



Marine Litter Monitoring Methods Handbook, Part I

Suggested citation

COBSEA & CSIRO (2022). *Marine Litter Monitoring Methods Handbook. Part 1*. Bangkok: United Nations Environment Programme.

Disclaimer

The designations employed and the presentation of the material in this publication is without prejudice to the legal status of any country, territory, city or area or of its authorities, or concerning delimitation of its frontiers or boundaries. Mention of a commercial company or product does not imply endorsement.

CSIRO advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

CSIRO is committed to providing web accessible content wherever possible. If you are having difficulties with accessing this document, please contact csiroenquiries@csiro.au.

Acknowledgments

This document was prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) with support from the Coordinating Body on the Seas of East Asia (COBSEA) and the United Nations Environment Programme (UNEP) through the SEA circular project, with funding from the Government of Sweden. The review responds to the need identified by COBSEA participating countries to strengthen and harmonise marine litter monitoring efforts toward preventing and reducing marine litter and its impacts, in line with the COBSEA Regional Action Plan on Marine Litter (RAP MALI) and guidance of the COBSEA Working Group on Marine Litter.

Lead authors

Lauren Roman and Britta Denise Hardesty, Commonwealth Scientific and Industrial Research Organisation, (CSIRO)

Contributors

Natalie Harms, Secretariat of the Coordinating Body on the Seas of East Asia (COBSEA), United Nations Environment Programme (UNEP)

The **Commonwealth Scientific and Industrial Research Organisation (CSIRO)** is an Australian Government’s national science research agency responsible for scientific and industrial research. CSIRO aims to solve the greatest challenges using innovative science and technology by using science to solve real issues to unlock a better future for our community, our economy, our planet. From its headquarters in Canberra, CSIRO works with leading organisations around the world and maintains more than 50 sites across Australia and in France, Chile and the United States. www.csiro.au

The **United Nations Environment Programme (UNEP)** is the leading global voice on the environment. UNEP provides leadership and encourages partnership in caring for the environment by inspiring, informing and enabling nations and peoples to improve their quality of life without compromising that of future generations. The UNEP Regional Office for Asia and the Pacific is working to support prosperity, build resilience and boost resource efficiency across the region and is located in Bangkok. www.unep.org

The **Coordinating Body on the Seas of East Asia (COBSEA)** is a regional intergovernmental mechanism and one of 18 Regional Seas programmes. It is the decision-making body for the East Asian Seas Action Plan, bringing together nine countries – Cambodia, China, Indonesia, Republic of Korea, Malaysia, the Philippines, Thailand, Singapore and Viet Nam – in protection and sustainable development of the marine and coastal environment. COBSEA focuses on marine pollution, ecosystem-based marine and coastal planning and management, and ocean governance. The COBSEA Secretariat is hosted by Thailand and administered by UNEP. www.cobsea.org | unep-cobsea@un.org

The **SEA circular project** is implemented by the UNEP Regional Office for Asia and the Pacific and COBSEA, with support from the Government of Sweden. SEA circular aims to reduce and prevent plastic pollution and its impact in partnership with governments, businesses, civil society, academia, and international partners. The initiative promotes market-based solutions and enabling policies to transform plastic value-chain management, strengthens the science base for informed decision making, creates outreach and awareness, and leverages COBSEA’s regional mechanism to tackle the transboundary challenge of marine litter. The project promotes a human rights-based approach to protect informal waste workers and coastal communities most vulnerable to the impacts of plastic pollution. www.sea-circular.org | sea-circular@un.org



List of abbreviations

COBSEA - The Coordinating Body on the Seas of East Asia

CSIRO - The Commonwealth Scientific and Industrial Research Organisation

GESAMP - Group of Experts on the Scientific Aspects of Marine Environmental Protection

NGO - Non-government organisation

NOAA - National Oceanic and Atmospheric Administration (United States of America)

NOWPAP - Northwest Pacific Action Plan

OC ICC - The Ocean Conservancy's International Coastal Cleanup programme

PA DAD - Project AWARE's Dive Against Debris programme

RAP MALI - Regional Action Plan on Marine Litter

UNEP - The United Nations Environment Programme

WGML - COBSEA Working Group on Marine Litter

Contents

Acknowledgments.....	i
List of abbreviations.....	ii
1 Background / preface	vi
1.1 Litter in marine and aquatic environments.....	vi
1.2 The Coordinating Body on the Seas of East Asia (COBSEA)	vii
2 Key reports: Guidelines for the Monitoring and Assessment of Plastic litter in the Ocean (GESAMP) and Regional Guidance on Harmonized National Marine Litter Monitoring Programmes	ix
2.1 The GESAMP report.....	ix
2.2 The Regional Guidance on Harmonized National Marine Litter Monitoring Programmes report	ix
2.3 What is the Marine Debris Monitoring Methods Handbook, Part I (this handbook)?.....	x

