards uneven distribution. OXM and NSB were somewhat similar, with NSB featuring a few more outliers towards evenness.

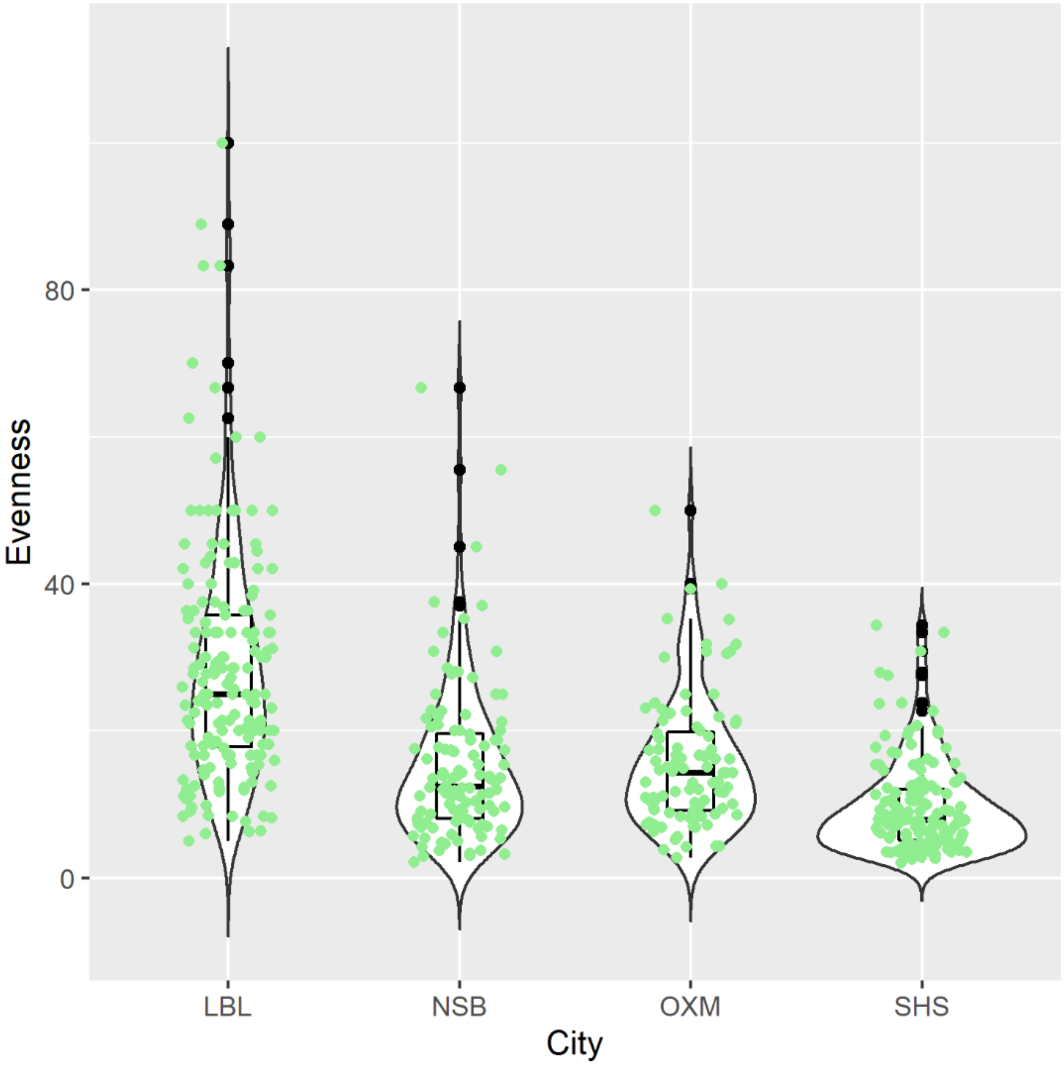


Figure 8.6 Violin plot of evenness by city shows greater distribution in LBL, while SHS is concentrated towards uneven distribution. Overall shape of violin represents the distribution of data. Dots represent actual data points. Box and whisker plots within violin represent interquartile intervals.

When pooled by street type, the violin plot (Figure 8.7) shows more instances of equal distribution in CBD, while HS is concentrated towards lower values, representing an uneven distribution.

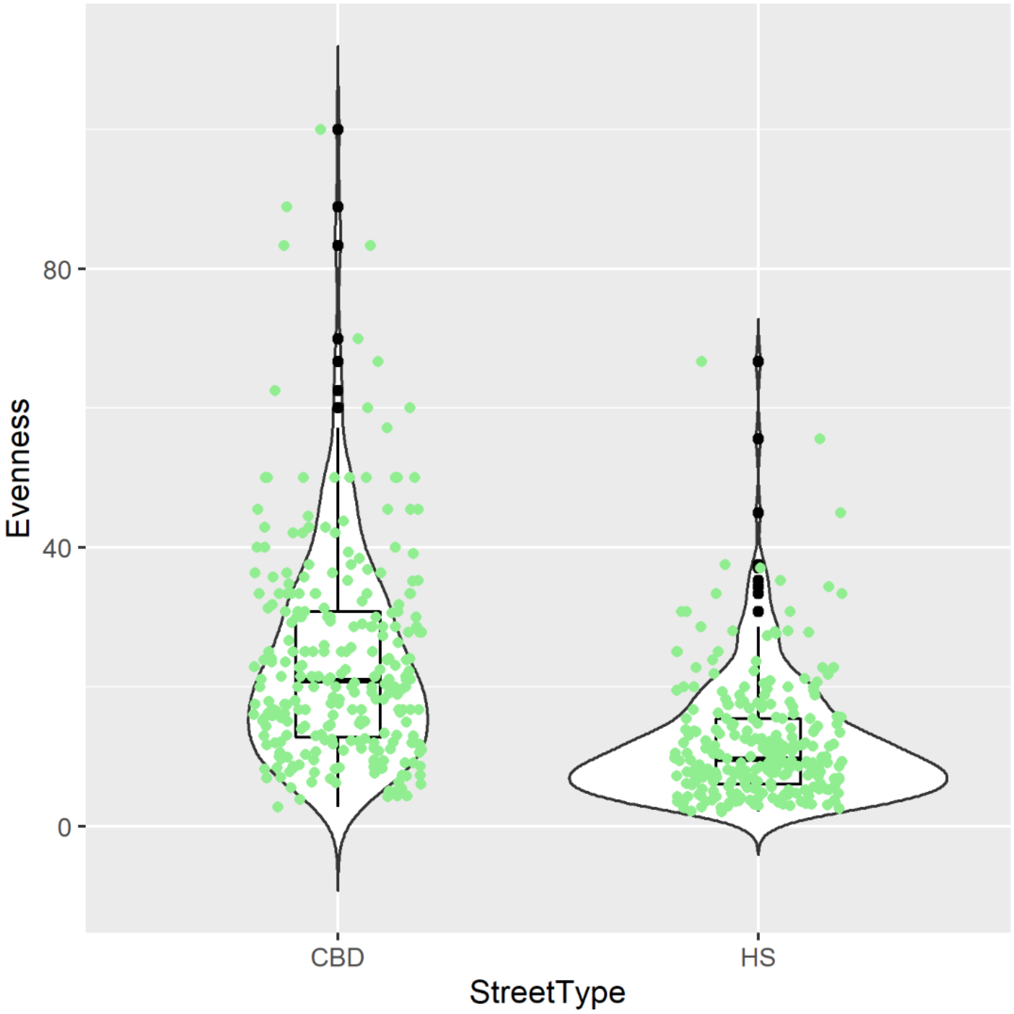


Figure 8.7 Violin plot of evenness by street type implies consistently lower litter types in HS, while CBD features a wider spread towards more diverse litter types. Overall shape of violin represents the distribution of data. Dots represent actual data points. Box and whisker plots within violin represent interquartile intervals.

8.3.2.4. Impact

Litter Impact values (LIV) were sourced from the Litter Impact Index (LII) (Figure 7.1, page 238) output in Chapter 7: Material Composition of Litter and represent the average value of litter items observed in each sampling unit. LIV are measured on a 0-100 point scale with higher values representing greater negative impact. Violin plot of impact by city (Figure 8.8) shows clear similarity in concentration and number of outliers between SHS and NSB (HS sites) and OXM and LBL (CBD sites). CBD sites appear to have a wider spread towards lower impact values.

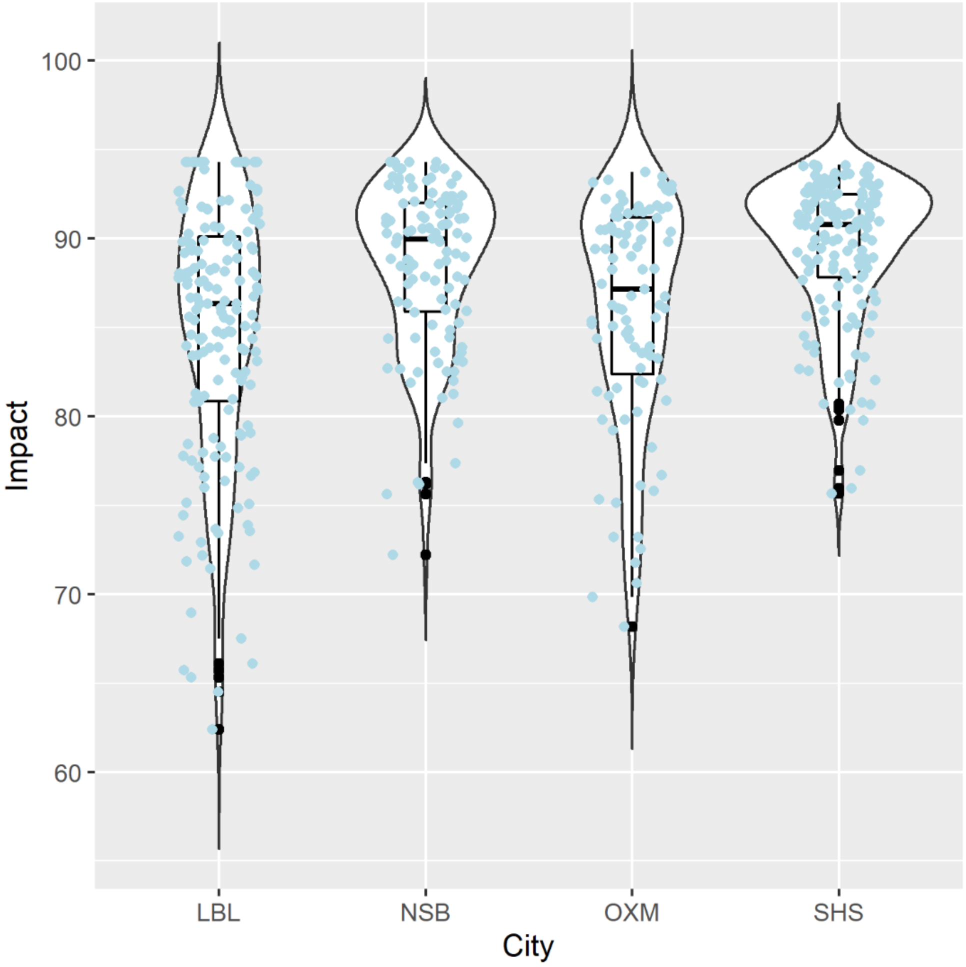


Figure 8.8 Violin plot of litter impact values by city shows distinct patterns of lower values and wider spreads in LBL and OXM with higher concentrations towards high impact in NSB and SHS. Overall shape of violin represents the distribution of data. Dots represent actual data points. Box and whisker plots within violin represent interquartile intervals.

This is further supported when LIV were pooled by street type. Violin plot (Figure 8.9) shows concentrated data towards higher values within HS and a wider spread in CBD towards lower values.

