Explaining Marine Debris on New Zealand Beaches: Empirical Beach Litter Data and an Evaluation of Waste Management Practices

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Abstract

Anthropogenic marine debris (AMD) is a widely researched topic, particularly for its impacts on marine wildlife. Terrestrial sources of AMD are substantial, increasing and primarily considered a result of mismanaged waste. Yet, large-scale empirical research linking losses from waste management with pollution on beaches is sparse. This thesis undertook a national assessment of AMD densities across 41 beaches, and evaluated correlated factors that might influence AMD densities, including beach characteristics (such as orientation, steepness), population density, catchment size, and waste management practices. The findings suggest a strong correlation between local waste management practices and variations in AMD densities across New Zealand's beaches. Methods applied in this multidisciplinary project include a comprehensive systematic literature review complemented with quantitative and qualitative research.

The results of empirical field work across 41 beaches demonstrated a significant spatial variance, with the South Island showing a significantly higher mean debris density than the more populated North Island by count ($P < .02$) as well as by mass ($P < .03$). The majority (78%) of all AMD detected was plastic, and 72% arrived through the water. Analyses of local waste management practices showed that waste loss to the environment likely occurs due to uncoordinated planning, confusion resulting from discrepancies between local kerbside collection methods, and the inadequate management of (closed) landfills and farm dumps.

Including waste management factors in generalized linear modelling resulted in a better fit. Models specified the following significant waste management predictors: 1) the presence of a regional coordinating waste management document (less AMD), 2) the presence of rubbish bins on the beach (more AMD), and 3) the manner in which waste management is financed locally. The type of waste receptacles (open crates or lidded bins) and the amount of the local waste budget were not significant. Environmental factors explaining variances in AMD detected included the orientation of the beach (NE significantly less then E and SE), type of backshore, steepness of beach, as well as the size and the relative location of the nearest catchment.

The findings of this thesis contribute to the field of AMD research in the Southern Hemisphere and in New Zealand by establishing a national baseline whilst also refining the understanding of factors that may drive local and national waste loss to the environment. This study serves as a reference for follow-up studies, including in other locations (i.e., New Zealand's West Coast) as well as accumulation studies, localized microplastic studies, invasive species transport and global ocean modelling. Furthermore, this research is useful for waste prevention, policy makers and local waste management planners in reviewing approaches to waste management at a local, regional and national level.

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Glossary

AMD	Anthropogenic Marine Debris
EA/NALG	National Aquatic Litter Group
GLM	Generalized Linear Model
MARPOL	International Convention for the Prevention of Pollution from Ships
MSFD	Marine Strategic Framework Directive
NIWA	National Institute of Water and Atmospheric Research
NI	North Island
NZ	New Zealand
OECD	Organisation for Economic Co-operation and Development
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
POP	Persistent Organic Pollutant
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
RA	Regional Authority
RMA	Resource Management Act 1991
SI	South Island
TA	Territorial Authority
UNCLOS	The United Nations Convention on the Law of the Sea
UNEP/IOC	United Nations Environment Programme Intergovernmental Oceanographic Commission
WMA	Waste Minimisation Act 2008
WMMP	Waste Minimisation and Management Plan

Chapter 1

Anthropogenic Marine Debris Literature Review

A day's catch, marine debris collected from a South Island beach in New Zealand.
Photo: van Gool, E.D.

1.1 Introduction

Human existence intricately relies on the health of the oceans. We depend on the seas for a variety of nature's contributions to people (Díaz et al., 2018), including our oxygen and long-term food security. Anthropogenic marine debris (AMD) has rapidly gained the awareness and attention of policymakers, researchers (across multiple disciplines), enterprises, non-governmental organizations and individuals around the world, as a grave potential threat to ocean health. Yet, this issue has long been known. In his insightful novel "*20,000 Leagues Under the Sea*", Verne already anticipated the problem of increasing AMD in the marine environment (Verne, 1870).

Almost 150 years since Verne highlighted the issue, ever-increasing amounts of anthropogenic waste entering the water, compounded with other existing environmental threats such as eutrophication, climate change and acidification (Crain et al., 2009), now capture our attention. The academic study of AMD (including flotsam, jetsam, and marine litter) was first referred to in published form in 1972 (Carpenter & Smith, 1972). Since then, many researchers globally have considered this topic (Cole et al., 2011; Derraik, 2002; Lynch, 2018; Serra-Gonçalves et al., 2019). A frequently used definition of AMD in the scientific literature is: "any manufactured or processed solid waste material that enters the marine environment from any source" (Coe & Rogers, 1997). Another often-used definition in policy is from the United Nations Environment Program (UNEP): "Marine litter is any persistent, manufactured, or processed solid material discarded, disposed of or abandoned in the marine and coastal environment".

Although variations exist, in general, about 80% of AMD is derived from land-based sources (Derraik, 2002; Sheavly & Register, 2007); a large proportion of which results from mismanaged terrestrial waste (Barnes et al., 2009; Jambeck et al., 2015; Lau et al., 2020; Ryberg et al., 2018). Coastal marine environments are a known sink for AMD (Galgani et al., 2015; Sherman & Sebille, 2016). Studies researching AMD loads in coastal zones occur in various coastal habitats, including mangroves (Cordeiro & Costa, 2010; Ivar do Sul et al., 2014; Martin et al., 2019; Mohamed Nor & Obbard, 2014), rocky shores (Adelir-Alves et al., 2016; Kuo & Huang, 2014; Thiel et al., 2013), and subtidal benthic environments including reefs (Alvito et al., 2018; Backhurst & Cole, 2000; Bauer-Civiello et al., 2018; Hess et al., 1999). However, most coastal AMD studies occur on sandy beaches (Browne, Chapman, et al., 2015; Serra-Gonçalves et al., 2019), as these are easier to access, more frequently visited, and generally, require no specialised equipment to research (Kershaw et al., 2019).

From an international management perspective, the member states of the United Nations (UN), which include New Zealand (NZ), have identified the shared risks and responsibilities to the ocean commons (Convention on the Law of the Sea [UNCLOS], 1982). A legal framework was developed to manage and prevent further environmental harm from AMD, as per each member state's scientific, technical and economic capabilities and as regulated in the UNCLOS. Part XII spells out shared resources and stewardship where member states are obliged to take all measures to prevent, reduce and control pollutants. Article 207 requires states to adopt laws and regulations, harmonise policies and establish regional rules. Standards must be designed to minimise the release of pollutants (UNCLOS, 1982). In NZ, Part XI of UNCLOS was translated into the United Nations Convention on the Law of the Sea Act 1996.

Other internationally binding (i.e., hard law) treaties that address AMD, and which are translated into NZ law are:

- The London Dumping Convention 1972, which is international legislation directly controlling the dumping of various classes of wastes into the ocean (from land), with a non-binding update in 1996 (London Convention Protocol), to prohibit all discarding, except for those items on the “reverse list” (Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972).
- The International Convention for the Prevention of Pollution from Ships (MARPOL) 1973, particularly Annex V, determines how far a vessel must be from shore before it can dump certain types of rubbish. However, it bans all disposal of plastics into the sea (MARPOL 1973).

These Conventions were ratified and implemented through a suite of NZ legislation, including the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012; Maritime Transport Act 1994; Resource Management Act 1991 and the Resource Management (Marine Pollution) Regulations 1998).

Other relevant non-binding (i.e., soft law) international agreements pertaining to the mitigation of AMD include the following UN interrelated initiatives, programmes and publications through its various organs:

- UN Conference on Environment and Development (UNCED) Agenda 21 sets out an international program of action for achieving sustainable development during the 21st century, including in Chapter 17, precautionary measures to prevent marine debris (UN, 1992).
- UN General Assembly resolution “Oceans and the law of the sea” (document A/75/239), which calls, amongst others, for all member states to become party to UNCLOS, harmonize legislation and build capacity, particularly regarding developing nations (UN, 2020).

- UNEP's Honolulu Strategy – a global planning framework for preventing and managing marine litter (Shevealy et al., 2012).
- UNEP's Guidelines on the Survey and Monitoring of Marine Litter (Cheshire et al., 2009).
- UNEP's Clean Seas Campaign, a catalyst for change, transforming habits, practices, standards and policies around the globe. In 2018, NZ joined 40 other countries in this global coalition to end marine plastic pollution.
- The implementation of UNEP's Regional Seas Programme through the South Pacific Regional Environment Programme (SPREP) promotes cooperation in the Pacific region and aids in protecting and improving the environment. Participation from NZ is through the Department of Conservation (SPREP, 2016).
- The UN's Transforming Our World: The 2030 Agenda for Sustainable Development, 2015, the Sustainable Development Goals (SDGs) that specifically address AMD are listed in Table 1.1 with a short description of NZ implementation specifics.

Table 1.1

Relevant Legislative Actions to United Nations Sustainable Development Goals Relating to the Management of Anthropogenic Marine Debris Sources

Goal	Description	New Zealand
11.6	By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	Resource Management Act 1991, Waste Minimisation Act 2008, Waste Minimisation (Microbeads) Regulations 2017, Waste Minimisation (Plastic Shopping Bags) 2018 (see Chapter 3)
12.5	By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	See 11.6 and the New Zealand Waste Strategy

Goal	Description	New Zealand
14.1	By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution	See 11.6 and Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012, Maritime Transport Act 1994, Resource Management (Marine Pollution) Regulations 1998 and United Nations Convention on the Law of the Sea Act 1996
14.2	By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration to achieve healthy and productive oceans	All of the above and a monitoring programme implemented through partnership between NGO, the Ministry for the Environment, and Stats NZ (see Chapter 5)
14a	Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular, small island developing States and least developed countries	Membership of South Pacific Regional Programme (SPREP) and Biodiversity Strategy and Environmental Reporting Act 2015

Note. Adapted from “Transforming our World”: The 2030 Agenda for Sustainable Development, Pub. L. No. A/RES/70/1 (2015).

Another relevant international agreement is Decision XI/18 of the Conference of the Parties (COP) to the Convention of Biological Diversity, (CBD), 2012, based on the Scientific and Technical Advisory Panel of the Global Environment Facility. In particular, Aichi Biodiversity Target 8 relates to AMD as it states that “by 2020 pollution has been brought to levels that are not detrimental to ecosystem function and biodiversity”. New Zealand is a party to the CBD and has adopted a corresponding Biodiversity Strategy (Department of Conservation, 2020) and the Environmental Reporting Act 2015 to report on progress against the strategy.

1.1.1 New Zealand Marine Environment

NZ is an archipelago bordered by the Tasman Sea and the South Pacific Ocean with about 18,200 km of shoreline (Hutching, 1998), which ranks it in a list of countries with the top 10 longest coastlines in the world (Kurian, 1998). The two main islands cover more than 12 degrees of latitude from 34.25° S – 46.45° S. Two main bodies of oceanic water surround NZ, with subtropical water travelling southwards from the South Pacific (via Australia) to NZ, and sub-Antarctic surface water moving northwards from the Southern Ocean (Chiswell et al., 2015). The country's climate extends from subtropical in the far north to cool-temperate in the south (NIWA, 2011).

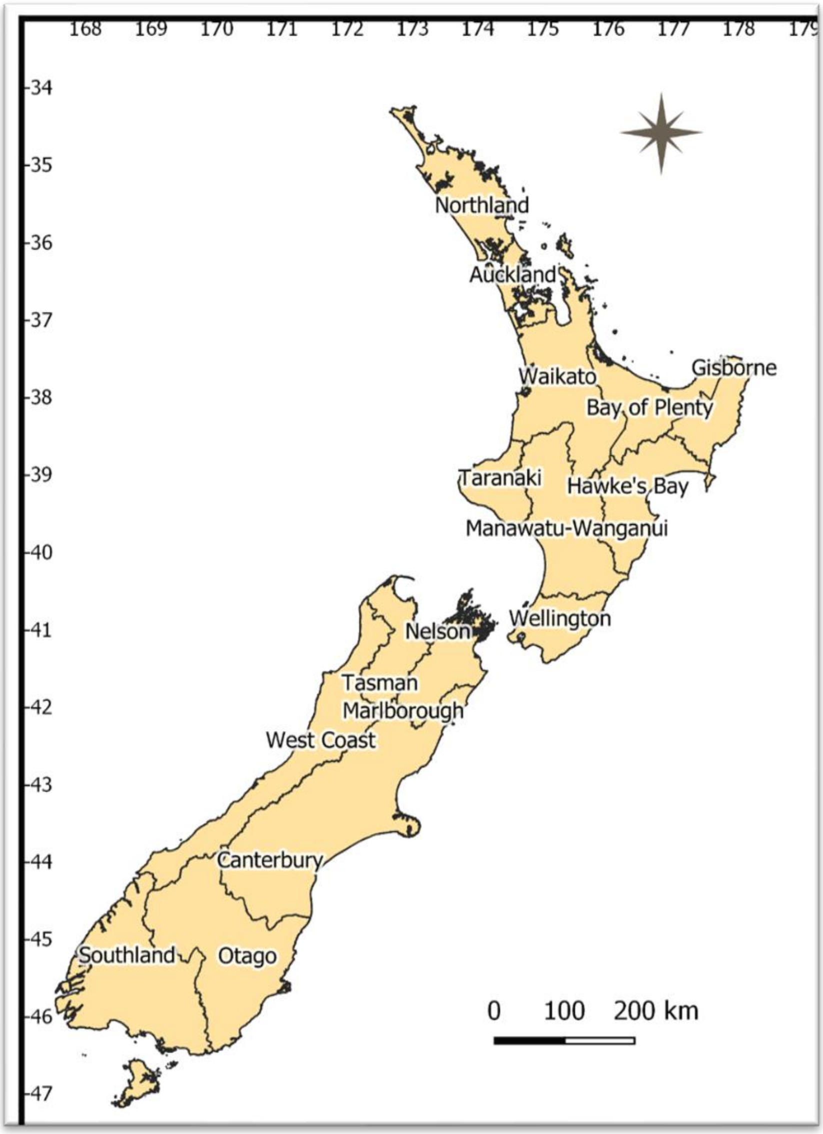
The isolation from other countries and proximity to Antarctica and sub-Antarctic Islands creates a unique ecosystem. NZ hosts an estimated 80,000 endemic species, including 15,000 marine species and breeding seabirds (Gaskin & Rayner, 2013). The latter are particularly vulnerable to floating AMD (Roman et al., 2019; Verlis et al., 2018). Many of the various species in NZ waters are endangered (Gaskin & Rayner, 2013; Godoy & Stockin, 2018; Miskelly et al., 2008) due to a mix of factors, including anthropogenic impacts.

New Zealand is also a destination for many domestic and international tourists. During the year ending March 2019, the tourism industry contributed 5.8% directly, and 4% indirectly, to NZ's gross domestic product (i.e., NZ$284.7 billion for the year ending March 2019; Stats NZ, 2020b). Fishing is quintessential to the NZ way of life, whether it be recreational fishing, the exercise of Māori customary fishing rights, or commercial fishing. Economic value of the latter was valued at NZ$1.5 billion in the year ending March 2019 (Stats NZ, 2020a). The exclusive economic zone in NZ spans 4.4 million km^2, ranking it in the top 10 of the world (Kurian, 1998). Furthermore, as of 2006, approximately 75% of the NZ population lives less than 10 km from the coastline, and about 97% within 50 km of it (Statistics New Zealand, 2016). The total estimated NZ population as of June 2019 is 4.92 million people (Stats NZ, 2019) of which 80% live in the North Island (NI).

New Zealand has currently no national coastal or AMD policy. Instead, beaches, coasts, estuaries, and the marine environment are managed under an array of, sometimes overlapping legislation, variously administered by the Ministry for the Environment, Department of Conservation, Maritime New Zealand, Ministry of Primary Industries, and the local (regional and territorial) authorities (Peart & Mulcahy, 2010). Administratively, the country is divided into 16 Regional Authorities (RAs) for which the geographic borders are mainly based on catchment areas. Nine of the RAs are in the NI and seven in the South Island (SI) (see Figure 1.1). Below the RAs are 67 Territorial Authorities (TAs), of which 42 are in the NI and 23 in the SI. The Chatham Islands is the 67th TA but is excluded from the research and analysis of this thesis due to time and resource constraints. In five of the regions, the administration of the RA and TA are combined into a “Unitary Authority” (i.e., Auckland, Gisborne, Tasman, Nelson and Marlborough).

Figure 1.1

Regional Authorities Across New Zealand



In 2017, New Zealanders were estimated to have produced 740.3 kg of waste per capita (OECD, 2021); 218.7 kg more (per capita) than the average (521.6 kg) of all other high-income countries (OECD, 2021). Also, NZ waste creation continues to increase, as evidenced by the 2018 per capita amount of 781.1 kg versus a 524.7 kg average of all OECD countries combined (OECD, 2021). The NZ waste and recycling industry is listed as one of the worst performers of all developed countries (Hoornweg & Bhada-Tata, 2012; OECD, 2017). This was also recognised in 2018 by the NZ Minister responsible for the waste portfolio (New Zealand Government, 2018b). All of NZ's waste goes to landfill, creating an increased potential for waste loss to the (marine) environment. One example of which is the rupture of the no longer operational Fox Glacier landfill (SI), which released decades of previously landfilled household rubbish onto 1,313 ha of sensitive riverbeds and banks, and 64 km of coastline (Todd, 2019).

One of the NZ government's tools to discourage waste creation is through the charging of a waste disposal levy (i.e., a fee paid to dump rubbish) (Waste Minimisation Act, 2008, Part 3). Half of the revenue generated by the levy is redistributed to the TAs to fund local waste minimisation projects. The other half is invested in waste minimisation-related projects through a contestable fund administered by the Ministry for the Environment. The NZ waste levy is low compared to other high-income countries and applies only to about 11% of all landfills (which accept roughly 30% of NZ's total waste to landfill) (Ministry for the Environment, 2017; Wilson et al., 2017), thus rendering it relatively ineffective as a tool to reduce inputs to the environment. Other waste minimisation instruments used by the NZ government include voluntary "product stewardship" programmes, where the manufacturer, producer or seller of a product takes responsibility for minimizing the products' environmental impact throughout all stages of its lifecycle, including end of life management. These programmes have shown limited success in NZ, mainly due to their voluntary nature resulting in low participation rates and susceptibility to freeloaders, whereby those that choose not to participate can gain short term economic advantage (Blumhardt, 2018; Hannon, 2018).

Recognizing the importance of addressing NZ's waste problem, in 2018, the Ministry for the Environment announced a waste work programme "Resource

Efficiency and Circular Economy Transition". The programme focusses on reassessing the waste levy, improving recycling infrastructure in NZ, and implementing mandatory product stewardship schemes for priority products such as tyres (Ministry for the Environment, 2020). The programme has resulted in public consultations on increasing and expanding the waste levy and establishing mandatory product stewardship schemes (Ministry for the Environment, 2019c, 2019d). Furthermore, the Office of the Prime Minister's Chief Science Advisor has issued the report *Rethinking Plastics in Aotearoa New Zealand* (Office of the Prime Minister's Chief Science Advisor, 2019). The report's recommendations include a range of strategic and operational actions, including improving plastics data collection, an integrated national plan, unifying recycling, innovation, and mitigation of plastic's environmental and health impacts (Office of the Prime Minister's Chief Science Advisor, 2019).

In NZ, the mechanisms and environmental effects of waste loss to the environment, which result in the accumulation of AMD on beaches, is sparsely studied. Campbell et al. (2017) measured the amount of AMD on beaches of the Coromandel Peninsula (NI), a popular vacation destination. However, prior AMD beach research is decades old (see section 1.4.4.1) in comparison. Despite this gap in scientific research, anecdotal evidence, personal observations, and the outcomes of ongoing volunteer efforts by groups such as Sustainable Coastlines (http://sustainablecoastlines.org) and Sea Cleaners (http://seacleaners.com), suggest that AMD on NZ's beaches and coastal waters is a real and ongoing issue.

In summary, NZ is a developed, high-income country and a UN member state with international obligations towards the ocean commons. The nation has an extensive coastline and economic zone featuring unique and endangered ecosystems. From an economic perspective, NZ depends on fisheries and tourism income, which are both profoundly affected by (and a cause of) AMD (see sections 1.4.1.3 and 1.4.1.4). Land-based sources of AMD include the mismanaged portion of overall waste, which is 40% higher (per capita) in NZ than the average of all high-income countries. Despite global recognition of AMD problems, the existence of international and national legal requirements, and calls for more research into the role of (waste) management (Blettler & Wantzen, 2019; Bonanno & Orlando-Bonaca, 2018; Borrelle et al., 2017), the current status of AMD on NZ's beaches remains unclear. The paucity of scientific information results in a data gap that is strongly worthy of further investigation.

Thus, the topic of this multidisciplinary thesis is the aetiology of AMD on the beaches of NZ, with a particular focus on the role of national and local waste management factors. The specific research question is: *What is the relationship between AMD found on beaches and local waste management practices*? To determine this, an understanding of the current load of AMD on NZ beaches is required. Under the guiding principles of this research question, this thesis aims to:

- Measure and describe AMD on NZ beaches at a latitudinal scale (Chapter 2);
- Describe the NZ waste management landscape at national and local levels and determine factors contributing to waste loss to the environment (Chapter 3);
- Create a predictive model for AMD on NZ beaches while considering environmental, location, and waste management predictors (Chapter 4); and
- Based on the outcomes in Chapters 2 - 4, recommend management and mitigative actions (Chapter 5).

A literature review was conducted to parse out and understand the issue of AMD at a global and a local (NZ) scale. This first chapter provides an explanatory background to the general and broad topic of matters relating to AMD. This review was based on the following questions:

1. Why is AMD a problem and what are the impacts?;
2. What are the sources, pathways and sinks of AMD?;
3. What is the role of waste management?;
4. How is AMD managed?;
5. How is AMD detected on beaches?;
6. What AMD research exists in an NZ context?; and
7. What are the global and NZ specific AMD research gaps?

1.2 Materials and Methods

A rigorous and systematic review of international AMD literature was conducted to address research questions 1 - 6. Relevant published papers from around the globe were retrieved from the Scopus database covering a period of 20 years (1998 - 2017). The search term included the following keywords and Boolean operators: “marine” OR “ocean” OR “coastal” OR “pelagic” AND “debris” OR “litter” OR “trash” OR “rubbish” OR “pollution” AND “plastic”. Articles from the following subject areas were included: Agricultural and Biological Sciences, Earth and Planetary Sciences, Environmental Science, Social Sciences, Engineering, Multidisciplinary, Psychology, Business, Management and Accounting, Economics, Econometrics and Finance and Decision Sciences. The process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Moher et al., 2010), and the search was restricted to peer-reviewed publications in English only.

To complement the Scopus search and to identify relevant policy articles, “snowballing” added another selection of (sometimes overlapping) documents (Hagen-Zanker & Mallett, 2013). The snowballing technique (i.e., adding literature identified from reference lists of key publications and experts) was particularly useful to locate research from different disciplines, (i.e., in other databases), or those articles which applied other terminology and jargon for the same phenomena.

To address research question 5) "How is AMD detected on beaches?" a primary review of 117 beach studies (76 resulting from the PRISMA process and 41 additional studies retrieved through snowballing) was conducted. The selected studies examined AMD on beaches but excluded publications that focussed on microplastic-only (< 1 mm). The resulting studies were organised by:

a) Year of publication;
b) Country or area of research and OECD membership at time of the survey, to facilitate comparisons between countries with similar socio-economic systems, including modern waste management systems and like-minded approaches to pollution control;
c) Study coverage (local, region, multi-regional, national, international);
d) Total number of beaches sampled;
e) Type of researcher (volunteer [if mentioned in the article] or scientist); and
f) Type of survey (standing stock or accumulation).

Next, to examine and compare the specific methodologies and results from standing stock studies (f) with a multi-regional or national scale (c), details were extracted from a qualified selection (secondary review). This subset included standing stock studies that surveyed 13 or more beaches which was the minimum number of beaches in studies covering multiple regions. Two studies published in 2018 were added for relevance and completeness. Of these resulting standing stock studies, the following information was recorded:

- Goal of the study;
- Sampling protocol and type of debris sampled;
- Location, type and direction of the sampling transect(s);
- Replication and area covered on the beach;
- Minimum debris size and categorisation protocol; and
- Reporting metrics, results, and percentage of plastic debris.

For NZ-specific information (research question 6), the search was expanded to include dates outside the initial timeframe. Grey literature (non-peer-reviewed reports and technical papers) were found through NZ government databases (e.g., www.knowledge-basket.co.nz) and ministerial websites (e.g., www.mfe.govt.nz).

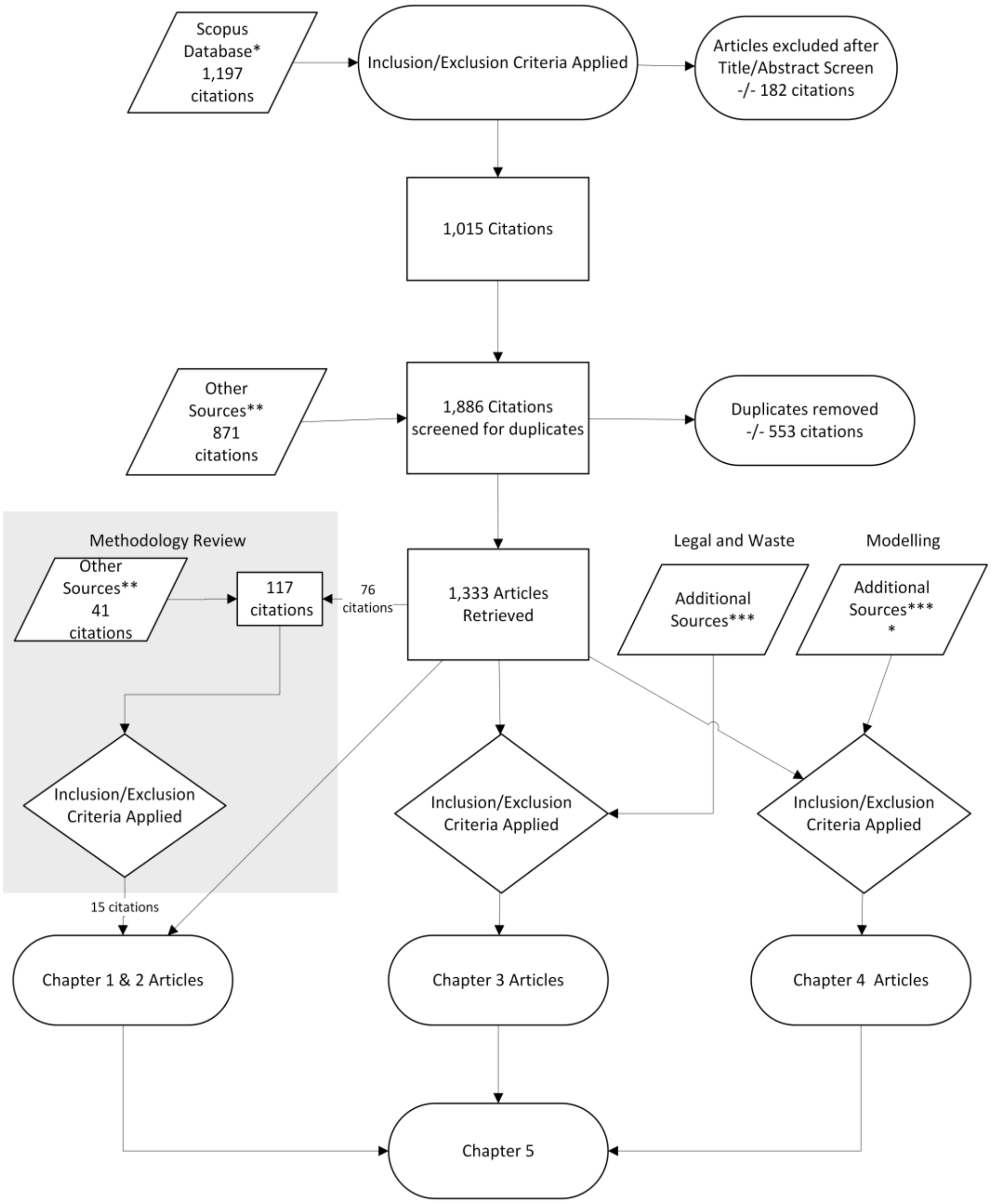
Gaps in research and the understanding of the field of AMD (research question 7) followed from the process as described above. Authors have (repeatedly) identified and recommended specific gaps for follow-up research. Other gaps, particularly those on the relationship between AMD and waste management factors, were determined after reviewing the information relating to the research questions described above.

1.3 Results

The search process for relevant AMD publications led to 1,197 citations for the period from 1998 through 2017. After checking for relevance, 1,015 publications remained. Snowballing and searches in the grey literature added a further 871 articles, which resulted in 1,333 unique publications after screening for duplicates (Figure 1.2). Until 2008, less than 20 articles a year described research relating to AMD. From 2009 on, a steady increase in publications is noted, with a sharp rise as of 2013 (Figure 1.3).

Figure 1.2

PRISMA Flow Describing Results from Anthropogenic Marine Debris Literature Search in Scopus Database (1998 - 2017)



* Search terms: published journal articles in English, between 1998 and 2017 including keywords marine/ocean/coastal/pelagic AND debris/litter/trash/rubbish/pollution AND plastic combined with Boolean operators

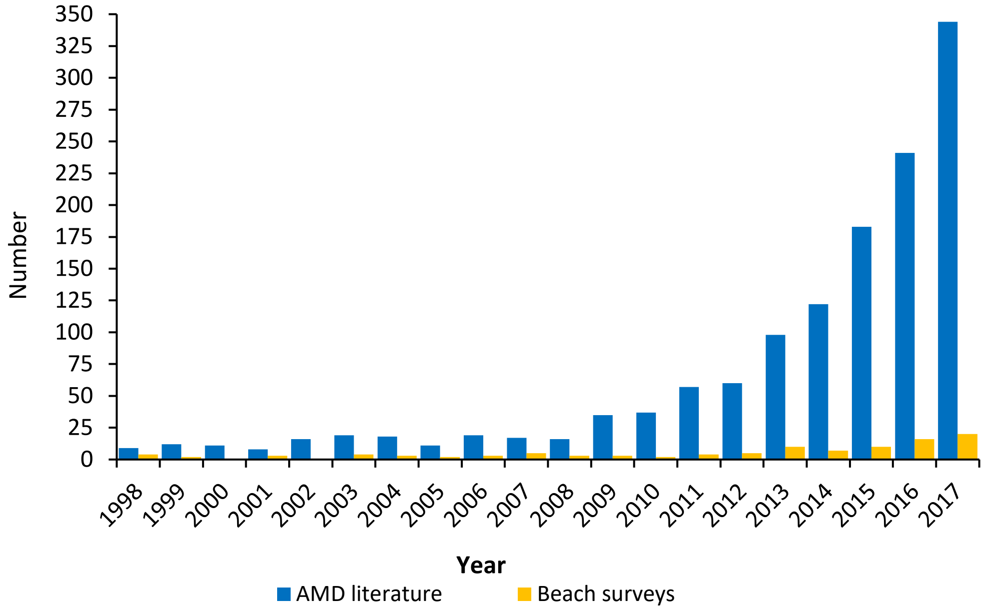
** Other sources: through references found in original papers or from other search engines (Google Scholar, Web of Science and Researchgate)

*** Articles including keywords: waste; rubbish, garbage, MSW, recycling, land based, landfill, collection

**** Articles on predictive modelling of count data

Figure 1.3

Number of Global Anthropogenic Marine Debris and Beach Survey Publications by Year (Scopus Database Search, 1998 - 2017)



The primary beach survey review included 117 AMD beach surveys in 50 countries. Of these, 75% sampled 20 beaches or fewer and addressed mainly local issues. The remaining 25% of studies focussed on a multi-regional (within a country) (n = 17), national (n = 11), or international (n = 2) coverage. Similar to the general AMD literature, beach surveys have seen increasing publication rates (Figure 1.3). Overall, 63% (n = 74) of all AMD beach surveys were accumulation studies, where the same (section of) beach was sampled multiple times (with varying intervals). The other 37% (n = 43) of the studies assessed the standing crop, where the results of a one-time measurement are calculated and compared.

The geographical distribution of published AMD articles is shown in Table 1.2. When the initial search was further refined with "New Zealand" as geography, ten publications (1999 - 2017) remained (Table 1.2). Thus, in contrast to the vast and growing body of international literature, NZ has produced very few

AMD related publications, despite being one of the first countries to initially report on this topic (e.g., Gregory, 1977, 1978).

Table 1.2

Anthropogenic Marine Debris Publications per Country as Retrieved from Scopus Database Search (1998 - 2017)

Country	No. of publications	Proportion (rounded)
United States [a]	205	20%
United Kingdom [a]	143	14%
Australia [a]	92	9%
Brazil [a]	87	9%
Other 45 countries combined (<9% and minus New Zealand)	478	47%
New Zealand [a]	10	<1%
Total	**1,105**	**100%**

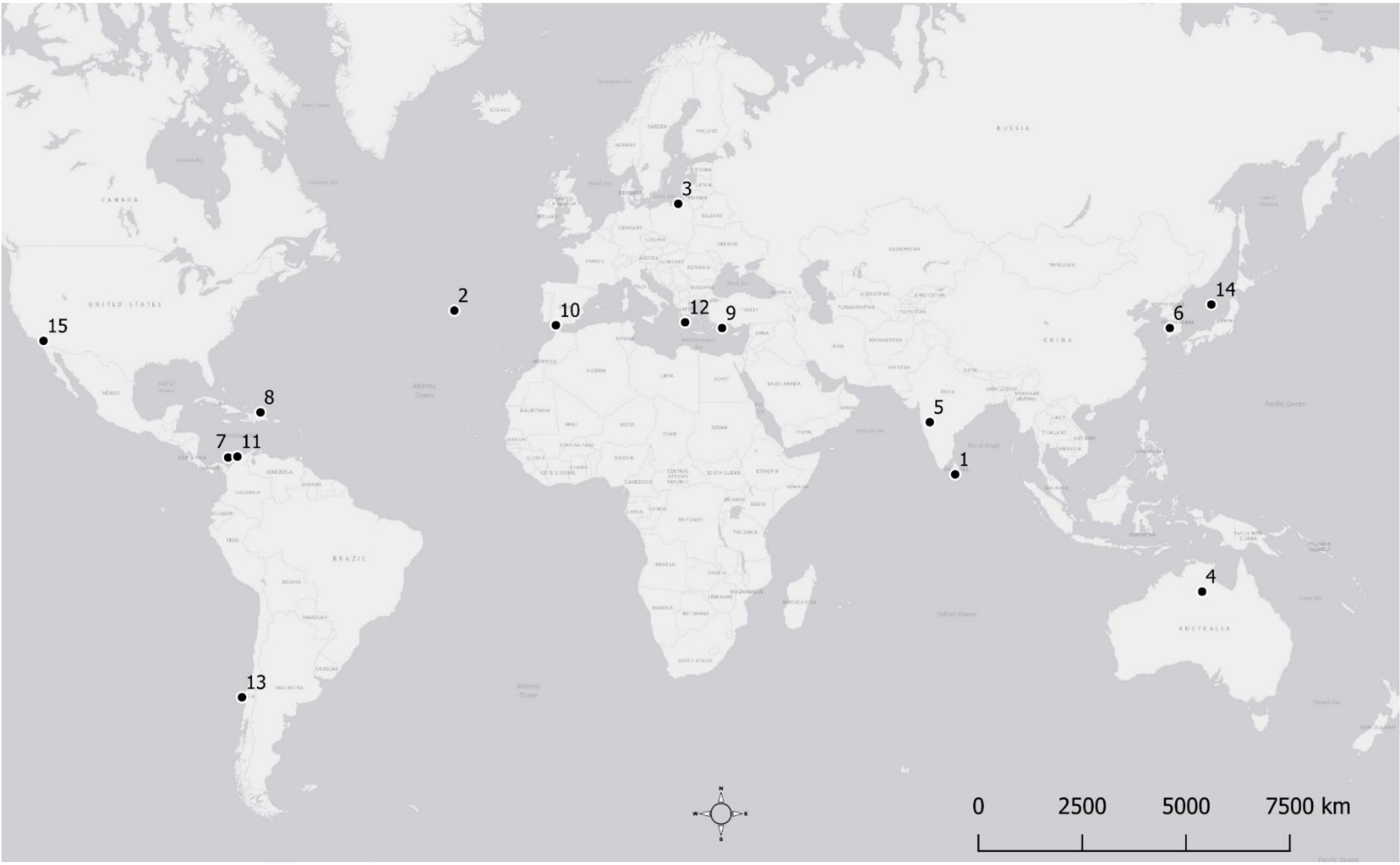
Note. [a] Indicates OECD country at time of review.

1.3.1 Beach Survey Methodology Review

A review of larger-scale (sampling 13 beaches or more) survey studies included 15 publications. Geographical details of the studies included in this secondary review are shown in Figure 1.4. Of the 15 studies, only two occurred in the Southern Hemisphere, i.e., in Chile and Australia (Figure 1.4). Table 1.3 summarizes details on number of beaches included, the coverage area, and results.

Figure 1.4

Locations Standing Crop Beach Studies Reviewed (1998 - 2018), Retrieved from Scopus Database



*Note***.** 1) Sri Lanka; 2) Azores; (Portugal) 3) Russia; 4) Australia; 5) India; 6) Korea; 7) Colombia; 8) Caribbean Islands; 9) Turkey; 10) Spain; 11) Colombia; 12) Greece; 13) Chile; 14) Japan and Russia; and 15) USA.

Table 1.3

Standing Crop Studies Researching ≥ 13 Beaches Included in Methodology Review, Retrieved from Scopus Database

Study	Beaches	Location	Coverage	Results	Reference(s)
1	22	Sri Lanka	National	Island-wide survey of composition and abundance of debris on beaches.	Jang et al., (2018)
2	42	Azores (Portugal) [a]	Multi-regional	Baseline information on spatio-temporal variability of macro-litter (> 20 mm) on beaches of 9 islands.	Ríos et al., (2018)
3	13	Russia	Region	Plastic pollution on the Baltic beaches of the Kaliningrad region.	Esiukova (2017)
4	175	Australia [a]	National	Estimating nationwide quantities and sources of debris.	Hardesty et al., (2017)
5	254	India	National	A preliminary account on debris quantities, origination, and composition.	Kaladharan et al., (2017)
6	20	Korea	Multi-regional	Characteristics of meso-sized (5 - 25 mm) plastic debris.	Jongsu Lee et al., (2017)
7	26	Colombia	Region	Magnitude, source, and management of beach litter along the Atlantic and Caribbean coasts.	Rangel-Buitrago et al., (2017)
8	24	Caribbean islands	International	Geophysical features influencing the accumulation of beach debris.	Schmuck et al., (2017)
9	13	Turkey [a]	Region	Baseline study identifying abundance, sources, and the influence of land use on coastal litter in the Cilician Basin.	Aydın et al., (2016)
10	20	Spain [a]	Region	Distribution of beach litter and beach cleaning effects along the coastline of a tourist environment.	Williams, Randerson et al. (2016)

Study	Beaches	Location	Coverage	Results	Reference(s)
11	35	Colombia	Multi-regional	Litter impacts on scenery and tourism on the north Caribbean coast.	Williams, Rangel-Buitrago et al. (2016)
12	80	Greece [a]	National	Litter composition and source contribution for beaches in the eastern Mediterranean, a nationwide voluntary clean-up campaign.	Kordella et al., (2013)
13	43	Chile [a]	National	Anthropogenic debris on beaches in the SE Pacific from a survey supported by ~ 1,500 high-school students.	Bravo et al. (2009)
14	26	Japan [a] and Russia	International	International survey on the distribution of stranded and buried litter on beaches.	Kusui & Noda (2003)
15	43	USA [a]	Region	Composition and distribution of beach debris in Orange County, California	S.L. Moore et al. (2001)

Note. [a] Indicates OECD country at time of review.

1.4 Discussion

A comprehensive literature research has been performed as a foundation for addressing the questions relating to the specifics of AMD at a global and national scale. The review included a (primary and secondary) methodology summary of beach surveys. An overview of existing research describes the problem, impacts, sources, management, and sampling methods. It concludes with the definition of certain gaps in existing AMD knowledge and research, which form the basis of this project as described in the subsequent chapters.

1.4.1 Why is AMD a Problem?

In general, most AMD impacts are described through one particular lens (i.e., biology, chemistry, economy, or social sciences) (Derraik, 2002). However, effects are often interlinked and cumulative, including impacts on wildlife, biosecurity, humans, food security and the economy. Once in the marine and coastal environment, AMD can move between ecosystems (for example, from the seafloor to the beach and vice versa) and can continue to cause synergistic and cumulative harm in several ways (Alimi et al., 2018; Browne, Underwood, et al., 2015). Alternatively, within an ecosystem, the impacts can cascade by affecting multiple species within that community (Galloway et al., 2017).

1.4.1.1 Marine Wildlife Impacts

As of August 2019, there are reportedly 2,249 species impacted by AMD (Tekman et al., 2019). Larger AMD (> 5 mm) is cited as leading to entanglement and strangulation (Boren et al., 2006; Coe & Rogers, 1997; Gregory, 2009; Hanni & Pyle, 2000; Page et al., 2004; Waluda & Staniland, 2013), or as stomach contents of animals such as whales and jumbo squid (Fernández et al., 2009;

Fukuoka et al., 2016). Smaller AMD (< 5 mm) is found in the nests or stomachs of seabirds, turtles and fish (Avery-Gomm et al., 2012; Buxton et al., 2013; Fukuoka et al., 2016; Godoy & Stockin, 2018; Markic et al., 2018; Plot & Georges, 2010; Roman et al., 2019; Verlis et al., 2014). The consumption of plastic debris creates blockages and can stunt or terminate the growth of seabird chicks (Bond et al., 2010; Cousin et al., 2015; Derraik, 2002; Hyrenbach et al., 2017). Projections estimate that 99% of all seabirds in the Tasman Sea will have ingested plastic debris by 2050 (Wilcox et al., 2015).

Microplastics can also act as a vector and sorb and accumulate other pollutants present in the aquatic environment, such as polycyclic aromatic hydrocarbons and polychlorinated biphenyls, also known as “POPs” (persistent organic pollutants) (Koelmans et al., 2013; Van Cauwenberghe et al., 2015). Such chemical pollutants can originate from the plastics manufacturing process or other sources such as fire retardants and can have a range of harmful effects (Guzzetti et al., 2018). Due to their small size, marine organisms ingest microplastic particles, possibly resulting in these pollutants entering the food chain (Andrady, 2011; Cole et al., 2011; Guzzetti et al., 2018, 2018; Setälä et al., 2014). When higher trophic organisms consume lower ones, the pollutants can bioaccumulate through the food web (Rummel et al., 2016; Watts et al., 2014). The ingestion of small plastic debris and the trophic transfer of sorbed pollutants on these microplastics can accumulate and affect endocrine functions (Franco-Trecu et al., 2017; Kershaw & Rochman, 2015; Vegter et al., 2014).

1.4.1.2 Other Ecosystem Impacts

Fauna and flora, including coral and seagrass, can be smothered or otherwise negatively impacted by the presence of AMD (Akoumianaki et al., 2008; Allen et al., 2017; Balestri et al., 2017; Gregory, 2009; Hall et al., 2015; Richards & Beger, 2011). At a molecular level, AMD affects phytoplankton and zooplankton, possibly reducing their ability to sequester carbon (Bhattacharya et al., 2010; Mao et al., 2018; Shen et al., 2020). Furthermore, AMD can pose a biosecurity threat when it facilitates the transport and introduction of species (Campbell et al., 2017; Gall & Thompson, 2015; Murray R Gregory, 1991). The resilience and lightweight properties of plastic AMD enable organisms that cannot otherwise travel (longer) distances to expand beyond their native range (Campbell et al., 2017; Carlton et al., 2017; Murray R Gregory, 2009). This transport mechanism applies at a local scale where aquaculture debris transports introduced species from marine-based facilities to nearby beaches, such as *Sabella spallanzanaii* in NZ (Campbell et al., 2017), or moves a variety of introduced species in European waters (Rech et al., 2018). At a larger spatial scale, tsunami debris from Japan washed up on the west coast of the United States with a count of at least 289 living Japanese coastal marine species (Carlton et al., 2017; Murray et al., 2018; West et al., 2016). Thus, tsunamis debris can act as a transport mechanism that covers large distances.

1.4.1.3 Human Impacts

The presence of AMD can adversely affect human physical and mental health (Campbell et al., 2016, 2019; Keswani et al., 2016; McKinnon et al., 2016; Wyles et al., 2015). Physical harm sustained on beaches by humans (and their pets) due to AMD is an understudied field, but Campbell et al. (2016) found that more than 20% of beachgoers in Tasmania were injured by beach litter. In NZ, insurance claims resulting from injuries on the beach increased significantly between 2007 and 2016 (Campbell et al., 2019), and demonstrated that AMD is a persistent threat to beachgoers, particularly children. The seemingly more subtle mental impacts of AMD can have a long-lasting effect on a person's well-being (Appleby et al., 2016; White et al., 2016; Wyles et al., 2015). An altered state of mind due to AMD also influences choices to visit a particular beach or any beach at all (Ballance et al., 2000; Corraini et al., 2018; Hartley et al., 2018; Jang et al., 2014; Krelling et al., 2017; K. Smith et al., 1997), depriving individuals of the salutogenic effects of the coastal environment (White et al., 2016).

1.4.1.4 Economic Impacts

A pristine beach is often cited as one of the most desirable vacation spots for tourists. Yet, polluted beaches are disliked and avoided (Ballance et al., 2000; Corraini et al., 2018). Reduced visits have a direct economic effect on the businesses surrounding these beaches (Ballance et al., 2000; McIlgorm et al., 2011; Newman et al., 2015). In South Korea, revenue loss due to highly polluted beaches was calculated between US$29 - 37 million (Jang et al., 2014). Other examples of economic impacts include damage to ships from AMD, and the impediment of safe navigation and vessel loss (Cho, 2005; Williams & Tudor, 2001a). The fishing industry is paradoxically both a cause of debris and a casualty of the consequences (Richardson et al., 2017). Fishing gear that becomes tangled or lost due to debris may compromise the catch and become future debris (e.g., ghost fishing). Similarly, aquaculture exacerbates (contributes to debris generation) AMD (Astudillo et al., 2009; Campbell et al., 2017) and suffers from its consequences, as the spread of introduced species on aquaculture generated debris creates a threat to aquaculture farming (Cho, 2005).

Direct costs for beach clean-up efforts are significant and are typically paid for by local authorities. Yet such clean-ups usually only address a minimal part of the problem. Most mechanical cleaning misses the most abundant AMD types (e.g., small, fragmented plastic debris and cigarette butts) (Williams, Randerson, et al., 2016; Zielinski et al., 2019). Shoreline clean-up costs can range from NZ$150 to more than NZ$30,500 per tonne, depending on the type of debris and method of removal (McIlgorm et al., 2011). The UK spends an annual NZ$19.7 million on cleaning their beaches, and The Netherlands and Belgium each spend similar amounts on beach cleaning (NZ$17.8 million) despite their much shorter coastlines (Mouat et al., 2010). Some ports and other organisations deploy (semi) automated clean-up machines for larger AMD (Miller, 2012; Newman et al., 2015).

The compounded negative impacts of AMD on ecosystem services are estimated at (~NZ$5,116 – NZ$51,116) per tonne of marine plastic per year (Beaumont et al., 2019). These total estimated costs include the social costs of greenhouse gas emissions which are considered to be ~NZ$3.4 trillion a year (Beaumont et al., 2019; Forrest et al., 2019). Ecosystem services included in these calculations are provisions for fisheries and aquaculture, heritage (such as the connection with charismatic marine mammals) and experiential recreation (Beaumont et al., 2019). Other notable ecosystem effects not included in these calculations include the AMD’s ability to alter the ecology and shift biodiversity; particularly when the AMD stressor acts in conjunction with other threats such as other pollutants, climate change effects and overexploitation (Galloway et al., 2017).

