

Australian anthropogenic litter monitoring data: how useful is it for decision making?

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Abstract

Anthropogenic litter is a significant environmental problem and the subject of global action. Substantial investments support monitoring and clean-up activities, but their effectiveness is often unknown. Quality information and the ability to harmonise across different data-collection programs are essential to build a comprehensive understanding of litter distribution and dynamics, and effectively direct future action. This study sought to determine how decision-useful Australian anthropogenic litter monitoring data are. A review of online and peer-reviewed sources found the literature to be marine-centric, and the ability to access and reuse data limited. Five key programs for large-scale anthropogenic macro-litter monitoring operate in Australia, but none had discoverable data, metadata or evidence of use of standards. An assessment using the Australian Research Data Commons FAIR data self-assessment method produced low scores ranging from 11 to 44%. The collective lack of data quality mechanisms (e.g. metadata, standards, quality control QA/QC) likely contributes to a generally poor understanding of the efficacy of Australian litter monitoring efforts. We recommend adopting socio-technical approaches that ensure access to program metadata, accompanied by clear methods and QA/QC documentation. This should be supported by the establishment of national minimum data collection standards and common vocabularies to improve the ability to inform decision-making at state and national levels. Evidence-based policy formulation and implementation that draws on robust data collection and reporting approaches will better support reducing the environmental impacts of anthropogenic litter.

Highlights

- Australian anthropogenic litter monitoring and research was typically marine-biased and most lacked sufficient information to enable reuse
- Data quality mechanisms and FAIR data were generally low across monitoring programs
- National approaches to reducing environmental impacts of anthropogenic litter will be greatly enhanced by the use of metadata, common vocabularies, standardised methodologies and data verification (QA/QC) procedures

Introduction

Anthropogenic litter is a pervasive and increasing global problem identified as one of the greatest modern environmental challenges faced by humankind (Rangel-Buitrago et al. 2022). The full extent and magnitude of the complex and rapidly evolving (Sorrentino 2022) global littering problem has so far eluded quantification (Zielinski et al. 2022).

Anthropogenic litter is 'any persistent, manufactured or processed solid material' that has been 'discarded, disposed of or abandoned' (UNEP 2009). Macro-litter items (> 5mm) are generally considered separately from micro-litter (< 5mm), although the latter is often derived from the former via degradation in the environment (Gallitelli and Scalici 2022). Anthropogenic litter can be made up of any type of manufactured material; however, litter containing plastic is the most ubiquitous material and can persist in the environment for more than 1000 years (Chamas et al. 2020; Liro et al. 2023). Plastic litter has been found in all environments around the world (Horton 2022). Around 80% of plastic litter originates on land (Lebreton et al. 2018) but ends up in the marine environment (Jambeck et al. 2015) where it has widespread impacts on marine organisms (Tuuri and Leterme 2023). In terrestrial environments, litter impacts are less well understood, but it is likely that organisms are sensitive to litter in a similar way to those species in the marine environment (Blettler and Mitchell 2021).

In 2015, 17 Sustainable Development Goals (SDGs) were agreed on at the United Nations (UN) General Assembly, of which one (Goal 14) addresses threats posed by anthropogenic litter. While there are no terrestrial-related litter indicators, Indicator 14.1.1 relates specifically to marine litter and has signatories aiming to "prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution" by 2025 (UNEP 2021).

The UN has identified a need to improve the underpinning monitoring and measurement standards for indicators (14.1.1a - index of coastal eutrophication, and 14.1.1b - plastic debris density), and raise these from their current Tier 3 category 'no internationally established methodology or standards are yet available' to Tier 2 'indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries' (UNEP 2021).

Research data quality

To address global litter pollution we need decision-useful information on the distribution, volumes, trends, sources and movement pathways of anthropogenic litter. To obtain this information, data quality needs to be maximised by ensuring data are collected in a manner that allows comparison between locations, time periods and observers. This hinges on agreed protocols, training and implementation of monitoring strategies, which are themselves underpinned by a common understanding of program objectives (Hanke et al. 2019). Clearly defined protocols and terminology for litter type classification are essential for consistent collection, exchange, and interpretation of data on indicators of anthropogenic litter. This is particularly true for the programs that rely on volunteers and citizen scientists (Corbau et al. 2025), and can be

supported by aiming for FAIR data (i.e., is findable, accessible, interoperable and reusable: Wilkinson et al. 2016) across all data collection efforts. Adopting the underlying principles of FAIR data enables secondary use of data and greatly increases its usefulness for decision making, especially as many programs have very specific objectives and use cases for monitoring.