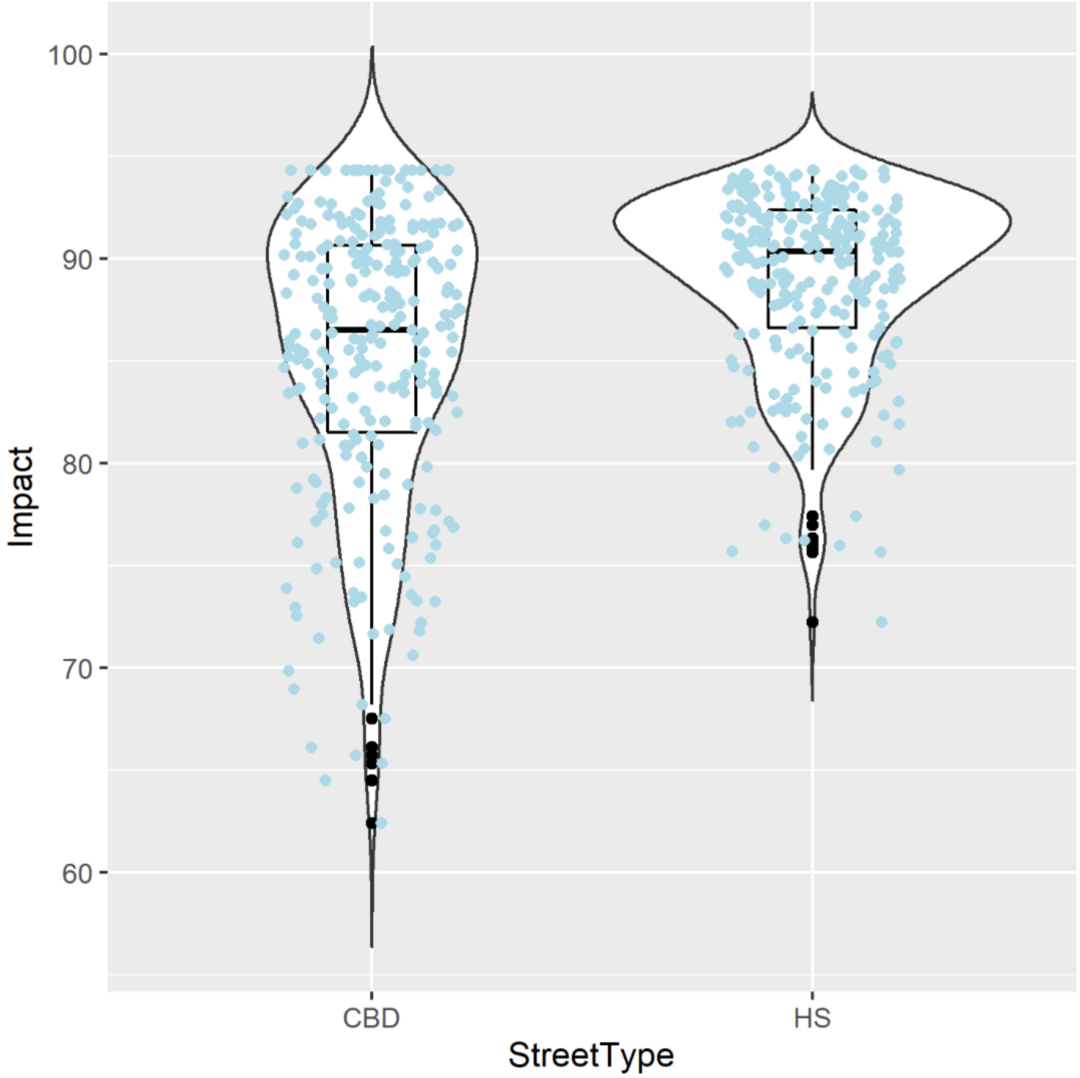


Figure 8.9 Violin plot of impact values by street type implies consistently higher impact values in HS while CBD features a wider spread towards less impactful litter types. Overall shape of violin represents the distribution of data. Dots represent actual data points. Box and whisker plots within violin represent interquartile intervals.

8.3.3. Regional influence

A one-way ANOVA between community parameters and sites tested for regional differences.

8.3.3.1. Richness

Overall, richness between cities (Table 8.4) was significantly different (P=<0.001).

Table 8.4 Kruskal-Wallis One way ANOVA on litter richness found significant differences between cities.

Influence of *city* on *richness* P<0.001				
City	**N**	**Median**	**25%**	**75%**
SHS	148	6	4	8
OXM	95	7	5	10
NSB	112	5	3	7
LBL	168	4	3	6

Means comparison analysis (Table 8.5) noted and significant similarities between NSB and LBL (P=0.915).

Table 8.5 Dunn's method all pairwise means comparison on litter richness finds significant similarities between NSB and LBL.

All Pairwise Multiple Comparison Procedures (Dunn's Method)			
Cities	**Diff of Ranks**	**Q**	**P<0.050**
OXM vs LBL	153.085	7.891	Yes
OXM vs NSB	126.712	6.011	Yes
SHS vs LBL	95.519	5.607	Yes
SHS vs NSB	69.145	3.653	Yes
OXM vs SHS	57.566	2.898	Yes
NSB vs LBL	26.374	1.431	No

There was no significant difference in richness (P=0.427) when sites were pooled by street type (Table 8.6).

Table 8.6 Wilcoxon One way ANOVA on litter richness found no significant differences between street types (P=0.427).

Influence of *street type* on *richness,* P=0.427				
Street Type	**N**	**Median**	**25%**	**75%**
HS	260	5.5	4	7
CBD	263	5	3	8

8.3.3.2. Density

Overall, density between cities (Table 8.7) was significantly different (P<0.001).

Table 8.7 Kruskal-Wallis One way ANOVA on litter density found significant differences between cities.

Influence of *city* on *density* P=<0.001				
City	**N**	**Median**	**25%**	**75%**
SHS	148	0.275	0.192	0.409
OXM	95	0.408	0.226	0.672
NSB	112	0.231	0.131	0.39
LBL	168	0.287	0.131	0.521

The means comparison analysis (Table 8.8) noted no significant differences between LBL and NSB (P=0.617) which are of different street types, LBL and SHS (P=1) which are of different street types, and both located in London, and SHS and NSB (P=0.712) which are of similar street types.

Table 8.8 Dunn's method all pairwise means comparison on litter density finds significant similarities between LBL and NSB, SHS and NSB and LBL and SHS.

All Pairwise Multiple Comparison Procedures (Dunn's Method)			
Cities	**Diff of Ranks**	**Q**	**P<0.050**
OXM vs NSB	102.589	4.867	Yes
OXM vs SHS	73.058	3.677	Yes
OXM vs LBL	72.514	3.738	Yes
LBL vs NSB	30.074	1.631	No
SHS vs NSB	29.53	1.56	No
LBL vs SHS	0.544	0.0319	No

There was a significant difference in density (P=0.003) when sites were pooled by street type (Table 8.9).

Table 8.9 Wilcoxon Test One way ANOVA on litter density found significant differences between street types.

***Influence of street type on density,* P=0.003**				
Street Type	**N**	**Median**	**25%**	**75%**
HS	260	0.263	0.165	0.406
CBD	263	0.321	0.176	0.601
Difference in ranks 39.458				

8.3.3.3. Evenness

Overall, evenness of litter types between cities (Table 8.10) was significantly different (P<0.001).

Table 8.10 Kruskal-Wallis One way ANOVA on litter evenness found significant differences between cities.

Influence of *city* on *evenness* P=<0.001				
City	**N**	**Median**	**25%**	**75%**
SHS	148	0.0787	0.0491	0.121
OXM	95	0.143	0.0909	0.2
NSB	112	0.124	0.0793	0.199
LBL	168	0.25	0.177	0.357

The means comparison analysis (Table 8.11) noted a significant similarity between OXM and NSB (P=1) which are of different street types and both located outside of London.

Table 8.11 Dunn's method all pairwise means comparison on litter evenness finds significant similarities between OXM and NSB.

All Pairwise Multiple Comparison Procedures (Dunn's Method)			
Cities	**Diff of Ranks**	**Q**	**P<0.050**
LBL vs SHS	230.117	13.507	Yes
LBL vs NSB	142.948	7.754	Yes
LBL vs OXM	127.74	6.585	Yes
OXM vs SHS	102.377	5.153	Yes
NSB vs SHS	87.169	4.606	Yes
OXM vs NSB	15.208	0.721	No

Overall, evenness of litter between street types (Table 8.12) was significantly different (P=<0.001).

Table 8.12 Wilcoxon Test One way ANOVA on litter richness found significant differences between street types.

Influence of *street type* on *impact,* P<0.001				
Street Type	**N**	**Median**	**25%**	**75%**
HS	260	0.0954	0.0602	0.154
CBD	263	0.208	0.125	0.308
Difference in ranks 146.425				

8.3.3.4. Impact

Overall, differences of LIV between cities (Table 8.13) was significantly different.

Table 8.13 Kruskal-Wallis One way ANOVA on litter impact values found significant differences between cities.

Influence of *city* on *impact* P=<0.001				
City	**N**	**Median**	**25%**	**75%**
SHS	148	90.768	87.783	92.506
OXM	95	87.146	82.057	91.237
NSB	112	89.971	85.867	92.018
LBL	168	86.341	80.835	90.159

Means comparison analysis (Table 8.14) noted significant differences between the two London locations (SHS and LBL: P<0.001) and between sites of different street types (HS and CBD). Sites of similar street types however were found to have strong similarities (HS: SHS and NSB, P=0.964 and CBD: OXM and LBL, P=1).

Table 8.14 Dunn's method all pairwise means comparison on litter impact values finds significant similarities between SHS and NSB as well as between OXM and LBL.

All Pairwise Multiple Comparison Procedures (Dunn's Method)			
Cities	**Diff of Ranks**	**Q**	**P<0.050**
SHS vs LBL	104.099	6.11	Yes
SHS vs OXM	86.482	4.353	Yes
NSB vs LBL	77.546	4.206	Yes
NSB vs OXM	59.929	2.843	Yes
SHS vs NSB	26.553	1.403	No
OXM vs LBL	17.618	0.908	No

There was a significant difference in impact (P<0.001) when sites were pooled by street type (Table 8.15).

Table 8.15 Wilcoxon Test One way ANOVA on litter impact values found significant differences between street types.

***Influence of street type on impact,* P<0.001**				
Street Type	**N**	**Median**	**25%**	**75%**
HS	260	90.354	86.589	92.361
CBD	263	86.48	81.402	90.663
Difference in ranks 86.297				

8.3.4. Diversity

8.3.4.1. Cities

For ease of comprehension, the Shannon's Diversity Index (H) was adjusted to the Shannon's Equitability Index (Q) (Table 8.16). The Q value measures diversity on a scale of 0-1, where the lower the value, the fewer species present in the sample. The Q value clearly shows higher diversity in OXM (Q = 0.4296) and LBL (Q=0.4546) while SHS (Q=0.2432) and NSB (Q=0.2704) feature lower diversity scores (Figure 8.10).

Table 8.16 Shannon's Index of Equitability indicate higher diversity of litter types in OXM and LBL while SHS and NSB feature lower diversity scores.

Shannon's Index

City	Diversity (H)	Equitability (Q)
SHS	0.8429	0.2432
OXM	1.4889	0.4296
NSB	0.9285	0.2704
LBL	1.5609	0.4546

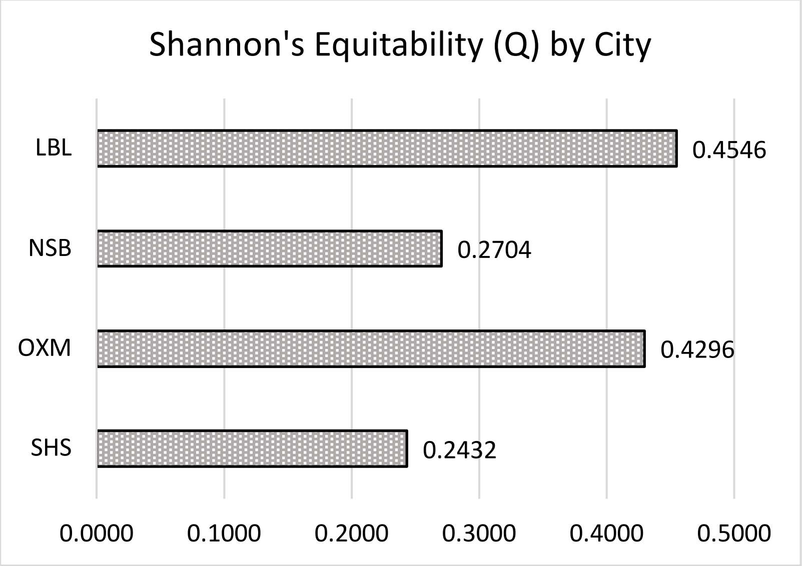


Figure 8.10 Shannon's Index of Equitability indicate higher diversity of litter types in OXM and LBL while SHS and NSB feature lower diversity scores.

8.3.4.2. Street types

Diversity is also calculated with cities pooled by street type (Table 8.17). As mentioned above, the Shannon's Diversity Index (H) was adjusted to an equitability (Q) scale of 0-1, where the lower the value the fewer species present in the sample. The Q value clearly shows higher diversity in in CBD (Q=0.4408) than HS (Q=0.2607) sites (Figure 8.11).

Table 8.17 Shannon's Index of Equitability pooled by street type indicate higher diversity of litter types in CBD, while HS feature lower diversity scores.