1.4.2 What are the Sources, Pathways and Sinks of AMD?

AMD originates either from the sea or from land (Derraik, 2002). The most commonly found types of debris (plastic, glass, metal and paper) might come from different locations and travel differently through the ecosystems. Sea-sourced AMD comes from activities such as illegal dumping or littering at sea, fishing, boat cleaning, aquaculture, maritime shipping, oil and gas exploration, natural disasters, items blowing off boats, or through discarded waste (Coe & Rogers 1997; Derraik 2002). An often-described source for ocean-based marine debris is abandoned, lost and discarded fishing gear (n = 274 citations). Considerable attention has been dedicated to this topic, as mismanaged fishing gear is not only a persistently found type of debris, its existence in the oceans can also continue to injure and kill wildlife (Page et al., 2004). The gear often clusters together and acts as "ghost nets", causing ongoing entanglement, starvation, laceration and death, while being a navigational hazard for ships (Hong et al., 2017; Reinert et al., 2017). Indeed, estimates suggest that at least 34% - 48% of all debris found in the ocean is from fishing-related sources (Lebreton et al., 2018; Pham et al., 2014).

Land-sourced AMD originates from mismanaged waste (which includes litter) and industrial outfall (Andrades et al., 2016; Barnes et al., 2009; Geyer et al., 2017; Jambeck et al., 2015; Sheavly & Register, 2007). Often, beachgoers leave litter behind, which ultimately will find its way into the ocean (Pruter, 1987; Santos et al., 2005; S. P. Wilson & Verlis, 2017). Terrestrial sources of waste loss can enter through storm drains, lakes, or waterways and wash, or blow into the marine environment (Lebreton et al., 2017; McCormick & Hoellein, 2016). Microplastics, like tyre and brake dust, as well as fibres, can also enter the marine environment through atmospheric transport, rain or wastewater (Boucher & Friot, 2017; Brahney et al., 2020).

As mentioned in the introduction of this Chapter, all of the ocean's surface waters, coastlines and seabeds contain AMD. Debris quantities are also found in the water, ice and snow of the poles (Barnes et al., 2010; Lusher et al., 2015; Tekman et al., 2017), on the seabed (Pham et al., 2014) and in the deepest trenches of the oceans (Peng et al., 2019). Debris is detected on remote and uninhabited islands (Bouwman et al., 2016; Gregory, 1999a, 1999b; Lavers & Bond, 2017; Perez-Venegas et al., 2017; Rangel-Buitrago et al., 2019) and floats on the water surface in accumulation zones (gyres) (Eriksen, Maximenko, et al., 2013).

In the coastal environment, floating and beached AMD appear to have a reciprocal relationship, meaning that there is a correlation between AMD in the water and on the beach (Thiel et al., 2013). However, global patterns of currents and prevailing winds can eventually also deposit AMD far from where it entered the ocean (Cozar et al., 2014; Eriksen, Maximenko, et al., 2013). Once the AMD is waterborne, it can become positively or negatively buoyant due to biofouling, biomagnification and ingestion or excretion by, for example, fish (Thompson et al., 2004). This, and processes such as turbulent mixing, down- and upwelling can cause the AMD to fluctuate vertically through the water column (Bagaev et al., 2017), resulting in a complex mix of pathways and sinks.

1.4.2.1 Increasing Plastic Production

The introduction and intensification of plastic production and consumption over the past 100 years, has directly increased AMD (Derraik, 2002; Jambeck et al., 2015; Kershaw et al., 2011). Global plastic production has grown from 15 million tonnes in 1964 to 359 million tonnes in 2018 (Geyer et al., 2017; PlasticsEurope, 2019), with an expected doubling of production over the following 20 years (Geyer et al., 2017; Kaza et al., 2018; OECD, 2018). Most of this plastic is for (single use) packaging (PlasticsEurope, 2018; World Economic Forum & Ellen MacArthur Foundation, 2017). An estimated 60 - 80% of all AMD consists of plastic debris, ranging in size from nanofibers to large ghost nets (Derraik, 2002; Eriksen, Maximenko, et al., 2013). The persistent nature of plastic will continue to increase and accumulate polymers in the natural environment. Over time, plastic debris breaks up into smaller and smaller particles, due to photodegradation and abrasion (under certain circumstances), but it does not break down (decompose) (Andrady, 1994; Thompson et al., 2004). The degradation of plastic debris into smaller particles is thought to mainly occur closer to coastlines (as compared to the open ocean) due to the combined energy from waves and exposure to warmer temperatures and sunlight on the coast (Song et al., 2017).

1.4.2.2 Terrestrial Waste Loss as AMD Inputs

Worldwide, in 2025, 100 - 250 million metric tons of mismanaged waste is expected to be released into the marine environment (Jambeck et al., 2015). Here, mismanaged waste includes (street) litter, and items misplaced or lost before, during or after waste collection, as well as items leaking from landfills (Barnes et al., 2009). Areas with high winds and those landfills in proximity to rivers or the coast (such as those in NZ) are prone to more waste loss into the marine environment than countries that have less coastline or cities further from the coast (Barnes et al., 2009).

1.4.3 How is AMD Managed?

Many international or multinational organisations, such as the European Commission, the G20 Summit, the East Asia Summit and the Association of Southeast Asian Nations, the Asia Pacific Economic Cooperation and the World Economic Forum, aim to address aspects of AMD pollution. Specific organisations to which NZ has links, other than those described in section 1.1, include:

- The Commonwealth Clean Oceans Alliance (https://bluecharter.thecommonwealth.org/), a Commonwealth Blue Charter action group, of which NZ is a member and is led by the UK and Vanuatu to address plastic pollution.
- The New Plastics Economy Global Commitment, which the Ellen MacArthur Foundation leads in collaboration with the UNEP, this commitment brings together governments, businesses and NGOs to address causes of plastic waste and pollution. Two of the subsequent declarations that NZ is a signatory to are:
  - The New Zealand Plastic Packaging Declaration, where signatories commit to using 100% reusable, recyclable or compostable packaging in their NZ operations by 2025 (New Zealand Government, 2018a).
  - ANZAC Plastics Pact with Australia, New Zealand and the Pacific Islands nations (https://www.ellenmacarthurfoundation.org/news/regional-plastics-pact-for-australia-new-zealand-and-the-pacific-island-nations).
- The Global Ghost Gear Initiative (https://www.ghostgear.org/), NZ is a member of this global and cross-sectoral organisation to address the problem of lost, abandoned and discarded fishing gear.

- UNEP’s Global Partnership of Marine Litter (GPML, https://www.gpmarinelitter.org/) coordinates all stakeholders working on marine debris management and prevention which is hosted through SPREP for the Pacific area.

The general reactive management of marine debris includes its removal and is typically performed by local government and volunteers (Kershaw et al., 2019). Prevention of AMD, as a form of more proactive management, can occur through banning certain items/activities and encouraging voluntary adjustments, all of which can be accompanied by economic disincentives (Blickley et al., 2016; Kuo & Huang, 2014; Schnurr et al., 2018).

To address the ongoing issue of AMD, cities, regions and countries across the globe are developing or have implemented policies that ban the use of specific products, such as plastic bags, microbeads and single-use plastics (Steensgaard et al., 2017; Wagner, 2017). Some of these actions combine the enactment of policies and legislation, voluntary campaigns, and industry-driven initiatives (Xanthos & Walker, 2017). The introduction of bans or taxes can have positive effects on the abundance of AMD (Axelsson & van Sebille, 2017; Schnurr et al., 2018). However, in some instances, the effect of these measures is temporary, or they fail to have the desired outcome (Martinho et al., 2017). For example, in Maui, Hawaii, a plastic bag ban reduced the number of bags found on the beach. Nevertheless, introducing a smoking ban did not lead to an expected decrease in smoking-related debris (Blickley et al., 2016). The latter suggests a lack of enforcement, which is also described as one of the reasons for Argentina’s failure in waste management mitigation efforts, where different layers of government lacked coordination and weak enforcement, resulting in mismanaged waste (González Carman et al., 2015).

In terms of general prevention of waste loss to the environment a broad range of measures, both mandatory and voluntary, have been introduced globally (Kato et al., 2019). Policies in nine global cities were compared and determined insufficient to prevent waste loss to the environment, especially during heavy rainfall (Axelsson & van Sebille, 2017). Lack of social motivation and engagement were listed as the most prominent limitation (Axelsson & van Sebille, 2017). In mainland Chile, citizens' willingness to engage in waste-reduction was not related to the levels of AMD on their local coast (Kiessling et al., 2017). However, on Easter Island (a Chilean island in the South Pacific), engagement to address AMD was high, likely due to the unique culture and connection to the natural environment and dependency on sustainable tourism income (Kiessling et al., 2017). In Taiwan, the effect of local waste management practices on marine litter was compared to those in the United States. They found that more local government involvement resulted in less debris on the beaches (Liu et al., 2013). However, another study in northern Taiwan found mostly land-based debris and recommended more robust enforcement of litter laws and additional policy addressing fishing gear and recyclable items (Kuo & Huang, 2014).

Overall, not one single legislation, measure, policy, or tool alone will make a difference to this complex problem. Nor is it assumed that a mix of efforts working in one location would necessarily apply to another place or situation (Coe & Rogers, 1997; Derraik, 2002; Gall & Thompson, 2015; Lau et al., 2020; Sheavly & Register, 2007; Vegter et al., 2014; Vince & Hardesty, 2017). Therefore, an in-depth understanding of the local, regional and national situation is essential to develop, deploy and assess AMD policies. The regulatory tools that NZ as a nation possesses and their effectiveness concerning AMD and waste management are discussed in Chapter 3.

1.4.4 How is AMD Detected?

Analytical methods of determining AMD, including sampling techniques, identification by type, and quantification, vary considerably (Velander & Mocogni, 1999). Techniques to measure AMD can range from microscopic identification to the application of webcams, drones and satellite imaging for the detection of macroscopic items (see Table 1.4 for a non-exhaustive list of examples). Dimensions (size) of AMD are usually classified as micro, meso and mega; but how these descriptions are interpreted in the metric system fluctuates (Hartmann et al., 2019). For example, the definition of microplastics (i.e., granules, fibres and fragments) can vary by order of magnitude ranging from < 0.15 mm to < 5 mm (Table 1.4). Larger debris (> microplastics) can be visually observed without instruments, although cameras and drones can be deployed to measure large areas. The measurement of microplastics in sediments, biota and water require explicit methods, techniques and equipment to determine abundance (Hidalgo-Ruz et al., 2012; Mai et al., 2018; Van Cauwenberghe et al., 2015).

Table 1.4

Examples of Anthropogenic Marine Debris Detection Techniques by Debris Size

Classification	Size	Environment	Technique used	Reference
Nano	< 1 µm	Seawater	Plunging glass bottle in water	Ter Halle et al. (2017)
Micro	< 5 mm	Beach sand	Visual detection	Clunies-Ross et al. (2016)
Micro	≤ 1 mm	Sediment	Van Veen grab	Claessens et al. (2011)
Micro	> 0.36 mm	Seawater	Neustonic net with manta trawl survey	C.J. Moore et al. (2002)
Micro	< 5 mm	Sea floor sediment	Underwater video-guided multiple corers	Bergmann et al. (2017)
Micro	0.15 cm -5 cm	Seawater	Manta trawl tow	Lebreton et al. (2018)
Meso	0.5 – 5 cm	Seawater	Manta and Mega trawl tow	Lebreton et al. (2018)
Macro	5 – 50 cm	Seawater	Manta and Mega trawl tow	Lebreton et al. (2018)
Mega	> 50 cm	Seawater	Mega trawl tow and aerial survey with camera	Lebreton et al. (2018)
Small	< 10 cm	Sea bottom	Towed underwater camera	Tekman et al. (2017)
Medium	10 – 50 cm	Sea bottom	Towed underwater camera	Tekman et al. (2017)
Large	> 50 cm	Sea bottom	Towed underwater camera	Tekman et al. (2017)
NA	2 – 30 cm	Beach sand	Visual detection	Pieper et al. (2015)
NA	> 5 cm	Rocky shores	Unmanned Aerial Vehicle	Fallati et al. (2019)
NA	> 5 cm	Seawater surface	Visual detection from ship	Ryan (2013)
NA	Not mentioned	Beach sand	Balloon assisted aerial camera	Nakashima et al. (2011)
NA	Not mentioned	Beach sand	Webcam	Kako et al. (2010)

1.4.4.1 Review of Beach Survey Protocols

The majority (80%) of the beach surveys reviewed aimed to identify abundance and type of AMD (primary goals). The goals of two studies differed from the rest, with one measuring management and tourism impacts and the other highlighting dissimilarities between beach cleaning management methods. Esiukova (2017) studied plastics on beaches in Russia, which included a microplastics (0.05 – 5 mm) component (Esiukova, 2017). Although microplastics (> 1 mm) only studies had been excluded from the original search, Esiukova also included larger plastics, of which the results have been included in the comparison.

Sampling protocols can be useful to harmonise methods (and therewith making results comparable). Protocols are typically applied where an overarching governing organization (in geographic or administrative areas) oversees the management and monitoring of marine debris data (e.g., the European Union). In other instances, studies utilise methods employed by previous studies to allow comparison at specific locations over time (Bravo et al., 2009; Williams et al., 2014), yet others developed their own protocols (e.g., Schuyler et al., 2018). The following international institutions have developed standardized sampling protocols:

- The United States' National Oceanic and Atmospheric Administration (NOAA) issued the *Marine Debris Shoreline Survey Field Guide* (Lippiatt et al., 2013; Ribic et al., 1992);
- The United Nation's Environment Program/International Oceanic Committee (UNEP/IOC) issued the *Guidelines on Survey and Monitoring of Marine Litter* (Cheshire et al., 2009);

- The Oslo/Paris Convention for the Protection of the Marine Environment of the North-East-Atlantic (OSPAR) issued the *Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area* (OSPAR Commission, 2010); and
- The European Commission et al. (2013) implemented the Marine Strategy Framework Directive" (MSFD) guidelines into the *Guidance on Monitoring of Marine Litter in European Seas*.

Only 6 of the 15 AMD studies reviewed applied a prior used sampling method, which included the MFSD guidelines (European Commission et al., 2013), OSPAR (OSPAR Commission, 2010) and Overton (Overton, 1987) (see Table 1.5). The type of sampling unit, as well as their placement on the beach vis-à-vis the waterline, varied from vertical (n = 3), to horizontal (n = 6). Measurements occurred with either belt (n = 6) or line (n = 3) transects (with varying widths and distances), or with quadrats (n = 5) (Table 1.5). About half of the studies (n = 8) replicated per beach, with the number of replicates varying between and, in some instances, within studies (e.g., Hardesty et al., 2017). Four studies did not always replicate their sampling per beach or were otherwise unclear in their description (Table 1.5).

Whilst most studies reviewed aimed to determine AMD abundance, the diversity in sampling methods resulted in a variety of outcome reporting units (Table 1.6). Namely, about half (n = 8) stated results in mean density, expressed per number of items m^{-2}. Others reported results by a count of items detected (n = 2), by mean weight (n = 1), in litter-grades "A, B and C" (n = 1), estimated total abundance (n = 1) or by proportion of mass (n = 1) (Table 1.6). Hence, due to these variations, detecting trends or making comparisons is complicated, if not impossible.

Table 1.5

Sampling Techniques Applied in Beach Studies Included in Methodology Review

Location	Protocol	Items measured	Technique [a]	Placement	Replication	Area (replicates)
Sri Lanka	Not mentioned	Manufactured or processed solid waste material	Quadrats (10 x 10 m)	Not mentioned	Yes	300 m^2 (3)
Azores [b]	OSPAR	Macro-litter items	Vertical transect	Systematically, waterline to vegetation	No	316 m^2-6,468 m^2
Russia	Not mentioned	Plastics, paraffin and amber	Horizontal transect	Wrackline (visually selected by most accumulation)	Yes	0.15 m^2, 2 cm of the top layer (2 - 7)
Australia [b]	Not mentioned	Detectable from head height	Vertical transect	Systematically, waterline, 2m into vegetation	Yes	2 x 1 m belt (3 - 6)
India	Not mentioned	Non-bio-degradable items	Quadrats (10 m x 10 m)	Systematically	Yes	300 m^2 (3)
Korea [b]	Not mentioned	Plastics	Quadrats (0.5 x 0. 5 m x 0.2 5 m)	Randomly at backshore, middle line, water line	Yes	30 m^2
Colombia	EA/NALG (2000), UNEP/IOC (2009)	Not mentioned, but including vegetation debris and organic	Horizontal line	Between low tide and backshore	No	100 m
Caribbean Islands	Not mentioned	Anthropogenic debris items	Horizontal transect	Along the high tide line	Unclear	200 – 400 m^2

Location	Protocol	Items measured	Technique [a]	Placement	Replication	Area (replicates)
Turkey [b]	MSFD	Artificial or processed material	Vertical transect	Waterline to vegetation	No	100 m
Spain [b]	EA/NALG (2000)	Not mentioned	Horizontal line	Systematically, between low tide and backshore	Yes	100 m
Colombia	EA/NALG (2000)	Not mentioned, included organic vegetation debris	Horizontal line	Systematically, between the highest high-water strandline and edge of the beach	Yes	100 m
Greece [b]	Not mentioned	All litter, including organic	Not mentioned	Not mentioned	No	Not mentioned
Chile [b]	Not mentioned	Anthropogenic debris items	Quadrats (3 m x 3 m)	Various stations	Mostly	72 m^2 (8)
Japan [b] and Russia	Not mentioned	Stranded and buried litter	Quadrats (10 m x 10 m)	Systematically, waterline to vegetation	Yes	200 – 1000 m^2 (2 – 10)
USA [b]	Overton (1987)	All “trash”	Horizontal transect	Randomly from waterline to vegetation	Unclear	22.9 m x width of the beach

Note. Abbreviations; OSPAR = Oslo/Paris Convention, Environment Agency, EA/NALG = National Aquatic Litter Group, UNEP/IOC = United Nations Environment Programme International Oceanic Commission, MSFD = Marine Strategy Framework Directive.
[a] Relevant to waterline. [b] OECD country at time of review.

Table 1.6

Reporting Units from Beach Studies Included in Methodology Review

Location	Density/Mass/Count	Metric	Proportion plastic	Reference
Sri Lanka	4.1 ± 9.2 items m^{-2}	Mean density	93%	Jang et al. (2018)
Azores [a]	0.62 ± 0.15 items m^{-2}	Mean density	87%	Ríos et al. (2018)
Russia	> 1% to 8.94% of dry sample	% of mass	100%	Esiukova (2017)
Australia [a]	0.15 items m^{-2}	Mean density	68%	Hardesty et al. (2017)
India	45.86 g m^{-2}	Mean weight	81% (excluding fishing line and Styrofoam)	Kaladharan et al. (2017)
Korea [a]	13.2 (± 28.7) items m^{-2}	Mean density	100%	Lee et al. (2017)
Colombia	2.9 items m^{-1}	Mean density	27% (vegetation included)	Rangel-Buitrago et al. (2017)
Caribbean Islands	6.34 ± 10.11 items m^{-2}	Mean density	90%	Schmuck et al. (2017)
Turkey [a]	0.92 ± 0.36 items m^{-2}	Mean density	> 73%	Aydın et al. (2016)
Spain [a]	2,277 items	Total count	63%	Williams, Randerson et al. (2016)
Colombia	Litter grades	Qualitative terms	Not mentioned	Williams, Rangel-Buitrago et al. (2016)
Greece [a]	110,423 items	Total count	43-51%	Kordella et al. (2013)
Chile [a]	1.8 items m^{-2}	Mean density	"Very common"	Bravo et al. (2009)
Japan [a] and Russia	3.41 (Japan), 0.02 (Russia) items m^{-2}	Mean number	80%	Kusui & Noda (2003)
USA [a]	106 million items	Estimated total abundance	99%	S.L. Moore et al. (2001)

Note. [a] OECD country at time of review.

1.4.5 What AMD Research Exists in New Zealand?

NZ was one of the first places on earth to report plastic pellet ingestion by storm-killed seabirds (*Pachyptila* spp.) found on beaches between 1958 and 1977 (Harper & Fowler, 1987). Likewise, Gregory (1977, 1978, 1991) and Hayward (1984, 1999) published early descriptions of AMD detected on NZ beaches. Despite these initial investigations and their international recognition (based on citations), very few NZ articles have ensued. Of those that did, one presented the results of research on subtidal debris originating from leisure boats at anchorages (Backhurst & Cole, 2000). Another publication became a seminal review paper on AMD (Derraik, 2002). Only decades after Gregory's initial beach research were microplastics researched on the Canterbury coast (Clunies-Ross et al., 2016). Campbell et al. (2017) published results of rafting of pests on debris found on Coromandel beaches, and human health impacts from AMD across all NZ beaches (Campbell et al., 2019) (Table 1.7). In 2020, the results of microplastics sampling around Auckland (NZ's most populated urban area on the NI) demonstrated high variability in AMD densities between sites and coasts, with open ocean beaches on the West Coast showing significantly higher densities (Bridson et al., 2020).

Table 1.7

Anthropogenic Marine Debris Research Published in New Zealand (1977 - 2020) Retrieved Through Scopus and Additional Sources

Year	Aim	Relevance to NZ	Reference
2020	Identify, quantify and characterise microplastics in the coastlines of New Zealand's largest city, Auckland	Large scale (39 sites) microplastics study around an urban area	Bridson et al. (2020)
2019	Examine the pattern of microplastic pollution in small streams spanning an urbanisation gradient expressed in human population density and percent of impervious surfaces in stream catchment	Small NZ streams have similar amounts of AMD as larger rivers	Dikareva (2019)
2019	Determine the extent of microplastic pollution in New Zealand's urban waterways	No regional variations in NZ in AMD in streams	Mora-Teddy & Matthaei (2019)
2019	Explore human health impacts associated with beach litter	Human injuries on NZ beaches based on insurance claims	Campbell et al. (2019)
2017	Determine the contribution of aquaculture derived debris as a secondary transport vector of non-indigenous marine species in coastal waters	AMD and invasive species on Coromandel beaches	Campbell et al. (2017)
2016	Quantify and characterise primary and secondary microplastic pollution	Microplastic research on South Island	Clunies-Ross et al. (2016)
2013	Compared the distribution of plastic fragments with the presence, local density, and occupancy of breeding burrows in order to test whether plastic was associated with seabird colonies.	Plastics in bird nests on offshore islands	Buxton et al. (2013)
2009	Determine the impact of plastic from facial cleansers on the marine environment	Microplastic research in water and on beach	Fendall & Sewell (2009)

Year	Aim	Relevance to NZ	Reference
2009	Review of problems associated with marine debris	Non-native species rafting on marine debris, multiple NZ coasts	Gregory (2009)
2006	Baseline information regarding levl of entanglement and entanglement-related mortality of *A. forsteri* in the Kaikoura region	Pinniped entanglement South Island	Boren et al. (2006)
2002	Review of plastic pollution impacts on the marine environment	Not NZ specific, but seminal AMD overview	Derraik (2002)
2000	Quantify subtidal litter and examine its persistence in a nearshore environment	North Island subtidal marine debris research	Backhurst and Cole (2000)
1999	Repeat survey of earlier work in Kawerua, North Island	23 years of beach litter detection on one beach	Hayward (1999)
1999	Determine marine debris prevalence of remote sites	Logs and cleanup efforts on Chatham and Stewart Island	Gregory (1999a)
1999	Review of marine debris issues in the South West Pacific	Call for regional AMD policy	Gregory (1999b)
1984	Recording and analyzing of 4 beach surveys	Washed up litter on one west coast beach	Hayward (1984)
1978	Results of microplastics sampling on 300 beaches	Distribution, characterization of microplastic pellets on NZ beaches	Gregory (1978)
1977	Determine plastic debris on NZ beaches	First recordings of microplastic pellets on NZ beaches and Pacific rim	Gregory (1977)

1.4.6 What are AMD Research Gaps?

Despite the global body of published articles relating to aspects of this topic, many knowledge gaps remain, both within and especially across disciplines (Bucci et al., 2020; Cigliano et al., 2016; Cvitanovic et al., 2015; Jahnke et al., 2017; Mendenhall, 2018; Rochman, 2016). Based upon the outcomes of this review, many areas are identified that need further study and explanation. These identified gaps include:

- Where do AMD sinks occur precisely? Where do specific types of debris reside in the water column and how fast or slow do various types of debris degrade? A known quantity of waste enters the marine environment (Jambeck et al., 2015). Ocean models predict where anthropogenic oceanic debris travels to (Eriksen et al., 2014; van Sebille et al., 2015). It is estimated that between 4.8 to 12.7 million metric tons of debris entered the seas in 2010 (Jambeck et al., 2015). However, only a small percentage of that total appears in oceanic (or beach) surveys (van Sebille et al., 2015);
- Microplastics occur in soil, rainwater, table salts, and drinking water; greater insight is needed as to how terrestrial and marine plastic pollution interact (Hoellein et al., 2014; Horton, Walton, et al., 2017). Substantial research has occurred on the presence of plastic debris in the marine, coastal and freshwater environments (Kershaw et al., 2011; Secretariat of the Convention on Biological Diversity, 2016; van Sebille et al., 2015), but plastic pollution on land remains understudied.
- What is the expected impact of climate change on AMD? As ocean temperatures rise, changes to the climate are expected (World Meteorological Organization, 2017). These will affect the current and wind patterns, which

can potentially redistribute plastic debris to other, or additional, locations (Beal & Elipot, 2016; Menezes et al., 2017). Arctic ice might act as a collection point for plastic debris (Lusher et al., 2015; Tekman et al., 2017). However, the rate at which melting ice will release these plastic sinks is unknown. With rising sea levels, buried rubbish (including those in closed landfills), currently submerged in beaches, or above the high tide line could be uncovered and enter the marine environment. Similarly, extreme weather conditions and catastrophic events, such as tsunami and flooding events, will also likely affect the levels, locations, and constitution of AMD entering our seas (Murray et al., 2018);

- Questions exist regarding the interaction of terrestrial mismanaged waste and AMD. For example, Jambeck et al.'s (2015) global model illustrates mechanisms (intentional or unintentional) of waste entering the ocean. In this model, AMD is linked to population density, the quality (or existence) of the national waste management system, and a country's economic status (Jambeck et al., 2015). The model potentially underestimates the NZ data, as it does not take into account the percentage of mismanaged waste produced by the population living further than 50 km from the coast (Jambeck et al., 2015). Additionally, the model assumes that NZ has an advanced waste management system, i.e., with modern, engineered (lined, drained and covered) landfills with environmental controls. However, this only applies to a small percentage of NZ landfills (Chapter 3).
- Very few publications address AMD matters at a national or multi-regional (multiple regions within a country) scale. In the United States, a 10-year accumulation study on 41 beaches on the Atlantic coast and 23 beaches on the Pacific coast and Hawaii, found complex geographical differences on both

coasts relating to population increases and fisheries (Ribic et al., 2010, 2012). In Israel, significant differences in the effects of a national clean beach policy were noted based on the quantities of AMD detected compared to other Mediterranean countries (Pasternak et al., 2017). In the United Kingdom (UK) studies have determined that regional variances in AMD composition and origin occur, possibly due to population density and proximity to rivers (Nelms et al., 2017). Lastly, in Australia, variations in AMD distribution were thought to result from population density and proximity to urban areas (Hardesty et al., 2017).

1.5 Thesis Structure

This chapter provided an overview of the literature focussed on AMD. In NZ, the status, composition, sources and pathways of AMD at both a regional and national scale remains relatively unknown. There is a dearth of peer-reviewed empirical research on waste management practices in NZ (addressed in Chapter 3). Thus, this research project aims to decrease information and awareness gaps pertaining to AMD and waste management in NZ. To achieve this objective, this thesis focussed on the relationship between and across NZ regions concerning AMD, specifically with reference to local waste management practices leading to waste loss to the environment. As such, this thesis will establish a national baseline of AMD amounts, types and sources, which will provide a reference for potential follow-up studies in multiple related fields (e.g., waste management, microplastic research, and oceanic modelling of debris fluxes and sinks). Additionally, the outcomes of this thesis can serve as input for coastal management and policy actions locally, by region and nationally. Lastly, the findings of this research will aid in developing a more comprehensive picture of AMD in the Southern Hemisphere and NZ’s oceanic AMD inputs.

The organization of the remainder of this thesis is as follows:

- In Chapter 2, an observational field study of NZ beaches will quantify the amount and type of AMD on 41 beaches across both North and South Islands (on a latitudinal scale);
- Chapter 3 examines the NZ waste management system. Based on a summary of the relevant law and literature, the waste management approaches of NZ localities will be methodically reviewed including strategic and regulatory instruments, collection methods and plastic recycling schemes;
- Based on the outcomes of Chapters 2 and 3, Chapter 4 will develop a predictive model to describe the associations of AMD debris counts on the beaches with location, environmental and waste management factors; and
- In Chapter 5, the main findings of the previous chapters will be synthesised, resulting in recommendations for mitigating actions and policy measures.

Declaration of the Contribution of Others

An article based on Chapter Two appeared in Frontiers in Environmental Science on 28 July 2021 (https://doi.org/10.3389/fenvs.2021.700415, see also Appendix A). Contributions of the co-authors were as follows: Marnie Campbell, Chad Hewitt and Ella van Gool designed the study, Marnie Campbell, Chad Hewitt and Ella van Gool analysed the data, Ella van Gool wrote the manuscript, Marnie Campbell, Pip Wallace, Chad Hewitt and Ella van Gool edited the manuscripts.

Chapter 2

A Snapshot in Time: A North to South Geography of Litter on New Zealand Beaches


Tape measure through the wrackline on a New Zealand beach. Photo: van Gool, E.D.

2.1 Introduction

Hayward (1984) likened beach litter to a modern version of midden, yet he reasoned that unlike with prehistoric middens, litter observations could now be checked against known trends in present society. This first New Zealand (NZ) publication describing macro debris on a remote west coast beach attributed variations in debris quantities and composition to changes in product consumption and packaging as well as to changes in fishing boat patterns (Hayward, 1984). In subsequent follow-up studies on the same beach, Hayward found that over 23 years, metal and glass item densities stayed stable. Yet, the proportion of plastic items significantly increased (Hayward, 1999), clearly indicating increased plastic usage and inadequate waste management.

To obtain a better understanding of the scope and current nature of the problem of anthropogenic marine debris (AMD), beach surveys are an often-applied tool. In addition to obtaining scientific data, beach surveys are performed by volunteers to raise public awareness, and for education and community outreach programs (Hidalgo-Ruz & Thiel, 2015). Studies conducted by scientists aim to obtain robust data or to measure the spatial or temporal distribution of pollution (Browne, Chapman, et al., 2015; Kershaw et al., 2019; Serra-Gonçalves et al., 2019; Velander & Mocogni, 1999), although many variations between studies exist (see section 1.4.4.1). Due to these different purposes and differences in the methodologies applied and the units of reporting (e.g., items m^{-2}, km^{-1}, litter grades, or discrete numbers); results are often not comparable. This makes evaluations and comparisons at a regional, national or global scale challenging.

Governments around the world are developing policies and laws to address the universal problem of AMD (Lau et al., 2020; UNEP, 2018; Vince & Hardesty, 2018). For example, in the European Union, the Marine Strategy Framework

Directive sets indicators and targets for litter reduction and requires its member states to implement relevant mitigation measures and monitoring systems (European Commission et al., 2013). At a country level, the Republic of Indonesia has implemented a national plan to reduce the litter in Indonesian waters by 70% in 2025 (with 2017 as a baseline) (Purba et al., 2019).

Although the problem of AMD is acknowledged and beginning to be addressed in NZ, many unknowns remain. As of 2019, monitoring of coastal AMD data occurs through a nationwide citizen science campaign orchestrated by the Ministry of the Environment and Statistics New Zealand, in cooperation with the non-governmental organization Sustainable Coastlines (https://litterintelligence.org/). However, prior to 2019, no national strategy existed, or monitoring occurred. As described in Chapter 1, recent scientific studies measured marine debris in the Coromandel Peninsula (NI) (Campbell et al., 2017) and microplastics from the coasts of the Canterbury region (SI) and around Auckland (NI) (Bridson et al., 2020). Beach data surveys in NZ preceding these studies are decades old. Together with the earlier mentioned Hayward (1984 & 1999) studies, microplastics were reported decades ago (Gregory, 1977). Since then, volunteers detected high concentrations of microplastics, especially near the more densely populated areas of Auckland and Wellington (both NI) (Smith & Tooker, 1990).

Currently, no nationwide research study of AMD exists that simultaneously covers the beaches of both the North and South Islands. Hence, it is difficult to determine the present status of AMD on the NZ coast, and to evaluate accurately the effects of any mitigation actions taken, or planned, to reduce waste loss to the marine environment. Understanding the actual AMD problem across both islands and creating management solutions based upon this realised data is an important gap to fill. Therefore, this chapter aims to further the understanding of the scale and composition of AMD loads at a local, regional and national level. A second aim is the development of a baseline against which future changes in AMD can be measured and the efficacy of mitigating actions assessed. The research questions supporting these goals are:

1) What is the distribution of AMD on NZ beaches by count, weight, type, source and group?
2) Are there significant differences in the results of the AMD distribution By island (North versus South)? and
3) How is AMD distributed at a regional management scale?

2.2 Materials and Methods

2.2.1 Sampling Design

The distribution of AMD, by count, weight, type and source (research question 1), was examined using empirical beach surveys applying transects. The resulting quantitative data provides a snapshot in time and as such is a standing stock survey. In recognition of the potential limitations of a one-time study (e.g., Ryan et al., 2014; Smith & Markic, 2013), an accumulation survey had initially been planned. However, the logistics of covering the distances between all sites across the two islands within the timeframe of a PhD proved unworkable. Hence, a standing stock approach was selected.

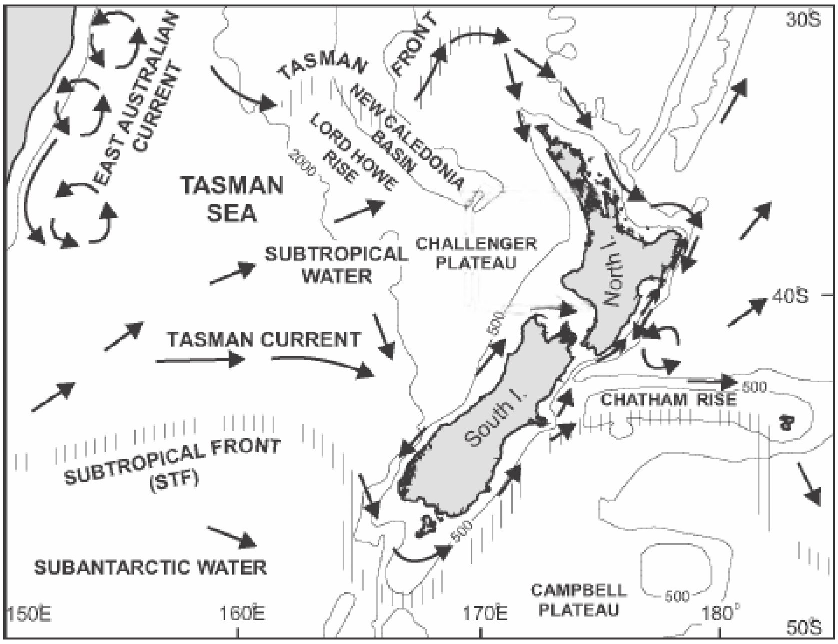
2.2.1.1 Study Area

The North Island (NI) has a southern current along the east coast that joins the northern current by the East Cape (Chiswell et al., 2015). The South Island (SI) features a northerly current along the east coast that bends off eastward near the

Chatham Rise (Figure 2.1). Between Gisborne (NI) and Otago (SI), waves usually arrive from the south and east (NIWA, 2017). The tides in NZ are semidiurnal, with two high and two low tides occurring over a 24-hr period.

Figure 2.1

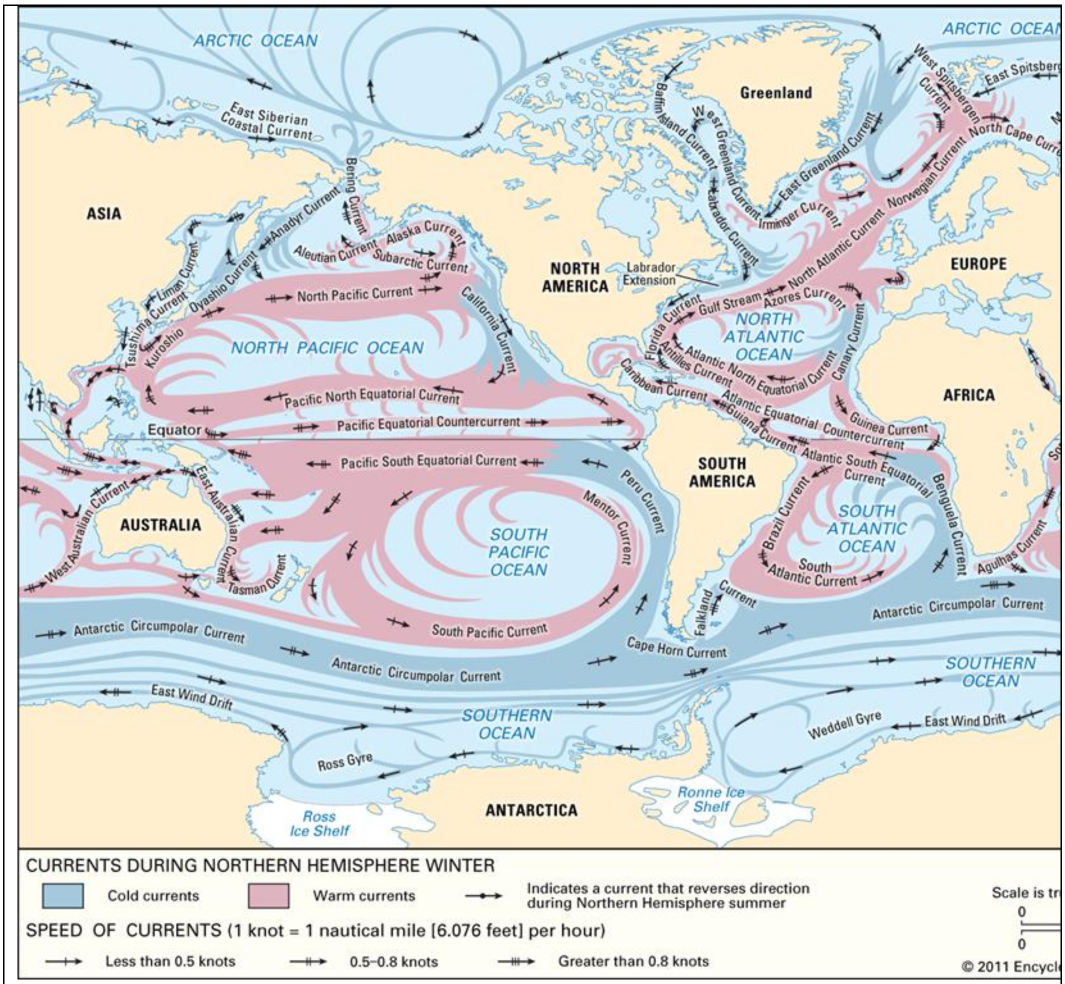
Surface Currents Around New Zealand (Adapted From Hayward et al., 2003)



How these coastal currents along both coasts are connected to the larger ocean currents is depicted in Figure 2.2

Figure 2.2

Ocean Currents (Cenedese et al., 2018)



Prevailing winds are from the west (Pickrill & Mitchell, 1979), with mountain ranges blocking and modifying this pattern over the eastern parts of the islands. The daily changing weather is a result of weather systems, the maritime position, and orography, resulting in predominantly westerly winds with average annual rainfall for NZ’s inhabited areas of 800 - 1,500 mm per annum (Tomlinson, 1992).

Study sites were located in 11 of NZ’s 16 regions (Table 2.1). Eight of these regions were on the NI and three on the SI (Figure 1.1). Thus, the sampling design is unbalanced. The random study design (east-facing beaches only, as described below) and regional structure of the SI (only three RAs on the east coast) made sampling in additional SI regions impossible. The study sites were distributed over 25 (of the 66) TAs including 14 TAs on the NI and 11 TAs on the SI (Table 2.1).

Table 2.1

New Zealand Study Locations (2017)

Site	Regional Authority	Territorial Authority	Latitude
		North Island	
1	Northland	Far North	-34.72
2	Northland	Far North	-35.03
3	Northland	Whangarei	-35.83
4	Auckland	Auckland	-36.24
5	Waikato	Thames-Coromandel	-36.71
6	Waikato	Thames-Coromandel	-37.08
7	Bay of Plenty	Western Bay of Plenty	-37.45
8	Bay of Plenty	Whakatane	-37.89
9	Gisborne	Gisborne	-38.02
10	Gisborne	Gisborne	-38.37
11	Gisborne	Gisborne	-38.68
12	Hawke's Bay	Wairoa	-39.02
13	Hawke's Bay	Hastings	-39.82
14	Hawke's Bay	Central Hawke's Bay	-40.17
15	Hawke's Bay	Central Hawke's Bay	-40.3
16	Manawatu-Wanganui	Tararua	-40.5
17	Manawatu-Wanganui	Tararua	-40.62
18	Wellington	Masterton	-40.87
19	Wellington	Masterton	-41.09
20	Wellington	Carterton	-41.24
21	Wellington	South Wairarapa	-41.51
		South Island	
22	Marlborough	Marlborough	-41.85
23	Marlborough	Marlborough	-41.91
24	Canterbury	Kaikoura	-42.13
25	Canterbury	Kaikoura	-42.3

Site	Regional Authority	Territorial Authority	Latitude
26	Canterbury	Hurunui	-42.64
27	Canterbury	Hurunui	-42.86
28	Canterbury	Hurunui	-43.24
29	Canterbury	Waimakariri	-43.38
30	Canterbury	Christchurch	-43.51
31	Canterbury	Ashburton	-44.13
32	Canterbury	Timaru	-44.42
33	Canterbury	Waimate	-44.51
34	Otago	Waitaki	-44.95
35	Otago	Waitaki	-45.21
36	Otago	Waitaki	-45.42
37	Otago	Dunedin	-45.64
38	Otago	Dunedin	-46.03
39	Otago	Clutha	-46.2
40	Otago	Clutha	-46.28
41	Otago	Clutha	-46.34

2.2.1.2 Beach Selection

Study sites were predetermined based on a stratified random sampling design. The sampling frame spanned the east coasts of both islands, starting at the top of the NI (34.4°S) to the bottom of the SI (46.5°S). These were stratified into 12 sections based on degrees of latitude. For each degree of latitude, three random numbers (without replacement) were generated to select a hundredth of degree location from where sample sites were determined. Google Earth (www.google.com/earth/) was used to determine sites as follows: from the randomly generated starting point, the coastline was followed southward (or to the right, facing the ocean) until the required ruleset of the beach was met.

The rule set was: (a) east facing (including northeast (NE), east (E), southeast (SE); (b) > 1 km in length; (c) open ocean; (d) away from (> 500 m) headlands, breakwater, a wharf, pier, or jetty; and (e) accessible from land through public roads.

The entry point to the beach was determined based on nearest access through public roads, as well as the presence of a straight (not concave or convex) segment of the beach. During fieldwork, two additional sites were added to the sampling plan (on the SI), and one site was removed due to access road restrictions. Therefore, in total 41 (20 on the NI and 21 on the SI) east (NE, E, SE) facing open ocean beaches were surveyed between latitudes 34.7°S and 46.3°S (covering a total of 11.6 degrees in latitude) (Figure 2.3).

Figure 2.3

New Zealand Beaches Sampled for Anthropogenic Marine Debris (> 2 mm) (2017)

2.2.1.3 Sampling Protocol

The standing crop of AMD was sampled during the austral spring (between 28th September and 3rd November 2017) to avoid localised effects of the busier (with tourists) austral summer and austral autumn seasons. The research protocol applied was a modified version based on the *UNEP/IOC Guidelines on Survey and Monitoring of Marine Litte*r (Cheshire et al., 2009).

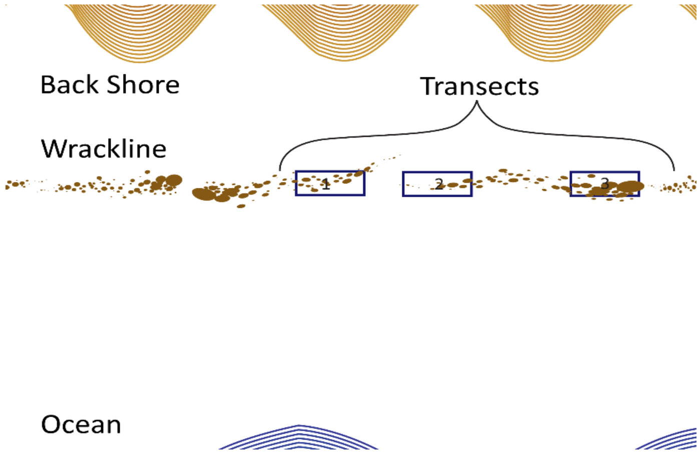
The wrackline (also called strandline) is a dynamic accumulation zone on the beach consisting of organic material (such as kelp, driftwood, seagrass, shells, deceased wildlife) as well as AMD (Corcoran et al., 2009; Ryan et al., 2009; Velander & Mocogni, 1999). The wrackline is usually visibly present on most beaches, independent of tides. Studies in England showed that less than 2% of all AMD is found in between the wrackline and the waterline (Williams et al., 2017; Williams & Tudor, 2001b). A nationwide survey in Chile showed similar results, with the majority of debris detected higher on the beach (Hidalgo-Ruz et al., 2018). As the goal of this study was to measure and characterise the magnitude, sources and composition of AMD, the wrackline was selected as the focal area where most anthropogenic marine debris was anticipated to occur. Thus, the highest visible wrackline was sampled using triplicate belt transects.

Upon arrival at the selected beach, a starting point was placed ~50 m (50 strides of ~1 m) to the left (when facing the ocean) of the access point. A random distance from the starting point between ~21 m and ~40 m (researcher [EvG] strides) determined the starting location of the first transect. Belt transects were 20 m^2 (10 m long by 2 m wide) and were arranged by placing a 10 m tape measure along the wrackline and examining one metre on each side of the tape.

Two further randomly generated numbers between 21 and 40 determined the distance in strides in between the next two transects (Figure 2.4).

Figure 2.4

Transect Placement for Anthropogenic Marine Debris (> 2 mm) Detection on Wrackline



When there was no visibly identifiable wrackline, the transect was placed along the highest noticeable high tide line. All visible (> 2 mm) AMD items present in the belt transect were collected, bagged, and labelled to identify transect and site. This visual survey did not include raking or disturbance of the top sediment. Large items (> 1 m) were counted and photographed *in situ*, but not collected or weighed. Visual interference from the substrate colour or type (sand, shells or pebbles) was minimized by observing the transects from multiple angles; thus, mitigating the possibility of obscured or camouflaged items being missed. After completing the examination of the transects, and before exiting the site, beach attributes as listed in Table 2.2 were recorded (for results, see Appendix B). To prevent inter-surveyor bias variances, the same researcher performed all measurements according to the same protocol.

Table 2.2

Variables Recorded During Sampling of Beaches in New Zealand (2017)

Variable	Responses	Comments
Gradient	1 = < 1 m, 2 = 1 - 2 m, 3 = 2 - 4 m, 4 = 4 - 8 m	Difference in elevation from waterline to transect
Substrate	Mud, sand, pebble, gravel	Type(s) in transect
Backshore type	Cliff, seawall, forest/tree (> 3 m), shrub (< 3 m), dune, grass- tussock, grass – pasture	
Beach shape	Concave, straight, convex	The shape of the beach where transects were placed.
Aspect	Northeast, East, Southeast	Compass direction when facing the water from transects
Wind speed	0 knots, 1 =– < 6 knots, 2 = 6 - 20 knots, 3 = 21 - 26 knots	
Wind direction	Onshore, offshore, side shore, side-onshore	
No. of people	0 - 24	
Rubbish bins	0 - 20	
No. of parking spaces	1 - 120	

Note. Adapted from the Marine Debris Shoreline Survey Guide (Lippiatt et al., 2013) and Handbook of Survey Methodology – Plastics Leakages (Schuyler et al., 2018).