Research data quality and the application of the FAIR principles have been well demonstrated in marine research globally, for example, through the UN Decade of Ocean Science for Sustainable Development, and the European Union with the OSPAR Commission. OSPAR data is provisioned to the European Marine Observation and Data Network (EMODnet) Central Beach Litter Database. For data to be included, data suppliers must follow a process that includes validation and standards compliance. EMODnet data follow the ISO 19115-2 standard, the INSPIRE Metadata Regulation, and adopt standard vocabularies developed and maintained by SeaDataNet (www.seadatanet.org) and registered with the British Oceanographic Data Service (see, for example, a micro-litter vocabulary <http://vocab.nerc.ac.uk/collection/H01/current/>). Following these or similar processes greatly increase data interoperability and long-term use and reuse (Partescano et al. 2021).

Data validation, quality assurance and quality control (QA/QC) are crucial when using data for policy decision and implementation (Hanke et al. 2019). However, QA/QC procedures for anthropogenic litter data are more challenging to develop than many other commonly monitored environmental indicators. For example, water quality monitoring measures such as pH are naturally bounded between 0 and 14 (Best et al. 2007). In contrast, anthropogenic litter data are typically unbounded, with no natural or predictable thresholds, making it difficult to apply automated quality control rules in data entry systems. Anthropogenic litter monitoring programs must therefore rely on adherence to standard collection protocols, sufficient metadata, detailed guidance materials, and user training to ensure data quality (Hanke et al. 2019). Adequate QA/QC procedures are particularly important where citizen scientists are involved in data collection, to ensure the resultant datasets are reliable and trustworthy in the eyes of decision-makers (Corbau et al. 2025).

Anthropogenic litter monitoring in Australia

Australia has signed up to several treaties and protocols that place obligations on Australian governments to address litter pollution and threats to wildlife. These include the Pacific Ocean Litter Project (2019-2027, which forms part of the Pacific Regional Action Plan, 2018), the Pacific Regional Waste and Pollution Management Strategy - Cleaner Pacific (2025), and the International Convention of Marine Pollution for Ships (MARPOL), the main convention for prevention of pollution of the marine environment by ships.

Early anthropogenic litter data collection and monitoring efforts in Australia, which began with the 'anti-litter' movement in the 1960s and subsequent formation of 'Keep Australia Beautiful' (2023). Anthropogenic litter data in Australia has been, and continues to be, collected as part of a number of monitoring programs organised by community groups, local councils, and government departments. Early grassroots movements focused on clean-up first and data collection second. In contrast, current government initiatives are increasingly focused on data for monitoring, policy development and assessment.

In the last decade there has been a shift in national policy to a circular economy approach for litter and waste, aimed at more productive use of waste resources that also reduces environmental impacts of production and consumption. Measures to reduce litter include a combination of voluntary and regulatory approaches; regulating export of waste (DAWE 2021), improvements and initiatives to promote household recycling (DELWP 2020), banning or regulating problematic litter items (DELWP 2020), promotion of the Australasian Recycling Label (DAWE 2021), economic incentivisation through the Container Deposit Scheme (CDS), source reduction plans targeting single use plastics (O'Dwyer et al. 2022; Serra-Gonçalves et al. 2023; Government of Western Australia 2024), and grants to communities and other organisations to remove litter, engagement and behaviour change initiatives.

The rapid expansion in policies and initiatives aimed at reducing plastic pollution highlights the need for a national information system accompanied by appropriate standards to evaluate outcomes and inform future actions, reinforced in the recent report from the Standing Committee on Climate Change, Energy, Environment and Water (Commonwealth of Australia 2024).