Shannon's Index

Street Type	Diversity (H)	Equitability (Q)
HS	0.9034	0.2607
CBD	1.5278	0.4408

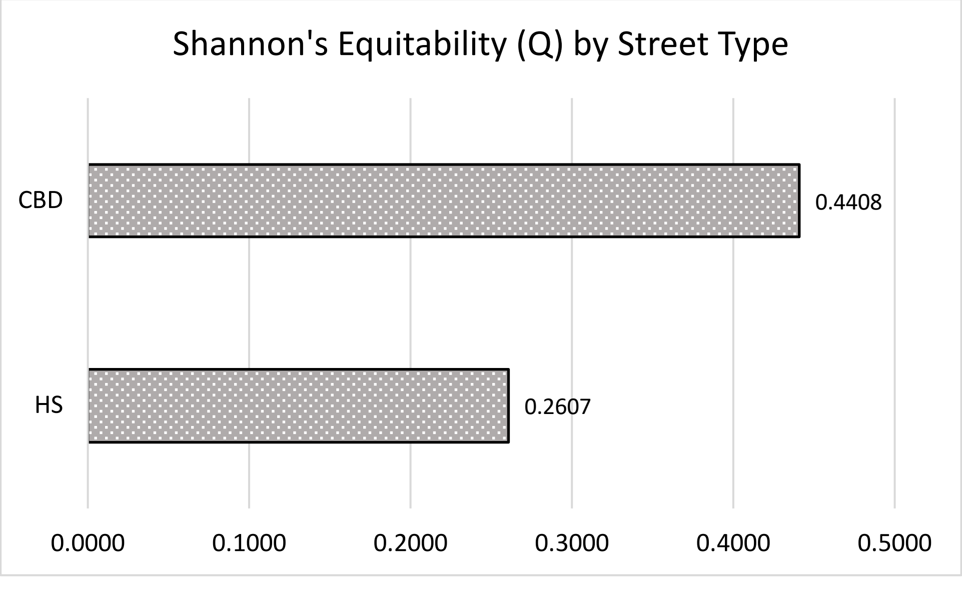


Figure 8.11 Shannon's Index of Equitability pooled by street type indicate higher diversity of litter types in CBD, while HS feature lower diversity scores.

8.3.5. Litter composition

8.3.5.1. Typology

The Analysis of Similarity (ANOSIM) results in an R value that is measured on a scale of 0-1 where a high value represents greater differences in typology composition between sites (RDocumentation, 2022a). Values were exceptionally low in comparisons between cities (R=0.04263, P<0.001) and street types (R=0.03735, P<0.001), implying high similarities between typology composition.

The Similarity Percentage analysis (SIMPER) output in Table 8.18, represents similarity in typology by city pairings. Similarity values were highest between LBL and OXM (58.57%) and LBL and NSB (55.86%), while lowest values were found between pairings of SHS and NSB (46.02%) and SHS and OXM (49.38%). The overall percentage of similarity explained by street types (HS-CBD) was 53.05%.

Table 8.18 SIMPER percentage of typology similarity between groupings of cities. Highest similarity was found between LBL and OXM (58.57%) with the lowest between NSB and SHS (46.02%).

	SHS	**OXM**	**NSB**
OXM	49.38%		
NSB	46.02%	54.18%	
LBL	52.54%	58.57%	55.86%

Breakdown of the SIMPER applies a percentage of contribution towards similarity by each litter typology (RDocumentation, 2022b). Table 8.19 lists typologies in order of greatest influence in similarity. Unsurprisingly cigarette ends were most influential (58%), followed by chewing gum (6%), general (3%) and sweet bags (3%).

Table 8.19 SIMPER of influence of litter types to similarity between street types HS-CBD. Cigarette ends (58%) were most influentianal followed by chewing gum (6%).

Type	Contribution
Cigarette end	**58%**
Gum	**6%**
General	**3%**
Sweet bag	**3%**
Tissue	**3%**
Flyers & leaflets	**3%**
Till receipts	**2%**
Cigarette packaging	**2%**
Cash point receipts	**2%**
Food	**2%**
Bus or train ticket	**2%**
Plastic bottle	**1%**
Cellophane food wrap	**1%**
Takeaway box	**1%**
Utensil	**1%**
Can	**1%**
Cigarette rolling paper	**1%**
Unsure	**1%**
Sandwich pack	**1%**
Paper cup	**1%**
Other drink	**1%**
Newspaper & magazine	**1%**
Paper bag	**1%**
Cardboard box	**1%**
Lighter & matches	**1%**
Hot drink cup	**0%**
Crisp bag	**0%**
Glass bottle	**0%**
Polystyrene box	**0%**
Bagged litter	**0%**
Plastic bag	**0%**
Textile	**0%**

8.3.5.2. Activity

The ANOSIM resulted in exceptionally low R values in comparisons of activity groups between cities (R=0.04172, P<0.001) and street types (R=0.04449, P<0.001), implying high similarities between activity grouping composition.

The SIMPER output in Table 8.20, represents similarity in activity groupings by city pairings. Similarity values were highest between LBL and OXM (53.93%) and LBL and NSB (52.38%) and lowest between SHS and NSB (42.89%) and SHS and OXM (45.71%). The overall percentage of similarity explained by street types (HS-CBD) was 49.59%.

Table 8.20 SIMPER percentage of similarity between activity groupings and pairs of cities. Highest similarity was found between LBL and OXM (53.97%) with the lowest between NSB and SHS (42.89%).

	SHS	**OXM**	**NSB**
OXM	45.71%		
NSB	42.89%	50.25%	
LBL	49.40%	53.93%	52.38%

Breakdown of the SIMPER applies a percentage of contribution towards similarity from each activity grouping (RDocumentation, 2022b). Table 8.21 lists activity groups in order of greatest influence between city pairings. Unsurprisingly cigarette ends were most influential across all pairings followed by eating.

Table 8.21 SIMPER contribution to similarity by activity between pairs of cities as well as between street types.

	Contribution		Contribution
LBL-OXM overall similarity: 53.93%		**LBL-SHS overall similarity: 49.40%**	
Cigarette	58%	**Cigarette**	63%
Eating	11%	**Eating**	11%
Shopping and Entertainment	9%	**Gum**	6%
Other	5%	**Shopping and Entertainment**	7%
Gum	6%	**Other**	5%
Drinking	5%	**Drinking**	4%
Smoking	4%	**Smoking**	4%
Transport	2%	**Transport**	0%
LBL-NSB overall similarity: 52.38.25%		**OXM-SHS overall similarity: 45.71%**	
Cigarette	62%	**Cigarette**	62%
Eating	12%	**Eating**	10%
Shopping and Entertainment	7%	**Shopping and Entertainment**	8%
Gum	6%	**Other**	7%
Drinking	5%	**Drinking**	4%
Smoking	4%	**Gum**	3%
Other	3%	**Smoking**	3%
Transport	1%	**Transport**	3%
OXM-NSB overall similarity: 50.25%		**NSB-SHS overall similarity: 42.89%**	
Cigarette	62%	**Cigarette**	72%
Eating	10%	**Eating**	7%
Shopping and Entertainment	9%	**Shopping and Entertainment**	7%
Other	5%	**Other**	4%
Drinking	5%	**Gum**	4%
Smoking	3%	**Smoking**	3%
Gum	3%	**Drinking**	3%
Transport	3%	**Transport**	0%

	Contribution
HS-CBD: Overall similarity: 49.59%	
Cigarette	63%
Eating	10%
Shopping and Entertainment	7%
Gum	6%
Other	5%
Drinking	4%
Smoking	4%
Transport	1%

8.3.6. Community structure

The non-metric multidimensional scaling model (nMDS) is interpreted in stress values, where those >.3 suggest clustered patterns and <.2 imply a weak random relationship (Clarke, 1993). The analysis on litter typology resulted in a stress value of 0.11, and the data are therefore considered random. Figure 8.12 illustrates the output, where both CBD and HS are clustered in the same central area, although there does appear to be a wider spread of LBL and OXM away from the cluster.

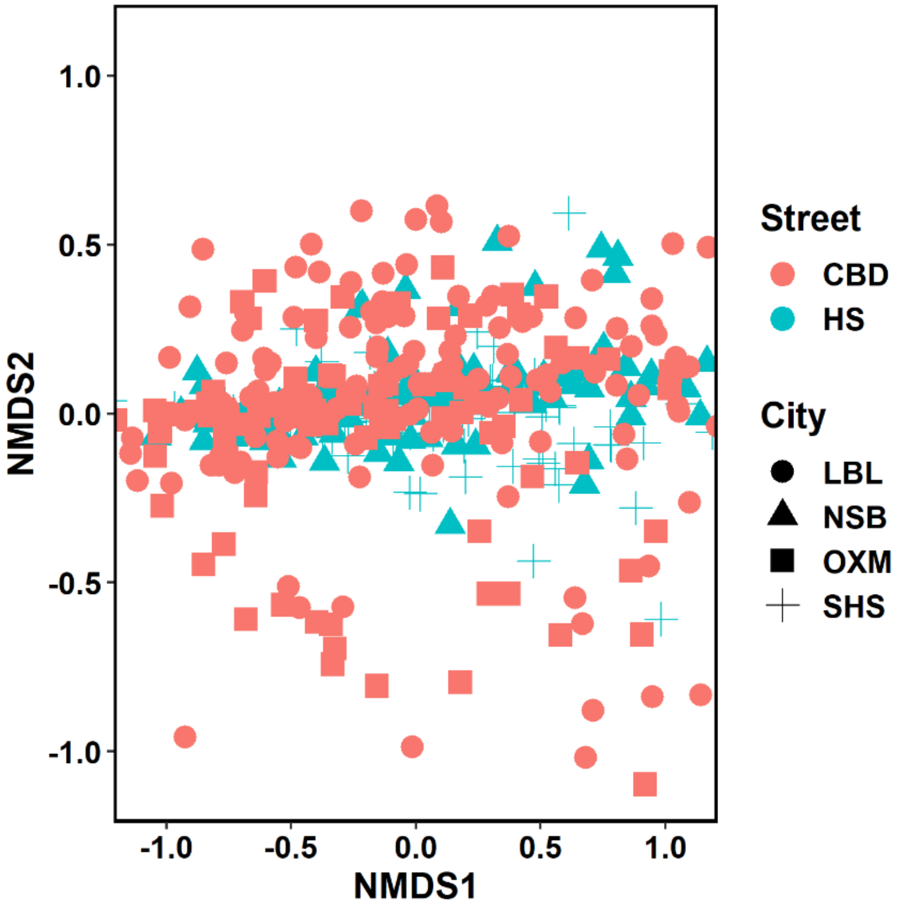


Figure 8.12 NMDS on litter typology resulted in a stress value of 0.11 and is considered random.

The nMDS on activity groups resulted in a stress value of 0.1, and the data are therefore considered random. Figure 8.13 illustrates the output and no clearly defined community clusters are apparent, with CBD sites exhibiting a wider spread from the centre.

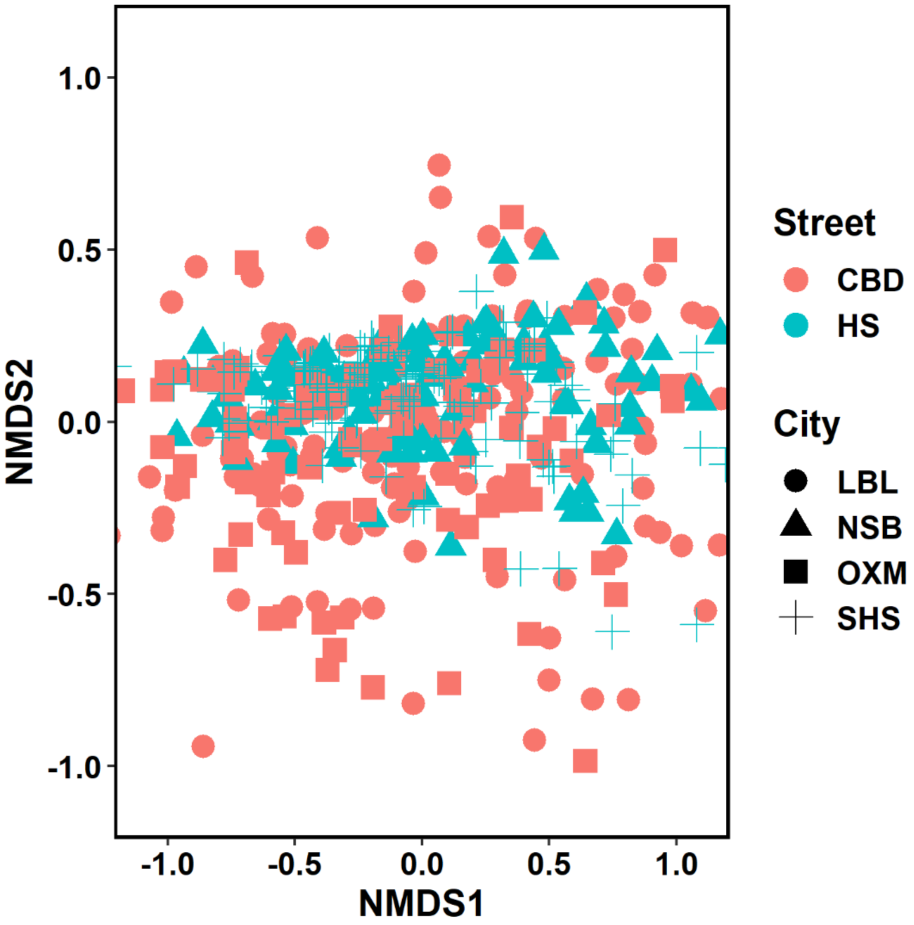


Figure 8.13 NMDS on litter activity grouping resulted in a stress value of 0.1 and is considered random.