2.2.1.4 Categorisation

The samples were processed in the field within 36 hours from sampling. Items from each transect were counted, grouped and weighed per a standardized litter classification system based on the type of material (plastic, foamed plastic, rubber, metal, glass and ceramic, cloth, paper and cardboard, wood, and other) (Cheshire et al., 2009). All items were counted individually; however, small and lightweight items were grouped by type to determine the mass (Figure 2.5).

Figure 2.5

Sample Processing of Small Debris During Fieldwork in 2017

For a better understanding of the (combined) origins of items, the following codes were applied to the most frequently found items: "mismanaged recyclables", "fishing", "food-related", "shotgun material", "smoking" and "undetermined" (Appendix C). Mismanaged recyclables (which includes litter) in this context is comprised of items that are typically recyclable in NZ, such as glass, metal and plastics.

Assessing an item for its source is subjective. Prior studies often classify the origination of AMD either from ocean-based or land-based sources (e.g., Coe & Rogers 1997; Sheavly & Register 2007). Other studies apply a probability matrix, assigning values to likely origin (Tudor & Williams, 2004; Verlis & Wilson, 2020; Whiting, 1998). Ocean-based AMD results from activities such as dumping at sea, boat cleaning, aquaculture, oil and gas exploration, natural disasters, items blowing off boats, or through discarded waste and fishing gear (Derraik, 2002). On the other hand, land-based sources for AMD include industrial outfall, deliberate or accidental littering, and items escaped from municipal waste collection and processing activities (Andrades et al., 2016; Sheavly & Register, 2007; Willis et al., 2017).

It is not always clear if waterborne items arriving on the beach came from freshwater systems or the ocean. Most debris are beyond recognition and could have come from either location. Items from land-based sources enter the marine environment through stormwater drains, lakes, waterways, or can be washed or blown out onto the beaches and into the ocean (Boucher & Friot, 2017; Lebreton et al., 2017; McCormick & Hoellein, 2016). These pathways delivering land-based items to the beach, particularly through waterways, can make it difficult to distinguish the source (land-based or ocean-based). Moreover, (recreational) fishing gear remnants can originate from vessels or upstream rivers and lakes or other beaches.

Therefore, in this study, the subjective distinction between origination is based on visual evidence of each item having been in water (whether the ocean or freshwater) and will hereafter be called "waterborne". Debris characteristics indicating a waterborne source included:

- A weathered appearance- porous look/feel, faded colours, bite marks, smoothened edges.
- Items from a foreign source typically not sold in NZ.
- The presence of biofouling, entanglement in other marine organisms.

In contrast, “land-based” items lacked a weathered appearance (pristine and intact) and lacked biofouling. If a decision on origin could not be determined, then the item was labelled “unknown”.

After processing the samples, all objects were repurposed, recycled or locally discarded in the proper receptacles.

2.2.2 Data Analysis

To address question 1): *What is the distribution of AMD on NZ beaches by count, weight, type, source and group?,* a robust and replicable sampling scheme was applied. The density of AMD items was calculated by dividing the total number of objects detected by the transect surface area, resulting in AMD items m^{-2}. Similarly, the mass of AMD items was determined by summing the total weight of items identified and dividing by total transect surface area (i.e., grams m^{-2}). The composition (type) of AMD item was described using standardised categories (Cheshire et al., 2009).

The second question: *Are there significant differences in the results of the AMD distribution by island (North versus South)?,* was calculated through mean AMD density and mass, and analysed with a Welch’s Test for Unequal Variances. Results are given in t Stat and P (T < = t). Significant differences in AMD composition, groups and sources between islands was determined through Pearson’s Chi-Square test of independence. The categories “other” and “paper and cardboard” were excluded from these tests due to low total count data (4 and 16 items respectively). Results are reported with (degrees of freedom and sample size) the Pearson chi-square value and the significance level.

The tests described above were used to test the following hypothesis:

- ***H1₀*** *= North Island's AMD density, mass, composition, group and source are the same as South Island's AMD density, mass, composition, group and source.*

The last research question: *How is AMD distributed at the regional management scale*?, was addressed by calculating the density and mass means per Regional Authority and reported in (*Means* ± *SE*). AMD composition was compared at a regional level by percentages of types by density. Sources were compared (by count) at a regional level. All resulting exploratory data is represented in graphs representing beach numbers from north to south (by increasing latitudes, with no overlapping longitudes). All statistical tests use an alpha level of .05.

2.3 Results

2.3.1 Baseline AMD Beach Data on Density, Mass, Composition and Source

Mean AMD density detected across 41 beaches on both islands ranged from 0 - 0.82 items m^{-2} per beach, with an overall mean of 0.16 (± 0.02) items m^{-2}. An overview of all AMD densities and mass per transect are provided in Appendix D. Across both islands, the highest AMD density was detected at Karitane Beach (site 37, SI) with 0.82 (± 0.02) items m^{-2}; more than five times the national mean. In contrast, three beaches (sites 6 [NI], 24 and 26 [SI]) had no items >2mm recorded (Figure 2.6). Mean mass of AMD items ranged from 0 – 83.38 g m^{-2} per beach, with an overall mean AMD mass of 9.17 (± 2.91) g m^{-2} per beach (see Figure 2.7).

Figure 2.6

Mean Anthropogenic Marine Debris (> 2 mm) Density (± SE) Across New Zealand Beaches in Spring 2017

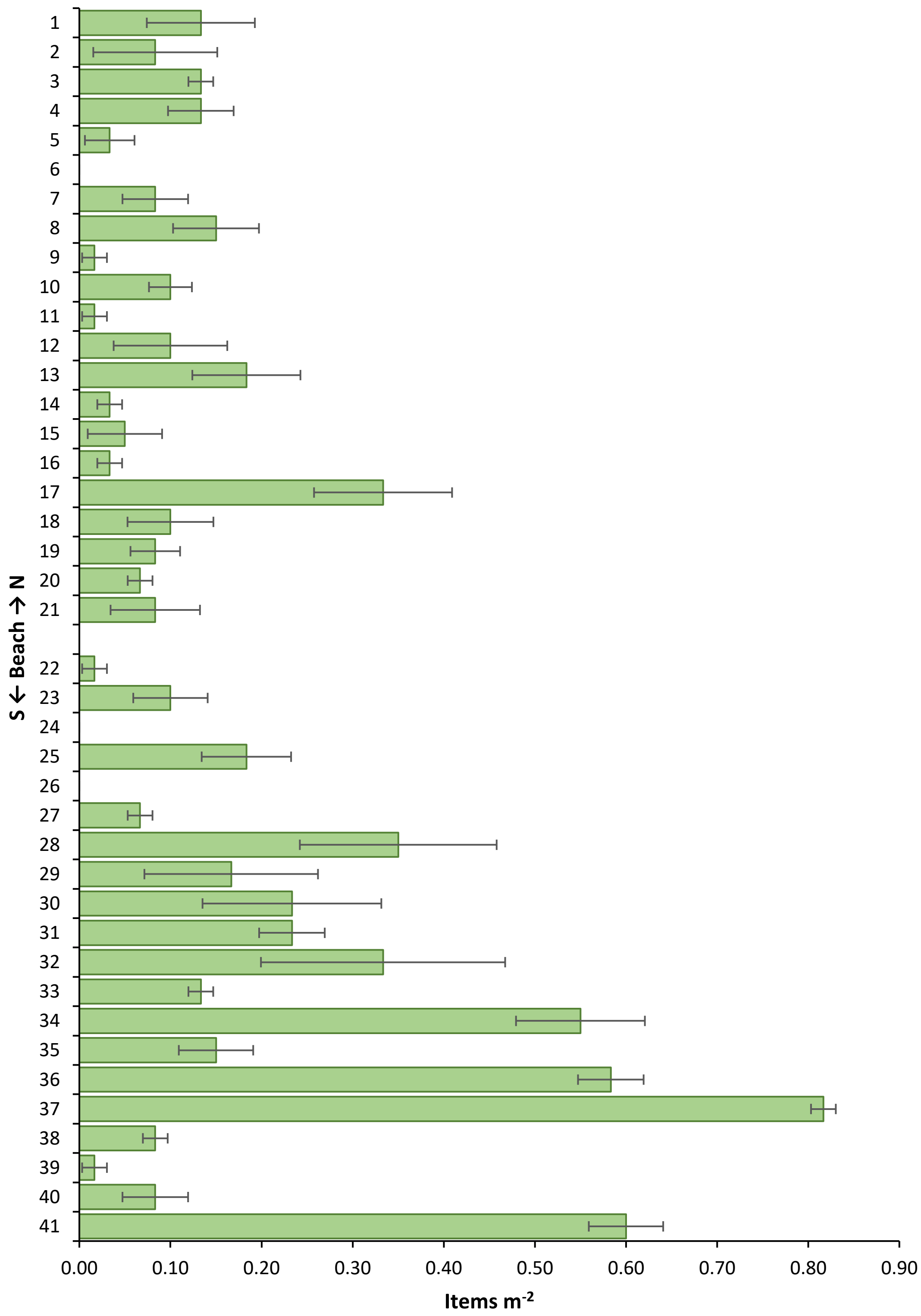
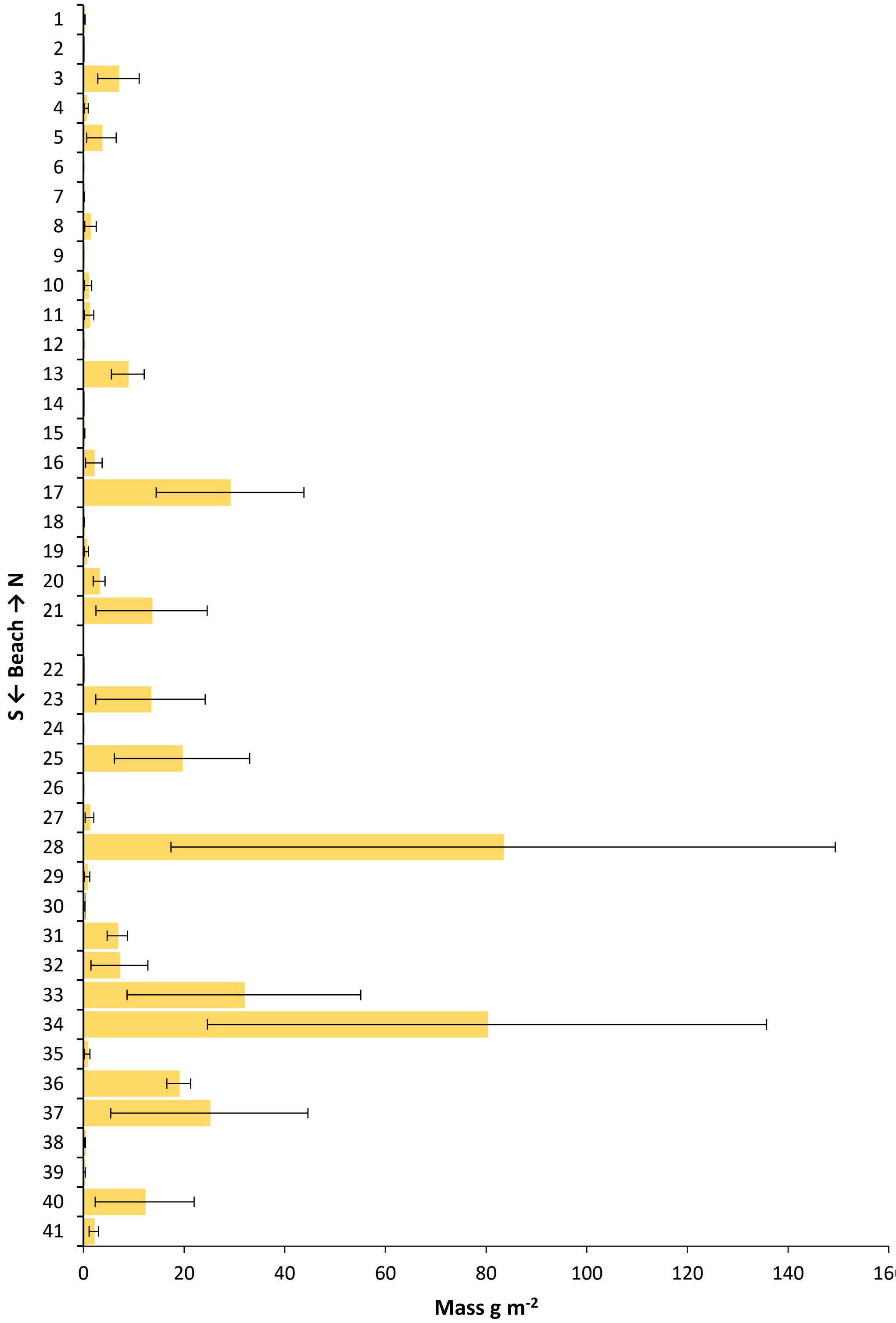


Figure 2.7

Mean Anthropogenic Marine Debris (> 2 mm) Mass (± SE) Across New Zealand Beaches in Spring 2017



The highest AMD mass was detected at Ashworths Beach (site 28, SI) with 83.38 (± 80.82) g m^{-2}, more than nine times the national mean. In contrast, six beaches (sites 2, 6, 14 [NI] and 22, 24, 26 [SI]), recorded no AMD mass > 0 gr, albeit three of those did show items, but their mass was < 0 gr.

By count, the most prevalent type of AMD was plastic (n = 261), followed by foamed plastic (n = 44), metal (n = 41), wood (n = 19), glass and ceramic (n = 9), cloth (n = 7), rubber (n = 6), other (n =2), and paper and cardboard (n = 1) (Figure 2.8). An overview of types of debris per transect is provided in Appendix E. By total mass, the highest AMD type was metal (6,739 g), wood (6,723 g), rubber (4,011 g) plastic (2,513 g), cloth (1,416 g), glass and ceramic (1,154 g), paper and cardboard (6 g), other (6 g), and foamed plastic (0 g) (Figure 2.9).

Figure 2.8

Anthropogenic Marine Debris (> 2 mm) Composition Count Across New Zealand Beaches in Spring 2017

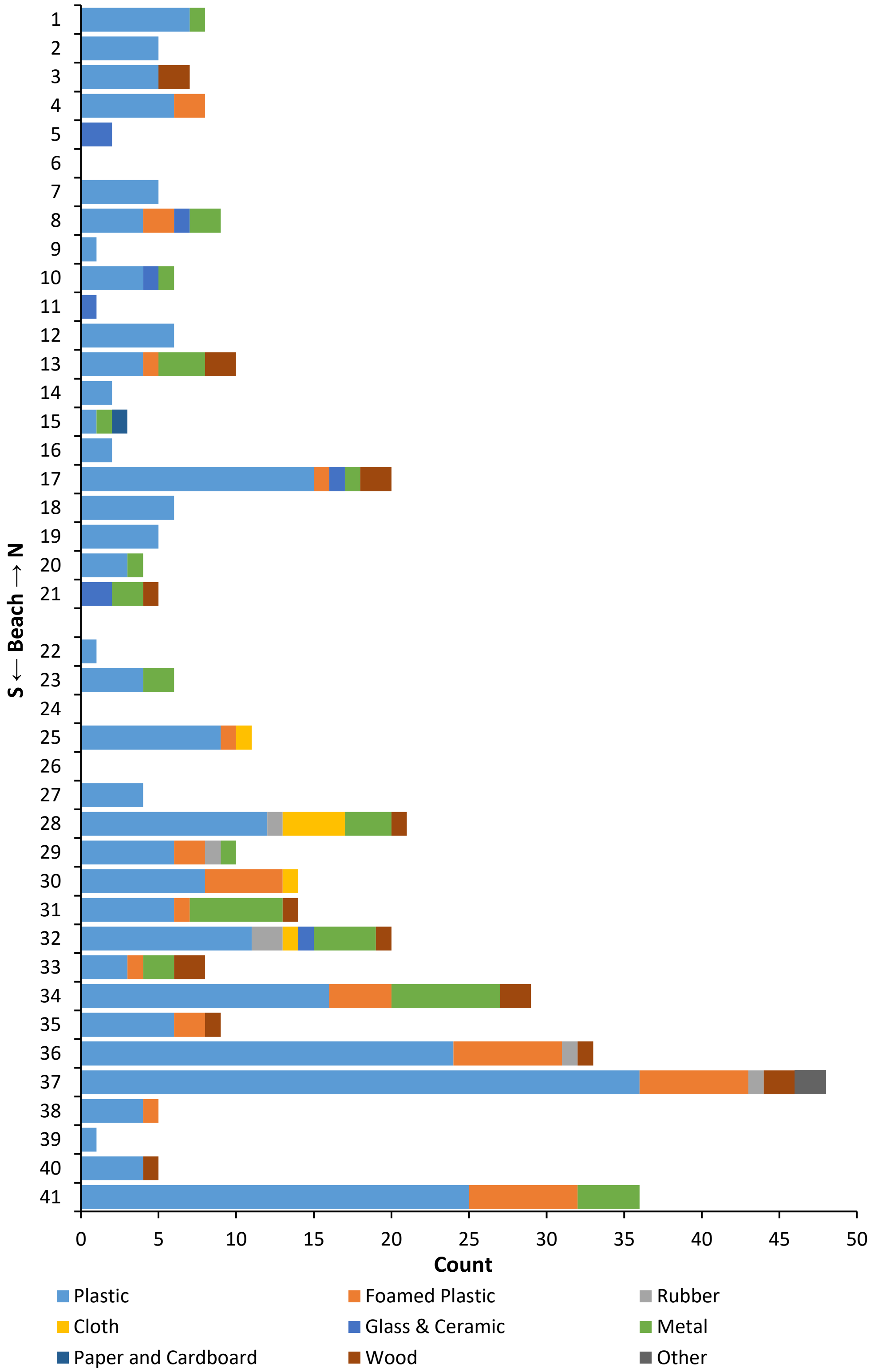
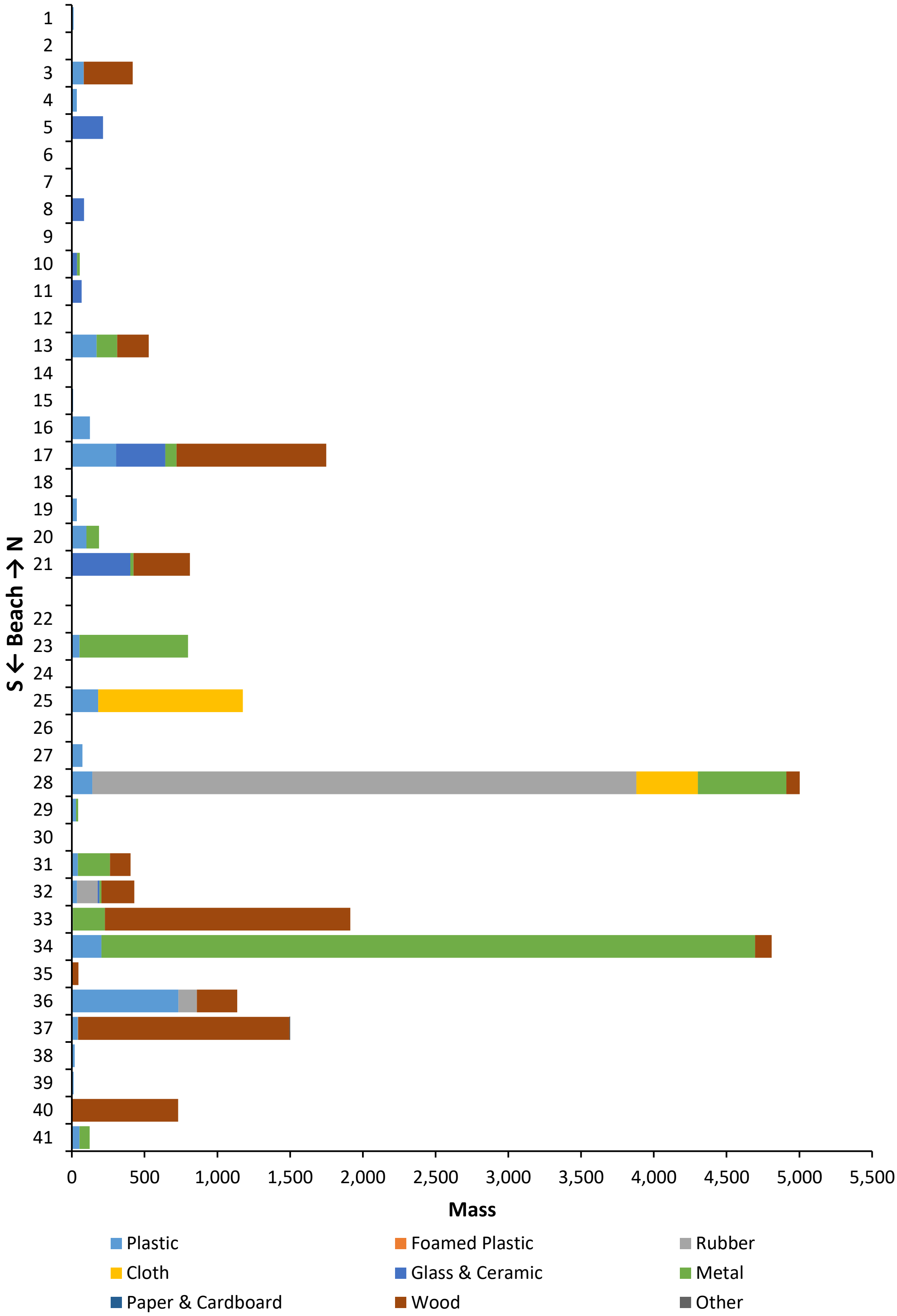


Figure 2.9

Anthropogenic Marine Debris (> 2 mm) Composition Mass Across New Zealand Beaches in Spring 2017



By debris origins, undetermined items made up 62% of all debris (Table 2.3). The next largest group was mismanaged recyclables with 16%, after which came fishing (10%), food-related (6%), shotgun material (4%) and smoking (2%).

Table 2.3

Origins of Anthropogenic Marine Debris (> 2 mm) by Count on New Zealand Beaches (2017)

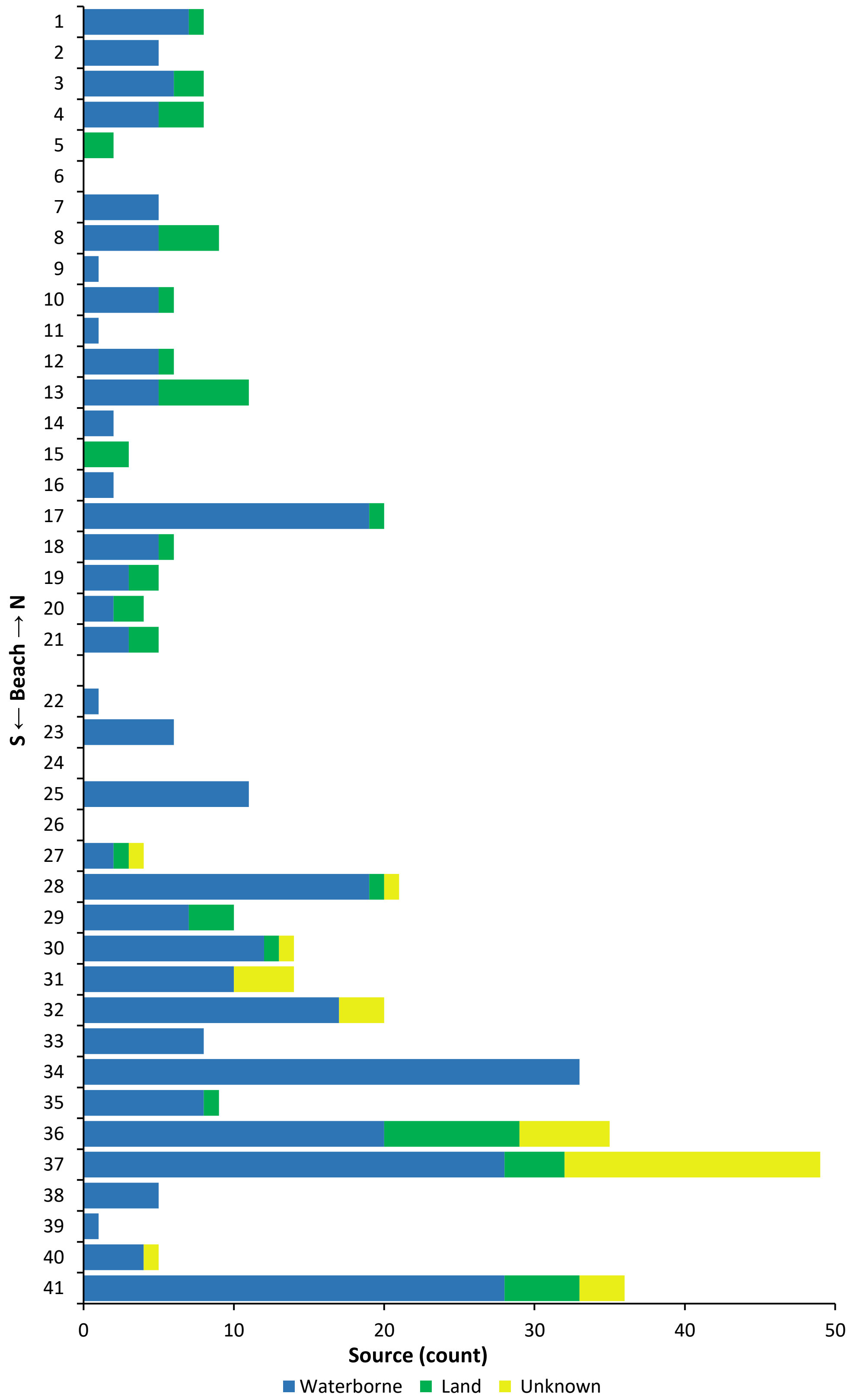
Origin	Count by Island				Total	
	North	(%)	South	(%)		
Undetermined	62	(53)	185	(66)	247	(62)
Mismanaged recyclables	30	(26)	35	(12)	65	(16)
Fishing	13	(11)	25	(9)	38	(10)
Food related (Take away)	8	(7)	15	(5)	23	(6)
Shotgun material	0	(0)	17	(6)	17	(4)
Smoking	4	(3)	5	(2)	9	(2)

Note. For UNEP/IOC codes included per group, see Appendix C. Percentages are based on column totals.

Of the 399 AMD items (including large items) detected, 306 (77%) were waterborne, 56 (14%) were land-based, and 37 items (9%) had an unknown source (Figure 2.10). All items of unknown source were detected on the SI, and almost all pieces of unknown source were found on beaches (except site 40) with higher than national mean densities (Figure 2.10).

Figure 2.10

Sources of Anthropogenic Marine Debris (> 2 mm) Across New Zealand Beaches in Spring 2017

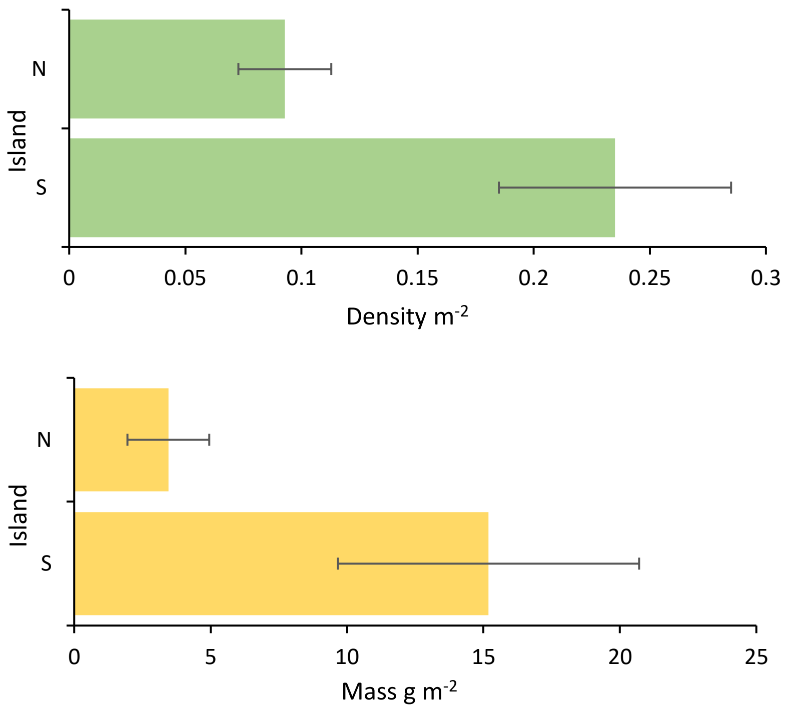


2.3.2 *Differences Between Islands*

When comparing the islands by AMD density, there was a statistically significant difference between the amount (number of items) of AMD detected, between the North and South Islands ($t_{[23]} = -2.60$; $P < .02$; Figure 2.11). There was a higher density of AMD items on the SI ($M = 0.24 \pm 0.05$ m^{-2}) compared to the NI ($M = 0.09 \pm 0.02$ m^{-2}; Figure 2.11). Similarly, AMD mass differed significantly between islands ($t_{[22]} = -2.05$; $P = .05$; Figure 2.11), with significantly higher AMD mass on the SI ($M = 15.18 \pm 5.52$ g m^{-2}) compared to the NI ($M = 3.45 \pm 1.50$ g m^{-2}).

Figure 2.11

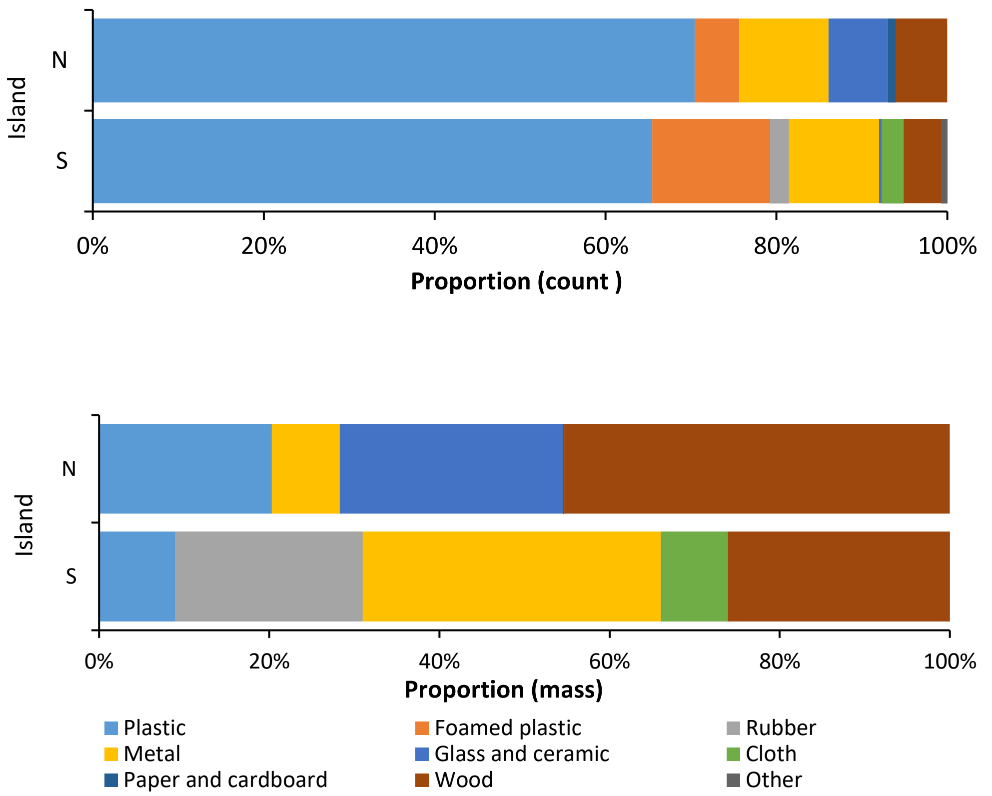
Anthropogenic Marine Debris (> 2 mm) on New Zealand Beaches (2017) per Island by (Upper) Mean Density (± SE) and (Lower) Mean Mass (± SE)



The composition of AMD was similar between islands (χ^2 (3, N = 399) = 6.13, $P < .11$). These results were based upon comparison between four AMD types only (i.e., plastic, foamed plastic, metal, and wood) because there was not sufficient count data to include the other groups (i.e., cloth, glass and ceramic, paper and cardboard, and other) in the statistical analysis. There were more types of AMD (by count) on the SI compared to the NI (eight versus six types, respectively: Figure 2.12). Wood was the most prevalent type on the NI by mass and metal was the most prominent group on the SI (Figure 2.12).

Figure 2.12

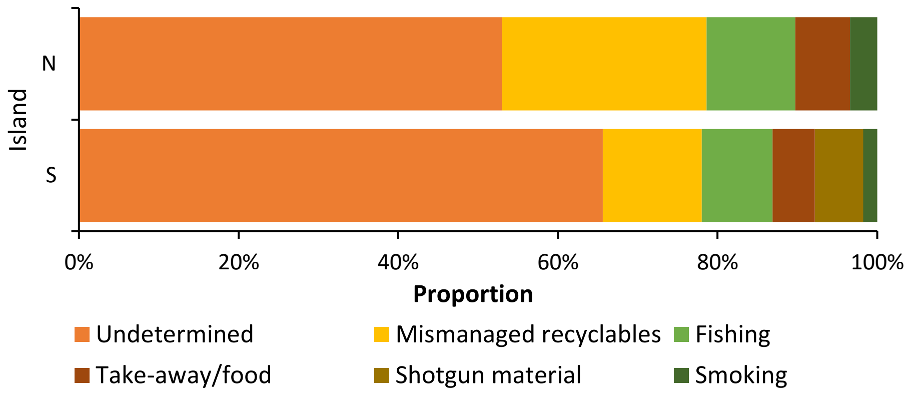
Anthropogenic Marine Debris (> 2 mm) Composition on New Zealand Beaches (2017) per Island by (Upper) Density and (Lower) Mass



The origins of items detected varied significantly between the islands (χ^2 (6, N = 399) = 19.82, P < .003). The NI had more mismanaged recyclables than the SI (26% and 12%, respectively; Figure 2.13). On the NI, no shotgun related material was found, but on the SI, it made up 6% of the items and was more than the proportion of food-related (5%) and smoking-related (2%) items. On the NI food-related items made up 7% and smoking 3% (Figure 2.13, Table 2.3).

Figure 2.13

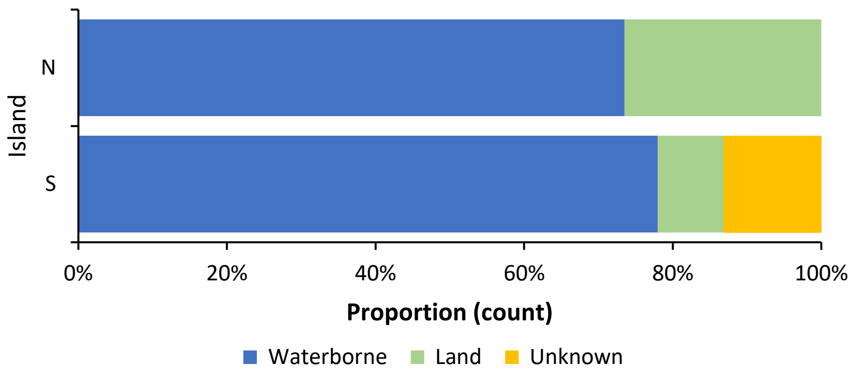
Origins of Anthropogenic Marine Debris (> 2 mm) on New Zealand Beaches (2017)



Overall, the sources of the AMD found between the islands were significantly different (χ^2 (2, N = 399) = 23.03, P < .01; Figure 2.14). North and South islands showed a similar proportion of waterborne items (74% and 78%, respectively). The NI had more land-based items than the SI, with 26% and 9%, respectively. The SI showed 13% of unknown items, of which the NI had none (Figure 2.14).

Figure 2.14

Sources of Anthropogenic Marine Debris (> 2 mm) on New Zealand Beaches (2017)



2.3.3 Comparison by Management Level

If AMD on the beach is an artefact of how a region is managed, then patterns may exist between the regions related to their waste management aspects. This concept is further explored in the following chapters, yet as a first step, an overview of AMD density, mass, composition and source per region is presented here.

2.3.3.1 AMD by New Zealand Region

The Otago region (SI) had the highest mean density of AMD (M = 0.36 ± 0.06 m^{-2}) and the Waikato region (NI) had the least mean density (M = 0.02 ± 0.02 m^{-2}) (Figure 2.15). The Otago region (SI) also had the highest mean mass (M = 17.45 ± 9.28 g m^{-2}), and Auckland (NI) the least mean mass (M = 0.57 ± 0.47 g m^{-2}) (Figure 2.15).

By composition count, Waikato stands out as it only features one type (glass & ceramic) (Figure 2.16). By composition mass, the four northern regions (i.e., Northland, Auckland, Waikato and Bay of Plenty) do not have any metal debris, which is present in all regions further south (Figure 2.16).

Figure 2.15

New Zealand Beach Anthropogenic Marine Debris (> 2 mm) per Region (Number of Beaches) in 2017 by (Left) Mean Density (± SE) and (Right) Mean Mass (± SE)

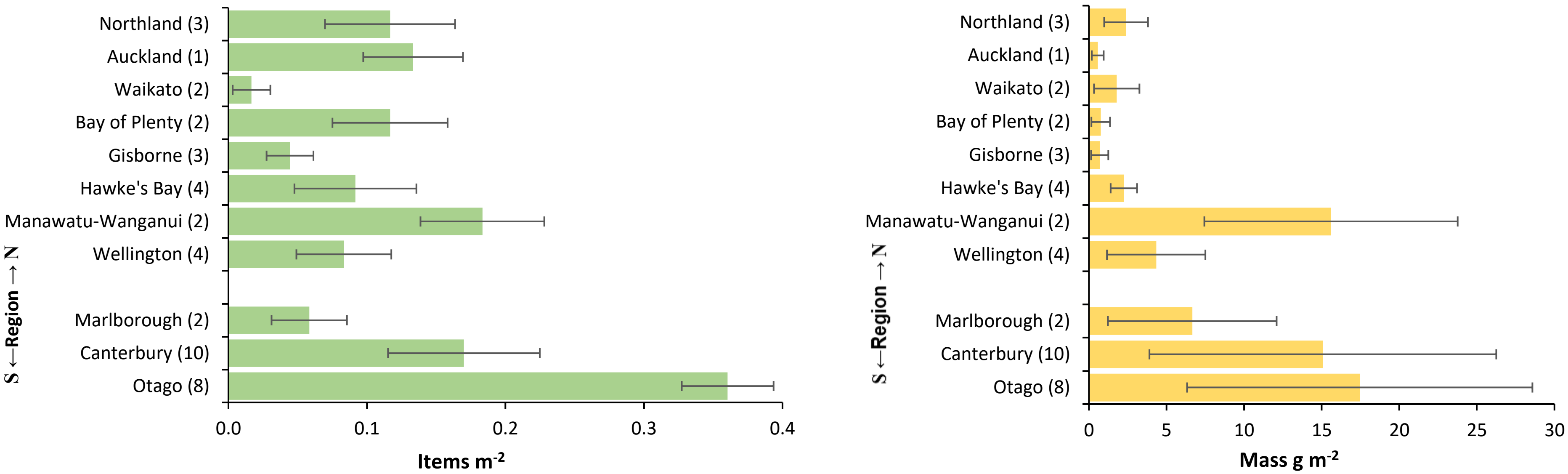
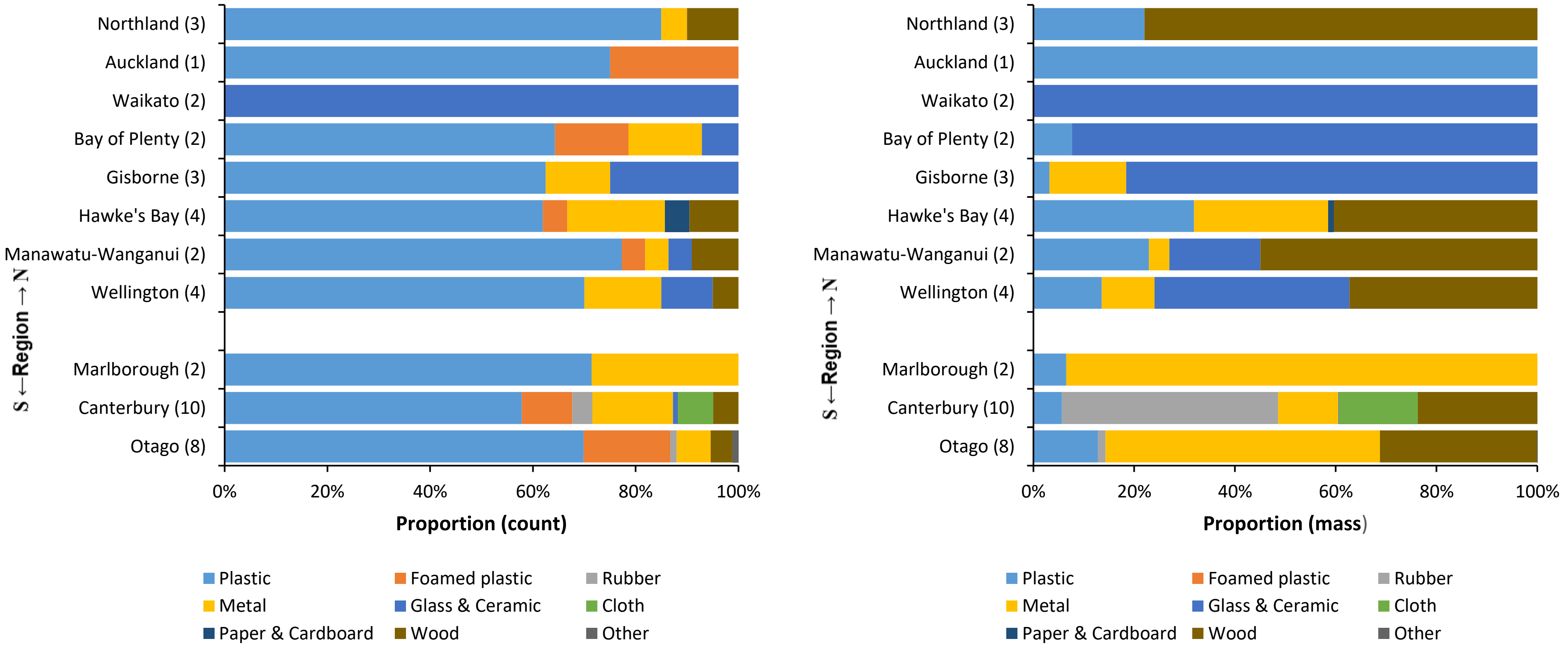


Figure 2.16

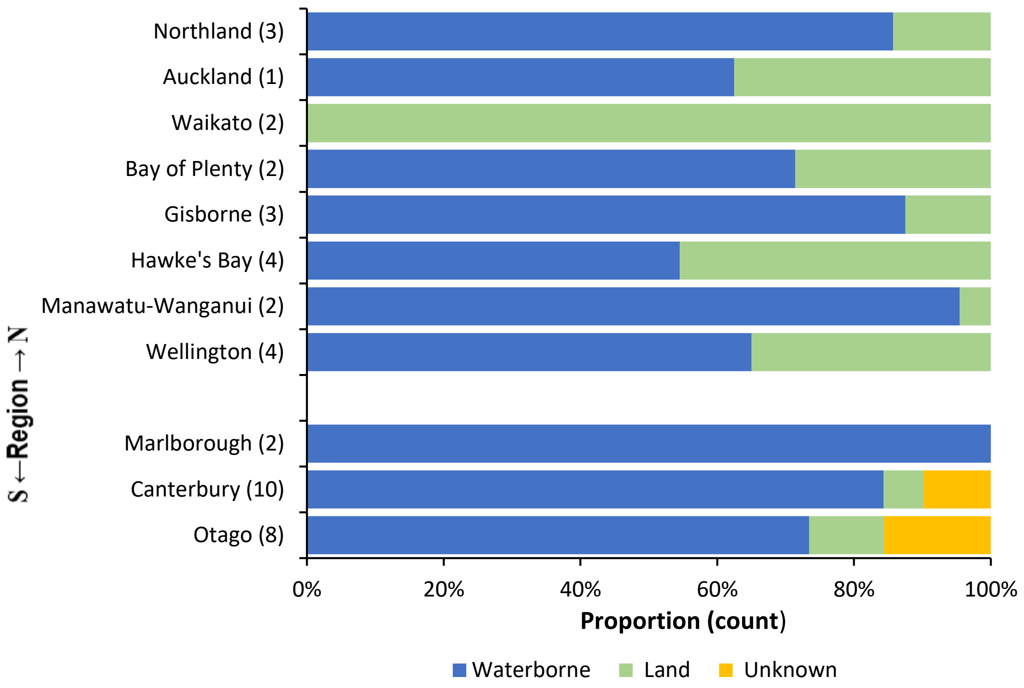
New Zealand Beach Anthropogenic Marine Debris (> 2 mm) Compostion per Region (Number of Beaches) by (Left) Count and (Right) Mass (2017)



In terms of AMD sources, all items detected in the Waikato region came from land sources (Figure 2.17). In contrast, all AMD items detected in Marlborough (SI), were classified as having a waterborne source (Figure 2.17). Only two of the 16 regions (Canterbury and Otago, SI) had items of an unknown source.

Figure 2.17

Sources of Anthropogenic Marine Debris (> 2 mm) per Region (Number of Beaches) on New Zealand Beaches in 2017



2.4 Discussion

This field study set out to establish a national baseline for the distribution of AMD across NZ beaches. It found significant differences in quantification and qualification of AMD between the islands and the regions. Between the North and South Islands, significant variations in AMD density ($P < .02$) and mass ($P = .05$) were detected, with the SI having both a higher density and mass than the NI. There was no significant difference in the composition of AMD between the islands ($P < .105$). Origins of AMD items ("undetermined", "mismanaged recyclables", "fishing", "food-related", "shotgun" and "smoking") differed significantly between islands ($P < .003$), as did the source ("waterborne" and "land-based") of AMD ($P < .01$).

2.4.1 Patterns of AMD Distribution on New Zealand Beaches

The overall mean density (0.16 ± 0.02 items m^{-2}) of AMD on NZ beaches, as determined in this study, is similar to results from a national survey in Australia, but less than in Turkey, Sri Lanka, and Portugal (Azores) (Table 2.4). However, results and comparisons must be considered with care as these studies did not necessarily apply comparable methods, and one overall mean number does not explain the overall nature of AMD distribution.

Table 2.4

New Zealand Beach Debris Density Results from This Study Compared With Other Studies

Location	No. Beaches	Items (m^{-2})	Reference
New Zealand [a]	41	0.16 ± 0.02	This study
Australia [a]	175	0.15	Hardesty et al., 2017
Portugal [a] (Azores only)	42	0.62 ± 0.15	Ríos et al., 2018
Turkey [a]	13	0.92 ± 0.36	Aydin et al., 2016
Chile [a]	43	1.8	Bravo et al., 2009
Panama	19	3.6	Garrity et al., 1993
Sri Lanka	22	4.1 ± 9.2	Jang et al., 2018
Indonesia (Ambon only)	56	4.6	Evans et al., 1995
Caribbean nations [b]	42	6.34 ± 10.11	Schmuck et al., 2017

Note. [a] Denotes OECD member state. [b] Includes The Bahamas, British Virgin Islands, Dominican Republic, Grenada, St. Vincent and the Grenadines, Turks & Caicos Islands, Cayman Islands, Martinique and St. Eustatius.