Aims

The aim of this study was to determine the suitability of data for informing policy and decision-making from anthropogenic litter monitoring (marine and terrestrial) in Australia. This knowledge is needed because successful reduction of plastic pollution and other anthropogenic litter impacts on the environment will depend on the quality and accessibility of the underlying monitoring data and the consistency of data collection across different programs (Haarr et al. 2022, Sorrentino 2022). Our key objectives were to (1) conduct an online search of sources of anthropogenic litter data in Australia and determine the nature of large-scale litter monitoring, (2) review the literature and explore what additional information sources are available to complement litter monitoring programs, (3) qualitatively determine data fitness for secondary use (i.e. data quality) of the sector in terms of use of standards (metadata, data, methods, QA/QC), and (4) undertake a FAIR assessment of Australian litter monitoring data. Findings will be used to determine the gaps hindering the harmonisation and interoperability of different information sources informing national litter pollution baselines and trends. This is a high priority to ensure data collection efforts can support the national litter pollution agenda.

Methods

Searches for online litter data sources

To identify sources of Australian anthropogenic litter data and information, the open data websites for the Australian federal, state and territory governments were searched using the term 'litter' (see Supplementary Table S1). Then, using a standard Google search (not AI tools), we searched for 'litter data and monitoring Australia' and 'plastic debris data Australia' and 'litter debris data Australia' (15 May 2024). A subsequent *ad hoc* Google search was conducted (27 May 2025) to seek findable (*sensu* Wilkinson et al. 2016) data beyond Australia) to inform development of a litter vocabulary. Identified URLs were visited to determine the nature of the dataset or data collection program. For search results about data collection programs, summary information was extracted for the primary organisation involved, the type of anthropogenic litter monitoring undertaken, the broad geographic focus, plus any specifics relating to data management and the use of specific anthropogenic litter data classification system or vocabularies.

Literature review searching strategy

We searched peer-reviewed literature to identify potential sources of research data on marine litter in Australia. A search of the Web of Science database was conducted (4 November 2024) using the search terms 'marine litter OR marine debris OR marine pollution OR marine plastic* OR terrestrial litter OR terrestrial plastic OR anthropogenic litter OR anthropogenic plastic' and 'Australia*' in the Abstract. This returned 414 articles published in English the past 20 years (i.e., from 2003 to 2024). Titles and abstracts were inspected and included in the review if they contained data quantifying anthropogenic litter on mainland or coastal Australia, but were excluded if they reported on the effects of anthropogenic litter on wildlife, in the water, or in reef environments. On the same day these search terms were used in the Scopus database within All Fields, and 'Australia*' in the Article Title, Abstract, Keywords, producing 236 articles in English. We also conducted searches in both these databases using the terms 'anthropogenic litter AND FAIR' within the same parameters. This returned eight articles, all of which were found in the previous searches.

Assessment of data quality mechanisms

We conducted a qualitative assessment of each case found in the data and literature review to determine the presence of data quality mechanisms / approaches. We define data quality simplistically here in terms of existence of metadata, data standards (e.g. use of a litter vocabulary or classification schema), the use of standardised methodologies accompanied by clear guidance, and data verification (QA/QC) procedures. Because QA/QC of anthropogenic litter data is challenging, QA/QC was inferred based on the existence (and presumed use) of guidance material and user registration and training approaches. It is important to note that where access to program details and metadata required user registration, some information required for this assessment may not have been captured.

Assessment against FAIR principles

We assessed each anthropogenic litter monitoring program using the FAIR data self-assessment method available on the Australian Research Data Commons website (<https://ardc.edu.au/resource/fair-data-self-assessment-tool/>). Digital FAIR assessment tools require that metadata and data are assigned globally unique, persistent, and resolvable identifiers such as Digital Object Identifier (DOIs) or Unique Resolvable Identifiers (URIs). However, because none of the monitoring programs had persistent identifiers associated with datasets or metadata, neither automated FAIR assessments nor FAIR Implementation Profiles (FIPs) could be conducted. Therefore, further assessment was done manually using the prompt questions at each FAIR step. The interpretation (and application) of each question is outlined in Table 1.

Table 1

Application and interpretation of the FAIR data self-assessment steps (<https://ardc.edu.au/resource/fair-data-self-assessment-tool/>) for online anthropogenic litter data collection programs.