8.4. Overview

This study examined patterns in litter typology and source activity between 4 English cities (SHS, OXM, NSB, LBL) as well as within two street type groupings, the high street (HS, SHS and NSB) and the central business district (CBD, OXM and LBL). Data were collected in each site during four sessions, and in line with previous research, sessions were considered to have no influence on litter patterns (Becherucci and Seco Pon, 2014).

Violin plots on density and impact indicate strong similarities in data distribution between street type groupings, while richness and evenness violin plots suggest the same yet to a lesser degree. Generally, results suggested community parameters (CP) were influenced by street type, with CBD sites exhibiting higher densities of varied items with lower impact values, and HS sites featuring fewer items of higher impact values with specific types dominating the sample.

Significant differences in CP were found by city in richness ($P<0.001$), density ($P<0.001$), evenness ($P<0.001$) and impact ($P<0.001$). In pairwise means comparisons, similarities were found in richness between NSB-LBL, in density between NSB-LBL, SHS-NSB and LBL-SHS, in evenness between OXM- NSB and in impact between SHS-NSB and OXM-LBL. When pooled by street type, no difference was found in richness ($P=0.427$) yet significant differences were found in density ($P=0.003$), evenness ($P<0.001$) and impact ($P<0.001$). Results suggest that there are some connections between street type and CP regarding quantities of litter and the level of impact of items present.

Diversity is highly influenced by factors of richness and evenness and the results of the Shannon's Equitability Index were in line with observations on community parameters. Both the HS (0.26) sites, SHS (0.24) and NSB (0.27), scored low on diversity while the CBD (0.44) sites, OXM (0.45) and (0.43) LBL were considerably higher. Results suggest a more varied and equal distribution of species in CBD.

Generally, litter composition was similar across sites in both typology and activity groupings. Highest similarities were found between LBL-OXM (CBD sites) in both litter typology (54.57%) and activity groupings (53.93%), while the lowest similarities were found between SHS-NSB (HS sites) in both categories (typology 46.02%, activity 42.89%). In typology the largest contributor to similarity was unsurprisingly cigarette ends (58%) followed by chewing gum (6%), while in activity groupings cigarette ends and eating were highest contributors to similarity. When grouped by street type, similarities in typology (53.05%) were higher than that observed in activity groupings (49.59%). Results suggest that cigarette ends were the most influential species, and although CBD sites had similarities in composition, HS sites did not.

No distinguishable typology or activity community structure were found, although the nMDS indicated spread was wider among CBD sites than HS.

8.5. Discussion

As is seen all over the world, urbans places have a set of unique and distinguishable characteristics. This applies not only to the language and aesthetics of inhabitants, but can apply to cultural and individual values, particularly in relation to consumption and post-consumption behaviour. A comparison of litter profiles between areas of high intensity of use has the potential to lend clues to local litter trends and highlight sources of contention to inform tailored solutions. Societal, environmental and economic problems associated with littering are plenty, however quantitative studies to evaluate numbers in urban spaces are limited. Given the current concerns about litter, understanding regional variations in composition and abundance is important to establish targeted solutions.

This study found that the density, impact and diversity of litter is influenced by the purpose of a street, and to a lesser degree, the items that are present. Sites that were designated CBD typically contained a wider range of items where HS were characterised specifically by dominant items. This can mostly be attributed to the overwhelming influence of cigarette ends, which led to high comparative similarities in litter composition.

Aspects of uncertainty are present in the use of evaluation parameters such as richness, evenness and diversity, where specifics of community structure can be overlooked through quantification of individual traits (Pielou, 1966; Barrantes and Sandoval, 2009). This study avoids this pitfall through the inclusion of litter impact values, lending weight to parameters and signalling differences in regional communities. For example, similarity in richness between HS and CBD coupled with higher density rates in CBD would suggest that the CBD be the focus for environmental enhancement initiatives. Although the CBD contains more litter items by density, impact values were significantly higher in HS, thus targeted initiatives in HS would lead to greater reductions in associated social and environmental ramifications. Data suggests that cigarette ends were more frequently observed in

HS sites where leisurely activities were taking place. Cigarette ends are an item that are not only littered more frequently, but are disposed of in uniquely specific ways (Novotny *et al.*, 2009; Wever *et al.*, 2010; Rath *et al.*, 2012; Castaldi, Cecere and Zoli, 2021).

Although the litter composition of a site does not appear to be predictable, there is merit in the influence of street type towards density and impact value. As the use of direct cues and tailored approaches has considerably higher success than generalised campaigns (Cialdini, 2003; Liu and Sibley, 2004; Brown, Ham and Hughes, 2010), a baseline understanding of litter profiles of a site can inform targeted mitigation initiatives and governing cleansing strategies.

8.5.1. Lesson learnt

There is a connection between litter and place

Regional variations in both litter abundance and composition exist not only in England, but within a metropolitan area.

Chapter 9: Conclusion

9.1. Introduction

Although litter has a pervasive and detrimental presence in the world, it has yet to be addressed with the gravity it deserves. Reduction efforts are dominated by street cleansing initiatives and behaviour change campaigns, with little evidence of effectiveness. As a result, this thesis investigated the physical properties of litter, with an aim to guide informed solutions to mitigation.

In revisiting the Lifecycle of Litter (Figure 9.1), individual chapters addressed gaps in knowledge associated with land-based litter dynamics. Chapter 4 identified specific Consumption activities that generate litter, Chapter 5 provided insight on the complex methods which litter is Deposited, Chapter 6 explored Pathways that enable litter to enter River and Ocean environments. Chapter 7 quantified the level of Impact associated with litter in this lifecycle and Chapter 8 investigated if there is an association between a space and the litter items that are Consumed and Deposited.

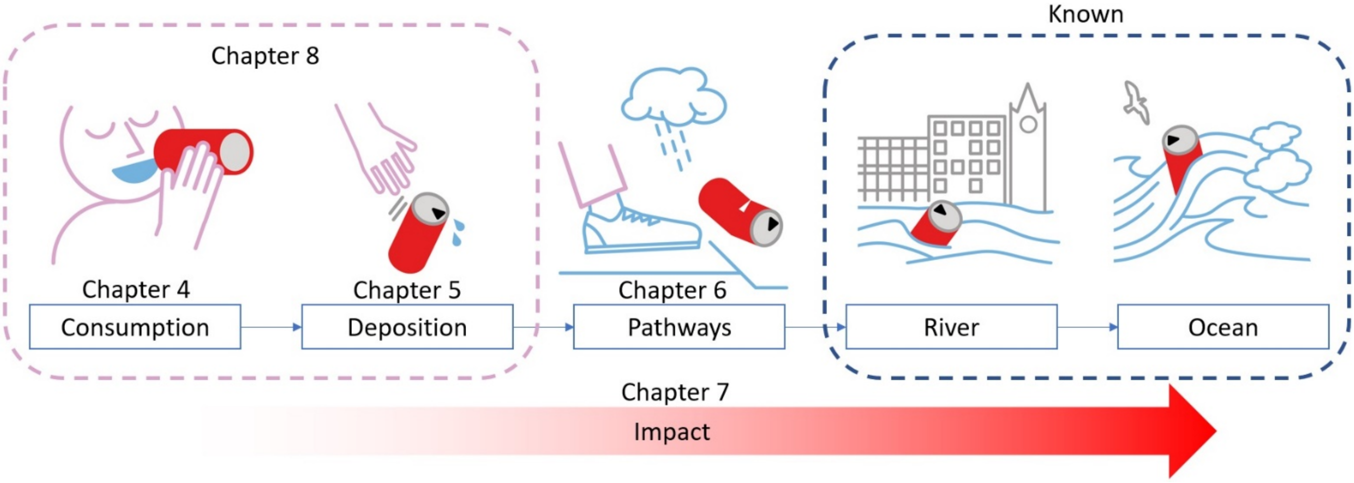


Figure 9.1 The Lifecycle of Litter revisited. Image indicates where specific chapters addressed gaps in knowledge within areas of potentially high impact in mitigation.

The results of the 5 exploratory studies conducted in England culminated in a series of lessons learnt which have the potential to shape the way litter is addressed in the future.

9.2. Litter is evidence of the activities that created it

Litter items maintain distinct characteristics after their primary use has been exhausted. These characteristics allow for assumptions on the activities that led to their fruition.

In Chapter 4: Litter Source Dynamics, litter was surveyed and recategorized by activity source in London, Manchester and Birmingham. The objective was to distinguish which consumption activities were the largest contributors to litter in target areas. Cigarette ends were the most prevalent item found (78.75%) and, as this is in line with prior research, omitted from the sample to investigate other sources. Analysis of non-cigarette litter identified eating (30%), shopping and entertainment (22.5%) and chewing gum (10%) as specific consumption activities that generate high volumes litter. It is suggested that these activities be targeted to stem the flow of debris before it can be littered, with focus on both the associated materials and the locations where they are consumed.

9.3. Litter and littering do not go hand in hand

Behaviour towards and deposition of litter is complex and varies regionally. The presence of litter does not always equate to littering.

Conclusion

Past studies have consistently equated the presence of litter to the act of littering; however, the results of the disposal behaviour analysis suggest that the connection is not as straightforward. In Chapter 5: Litter Deposit Methods, a series of covert observations in London, Manchester, Birmingham and Brighton, the concept of Polite Littering was established, where if there are no means for disposal, litter is placed neatly in creative spaces in lieu of littering. As common perception towards littering is that it is done in a flagrant and untidy way, in the act of unintentional littering, individuals negotiate their actions as non-contributory. Ultimately, the study found that methods of Unintentional and Polite littering accounted for 61% of all observed non-cigarette littering events. As a result, I suggest that a rebranding of the term and legislation of littering is crucial to include both intentional and unintentional acts, that product packaging design integrate characteristics that lead to packaging being less easy to misplace and that bin placement take into consideration needs of the end user.

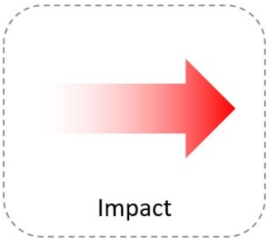
In addition, the identification of Vermin Dispersal furthers the disparity between the presence of litter and the act of littering. The influence of seagulls and foxes in distributing waste that had previously been binned, falsely attributes human behaviour to litter generation, and leads to misplaced mitigation efforts. This is exemplified in the case study of Brighton and Hove, who have since replaced bins to deter the contribution of seagulls to public waste issues; an initiative which has recently been awarded a King’s College London School of Social Science and Public Policy 2022 Research Impact Prize. This insight suggests structural and mechanical approaches such as bin design and proactive cleansing schedules that consider the influence of Vermin Dispersal would lead to significant litter reduction.

9.4. Litter can enter a site by means other than littering

After deposition, there are multiple forces at play in the pathways of litter throughout an environment.

There is a substantial input of inland litter via rivers to the ocean, it is estimated that 80% of marine plastics originated from land-based activities (European Commission, 2016). Once litter enters the ocean, it becomes a global issue that is far more difficult to manage (Leous and Parry, 2005). Despite increasing volumes, there are strict laws preventing the dumping of waste directly into rivers and the pathways of litter transport from land is purely speculative. In Chapter 6: Transfer Dynamics of Litter, observational exercises hypothesised the influence of foot traffic in litter dispersal, and this original study analysed the movement of GPS tagged litter, offering validity to this theory. These results question public complicity when ignoring or kicking litter, suggest packaging designs that reduce transportability and the use of physical barriers along river edges as means to stem the flow of litter to the ocean.

9.5. Not all litter is created equal

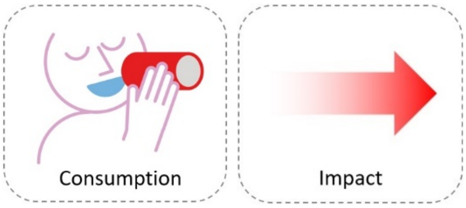


Litter items have varying degrees of adverse effects and cannot be considered equally impactful

Litter is a collective noun that encompasses a large variety of items, ranging from organic to synthetic, and from sharp to inert. Despite this, conversations and regulation on litter continue to group these items with little consideration towards the various levels of associated negative consequences. As a result, in Chapter 7: Material Composition of Litter, the Litter Impact Index was constructed to score individual items within indicators of toxicity, tenacity, threat and transportability (4T). The product of the index provides a clear visualisation of litter impact on a 0-100 point scale (Figure 7.1, page 238). This index is the first of its kind and was developed with the intention to inform packaging design in decreasing associated negative impacts by targeting 4T characteristics.

9.6. There is a connection between litter and place

Regional variations in both litter abundance and composition exist not only in England, but within a metropolitan area.