Based on a review of 47 studies, Barnes (2005) found that in the Southern Hemisphere, AMD density diminishes on a latitudinal gradient from the equator towards the pole, with higher concentrations of AMD at the equator. This trend is explained by population density, which reduces further away from the equator (Barnes, 2005). However, the results presented here, albeit on a subset of these latitudes, contradict those findings by showing an increasing AMD density in higher latitudes and with less population. Thus, AMD density on NZ beaches cannot be explained by latitude. Consequently, additional explanatory factors must be considered.

Variability in AMD density between locations or regions is typical in beach surveys and can result from many factors. For example, AMD in coastal waters washes on and off the beach (Critchell & Lambrechts, 2016; Nagelkerken et al., 2001), which also suggests a correlated abundance in the two environments for certain types of AMD (Thiel et al., 2013). On the beach, AMD can be buried and exhumed based on geophysical and environmental factors (Orr et al., 2005; Thiel et al., 2013), including tidal cycles and wind waves (Orr et al., 2005). Together, these variables cause AMD to move constantly, creating variability based on local circumstances.

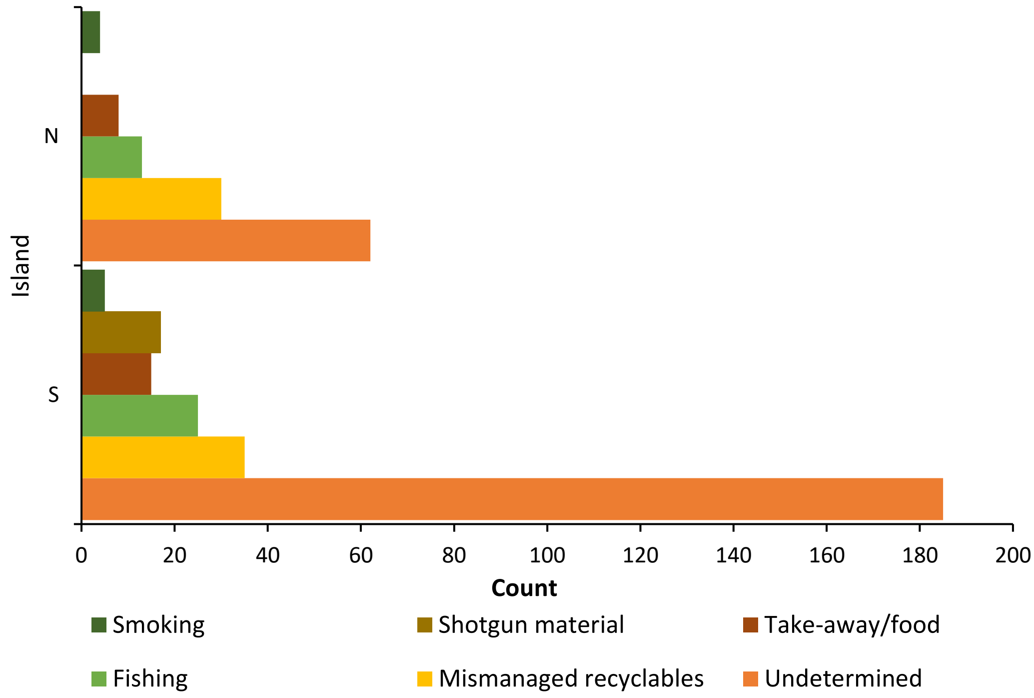
Furthermore, studies in Malaysia and Japan show that, depending on the type of recreational activities performed on the beach, similar litter quantities are buried in the top layer of the beach (Fauziah et al., 2015) as are observed on the surface (Kusui & Noda, 2003). Moreover, on a remote Pacific island, up to 68% of AMD items were found buried (Lavers & Bond, 2017), leading some to conclude that all AMD surveys should include measurement of items buried in the top layer (5 cm) of the beach (Serra-Gonçalves et al., 2019). In the present study, the sand was not raked nor sieved. Thus, it is possible that the actual density of

AMD is higher than represented in the results. In addition, variability in wind strength and direction before the sampling, as well as differences in time of sampling in relation to tidal cycles, might have influenced results.

To identify those items that might have resulted from waste loss from the kerbside collection (Chapter 3), the AMD items that are generally recyclable (e.g., plastic bottles, metal cans and glass) were grouped by origin and made up 16% of overall AMD density detected on the beaches (Figure 2.18). Note that a portion of these items could also be considered from “food-related”, or “fishing” origins yet are items that could or should be recycled. When lost waste items (eventually) transfer into the marine environment, they are likely to have broken into smaller and fragmented pieces, often beyond recognition from their original shape (Andrady, 1994). Therefore, the category “undetermined” (e.g., small and fragmented pieces of plastics, glass, and metal), probably contains broken down mismanaged waste, yet is not considered in the figure calculated above.

Figure 2.18

Origins of Anthropogenic Marine Debris (> 2 mm) on New Zealand Beaches in Spring 2017



Other waste items not captured in the "mismanaged recyclables" grouping are non-recyclable items lost from rubbish, through for example torn or uncollected rubbish bags and items released through littering and from (legacy) landfills and farm dumps. Thus, it is likely that the actual proportion of AMD detected on the beaches resulting from mismanaged waste estimated here is conservative.

Smoking-related items constituted a very small (2%) portion of the overall AMD detected in this study (Table 2.3). This was surprising since, globally, cigarette butts are a commonly encountered item on the beaches (Andrades et al., 2020; Aydin et al., 2016; Bravo et al., 2009; Gjyli et al., 2020; International Coastal Cleanup, 2017, 2018, 2019; Pasternak et al., 2017). Indeed, in NZ, smoking litter is one of the most prevalent types of terrestrial litter (Keep New Zealand Beautiful, 2019) and one of the items volunteers most frequently collect on beach cleans (Sustainable Coastlines, 2020). Cigarette butts contain toxins and are often mistaken for food by birds or mammals, thus causing damage (Slaughter et al., 2011). The fact that so few smoking-related items were found in this study might be a result of the timing of the survey (austral spring) when fewer people visit beaches than in the summer and autumn seasons.

2.4.1.1 More Debris on the Less Populated South Island

Land-based explanations for higher AMD densities on the SI could include factors around land use, waste management practises, or regional oversight and implementation. Otago and Canterbury (both SI) are predominantly agricultural regions, with dairy, sheep and beef farming as main activities (Ministry for the Environment & Stats NZ, 2020). Correspondingly, these regions have more farms, of which 92% dispose (or burn) waste in or on their land (Ministry for the Environment, 2019d). The SI also has more rivers discharging on the coast, which are known sources and pathways for AMD (Emmerik, Strady, et al., 2019; Lebreton et al., 2017; Schmidt et al., 2017; Williams, Randerson, et al., 2016).

Hunting related items (shotgun wads and casings), which are partly made of plastics, were solely detected on SI beaches and made up 6% of the grouped objects. On both islands, hunting is allowed on private land (including farms) and public conservation land. The latter offers 530 hunting blocks dispersed over NZ, of which 108 are located in Otago (SI) and 69 in Canterbury (SI) - considerably more than those in the other regions bordering the east coast (e.g., Manawatu-Wanganui (NI) and Hawke's Bay (NI) [35], Marlborough (SI) and Waikato (NI) [18], Northland (NI) [16], Bay of Plenty (NI) [6], Auckland (NI) [5] and Wellington (NI) [3] etc.) (Department of Conservation, n.d.). Hayward (1984, 1999) also reported detecting shotgun related items over 23 years (on one beach on the NI), indicating this is a common and recurring type of AMD in NZ. Overseas in Denmark, shotgun cases and wads feature in the top 10 of AMD items found on beaches (Kanstrup & Balsby, 2018). Whether discharged on land (shooting on or near beaches), on the water, or at upstream locations, shotgun related material is harmful and can contain lead (Fish & Game New Zealand, 2020).

2.4.2 Differences Between Regions

Population density and proximity are known to affect local AMD rates (Derraik, 2002; Naji et al., 2017). Yet, this study saw the highest mean density and mass (M = 0.36 ± 0.06 m^{-2} and M = 17.45 ± 9.28 g m^{-2}, respectively) in rural Otago (SI). In contrast, the most populated area of NZ, Auckland (NI) showed the least AMD mass (M = 0.57 ± 0.47 g m^{-2}) and Waikato the smallest density (M = 0.02 ± 0.02 m^{-2}). This might be explained that some beaches, specifically when frequented by tourists, are cleaned up more regularly than other beaches (e.g., in Israel; see Pasternak et al., 2017). The beaches sampled in Waikato were in the Coromandel, a popular tourist destination with many holiday homes close to the beach. Research in Australia and Easter Island (Chile) showed less debris at beaches in very close proximity (< 5 km) to homes (Hardesty et al., 2017; Kiessling et al., 2017), possibly a result of local stewardship.

Although beach cleaning information across NZ was not systematically available for this study, anecdotal evidence suggests that those beaches regularly visited by locals (e.g., for dog walking), often have AMD removed in a haphazard manner. Additionally, youth groups or other community-based groups organize annual beach cleans, but mainly in the summertime. At one beach (site 10, Tolaga Bay, NI) a community group had cleaned local streets, parks and the beaches the week before sampling (Duncan, personal communication, 31 October 2017). In this study, the region with the least debris density, Waikato, (NI), features homes near beaches and is a highly frequented tourist area. Hence, both these factors combined might partly explain low AMD density rates. Other reasons might include nearshore currents, wind patterns and other geophysical features.

Regional level comparisons are essential as they can identify those regions serving as a best-case management scenario (i.e., Waikato) as well as those regions warranting enhanced management attention (i.e., Otago). In addition to these distributive comparisons at the regional level, the following chapter compares waste management aspects at a regional scale (and further, drills down to the territorial scale). Regional Authorities (RAs) (whose geographic boundaries are based on catchment areas) have a range of functions under NZ legislation. Of primary importance are the responsibility to make decisions about the coastal marine area in general (in conjunction with the Minister of Conservation), as well as the control of discharges of contaminants into or onto land, air, or water within the entire catchment (*Resource Management Act*, 1991 ss 30(d) and 30(f)). To control discharges, RAs create "Regional Plans" describing (non-) permitted discharges. Chapter 3 takes a closer look at these plans and specifies how some of the contaminants found on beaches as described in this chapter, are regulated (or not) within those plans.

2.5 Conclusion

A comprehensive and reproducible (standing crop) survey of AMD on NZ beaches along the east coast of NZ provided a robust baseline. These results can now be used as a foundation to compare against similar research in the future and other geographies (e.g., NZ's west coast). This AMD survey indicates a substantial spatial variation in AMD density, mass and source with a concomitant variation per island and region, requiring targeted mitigation efforts. AMD density and mass are significantly higher on the SI than on the more densely populated NI, with an increase of AMD density with increasing latitude. Debris on the NI showed significantly more land-based sources and the SI more waterborne sources, possibly resulting from freshwater inputs. The results presented in this chapter provide a reference point against which the effectiveness of current and future management, mitigation and policy measures in NZ can be assessed and forecast.

Chapter 3

Finding Loose Ends: Are There Waste Management Inefficiencies in Regulation and Implementation That Drive Anthropogenic Marine Debris Issues?

Farm waste on a South Island beach, New Zealand. Photo: van Gool, E.D.

3.1 Introduction

The problem of anthropogenic marine debris (AMD) manifests in all the world's oceans and beaches (Crain et al., 2009; Tekman et al., 2019), yet often originates as waste in our own homes (Derraik, 2002). About 80% of all marine debris originates from land-based sources (Derraik, 2002; Sheavly & Register, 2007). The majority of these terrestrial sources is considered a result from mismanaged waste (Jambeck et al., 2015). However, little is known about the exact origins and pathways, including the proportion of AMD that originates directly from households. Since waste management aspects are measurable and contrastable between different regions, this chapter further explores the connection of specific factors with waste loss to the environment and the resulting AMD on beaches.

As defined in Chapter 1, mismanaged waste includes street litter, and items misplaced or lost before, during or after waste collection, transfer and processing (including items leaking from landfills) (Barnes et al., 2009). Mismanaged waste causes human illness and death, especially in developing countries (Harvey, 2019; Norsa'adah et al., 2020; D. C. Wilson et al., 2015), and results in harmful environmental impacts (Ferronato & Torretta, 2019). Waste loss to the marine environment has been modelled by calculating the potential mismanaged waste proportions of 192 coastal nations (Jambeck et al., 2015). According to Jambeck et al. (2015), 100 – 250 million metric tonnes of waste (per year) are estimated to be released into the ocean by 2025. Even with all currently known mitigating measures implemented, mismanaged waste will remain a persistent source of AMD (Borrelle et al., 2020; Lau et al., 2020).

A country's waste generation is positively correlated to population, urbanisation, and income levels (Hoornweg & Bhada-Tata, 2012). Lower-income countries create the least waste, and the world's 36 high-income countries produce more than 50% of the overall global waste streams (Hoornweg & Bhada-Tata, 2012; Karak et al., 2012; D. C. Wilson et al., 2015). These high-income countries are also considered to have better-developed waste management infrastructure (Hoornweg & Bhada-Tata, 2012; Kaza et al., 2018), hence more waste losses (or leakages) to the environment are estimated to occur in low-income countries (Jambeck et al., 2015; Lebreton et al., 2017; Schmidt et al., 2017). However, global waste trades generally see recyclable wastes shipped from high-income countries to low-income ones (Barnes, 2019).

In 2017, New Zealanders were estimated to have generated 42% more waste than the average of high-income (OECD) countries. Per capita, a total of 740.3 kg was generated in 2017, compared to the OECD average of 519.9 kg (Ministry for the Environment, 2017; OECD, 2021). However, actual, reliable and up-to-date NZ waste data are not available. This missing information is a situation that successive OECD environmental reports (OECD, 2000, 2007, 2017) and others (Blumhardt, 2018; Davies, 2009; Schofield, 2010), including the NZ government (Ministry for the Environment, 2019d), have flagged as problematic and requiring urgent attention.

Environmental impacts resulting from solid waste generation include resource depletion, the spread of disease vectors and climate change, as well as waste loss to the environment (Cherubini et al., 2008). Greenhouse gas emissions related to waste management primarily result from the transport, burning and processing of waste (including landfilling), and makes up 5% of total global emissions (Kaza et al., 2018), the same percentage as reported for NZ in 2017 (Ministry for the Environment & Statistics New Zealand, 2018). However, these NZ calculations do not include the emissions related to the transport of wastes.

Landfilled items are unlikely to be recovered and are prone to potential loss of waste to the environment, for example, through leachate (Alimi et al., 2018; He et al., 2019). Further unintended waste loss from landfills can occur during extreme weather events like with the Fox landfill opening (Chapter 1) and the opening of a local landfill near Gisborne (NI) (Sharpe, 2020). Other dispersion of landfilled waste can occur through wildlife and wind distribution from uncovered landfills. Many legacy and active NZ landfills do not comply with modern landfill requirements (including lining and capping) and are therefore prone to leaking waste to the environment, particularly when sea-level rises (Simonson & Hall, 2019; Tonkin & Taylor, 2014).

Mitigation of existing waste historically occurs through a diversion strategy (Wilson, 1976). This approach includes, for example, recycling, upcycling, repurposing, reusing and incineration (Hoornweg & Bhada-Tata, 2012). Recycling is favoured over landfilling as it lowers the environmental impacts of waste, decreases consumption of (energy) resources, and reduces economic costs (Cherubini et al., 2008; Eriksson et al., 2005). However, the recycling process is complex and consumes energy, releases greenhouse gases, often creates a product of a lesser quality and needs processing infrastructure, or (as is the case in NZ due to a lack of such infrastructure) transportation to an overseas country with typically less environmental controls (Hopewell et al., 2009; Maris et al., 2018).

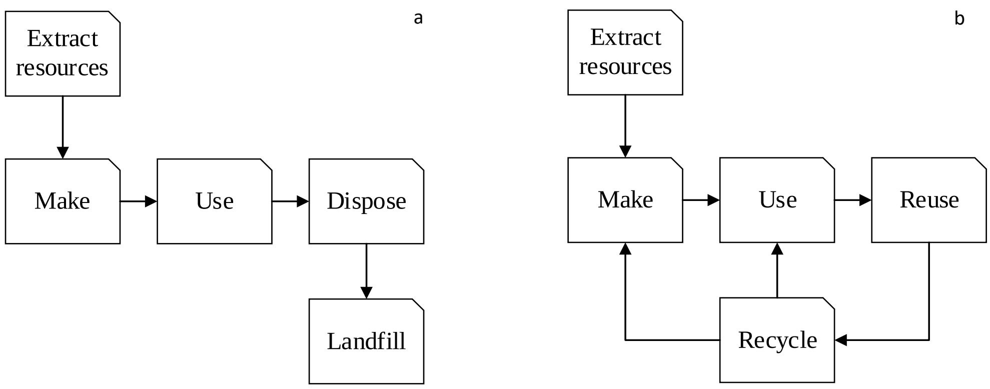
In NZ, overall recycling rates are low (and decreasing) at an estimated 11.3% in the period from 2013 - 2016 (compared to the period 2010 - 2013) and are therefore a likely factor contributing to the high and increasing waste creation (Ministry for the Environment, 2017). Countries with much higher recycling rates (i.e., Germany, Wales, Singapore, South Korea, Taiwan, The Netherlands, Austria, Slovenia, Belgium and Switzerland) show diversion rates of over 50% (Gillies et al., 2017; Kaza et al., 2018). Diversion rates are calculated based on material recycling and composting as a function of the total amount of waste generated (Gillies et al., 2017). Discrepancies in recycling rates between countries can be explained by several factors. For example, the existence (or the lack) of national policy and diversion targets, kerbside services, specific collection methods (Lane & Wagner, 2013; D. C. Wilson et al., 2012), social pressures, and economic (dis)incentives (Barr, 2007; Barr et al., 2013; Cox et al., 2010; Tonglet et al., 2004). The latter includes bottle return schemes, user-pay models and (higher) landfill levies. Specific explanations for NZ's low recycling record are the nation's remoteness and low population density, leading to complex and costly logistics to collect and recycle material (Office of the Prime Minister's Chief Science Advisor, 2019, p 47).

Until December 2017, over half of the world's recyclables were processed in China (Gregson & Crang, 2015; Wang et al., 2019). In January 2018, China's Green Fence and National Sword policies restricted the importation of other countries' (contaminated) waste streams (OECD, 2018). These policies subsequently disrupted global waste trade (Gregson & Crang, 2018; Wang et al., 2019). As such, formerly tradeable recyclables have lost economic value and have since been (locally) stockpiled, landfilled, sent to low-income countries, or are no longer collected (Brooks et al., 2018; OECD, 2018; D. Wilson et al., 2018).

In general, preventing and reducing waste is much preferred over attempts to manage waste once produced (Gentil et al., 2011), yet, a strategy of waste prevention requires a holistic approach and involves switching from a linear process (extract, produce, consume and disposal) to a closed-loop system in a *circular economy* (Figure 3.1). Here, resources are conserved and reused, thus reducing waste and further overexploitation of natural resources (Corvellec, 2016; Ghisellini et al., 2016; Kaza et al., 2018; Wilson et al., 2015; Zacho & Mosgaard, 2016). In a circular economy, extraction and design features aim to enable longevity, reuse, and the least amount of harm to the environment or humans during the creation, use, as well as the end-of-life stage of the product (Corvellec, 2016).

Figure 3.1

Two Different Waste Models in a) Linear; and b) Circular Economies



In addition to reducing the quantity of waste created (and related waste loss to the environment), a circular economy promises reduced greenhouse gas emissions, fewer resource inputs (as resources are reused) as well as more efficient businesses (Lau et al., 2020; Matsuda et al., 2018; Reh, 2013; Velenturf & Jopson, 2019). China, Japan, the USA, and countries in Europe are endeavouring to achieve a circular economy, albeit through differing approaches (Ghisellini et al., 2016; Q. Song et al., 2015; Xevgenos et al., 2015; Yuan et al., 2006). A circular economy is only feasible when applied throughout the entire lifecycle of a product or service, and implemented by all actors (e.g., manufacturers, distributors, consumers and waste service providers) involved in the product or service lifecycle (Cox et al., 2010; Lau et al., 2020; World Economic Forum & Ellen MacArthur Foundation, 2017). Due to the need for a system-wide approach, national coordination through legislation and strategic direction and management is essential (World Economic Forum & Ellen MacArthur Foundation, 2017).

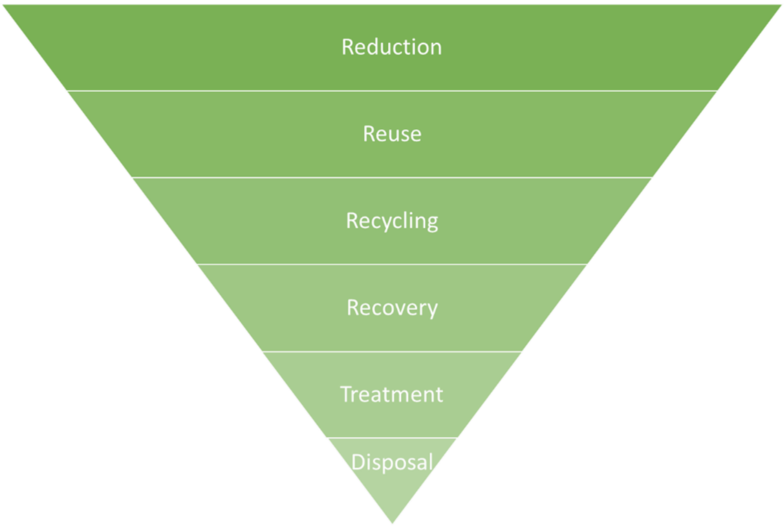
The New Zealand approach to waste management is primarily driven by the Waste Minimisation Act 2008 (WMA). The purpose of the WMA is to encourage waste minimisation to protect the environment from harm (s 3(a)), and to provide environmental, social, economic, and cultural benefits (s 3(b)). Part 2 of the WMA creates an outline for product stewardship schemes, including expansive regulatory powers (s 23). In particular, s 23(1)(b) permits controls on the manufacture or sale of specified products, which has been used to implement mandatory phase-outs of wash-off products containing plastic microbeads (Waste Minimisation (Microbeads) Regulations 2017), and plastic shopping bags (Waste Minimisation (Plastic Shopping Bags) Regulations 2018).

Part 4 of the WMA describes the responsibilities of the territorial authorities (TAs) as to encourage effective and efficient waste management and minimisation (s 42) as adopted in their "Waste Management and Minimisation Plan" (WMMP). The required contents of a WMMP are described in s 43 and include objectives and policies, the methods of collection, recovery, recycling, treatment, and disposal services for the district (whether provided by the TA or otherwise). A TA's WMMP should also describe any waste management and minimisation facilities, educational or public awareness activities to be provided by the TA, and how implementing the plan is to be funded.

In tandem with the WMA, the Ministry for the Environment has issued the NZ Waste Strategy 2010 (Ministry for the Environment, 2010). The strategy document sets two high-level goals: i.e. to “reduce harm to the environment”, and to “improve the efficiency of resource use” (Ministry for the Environment, 2010). When preparing, amending or revoking a WMMP, the TA must consider a strategy based on the inverted pyramidal hierarchy of waste management (Figure 3.2) (*Waste Minimisation Act*, 2008, s 44(a)). Therefore, management preference must be given to actions at the top of the pyramid (reduce, reuse, recycle and recover), with treatment and landfilling (disposal) as a last and least favoured approach (Figure 3.2). The WMMP is also required to ensure that waste collection and disposal do not, or are not likely, to cause a nuisance (s 44(b)).

Figure 3.2

Waste Management Methods Listed in Descending Order of Preference (Waste Minimisation Act, 2008, s 44(a))



Waste loss to the environment is directly proportional to the amount of waste generated, therefore, the enactment, implementation and enforcement of law to control this type of pollution is apposite. In NZ, the Resource Management Act 1991 (RMA) regulates environmental protection and promotes the sustainable management of natural and physical resources such as water, air and land (s 5).

The RMA enables significant restriction of discharges of any contaminant into air or water (s 15). Contaminants are broadly defined and include any substance likely to change the condition of the environment into which it is discharged (s 2). Discharges from trade or industrial premises to air, water or land are generally restricted unless allowed by regulation, a rule or a resource consent (s 15(1)). A more permissive approach applies to discharges to land other than from trade or industrial premises, such as farms (s 2). This permissive approach allows the discharge, unless restricted by a regional regulation or a rule.

Concerning waste management, the RAs regulate the environmental *effects* of waste disposal facilities by granting and monitoring resource consents. The RAs do not have specific waste management responsibilities or obligations under the WMA but can nevertheless facilitate the coordination and oversight of waste management amongst TAs in their region (Ministry for the Environment, 2010, p 7). The documents outlining such efforts are not mandatory and do not have a set form or prescribed format. Hereafter, we will call all documents in which the Regional Authority (RA) describes the coordination of waste management aspects a "regional waste document".

Of further legislative relevance is the Health Act 1956, which places a duty on local authorities to promote and conserve public health (s 23), including the provision of solid waste collection and disposal (s 25(1)(c)). As such, the Medical Officer of Health has statutory powers to manage health risks around waste and can impose conditions on offensive trades (s 54). Lastly, the Litter Act 1979, ss 12 and 13, provide TAs with the ability to create bylaws and issue infringement notices, or require the clean-up of litter from private land (s 10(1)(b)).

This NZ legal framework, as it relates to waste management, has been critiqued in the literature as “fragmented and with too many actors” (Schofield, 2010) due to the mix of laws and regulations administered by various institutions. In addition, the framework has been labelled as “disconnected between purpose and result” (Hannon, 2018), and Blumhardt (2018) argues that successive NZ governments have consistently underutilized the WMA since its inception. Nonetheless, the WMA provides a broad range of tools to enhance waste management at a national level. These tools include, for example, the ability under the WMA for the Minister to set waste reduction targets, recycling targets, declare priority products (which triggers the creation of mandatory product stewardship schemes) and adjust the waste levy (Blumhardt, 2018).

Reasons provided for central government’s inaction on waste during the past decade include the lack of political will, a disconnect between central and local government perspectives, ideological preferences for voluntary actions, and considerable industry influence (Blumhardt, 2018; Hannon, 2018). More recently (see Chapter 1), the NZ government has announced its aim to improve the nation’s undesirable waste status through a comprehensive work programme (Ministry for the Environment, 2020).

This chapter aims to improve the understanding of the policy context for waste management and pollution control; and in particular, any factors that may influence waste loss to the environment. Grounded in literature and law, and further complemented with a review of local waste planning documents, collection methods and schemes, this research is guided by the following questions:

1) What is the legal and policy framework for waste management and solid waste pollution control in NZ?

2) How is waste management implemented at the local level, both (a) strategically, and (b) tactically? and
3) What are the evident gaps, limitations and mechanisms contributing to waste loss to the environment?

3.2 Materials and Methods

3.2.1 Literature Review

A literature search was conducted to frame the discussion for all research questions explored in this chapter. The results of the literature search applied in Chapter 1 were further filtered with the words: “waste”, “trash”, “rubbish”, “kerbside”, “curbside”, “circular economy”, “zero-waste”, “mismanaged waste”, “waste management”, “collection”, “recycling”, “landfill” and “farm dump”. Secondary references were found through the iterative process of “snowballing” (Hagen-Zanker & Mallett, 2013). Next, a search for relevant NZ law and regulations was conducted in HeinOnline. Lastly, information on NZ’s waste data and local management details was obtained through reports issued by the Ministry for the Environment and local authorities. All resulting literature (primary, secondary and tertiary) was reviewed and synthesised to identify and interpret reach and impact of the relevant law and policy (question 1). Following which, local waste documents, enabled or mandated by the WMA and RMA, and deemed influential for waste management, were identified, collated, and evaluated for strategic intent (question 2a). For the tactical purpose of the local waste management plans (question 2b), waste management practices in NZ were examined, with a specific focus on collection methods and recycling schemes. These analyses then grounded an examination of factors limiting effective waste management in NZ (question 3).

3.2.2 Local Waste Management Documents

The WMA requires that all TAs complete waste assessments (ss 50(2), 51) and review their WMMP at least once every six years (s 50(1)(b)) starting no later than 1 July 2012 (s 50(1)(a)). Reach and impact of WMMPs were determined by establishing the existence and issue date of these mandatory documents. The WMMPs were identified and summarized from 2008 onwards, as that was the year of the WMA's enactment, requiring TAs to have a WMMP in place (s 43). Voluntary regional waste documents, as issued by the RAs, were assessed as of November 2017, the date of the beach survey (Chapter 2).

The WMMP planning guide states that "a common approach across councils can be beneficial by allowing for benchmarking and consistency" (Ministry for the Environment, 2015). To define implementation of collaborative actions, local (regional and territorial) waste documents were reviewed for specific mentions of cooperation with other authorities or entities. If lateral collaboration between TAs occurred, without mention of the RA, then the RA's role was presumed non-existent for the purpose of this examination.

Furthermore, strategic and tactical intent of the local waste documents was determined textually by defining the prevalence of keywords relating to waste minimisation on the one hand (recycling and minimisation), and waste prevention (zero-waste, prevention, circular economy) on the other. This distinction is based on the premise that these are two fundamentally different approaches (Zacho & Mosgaard, 2016).

To determine and summarize the details indicated above, the following information was identified from the local (RA and TA) waste management planning documents:

- Name of the local authority, issue date, name and objectives of document;

- Did the authority mention collaborating with others? (Y/N);
- Strategic intent through the relative prevalence of waste management concepts, identified via the presence of keywords: “waste minimisation” and “waste prevention”; and
- Tactical intent through the relative incidence of keywords: “recycling”, “zero-waste” and “circular economy”.

3.2.3 Webpage Data

The likelihood of waste loss to the environment was further determined by analysing inconsistencies in local waste collection methods and schemes. As such, specific details on each TA’s waste collection practices were compiled based upon information on the council’s webpage. Information regarding the collection, type of waste and recycling receptacle, and the plastic types collected, if available, was recorded.

Of the multiple recycling streams, plastic waste is more likely to create confusion at disposal and collection than for example, glass, metal or paper (Farrelly et al., 2014; Office of the Prime Minister’s Chief Science Advisor, 2019, p. 114). Although these other types of recyclable materials are essential for recovery purposes, they are not included in this overview. Plastic debris is often the most prolific (by count) type of AMD in beach studies (Table 1.6), including in NZ (Figure 2.8). Hence, webpages were reviewed for details on plastic collection between April 2017 and December 2017, and the following information was recorded:

- Is rubbish collected at the kerbside (Y/N);
    - By whom? (TA/private/both);
- Type and colour of the waste receptacle (wheeled bin/bags);

- Is kerbside recycling available (Y/N);
- Type and colour of the recycling receptacle (crate/wheeled bin/bags);
- Which plastic grades are collected (Grades 1 - 7)?
    - list exceptions; and
- Are lids and plastic bags collected (Y/N/specific instructions)?

3.2.4 Landfill and Farm Dumps

Landfill status was determined by defining the types and count of active and non-active sites, as well as the type of waste(s) accepted. Applicable national law and local regulations for these varying types of landfills and farm dumps were reviewed, as well as the roles and related documentation of local authorities. Almost all data is gleaned from secondary reports directly from or commissioned by central or local government agencies.

3.2.5 Limitations

The webpage data research was performed in 2017, with the information representing a snapshot of the situation at that time. Since then, TAs have adopted new WMMPs (e.g., Hamilton and Waipa), or have adjusted their collection schemes based on international market developments (Savory, 2020). Therefore, the overview as presented illustrates the communication of waste collection details at the time of sampling (2017) for the beach survey (Chapter 2) and is not an up to date nor a comprehensive guide of current practices. Furthermore, the data as obtained from the webpages were presented in various formats and levels of detail, leaving certain aspects open to interpretation. Lastly, although only one profile was summarized per TA, additional collection schemes may exist within that TA. In these instances, the collection scheme, as communicated through the TA's webpages and which covers the majority of the TA, was presented.

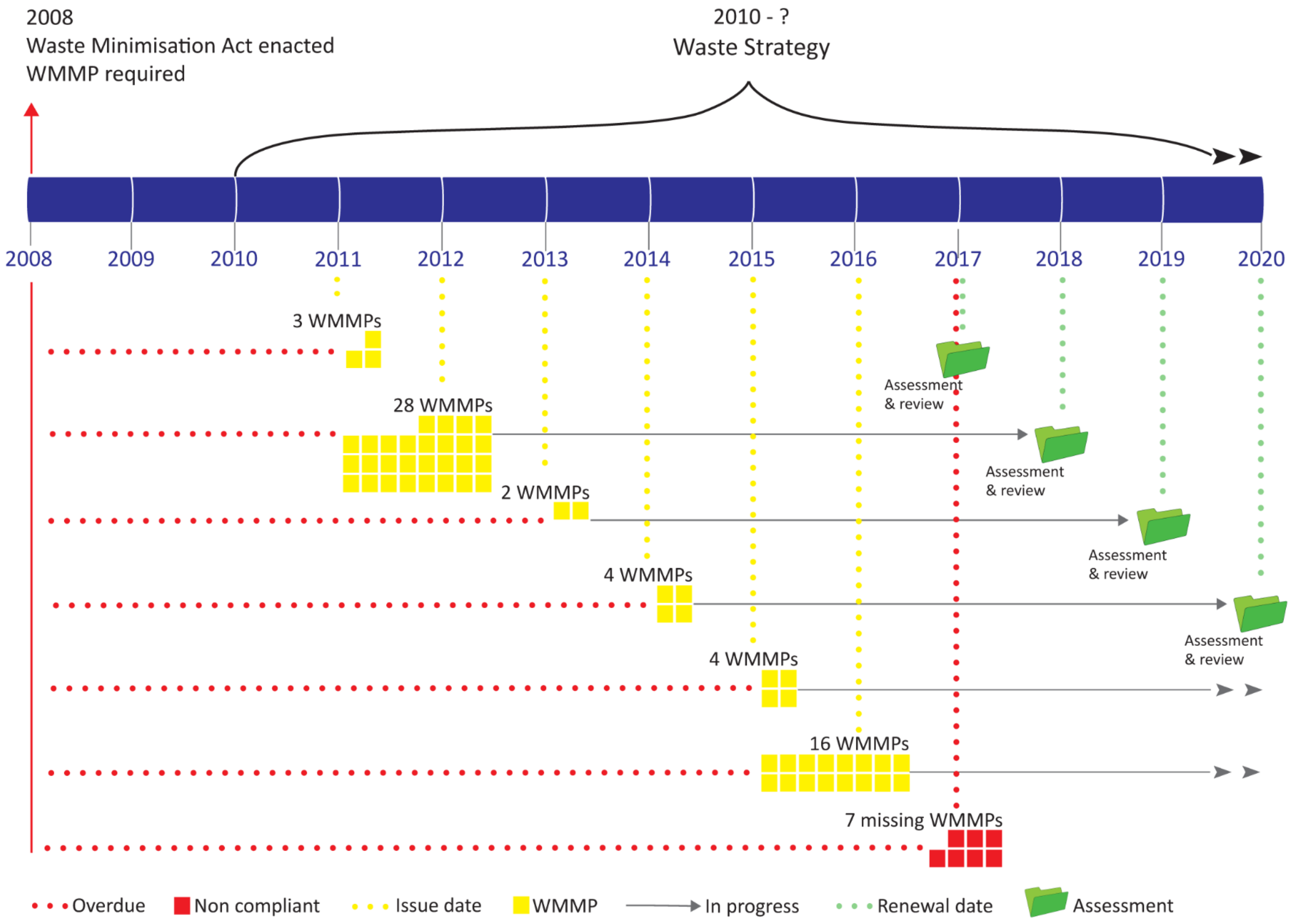
3.3 Results

3.3.1 Planning, Strategy and Collaboration

In total, 59 WMMPs and 8 regional waste documents were reviewed (Appendix F). In 2012 (four years after implementation of the WMA), only 31 (out of 66) TAs had complied with s 43(1) of the WMA by issuing a mandatory WMMP, and an additional 26 TAs issued documents between 2012 and 2017 (Figure 3.3). As of December 2017, 10% (n = 7) of the TAs with a combined population of 68,019 (~1.5% of total NZ population), did not comply and had no WMMP in place (Figure 3.3).

Figure 3.3

Compliance With Required Issuance of Waste Minimisation and Management Plans (WMMPs) Between 2008 and 2020



At the regional level, 44% (n = 7) of the RAs, with a combined population of 854,497 (~18% of total NZ population), did not have a (voluntary) regional waste management document (Table 3.1). Six of the seven TAs without a (mandatory) WMMP were located in regions without a (voluntary) waste document, indicating a possible link between regional coordination and statutory document compliance in the underlying TAs. The goals described in the regional waste document ranged from aspirations of becoming a zero-waste region, to providing leadership on waste minimisation, to work together, and to reduce amount of waste to landfill (Table 3.1).

Table 3.1

Voluntary Regional Waste Management Documents Details (2017)

Region	Collaboration	Document name	Year	Goals	
				Strategic	Tactical
			North Island		
Northland	Nil	Nil	Nil	Nil	Nil
Auckland [a]	TAs	Auckland WMMP	2012	Zero-waste city by 2040; all waste is turned into resources	Reduce waste per capita with 40% by 2018
Waikato	Bay of Plenty	Waikato Waste and Resource Efficiency Strategy	2015	Become a zero-waste region	Collaborate with key industry, local government and partners
Bay of Plenty	Waikato	Bay of Plenty waste and resource efficiency strategy	2016	Providing leadership on minimising waste	Collaborative partnerships
Gisborne	Nil	The Waste Management Minismisation (sic) Plan 2012-2018	2012	Working towards zero-waste to landfill	Reduced quantity of waste to landfill per capita
Hawke's Bay	Nil	Nil	Nil	Nil	Nil
Taranaki	TAs	Waste Management and Minimisation Strategy for Taranaki	2016	Reduce harmful effects of waste and improve efficiency of resource use	Reduce waste to landfill; reduce waste collected through kerbside and keep increase in waste to landfill below increase in regional economic performance

Region	Collaboration	Document name	Year	Goals	
				Strategic	Tactical
Manawatu-Wanganui	Nil	Nil	Nil	Nil	Nil
Wellington	TAs	Wellington Region Waste Management and Minimisation Plan 2017-2023	2017	Waste free by working together	Reduce per capita waste to Class 1 landfills from 600kg to 400 kg by 2026
			South Island		
Tasman Nelson [a]	TAs	Nelson City Council and Tasman District Council Joint Waste Management and Minimisation Plan	2012	Avoid waste creation, improve efficiency, reduce harmful effects	Investigate joint landfill, gather better data on waste; divert organic waste from landfill
Marlborough [a]	Nil	Waste Management and Minimisation Plan (WMMP)	2015	Reduce amount of waste to landfill	Establish sorting facility by 2016, investigate options for reduction of food waste, co-mingled recycling, public place recycling schemes, expanding green waste into compost
West Coast	Nil	Nil	Nil	Nil	Nil
Canterbury	Nil	Nil	Nil	Nil	Nil
Otago	Nil	Nil	Nil	Nil	Nil
Southland	Nil	Nil	Nil	Nil	Nil

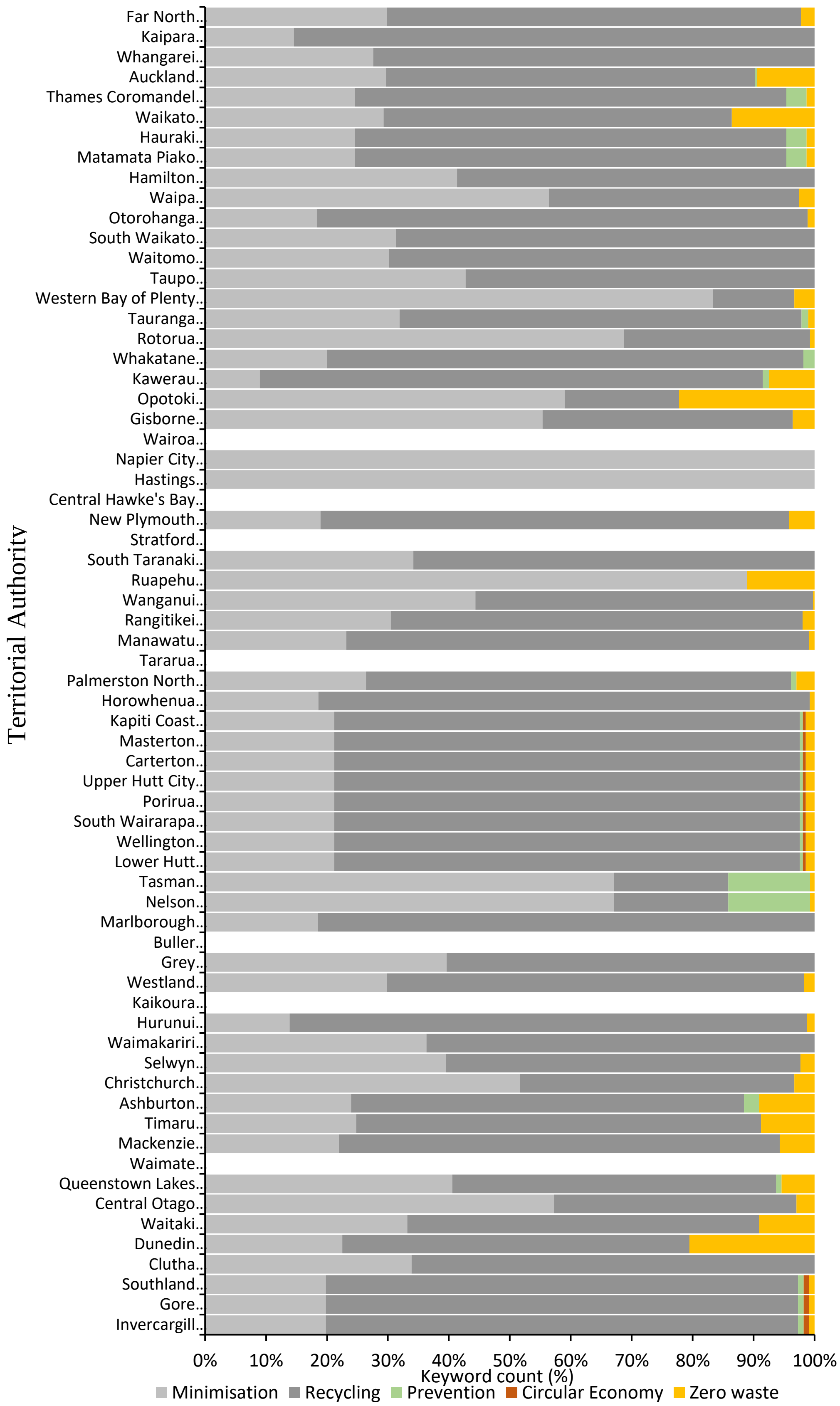
Note. [a] = Unitary Authority where Territorial Authority also has responsibilities, duties and powers of a regional council. TAs = Territorial Authorities.

The goals described in the WMMPs ranged from literal copies of those of the Waste Strategy (i.e., "reduce harmful effects of waste and improve the efficiency of resource use") to specific tactical goals such as "reduce waste from 600 kg per capita to 400 kg per capita by 2029" in the Wellington region (Appendix F). Furthermore, the WMMPs generally followed the suggested format as provided in the "Waste Assessments and Waste Management and Minimisation Planning – A Guide for Territorial Authorities" (Ministry for the Environment, 2015), indicating the impact of language used in such guiding documents.

Strategic or tactical implementation of the higher (preventative) levels of the waste hierarchy is almost non-existent in the WMMPs, based on the prevalence of relevant keywords (Figure 3.4). Logically, all documents mention "minimisation" and "recycling" (of existing waste streams), but only a few documents discuss the prevention of waste through, for example, zero-waste and the circular economy (Figure 3.4). The latter was solely mentioned in those plans developed in cooperation with other TAs (Southland and Wellington) (Appendix F). This may suggest that collaboration between TAs and the RA is linked with more progressive waste management strategies higher in the waste hierarchy.

Figure 3.4

Strategic and Tactical Intent of Waste Minimisation and Management Plan per Territorial Authority Based on Keyword Prevalence in 2017

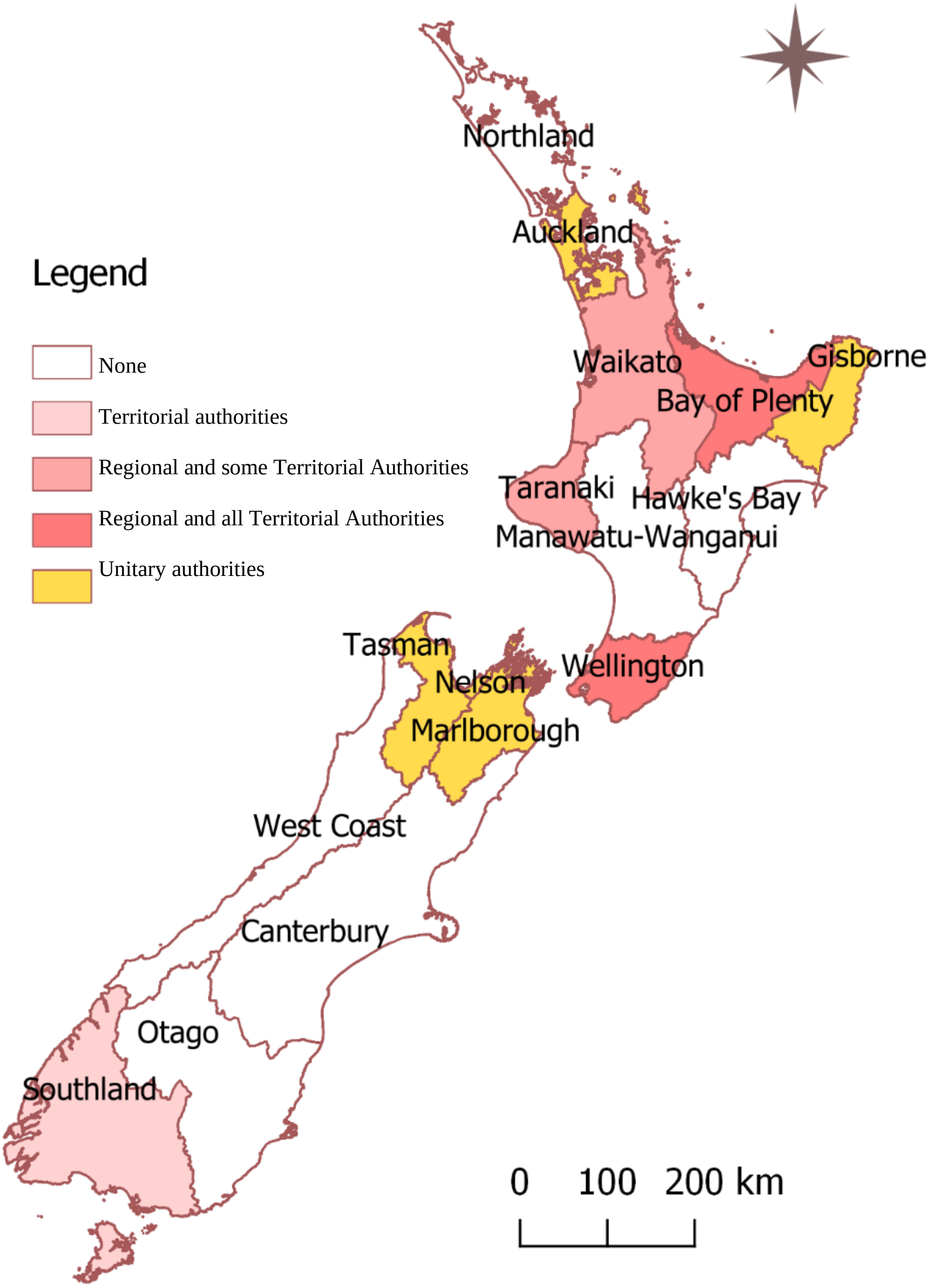


In total, 35% (n = 25) of the TAs indicated collaborating in their waste management planning (Figure 3.5). At a regional level, six RAs collaborated with TAs in their region or with other RAs as documented in a waste plan (Appendix F). Two of the six collaborating RAs were unitary authorities, where the roles of the RA and TA are combined (and therefore requiring a WMMP), thus leaving Waikato, Bay of Plenty, Taranaki and Wellington (all NI) the only regions to develop a truly voluntary coordinating regional waste document.