Section	FAIR assessment question	How the question was applied to this study (to be read with multi-choice responses of ARDC tool)
Findable	Does the dataset have any identifiers assigned?	Online searches for dataset identifiers including exploration of any publicly-accessible program guidance material or data entry forms.
	Is the dataset identifier included in all metadata records/files describing the data?	Online searches for the existence of metadata including exploration of any publicly-accessible program guidance material or data entry forms.
	How is the data described by a metadata record?	Where no dataset description or metadata discovered, assessed on information contained in any publicly-accessible program guidance material or data entry forms.
	What type of searchable repository or registry is the metadata record in?	No program had any discoverable evidence of standard metadata and this question was universally answered as "not described in any registry or repository".
Accessible	How accessible is the data?	Assumed based on any information available, on website or program documentation, to request data. Where clearly states full access via email request, assumed entire dataset would be made available upon reasonable request. Otherwise, assumed unspecified or no access based on website / program documentation.
	Is the data available online once access has been approved?	Unless explicitly stated, assumed dataset was not available online.
	Will the metadata record be available even if the data is no longer available?	No information found to assess this for any program.
Interoperable	What (file) format(s) is the data available in?	Where file formats not disclosed, file formats were assumed based on whether an online database existed or if program materials implied some sort of electronic data storage system. At a minimum, all were assumed could be made available in an open (non-proprietary) format.
	What best describes the types of vocabularies used to describe/define the data elements?	Where no reference to standards or vocabularies discovered, assumed not applied and level of data element description was inferred from available publicly-accessible program guidance material or data entry forms.
	How is the relationship to other data and resources described in the metadata?	As no program had discoverable metadata that used established metadata standards, no links to other resources could likewise be determined.
Reusable	Which of the following best describes the licence/usage rights assigned to the data and included in the metadata record?	Where a reference to a data licence could not be discovered but a reference to copyright was stated, assumed non-standard, text-based licence.
	How much provenance information has been captured to facilitate data reuse?	Where data collection protocols and data elements were clearly described in any publicly-accessible program guidance material or data entry forms, dataset provenance was considered to be recorded in a format that is not machine-actionable. Otherwise, "No provenance information recorded"

Results

Litter data sources

Anthropogenic litter data searches revealed relevant accessible datasets, metadata records and controlled vocabularies available from several sources. Most were outside Australia - EMODnet, HELCOM, UNEP and OSPAR - with just two by Australian state governments (Queensland and Victoria, Supplementary Table S2). Two additional resources provided summaries: Litterbase provided a synthesis of research projects but not the underlying research data, and PlastiCount Pilipinas provided data summaries from aggregated published sources (Supplementary Table S2).

Online searching identified 15 sources for information (e.g., activities, reports, data submission systems) on anthropogenic litter in Australia (Supplementary Table S3). Five of these were notably larger and better developed than the others. These were the Australian Marine Debris Initiative (AMDID) database, the National Sea Shepherd Australia (Sea Shepherd) database, LitterWatch Victoria (LitterWatch), the Key Littered Items Study (KLIS), and the Clean Up Australia Annual Rubbish Reports (Table 2). The Australian Microplastic Assessment Project (AUSMAP) was excluded because it focuses exclusively on micro-plastics and thus requires a specialised methodology for data collection that cannot be compared with macro-litter more generally.

Table 2

Overview of anthropogenic litter monitoring programs in Australia including high level details of litter classification system and results of the FAIR data assessment. Percentages were the results produced by the self-assessment steps (see Table 1). Coverage: C = coastal, T = terrestrial, M = marine, O = offshore and remote islands