In Chapter 8: Regional Variations in Litter, a classic ecological approach was applied to litter surveys to investigate trends in abundance and diversity of items between sites in London, Manchester and Birmingham. Results indicate that sites characterised as a High Street (predominantly leisure activities such as shopping and dining) contained lower densities, less variety, yet featured items with higher impact values than sites categorised as Central Business District (identified by high numbers of professional workers and transport links). Although communities were significantly different between sites, the structure of the items that composed litter communities was not, with cigarette ends being the dominant factor to similarity. These results suggest that litter is not predictable and specific knowledge of key influential items in a site can be considered in maximizing effective mitigation approaches.

9.7. Implications

Often when social and environmental issues come to light, the need for policy to react sparks interest in scientific research, a process that is referred to as the Linear Model (Beck, 2011). As is seen in the case of litter, when the need to intervene initiates paths of inquiry this establishes a narrow context, where many important aspects can be missed. There is an ultimately thin narrative that is achieved through a purely quantitative approach to issue identification (Geertz, 2008); litter is present, therefore littering must be addressed. This has led to an immense body of literature and outreach initiatives that repeatedly fail at mitigating the issue, bringing into question the value of allocating public funds to keeping streets clean. In misunderstanding the subtleties of litter and littering, approaches to address litter have been historically unsuccessful, resulting in an increasing trend towards low-cost, quick fixes with little interest in structural adjustments for long-term and sustainable solutions (Voulvoulis *et al.*, 2015).

Given the insights gained in this thesis, new approaches to mitigation can be established among governing bodies, producers and the public.

Reducing litter through governance is achieved both on a local and national scale. Locally, councils should step away from conventional methods of street cleansing and consider these insights in adjusting procedures. This includes regular inventories of litter to provide targeted treatments, an investment in long-term structural solutions such as effective bin placement and design, and proactive cleansing schedules that consider fluctuations in weather and public space use. With effective cleansing strategies financial burdens are decreased in the long-term, while amenity and taxation income increase.

Nationally, governing bodies must take greater action and accept that penalties are not a magic bullet solution to litter reduction. This includes stricter legislation on the production and distribution of non-essential highly littered items (e.g., cash point and till receipts, free newspapers, flyers, leaflets, and transport tickets). Concerning the largest offender, cigarette ends, there is sufficient evidence to classify them as toxic within the Waste Framework Directive, even though the full extent of their environmental and health impact has yet to be understood (Rebischung *et al.*, 2018). Given this uncertainty, and that the use of cigarette filters provide no known benefits to public health (Freund *et al.*, 1993; Pollay and Dewhirst, 2002; Novotny *et al.*, 2009; Curtis *et al.*, 2014), cigarette filters should be categorised as an environmental and public health risk under the Precautionary Principle, and their availability in the public market must be revaluated (Novotny *et al.*, 2009; Curtis *et al.*, 2014).

This study has found that food packaging is not only the most prevalent (non-cigarette) source of litter in England but repeatedly scored high within the Litter Impact Index (Figure 7.1, page 238). The recently proposed Extended Producer Responsibility for Packaging (EPRP) would address this issue at its source by placing responsibility on the producers, and insight from this study can develop criteria for implementation. In applying Litter Impact Index values to packaging, a scaled method of taxation would not only target high offenders, but guide producers in methods of reducing the impact of their product. A consideration of aspects of toxicity, tenacity, threat and transportability in design would have a dramatic effect in associated environmental and social consequence.

Most difficult in application is appealing to the public, where responsibility of implementation does not fall on any specific entity; although I suggest the use of environmental charities (i.e., Keep Britain Tidy, Clean Up Britain, the Marine Conservation Society, etc) as means for fulfilling this objective. Classic approaches of litter picking and inspiring communications need to end, and campaigns geared to adjust litter risk perception would be infinitely more influential. Successful communication of complex subjects like litter must be delivered in a context that applies to the recipient (Fischhoff, 2013). This can be achieved by internalising the risk of litter to the individual (Slovic, Fischhoff and Lichtenstein, 1981; Slovic, 2000), highlighting the negative impacts it has on their own property, health and quality of life, and stressing how they benefit from a clean environment (Moore, 1995; Myers *et al.*, 2012; Cox, 2013; Joshi, 2022). For example, cigarette ends are routinely littered as part of the ritual of smoking and aren't widely perceived as litter (Rath *et al.*, 2012; Castaldi, Cecere and Zoli, 2021). As a result, they are discarded in astounding quantities, often in proximity of bins or directly into sewage drains. Through an emphasis that littered cigarettes enter drinking water reserves, contribute to nicotine levels in tap water (Green, Putschew and Nehls, 2014; Ebele *et al.*, 2020), and by highlighting the associated research on nicotine and decreased testosterone levels (Oyeyipo, Raji and Bolarinwa, 2013; Mosbah, Yousef and Mantovani, 2015), new connections can be made between cigarette littering and personal health.

Although this does seem extreme, pictographs of a similar nature on cigarette packaging have been successful in reducing smoking rates all over the world (Francis *et al.*, 2019; Kuehnle, 2019; Thrasher *et al.*, 2019).

Ultimately, this study argues that small adjustments by Government, producers and public perception can dramatically decrease the level of litter in urban spaces. In lieu of penalties and widespread campaigns urging the public not to litter, a series of structural, mechanical and attitude adaptations that generate automatic responses would be far more affective in widespread and sustainable litter mitigation.

9.8. Next steps

This thesis has made a contribution to understanding the complexities of litter, establishing original and creative approaches to furthering knowledge. Nonetheless, the exploratory nature of these studies are to be considered prototypes, and this thesis is only the beginning of an alternative path of inquiry towards mitigation. There are many ways these studies could be improved and built upon, and I propose the following future investigations:

- Conducting litter typology surveys in more diverse sites. This could include either a wider range of street use types or surveys among similar street use types in different countries. Activity groupings and regional comparative studies would benefit from the added complexity, and results would lead to further understanding of variations is national post-consumption trends.

- In a similar query, explorations in disposal behaviour habits of different countries would add validity to theories of cultural influences on attitudes towards littering.
- There are many opportunities to expand on investigations on litter transfer dynamics. Examples include scaling the study to involve more trackers, conducting the study on different dates with varying numbers of patrons, releasing trackers under different weather conditions and using a more restricted site with linear traffic such as a bridge. The design of these units could do with increased battery capacity and greater protection of trackers to reduce the potential for damage.
- The Litter Impact Index could be improved on with more detailed quantitative research. Specifically, measuring accurate rates of transportability in terms of surface to volume ratios, integrating a calculation of volume in part-plastic items, or incorporating specific degradation rates in tenacity scores.
- The litter typology dataset in this thesis has a high spatial resolution which would lend well to methods of geospatial analysis. Map based analysis methods such as local spatial autocorrelation (Anselin, 2010) decipher cluster patterns and could identify litter typology structure within the length of study site streets. By integrating building use type data on study site streets (e.g., clothing store, restaurant, office etc) a distance-based spatial weight analysis (Marcon and Puech, 2017) can be employed to determine connections between establishments and litter structure. This could lead to methods of predicting litter typology and density through knowledge of building configuration.

9.9. Closing remarks

This thesis applied original and interdisciplinary approaches to a subject that is not widely considered as academic. Thus, I often struggled to fit in constructed academic disciplines and was unsuccessful in securing funding. Despite this, I saw the potential impact of this line of inquiry and persisted. As a result, the scope and resolution of the studies within are limited to what could be negotiated through partnerships, and there are an infinite number of improvements that could have been made to the process. Considering these hinderances, I am exceptionally proud of what was achieved, and I hope that this research will encourage others to use creative and novel approaches to explore topics that inspire them.

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Appendices

List of Appendix Figures

Appendix A: Data share agreement with the Hubbub Foundation UK

20 March 2017

To Whom it may Concern,

As co-founder and representative to Hubbub Foundation UK, I agree that Randa Kachef have free access to and is granted use of data collected on projects where she has been involved in the structuring, measurement and analysis of data. This includes but is not limited to Neat Streets campaigns in London, Sutton, Manchester, Birmingham and Brighton as well as #FFS – For Fishes' Sake.

In using the data mentioned in this document, Randa is required to credit the involvement of Hubbub Foundation UK in their capacity as project founders, managers and implementers. Inversely, if requested, Hubbub Foundation UK should fully disclose Randa's involvement in her capacity as scientific consultant and independent analyst.

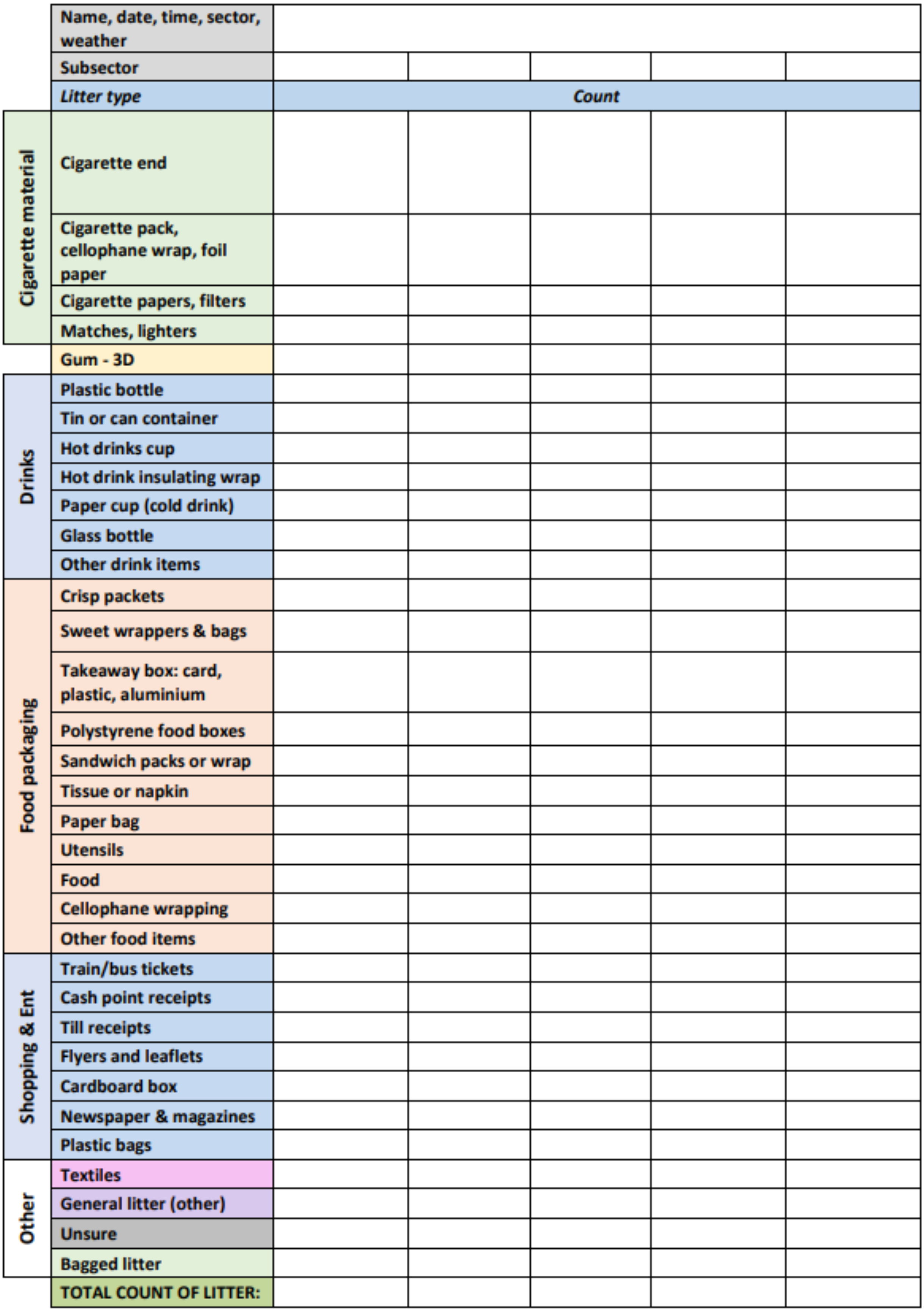
By signing this document both parties agree to its content.