Cooperation between parties was most prolifically described for the Bay of Plenty (NI) region (Bay of Plenty Regional Council, 2013). The WMMP was drafted not only with input from all the TAs in the region, but the process also included a neighbouring RA (Waikato) and dozens of stakeholders representing industry, retailers, waste transporters and processors, researchers and non-government organizations (Bay of Plenty Regional Council, 2013). In the greater Wellington region, all eight TAs collaborated and adopted the same WMMP, albeit with different operational and collection aspects (Councils in Wellington region, 2017). A slightly different approach was applied in Taranaki, where the regional waste management strategy was drafted in collaboration with the TAs (Stratford, New Plymouth and South Taranaki) (Taranaki Solid Waste Management Committee, 2016). Consequently, New Plymouth and South Taranaki further developed individual WMMPs, whereas Stratford did not (Appendix F). Lateral collaborative efforts between TAs (without RA involvement) were established between Southland, Invercargill and Gore, resulting in one single combined WMMP (WasteNet Southland, 2012), Napier and Hastings, and in Eastern Waikato between Thames-Coromandel, Matamata-Piako and Hauraki (Appendix F).

Figure 3.5

Levels of Collaboration between Local Authorities in Waste Planning (2017)



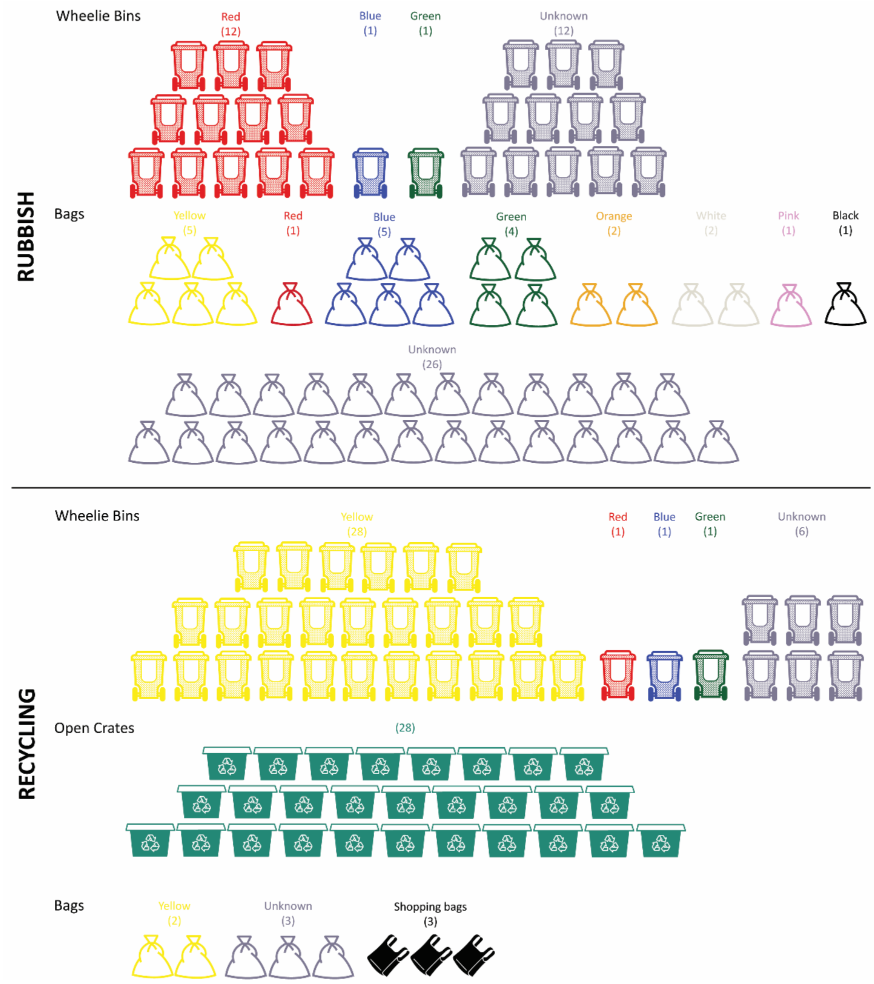
3.3.2 Collection Methods

The review of the TAs' webpages (for details see Appendix G) indicated that in only one TA no kerbside rubbish collection existed (Kaikoura), and three other TAs lacked kerbside recycling services (i.e., Wanganui, Rangitikei and Waitaki). Rubbish was collected in plastic bags in 48 (of the 65) TAs, of which 26 were colour unspecified (Figure 3.6).

Some TAs solely collect bags in defined colours, ranging from white, blue, green, orange, and red, pink, yellow and in some instances, supermarket bags (Figure 3.6). When the "wrong" colour bag is placed at the kerbside, the bag might not be collected. One such example is Hurunui (SI), which state that any bag other than official council bags will not be collected and will be considered illegally dumped as described in the Litter Act 1979 ss 14 and 15 (Hurunui District Council, n.d.).

Figure 3.6

Types and Colours of Rubbish and Recycling Collection Methods in New Zealand (2017) by Count of Territorial Authority



Uptake of the WasteMINZ (a representative body of the waste industry in NZ; https://www.wasteminz.org.nz/) recommended (voluntary) colour schemes for wheeled bins is moderate, with 75% (26 of 35) of those TAs collecting recyclables with wheeled bins complying with the agreed (yellow) colour scheme. Yet, in South Waikato, the recycling bin is red, which is the suggested colour for rubbish. Eight of the TAs that collect recycling in bags have overlapping colour schemes with rubbish bags from other TAs (Figure 3.6).

3.3.3 Plastic Collection Schemes

Plastic recycling schemes are commonly defined by grades (Table 3.2), which refer to the different resin codes of which plastics are made. These codes designate the range of qualities relating to the plastic's flexibility, durability, and heat resistance. Each plastic resin has distinct characteristics that also influences its recyclability (Gregory, 2003; OECD, 2018). Some plastic grades are easier to recycle (e.g., Grades 1, 2), and some are virtually un-recyclable (Grades 3, 4, 5, 6 & 7). The types of plastics collected and recycled at a TA is dependent on the collection methods, infrastructure, processing ability, contracts (with operators) and international market pressures (Wilson et al., 2018).

Table 3.2

Plastic Grade Descriptions and Collection Data From 66 Territorial Authorities (2017)

Grade	Acronym	Description	Examples	No. TAs	%
1	PET and PBT	Thermoplastic polyester Polybutylene terephthalate	Soft drink bottles, food condiment containers	63	95
2	HDPE	High-density Polyethylene	Water and milk bottles, cleaning products	63	95
3	PVC	Polyvinylchloride	Food packaging, wrap shampoo bottles, squash bottles (water), food trays	49	74
4	LDPE	Low-density polyethylene	Cling wrap, ziplock bags, bubble wrap, grocery bags and bin liners	49	74
5	PP	Polypropylene	Bottle caps, take away containers, medicine bottles, plastic cutlery, ropes and fibre	51	77
6	PS	Polystyrene	Foam meat trays, egg cartons, styrofoam cups, take away cartons	47	71
7	Other	Polycarbonate	Any plastics not 1-6; including biobased plastics	44	67

All TAs that collect plastics in their recycling scheme included Grades 1 and 2. About 75% of the TAs collected Grades 3, 4, 5 and 6, although the exact combination of collected resin codes varied by (or within) a TA. In addition to an existing array of collection methods, there are (at least) nine different schemes for plastic collection and another seven different instructions for lids (Table 3.3).

Table 3.3

Combinations of Plastic Grades Collected at Kerbside and Lid Instructions by Count of Territorial Authorities in 2017

Recycling collections	TAs accepting	% of overall
Plastics recycling		
None	3	5
1+2	9	14
1+2+3+5	1	2
1+2+3+4+5	1	2
1+2+3+4+5+7	1	2
1+2+3+4+5+6	3	5
1+2+3+4+5+6+7	41	62
1+2+4+5	1	2
1+2+5	1	2
Lids		
No specific instructions	27	41
No lids	24	36
Lids on containers	8	12
Lids separate from containers	3	5
No lids, except on milk bottles	1	2
Lids only when recyclable	1	2

Note. Description of plastic grades in Table 3.2.

3.3.4 Landfills and Farm Dumps

The primary legislation governing landfills in NZ is the RMA. Management of sites occurs through regulating the effects of waste management facilities with policies, plans and resource consents. Under s 43 of the RMA, the central government can set binding National Environmental Standards (NES). The Resource Management (National Environmental Standards for Air Quality) Regulations 2004, require landfills with a capacity < 1 million tonnes of waste to collect landfill gasses (to flare or use as fuel) (cls 25 and 27). The NES for air quality furthermore prohibits the burning of wastes at landfills (cl 6(1)) and the burning of tyres (cl 7(1)) (RMA, 1991). This NES serves as a basis to monitor air quality and to report against NZ's carbon reduction efforts under the Climate Change Response (Zero Carbon) Act, 2019. This constitutes the only official monitoring requirements of NZ (Class 1) landfills. Other relevant legislation to NZ landfills includes the Health and Safety at Work Act 2015 and the Hazardous Substances and New Organisms Act 1996.

Part 4 of the RMA describes the roles of the local authorities in the management of natural and physical resources. Amongst other things, the RA is responsible for preparing, implementing and reviewing objectives, policies and methods to achieve the RMA's goals (s 30(1)). In addition to controlling discharges of contaminants into or onto land, air, or water and discharges of water into water (s 30(1)(f), it controls (in conjunction with the Minister of Conservation) discharges of contaminants in the coastal marine area (s 30(1)(d)(iv)). Section 31 describes the role of the TA under the RMA, which includes the establishment, implementation and review of district plans outlining resource management issues, objectives, policies and methods to control the effects of activities on land and water, to prevent or mitigate the potential impact of natural hazards (s 31(1)(a)).

Under Part 5 of the RMA, resource management plans are established by local authorities to guide and regulate activities. Of importance to landfill activities are district plans (ss 72 - 77) prepared by TAs, which (amongst other things) regulate land use. RAs are responsible for developing and implementing regional and coastal plans that may regulate the control of discharges and water quality (ss 63 - 71).

Part 6 of the RMA sets out a detailed consenting regime, which is founded upon the requirements of resource management plans and resource use presumptions. Most of the *active* landfills in NZ are now consented, yet only 11% (45 of the 426) have actual monitoring and reporting requirements (Ministry for the Environment, 2019d; Tonkin & Taylor, 2014; D. Wilson et al., 2017). Hence, the waste disposed at the remaining *381* consented landfills remains unmonitored, unreported and therefore, unknown (Ministry for the Environment, 2019d) (Figure 3.7). An additional 1,000 now “closed” (meaning they no longer accept waste) landfills are not subject to any reporting requirements (Simonson & Hall, 2019). With the exception of levied Class I landfills, all other style landfills (Figure 3.8) do not meet modern landfill requirements nor have preventative waste loss capture systems in place (Simonson & Hall, 2019; WasteMINZ, 2018).

Figure 3.7

Levied and Unlevied Waste Disposal in the New Zealand Waste Management System

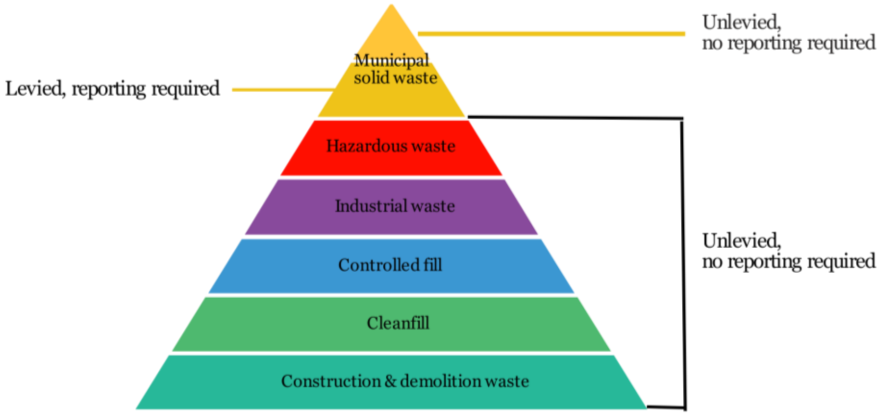


Figure 3.8

Count of Consented Landfills by Class and Status in New Zealand (2017)

Class 1: Levied and unlevied, accepts municipal solid waste, hazardous waste, industrial waste and all waste types accepted in other classes.

Class II: – Unlevied, accepts construction and demolition waste, as well as waste accepted in classes III & IV

Class III: Unlevied, accepts controlled fill, manufactured inert materials, as well as waste accepted in class IV

Class IV: Unlevied, accepts cleanfill, natural and uncontaminated materials

Class "?": Unlevied, and unknown which materials are accepted

Note. Adapted from Ministry for the Environment (2017). Review of the effectiveness of the waste disposal levy.

Farm dumps are treated separately to other landfill activities in NZ. Regional plans regulate discharges, and although voluntary (s 65(1)), they are in existence in all regions. A review of these regional plans demonstrated that plans generally allow the discharge of farm waste to land (Table 3.4). Most RAs do require the farm dump to be a certain distance away from waterways and pose restrictions on the items allowed (e.g., no toxic waste). An example of such a rule in the Bay of Plenty (NI) defines that farm dumps are permitted as long as the waste is "produced from normal farm operations or if it is (the farm's) household waste" (Bay of Plenty Regional Council, 2018, rule 25). It does exclude the dumping of hazardous substances (b)(i) and prescribes conditions that the dump must not be located within 50 m of a stream, river or lake (d)(i). The plan also includes an advisory note that the farmer's neighbours should be considered and therefore *control of the nuisance effects of windblown litter* is advised (Bay of Plenty Regional Council, 2018).

Table 3.4

New Zealand Regional Plan Details (2017) Regarding Farm Dump Rules

Region	Name	Year	Farm dumps
		North Island	
Northland	Regional Water & Soil Plan for Northland	2010	Permitted activity (Rule 19.1.3)
Auckland	Auckland Regional Plan: Air, Land and Water	2010	Permitted activity for non-residential farm waste (A11, A12 in Rural zones, A14, A15 in Waitakere Foothills, A15, A16 in Waitakere Ranges)
Waikato	Waikato Regional Plan	2012	Permitted activity (Rule 5.2.6.1)
Bay of Plenty	Bay of Plenty Natural Resources Plan	2017	Permitted activity (Rule 25)
Gisborne	Regional Plan for Discharges to Land, Water, Waste Management and Hazardous Substances	2015	Permitted activity (Rule 3.5.2)
Hawke's Bay	Regional Resource Management Plan	2006	Permitted (Rule 16)
Taranaki	Taranaki Regional Council Requirements for good farm management in Taranaki	2017	Permitted
Manawatu-Wanganui	One Plan – The Consolidated Regional Policy Statement, Regional Plan and Regional Coastal Plan for the Manawatu-Wanganui Region	2014	Permitted (Rule 14 - 27, 28)
Wellington	Regional Plan for discharges to land for the Wellington Region	2014	Permitted (Rule 9)
		South Island	
Tasman	Tasman Resource Management Plan	2011	Resource consent required (Rule 36.1.5.1)
Marlborough	Marlborough Sounds Resource Management Plan	2003	Not permitted
West Coast	Regional Land and Water Plan	2014	Permitted (Rule 72, 73)

Region	Name	Year	Farm dumps
Canterbury	Canterbury Land and Water Regional Plan	2017	Permitted (if no kerbside services, Rule 5.27)
Otago	Regional Plan: Waste for Otago	1997	Permitted (Rule 7.6.8)
Southland	Southland Water and Land Plan	2018	Permitted (Rule 43)

3.4 Discussion

This chapter provides an insight into aspects of the legal, strategic and operational landscape of waste management and related pollution control in NZ. The overarching focus was to identify factors and mechanisms associated with high waste creation and ensuing waste loss to the environment. Local details of methods and plastics collection illustrated inefficiencies likely to result in waste loss to the environment, which are discussed in more depth below.

In theory, the WMA provides a comprehensive framework for effective waste management, yet the fact of increasing waste creation remains (OECD, 2021). Unlike countries with much better (lower) waste and (higher) recycling records, many of the available waste prevention tools remain unused in NZ (Blumhardt, 2018; Hannon, 2018; Schofield, 2010). A strategic shift from waste minimisation to waste prevention necessitates the involvement, regulation and collaboration of all stakeholders in the waste cycle, including all government layers, private waste industry and product manufacturers (Ghisellini et al., 2016; Pietzsch et al., 2017; World Economic Forum & Ellen MacArthur Foundation, 2017; Zacho & Mosgaard, 2016). Although multiple efforts are underway to address some of these aspects (New Zealand Government, 2018b), TAs currently developing a new WMMP are still bound by outdated guidance documents that lack specific instructions and language on waste prevention.

3.4.1 Ineffective Planning

Since the onus of operational waste planning lies with the TAs, a holistic and system-wide change (i.e., a shift from a linear to a circular economy) in NZ seems unlikely without legislative direction at central government level. In addition, collaboration at local government levels is hindered by a lack of direction and the lack of a coordinating role mandated for RAs. Implementation of statutory functions is uneven and the failure to adopt a mandatory WMMP arose in seven TAs, six of which were located in regions that did not oversee waste management through a (voluntary) regional waste document. Next, the staggered issue dates of 6-year WMMPs (Figure 3.3) mire cooperative waste planning progress at the local government level.

This is partly a result from a TA's obligation to operate as described in its WMMP (s 43), with service contracts generally based on the period as described in the multi-year plan. It is therefore difficult to collaborate with other TAs, when the planning cycles and terms of the legal contracts start and end in different years (Figure 3.3). To coordinate these cycles would mean to either to break a current contract, or to introduce an interim situation, until timelines with potential collaborators are synced. This has potentially far-reaching implications for the budgets, funding, operators, and residents in a TA. Therefore, central direction to align such dates, at a minimum per region, would be necessary.

Lastly, when creating or reviewing a WMMP, TAs are obligated under the WMA to consult and consider the NZ Waste Strategy (s 44(c)). This guidance document, however, is now 10-years old and may have limited fitness for purpose in the changing waste management landscape. For example, the strategy mainly focuses on minimisation of waste through recycling and lacks crucial information on how to prevent waste or how to promote more systemic changes in the waste industry. These combined factors hinder local authorities' planning and implementing of modern and timely waste prevention strategies through increased collaboration.

The inability of different layers of NZ's government to work together towards a more efficient waste management system has been identified as worrisome both internationally (OECD, 2000, 2007, 2017), and nationally (Wagener, 2009).

A similar situation is described in Argentina, where different layers of government avail of multiple legal tools and instruments, yet the lack of coordination between these layers, coupled with weak enforcement, results in ongoing waste loss to the environment (González Carman et al., 2015). Likewise, in Europe, variations between national and international regions with nonuniform environmental policies created waste management inefficiencies and increased waste (Halkos & Papageorgiou, 2016). The challenges described there merely relate to the lack of collaboration of different government levels and do not yet account for the much-needed collaboration with all other stakeholders in the waste management process such as manufacturers (Brody, 2003).

Countries with high and increasing recycling rates (and decreasing amounts to landfill) demonstrate analogous features, including the separated collection of recycling and organic waste, (partial) landfill or incineration bans, variable rate charging, statutory recycling rates, mandatory product stewardship, and deposit refund schemes (Gillies et al., 2017). None of these measures apply systematically in NZ, except for the 23% of TAs who apply some form of variable rate charging and/or are trialling organic waste collection (e.g., Auckland). An estimated 30% of all NZ landfilled waste is organic (Perrot & Subiantoro, 2018), and could not only be prevented, but be reused as a resource (composting). Once in the landfill, organic wastes contribute to the generation of greenhouse gasses (methane in particular) (US EPA, 2020). In NZ, only the larger landfills (< 1 million tonnes) are required to capture such gasses (Resource Management (National Environmental Standards for Air Quality) Regulations 2004), resulting in all inorganic waste deposited to other landfills as a contributor to harmful emissions.

Despite the NZ Waste Strategy and ensuing WMMPs predominantly centring on waste minimisation through recycling; actual recovery rates through recycling are low and decreasing (Ministry for the Environment, 2017). This solicits the query of what is the purpose, relevance and reach of these documents, and what other influences trigger NZ’s adverse waste status with such low recycling rates?

3.4.1.1 Disparate System

Almost all TAs in NZ offer kerbside waste and recycling collection services (Appendix G). Sometimes, the TA provides these kerbside services themselves, although more frequently they are either contracted or operated through private parties (Table 3.5). When services are offered through private operators, it might entail one single provider (e.g., in Kaipara) or a range of providers (e.g., seven in Tauranga) (Ministry for the Environment, 2014).

Table 3.5

Service Providers by Type of Collection within Territorial Authorities (TAs)

Collection	TA	TA contracted	TA contracted & Private	Private
Rubbish	6%	43%	36%	15%
Recycling	13%	64%	Nil	23%

Note. Adapted from D. Wilson et al. (2018). National resource recovery project—Situational analysis report. Eunomia Research & Consulting.

When contracted, the TA can impose requirements upon the service provider concerning data provision and service level expectations. However, local contracts are negotiated (and evaluated) on an individual basis. As a result, private service providers might not be bound by the requirements of the local WMMP, resulting in potential market asymmetries (Dolla & Laishram, 2019). Hence, where TAs are destined to operate as described in the WMMP (e.g., prioritise prevention over recycling or landfilling), private operators function based on economic principles. In 2018, over 20 private parties were active in the NZ waste markets, with operations in multiple system layers (Wilson et al., 2018). In addition to not necessarily being bound by the WMMP, most available industry data is kept confidential (Ministry for the Environment, 2019a), and remains therefore, unmonitored and unaccountable.

One of those system layers is the *end of the pipeline* of all rubbish in NZ: the landfill. Some local authorities own and operate, or contract out operations of their landfills (e.g., Waitomo, Rotorua and Clutha) (Denne & Bond-Smith, 2012; Ministry for the Environment & Statistics New Zealand, 2018). Other landfills are privately owned (e.g., Tirohia and Hampton Downs in Waikato), and some are in a private/public partnership (e.g. Kate Valley in Canterbury) (Denne & Bond-Smith, 2012). In 2012, the two national waste processors (TPI Waste Management, [https://www.cleanaway.com.au/] and EnviroWaste [https://www.envirowaste.co.nz/]) owned operations throughout the entire waste management value chain, including kerbside collection, transfer centres, processing operations, as well as landfills, (Denne & Bond-Smith, 2012).

Private companies operating in the waste management industry are not economically driven by minimising (let alone preventing) waste, particularly not with low landfilling costs (Ministry for the Environment, 2019d). Moreover, private parties are not bound (unless stipulated in their contract) to report on quantities and composition of collected waste streams. Therefore, TAs cannot know what percentage of their areas' overall kerbside waste is captured and recycled (Matthews, 2014). This leaves most planning and reporting of waste management to be speculative at best. For example, in Auckland (~ 35% of total NZ population), the TA's waste service providers (following the local WMMP) cover and report only an estimated 17% of total waste collections (Auckland Council, 2012). This is problematic and flagged as such in Auckland's regional waste document (Auckland Council, 2012).

Hence, in addition to the WMMPs lacking proper strategic directions and facing barriers to collaboration, the WMMPs only apply to a small portion of the service providers. This leaves the private waste industry in NZ not only unregulated, unmonitored and uncontrolled, but also largely responsible for the past and current undesirable waste status of the country. Uptake of voluntary guidelines created by the industry to reduce waste contamination are poor (Figure 3.6), indicating a need for mandatory system wide regulation. The uneven systemic market influences the manner and method by which collection occurs (Tables 3.2 and 3.3) and results in inefficiencies due to inconsistent collection methods and schemes (Office of the Prime Minister's Chief Science Advisor, 2019; Reams et al., 1996; Wagner & Broaddus, 2016; WasteMINZ TAO Forum, 2020).

3.4.1.2 Confusing Collections

Before collection occurs, but after receptacles are placed at the kerbside, items are prone to removal by wildlife, humans, or the elements. During collection, when a recycling crate is manually sorted at the kerbside, waste items may inadvertently 'escape' (Wagner & Broaddus, 2016). Such waste loss can also happen deliberately when the service provider removes non-compliant (according to local rules) items placed in the recycling and leave them behind (Wagner & Broaddus, 2016). Recycling behaviour, and the quality of the waste streams, can be affected by waste bin sizes, types, and colours (Lane & Wagner, 2013). In 2015, WasteMINZ, the Glass Packaging Forum (http://www.glassforum.org.nz/) and local councils agreed upon a voluntary standardised set of (lid) colours for, amongst others, recycling (yellow) and rubbish (red) receptacles. Uptake of this voluntary scheme is limited (Figure 3.6), indicating a need for a more stringent approach.

Disposal of bottles and containers have the added complexity that it is unclear what to do with the lids (Table 3.3). Lids can be plastic or metal, and their recyclability in a TA is rarely clarified. A likely result is that lids either inadvertently end up in the rubbish or are incorrectly recycled. The latter can leave the lids (as well as other misplaced items) left behind by the collectors, especially where collection occurs through open crates (Wagner & Broaddus, 2016). Both scenarios may contribute to an increase in mismanaged waste in the form of litter. This is substantiated by the fact that lids are unfailingly in the top 10 of terrestrial littered items found in streets and parks (Keep New Zealand Beautiful, 2019), on the beaches in NZ (Sustainable Coastlines, 2020), as well as globally (International Coastal Cleanup, 2002, 2017, 2018, 2019; Kuo & Huang, 2014; Liu et al., 2013). In response to this similar issue, the EU Council has adopted the requirement that beverage containers products are to be designed to have attached or tethered lids (Directive (EU) 2019/ of the European Parliament and of the Council of 5 June 2019 on the Reduction of the Impact of Certain Plastic Products on the Environment, 2019).

Roadside litter in NZ is omnipresent and suggested to (partly) result from inefficient waste collections (Keep New Zealand Beautiful, 2019). Such mismanaged waste can invoke additional and intentional littering (Al-mosa et al., 2017; Weaver, 2015), further cascading the impacts. Lingering litter items clog drainage systems and can cause flooding and property damage, as well as create odour, health and aesthetic nuisances (Armitage & Rooseboom, 2000; Lamond et al., 2012; Wagner & Broaddus, 2016). Indeed, those exposed to litter have higher anticipation of incivilities and experience higher crime prevalence (Medway et al., 2016).

The TAs have a statutory obligation to remove litter and to provide bins in public places (Litter Act, 1979, s 9), although ample litter remains (Keep New Zealand Beautiful, 2019). Enforcement of the Litter Act is, with a few exceptions (e.g., Auckland and Christchurch), rarely applied. Main provided reasons for this lack of enforcement are the need for specific litter officers to witness the offence, as well as complicated and lengthy legal procedures resulting in low success rates (New Zealand Parliament, 2019).

Tourists and individuals who spend time in multiple localities, for example, between home, work, recreation, sports, or visits, are likely to encounter differences in recycling instructions and schemes as they move between TAs (Table 3.3). All TAs that collect plastics included Grades 1 and 2, with ~75% of the TAs collecting Grades 3, 4 and 6. Yet, the exact combinations of which grades are collected where, varies by (or even within) a TA. Thus, in addition to an existing array of collection methods, there are at least nine different schemes for plastic collection and another seven different instructions for lids (Table 3.3).

Altogether, these inconsistencies in collection methods, bin receptacle colours and recycling schemes are likely to result in lower recycling rates (and higher waste). Incorrectly deposited recyclables in the waste were found with 41% of recyclable items going into the kerbside rubbish instead of the recycling bin (WasteMINZ TAO Forum, 2020). Equally, different and confusing variations in collection methods and schemes can furthermore result in contamination of recycling streams (by erroneously including non-recyclables) making those streams impure, of lesser value, and potentially rejected (Moura et al., 2018). Similar results were found in Australia in surveys of 79 municipal councils within one region (Agarwal et al., 2020). Inconsistent waste management practices between the councils were considered responsible for contamination of waste streams (Agarwal et al., 2020).

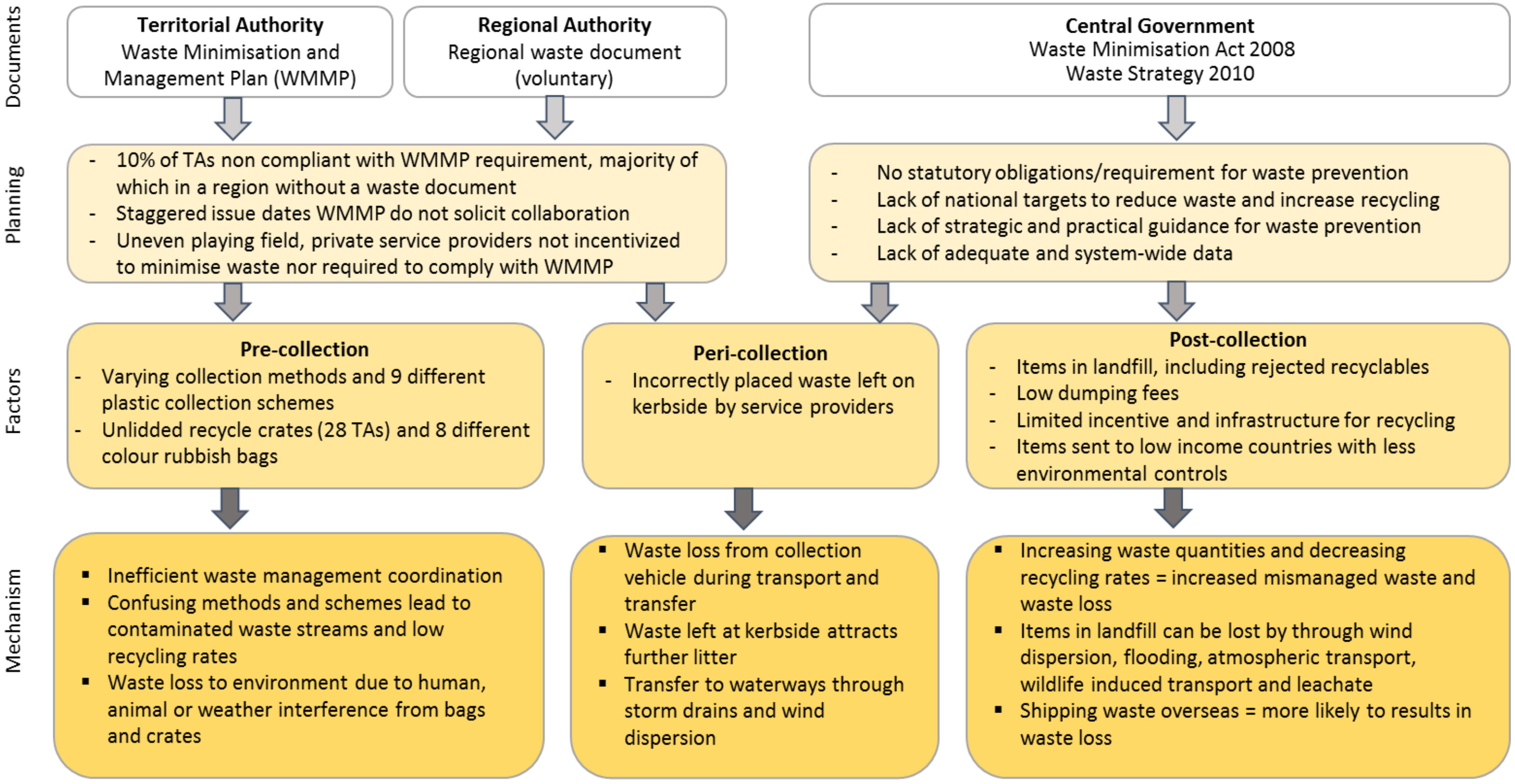
Misunderstandings around recycling methods and schemes are not unique to NZ and Australia. Global estimates suggest that of all the plastics ever produced in the world, only 9% are recycled, 12% are incinerated, and the remaining 79% landfilled or released to the environment as litter (Geyer et al., 2017).

However, a nation-wide overhaul and simplification of collection methods and schemes requires an adaption and coordination of strategy, planning in waste management documents, and unified collection bins and vehicles - all (significant) infrastructure investments (Pires et al., 2018). Using lidded wheeled bins over bags or open crates has shown to increase recycling rates (Wilson et al., 2018) in addition to eliminating the plastic waste bags from going to landfill (i.e. prevents waste). Wheeled bins seem less likely to result in environmental leakages at the kerbside as animals, humans and the elements are less likely to displace items. On the other hand, contamination of co-mingled recyclables collected in wheeled bins versus crates is often higher (Brouwer et al., 2019; Wilson et al., 2018) as was demonstrated in Australia (Commonwealth of Australia, 2018) and the Netherlands (Brouwer et al., 2019). Reasons provided included different types of processing confusion, the size of the wheeled bin, frequency of collection or the fact that the contents are invisible (Brouwer et al., 2019; D. Wilson et al., 2018). Collecting recyclables in lidded bins could thus at best minimize, and at worst displace, the location of waste loss to the environment. Specifically, lidded bins might cause less waste loss at the kerbside, but could create more rejects while processing, and potentially increase exports of contaminated recyclables to countries with less environmental controls (Brouwer et al., 2019; Moura et al., 2018).

Figure 3.9 summarizes the factors described in this section, leading to mechanisms of waste loss to the environment, in their relation to NZ’s primary legislation on waste management (WMA). Key factors include outdated strategic guidance, lack of collaboration due to asynchronous planning cycles as well as confusion resulting from variations in waste management operations factors.

Figure 3.9

Waste Planning and Collection Factors Leading to Inefficiencies and Waste Loss Mechanisms in New Zealand



3.4.2 *Unknown and Uncontrolled Landfills but Permitted Farm Dumps*

In NZ, all kerbside collections that are not recycled go to the 45 landfills permitted to accept municipal solid waste (from households, businesses, public waste bins, and street sweepings) (Figure 3.8). This waste stream approximates 30% of NZ's overall landfill influx (Ministry for the Environment, 2017, 2019d). The other 70%, which includes industrial waste, wastewater treatment residue, construction and demolition waste, and agricultural waste, goes to consented but unlevied landfills and is therefore not monitored or reported. Other than the newer Class 1 and 2 landfills, sites are not built to modern environmental specifications (Ministry for the Environment, 2000, 2011; WasteMINZ, 2018). In addition to the 426 consented and active landfills, there are 1,000 known inactive and unregulated landfills (Ministry for the Environment, 2019d). Of these, 110 (with unknown contents), as well as 2 active landfills (SI) are vulnerable to exposure with a 0.5 m sea-level increase, and another 129 inactive and 2 active with 1 m rise (Simonson & Hall, 2019), further increasing the risk of inadvertent landfill openings and concomitant waste loss to the environment.

In lieu of sending their waste to (consented, regulated and controlled) landfills, an estimated 46,680 NZ farms dispose an estimated 1,557,033 tonnes per annum of their waste by disposing (or burning) on or into their land (Ministry for the Environment, 2019d). This is an expressly permitted activity (through regional rules) in all but three NZ regions (Table 3.4). Items disposed of on, or into, farmland includes plastic, rubber and petrochemicals (Hepburn & Keeling, 2013; Matthews, 2014), of which 2% is burnt (Ministry for the Environment, 2019b). At least half of these farm dumps are located near waterways or drainage ditches (Hepburn & Keeling, 2013; Matthews, 2014), facilitating likely waste loss to the environment through the soil, wind dispersion, wildlife, or groundwater.

Depending on the type of waste deposited, site specifics, and climatic circumstances (Umar et al., 2010), leachate from landfills (and farm dumps) can contain, amongst others, ammonia, nitrogen, heavy metals and chlorinated organic and inorganic salts (Renou et al., 2008), as well as microplastics (He et al., 2019). These contaminants can enter the groundwater and seep into nearby waterways (He et al., 2019; Sharma et al., 2020), and cause (cumulative) negative impacts (Chapter 1). Whether or not waste is directly discharged into water, the failure to control and prevent these polluting activities under the RMA results in ongoing waste loss to the environment. Allowing those activities is seemingly inconsistent with the core purpose of both the WMA and RMA as described in s 3(b) *protect the environment from harm,* and s 5(2) *promote sustainable management of natural and physical resources,* respectively.

With regards to NZ's international commitments, open farm dumps are contrary to the targets of multiple Sustainable Development Goals (Table 1.1), and in particular to the derived virtual goal to eliminate all uncontrolled dumping and open burning (Rodić & Wilson, 2017). In Europe, the "Council Directive 1993/31/EC of 26 April 1999 on the landfilling of waste*"* requires countries to act appropriately to avoid dumping or the uncontrolled disposal of waste. In countries with developed waste management systems, the backyard or farm burning of wastes is not permitted and considered an example of mismanaged waste (Asari et al., 2019; Jambeck et al., 2015), and others include all non-modern landfills in that category as well (Lau et al., 2020). Waste loss from farm dumps and landfills is considered a main source of AMD (Alkalay et al., 2007) and necessitates legislative and management action to cease ongoing waste loss.

Wagener (2009) finds that the RMA does not require national nor local authorities to provide or adhere to any specified system of waste management and therefore results in inconsistencies. Furthermore, the process for resource consents relating to solid waste disposal does not consider the waste hierarchy (i.e., prevention over landfilling) and only deals with the environmental *effects* of the location of the site (Wagener, 2009). Enabling farm dumps as permitted activities potentially fails to assess and manage cumulative effects upon the environment (as required under s 3(d)). The use of permitted activity conditions is not a robust mechanism for limiting environmental harm. These concerns are recognized by the Resource Management Review Panel (2020), who conclude that weak compliance, monitoring and enforcement across the resource management system has undermined rules in plans that protect the environment. The report furthermore concludes that penalties are weak, cost recovery is poor, especially in relation to permitted activity monitoring and the investigation of unauthorised activities (Resource Management Review Panel, 2020).

The key factors described above that lead to mechanisms of waste loss to the environment in their particular relation to NZ's primary legislation on pollution control (RMA). Specifically, the permissive nature of regional rules towards farm dumps are considered main contributors to waste loss to the environment.

Overall, based on the evidence presented in this chapter, strategy, planning, compliance and enforcement of NZ legislation relating to waste management and pollution control needs reviewing and upgrading. Changes are required to better manage and avoid ongoing and future pollution resulting from mismanaged waste. In particular, the failure to adequately regulate (or prohibit) farm dumps and the potential for compliance failures in consented landfills are recognized deficits under the RMA.

3.5 Conclusions

Some factors of the formal waste management system governed by the WMA are prone to facilitate waste loss to the environment. The two leading causes identified are: 1) the failure to reduce NZ's high waste creation; and 2) mismanaged waste resulting from inefficiencies in the formal waste planning and operational phases, including landfilling.

Despite the need to emphasize waste prevention, NZ's law and policies do not provide firm direction nor create strong obligations for local authorities to implement such actions. At the central government level, the WMA is not utilized to guide the implementation of systemic change. Tools available, but not employed in NZ, have proven effective in other countries. Examples comprise adequate waste monitoring, national waste reduction targets, national recycling targets, mandatory product stewardship (including a container refund scheme) and an increased waste levy on all types of landfills.

Inconsistencies in plastic recycling schemes (Table 3.3) and colour and type of receptacles (Figure 3.6) lead to potential increased amounts of mismanaged waste due to inconvenience and confusion. Furthermore, the waste management system is not a level playing field in NZ. Collection and processing are predominantly performed by private operators (Table 3.5) who are not (always) bound by WMMPs, and (given their roles in multiple layers of the system) have no economic incentive to minimise or prevent waste. Except for the small number of levied landfills, no requirements exist for ongoing monitoring and on NZ landfills; leaving the unlevied (but consented) landfills mainly unreported. A further 1,000 closed landfills are under-monitored, and 46,680 farm dumps are permitted (Ministry for the Environment, 2000, 2011; Ministry for the Environment & Statistics New Zealand, 2018).

Although the exact quantification of waste loss to the environment in the NZ setting is impossible to determine without reliable and complete waste data and further research, it is probable that waste loss to the environment from the formal waste management system is > 0% (the assumed percentage for high-income countries) (Jambeck et al., 2015). In the next chapter, a selection of local waste management factors are modelled against the AMD found on the local NZ beaches (Chapter 2).

Chapter 4

Connecting the Dots: Extracting Significant Predictors Associated with Beach Litter

Plastic leakages to the environment in New Zealand, van Gool, E.D.

4.1 Introduction

The ubiquitous presence of anthropogenic marine debris (AMD) on beaches is a result of systemic failures. Coasts have a recreational, spiritual, food-gathering, and cultural heritage role, and the existence of AMD compromises these values when compared to a pristine environment (Ballance et al., 2000; White et al., 2016). Ecologically, the multitude of cumulative AMD impacts can lead to displacement, death and local extinction of species (Hanni & Pyle, 2000; Tekman et al., 2019). In order to address and prevent AMD, a better understanding is first needed of the specific factors causing this phenomenon.

AMD abundance varies widely in general, and between specific locations, despite the plenitude of global beach surveys conducted in the past decades (Figure 1.3). Yet it remains unclear what are the primary contributors of AMD abundance. Aside from complications due to differing sampling procedures, it is difficult to distil general trends in significant factors relating to AMD. For example, currents, surface waves, tides and prevailing winds, can contribute to the deposition of AMD far from where items entered the ocean (Aliani et al., 2003; Cozar et al., 2014; Eriksen, Maximenko, et al., 2013; Winston, 1982). Such results are demonstrated by AMD found on remote and uninhabited islands (Lavers & Bond, 2017) and in oceanic gyres (Eriksen et al., 2016; Lebreton et al., 2018). However, the coastal area is considered a (temporary) sink for debris (Lebreton et al., 2019), particularly for larger items (Olivelli et al., 2020).

Undisputedly, items are left behind by visitors on beaches (Santos et al., 2005; Wilson & Verlis, 2017) and, depending on local circumstances, they become entrained in the swash zone (de Santana Neto et al., 2016; Turrell, 2018). However, in most locations, more debris arrives at the beach from further inland by a number of means including wind and freshwater dispersal (Martinez-Ribes et al., 2006; Schmidt et al., 2017).

Initial reports of riverine litter ultimately deposited on beaches date back to 1999 and were attributed to upstream fly-tipping and malfunctioning sewerage systems (Williams & Simmons, 1999). Whereas on an isolated beach in Brazil, it was mainly household waste, and to a lesser degree, medical waste, that had come down the river (de Araújo & Costa, 2007). In Germany, an analysis of 25 years of AMD data shows higher debris densities on beaches around river mouths (Schöneich-Argent et al., 2019), similar to results in Italy (Giovacchini et al., 2018) and Sri Lanka (Jang et al., 2018), suggesting that a portion of beach debris arrived through these freshwater systems.

In general, explanations for variations in beached AMD densities range from local physical aspects (e.g., the shape of the beach, presence of hardened coastline), to environmental circumstances (e.g., wind direction and speed, rainfall), oceanographic factors (e.g., wind waves, currents, eddies) and socio-economic factors (e.g., population, income and education levels). None of these explanations applies uniformly to all beaches, hence the need to perform local, regional, and national research to develop tools to mitigate localized effects. To complicate matters, many of these explanatory features can either exacerbate or negate the effects of several others.

For example, the proximity of population centres can result in higher AMD beach loads (Barnes et al., 2009; Santos et al., 2005), with even further intensification as the density (of population) increases (Barnes et al., 2009; de Araújo et al., 2018). Nonetheless, proximity to population effects are not universally evident (Brignac et al., 2019; Martinez-Ribes et al., 2007; Nel et al., 2016; Ribic et al., 2010). In another example, a nationwide study in Australia showed that when a coastal community is nearby (within 5 km), beaches have significantly less AMD. A possible explanation of which is environmental stewardship, beach cleaning, and social controls within those communities, compared to beaches further away from population centres (Hardesty et al., 2017).

There are a number of other reported location variables associated with increased AMD densities. Such as the proximity to a port (Nel et al., 2016; Ribic et al., 2010), a nearby stormwater outlet (Duckett & Repaci, 2015; Horton, Svendsen, et al., 2017), or discharges from wastewater and sewage sludge (Browne et al., 2011; Eriksen, Mason, et al., 2013; Habib et al., 1998).

Examples of environmental factors that influence debris density on beaches includes exposure to wind and currents (Ambrose et al., 2019; Brignac et al., 2019; Corbin & Singh, 1993; Debrot et al., 2013); albeit at times these factors indicate opposing effects.

There is moderate evidence that a substantial quantity of AMD originates from mismanaged terrestrial waste (Barnes et al., 2009; Jambeck et al., 2015; Kershaw & Rochman, 2015; Pruter, 1987; Terzi & Seyhan, 2017). However, relatively few studies determine explicit links between AMD on beaches and specific local waste management aspects. In Taiwan, AMD densities on four beaches were (indirectly) compared with those of a nationwide study in the US, while simultaneously contrasting respective waste management measures of the two countries (Liu et al., 2013). Liu et al. (2013) found that plastic bags and bottles are less abundant in Taiwan due to relevant policy measures. Furthermore, in Australia, there is a significant correlation between a locality's waste management spending and the amount of debris detected on their beaches. When more money is invested in waste management, the amount of debris on beaches is diminished (Willis et al., 2018). The existence of a dedicated coastal budget also resulted in less debris, although the relative dollar amount was not significant (Willis et al., 2018). Willis et al. (2018) also found that, in Australia, kerbside recycling and awareness campaigns addressing littering and illegal dumping significantly reduced the amounts of AMD on beaches.

In New Zealand (NZ), Territorial Authorities (TAs) are responsible for the planning and processing of waste. As such, TAs are obligated to produce a six yearly Waste Management and Minimisation Plan (WMMP) (see Chapter 3). The Regional Authorities (RAs), who have an environmental protection and oversight role, may coordinate or collaborate in the waste planning process as specified in a voluntary regional waste document. Because of this decentralized, and not always synchronized or coordinated planning process, many differences exist between waste management factors of the TAs. Specifically, households in 33 of the 66 territorial authorities (TAs) in NZ set out their recycling in open bins or plastic bags (Figure 3.6). In addition, there are 14 different variations of plastic collection schemes, with at least six differing bottle cap and lid instructions (Table 3.3). Furthermore, 48 of the 67 TAs use more than 10 different coloured plastic bags for rubbish collection (Figure 3.6).

These potentially confusing disparities in collection methods and schemes, result in inconvenience (WasteMINZ TAO Forum, 2020) and therewith increased likelihood of waste loss to the environment. Not only does the irregular mix of receptacle types and colours increase the likelihood of mistakes in recycling, but the inconsistencies in plastic collection schemes combined with an open crate or plastic bag collection also add to increased street litter (Wagner & Broaddus, 2016). What is more, the described discrepancies only relate to the smaller portion of waste services provided by TAs (Table 3.5), leaving the larger privately operated services undetermined.

A national litter behaviour report stated that although New Zealanders generally disposed of rubbish correctly, litter was still present on streets (Keep New Zealand Beautiful, 2019). One of the reasons for this, as suggested in the report, was the usage of open bins for recycling and potentially through ineffective waste collection services (Keep New Zealand Beautiful, 2019).

Likely waste loss to the environment results from inefficient planning, varying kerbside collection processes and uncontrolled landfills (Chapter 3). Combined with NZ's prevailing weather patterns (including wind and rain), and an increase in expected flooding events due to climate change (Trenberth, 2011), suggest that mismanaged waste will be transported through stormwater drains, streams and rivers to the coastal environment (Axelsson & van Sebille, 2017; Wagner & Broaddus, 2016).