Program name	Owner	Description	Coverage	Key data fields	Litter classification	Reporting	FAIR assessment
AMDI	Tangaroa Blue Foundation	Conducts litter clean-up surveys. Contributions from registered users nationally.	C, M	Survey coordinates Date & time No. of surveyors Area length and average width	Top level - cloth, dangerous, foam, glass and ceramic, metal, oil spill, other, paper and cardboard, plastic, rubber Sub-categories in each top level	Peer-reviewed scientific publications. Annual state-based reports. Targeted reports	27%
Clean Up Australia	Clean Up Australia	National program focuses on event-based rubbish removal across all possible terrestrial site types. No quantitative data collected on litter.	C, T	Survey coordinates Date & time No. of surveyors	Top level – plastic, electrical waste, glass, metal, paper/cardboard, rubber, textiles, wood, miscellaneous, fishing, other Sub-categories in each top level Uncontrolled items, option to include under top level.	Annual national & state-based rubbish reports	11%
KLIS NSW	Department of Environment and Heritage (NSW)	Long-term monitoring programs. Quarterly surveys conducted at designated sites to quantify marine debris.	C	Survey coordinates Date & time No. of surveyors Area surveyed	Top level – cigarette butts, plastic, paper/cardboard, metal, foam, rubber, glass, cloth, wood, other Unknown if uncontrolled items included.	EPA annual reporting. Container Deposit Scheme reporting	11%
LitterWatch Victoria	Department of Energy, Environment and Climate Action (VIC)	Data system for community & government litter clean-ups and surveys. Contributions from community groups and registered users. Provides mapping and charting data summaries online.	C, T	Survey coordinates Date & time No. of surveyors Area surveyed	Top level - glass, metal, plastic, polystyrene, other Broken down into level 2 and level 3 sub-categories Uncontrolled items within hierarchy	Port Phillip Litter Index reporting	44%
Sea Shepherd	Sea Shepherd (Marine Debris Campaign)	Conducts regular litter clean-up events nationally.	C, M, O	Street address Date & time No. of surveyors †	Top level - plastic, polystyrene, glass, rubber, paper/cardboard, metals, wood	None located	19%
† temporary portal access provided to one researcher. Not discoverable on the public site							

Published litter research

Sixteen peer-reviewed articles were eligible for inclusion in the literature review (Table 3). All 16 focussed on marine and coastal environments. Ten of the 16 studies included citizen scientists in the data collection process, of which three used the AMDI database, and a further seven used a combination of trained scientists and volunteers, community or school groups. Other data quality mechanisms varied across studies. Most provided sufficient details of litter types to enable the work to be replicated or, in some cases, to be combined with other work. Six studies used classification based on those used in the AMDI database. Several studies included only a single category for litter type. For example, Duckett and Repaci (2015) counted only 'plastic' in their surveys, and Smith et al. (2014) counted bottles only. Smith and Markic (2013) lacked sufficient

details of litter types to enable replication of the study, providing only comments in the results stating that there were differences between 'various types of litter' within the total debris accumulated.

Table 3

Details of key sources of anthropogenic macro-litter data in peer-reviewed research articles in Australia. Note that relevant information only accessible via a user administration system (i.e., a login) may be misrepresented here. Uncontrolled [litter] items are those needing to be classified later (if sufficient additional information was supplied) or treated as an 'unknown' litter type. Articles relating to animal-litter interactions (e.g., ingestion, nesting) were excluded.

Authors	Year	Data access	Study type	Spatial coverage	Coordinates (lat/long)	Date / time	Duration	No. surveyors	Area surveyed	Uncontrolled items
Cunningham and Wilson	2003	X	beach survey	Sydney, NSW	☐	X	X	X	☐	X
Davies et al.	2022	X	beach survey	Cockburn Sound, WA	☐	X	X	☐	☐	☐
Duckett and Repaci	2015	X	beach survey	Sydney, NSW	X	X	X	X	☐	X
Edyvane et al.	2004	X	beach survey	Great Australian Bight, SA	X	X	X	X	X	X
Frost and Cullen	1997	X	beach survey	Northern NSW	X	X	X	X	☐	X
Gacutan et al.	2022	via AMDI (email)	database investigation of beach survey	Australian marine bioregions	☐	☐	☐	☐	☐	☐
Hardesty et al.	2017	X	beach survey	175 coastal sites around Australia	☐	☐	☐	☐	☐	☐
Olivelli et al.	2020	upon request	beach survey	365 coastal sites around Australia	☐	☐	☐	☐	☐	X
Roman et al.	2021	X	beach survey, sea-surface trawls	QLD	☐	☐	X	☐	☐	☐
Serra-Goncalves et al.	2023a	from AMDI (email)	database investigation of beach survey	SW WA, QLD	☐	☐	☐	☐	☐	☐
Serra-Goncalves et al.	2023b	from AMDI (email)	database investigation of beach survey	SW WA	☐	☐	☐	☐	☐	☐
Smith and Markic	2013	X	beach survey	mid-coast NSW	☐	X	X	X	X	☐
Smith et al.	2014	X	beach survey	Rottneest Island, WA	X	X	X	X	☐	☐
Smith et al.	2018	X	beach survey	NSW	☐	X	X	☐	☐	☐
van der Velde et al.	2017	X	beach survey	around coastal Australia	☐	☐	☐	☐	☐	☐
Westlake et al.	2022	X	beach survey	Ningaloo Marine Park, WA	☐	X	X	☐	☐	☐
Willis et al.	2017	X	beach survey	Derwent Estuary, TAS	☐	☐	☐	☐	☐	☐
Wilson and Verlis	2017	X	beach survey	Capricorn-Bunker Group of	☐	☐	X	X	☐	X