Gavin Ellis

Gavin Ellis

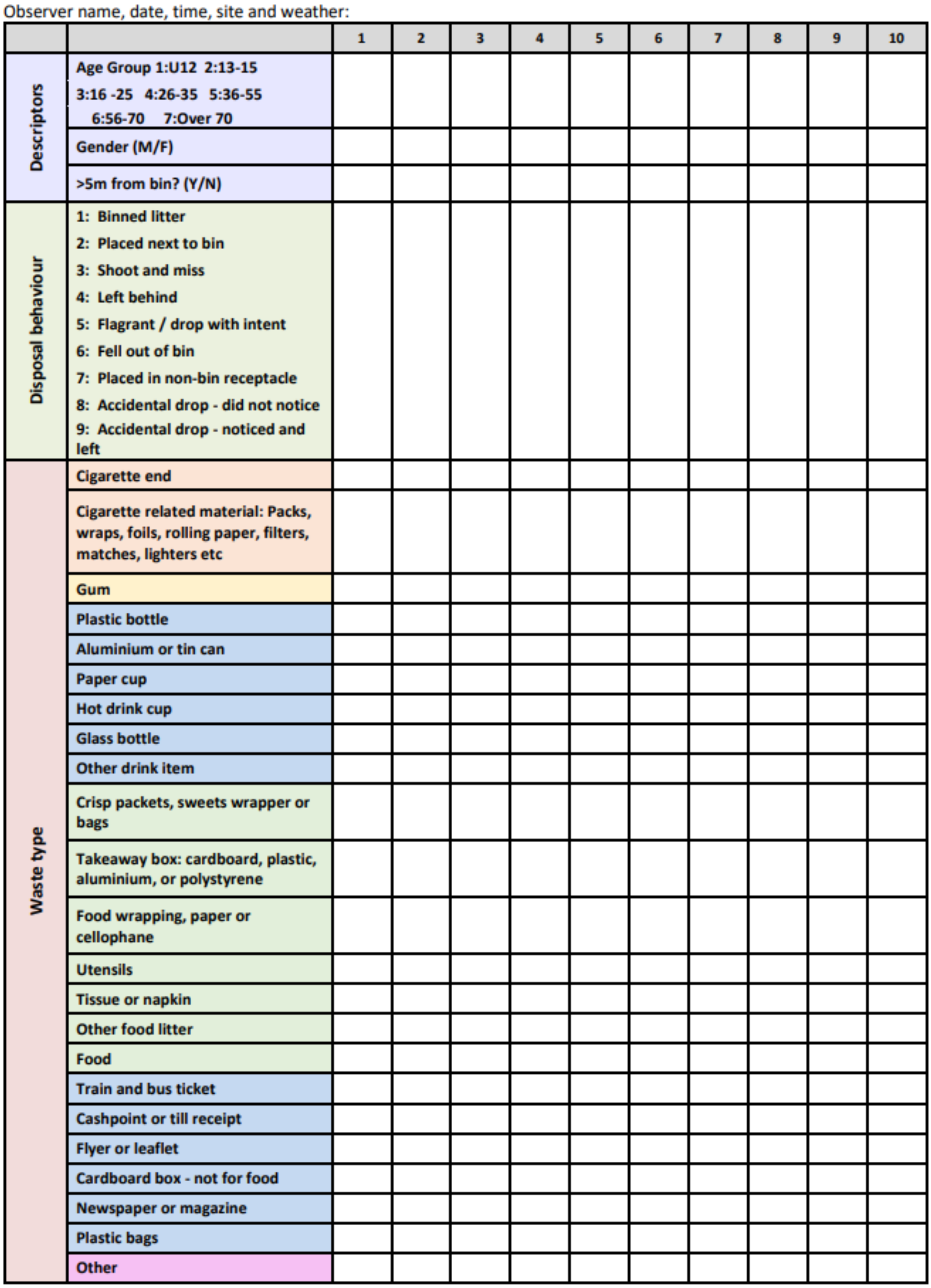
Randa Kachef

Appendix B: Litter typology data collection form template



	Name, date, time, sector, weather					
	Subsector					
	Litter type	***Count***				
Cigarette material	**Cigarette end**					
	Cigarette pack, cellophane wrap, foil paper					
	Cigarette papers, filters					
	Matches, lighters					
	Gum - 3D					
Drinks	**Plastic bottle**					
	Tin or can container					
	Hot drinks cup					
	Hot drink insulating wrap					
	Paper cup (cold drink)					
	Glass bottle					
	Other drink items					
Food packaging	**Crisp packets**					
	Sweet wrappers & bags					
	Takeaway box: card, plastic, aluminium					
	Polystyrene food boxes					
	Sandwich packs or wrap					
	Tissue or napkin					
	Paper bag					
	Utensils					
	Food					
	Cellophane wrapping					
	Other food items					
Shopping & Ent	**Train/bus tickets**					
	Cash point receipts					
	Till receipts					
	Flyers and leaflets					
	Cardboard box					
	Newspaper & magazines					
	Plastic bags					
Other	**Textiles**					
	General litter (other)					
	Unsure					
	Bagged litter					
	TOTAL COUNT OF LITTER:					

Appendix C: Disposal behaviour observation data collection form template



Observer name, date, time, site and weather:

		1	2	3	4	5	6	7	8	9	10
Descriptors	Age Group 1:U12 2:13-15 3:16 -25 4:26-35 5:36-55 6:56-70 7:Over 70										
	Gender (M/F)										
	>5m from bin? (Y/N)										
Disposal behaviour	1: Binned litter 2: Placed next to bin 3: Shoot and miss 4: Left behind 5: Flagrant / drop with intent 6: Fell out of bin 7: Placed in non-bin receptacle 8: Accidental drop - did not notice 9: Accidental drop - noticed and left										
Waste type	Cigarette end										
	Cigarette related material: Packs, wraps, foils, rolling paper, filters, matches, lighters etc										
	Gum										
	Plastic bottle										
	Aluminium or tin can										
	Paper cup										
	Hot drink cup										
	Glass bottle										
	Other drink item										
	Crisp packets, sweets wrapper or bags										
	Takeaway box: cardboard, plastic, aluminium, or polystyrene										
	Food wrapping, paper or cellophane										
	Utensils										
	Tissue or napkin										
	Other food litter										
	Food										
	Train and bus ticket										
	Cashpoint or till receipt										
	Flyer or leaflet										
	Cardboard box - not for food										
	Newspaper or magazine										
	Plastic bags										
	Other										

Appendix D: Observer comments

Site	Date	Comment
SHS	04.04.2016	Noticed that Council street sweeper came by and as he emptied bin, the contents of the bin top ashtray fell on the floor. He did not notice that the cigarettes were over the floor and did not sweep them up.
SHS	04.04.2016	No table ashtrays outside Patisserie Valerie, 3 incidents of seated customers throwing cigarettes on the floor
SHS	04.04.2016	Wet conditions may have led to lower cigarette counts than on other days
SHS	04.04.2016	Trees seem to have a lot of cigarette buts at the base which have never been cleared
SHS	04.04.2016	Person threw cigarette butt straight into drain
SHS	03.04.2016	Shop had left 3 bin bags out, now others are leaving their rubbish there
SHS	04.04.2016	Same person binned can not cigarette
SHS	04.04.2016	Litter consistently spotted rolling into other zones with slight breeze especially light plastic and tissues
SHS	03.04.2016	Left Lucozade bottle on top of receipt disposal at nationwide cash ATM
SHS	03.04.2016	Dropped Greggs food and packaging on floor - picked up packaging but left food
SHS	03.04.2016	Put cigarette out on bin and left on top (not in cigarette section on top of bin).
SHS	03.04.2016	Smoking outside pub with pint, walked over to sewer to throw away cigarette
SHS	05.04.2016	People are using wall mounted cigarette bin outside of pub and Morrisons
SHS	05.04.2016	People are using wall mounted cigarette bin outside of Morrisons
SHS	05.04.2016	Went into Greggs to bin their food wrappers
OXM	19.05.2017	Biffa came out and emptied bins at 4.15pm
OXM	19.05.2017	MacDonalds staff do hourly clean up around their store
OXM	27.05.2017	Waiting for bus, threw cigarette into sewer when bus arrived
OXM	20.05.2017	Walked to bin to throw out juice bottle, kept walking and threw cigarette on floor.
OXM	20.05.2017	Person walking threw cigarette into sewer
OXM	27.05.2017	O2 Ritz had litter cleaner came out and cleared area
OXM	25.05.2017	People outside of office building threw cigarette straight into drain
OXM	25.05.2017	Construction barriers meant I couldn't count in area 45
LBL	22.04.2018	Items appear out of nowhere with the rush of city workers from across London Bridge.
LBL	22.04.2018	Food wrappings from shops that are not in the vicinity keep appearing.
LBL	22.04.2018	Went to bin to throw away beer tin and then threw cigarette butt on floor.
LBL	22.04.2018	Long discussion on movement across the bridge. Items appearing during heavy foot traffic from north to south.
LBL	22.04.2018	Person relaxing on statue smoking cigarette, got up to throw it into sewer
LBL	06.04.2018	After eating, couple have a cigarette. When finished they throw cigarette butt on floor but collect their rubbish and take with them
LBL	06.04.2018	Lots of new litter appeared after work rush began with people walking across bridge
LBL	06.04.2018	Street cleaner swept the street at 4pm exactly
LBL	06.04.2018	Lady working at news store, smoking, throwing them and stamping out
LBL	08.04.2018	Employees from Colechurch House come out for a smoke and drop cigarettes
LBL	08.04.2018	Employee from the Sun Newspaper Shop smoking regularly and throwing cigarettes

LBL	08.04.2018	Person walked around for a while looking for a bin, then left bottle in corner under the overpass
LBL	20.04.2018	Smokers walking towards bridge stubbed out and left butts on terrorist barrier
LBL	08.04.2018	Lots of cigarette butts and chewing gum under subway especially 316
LBL	20.04.2018	There are no bins here, I keep seeing people looking for somewhere to throw out their rubbish and not finding anywhere
LBL	20.04.2018	Person was looking for a bin, couldn’t find one and took their rubbish back to the food stall where they bought it
BRI	28.06.2018	No bins around square
BRI	28.06.2018	Walked for a while holding cigarette, then littered
BRI	28.06.2018	Dropped cigarette down drain
BRI	28.06.2018	Stubbed out cigarette on top of general waste bin, but there is no ashtray on bin so leaves end on bin. Falls off after they walk away
BRI	28.06.2018	Stubbed out on bin very thoroughly and leaves end on top of bin.
BRI	28.06.2018	Throwing food to feed seagulls
BRI	28.06.2018	Put out cigarette on floor while drinking coffee.
BRI	28.06.2018	Put out cigarette on floor while sitting on bench.
BRI	28.06.2018	Watched seagulls pull lots of rubbish from bin and spread around.
BRI	28.06.2018	Running into train station, throws cigarette down before entering.
BRI	29.06.2018	Threw cigarette into sewer.
BRI	28.06.2018	Hanging out in front of station for smoke. No bins close, throws cigarette in a puddle.
BRI	29.06.2018	Guy lying on beach stubbed out cigarette in pebbles/sand.
BRI	29.06.2018	When bus arrived, threw cigarette butt on floor
BRI	29.06.2018	Did it (littered cigarette end) discretely, trying not to be noticed.
BRI	29.06.2018	Was stood by the bin, but walked for the bus before throwing on the ground.
BRI	29.06.2018	Chucked cigarette down drain
BRI	29.06.2018	Didn't use ash tray because there was no longer one on the table
BRI	29.06.2018	Waiting for bus standing next to bin, throws butt on ground directly before getting on
BRI	01.07.2018	There is no ashtray or bins outside the library but many people sitting and smoking
BRI	01.07.2018	The seagulls are taking over, landing on people’s heads and taking their food
BRI	01.07.2018	Seagulls aggressively take peoples food and then drop packaging
BRI	01.07.2018	People are taking their food litter but still dropping their cigarette butts
BRI	01.07.2018	Person looked everywhere for a bin but there were none, eventually went into the library to throw away
BRI	02.07.2018	Many people sitting on beach stairs smoking
BRI	02.07.2018	Cigarette butts fall straight through bin top ashtray on to floor
BRI	02.07.2018	People looking for bins can't find any, eventually leave bagged litter by beach stairs
BRI	02.07.2018	People in groups aren't dropping litter but individuals are
BRI	02.07.2018	Bins are well spread out and people are using them
BRI	02.07.2018	People are throwing out their rubbish and littering their cigarettes

Appendix E: How to build a GPS bottle tracker

Premade mini live GPS trackers were used in this study. The specific tracker was the unbranded model TK102B GPS with dimensions of 66 x 46 x 17 mm. The tracker cost £12.22 and was purchased on Ebay (http://www.ebay.co.uk). The TK102B GPS uses mobile networks to send an SMS with its current location and has an accuracy of 5 metres, thus all coordinates have a 5-metre margin of error. Each unit requires a SIM card and an active mobile connection to send its location. Accounts were made for each unit using the mobile network GiffGaff and a mobile phone number was assigned to each.

The GPS tracker is housed in a single casing which includes one rechargeable 3.7 v 850mAh Li-ion battery. As the trackers had the potential to be lost in the river, the original lithium-ion batteries were replaced with 4 AA alkali batteries, which have a lower environmental impact and a longer battery life. In tests prior to the launch, this unit proved to have an undisturbed battery life of up to 6 days.

Appendix figure 1 GPS tracker with battery retrofit.

Due to their wrap around labelling and littering frequency (DEFRA, 2020), Lucozade bottles (380ml) were chosen to house the GPS units. The mouths of Lucozade bottles are not wide enough for the GPS tracker to be inserted in the bottle, thus, once they were emptied of their contents and dried, bottles were cut open along the side to insert the units. Units were turned on before they were inserted in the bottle but were left in passive mode to save battery life.