Results of the NZ beach study (Chapter 2) showed that 72% of all items detected on the beach had been in the water (2.3.1). This finding suggests a possible correlation with upstream or upwind sources for these items. Therefore, in addition to modelling AMD densities against location and environmental variables, this chapter also studies associated factors relating to NZ's waste management system.

In this context, the current chapter aims to identify any relationships between the various location-based, environmental, and waste management factors with the AMD loads on NZ beaches. To achieve this, combined data from the prior chapters (Chapters 2 and 3) are statistically explored through testing a series of predictive models. Waste management factors included are: 1) strategic intent gleaned from keyword frequency in the planning documents; 2) financial information (type of rates and proportion of waste budget) found in the TAs financial statements; as well as 3) the TA's waste collection details communicated through webpages. The role of the nearest catchment (to the study site) was explored by factoring in the overall catchment size, the distance to the sampling site, as well as relative location to the sampling site. These associations are addressed through the following research questions that are examined in this chapter:

1) What are the location (in relation to the sampling site) and environmental factors that are significantly associated with AMD found on the beaches?
2) Does the model improve when adding waste management variables?
3) Are these results different when examining plastic debris only?

4.2 Materials and Methods

4.2.1 Generalized Linear Model (GLM)

The response variables used for this chapter were obtained from data collected during the AMD beach study as described in Chapter 2. A model was applied to the response variables (AMD detected) to determine which variables significantly influenced the variances in predicting (a) the amount of AMD (all debris, including plastic), and (b) the amount of plastic debris.

4.2.2 Predictor Variables

The independent predictor variables as described and measured in the prior chapters are divided into three main groups: 1) location (subdivided into social and geographical features); 2) environmental; and 3) waste management variables (Table 4.1).

Although population density is a known indicator for AMD densities in some studies (Schmuck et al., 2017), the NZ beach study showed that AMD densities are not explained by population density per island (Chapter 2). To tease this further apart, the population of the RA instead of island will be examined.

The size of the nearest catchment, and a study site location, are significant determinants for variations in AMD density in prior studies (Rech et al., 2014; Williams & Simmons, 1999). Here, the potential role of catchments was examined by modelling the results (count data) against the overall catchment size as well as the location of the catchment and distance to the study site.

Table 4.1

Descriptions of Social and Geographic Location Variables Tested in GLM Models Predicting Debris Variance on New Zealand Beaches

Variable	Description
	Social
Population	Continuous variable, the total number of residents in Regional Authority in which sampling site is located, as per the latest census at time of sampling (New Zealand Statistics, 2013)
People	Continuous variable, the number of people present on the beach at the time of sampling
Parking	Continuous variable, the number of available parking spots at the sampling site
	Geographical
Island	Categorical with two levels: (North) and (South)
Size (area) of catchment	Continuous variable, nearest catchment size in square kilometres based on national data retrieved from the NZ River Maps (https://shiny.niwa.co.nz/nzrivermaps/)
Location of catchment	Categorical with two levels: (north) or (south), location of catchment vs the nearest study site
Distance to catchment	Continuous, distance in kilometres, determined by overlaying NZ River Maps (https://shiny.niwa.co.nz/nzrivermaps/) with Google Earth. Distance from the sampling site to the nearest catchment was estimated by applying a path through the water, as close to the shore as possible

Environmental predictor variables for AMD densities can vary greatly by location and study (Monteiro et al., 2018). For example, in the Azores, substrate and wind explained variability in debris on 42 beaches (Ríos et al., 2018). In this NZ field study (Chapter 2), east coast beaches were randomly chosen on the two main islands of NZ. To minimize spatial variances, the selected beaches were an open ocean, > 1 km length, east facing, away from headlands and artificial structures, and accessible by public roads. Since no prior nationwide beach study data were available, common determinants explaining AMD variances reported in overseas studies were included (Table 4.2).

Table 4.2

Descriptions of Environmental Variables Tested in GLM Models Predicting Debris Variance on New Zealand Beaches

Variable	Description
Wind speed	Categorical variable with four levels: (A) = no wind, (B) = < 10km/hr, (C) = 10 - 25km/hr (D) = 25 - 49km/hr
Wind direction	Categorical variable with four levels: (none), (offshore), (onshore) and (side shore); categories side on and side shore were combined into a broad "side shore" category due to singularities
Aspect	Categorical variable with three levels: (E), (NE), and (SE); the cardinal compass direction of the sampling site when facing the water
Backshore	Categorical variable with five levels: (cliff), (dune), (grass), (seawall) and (shrub); the type of vegetation or structure connecting the beach with its hinterland
Gradient	Categorical variable with four levels indicating the steepness of the slope of the beach from the waterline to the sampling site, with (A) = < 1 m, (B) = 1 - 2 m, (C) = 2 - 4 m, (D) = 4 - 8 m
Substrate	Categorical variable with 2 levels: (pebble) and (sand). If original data included combined levels, the first descriptor was used. The one gravel beach was included in the sand category

The waste management predictor variables were drawn from the research performed in Chapter 3. Adoption by local authorities of waste management documents was tested by modelling the existence of these documents at two levels - regional and territorial. International research shows that collaboration increases waste management efficiencies (and therewith-reduced waste losses to the environment), hence, the factor "Collaboration" was included in the model.

Overseas, a user-pay system is linked to lower waste and higher recycle rates (Gillies et al., 2017; Kaza et al., 2018). In NZ, households pay for waste collection through either general rates, targeted rates, or both, with targeted rates most resembling a user-pay system. In Australia, larger proportions of the council's total budget spent on waste management resulted in decreasing debris on their beaches, though it plateaued at 8% (Willis et al., 2018). Therefore, to investigate if these effects apply in NZ, the type of payment and the percentages of local budgets allocated to waste management were retrieved from the TA's published "Funding Impact Statement" as reported in the Annual Plan and was included in the models.

To model the potential effects of waste collection methods, the type of rubbish and recycling receptacles used is included in the waste predictor variables. In Maine (USA), open recycling bins at kerbsides resulted in 20 pieces of extra litter (> 25.4 mm) in the street per household per week (Wagner & Broaddus, 2016). This waste loss occurred due to overflowing bins, collection methods (manual sorting of open crates at kerbside), return mode of the bin post collection (upside down) and "scavenging" (by humans or animals) (Wagner & Broaddus, 2016). Here, we included the type of receptacle for rubbish and recycling collection in the full model. Lastly, the number of rubbish bins at the beach or parking area were included in the modelling of waste management factors (Table 4.3). All variables described in this section are presented in Table 4.4.

Table 4.3

Descriptions of Waste Management Variables Descriptions Tested in GLM models Predicting Debris Variance on New Zealand Beaches

Variable	Description
	Planning
Regional waste document	Categorical with two levels: (no) or (yes) indicates the presence of a (voluntary) regional waste management document
Waste Management and Minimisation Plan (WMMP)	Categorical with two levels: (no) or (yes) indicates the adoption of a current WMMP by TA
Collaboration	Categorical with two levels: (no) or (yes) indicates whether TA mentions collaborating with other TAs or RAs on waste management topics in their WMMP
	Financial
Rates	Categorical with three levels: (both), (general), or (targeted), indicates whether local waste management (where sampling site is located) is financed through general or targeted rates. Data retrieved from the TA's yearly financial reporting against their Annual Plan.
Percentage of budget	Continuous and represents the percentage of total TA budgeted expenditures dedicated to waste management (TA's yearly financial reporting against its Annual Plan). Percentages were obtained from the "Funding impact statement" in the TA's annual report. Where waste management was integrated with other budget items (Auckland, Hastings and Hurunui), the overall average of 7 % was applied
	Methods
Rubbish bins at beach	Continuous, number of rubbish bins at parking area or on the beach by sampling site
Waste receptacle	Categorical with two levels: plastic (bags) or wheeled and lidded (bins); type of receptacle used for waste collection
Recycle receptacle	Categorical with two levels: wheeled and lidded (bins) or open (crates); the type of receptacle used for recycling collection

Note. TA = Territorial Authority and RA = Regional Authority.

Table 4.4

Overview Predictor Variables Data Applied in Generalized Linear Models

Site	Population	Catchment			Waste Documents		Collection Methods		Financial		Collaboration
		Distance (km)	Location	Size (km^2)	RA	TA	Rubbish	Recycle	Rates	% budget	
					North Island						
1	62,000	42	S	367	No	Yes	Bags	Crates	General	5	No
2	62,000	9	S	66	No	Yes	Bags	Crates	General	5	No
3	87,600	17	S	82	No	Yes	Bags	Bins	Targeted	7	No
4	1,614,400	37	N	217	Yes	Yes	Bags	Bins	Both	7	No
5	28,400	38	S	77	Yes	Yes	Bags	Bins	Both	11	Yes
6	28,400	3	S	57	Yes	Yes	Bags	Bins	Both	9	Yes
7	47,800	26	S	453	Yes	Yes	Bags	Bins	Targeted	2	Yes
8	35,000	11	S	820	Yes	Yes	Bins	Bins	Both	7	Yes
9	47,800	30	N	1,574	Yes	Yes	Bags	Crates	Both	5	No
10	47,800	1	S	537	Yes	Yes	Bags	Crates	Both	5	No
11	47,800	9	S	226	Yes	Yes	Bags	Crates	Both	5	No
12	8,150	27	N	78	Yes	No	Bags	Crates	Targeted	9	No
13	78,600	35	N	2,501	Yes	Yes	Bags	Crates	Both	7	Yes
14	13,600	16	S	847	Yes	No	Bags	Crates	Both	9	No
15	13,600	5	N	847	Yes	No	Bags	Crates	Both	9	No
16	17,550	16	S	589	No	No	Bags	Crates	Both	8	No
17	17,550	1	N	589	No	No	Bags	Crates	Both	8	No
18	24,600	10	N	191	Yes	Yes	Bags	Crates	Targeted	9	Yes
19	24,600	8	N	531	Yes	Yes	Bags	Crates	Targeted	13	Yes
20	8,900	20	S	650	Yes	Yes	Bags	Crates	Both	6	Yes
21	10,100	1	S	152	Yes	Yes	Bags	Crates	Both	12	Yes

Site	Population	Catchment			Waste Documents		Collection Methods		Financial		Collaboration
		Distance (km)	Location	Size (km^2)	RA	TA	Rubbish	Recycle	Rates	% budget	
					South Island						
22	45,500	1	S	154	Yes	Yes	Bags	Crates	Both	10	No
23	45,500	9	N	154	Yes	Yes	Bags	Crates	Both	10	No
24	3,730	5	S	3,300	No	No	Bags	Crates	Both	5	No
25	3,730	21	N	3,300	No	No	Bags	Crates	Both	5	No
26	12,700	16	S	3,331	No	Yes	Bags	Crates	Both	7	No
27	12,700	12	N	3,331	No	Yes	Bags	Crates	Both	7	No
28	12,700	5	S	1,150	No	Yes	Bags	Crates	Both	7	No
29	57,800	2	S	3,608	No	Yes	Bags	Bins	Both	10	No
30	374,900	13	N	3,608	No	Yes	Bins	Bins	General	4	No
31	33,700	4	N	452	No	Yes	Bins	Bins	Both	9	No
32	46,700	11	S	539	No	Yes	Bins	Bins	Targeted	10	No
33	7,950	1	N	539	No	No	Bags	Crates	Targeted	7	No
34	22,100	1	N	11,888	No	Yes	Bags	Crates	General	3	No
35	22,100	3	N	894	No	Yes	Bags	Crates	General	3	No
36	22,100	29	N	894	No	Yes	Bags	Crates	General	3	No
37	127,000	56	S	894	No	Yes	Bags	Bins	Both	5	No
38	127,000	3	S	5,702	No	Yes	Bags	Bins	Both	5	No
39	17,450	4	S	397	No	Yes	Bins	Bins	Both	4	No
40	17,450	10	N	224	No	Yes	Bins	Bins	Both	4	No
41	17,450	1	N	20,822	No	Yes	Bins	Bins	Both	4	No

4.2.3 Statistical Analysis

Initial data exploration occurred in Chapter 2, generally following the protocol as described by Zuur et al. (2010). To model the discrete count data, a Poisson GLM with a log link function was applied. The results were modelled as a function of the variables (covariates) for both "all AMD" and "plastic debris (only)" counts. Overdispersion, where the observed variance is greater than the mean, is typical in observational and ecological studies and normally indicates the omission of significant explanatory factors. In this study, overdispersion was addressed by correcting the standard errors with a quasi-Poisson distribution (Ver Hoef & Boveng, 2007). Collinearity of the response variables indicates how one, or more, variables are influenced by interaction with other variables. Variance in inflation factor (VIF) was used to identify such collinearity between response variables. A conservative approach was applied and those variables with VIF values of four or higher were removed from the regression (Zuur et al., 2010).

Models were constructed for all AMD and independently for the subset of plastic debris. A systematic iterative approach (hereafter referred to as Drop1) was used to identify the most relevant location and environmental variables restricted for each dependent variable set. A full GLM was calculated starting with all predictive variables, the most non-significant variable (as determined by F-ratio), was removed from the full GLM and the overall model recalculated. This process was repeated until all remaining predictive variables were significant, and the residual deviance did not decrease further. Results of these models were compared with those where waste management factors were added. Since AIC is not available in GLM models with a (quasi) Poisson distribution, residual deviance is used as the goodness-of-fit measure. The results were compared with the full model (including all the variables), using an ANOVA test. Additionally, independent variables were checked for significant interactions between variables that were contextually relevant. These were added to the model after which the Drop1 process described above was applied to determine if it improved the fitted model without interactions.

For validation of the model, response residuals, normalised (Pearson) residuals and deviance residuals of both models were plotted against the fitted values, explanatory variables included in the model, and those variables that were excluded from the model. Results of the models are presented with the estimators and standard errors for the regression parameters. All models are visually presented through a forest plot with 95% confidence intervals of significant variables in the best fitting model. Statistical analysis was performed in R v3.5.1 (R Development Core Team, 2018) and the car (Fox et al., 2011), readxl (Wickham et al., 2018), jtools (Long, 2019) and ggstance (Henry et al., 2019) packages. All tests were performed with a significance level of .05.

4.3 Results

Four models were fitted resulting in (slightly) differing sets of predictor variables for all AMD and one limited to the subgroup of plastic debris, without and with waste management variables. Adding waste management factors improved both models (Table 4.5). Factors that were not significant in any of the models included “Parking”, “WMMP”, “Collaboration”, “Substrate”, “Rubbish Collection Methods” and “Percentage of Budget Spent on Waste Management”. The factors “Wind Speed” and “Wind Direction” were strongly correlated; hence, only the wind direction was applied but did not yield any significant effects.

Table 4.5

Goodness-of-Fit of GLM Models Predicting Anthropogenic Marine Debris (AMD) (> 2 mm) With Waste Management Variables on New Zealand Beaches

Model	Deviance (*df*)	
	AMD	Plastic debris
Null (including all variables)	537.40 (122)	482.72 (122)
Residual model including significant location and environmental variables	284.59 (114)	241.47 (113)
Residual model including significant location, environmental and waste management variables	**217.46** (106)	**183.08** (105)

4.3.1 Predictive Variables for Beached Debris

The residual model (including location, environmental and waste management predictor variables for all AMD) explained ~60% of the variation (based on the post and pre-model deviation), with undiscernible patterns in the residuals (Appendix H). The variables “Wind Speed”, “Substrate”, and “Recycle” were excluded because of high collinearity. No relevant interactions improved the model. The model equation for all AMD was:

$AMD = -0.82$ + 0.00 * Size Catchment + 0.07 * Distance to Catchment – 1.64 * Aspect NE + 0.85 * Aspect SE + 1.13 * Backshore Dune – 0.65 * Backshore Grass – 0.38 * Backshore Seawall – 1.33 * Backshore Shrub + 0.98 * Gradient B + 1.10 * Gradient C + 1.15 * Gradient D + 0.23 * Rubbish Bins – 0.68 * Regional Waste Document-Yes + 1.30 * Rates General + 0.40 * Rates Targeted – 1.12 * Recycle Crates

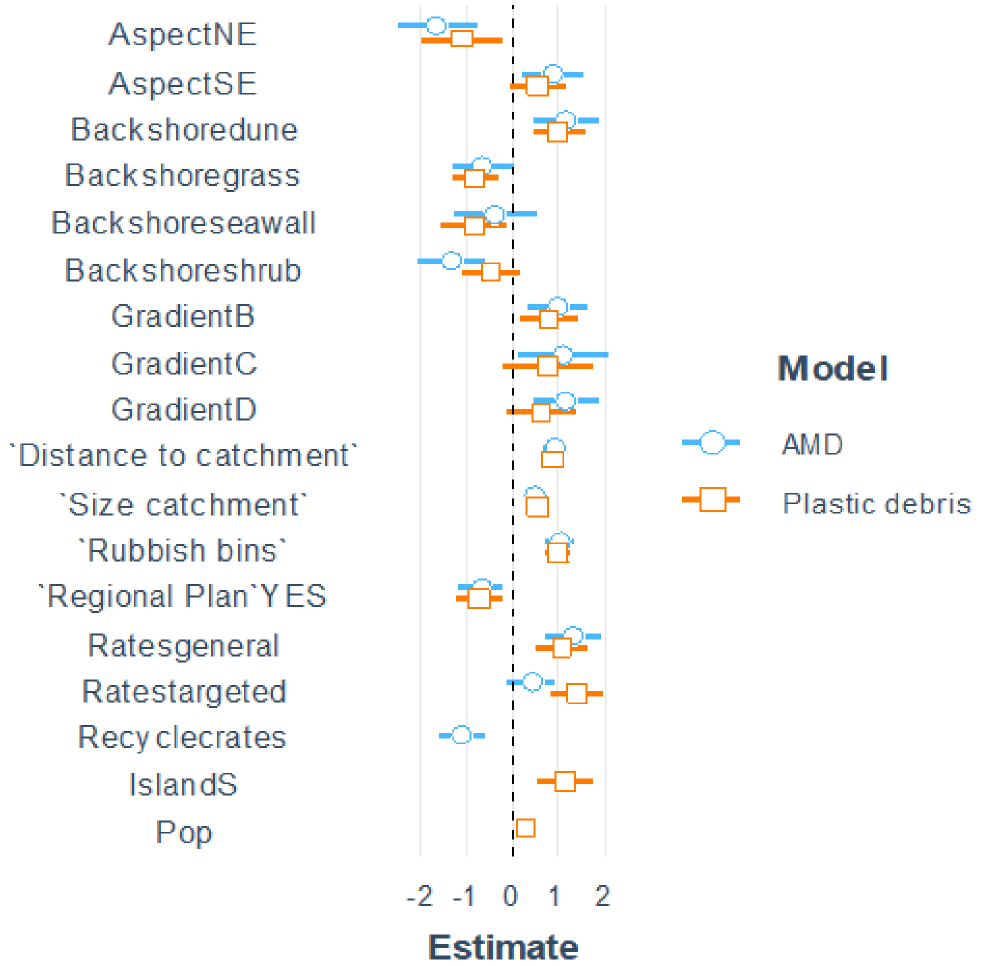
The variation of plastic debris only was explained for 62% by a model without interactions, with no discernible patterns in the residuals (Appendix H). The variables “Wind Speed”, “Substrate” and “Recycle” were removed because of high collinearity. The resulting model equation for plastic debris only was:

$Plastic\ debris = -2.51 + 1.15 *$ Island South + 0.00 * Population + 0.00 * Size Catchment + 0.07 * Distance to Catchment – 1.12 * Aspect North East + 0.54 * Aspect South East + 0.99 * Backshore Dune – 0.82 Backshore Grass – 0.84 * Backshore Seawall + 0.79 * Gradient B + 0.75 * Gradient C + 0.62 * Gradient D + 0.22 * Rubbish Bins – 0.72 * Regional Waste Document Yes + 1.05 * Rates General + 1.39 * Targeted

Both model’s significant variables (95% CI) and their direction are shown in Figure 4.1, with negative and positive estimates indicating a decrease and an increase in AMD amounts (densities), respectively.

Figure 4.1

Significant Variables Influencing All Anthropogenic Marine Debris (AMD) and Plastic Debris (> 2 mm) Densities on New Zealand Beaches



Note. Negative estimates represent a decrease in debris density and positive estimates an increase. Length of line represents 95 % CI. Reference levels as described in Table 4.6.

Beaches with a NE orientation were associated with lower AMD counts, and those with SE orientation, higher AMD counts (compared to east-facing beaches) (Table 4.6). Sites with either grass, a seawall or shrub as backshore showed lower AMD densities, whereas those with dunes had higher debris densities (compared to those with a cliff). Furthermore, the existence of a regional waste document, and, unexpectedly, the use of recycling crates (over wheeled bins) resulted in less AMD. The further away a site was from a catchment, the more AMD was detected. A similar effect applied for the size of catchment; a larger catchment correlated with greater AMD density. Rubbish bins on the beach or parking lot were associated with higher AMD counts. Lastly, when the financing of waste management occurred through either targeted or general rates (i.e., single method only), it resulted in significantly more debris on the beach than if financed through both.

Plastic debris makes up a substantial proportion (78%) of overall debris, hence similarities in the models were expected. Except for the recycling method, which was omitted due to collinearity, the same variables in the AMD model were included in the plastic debris model. All variables showed the same direction (as in the AMD model), but not necessarily the same level of significance or strength (Table 4.6). The two additional predictor values included in the plastic debris model were "South Island" (more plastic than on the North Island [NI]) and RA population size (i.e., the more population in a RA, the more plastics detected).

Table 4.6

Regression Models Showing Significant Predictor Coefficients (±SE) for Anthropogenic Marine Debris (AMD) (> 2 mm) on New Zealand Beaches in 2017

Predictor	Estimates			
	AMD	*p*	Plastic	*p*
	Location variables			
Island - *North*				
Island - South			1.15 (0.33)	***
Population			0.00 (0.00)	**
Size Catchment	0.00 (0.00)	***	0.00 (0.00)	***
Distance to catchment	0.07 (0.01)	***	0.07 (0.01)	***
	Environmental variables			
Aspect - *East*				
Aspect - Northeast	-1.64 (0.44)	***	-1.12 (0.45)	*
Aspect - Southeast	0.85 (0.34)	*	0.54 (0.35)	
Backshore - *Cliff*				
Backshore – Dune	1.13 (0.36)	**	0.99 (0.38)	*
Backshore – Grass	-0.65 (0.36)		-0.82 (0.41)	*
Backshore – Seawall	-0.38 (0.47)		-0.84 (0.54)	*
Backshore - Shrub	-1.33 (0.35)	***	-0.48 (0.38)	
Gradient - *A*				
Gradient - B	0.98 (0.34)	**	0.79 (0.38)	*
Gradient - C	1.10 (0.51)	*	0.75 (0.57)	
Gradient - D	1.15 (0.37)	**	0.62 (0.44)	
	Waste management variables			
Rubbish bins	0.23 (0.04)	***	0.22 (0.04)	***
Regional waste document - *No*				
Regional waste document - Yes	-0.68 (0.23)	**	-0.72 (0.32)	*
Rates - *Both*				
Rates - General	1.30 (0.30)	***	1.05 (0.29)	***
Rates – Targeted	0.40 (0.28)		1.39 (0.36)	***
Recycle - *Bins*				
Recycle - Crates	-1.12 (0.26)	***		
Constant	-0.82 (0.51)		-2.51 (0.70)	***

Note. N = 123, estimated dispersion parameter for AMD = 1.97 and for plastic debris = 1.86. * $p < .05$ ** $p < .01$ *** $p < .001$.

4.4 Discussion

The goal of this chapter was to determine which (combination of) location and environmental variables were significantly associated with AMD and plastic debris densities on NZ beaches. An additional goal was to determine whether adding waste management factors would improve the predictive model. The models (for AMD and plastic debris) presented here indicate that including predictors from all three groups (location, environmental and waste management) together results in the best fit (Table 4.5). Significant predictors were “Island”, “Population”, “Size of Catchment”, “Distance to Catchment”, “Aspect”, “Backshore”, “Gradient”, “Rubbish bins”, “Regional waste document”, “Rates” and “Recycling”. Below, all significant predictor variables are discussed per group (location, environment, and waste management). It is important to note that these results can only be interpreted in their entirety as presented in Table 4.6.

4.4.1 Location Variables

All significant location variables in both models (AMD and plastic debris) are associated with an increase in debris densities (Table 4.7). Both the size of, and distance to the catchment are highly significant ($p < .001$) and with small confidence intervals, yet with small effects (<0.00 and 0.07, respectively) (Table 4.6). In other words, the larger the nearest catchment, and, surprisingly, the further away from the catchment, the more debris. The plastic debris model also included the population and South Island as significant factors. Population showed a small (>0.00) effect, and the South Island showed a larger estimate (1.15) in the model.

Table 4.7

Effects of Social and Geographical Location Variables in GLM models, + Indicates an Increased and - a Decreased Effect on Anthropogenic Marine Debris (AMD) (> 2 mm) Densities on New Zealand Beaches

Predictor	AMD	Plastic debris
Island - *North*		
Island - South		+
Population		+
Size catchment	+	+
Distance to catchment	+	+

Rivers are considered to be a major pathway for mismanaged waste to the marine environment (Acha et al., 2003; Emmerik & Schwarz, 2020), with larger rivers (based on catchment size) contributing disproportionately more riverine litter (Lebreton et al., 2017; Schmidt et al., 2017). Riverine litter, and in particular plastic debris, is prone to getting captured in riparian areas and will flush out with flooding events, creating seasonal pulses of debris in some places (Emmerik, Tramoy, et al., 2019; McCormick & Hoellein, 2016). Litter in rivers is abundant (Emmerik, Tramoy, et al., 2019; McCormick & Hoellein, 2016; Rech et al., 2014), hence these waterways are considered a main pathway for transfer of land-based items to the marine environment (Cordova & Nurhati, 2019; Jambeck et al., 2015; Schmidt et al., 2017).

Hydrodynamic, hydrological, climatic and oceanographic factors all influence how different types of debris transport down the river to the river mouth (Carson et al., 2013) and beyond (the benthic compartment, surrounding beaches, or out to sea), based on the item's characteristics (McCormick & Hoellein, 2016). Heavier objects made from metal and glass typically sink, and persistently buoyant objects (e.g., wood and plastic debris), wash up on the beaches (Galgani et al., 2000; McCormick & Hoellein, 2016; Rech et al., 2014).

Similar to other studies, this study shows an increase of AMD as the size of the nearest catchment increases. Global models suggest that rivers are responsible for a litter discharge of between 1.15 and 2.41 million tonnes of plastic every year (Lebreton et al., 2017). Larger watersheds are postulated to transport the majority of debris into the oceans (Lebreton & Andrady, 2019), although empirical data on riverine outputs are scarce. Analogous to the quantification of AMD on beaches, methods of measuring the different types and sizes of debris at different riverine locations vary (Calcar & Emmerik, 2019; González-Fernández & Hanke, 2017). These discrepancies hinder the modelling associations between riverine and beached debris. However, one NZ study showed that microplastics densities in a freshwater system are not related to the size of the stream (Dikareva & Simon, 2019). This could be a result of microplastics having dissimilar sources and pathways than larger debris (Chapter 1) or, alternatively, that the river size does not control the quantity of debris transported.

The distance to catchment had a positive effect on both AMD and plastic debris; meaning that the further away the sampling site was from the catchment, the more AMD and plastic debris were detected. This seemingly counterintuitive result is contrary to results from a study in Chile, where researchers demonstrated that more debris was found closer to the river mouth (Rech et al., 2014). However, more complex catchment influences were shown in Europe, where riverine transport of AMD was influenced by bottom currents, submarine river extensions and riverbed depth (Galgani et al., 2000). Particularly non-tidal rivers with deeper beds deposited marine debris further away from the river mouth (Galgani et al., 2000). Another factor that showed the influence on the distance of debris deposition (relating to the river mouth) include heavy rainfall events (Lattin et al., 2004). This study suggests a link between debris variation and the distance to the nearest catchment which requires further research for a better understanding.

4.4.2 Environmental Variables

The effects of the environmental variables are summarized in Table 4.8. Beaches facing northeast showed less AMD and plastic debris in comparison to those that face east. Beaches facing southeast showed more AMD than those facing east. This could be due to (a mix of) the currents, coastline and basin morphology, or prevailing surface winds when the AMD was captured on the beach. Although the wind's direction at the time of sampling was found insignificant in the models, the deposit, capture, burying and resurfacing of AMD on the beach is a complex process (Bowman et al., 1998), and can depend on many factors, including the size of the debris, Stokes drift velocity (Olivelli et al., 2020) and onshore wind transport (Brennan et al., 2018).

Table 4.8

Effects of Environmental Variables in GLM Models, + Indicates an Increased and - a Decreased Effect in Anthropogenic Marine Debris (AMD) (> 2 mm) Densities on New Zealand Beaches

Predictor	AMD	Plastic debris
Aspect – *East*		
Northeast	-	-
Southeast	+	+
Backshore – *Cliff*		
Dune	+	+
Grass	-	-
Seawall	-	-
Shrub	-	-
Gradient – *A (flat beach)*		
B (little slope)	+	+
C (more slope)	+	
D (steepest beach)	+	

The mixed effects model of the backshore indicate that dunes are associated with an increase, and all other backshore types with a decrease, of AMD and plastic debris (compared to a cliff).

The tendency of dunes to "trap" debris has been demonstrated in other studies (Andriolo et al., 2020; Rangel-Buitrago et al., 2018; Šilc et al., 2018). In Australia, larger debris was found higher up the beach and into the backshore (independent of type), leading the researchers to conclude the backshore could be an AMD sink, thus explaining where part of the "missing plastic" (Thompson et al., 2004) resides (Olivelli et al., 2020). Although the exact dynamics between backshore and wrackline are unknown, the significance of the backshore on the variance of AMD in the wrackline, as shown in this study, indicates a need to investigate further and understand that interrelation.

A steeper beach was generally associated with more AMD. Plastic debris was mainly affected by a slight increase in the beach steepness (resulting in higher densities), and less so by steeper beaches. The movement of sand and debris in the swash zone of a dynamic beach is complex, with prior research finding that items are more likely to stay put on the shallow part of the beach then on a steeper part (Dixon & Cooke, 1977). Whereas Dixon and Cooke (1977) measured the entire area from waterline to backshore, sampling in this NZ study occurred at the highest high-tide line. Entrapment of debris higher on the beach makes it less likely to be washed away in the next high tide (Bowman et al., 1998).

4.4.3 Waste Management Variables

Significant waste management factors included in the model are summarized in Table 4.9. Rubbish bins at beaches and parking lots were associated with increases in AMD and plastic debris. Existing research relating to rubbish bins on or near the beach mainly focuses on beachgoer's reduced tendency to litter when receptacles are present (Santos et al., 2005), provided they are close enough (Al-mosa et al., 2017; Schultz et al., 2013). Also, the design and maintenance aspects of rubbish bins have been studied, with specific features soliciting better (i.e., non-littering behaviour) compliance (Al-mosa et al., 2017; Portman et al., 2019). Yet other litter research (not explicitly aimed at beaches) determined that rubbish bins alone are less effective (in reducing littering) than efforts such as awareness, education, and community engagement projects (Campbell et al., 2014; Roales-Nieto, 1988). It is, of course, possible and even likely that rubbish bins are placed on popular and highly frequented beaches, where more rubbish is present (Silva-Cavalcanti et al., 2009). As an alternative, overflowing (i.e., poorly managed) rubbish bins could also, under the influence of wind or wildlife, release litter into the water, causing it to wash up in the wrackline.

Table 4.9

Effects of Waste Management Variables in GLM models, + Indicates an Increased and - a Decreased Effect in Anthropogenic Marine Debris (AMD) (> 2 mm) Densities on New Zealand Beaches

Predictor	AMD	Plastic debris
Rubbish bins on beach – *No*		
Rubbish bins on beach – Yes	+	+
Regional waste document – *No*		
Regional waste document – Yes	-	-
Rates – *Both*		
General	+	+
Targeted	+	+
Recycle – *Bins*		
Crates	-	

The unexpected finding that a voluntary regional waste document (without a set form) is associated with significantly lower AMD densities is not replicated by the effect of a mandatory WMMP. Each TA must prepare such a WMMP, yet the six out of seven TAs without this document were located in regions without a coordinating waste document (Chapter 3), indicating a lack of emphasis at both local government levels. The South Island (SI) shows overall significantly higher AMD counts and mass than the NI, and all SI beaches, except two (Ward Beach and Waima River), are located in regions without a regional waste document. These regions' lack of focus on waste is further illustrated by the absence of public information services. Specifically, Canterbury (SI) does not (as of December 2017, but also not in 2018, 2019 and 2020) mention waste topics on its website. The other major SI region, Otago, refers to a waste document dated 1997, which expired as of 2007 and was not renewed, but is still being displayed on the website. These are indications that these two SI regions, with a combined population of 741,903 (~74% of SI population), do not prioritize waste management.

The region with the highest AMD count and mass on the North Island (NI) was Manawatu-Wanganui, which also had no regional waste document. However, the two other regions on the NI without a regional waste document, Northland and Hawke's Bay did not show AMD counts or mass above the country average. Altogether, these three regions represent ~16% of the NI population.

These findings of noncompliance based on regional coordination align with research in Europe that compared indicators of waste generation in 116 regions across five countries. That research concluded that the lack of overarching regional environmental policy results in environmental inefficiencies (Halkos & Papageorgiou, 2016), leading to an increase in mismanaged waste and therewith more waste loss to the environment. In NZ, the Waste Strategy states that RAs "can also play an important role in facilitating a collaborative approach to waste management and minimisation planning amongst territorial authorities", but this is voluntary and not applied uniformly.

On the other hand, whether TAs had a WMMP in place, or collaborated, did not prove significant in any of the models. This could be a result of oversimplifying the collaboration factor as binary, with actual collaborations being more complex and potentially existing at a regional or local level, both regarding planning as well as implementation. Alternatively, it could be related to most waste management services being operated by private parties.

Furthermore, the model indicated that the manner of financing waste management, by charging through one of the two "General" or "Targeted" rates, resulted in significantly more plastic debris on the beach, than if financed through both options combined. A similar effect was found for AMD if financed through general rates (only). In NZ, local authorities apply rates in the form of property taxes and waste management is either included in the overall property taxes (general) or as a type of user-pays system (targeted), possibly supplemented with fees (e.g., paid bags, gate fees for drop off). The former does not offer an economic incentive for individuals to lower their waste (or enhance recycling rates and thus minimize mismanaged waste), as it is a fixed amount that will not alter with an individual's improved waste minimisation efforts. Yet the latter is known, under specific circumstances, to deliver favourable results in terms of waste minimisation if the price to dispose of waste is high enough, or otherwise regulated (through for example enforcement) (Dahlén & Lagerkvist, 2010; Gillies et al., 2017).

Nonetheless, waste management is a significant proportion of a local authority's expenditure (Hoornweg & Bhada-Tata, 2012; Kaza et al., 2018) and requires fixed infrastructural investment with ongoing operational costs (Table 4.4). For example, managing street litter, storm drains, and emptying municipal rubbish bins in parks and on beaches must be financed regardless of how much individuals minimise their kerbside waste. Therefore, it appears intuitive that a combination of the two rates results in less waste loss to the environment and eventually, AMD on the beach.

Methods of recycling collection were only significant in the AMD model, but were excluded from the plastic debris model due to high collinearity (Table 4.9). Use of open recycling crates (instead of lidded and wheeled bins) resulted in decreased AMD on beaches. This is opposite of what was observed in a study in the USA (Wagner & Broaddus, 2016). It is likely that this result is due to other factors not included in this model. One explanation could be that this study did not consider upstream or upwind waste collection methods from other TAs, only those as applied in the TA where the beach is located.

Based on the results provided in this chapter, the unchangeable environmental and location variables that are a best fit for a model predicting marine debris included “Island”, “Population”, “Distance to catchment”, and “Size of the nearest catchment”, the beach’s “Aspect”, “Backshore”, and “Gradient”. In terms of (modifiable) waste management variables to include in the model are the presence of “Rubbish bins” on the beach, the existence of a “Regional waste document”, the type of “Rates” and the collection methods for “Recycling”.

Based on the findings of this chapter, further research is recommended with reference to expanding the role of the RAs in coordinating waste management in the region. Furthermore, links between AMD and the types of rates charged in a TA, suggest that financing waste management through both types ameliorates AMD and should be further examined in an effort to reduce AMD.

4.5 Conclusions

The models that explained the variation in AMD and plastic debris densities included predominantly similar predictors. Adding waste management variables improved both models, although unexplained variances remain.

All significant location variables were associated with increases in AMD, including the size and the distance to the catchment. The model for plastic debris also included the SI and regional population size as additional predictors. The influence of catchments was highly significant with their size and distance both resulting in increases in AMD and plastic. An increase in debris further away from the catchment is a possible result from river flows, seasonal effects and the type of debris.

Significant environmental factors for both AMD and plastic debris models included the aspect, backshore, and gradient of the beach, with mixed effects. Beaches facing northeast had less debris, and beaches facing southeast more debris (compared to east facing beaches), likely due to nearshore currents and wave and wind patterns. Dunes as backshore were associated with an increase in both AMD and plastic debris, whereas all other backshore types, and especially shrubs, reduced AMD on beaches. A steeper beach had more AMD, but only the first level of steepness showed more plastic.

Significant waste management factors in the model included the presence of rubbish bins at the beaches, which was associated with increased effects on AMD (but not on plastic debris). Other waste management factors that significantly influenced the model included the existence of a voluntary regional waste planning document and the method of payment for waste collection. Less debris is found on beaches in TAs that finance their waste management through both general and targeted rates, compared to those that finance through only one of these options (while keeping all other factors constant).

Chapter 5

A Route to Less Waste (Loss) and Cleaner Beaches

Sign at beach entrance in Whangarei, New Zealand. Photo: van Gool, E.D.

This research addressed the anthropogenic marine debris (AMD) knowledge gap in New Zealand (NZ). This thesis found that the pattern of AMD distribution on beaches across NZ is associated with local waste management factors. This now provides an evidentiary base for addressing mismanaged waste and subsequent waste loss mechanisms. For the first time, there is a baseline of AMD densities across the east coast beaches of both the North and South Islands.

The research performed for this project included a systematic literature review of 1,333 articles describing AMD topics and comprised a general review of 117 beach studies, of which 15 were appraised in-depth (Chapter 1). Quantitative research was performed to determine the status of AMD on the NZ beaches at a latitudinal scale (Chapter 2). Following this, an account of NZ's waste management landscape was grounded in literature and the law, supplemented by a review of local waste management details. A comprehensive overview of waste documents and details qualifying aspects of kerbside collection methodologies rounded up Chapter 3. Based on the outcomes of Chapters 2 and 3, a predictive model was developed to explain associations and variances of predictor variables and AMD quantities on NZ beaches (Chapter 4). The combined results of this research lead to the formulation of a pollution index in this last chapter (5) and subsequent conclusions and recommended research and suggestions for mitigative management actions.

5.1 New Zealand Beach Survey Summary and Synthesis

In total, 123 belt transects on 41 beaches quantified AMD abundance, mass, composition and sources. Sampling occurred on east coast beaches across 11.6 degrees in latitude across the two main islands (North Island [NI] and South Island [SI]) and yielded significant variations in abundance, mass and sources (but not composition) between the islands and regions (2.3). The SI beaches collectively showed significantly higher AMD densities and mass than NI beaches. About half of all the debris detected was recognizable, and of that, 16% constituted mismanaged waste.

The first NZ beach survey dates back to the seventies (Hayward, 1984) with a follow-up study 15 years later (Hayward, 1999). Since then, only a few studies surveyed NZ beaches (Campbell et al., 2017; Clunies-Ross et al., 2016), none of them sampling at a multi-regional or national scale. One study in the Coromandel region (NI), included 27 beaches and had similar overall AMD abundance (0.146 ± 0.027 items m^{-2}) and plastic AMD percentage (74%), as the results from this study (0.16 ± 0.02 m^{-2} items and 78% respectively) (Campbell et al., 2017). However, the criteria for beach selection differed between the two studies (cardinal position, open-ocean, and > 1 km away from obstructions). In addition, Campbell et al. (2017) sampled debris on the high tide mark during spring tides. Likewise, a nationwide study in Australia produced similar results to this study (0.15 items m^{-2}), but Hardesty et al. (2017) applied a different transect placement (vertical - from waterline into the backshore) to this study.

5.1.1 Comparing Debris Loads by Coastline and Population Density

When contrasted with those studies reviewed in Chapter 1, NZ AMD densities showed either similar results or smaller densities (Table 2.4). However, these comparisons do not explain per capita debris contributions, nor do they take into account the length of a nation's coastline. For example, if AMD density in one country is similar to that of another country with a population or length of coastline an order of magnitude larger, it could signify, amongst other things, a variance in overall waste loss mechanisms such as described in Chapter 3. Therefore, considering these factors in relation to AMD density could provide a better understanding of a nation's waste loss to the environment on a per capita basis. Thus, an index was developed to determine a nation's pollution as a function of the overall coastline and total population. To that effect, the mean AMD density (items m^{-2}) was extrapolated over the nation's overall coastline (m) and then divided by the total population (in the year of the study's publication). The resulting pollution index is expressed through the following formula:

$$I = \frac{C * L}{P}$$

where:

PI = pollution index (AMD items $person^{-1}$)

C = mean density of AMD (items m^{-2})

L = total length of coastline (m), and

P = total population

Table 5.1 shows the resulting pollution index per capita for NZ compared to countries and AMD densities presented in Table 2.4. Given the relatively long coastline and low population size in NZ, the initial low AMD density translates into a high number of AMD items $person^{-1}$ and now indicates that the pollution per capita is actually more than three times that of Australia, but less than that of Panama, Chile and the Azores (Portugal) (Table 5.1).

Table 5.1

Pollution Index Based on Debris Density per Capita on Beaches in New Zealand, Australia, Portugal (Azores), Turkey, Chile, Panama and Sri Lanka

Country	Beaches	Density (items m^{-2})	Population size [a]	Coastline (km)	**Pollution Index** items $person^{-1}$	Pollution Index based on coastal population only [b]	Reference
New Zealand [c]	41	0.16 ± 0.02	4,793,900	15,134	**0.50**	0.63	This study
Australia [c]	175	0.15	24,601,860	25,760	**0.15**	0.22	Hardesty et al. (2017)
Portugal [c] (Azores)	42	0.62 ± 0.15	243,862	667	**1.70**	1.70	Rios et al. (2018)
Turkey [c]	13	0.92 ± 0.36	79,821,724	7,200	**0.08**	0.19	Aydin et al. (2016)
Chile [c]	43	1.8	16,886,186	6,435	**0.69**	2.06	Bravo et al. (2009)
Panama	19	3.6	2,629,580	2,490	**3.41**	2.76 [d]	Garrity et al. (1993)
Sri Lanka	22	4.1 ± 9.2	21,670,000	1,340	**0.25**	0.38	Jang et al. (2018)

Note. Coastline data retrieved from The World Factbook 2019. Azores data retrieved from Instituto Nacional de Estatística. (2018). As Pessoas People 2017. All other population data retrieved from the World Bank (https://data.worldbank.org/indicator). [a] Population at time of study. [b] Coastal population as applied in Jambeck et al (2015) [c] = OECD country (2020). [d] Decrease due to population increase between 1993 and 2010.

It is important to note that this index does not consider total landmass and non-coastal borders potentially affecting a nation's (mismanaged) waste fluxes. Other global modelling studies determining mismanaged waste inputs to the oceans include coastal populations only (Jambeck et al., 2015; Lebreton et al., 2019). Here, we include the nation's entire population since 75% of NZ population lives within 10 km of the coast (Statistics New Zealand, 2016). Furthermore, landfills are often positioned near waterways and have, in case of failure, a direct effect of AMD densities on beaches around the mouth of estuaries (Todd, 2019). In addition, NZ's weather systems including frequent high winds and high rainfall render it likely that a substantial proportion of terrestrial litter will end up in the coastal environment. However, these considerations might not apply to all countries in the comparison.

Further refinement of the pollution index may aid in measuring and understanding per capita waste loss to the coastal environment and can be used for regional monitoring. Furthermore, when paired with waste management data and riverine litter data, the pollution index would enable the creation of a mismanaged waste budget (per capita). Not only would the pollution index identify and measure the underlying mismanaged waste mechanisms and fluxes, but it could also be a tool to assess the impact of mitigating actions. Lastly, regular updating of the index may aid in a better monitoring and understanding of the cumulative effects of mismanaged waste. The relatively high per capita waste creation in NZ (Chapter 3), coupled with projected increases in population and income, render ongoing waste loss to the environment inevitable. Thus, the NZ beach pollution index is likely to increase in the absence of systemic changes and mitigation of inputs.

Since the beach survey's conclusion (Chapter 2), a nationwide, government-funded citizen science, beach monitoring project has started collecting seasonal AMD data on more than 100 NZ beaches (https://litterintelligence.org/). Sampling occurs in a single transect covering the wrackline and 10 meters above and below it (subject to local circumstances). All material larger than 2.5 cm in diameter is collected and categorized based on the UNEP/IOC (Cheshire et al., 2009) guidelines. These datasets support the implementation of United Nation's Sustainable Development Goal 14.1.1: "describing floating plastic debris as a global indicator of marine pollution" (Kershaw et al., 2019; Transforming Our World: The 2030 Agenda for Sustainable Development, 2015).

However, even with seasonal monitoring of 100 sites, the total beach length monitored covers approximately 0.07% of NZ's total coastline. The sampling methodology also excludes AMD < 2.5 cm, leaving substantial quantities of debris unmonitored. Moreover, survey sites are not randomly selected, but rather chosen by volunteer's preferences. These factors, combined with the non-replication of sites, could lead to biased and less rigorous results.

Coastal AMD also exists in mangroves (Ivar do Sul et al., 2014; Martin et al., 2019; Mohamed Nor & Obbard, 2014) and rocky shores or inaccessible beaches (Adelir-Alves et al., 2016; Gestoso et al., 2019; S. L. Moore et al., 2001); neither have (yet) been sampled in NZ, but could contain significantly different AMD densities. This is where the use of technology, such as aerial or underwater unmanned vehicles, could aid in obtaining a more complete picture of AMD accumulation and composition along the entire coast (Bo et al., 2014; Fallati et al., 2019; Ma et al., 2016; Martin et al., 2018). Similarly, accumulation studies that determine not just the standing stock of AMD but the rate of arrival and accumulation through time, would be of great import to inform management action.

As described in Chapter 1, the Southern Hemisphere seems underrepresented in national or multi-regional standing crop beach studies covering more than 12 beaches (see also Hidalgo-Ruz & Thiel, 2015). The results of this NZ beach study contribute to the understanding of AMD aetiology south of the equator, as do the studies included in the review (Australia and Chile), and studies outside the scope of the review (e.g. in South Africa (Naidoo et al., 2015), Tasmania (Campbell et al., 2012) and NZ (Campbell et al., 2017)). Additionally, the results of this study contribute to the understanding of NZ's oceanic AMD inputs and fluxes. Sources in Australia are modelled to result in AMD items in NZ waters and coast (Galaiduk et al., 2020). Likewise, NZ's AMD has been found in the South Pacific (Cann, 2017). Including this combined data into models estimating AMD inputs and flows around NZ will support enhanced estimates of AMD accumulations in local, regional and national AMD budgets (Turrell, 2019).

5.2 Significant Predictor Variables and Waste Loss Mechanisms

Despite the general assumption that around 80% of AMD derives from land-based sources, not much existing research describes specific links or mechanisms leading to waste loss to the environment. Other studies identified local and environmental predictors of AMD on beaches, albeit with localized effects. Here, waste management predictors were included, which resulted in a better fit of the statistical models describing variance in AMD and plastic debris (Chapter 4). In total, seven factors were associated with increased AMD on beaches (catchment size, distance to catchment, backshore, steepness and aspect of the site, presence of rubbish bins and waste management financing). Another four factors significantly decreased the amount of debris on the beach (backshore, aspect, presence of a regional waste document and method of recycling collection).