Authors	Year	Data access	Study type	Spatial coverage	Coordinates (lat/long)	Date / time	Duration	No. surveyors	Area surveyed	Uncontrolled items
				Islands, QLD						

Use of comparable data fields (i.e. able to be harmonised) was mixed across studies. Most provided either survey site (n = 13) and/or transect coordinates (n = 10), and the number of people involved in litter data collection (11), but few provided details on date or time of data collection. Data availability was low as only four of the 16 articles provide information on how to access their data (Table 3).

Anthropogenic macro-litter monitoring programs

Three of the five programs (AMD, Clean Up Australia and Sea Shepherd Marine Debris Campaign) have national coverage, and the other two were state-based programs (Table 2). All programs focussed on coastal and marine environments, using clean-up and sorting activities by citizen scientists as their primary data collection method rather than *in situ* census without removal of litter. This reflects the strong community engagement and education underpinnings of these programs. Spatial data to identify the location of litter surveys was recorded by most programs, but other key data fields typically required to undertake any spatial or temporal interpretation such as date, time of day or survey effort were not consistently collected.

Since there was no common vocabulary (*sensu* Molima Jack et al. 2023) adopted across programs, all litter classification systems were program specific and all studies used locally-controlled vocabularies. Classification of items was usually based first on material type (e.g., plastic, glass, paper), then further sorted into specific items or classes of items (e.g., drink containers, plastic wrap). All programs appeared to include an option for entry of uncontrolled items, which would either have to be classified later (if sufficient additional information was supplied) or treated as an 'unknown' litter type in analyses. This absence of standard terms and classification across the five programs means that future data harmonisation to inform any broad scale litter assessment will be challenging.

Similarly, the use of data quality procedures was not systematically reported, and for some programs we were unable to determine from the publicly-accessible material whether they were used at all. Some programs such as AMD and LitterWatch Victoria provided online guidance material including information on data elements and QA/QC approaches (e.g., user registration and training). While the New South Wales Litter Data Framework (NSW EPA 2023) makes reference to a peer-reviewed scientific protocol, no detail is provided about this protocol or any user guidance and training. The KLIS is a subset of several litter monitoring approaches reported on in the Litter Data Framework. Nevertheless, the pairing of professionals and citizen scientists for data collection suggests that QA/QC processes are adopted in the KLIS program. Clean Up Australia and the Sea Shepherd Marine Debris Campaign provided only vague information about the nature of data collection and no information about data management, QA/QC processes or user registration and training. In many cases, inferences about data structure had to be inferred from reports and no clear contact was identified for the program data manager(s).

FAIR data assessment outcome

The level of FAIRness across the five anthropogenic litter monitoring programs was generally low, with values ranging from 11 to 44% (Table 2). There were two fundamental features missing from all programs that hindered automatic FAIR assessment: datasets with a persistent identifier, and evidence of the existence of metadata. All programs therefore failed to pass the FAIR first test, which is the ability to find the data. However, in the case of AMD and LitterWatch, there was sufficient information contained in the user guides, monitoring manuals and / or data entry sheets to describe the data elements and infer data formats and provenance. No program data were publicly accessible and data access mechanisms were not always clear, with most referring to an email contact to request access to all or part of the data. Similarly, reuse mechanisms were obscure, with few programs providing clear licensing and usage rights. The lack of public access to primary information like metadata records, that declare the use of any data standards either in the collection, description, or exchange of the data, made it difficult to assess FAIRness, and much had to be inferred from secondary documents such as project summary reports.

Discussion

Anthropogenic litter data has been collected in Australia for over 40 years. The tens of millions of data points could provide a detailed understanding of spatio-temporal distribution of litter pollution from which policy can be formulated and action taken. However, no monitoring program or accompanying data are interoperable, meaning their insights are constrained to a specific program and cannot be contextualised or utilised to effectively address the broader litter pollution problem. Only a single program, AMD, has been used to generate broad-scale quantitative insights on anthropogenic litter pollution and help assess the effectiveness of reduction strategies (Gacutan et al. 2022). Furthermore, research data from Australian studies, which are all marine focussed, are largely inaccessible for further research reuse (but see Bergmann et al. 2018). Thus, current data resources fail to meet their potential for informing effective, multi-scale actions to reduce anthropogenic litter pollution and the environmental damage it causes.