To seal the bottle, a patch was made by cutting a separate bottle into strips and glued to the outside using a polyurethane polymer-based glue that is appropriate for soft plastics, is waterproof, clear and has a quick drying time. Along with the tracker a highly absorbent silica was placed inside the bottles to avoid any issues of condensation.

Appendix figure 2 Bottle with tracker inside before and after application of concealing label.

Once the patch was dry and secure, the label and bottle top were reapplied and glued in place. Aside from a small gap in the label, the final product appeared to be untampered with, and the GPS tracking unit was only noticeable under close inspection. The final product weighed on average 147g, which is 120g heavier than the original empty bottles, which weighed approximately 27g. When full, a 380ml bottle of Lucozade weighs about 430g.

Appendix figure 3 Completed bottles with GPS tracker.

Appendix F: GPS Data collection and formatting process

The TK102B GPS tracker depends on cellular data to communicate its current location. Each unit was fitted with a SIM card and a GiffGaff (https://www.giffgaff.com/) account was created for each. GiffGaff is a contract-free mobile network service that offers monthly plans for £5 which include an allowance of 500 SMS messages. This was determined to be a sufficient number of text messages for the study and each unit was signed up to this monthly plan. Each tracker was assigned a unique phone number associated with their account and SIM card.

The TK102B GPS tracker is operated via text message. To activate the tracking function, an SMS is sent to the associated phone number of each tracker. This SMS includes a begin command as well as information on the preferred interval of texts. Once the tracker has received this information, a confirmation text is sent from the tracker and regular location SMS messages are initiated. For the first 24 hours trackers were programmed to send coordinates every 10 minutes. Afterwards the trackers were reprogrammed to send coordinates every 30 minutes.

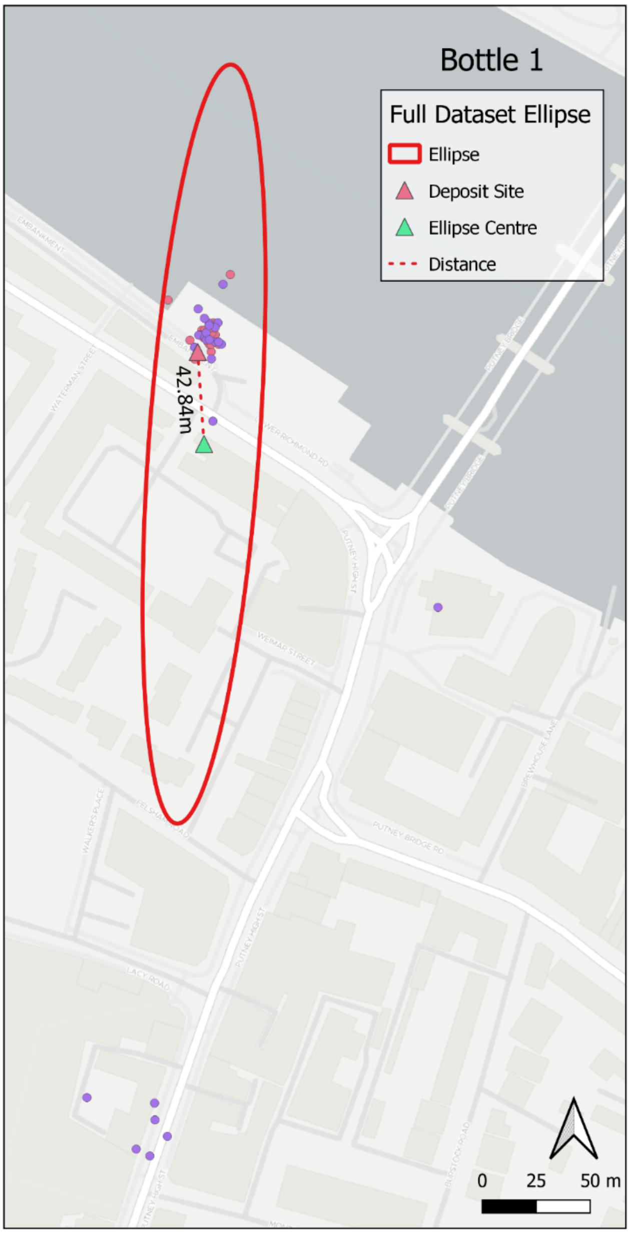
A service called Text Magic (https://www.textmagic.com) was used to collect tracker data. Text Magic is a website that allows users to send and receive SMS messages from an online dashboard. Through this service, SMS messages can be scheduled in advance and text strings are grouped by recipient; in this case each GPS tracking unit had its own chat profile on the dashboard labelled by bottle ID number. Finally, Text Magic allows for users to export chat profiles with all SMS messages into an CSV file. Text Magic charges £0.04 per sent SMS, but there is no fee for received SMS messages.

Once it was confirmed all trackers had either lost signal, the complete chat logs of each tracker was downloaded from Text Magic in CSV format.

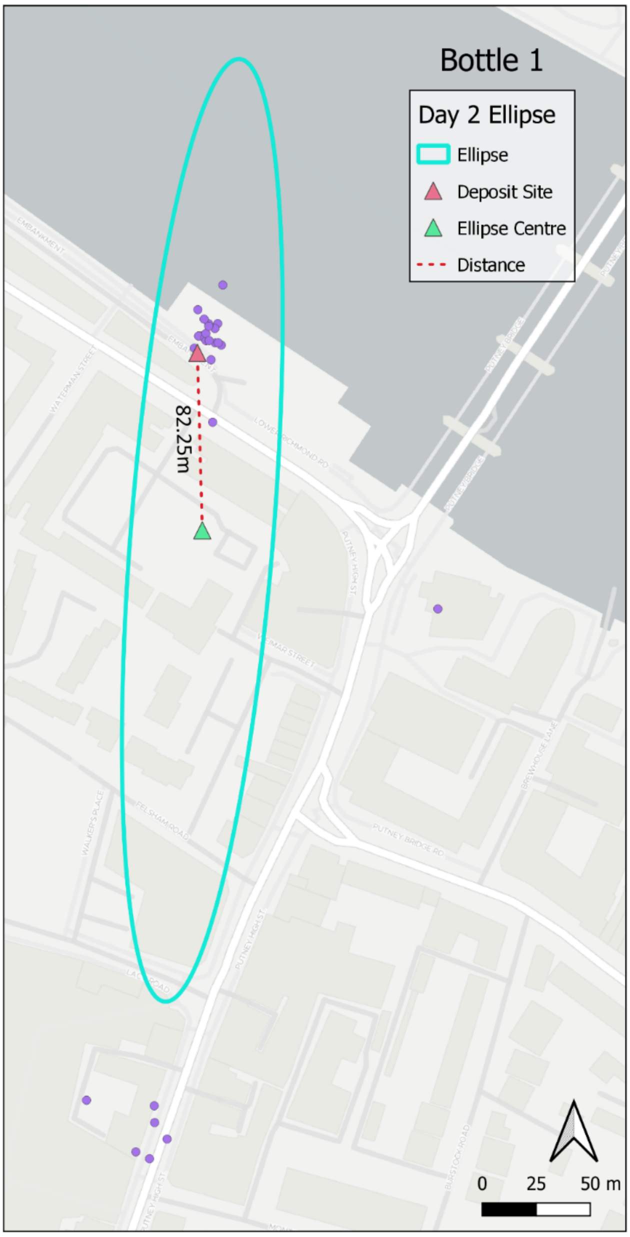
The messages sent by the trackers included all information in a single message, meaning the exported CSV included the full string text in one individual cell. The CSV had to be reformatted using the *Text to Columns* function to parse the message and separate data into individual columns. Columns generated from each SMS were, Bottle Name, Date, Time, Latitude, Longitude and Speed.

The deposit time of each bottle was then cross referenced with the reformatted CSV file, and any GPS locations that were collected before the bottle was released was deleted from the dataset.