About 40% of the variance remains unexplained in the models, which is not unusual for ecological data based on observational studies. Supplementary predictive factors that might explain the remaining variance (and therefore topics for further research) include weather and oceanic circumstances prior to sampling, location and status of landfills and farm dumps and land-use specifics relating to farming, hunting and fishing. In addition, catchment population densities and upstream waste management factors warrant further investigation based on this study's results.

Throughout this thesis, sources of ocean-based AMD have not been considered. The majority of ocean-based debris comes from aquaculture, shipping, and fishing activities (Eriksen et al., 2014), of which the specific NZ dynamics, regulations and potential mitigating actions certainly warrant further research.

The inexplicable yet unequivocal effect of the regional waste document resulting in less AMD is one finding that not only warrants further research but can also be translated into prompt mitigating action(s). Coordination of waste management at a regional level has proven beneficial elsewhere (Dolla & Laishram, 2019; Halkos & Papageorgiou, 2016). Here, this study documented less debris in regions with a (voluntary) regional waste document (Table 4.6). Similar effects were reported in Australia, where the existence of a local (voluntary) coastal AMD plan correlated to less AMD on beaches (Willis et al., 2018). In addition, RAs with a waste document showed a higher compliance of a Waste Minimisation and Management Plan (WMMP) issuance by the underlying TAs.

Further research examining the relationship between the regional waste document and other related factors with the decrease of AMD on the beaches seems merited.

Prior literature often attributes land-based sources of AMD on the beach to an individual's behaviour (i.e., littering), often in relation to single-use packaging and take-out food (Barnes et al., 2009). This study examined a systemic aspect of land-based sources of AMD, i.e., mismanaged waste resulting from the formal waste management process. Mismanaged waste does include an aspect of street litter, but with less emphasis on individual behavioural aspects. Street litter can also result from leaky recycling crates and plastic bags, inadequate collection techniques, and items escaping during transport, transfer, and upon (and after) landfilling (Sharma et al., 2020; Wagner & Broaddus, 2016).

5.2.1 Regulatory Challenges

The analysis of relevant legislation and waste planning at the various government levels found delayed issuance of WMMPs and asynchronous (in time) waste management planning cycles for the TAs (Figure 3.3). The WMMPs apply to only a small portion of waste service providers (Table 3.5) in a TA, creating an uneven playing field. This leaves a large part of waste management unregulated, uncoordinated and unmonitored, inevitably leading to market irregularities. Therefore, it is suggested that a TA's WMMP contractual requirements apply to all waste service providers in the TA, irrespective of whether they are council operated, contracted, or a private provider. Levelling the playing field would enable better monitoring and enforcement, enable enhanced data collection and highlight systemic waste losses.

Bans on plastic bags seem popular as proven by the fact that plastic bag policies are implemented globally in one form (e.g., bans) or another (e.g., pricing mechanisms) in 160 international regions (Nielsen et al., 2019). Whereas in many cases, bans show favourable outcomes (Pasternak et al., 2017; Schnurr et al., 2018; Xanthos & Walker, 2017), in other instances results remain unproven (Macintosh et al., 2020). Despite increasing popular support for the measure, a study in the capital state of Australia indicates that local effects on plastic bag usage did not yield discernible results in a reduction of litter after passing the Plastic Shopping Bags Ban Regulation 2011 (Macintosh et al., 2020). In NZ, the environmental effects of the Waste Minimisation (Plastic Shopping Bags) Regulations 2018 (as well as the Waste Minimisation (Microbeads) Regulations 2017) before and after implementation remain unknown and unmeasured and therefore the efficacy of such strategies cannot be determined.

Regardless of the effects though, such bespoke legislation for a single product is time-consuming, costly and cumbersome. More importantly, it fails to address the larger issue of similar forms of wastes uncaptured by the system and "lost" to the environment due to regulatory failure or weak enforcement. This AMD study (completed before the implementation of the NZ plastic bag ban), detected (only) 25 plastic bags on all 41 beaches combined, suggesting that plastic bags were relatively uncommon. Yet, another frequently detected item included, for example, shotgun material. Wads and casings were first detected on NZ beaches decades ago (Hayward, 1984), yet their "leakage" to the environment continues and remains mainly unregulated or unenforced. Items lost from the formal waste management system appear loosely regulated. Whether partly regulated under the Waste Minimisation Act, the Resource Management Act, or Litter Act, compliance and enforcement is weak and must improve to stop the ongoing flow of waste loss. This study indicated that these items are still being detected on NZ beaches, and therefore, require enhanced attention and management.

5.2.2 *Mechanisms of Mismanaged Waste*

Inconsistencies in plastic recycling schemes between TAs are illustrated in Table 3.3. All TAs that collect plastics in their recycling scheme included Grades 1 and 2. About 75% of the TAs also collected Grades 3, 4, 5 and 6, although the exact combination of grades collected varied by (or within) a TA. At least nine different schemes for collection and another seven for lid instructions were determined (Table 3.3), in addition to an array of collection methods (Figure 3.6). Together, these inconsistencies lead to confusion and misinterpretation. The Ministry for the Environment, local authorities and industry have all indicated the need for standardisation of recycling schemes and methods to reduce such confusion, enhance recycling rates and minimise contaminated waste streams (Ministry for the Environment, 2020; WasteMINZ, 2019; WasteMINZ TAO Forum, 2020).

In addition to the household level kerbside errors and at times uncoordinated waste management planning between local governments, the pressures on the international recycling markets have led to recyclables either being left at kerbside, stockpiled, landfilled, or transported to lower-income countries with weaker environmental controls (Gregson & Crang, 2018; OECD, 2018). All these circumstances increase the likelihood of waste loss to the environment. This behaviour is further evident in NZ (and exacerbated by COVID-19 measures), where some TAs have stopped collecting certain plastic grades altogether or started stockpiling or landfilling collected plastics (Desmarais, 2020).

The NZ government has announced its intention to process all waste and recycling onshore and has invested in infrastructure feasibility studies (Ministry for the Environment, 2020). A public consultation is called on the phasing out (and banning) of plastics made from hard to recycle grades (i.e., Grades 3, 4, 6 and 7) (Ministry for the Environment, 2020). Other funded waste minimisation projects in NZ include waste prevention on the meeting grounds of Māori communities (Para Kore) and research into the development of a national container deposit refund scheme (New Zealand Government, 2020a).

In Thailand, (considered one of the top ocean polluters) all landfills and dumpsites were mapped (Sharma et al., 2020). Results showed that the majority (973) of these sites were located near water bodies or the ocean, creating a direct threat of waste loss to the marine environment (Sharma et al., 2020). Similarly, in NZ, although at a smaller scale, the risk of landfill leakage is identified and demonstrated (Simonson & Hall, 2019). Since the exact amount, location and status of most NZ landfills and the estimated 46,680 (farm) dumps are unclear and unknown, urgent attention and management is warranted to avoid further waste loss, such as experienced on the SI in 2019 (Todd, 2019), and on the NI in 2020 (Sharpe, 2020).

5.2.3 Estimated Quantities of Mismanaged Waste in New Zealand

In 2010, NZ's mismanaged plastic waste was modelled to be 9,286 tonnes, with an expected increase to 11,517 tonnes in 2025 (Jambeck et al., 2015). Of this, a proportion (40%, 25% or 15%, depending on local environmental circumstances) is speculated to enter the marine environment (Jambeck et al., 2015). However, estimates such as Jambeck's (2015) are based on the assumption that NZ (similar to other OECD countries) has no mismanaged waste within the formal waste management system. The model further estimates the plastic content of the NZ waste stream at 9% (Jambeck et al., 2015). Unfortunately, the results from this thesis indicate that Jambeck et al.'s (2015) model underestimates the amount of mismanaged waste in NZ. The underestimates are based on assumption within their model that are inaccurate (for NZ), such as:

- The NZ Ministry for the Environment indicates that plastics make up 12% of the waste in levied landfills, not 9% (Ministry for the Environment, 2019d; Perrot & Subiantoro, 2018). This 12% excludes any of the waste streams (and the plastics therein) of the other consented and unlevied landfills, closed landfills and farm dumps (neither belonging to the category “modern” landfills, thus considered mismanaged waste). Given the increased plastic production amounts (Geyer et al., 2017; PlasticsEurope, 2019), low recycling rates, international developments in the (plastic) waste trades, and the results of halted recycling handling due to the COVID-19 pandemic, it is highly likely that this percentage has further increased.
- The assumption that no waste loss occurs from the formal waste management system is incorrect. Suboptimal systems are prone to leaks and the NZ systems are suboptimal, as evidenced by the disparate and confusing collection methods (including open crates) and schemes across the 66 local authorities, and uncoordinated planning in most RAs. Furthermore, evidence suggests that problems exist around the unknown status of landfills and waste going to (unlined and uncovered) landfill. Similarly, NZ’s prolific farm dumps are likely to contribute to waste loss to the environment. Thus, NZ’s formal waste management system cannot be considered “modern” and the accompanying proportions of waste loss to the environment should be adjusted accordingly.

These combined factors suggest that the Jambeck et al. (2015) forecast that NZ's waste losses to the environment will amount to 11,517 tonnes by 2025 is an underestimate.

5.2.4 Goals and Commitments

Clear evidence demonstrates that waste loss occurs in NZ and that it impacts humans, the economy, and the environment. This is particularly worrisome when seen in the context of NZ's high per capita waste creation, expected increases in population, and ongoing increases in plastics production and consumption (Geyer et al., 2017; OECD, 2021; PlasticsEurope, 2019). The high and increasing waste production contradicts the commitment to international goals to substantially reduce waste generation and greenhouse gasses (Climate Change Response (Zero Carbon) Act 2019; Paris Agreement, 2016). Likewise, landfilling is the most polluting form of waste disposal and does not support the environmentally sound processing of all wastes (Transforming Our World: The 2030 Agenda for Sustainable Development, 2015), nor the principles of the waste hierarchy (See Figure 5.1; *Waste Minimisation Act*, 2008, s 44).

Figure 5.1

New Zealand's Actual Waste Management Situation (Right) vs Preferences According to the Waste Hierarchy (Left)

Note. Treatment (incineration) does not occur in NZ. ▲=some community recyclers (e.g., Wanaka Waste Busters and Xtreme Zero Waste in Raglan) reduce, reuse and recover, although not measured at national scale.

Since mismanaged waste is proportionally linked to the total amount of waste created (Jambeck et al., 2015), the failure to reduce, or stop further increases in waste creation, results in sustained or increased waste loss to the environment. With reference to international goals and commitments described in Chapter 1, NZ has agreed to measure, prevent and control pollutants (Convention on the Law of the Sea, 1982). Based on the evidence presented in this thesis, many actions can and must be taken to minimise, "to the fullest extent", the release of pollutants to the marine environment. Similarly, NZ is obligated to adhere to the Sustainable Development Goals 11.6, 12.5, 14.1, 14.2 and 14a (Table 1.1), relating to reducing waste and waste inputs into the ocean.

5.3 Conclusions

This thesis has enhanced the understanding of the extent of AMD contamination on NZ beaches, with the thesis outcomes providing a heightened understanding of waste loss from the NZ waste management system. This knowledge can aid mitigation and management of AMD by assisting in better defining and streamlining monitoring and assessment systems. The main conclusions of this thesis are:

- NZ’s high waste creation per capita translates into a high pollution index on the beach;
- Waste management factors improve statistical models explaining AMD on beaches;
- Both the high waste creation and mechanisms of waste loss to the environment must be addressed to stem the flow of mismanaged waste into the ocean;
- New Zealand’s waste management system is suboptimal and therefore not “modern” in comparison to other OECD countries; and
- The inaction to address the high waste creation and concomitant waste loss to the environment leaves the nation at odds with various international, national and regional goals and commitments.

I have provided a list of 11 research recommendations and 4 main action items based on the conclusions from this thesis. Recommendations for further research are divided into suggested studies to occur on the coast, in waste management, and predictive modelling. The aim of these recommendations is to improve understanding of, and find targeted solutions to prevent, waste loss to the environment in order to reduce NZ’s overall pollution index.

5.3.1 Beach Research

1. Seasonal AMD testing: To measure seasonal effects, the quantification and qualification of debris that occurs over the different NZ seasons needs to be determined. Seasonal research requires measuring of beach debris over a

period of three years (minimum) to ensure that seasonal patterns are detected that can be differentiated from random patterns.

2. A standard method, including replication, needs to be applied to the sampling of debris that will appropriately sample the extent of all coastal landscapes (beach, mangroves wharves, rocky riprap, etc.). Standardisation and use of a proper sampling design will ensure comparability between studies and sites and produce robust data.
3. The connection between backshore and wrackline needs further exploration for patterns, results of which can be included in the method suggested under 2.
4. Accumulation studies of AMD fluxes, to determine the rates of arrival and loss of AMD at NZ beaches.

5.3.2 Waste Management Research Suggestions

5. Quantitative research on items that escape from the formal waste management infrastructure (including kerbside collection techniques, transport and processing) is needed for NZ. The current lack of such information presents a barrier. This is partly a result from numerous different organisations (government and private), with varying reporting requirements, who manage, collect, dispose, and recycle. Understanding the losses along the entire waste management logistics chain will help identify problem areas and best practices.
6. Locations of all NZ landfills (operating and retired) and farm dumps must be recorded to understand the spatial pressures on waste infrastructure and to quantify space available, leakages and their potential overall waste loss.
7. Quantitative research to identify AMD that is derived from methods of deployment not currently subject to regulation and/or regulatory

enforcement, such as shot gun wadding, smoking related waste and waste resulting from imperfect waste collections.

8. Research the validity, benefits and downsides of a centralized NZ waste management system, versus the current decentralized one, particularly in a role to eventuate systemic changes towards a circular economy.

5.3.3 Predictive Modelling Data Needs

9. To have a full understanding of the NZ patterns of AMD, ocean sources of debris must be determined and quantified. Ocean-based predictors (e.g., maritime traffic, fishing, aquaculture and offshore industries) were not examined in this thesis, but research indicates that in some regions, ocean sources are higher than land sources of debris.
10. More comprehensive catchment-based analysis of mismanaged waste, where the entire catchment's population, waste management practices and land use is considered.
11. Oceanic influences, to get a better understanding of the role of currents and wave action on AMD on the coasts of NZ.

5.3.4 Suggested Actions

1. Reduce the overall amount of waste generated.
    a. Establish compulsory national, regional and local waste reduction and recovery targets, supported by a wider range of phase-outs (bans) and/or levies on problematic materials by product or material type (rather than addressing individual items in the waste stream).

    b. Increase waste levies to disincentive landfilling and generate funding for waste minimisation and prevention initiatives (implementation planned for 2021, see section 5.5).
    c. Introduce mandatory product stewardship (implementation planned for certain priority products, see section 5.5), including container deposit scheme with non-detachable lid requirement.
    d. Provide and improve waste education and awareness through schools and local councils to emphasise the need to minimise waste and the cumulative impacts of waste loss to the environment.
2. Improve how waste loss to the environment is managed, to reduce and preferably prevent waste loss from the formal waste management system.
    a. Simplify recycling schemes and unify collection methods across NZ by making recycling instructions more obvious.
    b. Hold waste collectors accountable for any waste loss during waste collection and transport.
    c. Improve overall compliance with waste management regulations. This can be achieved in a manner where individuals, industries, and agencies are held responsible for incorrect waste disposal and/or failure to remove items from their kerbside through education, awareness, and enforcement of the NZ Litter Act.
    d. Compulsory and uniform waste collection and diversion data gathering and reporting for all industry actors, including all types of landfill and materials collected for recycling as those sent to disposal.
    e. Regulate farm dumps for household, farming and other non-biological waste. This would result in Regional Plans no longer

being able to allow farm dumps as a permitted activity, instead farm dumps would be subject to consenting requirements to scrutinise impacts and provide for ongoing monitoring and enforcement.

3. Improve the waste planning process
   a. Enable the synchronization of local waste planning in space and time, by having similar start and end dates of WMMPs in all TAs.
   b. Coordinate RA involvement through a regional waste document outlining practices in and between underlying TAs, as well as with adjacent RAs.
   c. Strengthen legislative requirements and related planning documents to support stronger adherence to (through specific language) the waste hierarchy (e.g., favour prevention over recycling) including revision of the Waste Minimisation Act and the NZ Waste Strategy.
4. Regulatory
   a. Resource Management Act – review the regulation of farm dumps by resource management plans to enable more stringent control.
   b. Resource Management Act – conduct research to review Regional Plans to identify extent of capture of AMD items as discharges to the environment.
   c. Waste Minimisation Act – review and consider the role of RAs in coordinating WMMPs in underlying TAs.

5.4 Lessons Learned - What Could or Should Have Been Done Differently?

Although intriguing, the mission of describing “the NZ waste management system”, as part of explaining AMD occurrence throughout the country, was a massive undertaking. Publicly available documents and communications formed the basis of local comparison, to address the existing gaps in national AMD and waste management research. These methods may have been improved by adding structured interviews with the TAs and RAs. Such interviews could have provided information about specific challenges and opportunities regarding waste management options in their jurisdiction, as well as (perceived) challenges and options.

Measuring AMD on beaches, as evidenced in the methodology review (Chapter 1), is not straightforward. The replicable and robust methodology applied in this study has since been recommended as a standard for harmonization purposes by international experts (Kershaw et al., 2019). However, in retrospect, additional belt transects further towards and into the backshore, would have provided valuable insights. Additionally, if time (and resources) had permitted, repeat studies on (a selection of) beaches would have allowed further testing for seasonal effects.

5.5 Developments

Since commencing this thesis, much has changed in NZ’s social and political attitudes towards AMD, and in particular, plastics. In 2017, after 9 years (of governments led by the NZ National Party, in coalition or with the support of the United Future, ACT and Māori parties), a different political coalition (a Labour-led government, in coalition with the NZ First and Green parties) came to power in NZ, with increased attention on environmental matters. In 2018, the top concern for 72% of New Zealanders was the build-up of plastic waste in the environment (Colmar Brunton, 2019). This sentiment was sustained in 2019, with NZ consumers demanding businesses and brands to be more conscious about waste and pollution (Colmar Brunton, 2020). The government introduced bans on the sale of products with microbeads and plastic bags (Waste Minimisation (Microbeads) Regulations 2017; Waste Minimisation (Plastic Shopping Bags) 2018). Albeit the former was initiated and consulted on by the prior government. In 2019, the Prime Minister's Chief Science Advisor released the seminal report *Rethinking Plastics in Aotearoa New Zealand*. In addition, NZ waste industry representatives and local authorities issued a report highlighting the flawed status of NZ's kerbside plastics recycling (WasteMINZ TAO Forum, 2020).

Estimated damages to NZ's blue economy (all economic activity related to oceans, seas and coasts) from AMD in 2015 are estimated at NZ$22,949,408 (US$15,066,675) and likely to increase (McIlgorm et al., 2020). These estimates include direct costs to fisheries and aquaculture, shipping and marine tourism, but exclude the costs of beach cleaning, volunteer activities, and beneficial ecosystem services provided by the marine environment, such as heritage and wellbeing (Royal Society Te Apārangi, 2019).

In 2019, international developments on the recycling markets led to an amendment of the Basel Convention to curtail the uncontrolled "dumping" of contaminated waste streams from developed to lesser-developed countries. Annexes II, VIII and IX now include plastic waste trades in a legally binding framework, requiring the importing countries to agree to the specific content being received (Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, 1989).

In 2020, in reaction to the global COVID-19 pandemic, collection and processing of recyclable materials ceased or were postponed in many TAs in NZ. Manual sorting of the recycling crates at the kerbside was halted due to safety concerns, and international trade in recyclables came to a standstill. This left NZ's collected recyclables stockpiled or sent to landfills (Desmarais, 2020).

These externalities, coupled with already low recycling rates in NZ, highlight the ongoing need to further prioritize actions higher in the waste hierarchy, with a proactive, driven focus on waste prevention. Systemic changes are needed to move away from the current business as usual (linear model) towards a model where resources are conserved, reused, repurposed or fully recycled (circular economy). Such changes require national and regional coordination through legislation, economic instruments, awareness and education programs and enforcement. In this light, the NZ government has announced, based on the results of public consultation, the first ever increase of the waste levy from 1 July 2021 (New Zealand Government, 2020b), the proceeds of which will go (amongst others) towards building a national recycling infrastructure and improved data gathering.

Furthermore, priority products have been declared for the first time, requiring product stewardship schemes be developed for plastic packaging, tyres, e-waste, agrichemicals and their containers, refrigerants and farm plastics (New Zealand Government, 2020c). Once developed and accredited, these schemes can be made mandatory through regulations under s 22 of the WMA. Moreover, as of 1 January 2021, permits will be required to export of hard-to-recycle plastics, as part of New Zealand's commitments to the Basel Convention (New Zealand Government, 2020d). Altogether, these represent an unprecedented set of waste management measures, indicating serious efforts to address some of the waste management issues described in this thesis. Notably absent from the list of actions, is the issue of farm dumps and concrete policies focussing on waste prevention and activities at the top of the waste hierarchy. Furthermore, a panel reviewing the Resource Management Act has concluded that the Act does not perform its purpose and shows weak compliance, monitoring and enforcement across the resource management system; undermining rules that protect the environment. The panel recommends an overhaul into 2 separate acts (Resource Management Review Panel, 2020).

The international literature describing AMD has continued to balloon since the original literature review (Chapter 1) occurred, with many articles delving into topics related to micro-(or nano-) plastics. Most microplastics are ultimately derived from larger plastics (Costa et al., 2010; Heo et al., 2013; Hidalgo-Ruz et al., 2012; Lee et al., 2013; Velez et al., 2019), of which production, consumption, waste loss and fragmentation will continue to rise in the following decades (Andrady, 2011; Hoornweg et al., 2015; PlasticsEurope, 2019). Thus, baseline knowledge of the location and abundance of larger plastic debris can aid in understanding and prioritizing future microplastics research. In addition to a published study of sediment pollution on 39 beaches around Auckland (NI) (Bridson et al., 2020), other NZ microplastics research is in motion (ESR, n.d.; NIWA, 2019). These studies aim to understand the degradation of plastic debris in the marine environment, microplastics in freshwater systems, and the distribution of plastic debris through the water column (Valois and Panthos, personal communications, November 2019). Other studies in NZ focus on the relationships between microplastic pollution and NZ's history of imperialism, indigenous rights and the Treaty of Waitangi (Ngata & Liboiron, 2020).

Microplastics are extensively researched (globally and in NZ) because of their ability to enter and bioaccumulate throughout the food chain (Chapter 1). Many organisms, including commercially available sea fish in NZ, contain microplastics in their digestive systems (Forrest & Hindell, 2018; Markic et al., 2018). What the exact consequences are for humans remains unclear (Prata et al., 2019; Sharma & Chatterjee, 2017; Smith et al., 2018), but a matter of concern

(Azoulay et al., 2019; Campanale et al., 2020). Our daily interactions with plastics allow for oral, dermal and inhalation exposure, not only to the plastics themselves, but also their many additive chemical substances, including known carcinogenic and mutagenic monomers (Galloway, 2015).

In conclusion, anthropogenic oceanic stressors, including marine debris, are threatening all life on earth. This thesis demonstrated specific links between waste management, emissions to the oceans, and litter on NZ beaches, which can now serve as evidence for further mitigative actions.

During this research project, the NZ government has taken unprecedented national measures and has engaged in multiple international commitments to address the wicked problems of waste and AMD. However, NZ's role as a high-income country in the Pacific region and guardian of the surrounding waters and connected oceans requires a further-reaching, holistic, and more swiftly implemented approach to counter AMD's impacts from ongoing land-based inputs.

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Appendix A

Marine Debris on New Zealand Beaches - Baseline Data to Evaluate Regional Variances

The article included in this appendix is based on Chapter Two and was published on July 28, 2021, in Frontiers in Environmental Science (van Gool et al., 2021). Contributions of the co-authors were as follows: Marnie Campbell, Chad Hewitt and Ella van Gool designed the study, Marnie Campbell, Chad Hewitt and Ella van Gool analysed the data, Ella van Gool wrote the manuscript, Marnie Campbell, Pip Wallace, Chad Hewitt and Ella van Gool edited the manuscripts. See also the statement of contributions of co-authors is included at the end of the appendix.

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BRIEF RESEARCH REPORT
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Marine Debris on New Zealand Beaches - Baseline Data to Evaluate Regional Variances

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Terrestrial sources of marine debris on beaches are substantial, increasing, and are primarily a result of mismanaged waste on land. The scale, source, and composition of beached marine debris in New Zealand was determined by surveying 41 beaches, with triplicate belt transects, across the North and South Islands. Results demonstrated a significant spatial variance, with the South Island showing a significantly higher mean density than the more populated North Island by count as well as by weight. The majority of all anthropogenic marine debris detected was plastic and arrived through the water. Explanations for regional variances in debris presence are difficult to ascertain with certainty but could not be explained by population density and proximity. These findings contribute to the understudied field of marine debris research in New Zealand and the Southern Hemisphere and provide a starting point for evidence-based mitigation. Recommended changes to future monitoring programs are made. This first national baseline study of marine debris in New Zealand serves as a reference for follow-up studies, including research at other locations.

Keywords: marine debris, marine litter, marine pollution, New Zealand, mismanaged waste, beach survey, baseline study, plastic pollution

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INTRODUCTION

Globally, about 80% of anthropogenic marine debris (AMD) is derived from land-based sources (Derraik, 2002; Sheavly and Register, 2007); a large proportion of which results from mismanaged terrestrial waste (Barnes et al., 2009; Jambeck et al., 2015; Lau et al., 2020). Coastal marine environments are a known accumulation zone for AMD (Galgani et al., 2015; Sherman and Sebille, 2016), and beach surveys are an often-applied tool to better understand the scope and current nature of the problem of AMD (Slavin et al., 2012; Jang et al., 2018). Most coastal AMD studies occur on sandy beaches (Browne et al., 2015; Serra-Gonçalves et al., 2019) due to easy access and generally require no specialized equipment (GESAMP, 2019). In addition to obtaining scientific data, beach surveys are also performed by volunteers (citizen scientists) to support scientists, raise public awareness, and as education and community outreach programs (Ribic et al., 2010; Hidalgo-Ruz and Thiel, 2015; Murray et al., 2018). There are many different methods to obtain data and/or measure the spatial and temporal distribution of debris (Velander and Mocogni, 1999; Browne et al., 2015; GESAMP, 2019), and many variations exist.

Abbreviations: AMD, Anthropogenic Marine Debris; NZ, New Zealand; NI, North Island; SI, South Island.

Such variations occur, for example, in measurement units (e.g., transect, quadrant, line), placement of sampling unit (horizontally or vertically relating to the waterline), location of sampling unit on the beach (anywhere between the waterline and into the backshore), sample replication, and reporting units (e.g., total item count, litter density (Kordella et al., 2013; Kaladharan et al., 2017; Rangel-Buitrago et al., 2017; Schmuck et al., 2017). Due to these differences, results are often not comparable, rendering an evaluation and comparison of associated mitigation actions at a regional, national, or global scale challenging (Serra-Gonçalves et al., 2019).

Debris studies often classify the origin of AMD either from ocean-based, land-based, or unknown sources (e.g., Coe and Rogers 1997; Sheavly and Register 2007) or through a likely origin (Whiting, 1998; Tudor and Williams, 2004; Pieper et al., 2019; Verlis and Wilson, 2020). However, in New Zealand (NZ), it is not always clear whether the origin of an item is freshwater or ocean. Land-based sourced items can have multiple pathways: entering the aquatic environment through stormwater drains, lakes and waterways, washed or blown out onto the beaches and into the ocean (McCormick and Hoellein, 2016; Boucher and Friot, 2017; Lebreton et al., 2017). Hence, most debris in the marine environment may have had a land origin.

In NZ, boundaries of regional management areas are roughly based on catchment areas. The respective administrative agencies, "Regional Authorities", are responsible for, amongst others, the region's environmental management. The underlying local municipalities, "Territorial Authorities", are among other things, responsible for waste management and the control of the effects of land use. In 2017, the year of this study, NZ was estimated to have produced 740.3 kg of waste per capita, 218.7 kg more (per capita) than the average (521.6 kg) of all other OECD countries combined (OECD, 2021). Furthermore, waste creation in NZ continued to increase, as evidenced by the 2018 per capita amount of 781.1 kg versus a 538.3 kg average of all OECD countries. The NZ waste and recycling industry is listed as one of the least efficient of all developed countries (Hoornweg and Bhada-Tata, 2012; OECD, 2017). All of NZ's residual waste goes to landfills, creating an increased potential for waste loss to the (marine) environment (Office of the Prime Minister's Chief Science Advisor, 2019). One example of such waste loss is the Fox Glacier landfill (SI) rupture in 2019, which released decades of previously landfilled household rubbish onto 1,313 ha of sensitive riverbeds and banks, and 64 km of coastline (Office of the Prime Minister's Chief Science Advisor 2019, page 194).

Previous NZ studies measured marine debris on beaches in the Coromandel Peninsula on the North Island (NI) (Campbell et al., 2017), from the coasts of the Canterbury region on the South Island (SI) (Clunies-Ross et al., 2016), and around Auckland (NI; Bridson et al., 2020). Earlier beach surveys were decades old (Gregory, 1978), and all studies were localized. Currently, no nationwide research study of AMD exists that contemporaneously covers both the NI and SI beaches. Hence, it is difficult to accurately determine the national status of AMD and its environmental effects and relationship to local or national mitigation actions to reduce waste loss to the marine environment. Understanding the actual AMD problem across both islands and the relevant management areas is an important gap to fill. Therefore, this study aims to understand further the scale and composition of AMD loads at a local, regional, and national level. A second aim is to develop a baseline of AMD on NZ beaches against which future changes in AMD can be measured and the efficacy of mitigating actions assessed. The three research questions supporting these goals are:

- What is the distribution of AMD on NZ beaches by count, weight, type, and source?
- Are there significant differences in the results of the AMD distribution by island (north versus south)?
- How is AMD geographically distributed across regional management scales?

MATERIALS AND METHODS

Regions and Sample Sites

The human population is unevenly distributed over the islands, with the NI and SI having 3,642,900 and 1,149,576 inhabitants, respectively (Stats, 2019). NZ is an archipelago bordered by the Tasman Sea and the South Pacific Ocean with approximately 18,200 km of shoreline (Hutching, 1998). A subtropical, southern current flows along the NI's east coast that joins the northern current by the East Cape (NI) (Chiswell et al., 2015). The SI has sub-Antarctic surface water moving northwards along the east coast (Hayward et al., 2003). Between Gisborne (NI) and Otago (SI), waves usually arrive from the south and east (NIWA, 2017). The daily changing weather is a result of weather systems, the maritime position, and orography, causing predominantly westerly winds and an average annual rainfall of 800 – 1,500 mm y^{-1} (Pickrill and Mitchell, 1979; Tomlinson, 1992).

Study sites were predetermined based on a stratified random sampling design. The sampling frame spanned the east coasts of both islands, starting at the top of the NI (34.4°S) to the bottom of the SI (46.5°S). Three random numbers were generated per latitude to select a location from where the nearest sampling site was determined. From this random starting point, the coastline was followed to the right (when facing the water), until the following criteria were met for a site:

1) East-facing (when facing the water, compass direction was either NE, E, or SE)
2) Length was > 1 km
3) Faced open ocean
4) Away from (> 500 m) obstructions (such as headlands, breakwaters, jetties)
5) Accessible from the land through public roads

These site criteria were applied to reduce potential confounding factors such as fluctuations in oceanic and climatic influences or localized effects (e.g. urban marine structures; Campbell et al., (2017). Furthermore, a large part of the SI's west coast is inaccessible from land.

Forty-one beaches (20 on the NI and 21 on the SI) were surveyed between latitudes 34.7°S and 46.3°S, covering a total of

FIGURE 1 | New Zealand Beaches Sampled for Anthropogenic Marine Debris (> 2 mm) (Spring 2017).

11.6° in latitude (**Figure 1**). Study sites covered 11 of NZ's 16 regions (8 on NI and 3 on SI), with the remaining regions not sampled because they did not border the east coast. One exception was Southland, which was excluded because of random sampling and the criteria (i.e., east facing). Sites were distributed over 25 out of 66 territorial authorities (14 on the NI and 11 on the SI).

Sampling Method

A one-time-only, standing stock survey at each beach provided a temporal snapshot of the AMD distribution by count, weight, type, and source. We note that standing stock surveys are subject to limitations in comparison to an accumulation study (Smith and Markic, 2013; Ryan et al., 2014). In addition, sampling occurred during the austral spring (between 28th September and November 3, 2017) to avoid localized effects of the busier (with tourists) austral summer and autumn seasons.

The adapted research method was based on Cheshire et al. (2009) and sampled the highest visible wrack line using triplicate belt transects (10 m long by 2 m wide). Instead of sampling the entire beach surface between the waterline and backshore, the wrack line was selected, as it can be sampled irrespective of tides and is a known accumulation zone of AMD (Velander and Mocogni, 1999). In addition, prior studies indicate that AMD is rarely detected between the waterline and wrack line (Williams and Tudor, 2001; Hidalgo-Ruz et al., 2018), and the wrack line was, therefore, our focus to determine the AMD standing stock.

A starting point at the beach was placed 50 strides (about 1 m each) to the left (when facing the water). Randomly generated distances (between 21 and 40 strides) determined the distance of the starting point for each belt transect. A 10 m long tape measure was placed on the middle of the wrack line, and 1 m on each side of the tape was examined (creating a 2 m wide transect). All visible items (> 2 mm) from the surface of each transect were collected by a visual survey without raking or digging. Items were bagged and labeled after which the (detangled) debris was counted, weighed, and classified based on the type of material (plastic, foamed plastic, rubber, metal, glass and ceramic, cloth, paper and cardboard, wood, and other) (Cheshire et al., 2009). Large items (> 1 m) were counted but not weighed. Other variables recorded during sampling included the gradient of the beach, substrate, backshore type, beach shape, aspect, wind speed, wind direction, number of people on the beach, number of rubbish bins, and number of parking spaces (adapted from Lippiatt et al., 2013; Schuyler et al., 2018).

In this study, a subjective distinction between the source of an item was based on visual evidence of an item having been in water (whether the ocean or freshwater) and will hereafter be called "waterborne". Debris characteristics indicating a waterborne source include:

- A weathered appearance-porous look/feel, faded colors, bite marks, smoothened edges.
- Items from a foreign source that are typically not sold in NZ.
- The presence of biofouling, entanglement in other marine organisms.

In contrast, "land-based" items lacked a weathered appearance (were pristine and intact) and lacked biofouling. If a decision on origin could not be determined, then the item was labeled "unknown".

Analysis

Differences between AMD distribution by island (north versus south) were calculated through mean density and weight and were analyzed with Welch's *t*-test (Welch, 1947). This adaptation of the Student's *t*-test is better suited for testing the means of two populations with unequal variances (Ruxton, 2006). Results are given in $t_{[\text{degrees of freedom}]} = t$, p (T ≤ t).

Significant differences in AMD composition and sources between islands were determined using Pearson's Chi-Square test of independence (Pearson, 1900). Results are reported with (degrees of freedom and sample size) the Pearson chi-square value and the significance level. All statistical tests were performed in Microsoft Excel™ (version 2105) with a significance level of 0.05.

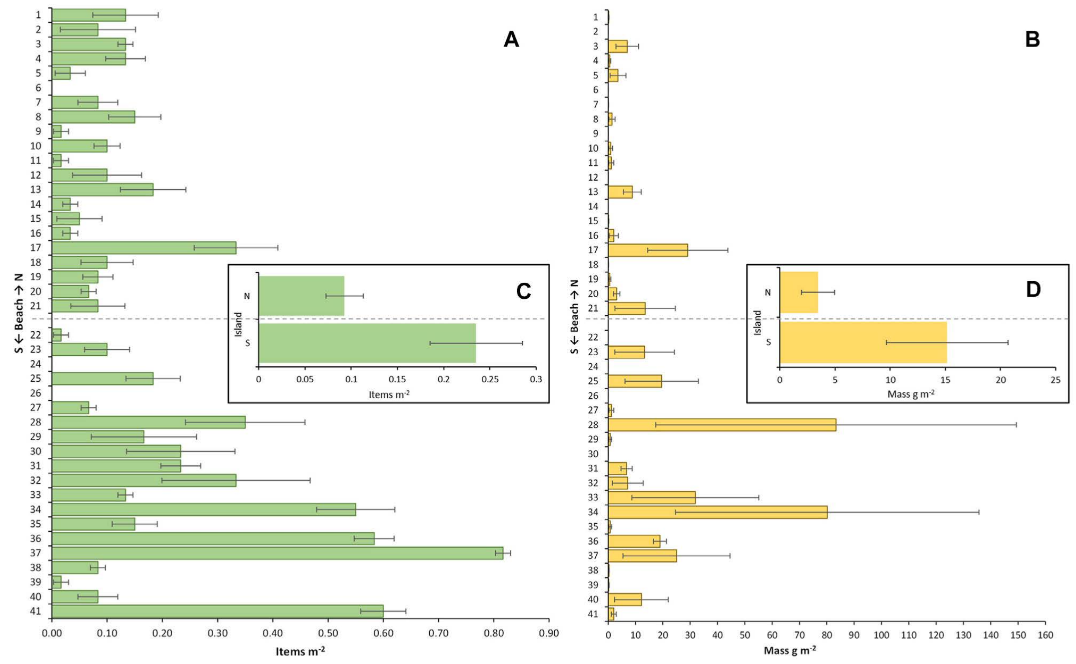

FIGURE 2 | Mean Anthropogenic Marine Debris (> 2 mm) Across New Zealand Beaches by **(A)** Density (± SE), and **(B)** Weight (± SE); and Across Islands by **(C)** Density (± SE), and **(D)** Weight (± SE).

Mean densities and weights for each region were calculated and reported as *Mean* ± *SE* items m^{-2} and g m^{-2}, respectively, to determine distribution at a regional scale. AMD composition was compared at a regional level by percentages of types by count density. The resulting exploratory data is represented in a graph illustrating beach numbers from north to south (increasing latitudes, with no overlapping longitudes).

RESULTS

Baseline AMD Beach Data on Density, Mass, Composition, and Source

The mean AMD density detected across 41 beaches on both islands of NZ ranged from zero to 0.82 items m^{-2} per beach, with an overall mean of 0.16 ± 0.02 items m^{-2}. Overall, the highest AMD density was detected at Karitane Beach (site 37, SI, **Figure 2A**) with 0.82 ± 0.02 items m^{-2}, more than five times the national mean. In contrast, three beaches [sites 6 (NI), 24 and 26 (SI)] had zero items >2 mm recorded (**Figure 2B**).

The mean weight of AMD items ranged from zero to 83.38 g m^{-2} per beach, with an overall mean AMD weight of 9.17 ± 2.91 g m^{-2} per beach. Overall, the highest AMD weight was detected at Ashworths Beach (site 28, SI) with 83.38 ± 80.82 g m^{-2}, more than nine times the national mean. In contrast, six beaches [sites 2, 6, 14 (NI) and 22, 24, 26 (SI)] recorded no AMD weight, albeit three of those did record items by count, but their weight was < 1 gr.

By count, the most prevalent type of AMD was plastic (n = 261 items), followed by foamed plastic (n = 44 items), metal (n = 41 items), wood (n = 19 items), glass and ceramic (n = 9 items), cloth (n = 7 items), rubber (n = 6 items), other (n = 2 items), and paper and cardboard (n = 1 item).

By weight, the most prevalent type of AMD was metal (6739 g), followed by wood (6723 g), rubber (4011 g), plastic (2513 g), cloth (1416 g), glass and ceramic (1154 g), paper and cardboard (6 g), other (6 g), and foamed plastic (0 g). Of the 399 AMD items (including large items) detected, 306 (77%) were waterborne, 56 (14%) were land-based, and 37 items (9%) had an unknown source.

Differences Between North and South Island

When comparing the islands by AMD density, there was a significant difference between the amount (number of items) of AMD detected, between the NI and SI ($t_{[23]}$ = -2.60; p < .02) (**Figure 2C**). There was a higher mean density of AMD items on the SI (M = 0.24 ± 0.05 m^{-2}) than the NI (M = 0.09 ± 0.02 m^{-2}). Similarly, the mean weight of AMD differed significantly between islands ($t_{[22]}$ = -2.05; p = 0.05), with significantly higher mean AMD weight on the SI (M = 15.18 ± 5.52 g m^{-2}) compared to the NI (M = 3.45 ± 1.50 g m^{-2}) (**Figure 2D**).

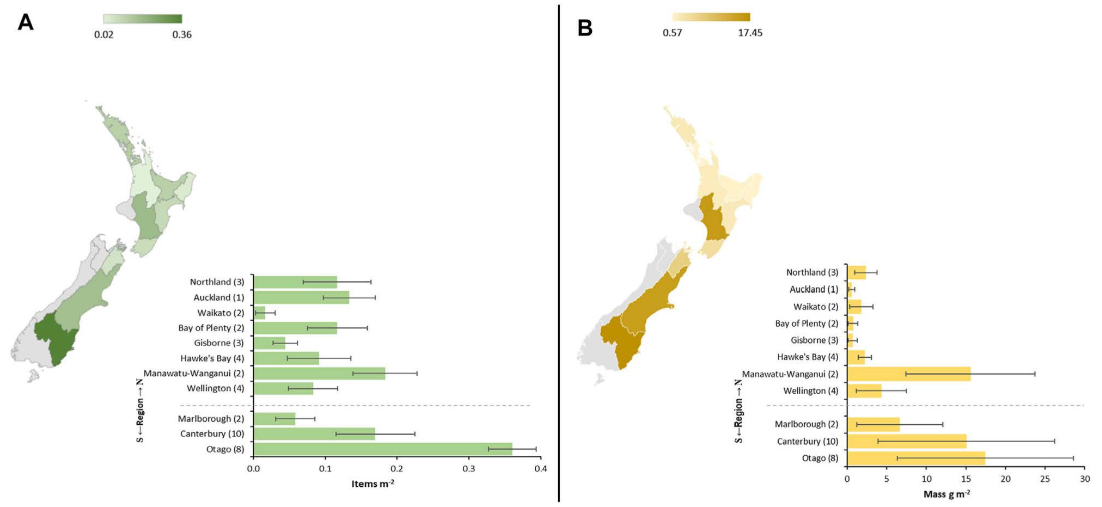

FIGURE 3 | New Zealand Beach Anthropogenic Marine Debris (> 2 mm) per Region (Number of Beaches) in Spring 2017 by **(A)** Mean Density (± SE) and **(B)** Mean Weight (± SE).

The composition of AMD, however, was similar between islands (χ^2 (3, N = 399) = 6.13, p < 11). These results were based upon comparing four AMD types only (i.e., plastic, foamed plastic, metal, and wood) due to a lack of sufficient count data in the other categories. Overall, the sources of the AMD found between the islands were significantly different (χ^2 (2, N = 399) = 23.03, p < .01); NI and SI showed a similar proportion of waterborne items (74 and 78%, respectively). The NI had more land-based items than the SI, with 26 and 9%, respectively. The SI showed 13% of unknown items, of which the NI had none.

Comparison of Debris by Regional Management Level

The Otago region (SI) had the highest mean density of AMD (M = 0.36 ± 0.06 m^{-2}), and the Waikato region (NI) had the least mean density (M = 0.02 ± 0.02 m^{-2}) (**Figure 3A**). The Otago region also had the highest mean weight (M = 17.45 ± 9.28 g m^{-2}), and the Auckland region (NI) the least mean weight (M = 0.57 ± 0.47 g m^{-2}) (**Figure 3B**).

The Waikato region (NI) stood out as only one AMD category (glass and ceramic) was detected here by count (n = 2). When considering the weight of AMD categories, metal debris was not found on a substantial scale in the four most northern regions (Northland, Auckland, Waikato, and Bay of Plenty), which was otherwise detected in significant amounts (>1 g) in all other regions.

DISCUSSION

The etiology of beached AMD results from multiple and often interwoven factors (Hardesty et al., 2017; Willis et al., 2018; Schuyler et al., 2021). This study contributes to the understanding of AMD on NZ beaches by providing a first national baseline. We found that on NZ beaches, population density does not explain variations in AMD between islands and regions.

Patterns of AMD Distribution

This study showed a similar mean AMD density to a prior NZ study on 27 beaches in one region (Waikato, NI), however, measurements were made on sample sites with a different aspect, smaller size, and on a different part of the beach (Campbell et al., 2017). Other NZ debris studies have reported results in different units and measured fewer beaches, making comparisons challenging (Gregory, 1999; Hayward, 1984, 1999). When comparing to standing stock studies of more than 20 beaches in other locations, the overall mean density as determined in this study is similar to results from Australia, but less than surveys from Turkey, Sri Lanka, and Portugal (Azores) (**Table 1**). Although these studies did report results in an equivalent format (items m^{-2}), not all studies measured the same part of the beach, thus making results incomparable. Specifically, the studies in Australia, Turkey, and the Azores, measured from the waterline into the backshore, whereas in Sri Lanka, quadrats were used with an unknown location on the beach (Aydin et al., 2016; Hardesty et al., 2017; Jang et al., 2018; Ríos et al., 2018). To address this universal challenge of incomparable results of beach surveys, international recommendations to harmonize beach study methods have been made (GESAMP, 2019).

Studies from Malaysia and Japan show that the types of recreational activities performed on a beach may cause a similar amount of litter to become buried in the top layer of

TABLE 1 | New Zealand Beach Debris Density Results from This Study (Spring 2017; numbers in bold) Compared With Other Multi Regional Studies.

Location	No. Beaches	Items (m^{-2})	Reference
New Zealand	41	**0.16 ± 0.02**	This study
Australia	175	0.15	Hardesty et al. (2017)
Portugal (Azores only)	42	0.62 ± 0.15	Ríos et al. (2018)
Turkey	13	0.92 ± 0.36	Aydin et al. (2016)
Chile	43	1.8	Bravo et al. (2009)
Panama	19	3.6	Garrity and Levings (1993)
Sri Lanka	22	4.1 ± 9.2	Jang et al. (2018)
Indonesia (Ambon only)	56	4.6	Evans et al. (1995)
Caribbean nations[a]	42	6.34 ± 10.11	Schmuck et al. (2017)

Note. [a] *Includes the Bahamas, British Virgin Islands, Dominican Republic, Grenada, St. Vincent and the Grenadines, Turks and Caicos Islands, Cayman Islands, Martinique, and St. Eustatius.*

the beach sediment (Fauziah et al., 2015) as observed on the surface (Kusui and Noda, 2003). Moreover, on a remote Pacific Island, up to 68% of AMD items were found buried (Lavers and Bond, 2017), leading some to conclude that all AMD surveys should include measurement of items buried in the top layer (5 cm) of the beach (Serra-Gonçalves et al., 2019). In the present study, the sand was not raked nor sieved. Thus, it is likely that the actual density of AMD is higher than is represented in the results.

While debris count and weight on the SI were significantly higher, they also showed greater variation in density, weight, and material type. We did not detect a significant difference in the composition of AMD between the islands, but the SI had two additional types of debris: rubber and cloth. The overall proportion of plastics by count in this study is similar to other studies both in NZ and in Australia (Campbell et al., 2017; Hardesty et al., 2017), and plastic debris was present on all beaches where AMD was detected. Whereas the proportion of waterborne sources of AMD were comparable between the NI and SI, the NI had more land-based sources and AMD with an unknown source was only found on the SI.