The nature of litter monitoring and research in Australia

The finding that most anthropogenic litter monitoring programs and research in Australia has focused on coastal and marine systems reflects global patterns (Bletter et al. 2018). Internationally, recent work has expanded to terrestrial systems including groundwater, surface water and riparian environments (Cesarini and Scalici 2022; Liu et al. 2023; van Emmerik and Schwarz 2020; Yang et al. 2023), livestock and soils (Meyer et al. 2023; Ren et al. 2023; Sa'adu et al. 2023), and land system types (Hengstmann and Fischer 2020). However, this shift toward addressing terrestrial knowledge gaps has not yet translated to similar efforts in Australia where there is still a paucity of terrestrial data to understand and manage anthropogenic litter at its source. And this represents an opportunity to establish a standardised data framework based on learnings from marine focussed initiatives before *ad hoc* terrestrial data collection further fragments national litter datasets.

All monitoring programs and many published research studies relied either partially or fully on citizen-generated data. This reflects the historical foundations and purpose of litter programs, which were traditionally focused on rubbish removal and involved large numbers of volunteers. Clean Up Australia data collected since 1989 has involved more than 20 million volunteers spending 38.5 million hours on rubbish removal (Clean Up Australia 2022). AMDI has involved a network of communities, schools, industries, government agencies, and individuals who have contributed over 20 years to clean-up events as well as ongoing debris monitoring. These contributions provide large datasets beyond the capacity of formal government or research monitoring programs to collect, so are of great importance (Gacutan et al. 2022). Other programs using citizen scientists and volunteers rely on well-developed guidance documents and training to ensure data and metadata quality (e.g. WaterWatch). However, QA/QC procedures were not a common feature of litter clean-up programs. This reflects research conducted in other domains that highlighted issues with citizen-based monitoring programs lacking consistent data standards, methodologies and QA/QC (Corbau et al. 2025).

In the EU, OSPAR addresses QA/QC through its standardised methodology and rigorous data entry requirements, which are based on standard formats and common vocabularies. Because of these data quality control mechanisms, the EMODnet database provides a source of robust data for scientific studies (Murray et al. 2023), which further encourages other researchers to share their data, enhancing the decision-usefulness of this resource. Conversely, Australia lacks a similar centralised approach to litter pollution research and monitoring. For Australia, where volunteers are a key source of information, the approach should be designed for volunteer-generated data and the additional curation and vetting required. A small amount of Australian research has drawn on AMDI data to inform specific policy actions (e.g., a regional ban on plastic drinking straws; Serra-Goncalves et al. 2023b), but most research studies are snapshots that are unable (or not designed) to provide insights over the larger scales and longer time periods that are needed to formulate national management responses. Thus, at a national scale, the overall quality and useability of Australian data is inadequate for evidence-based decision-making.

Litter research data management in Australia

Large-scale and long-term litter monitoring programs provide the most promise for tracking litter pollution trends and prioritising management responses at multiple scales. However, our FAIR data assessments indicate that Australian litter information systems are not fit for secondary use (i.e. lack data quality mechanisms) because none were discoverable, all lacked metadata and most were largely inaccessible. This contrasts with equivalent data systems in the northern hemisphere (e.g., EMODnet and HELCOM). Further, Australian records do not use common vocabularies and litter data classification systems all differed significantly. In the EU, there is a comprehensive list of anthropogenic litter categories known to occur in the coastal and marine environment for the European Union Member States (Fleet et al. 2021), and EMODnet Chemistry uses common controlled vocabularies and standard metadata for litter survey data (Gonzalez-Fernandez et al. 2016; Molina Jack et al. 2023). The lack of metadata standards and common vocabularies in Australia hinders practicable harmonisation of local data with global data sources and prevents development of universal insights.