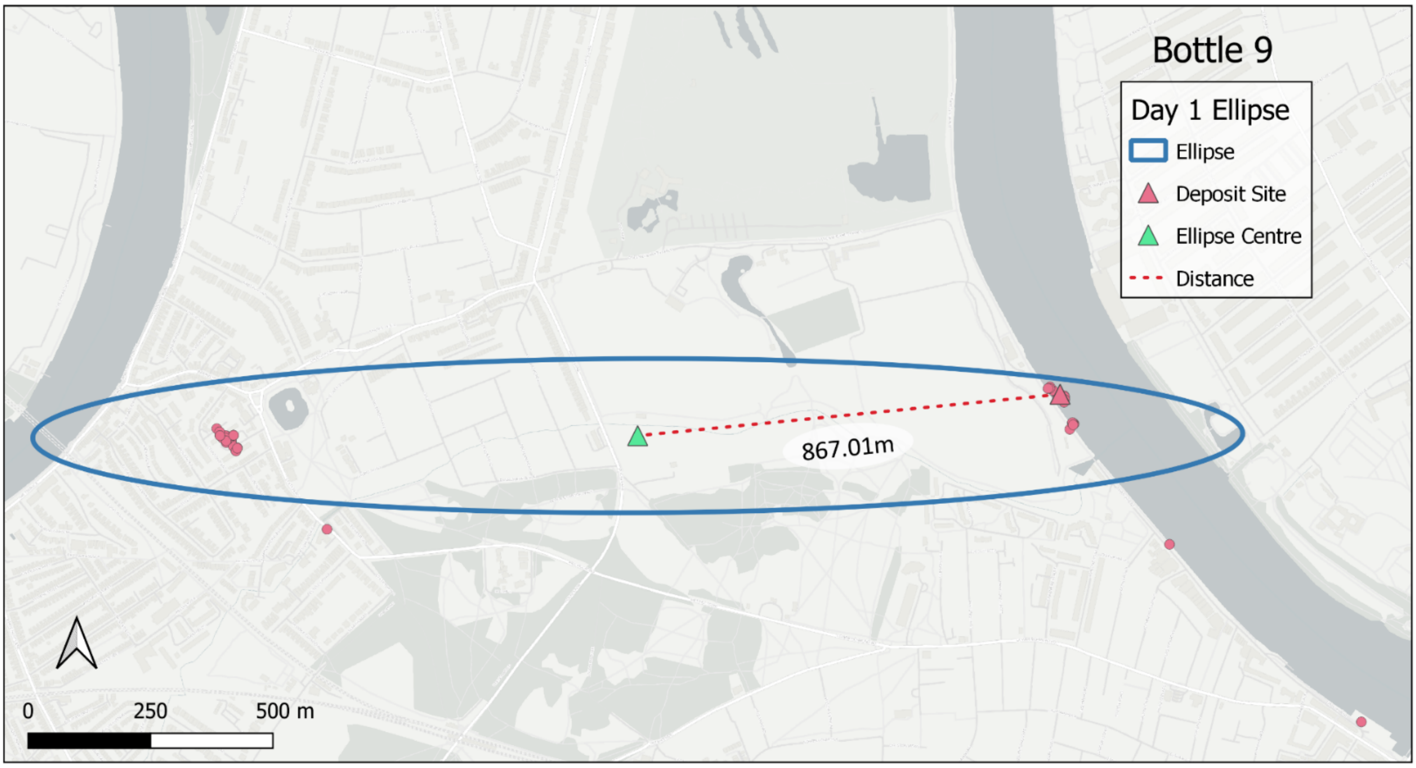
Appendix G: Omitted ellipses



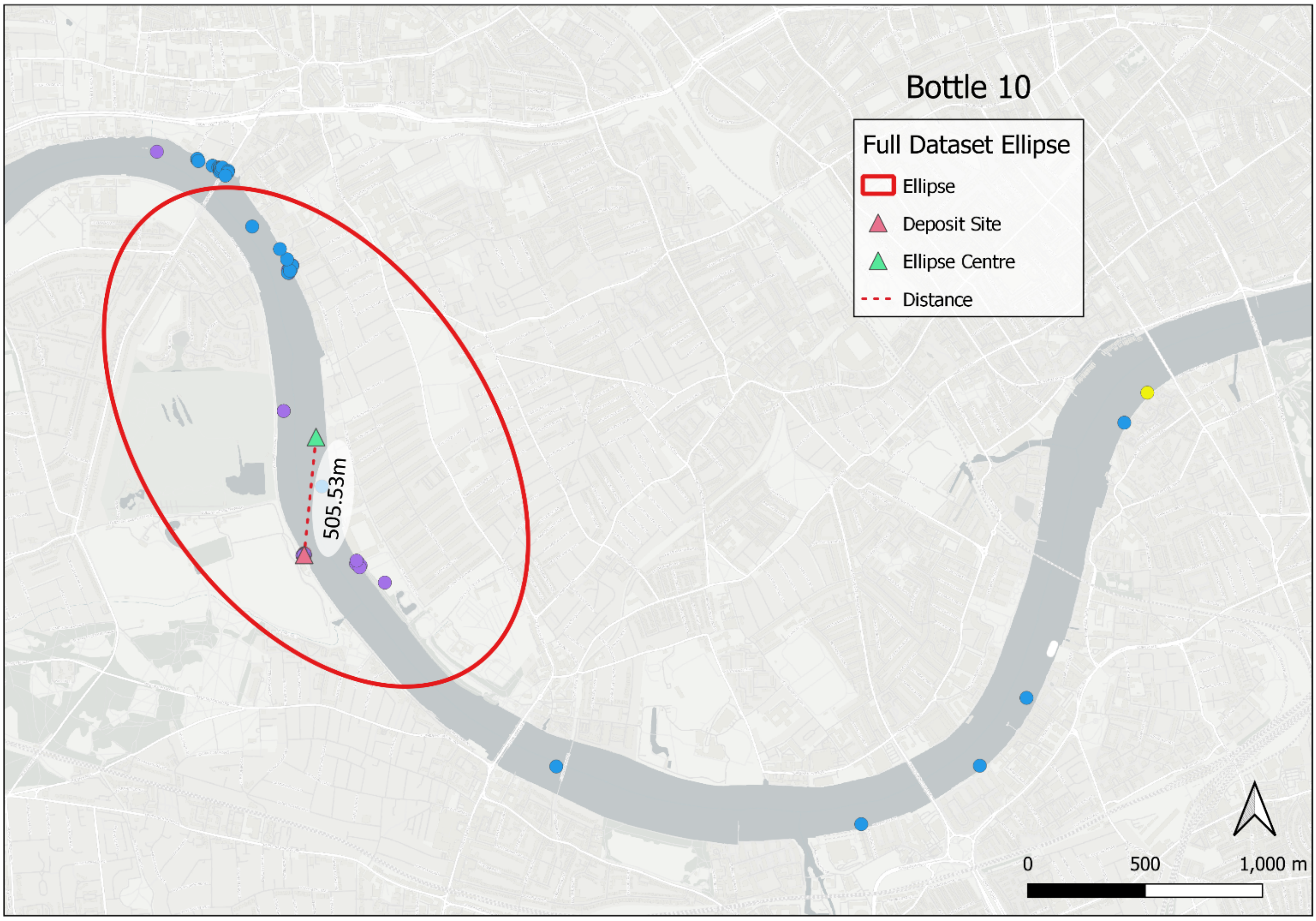
Appendix figure 5 Bottle 1 full dataset ellipse



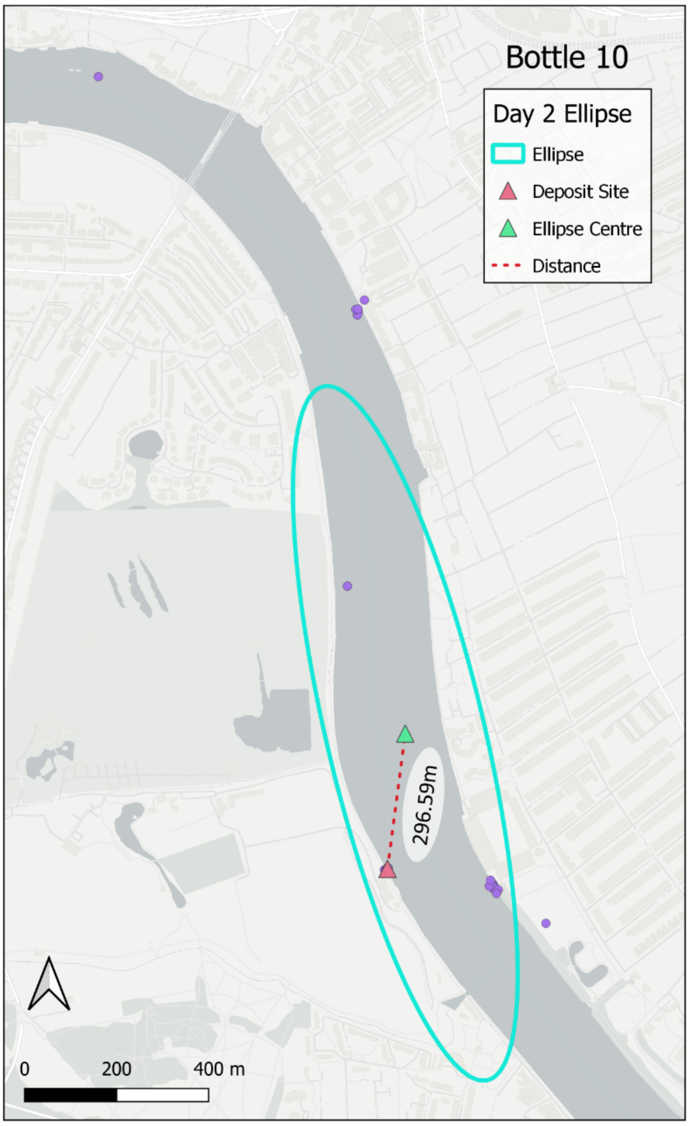
Appendix figure 4 Bottle 1 day 2 ellipse



Appendix figure 7 Bottle 9 day 1 ellipse



Appendix figure 6 Bottle 10 full dataset ellipse



Appendix figure 8 Bottle 10 day 2 ellipse

Appendix H: Indicator Score Guide for the Litter Impact Index

		Plastic	Part Plastic	Rubber	Plastic-coated	Uncoated Paper	High Surface to Volume Ratio	Low Surface to Volume Ratio
Hygiene	Condoms			X				X
	Hair tie			X				X
	Sanitary napkin		X					X
	Syringe	X						X
	Tampon		X					X
	Tissue: Unused					X	X	
	Tissues: Used					X		X
	Wet wipe		X				X	
Other	Balloon: Rubber and latex			X			X	
	Dog faeces							X
	Textiles							X
	Zip ties	X						X
PPE	Face mask: Textiles							X
	Face mask: Single use	X					X	
	Surgical gloves			X				X
Shopping and Entertainment	Cardboard box					X		X
	Cash point receipts				X		X	
	Flyers and leaflets				X		X	
	Magazine				X			X
	Newspaper					X		X
	Paper bag: Shopping					X	X	
	Plastic bag: Shopping	X					X	
	Till receipt				X		X	
Smoking	Cigarette cellophane wrapping	X					X	
	Cigarette foil paper						X	
	Cigarette packs				X			X
	Cigarette rolling papers					X	X	
	Cigarettes ends		X				X	
	Lighters	X						X
	Matches: Wood							X
	Unsmoked filters	X					X	
Transport	Bus ticket				X		X	
	Plane ticket				X		X	
	Train ticket				X		X	
	Tram ticket				X		X	

		Plastic	Part Plastic	Rubber	Plastic-coated	Uncoated Paper	High Surface to Volume Ratio	Low Surface to Volume Ratio
Chewing Gum	Chewing Gum	X						X
	Gum packaging: Card outer				X			X
	Gum packaging: Plastic and foil inner		X					X
	Gum wrapper: Paper	X					X	
Drinking	Aluminium drink tin				X			X
	Glass bottle							X
	Hot drink cup				X			X
	Hot drink insulating wrap					X		X
	Hot drink lid	X					X	
	Metal bottle top							X
	Paper cup				X			X
	Paper cup lid	X					X	
	Plastic bottle	X					X	
	Straw: Paper				X		X	
	Straw: Plastic	X					X	
	Yokes	X						X
Eating	Burger box				X			X
	Cellophane wrapping: Food	X					X	
	Chocolate wrapper	X					X	
	Crisp packets	X					X	
	Foil wrapping: Food						X	
	Food							X
	Ice cream stick: Wood							X
	Ice cream wrapper	X					X	
	Napkins					X	X	
	Paper bag: Food					X	X	
	Pastry bag				X		X	
	Plastic bag: Food	X					X	
	Polystyrene food boxes or trays	X					X	
	Sandwich pack: Card with plastic window		X		X			X
	Sandwich wrap: Paper				X		X	
	Sandwich wrap: Plastic	X					X	
	Sweets bag	X					X	
	Sweets wrapper	X					X	
	Takeaway box: Aluminium						X	
	Takeaway box: Cardboard				X			X
	Takeaway box: Plastic	X						X
	Utensil: Plastic	X						X
	Utensil: Wood							X

Appendix I: Executed Litter Impact Index with scaled values

		Toxicity	Tenacity	Threat	Transportability	Total	Weighted Value	Scaled Value
Chewing Gum	Chewing Gum	3	3	1	0	7	26	74.29
	Gum packaging: Card outer	2	2	1	1	6	19	54.29
	Gum packaging: Plastic and foil inner	2	2	1	1	6	19	54.29
	Gum wrapper: Paper	2	2	1	2	7	20	57.14
Drinking	Aluminium drink tin	2	2	1	1	6	19	54.29
	Glass bottle	0	1	3	1	5	9	25.71
	Hot drink cup	2	2	1	1	6	19	54.29
	Hot drink insulating wrap	0	0	1	1	2	3	8.57
	Hot drink lid	3	3	1	3	10	29	82.86
	Metal bottle top	0	1	3	0	4	8	22.86
	Paper cup	2	2	1	1	6	19	54.29
	Paper cup lid	3	3	1	3	10	29	82.86
	Plastic bottle	3	3	1	3	10	29	82.86
	Straw: Paper	2	2	1	2	7	20	57.14
	Straw: Plastic	3	3	2	3	11	31	88.57
	Yokes	3	3	2	1	9	29	82.86
Eating	Burger box	2	2	1	1	6	19	54.29
	Cellophane wrapping: Food	3	3	1	3	10	29	82.86
	Chocolate wrapper	3	3	1	3	10	29	82.86
	Crisp packets	3	3	1	3	10	29	82.86
	Foil wrapping: Food	0	1	1	3	5	7	20.00
	Food	1	0	1	0	2	8	22.86
	Ice cream stick: Wood	0	1	1	0	2	4	11.43
	Ice cream wrapper	3	3	1	3	10	29	82.86
	Napkins	0	0	1	2	3	4	11.43
	Paper bag: Food	0	0	1	2	3	4	11.43
	Pastry bag	2	2	1	2	7	20	57.14
	Plastic bag: Food	3	3	2	3	11	31	88.57
	Polystyrene food boxes or trays	3	3	2	3	11	31	88.57
	Sandwich pack: Card with plastic window	3	2	1	2	8	26	74.29
	Sandwich wrap: Paper	2	2	1	2	7	20	57.14
	Sandwich wrap: Plastic	3	3	1	3	10	29	82.86
	Sweets bag	3	3	1	3	10	29	82.86
	Sweets wrapper	3	3	1	3	10	29	82.86
	Takeaway box: Aluminium	0	1	1	2	4	6	17.14
	Takeaway box: Cardboard	2	2	1	2	7	20	57.14
	Takeaway box: Plastic	3	3	1	3	10	29	82.86
	Utensil: Plastic	3	3	2	1	9	29	82.86
	Utensil: Wood	0	1	1	0	2	4	11.43
Hygiene	Condoms	0	1	1	0	2	4	11.43
	Hair tie	0	1	2	0	3	6	17.14
	Sanitary napkin	2	2	1	0	5	18	51.43
	Syringe	3	3	3	1	10	31	88.57
	Tampon	2	2	1	0	5	18	51.43
	Tissue: Unused	0	0	1	2	3	4	11.43
	Tissue: Used	1	0	1	1	3	9	25.71
	Wet wipe	2	2	1	2	7	20	57.14
Other	Balloon: Rubber and latex	0	1	2	3	6	9	25.71
	Dog faeces	1	0	1	0	2	8	22.86
	Textiles	0	0	1	0	1	2	5.71
	Zip ties	3	3	1	1	8	27	77.14
PPE	Face mask: Textiles	1	1	2	0	4	12	34.29
	Face mask: Single use	3	3	2	3	11	31	88.57
	Surgical gloves	0	1	1	0	2	4	11.43
Shopping and Entertainment	Cardboard box	0	0	1	1	2	3	8.57
	Cash point receipts	4	2	1	2	9	28	80.00
	Flyers and leaflets	2	2	1	2	7	20	57.14
	Magazine	2	2	1	1	6	19	54.29
	Newspaper	0	0	1	1	2	3	8.57
	Paper bag: Shopping	0	0	1	2	3	4	11.43
	Plastic bag: Shopping	3	3	2	3	11	31	88.57
	Till receipt	4	2	1	2	9	28	80.00
Smoking	Cigarette cellophane wrapping	3	3	1	3	10	29	82.86
	Cigarette foil paper	0	1	1	3	5	7	20.00
	Cigarette packs	2	2	1	1	6	19	54.29
	Cigarette rolling papers	0	0	1	2	3	4	11.43
	Cigarette ends	4	2	1	3	10	33	94.29
	Lighters	3	3	1	1	8	27	77.14
	Matches: Wood	0	1	1	0	2	4	11.43
	Unsmoked filters	3	2	1	3	10	27	77.14
Transport	Bus ticket	2	2	1	2	7	20	57.14
	Plane ticket	2	2	1	2	7	20	57.14
	Train ticket	2	2	1	2	7	20	57.14
	Tram ticket	2	2	1	2	7	20	57.14