Some variations between the islands and regions might be because the SI has more rivers discharging on the east coast as these are known pathways for land-based AMD (Lebreton et al., 2017; Schmidt et al., 2017; Meijer et al., 2021). Alternatively, variations could be related to circulation and currents in coastal waters, and AMD washing on and off the beach (Nagelkerken et al., 2001; Critchell and Lambrechts, 2016). The difference in currents and wind waves between the islands (Chiswell et al., 2015) may also result in mixed effects on the different types and sources of materials (Pieper et al., 2015). The circulation and currents in coastal waters which cause AMD to wash on and off the beach (Nagelkerken et al., 2001; Critchell and Lambrechts, 2016), also suggests a correlated abundance between certain types of AMD found on the beach and in the adjacent coastal waters (Thiel et al., 2013). On the beach, AMD can be buried and exhumed based on geophysical and environmental factors (Orr et al., 2005; Thiel et al., 2013), including tidal cycles and wind waves (Orr et al., 2005). Together, such variables cause AMD to move constantly, creating variability based on the specific local environmental circumstances at a particular time.

Regional Variations

This study did not find a relation of AMD density with population density as the highest mean density and weight was found in a region (Otago, SI) with a population of 239,313 (Stats, 2019) (**Figure 3**). In contrast, the most populated region (Auckland, NI) with a population of 1,590,261, showed the least AMD by weight and the lowest mean density by count was in a region (Waikato, NI) with a population of 466,110 (Stats, 2019). Waikato beaches are popular tourist destinations with many holiday homes close to the beach. Studies in Australia and Easter Island (Chile) showed less debris at beaches in proximity (< 5 km) to homes (Hardesty et al., 2017; Kiessling et al., 2017), perhaps a result of local stewardship. It is likely that debris on those beaches, specifically when frequented by tourists, are cleaned up more regularly than others (e.g., in Israel; Pasternak et al., 2017).

Similar to the differences between the islands, the contrast between the three regions on the SI (**Figure 3**) might also be due to geophysical and oceanic factors. Marlborough is located on the Northern part of the South Island, and its coast is exposed to different current and wind wave patterns. Marlborough is also located further away from (larger) watersheds, possibly being less affected by waterborne sources. Alternatively, the large proportion of rubber, cloth, and wood in Canterbury might be partially explained by local use factors, as beaches in Canterbury had more vehicles and horses on the beach than the other regions at the time of sampling.

A better understanding, of the combined reasons for the regional variations in AMD density, weight, composition, and source, is needed to develop tailored mitigative action. Therefore, the establishment of monitoring programs is critical to facilitate the understanding of variability in AMD (Schuyler et al., 2021). Since the conclusion of this baseline study, a nationwide citizen science beach monitoring project has started collecting seasonal AMD data on more than 100 NZ beaches[1]. The data collection is based on similar categorizations as this study and is according to international guidelines on the monitoring and assessment of litter in the ocean (GESAMP 2019), rendering future comparisons feasible. Based on the results of this study, we

[1]https://litterintelligence.org/

recommend measuring the effects of beach cleaning, watersheds, buried debris, ocean currents, and the type of activity on the beach.

In a meta-analysis of studies in the Southern Hemisphere, Barnes (2005) found that AMD density diminished on a latitudinal gradient from the equator towards the pole, with higher concentrations of AMD at the equator. Based on a review of 47 studies, this trend was explained by population density, which reduced further away from the equator (Barnes, 2005). Other studies have also shown that the proximity of population centers can result in higher debris loads on beaches (Santos et al., 2005), with even further intensification as the population density increases (Araújo et al., 2018). However, other studies show that the vicinity to population on increased AMD densities is not universally evident (Martinez-Ribes et al., 2007; Ribic et al., 2010; Lavers and Bond, 2017). Similarly, a comparison of AMD data from seven countries, although not all in the Southern Hemisphere, found that the determining drivers for AMD variability did not include population density (Schuyler et al., 2021). The results presented here, albeit on a subset of latitudes, also contradict Barnes findings by showing increasing AMD densities in higher latitudes with less population (SI). Thus, AMD density on NZ beaches cannot be explained by latitude nor population density.

CONCLUSION

A comprehensive and reproducible (standing crop) survey of AMD on beaches along the east coast of NZ provided a robust and reproducible baseline. This study indicated a substantial spatial variation in AMD density, mass, and source with a concomitant variation per island and region, requiring targeted mitigation efforts. Both AMD density and weight were significantly higher on the SI than on the more densely populated NI, showing increasing AMD densities with increasing latitudes. Debris on the NI showed significantly more land-based sources and the SI, more unknown sources, possibly resulting from inland sources through freshwater inputs. Further research explaining regional variances is needed and we recommend adding in monitoring the effects of beach cleaning, ocean currents, buried debris, watersheds, and type of activity on the beach. These results can be used as an evidence base for mitigative actions and can be compared against similar research in the future (e.g., NZ's west coast and other countries).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

EV, MC, and CH contributed to the conception and design of this study. EV collected the data, prepared figures, and wrote the manuscript. EV, MC, and CH analysed the data and all authors reviewed the manuscript.

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Appendix A:
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Nature of contribution by PhD candidate	Conception, Data Collection, Data Analysis and Interpretation, Drafting, Revision, Approval
Extent of contribution by PhD candidate (%)	70%

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Name	Nature of Contribution
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Pip Wallace	Revision, Approval

Certification by Co-Authors

The undersigned hereby certify that:

❖ the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and

Name	Signature	Date
Marnie Campbell	[signature]	10/08/2021
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Appendix B

Beach Variables Recorded During Sampling of New Zealand Beaches in 2017

Beach	Gradient	Substrate	Backshore	Aspect	Wind-speed	Wind-direction	People	Rubbish bins	Parking
1	1	Sand	Dune	NE	2.0	Onshore	3	0	15
2	2	Sand	Shrub	SE	1.0	Side shore	24	0	120
3	2	Sand	Dune	NE	2.0	Onshore	0	0	6
4	1	Sand	Dune	NE	2.0	Onshore	0	0	2
5	2	Sand	Shrub	NE	2.0	Onshore	5	5	10
6	2	Sand	Shrub	SE	2.5	Side-on	0	4	20
7	1	Sand	Dune	NE	2.0	Onshore	2	0	20
8	2	Sand	Dune	NE	2.0	Side shore	0	2	20
9	2	Sand	Shrub	SE	1.0	Side shore	1	0	20
10	1	Sand	Grass-tussock	E	0.5	Offshore	0	20	100
11	1	Sand	Shrub	SE	2.5	Side-on	2	1	20
12	1	Sand	Dune	E	2.5	Side-on	0	0	80
13	1	Sand	Dune	NE	2.0	Side shore	1	4	10
14	1	Sand	Shrub	SE	1.0	Side shore	0	4	10
15	1	Sand	Dune	SE	2.0	Side shore	2	0	2
16	1	Mud	Dune	SE	1.5	Side shore	0	0	1
17	1	Sand	Shrub	E	1.0	Side shore	1	20	100
18	1	Sand	Dune	SE	2.0	Offshore	0	0	6
19	1	Sand	Dune	SE	2.0	Offshore	3	2	80
20	1	Sand	Dune	E	1.0	Offshore	0	0	3
21	3	Sand	Grass-pasture	SE	1.0	Side shore	0	3	100

Beach	Gradient	Substrate	Backshore	Aspect	Wind-speed	Wind-direction	People	Rubbish bins	Parking
22	2	Gravel	Dune	E	2.0	Side shore	0	0	8
23	4	Pebble	Dune	SE	0.5	Offshore	0	0	30
24	3	Pebble/gravel	Grass-pasture	E	1.0	Onshore	0	0	3
25	2	Pebble	Grass-tussock	SE	2.5	Onshore	0	0	8
26	1	Sand	Cliff	SE	1.0	Onshore	0	0	5
27	2	Pebble	Seawall	SE	0.0	Na	0	0	4
28	2	Sand/pebble	Dune	SE	1.0	Side shore	10	0	15
29	1	Sand	Dune/forest	E	1.0	Onshore	4	1	20
30	1	Sand	Dune	NE	0.0	Na	6	1	100
31	4	Sand/pebble	Cliff	SE	0.0	Na	3	0	5
32	3	Sand/pebble	Seawall	SE	0.0	Na	2	0	20
33	4	Pebble/gravel	Seawall	SE	1.0	Side shore	1	0	50
34	4	Pebble/gravel	Grass-pasture	SE	1.0	Side shore	0	0	75
35	1	Sand	Dune	E	0.0	Na	0	0	20
36	1	Sand	Cliff	SE	2.0	Side shore	4	0	20
37	1	Sand	Shrub	SE	2.0	Side shore	2	0	4
38	2	Sand	Shrub	SE	0.0	Na	1	0	5
39	4	Sand	Shrub	SE	0.0	Na	0	0	8
40	3	Sand	Shrub	SE	3.0	Side shore	0	0	2
41	4	Sand	Shrub	SE	1.5	Side-on	0	0	25

Note. Variables are explained in Table 2.2 and for beach details see Table 2.1.

Appendix C

Codes Used for Classification of Anthropogenic Marine Debris

Material	Code	Origin	Litter form (and examples)
Plastic	PL01	MMW	Bottle caps & lids
Plastic	PL02	MMW	Bottles, 2L
Plastic	PL03	Undetermined	Bottles, drums, jerry cans & buckets > 2L
Plastic	PL04	Food related	knives, forks, spoons, straws, stirrers, (cutlery)
Plastic	PL05	Food related	Drink package rings, six-pack rings, ring carriers
Plastic	PL06	Food related	Food containers (fast food, cups, lunch boxes & similar)
Plastic	PL07	MMW	Plastic bags (opaque & clear)
Plastic	PL08	Undetermined	Toys & party poppers
Plastic	PL09	Undetermined	Gloves
Plastic	PL10	Smoking	Cigarette lighters
Plastic	PL11	Smoking	Cigarettes, butts & filters
Plastic	PL12	Undetermined	Syringes
Plastic	PL13	Undetermined	Baskets, crates & trays
Plastic	PL14	Fishing	Plastic buoys
Plastic	PL15	Fishing	Mesh bags (vegetable, oyster nets, mussel bags)
Plastic	PL16	Undetermined	Sheeting (tarpaulin or other woven plastic bags, palette wrap)
Plastic	PL17	Fishing	Fishing gear (lures, traps & pots)
Plastic	PL18	Fishing	Monofilament line
Plastic	PL19	Fishing	Rope
Plastic	PL20	Fishing	Fishing net
Plastic	PL21	Fishing	Strapping
Plastic	PL22	Undetermined	Fibreglass fragments
Plastic	PL23	Undetermined	Resin pellets
Plastic	PL24	Undetermined	Other (specify)
Foamed Plastic	FP01	Undetermined	Foam sponge
Foamed Plastic	FP02	Food related	Cups & food packs
Foamed Plastic	FP03	Fishing	Foam buoys
Foamed Plastic	FP04	Undetermined	Foam (insulation & packaging)
Foamed Plastic	FP05	Undetermined	Other (specify)
Cloth	CL01	Undetermined	Clothing, shoes, hats & towels
Cloth	CL02	Undetermined	Backpacks & bags
Cloth	CL03	Undetermined	Canvas, sailcloth & sacking (hessian)
Cloth	CL04	Undetermined	Rope & string
Cloth	CL05	Undetermined	Carpet & furnishings
Cloth	CL06	Undetermined	Other cloth (specify)
Glass & ceramic	GC01	Undetermined	Construction material (brick, cement, pipes)
Glass & ceramic	GC02	MMW	Bottles & jars
Glass & ceramic	GC03	Undetermined	Tableware (plates & cups)
Glass & ceramic	GC04	Undetermined	Light globes/bulbs
Glass & ceramic	GC05	Undetermined	Fluorescent light tubes

Material	Code	Origin	Litter form (and examples)
Glass & ceramic	GC06	Undetermined	Glass buoys
Glass & ceramic	GC07	Undetermined	Glass or ceramic fragments
Glass & ceramic	GC08	Undetermined	Other (specify)
Metal	ME01	Food related	Tableware (plates, cups & cutlery)
Metal	ME02	MMW	Bottle caps, lids & pull tabs
Metal	ME03	MMW	Aluminium drink cans
Metal	ME04	MMW	Other cans (< 4L)
Metal	ME05	Undetermined	Gas bottles, drums & buckets (> 4L)
Metal	ME06	Food related	Foil wrappers
Metal	ME07	Fishing	Fishing related (sinkers, lures, hooks, traps & pots)
Metal	ME08	Undetermined	Fragments
Metal	ME09	Undetermined	Wire, wire mesh & barbed wire
Metal	ME10	Undetermined	Other (specify), including appliances
Paper & Cardboard	PC01	MMW	Paper (including newspapers & magazines)
Paper & Cardboard	PC02	MMW	Cardboard boxes & fragments
Paper & Cardboard	PC03	Food related	Cups, food trays, food wrappers, cigarette packs, drink containers
Paper & Cardboard	PC04	Undetermined	Tubes for fireworks
Paper & Cardboard	PC05	Undetermined	Other (specify)
Rubber	RB01	Undetermined	Balloons, balls & toys
Rubber	RB02	Undetermined	Footwear (flip-flops)
Rubber	RB03	Undetermined	Gloves
Rubber	RB04	Undetermined	Tyres
Rubber	RB05	Undetermined	Inner-tubes & rubber sheet
Rubber	RB06	Undetermined	Rubber bands
Rubber	RB07	Undetermined	Condoms
Rubber	RB08	Undetermined	Other (specify)
Wood	WD01	Undetermined	Corks
Wood	WD02	Undetermined	Fishing traps & pots
Wood	WD03	Food related	Ice-cream sticks, chip forks, chopsticks & toothpicks
Wood	WD04	Undetermined	Processed timber & pallet crates
Wood	WD05	Undetermined	Matches & fireworks
Wood	WD06	Undetermined	Other (specify)
Other	OT01	Undetermined	Paraffin or wax
Other	OT02	Undetermined	Sanitary (nappies, cotton buds, tampon applicators, toothbrushes)
Other	OT03	Undetermined	Appliances & Electronics
Other	OT04	Undetermined	Batteries (torch type)
Other	OT05	Undetermined	Other (specify)

Note. MMW is mismanaged waste. Codes are adapted from Cheshire and Adler (2009).

Appendix D

Results of New Zealand Anthropogenic Marine Debris Beach Study (2017) Results by Transect, Beach and Island

The results from the New Zealand beach survey that occurred in 2017 are provided in this Appendix. Table D.1 shows AMD counts per transect, means per beach, and means per island. Table D.2 provides AMD mass per transect, means per beach and means per island. The details of the method used are in section 2.2 within the thesis text.

Table D.1

Anthropogenic Marine Debris (AMD) Density (Number of Items m^{-2}) Results NewZealand Beach Study (2017) per Transect, Beach and Island

Beach	Transect			*M*	*SD*
	1	2	3		
			North Island		
1	0.25	0	0.15	0.13	0.13
2	0.25	0	0	0.08	0.14
3	0.15	0.15	0.1	0.13	0.03
4	0.05	0.15	0.2	0.13	0.08
5	0.1	0	0	0.03	0.06
6	0	0	0	0.00	0.00
7	0	0.15	0.1	0.08	0.08
8	0.15	0.25	0.05	0.15	0.10
9	0	0	0.05	0.02	0.03
10	0.1	0.15	0.05	0.10	0.05
11	0.05	0	0	0.02	0.03
12	0.25	0	0.05	0.10	0.13
13	0.2	0.3	0.05	0.18	0.13
14	0.05	0	0.05	0.03	0.03
15	0	0	0.15	0.05	0.09
16	0.05	0	0.05	0.03	0.03
17	0.4	0.15	0.45	0.33	0.16
18	0	0.2	0.1	0.10	0.10
19	0.05	0.15	0.05	0.08	0.06
20	0.1	0.05	0.05	0.07	0.03
21	0	0.2	0.05	0.08	0.10
Total	0.1	0.09	0.08	0.09	
			South Island		
22	0	0	0.05	0.02	0.03
23	0	0.15	0.15	0.10	0.09
24	0	0	0	0.00	0.00
25	0.3	0.1	0.15	0.18	0.10
26	0	0	0	0.00	0.00
27	0.05	0.1	0.05	0.07	0.03
28	0.15	0.6	0.3	0.35	0.23
29	0.05	0.05	0.4	0.17	0.20
30	0.4	0.3	0	0.23	0.21
31	0.15	0.25	0.3	0.23	0.08

Beach	Transect			*M*	*SD*
	1	2	3		
32	0.25	0.1	0.65	0.33	0.28
33	0.15	0.15	0.1	0.13	0.03
34	0.4	0.55	0.7	0.55	0.15
35	0.2	0.2	0.05	0.15	0.09
36	0.5	0.6	0.65	0.58	0.08
37	0.8	0.8	0.85	0.82	0.03
38	0.1	0.05	0.1	0.08	0.03
39	0	0	0.05	0.02	0.03
40	0	0.15	0.1	0.08	0.08
41	0.55	0.7	0.55	0.60	0.09
Total	0.2	0.24	0.26	0.24	
Overall	**0.15**	**0.16**	**0.17**	**0.16**	

Table D.2

AMD Mass (g m^{-2}) Results New Zealand Beach Study (2017) per Transect, Beach and Island

Beach	Transect			*M*	*SD*
	1	2	3		
		North Island			
1	0.5	0	0.15	0.22	0.26
2	0	0	0	0.00	0.00
3	0.15	3.95	16.8	6.97	8.73
4	0	1.5	0.2	0.57	0.81
5	10.75	0	0	3.58	6.21
6	0	0	0	0.00	0.00
7	0	0.25	0.1	0.12	0.13
8	0	0	4.2	1.40	2.42
9	0	0	0.1	0.03	0.06
10	0.1	2.65	0	0.92	1.50
11	3.4	0	0	1.13	1.96
12	0.1	0	0	0.03	0.06
13	3.6	16.65	6.2	8.82	6.91
14	0	0	0	0.00	0.00
15	0	0	0.45	0.15	0.26
16	0.1	0	6.1	2.07	3.49
17	5.85	17.05	64.5	29.13	31.14
18	0	0.15	0.15	0.10	0.09
19	0	0.15	1.6	0.58	0.88
20	4.75	0.25	4.35	3.12	2.49
21	0	40.6	0	13.53	23.44
Total	1.40	3.96	5.00		
		South Island			
22	0	0	0	0.00	0.00
23	0	0	39.95	13.32	23.07
24	0	0	0	0.00	0.00
25	6	0.4	52.35	19.58	28.51
26	0	0	0	0.00	0.00
27	0	0.3	3.3	1.20	1.82
28	0.45	245	4.7	83.38	139.98
29	0.2	0	2	0.73	1.10
30	0	0.2	0	0.07	0.12
31	8	10.25	1.95	6.73	4.29

Beach	Transect			*M*	*SD*
	1	2	3		
32	0.25	0.2	21	7.15	11.99
33	2.45	4.45	88.75	31.88	49.26
34	1.05	215.6	23.85	80.17	117.84
35	0	0.2	2.05	0.75	1.13
36	24.6	17.15	15.05	18.93	5.02
37	1.15	73	0.9	25.02	41.55
38	0.35	0.45	0.2	0.33	0.13
39	0	0	0.6	0.20	0.35
40	0	0.25	36.25	12.17	20.86
41	4.3	1.05	0.8	2.05	1.95
Total	2.44	28.43	14.69		
Overall	**1.90**	**15.90**	**9.72**	**9.17**	

Appendix E

Results of New Zealand Anthropogenic Marine Debris Survey (2017) by Composition per Beach (Table E.1) and Island (Table E.2)

Table E.1
Results of New Zealand Anthropogenic Marine Debris Survey (2017) by Composition per Beach, FP = Foamed plastic, G&C = Glass and ceramic, P&C = Paper and cardboard

Beach	Transect	Plastic	FP	Rubber	Cloth	G&C	Metal	P&C	Wood	Other
North Island										
1	1	5	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	2	0	0	0	0	1	0	0	0
2	1	5	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0
3	1	2	0	0	0	0	0	0	0	0
	2	3	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	2	0
4	1	1	0	0	0	0	0	0	0	0
	2	2	1	0	0	0	0	0	0	0
	3	3	1	0	0	0	0	0	0	0
5	1	0	0	0	0	2	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0	0	0
	2	3	0	0	0	0	0	0	0	0
	3	2	0	0	0	0	0	0	0	0
8	1	2	1	0	0	0	0	0	0	0
	2	2	1	0	0	0	2	0	0	0
	3	0	0	0	0	1	0	0	0	0
9	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0
10	1	2	0	0	0	0	0	0	0	0
	2	1	0	0	0	1	1	0	0	0
	3	1	0	0	0	0	0	0	0	0
11	1	0	0	0	0	1	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0
12	1	5	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0
13	1	3	0	0	0	0	1	0	0	0
	2	0	1	0	0	0	2	0	2	0
	3	1	0	0	0	0	0	0	0	0

Beach	Transect	Plastic	FP	Rubber	Cloth	G&C	Metal	P&C	Wood	Other
14	1	1	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0
15	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	1	1	0	0
16	1	1	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0
17	1	8	0	0	0	0	0	0	0	0
	2	1	1	0	0	1	0	0	0	0
	3	6	0	0	0	0	1	0	2	0
18	1	0	0	0	0	0	0	0	0	0
	2	4	0	0	0	0	0	0	0	0
	3	2	0	0	0	0	0	0	0	0
19	1	1	0	0	0	0	0	0	0	0
	2	3	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0
20	1	2	0	0	0	0	0	0	0	0
	1	1	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	1	0	0	0
21	3	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	2	1	0	1	0
	2	0	0	0	0	0	1	0	0	0
Total NI	81	6	0	0	0	8	12	1	7	0
					South Island					
22	3	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0
23	3	0	0	0	0	0	0	0	0	0
	1	3	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	2	0	0	0
24	3	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
25	3	6	0	0	0	0	0	0	0	0
	1	1	1	0	0	0	0	0	0	0
	2	2	0	0	1	0	0	0	0	0
26	3	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
27	3	1	0	0	0	0	0	0	0	0
	1	2	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0

Beach	Transect	Plastic	FP	Rubber	Cloth	G&C	Metal	P&C	Wood	Other
28	3	3	0	0	0	0	0	0	0	0
	1	4	0	1	3	0	3	0	1	0
	2	5	0	0	1	0	0	0	0	0
29	3	1	0	0	0	0	0	0	0	0
	1	0	0	1	0	0	0	0	0	0
	2	5	2	0	0	0	1	0	0	0
30	3	4	3	0	1	0	0	0	0	0
	1	4	2	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
31	3	1	0	0	0	0	2	0	0	0
	1	2	0	0	0	0	2	0	1	0
	2	3	1	0	0	0	2	0	0	0
32	3	3	0	0	1	0	1	0	0	0
	1	1	0	0	0	0	1	0	0	0
	2	7	0	2	0	1	2	0	1	0
33	1	1	1	0	0	0	1	0	0	0
	2	2	0	0	0	0	0	0	1	0
	3	0	0	0	0	0	1	0	1	0
34	1	4	2	0	0	0	1	0	0	0
	2	6	0	0	0	0	3	0	1	0
	3	6	2	0	0	0	3	0	1	0
35	1	4	0	0	0	0	0	0	0	0
	2	2	2	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	1	0
36	1	6	3	0	0	0	0	0	1	0
	2	10	1	0	0	0	0	0	0	0
	3	8	3	1	0	0	0	0	0	0
37	1	11	4	0	0	0	0	0	1	0
	2	10	2	1	0	0	0	0	1	1
	3	15	1	0	0	0	0	0	0	1
38	1	2	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0
	3	1	1	0	0	0	0	0	0	0
39	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	1	1	0	0	0	0	0	0	0	0
40	2	0	0	0	0	0	0	0	0	0
	3	3	0	0	0	0	0	0	0	0
	1	1	0	0	0	0	0	0	1	0
41	2	8	1	0	0	0	2	0	0	0
	3	12	2	0	0	0	0	0	0	0
	1	5	4	0	0	0	2	0	0	0
Total SI		180	38	6	7	1	29	0	12	2
Overall		**261**	**44**	**6**	**7**	**9**	**41**	**1**	**19**	**2**

Table E.2

Results of New Zealand Anthropogenic Marine Debris Study (2017) by Composition Count (%) per Island, FP = Foamed plastic, G&C = Glass and ceramic, P&C = Paper and cardboard

Island	Plastic	FP	Rubber	Cloth	G&C	Metal	P&C	Wood	Other	Total
North	81 (70)	6 (5)	0 (0)	0 (0)	8 (7)	12 (10)	1 (1)	7 (6)	0 (0)	115
South	180 (65)	38 (14)	6 (2)	7 (3)	1 (0)	29 (11)	0 (0)	12 (4)	2 (1)	275
Total	**261 (67)**	**44 (11)**	**6 (2)**	**7 (2)**	**9 (2)**	**41 (11)**	**1 (0)**	**19 (5)**	**2 (1)**	**390**

Appendix F

Waste Minimisation and Management Plans

This appendix presents an overview of the details of all Waste Minimisation and Management Plans (WMMPs) in New Zealand. The summary is based upon WMMP documents that were publicly available in December 2017. Section 45 of the Waste Minimisation Act 2008 defines that Territorial Authorities (TAs) are permitted to collaborate with others in the process of adopting their waste planning and operations. Those TAs who indicated joint development of the WMMPs are listed with the names of TA's collaborated with (as indicated in the WMMP). The goals of the WMMPs are summarized, and the strategic (green) and tactical (grey) intent is derived from a key word count in the WMMP.

Territorial Authority	Name Document	Collaboration with others	Goals	Keyword occurrence (count)				
				M	R	P	ZW	CE
Far North	WMMP		Reduce waste to landfill from 350 to 200 kg/cap by 2023	40	91	0	3	0
Kaipara	WMMP		"Not aspirational but achievable" as per planning guide	8	47	0	0	0
Whangarei	Whangarei WMMP		Reduce, recycle etc.	91	239		0	0
Auckland	Auckland WMMP		Long term: Zero-waste, medium term: significantly reduce waste	100	204	1	32	0
Thames Coromandel	Eastern Waikato WMMP	Hauraki, Matamata Piako	Promote waste reduction, increase recovery and reuse, maintain cost effective sustainable waste services, minimise harm to the environment and public health	74	213	10	4	0
Waikato	WMMP		Managing waste locally, working with the community, reduce the amount of waste, lower the cost of waste management, reduce the risk of environmental damage, protect human health	41	80	0	19	0
Hauraki	Eastern Waikato WMMP	Thames Coromandel, Matamata Piako	Promote waste reduction, increase recovery and reuse, maintain cost effective sustainable waste services, minimise harm to the environment and public health	74	213	10	4	0
Matamata Piako	Eastern Waikato WMMP	Thames Coromandel, Hauraki	Promote waste reduction, increase recovery and reuse, maintain cost effective sustainable waste services, minimise harm to the environment and public health	74	213	10	4	0
Hamilton	Hamilton City Council WMMP		Improve the efficiency of resource use and reduce the harmful effects of waste	43	61	0	0	0
Waipa	Waipa WMMP	15	Reduce waste, and increase resource recovery, collect waste information, connect with the community, progressive, affordable and effective waste management	22	16	0	1	0

Territorial Authority	Name Document	Collaboration with others	Goals	Keyword occurrence (count)				
				M	R	P	ZW	CE
Otorohanga	WMMP		No specific targets due to lack of baseline information	64	281	0	4	0
South Waikato	WMMP		Encourages individuals and businesses to take greater responsibility, providing collection and processing for reuse and recycling, waste disposal	21	46			
Waitomo	Solid Waste (activity) WMMP		Ensure safe disposal of waste and minimise waste disposal	29	67	0	0	0
Taupo	WMMP		Reduce waste to landfill by 3%	53	71			
Western Bay of Plenty	WMMP	RA	Reduce and recover more waste, effective waste management, collect information, create benefit for the community	25	4	0	1	0
Tauranga	WMMP	RA	Reduce and recover more waste, collect information, create benefit for the community, apply cost-effective methods	30	62	1	1	0
Rotorua	WMMP Rotorua's Waste Strategy		4r's, lower health and safety risks, improve statutory compliance, improve environmental outcomes, provide economic benefit, gain better information	90	40	0	1	0
Whakatane	WMMP	RA	Provide quality and affordable services; reduce the amount of waste sent to landfill, reduce risk of environmental damage	11	43	1	0	0
Kawerau	WMMP	RA	Reduce the volume of waste going to landfill	18	166	2	15	0
Opotoki	WMMP	RA	Committed community, to reduce, reuse and recycle and minimise waste to landfill, litter management and addressing illegal dumping	69	22	0	26	0
Gisborne	The Waste Management Minismisation (sic) Plan		Effective, efficient and equitable, greater responsibilities from individuals, reduce harmful effects, the efficiency of resources use	31	23	0	2	0
Wairoa	nil							

Territorial Authority	Name Document	Collaboration with others	Goals	Keyword occurrence (count)				
				M	R	P	ZW	CE
Napier City	Joint WMMP for Hastings DC and Napier CC	Hastings	Reduce the harmful effects of waste; improve the efficiency of resource use	55		0	0	0
Hastings	Joint WMMP for Hastings DC and Napier CC	Napier City	Reduce the harmful effects of waste; improve the efficiency of resource use	55		0	0	0
Central Hawke's Bay	nil							
New Plymouth	WMMP	RA, Stratford South, Taranaki	ZW by 2050; reduce waste to landfill, reduce harmful and costly effects of waste, improve the efficiency of resource use	36	146	0	8	0
Stratford	nil	RA, New Plymouth, Taranaki						
South Taranaki	WMMP	RA, New Plymouth, Stratford South	Minimise waste	54	104	0	0	0
Ruapehu	Waste Management and Minimisation Asset Management Plan		Lower cost and risk of waste to society, create a waste minimisation culture, reduce environmental damage, increase economic benefit through more efficient material resources	16		0	2	0
Wanganui	WMMP		Reduce the harmful effects of waste; improve the efficiency of resource use	161	201	0	1	0
Rangitikei	WMMP		Reduce quantity of solid waste to landfill by 10% (2005), further reduce to 20% (2010)	46	102	0	3	0
Manawatu	WMMP		Promote waste reduction and deliver efficient and cost-effective services	25	82	0	1	0
Tararua	nil							

Territorial Authority	Name Document	Collaboration with others	Goals	Keyword occurrence (count)				
				M	R	P	ZW	CE
Palmerston North	WMMP		Divert waste to beneficial use, minimise environmental impact, fund activities to promote, collaborate with community and private sector, continue to educate	62	164	2	7	0
Horowhenua	WMMP		Improve the efficiency of resource use and reduce the harmful effects of waste	92	399	0	4	0
Kapiti Coast	Wellington Region WMMP	RA, Masterton, Carterton, Upper Hutt City, Porirua, South Wairarapa, Wellington, Lower Hutt	Waste free together, reduce waste from 600kg pc to 400kg pc by 2026	88	317	2	6	2
Masterton	Wellington Region WMMP	RA, Kapiti Coast, Carterton, Upper Hutt City, Porirua, South Wairarapa, Wellington, Lower Hutt	Waste free together, reduce waste from 600kg pc to 400kg pc by 2027	88	317	2	6	2
Carterton	Wellington Region WMMP	RA, Kapiti Coast, Masterton, Upper Hutt City, Porirua, South Wairarapa, Wellington, Lower Hutt	Waste free together, reduce waste from 600kg pc to 400kg pc by 2032	88	317	2	6	2
Upper Hutt City	Wellington Region WMMP	RA, Kapiti Coast, Masterton, Carterton, Porirua, South Wairarapa, Wellington, Lower Hutt	Waste free together, reduce waste from 600kg pc to 400kg pc by 2029	88	317	2	6	2
Porirua	Wellington Region WMMP	RA, Kapiti Coast, Masterton, Carterton, Upper Hutt City, South Wairarapa, Wellington, Lower Hutt	Waste free together, reduce waste from 600kg pc to 400kg pc by 2031	88	317	2	6	2

Territorial Authority	Name Document	Collaboration with others	Goals	Keyword occurrence (count)				
				M	R	P	ZW	CE
South Wairarapa	Wellington Region WMMP	RA, Kapiti Coast, Masterton, Carterton, Upper Hutt City, Porirua, Wellington, Lower Hutt	Waste free together, reduce waste from 600kg pc to 400kg pc by 2028	88	317	2	6	2
Wellington	Wellington Region WMMP	RA, Kapiti Coast, Masterton, Carterton, Upper Hutt City, Porirua, South Wairarapa, Lower Hutt	Waste free together, reduce waste from 600kg pc to 400kg pc by 2033	88	317	2	6	2
Lower Hutt	Wellington Region WMMP	RA, Kapiti Coast, Masterton, Carterton, Upper Hutt City, Porirua, South Wairarapa, Wellington	Waste free together, reduce waste from 600kg pc to 400kg pc by 2030	88	317	2	6	2
Tasman	Nelson City Council and Tasman District Council Joint WMMP	Nelson	Avoid the creation of waste, improve the efficiency of resources, reduce harmful effects	175	49	35	2	0
Nelson	Nelson City Council and Tasman District Council Joint WMMP	Tasman	Avoid the creation of waste, improve the efficiency of resources, reduce harmful effects	175	49	35	2	0
Marlborough	WMMP		Establish sorting facility by 2016, investigate options for reduction of food waste, co-mingled recycling, public place recycling schemes, expanding green waste into compost	25	110	0	0	0
Buller	nil							
Grey	Final WMMP		Improve the efficiency of resource use and reduce the harmful effects of waste	84	128	0	0	0
Westland	WMMP		Reduce the amount of waste to landfill, reduce recyclable wastes, provide financial incentives to reduce waste, provide a network of collection methods, provide safe disposal, no hazardous waste in waste stream	34	78	0	2	0

Territorial Authority	Name Document	Collaboration with others	Goals	Keyword occurrence (count)				
				M	R	P	ZW	CE
Kaikoura	nil							
Hurunui	WMMP		Divert waste from landfill, cost effective waste management, reduce damage to the environment, ensure public health, accumulate improved information, collaborate with contractors, increase economic benefits, review and assess performance and effectiveness, engage with the community	33	202	0	3	0
Waimakariri	WMMP		Improve the efficiency of resource use and reduce the harmful effects of waste	212	372	0	0	0
Selwyn	WMMP		Reducing the harmful effects of waste and improve the efficiency of resource use	34	50	0	2	0
Christchurch	WMMP		Zero-waste to landfill in future. Individuals and organizations take greater responsibility for waste minimisation, council support waste reduction, and the council provides environmentally sounds recovery and disposal	31	27	0	2	0
Ashburton	WMMP		Engage community, reduce amounts of waste, lower cost of waste management, reduce risk of environmental damage, protect public health	29	78	3	11	0
Timaru	WMMP		Protect public health from waste, protect the environment from waste, provide effective and efficient services	93	249	0	33	0
Mackenzie	WMMP		Protect public health from waste, protect the environment from waste, provide effective and efficient services	84	277	0	22	0
Waimate	nil							
Queenstown Lakes	WMMP		Towards zero-waste, waste minimisation activities to promote the efficiency of resource use, waste management to reduce harm from waste	45	59	1	6	0

Territorial Authority	Name Document	Collaboration with others	Goals	Keyword occurrence (count)				
				M	R	P	ZW	CE
Central Otago	WMMP		Towards zero-waste; Reduce the harmful effects of waste; improve the efficiency of resource use	115	80	0	6	0
Waitaki	WMMP		Incentivising waste minimisation through user charges and personal responsibility. Reduce the harmful effects of waste; improve the efficiency of resource use	62	108	0	17	0
Dunedin	WMMP		Zero-waste city where resources are valued by the community. Build community capability and encourage proactive engagement, improve the efficiency of resources and minimise waste, minimise harmful effects of waste	34	86	0	31	0
Clutha	WMMP		Reduce the harmful effects of waste; improve the efficiency of resource use	22	43	0	0	0
Southland	Southland WMMP	Gore, Invercargill	Collaborate to improve the efficient use of resources, use waste hierarchy, reduce the harmful effects of waste on health and environment	22	86	1	1	1
Gore	Southland WMMP	Southland, Invercargill	Collaborate to improve the efficient use of resources, use waste hierarchy, reduce the harmful effects of waste on health and environment	22	86	1	1	1
Invercargill	Southland WMMP	Southland, Gore	Collaborate to improve the efficient use of resources, use waste hierarchy, reduce the harmful effects of waste on health and environment	22	86	1	1	1

Note. RA = Regional Authority, WMMP = Waste Management and Minimisation Plan, M = Minimisation, R = Recycling, P = Prevention, ZW = Zero-waste, CE = Circular Economy

Appendix G

Waste Collection Methods and Plastic Grade Collection Schemes per Territorial Authority in 2017

This appendix presents an overview of rubbish and recycling methods, and collection schemes from the Territorial Authorities on the North and South Islands of New Zealand in December 2017. Information is obtained from the territorial authorities' webpages, as described in "Materials and Methods" (Chapter 3).

Territorial authority	Kerbside rubbish	Rubbish receptacle	Rubbish colour	Kerbside recycle	Recyclables receptacle	Recycle colour	Plastic bags	Plastic grades collected
Far North	Yes	Bags		Yes	Crates		No	1, 2, 3, 4, 5, 6
Kaipara	Yes	Bags	Blue	Yes	Bags	Yellow	No	1, 2, 3, 4, 5, 6, 7
Whangarei	Yes	Both		Yes	Crates		No	1 & 2
Auckland	Yes	Both		Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Thames Coromandel	Yes	Bags	Blue	Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Waikato [a]	Yes	Bags		Yes	Crates		No	1, 2 & 5
Hauraki	Yes	Bags	Yellow	Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Matamata Piako	Yes	Bags		Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Hamilton	Yes	Bags		Yes	Crates		No	1 & 2
Waipa	Yes	Both		Yes	Crates		No	1, 2, 3, 4, 5, 6, 7
Otorohanga	Yes	Bags		Yes	Crates		No	1 & 2
South Waikato	Yes	Bags	Green	Yes	Crates	Red	No	1, 2, 3, 4, 5, 6, 7
Waitomo	Yes	Bags	Blue	Yes	Crates		No	1 & 2
Taupo	Yes	Bags	Orange sticker	Yes	Crates		No	1, 2, 3, 4, 5, 6, 7
Western Bay of Plenty	Yes	Bags		Yes	Wheeled bins		No	1 & 2
Tauranga	Yes	Bags	Pink sticker	Yes	Wheeled bins		No	1 & 2
Rotorua	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Whakatane	Yes	Wheeled bins		Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Kawerau	Yes	Wheeled bins		Yes	Crates		Yes	1 & 2
Opotoki	Yes	Bags		Yes	Crates		No	1 & 2
Gisborne	Yes	Bags		Yes	Crates		No	1, 2, 3, 4, 5, 6, 7
Wairoa	Yes	Bags		Yes	Crates		No	1, 2, 3, 4, 5, 6, 7
Napier City	Yes	Bags		Yes	Bags or cartons		No	1, 2, 3, 4, 5, 6, 7
Hastings	Yes	Both	Orange	Yes	Bags or crates	Shopping	No	1, 2, 3, 4, 5, 6, 7

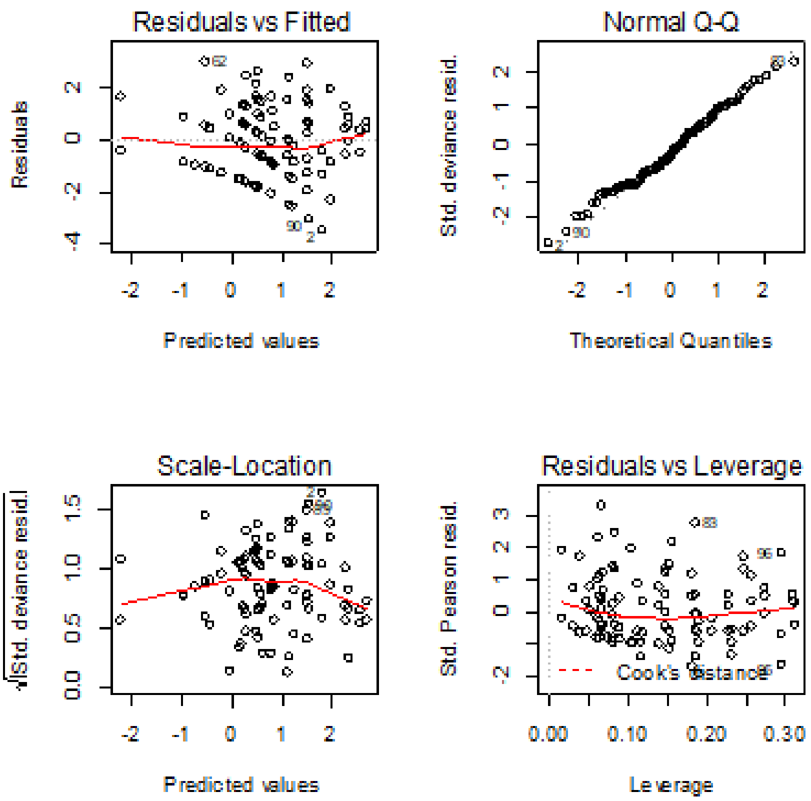
Territorial authority	Kerbside rubbish	Rubbish receptacle	Rubbish colour	Kerbside recycle	Recyclables receptacle	Recycle colour	Plastic bags	Plastic grades collected
Central Hawke's Bay	Yes	Bags	Yellow or green	Yes	Crates		No	1, 2, 3, 4, 5, 6
New Plymouth	Yes	Bags	Red	Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Stratford	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
South Taranaki	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Ruapehu	Yes	Bags	Pink	Yes	Crates		No	1 & 2
Wanganui	Yes	Both	Orange	No			No	None
Rangitikei	Yes	Both		No			No	None
Manawatu	Yes	Bags	Blue	Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5
Tararua	Yes	Bags	Yellow	Yes	Bags	Shopping	No	1, 2, 3 & 5
Palmerston North	Yes	Bags		Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Horowhenua	Yes	Bags	White	Yes	Crates		Yes	1, 2, 3, 4, 5, 6, 7
Kapiti Coast	Yes	Both	Yellow	Yes	Crates or wheeled bins		Yes	1, 2, 3, 4, 5, 6, 7
Masterton	Yes	Bags		Yes	Crates		No	1, 2, 3, 4, 5, 6, 7
Carterton	Yes	Bags	Green	Yes	Crates		No	1, 2, 3, 4, 5, 6, 7
Upper Hutt City	Yes	Both	Green	Yes	Wheeled bins		No	1, 2, 3, 4, 5, 6, 7
Porirua	Yes	Bags	Black	Yes	Bags or crates		No	1, 2, 3, 4, 5, 6, 7
South Wairarapa	Yes	Bags		Yes	Crates or shopping bags		No	1, 2, 3, 4, 5, 6, 7
Wellington	Yes	Bags	Yellow	Yes	Bags or wheeled bins	Yellow, green	No	Food, drink and household containers, no polystyrene
Lower Hutt	Yes	Bags		Yes	Crates		Yes	1, 2, 3, 4, 5, 6, 7
Tasman	Yes	Bags	Yellow and white	Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Nelson	Yes	Both		Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7

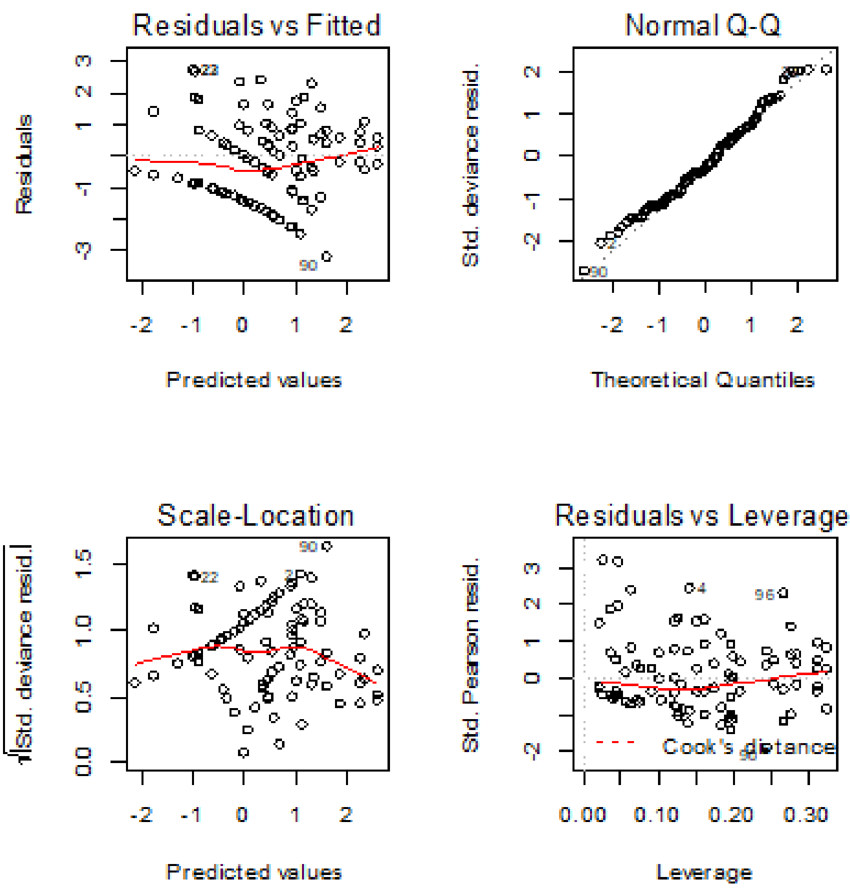
Territorial authority	Kerbside rubbish	Rubbish receptacle	Rubbish colour	Kerbside recycle	Recyclables receptacle	Recycle colour	Plastic bags	Plastic grades collected
Marlborough	Yes	Bags		Yes	Crates		No	1, 2, 3, 4, 5, 6, 7
Buller	Yes	Bags		Yes	Crates		No	1, 2, 3, 4, 5, 6, 7
Grey	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6
Westland	Yes	Wheeled bins	Green lid	Yes	Wheeled bins	Yellow	No	1, 2, 4, 5
Kaikoura	No			Yes	Crates		Yes	1, 2, 3, 4, 5, 6, 7
Hurunui	Yes	Bags		Yes	Bags		No	Bottles, containers, polypropylene meat trays
Waimakariri	Yes	Bags		Yes	Wheeled bins		Yes	Most household plastic
Selwyn	Yes	Both	Red lid	Yes	Crates, wheeled bins	Yellow	Yes	1, 2, 3, 4, 5, 6, 7
Christchurch	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	Yes	1, 2, 3, 4, 5, 6, 7
Ashburton	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	Yes	1, 2, 3, 4, 5, 6, 7
Timaru	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	No	All rigid plastics
Mackenzie	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	Yes	1, 2, 3, 4, 5 & 7
Waimate	Yes	Both		Yes	Crates		No	Bottles, jars
Queenstown Lakes	Yes	Both	Blue, red lid	Yes	Wheeled bins	Blue	No	1, 2, 3, 4, 5, 6, 7
Central Otago	Yes	Wheeled bins	Blue lid	Yes	Wheeled bins	Yellow	Yes	1, 2, 3, 4, 5, 6, 7
Waitaki	Yes			No			No	None
Dunedin	Yes	Bags		Yes	Wheeled bins	Yellow	No	1, 2, 3, 4, 5, 6, 7
Clutha	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	Yes	1, 2, 3, 4, 5, 6, 7
Southland	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	Yes	1, 2, 3, 4, 5, 6, 7
Gore	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	Yes	1, 2, 3, 4, 5, 6, 7
Invercargill	Yes	Wheeled bins	Red lid	Yes	Wheeled bins	Yellow	Yes	1, 2, 3, 4, 5, 6, 7

Note. [a] Raglan, accepts 1 - 7

Appendix H

Validation of GLM for Anthropogenic Marine Debris (Upper) and Plastic Debris (Lower)


Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. Pearson resid.
Cook's distance
Leverage


Residuals vs Fitted
Residuals
Predicted values
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
Scale-Location
√|Std. deviance resid.|
Predicted values
Residuals vs Leverage
Std. Pearson resid.
Cook's distance
Leverage