The relatively low FAIRness of Australian anthropogenic litter datasets and the differences in collection, monitoring, and reporting protocols, have contributed to limitations in making comparisons and subsequent data reuse (Partescano et al. 2021). For example, Gacutan et al. (2022) had to undertake significant filtering of data housed in AMDI prior to analyses, despite this database being the richest source of anthropogenic litter information. Davies et al. (2022) emphasised the importance of accurate site metadata (e.g., site location, date and time, the number of collectors (surveyors), sampling area and survey duration) combined with environmental covariates to explain temporal trends in beach litter accumulation. Of the reviewed research studies, only four (three of which used AMDI data) disclosed data availability, and data collection methodologies often lacked basic survey information. Further, few studies provided site coordinates and only some reported the number of people involved in data collection, but this information is essential if data are to be unified with other sources. At a national scale, a lack of this information results in lost opportunities to capitalise on the efforts of thousands of Australians (professionals and volunteers alike) by deep interrogation of data for prioritising mitigation actions.

Opportunities for improvement

Each litter monitoring program investigated here was developed with a unique primary purpose, so provides valuable information for tackling a specific litter problem albeit mostly at a local scale. This is likely because mitigation actions are commonly subsidised at this level (Alencar et al. 2022), and the value of such data should not be discounted. However, it has led to the *ad hoc* development of anthropogenic litter monitoring in Australia, which means that historical data is unstructured, highly variable and lacks metadata (Ansari and Farzadkia 2022). Because of this inconsistent data collection, data from clean-up activities is not directly comparable across programs or studies.

Recently, two Australian government-driven initiatives were developed with the intent to address some of these issues. The first - the Australian Litter Measure (AusLM) - describes a methodology to capture standardised litter data across all states of Australia (Sustainability Victoria 2022). AusLM was intended to be an adaptable, multi-use method that can accommodate citizen science data as well as professional data. The method has been well documented and provides sufficient user guidance to address QA/QC needs (Sustainability Victoria 2022). However, uptake of this method outside of government organisations is unknown, and it has not been linked to or integrated with any existing program or data system. Thus, it has limited opportunity to address the issues of data accessibility, interoperability and reusability. The second initiative - the National Plastics Pollution (NPP) portal (<https://dev.npp-australia.org/>) - was designed to store, display and enable basic analysis of marine debris data from across Australia; however, it is not currently slated to proceed to public deployment (<https://research.csiro.au/marinedebris/national-plastics-portal/>), and there is no access to underlying information used or created in the project.

Anthropogenic litter data harmonisation requires both technical and social solutions. Technical solutions include the use of standards and vocabularies. Social solutions require a substantive engagement journey with the stakeholders that collect and manage data. This is imminently possible through the different programs, as each are well connected with their participants and in many cases, to researchers and professionals. The establishment of minimum data standards that are embedded in program methods will help strengthen QA/QC procedures and provide more trust in the reliability of the data to inform decision-making. A standardised hierarchical vocabulary would significantly improve the ability to harmonise individual datasets, while still providing for the more specific community-focus of litter data collection initiatives.

Conclusion

The Australian Government is a signatory to a legally-binding United Nations Environment Assembly global treaty to end plastic pollution (UNEP, 2022). However, there are clear barriers to implementation in Australia given the generally low data quality and data reuse mechanisms across Australian litter information systems. We make the following recommendations for bringing litter monitoring to a standard to support decision making in Australia: (1) increased and targeted government investment, (2) development and use of minimum data collection standards to allow comparisons between disparate data collection activities, (3) inclusion of robust QA/QC processes to ensure data confidence for use of data from decision-making, (4) development and use of common (macro-litter) vocabularies for consistent terminology across the domain, and (5) making data, vocabularies, metadata and information on QA/QC processes available for broader use, ideally via a nationally-managed public portal.

Declarations

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Authors' Contributions

BH and KM developed the study design, contributed to data review, analyses and writing

JW contributed to data review, analyses and writing

SL developed the LitterWatch system and contributed to data review and writing

MW contributed to data review and writing

Ethical Approval

This study did not involve research with humans or animals.

Consent to participate and consent to publish

Not applicable.

Competing Interests

The Centre for eResearch and Digital Innovation developed the platform *LitterWatch Victoria*, which is subject to the same review / assessment process as other monitoring programs. KM provided advice to AusLM during early development stages.

Data Availability Statement

There were no new data generated from this review study, other than that presented in the manuscript and supplementary material.

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