Part I What is Marine Litter Monitoring? 1

3 What is marine litter monitoring?	2
4 Why monitor or survey marine litter?.....	2
4.1 Marine litter monitoring programmes	3
4.2 One-off marine litter survey programmes	3
5 Habitats/compartments	4
5.1 Shorelines and coastal environments	4
5.2 Rivers and waterways.....	4
5.3 Oceans (sea surface, water column and seafloor)	5
5.4 Biota.....	5
6 Use of citizen science marine litter surveys	6
7 Scientific best-practice for marine litter monitoring programmes	7
7.1 Scientific best practice for survey design	7
7.2 Size of marine debris items and litter surveys	9
7.3 Different approaches to apply monitoring survey design.....	Error! Bookmark not defined.

Part II Different approaches to marine litter monitoring methods 11

8 Different types of marine litter monitoring methods	12
9 Clean ups.....	12

9.1	Summary of the ‘clean-up’ approach to litter monitoring.....	12
9.2	Benefits of the ‘clean-up’ approach to litter monitoring.....	13
9.3	Disadvantages of the ‘clean-up’ approach to litter monitoring.....	14
9.4	Best-practice in the ‘clean-up’ approach to litter monitoring	15
10	Quadrat surveys.....	17
10.1	Summary of the quadrat survey approach to litter monitoring	18
10.2	Benefits of the quadrat survey approach to litter monitoring.....	18
10.3	Disadvantages of the quadrat survey approach to litter monitoring	18
10.4	Best-practice in the quadrat survey approach to litter monitoring.....	19
11	Transect surveys	20
11.1	Summary of the transect survey approach to litter monitoring.....	20
11.2	Benefits of the transect survey approach to litter monitoring.....	20
11.3	Disadvantages of the transect survey approach to litter monitoring.....	21
11.4	Best-practice in the transect survey approach to litter monitoring	22
12	Volume-based surveys (sediment sampling and water sampling).....	24
12.1	Summary of the volume survey approach to litter monitoring	24
12.2	Benefits of the volume-based survey approach to litter monitoring	24
12.3	Disadvantages of the volume-based survey approach to litter monitoring	25
12.4	Best-practice in the volume-based survey approach to litter monitoring.....	26

Part III Global marine litter monitoring programmes 28

13	Examples of global marine litter monitoring programmes	29
13.1	Ocean Conservancy International Coast Cleanup (ICC)	30
13.2	#BreakFreeFromPlastic Brand Audit (BFP-BA)	32
13.3	PADI AWARE Dive Against Debris.....	34
13.4	National Oceanic and Atmospheric Administration (NOAA) Standing Stock Surveys	36
13.5	OSPAR guidelines – Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area	38
13.6	APEC Marine Environmental Training and Education Center (AMETEC) protocol	40
13.7	CSIRO Global Leakage Baseline Project (GLBP)	41
13.8	Survey design in global marine litter monitoring programmes	42

Part IV Best practice recommendations for adapting existing monitoring programmes 43

14	Recommendations for improving scientific best practice in existing monitoring programmes	44
14.1	Recommendation overview	44
14.2	Attention to reporting survey effort across all monitoring programmes.....	Error! Bookmark not defined.
14.3	Representative survey design recommendations for implementation of Ocean Conservancies 'International Coastal Cleanup' programme, the NOAA programme, and other coastline clean-ups (Coastlines).....	Error! Bookmark not defined.
14.4	Representative survey design recommendations for implementation of Project AWARE's Dive Against Debris programme (ocean - seafloor), and other seafloor clean-up programmes.....	Error! Bookmark not defined.

Part V New and emerging technologies for marine litter monitoring programmes 49

15	New and emerging technologies	50
15.1	Summary of new and emerging technologies in litter monitoring	50
15.2	Remote sensing (Aerial footage and photography): Satellite and drone surveys	51
15.3	Mounted camera surveys.....	53
15.4	Sensor technologies	53
15.5	Surveys of pollutant traps	54
15.6	Automated survey tools offered by private companies.....	56
15.7	Social media surveys.....	55
15.8	Artificial intelligence and machine learning (ML).....	57
15.9	Summary.....	59

1 Background / preface

1.1 Litter in marine and aquatic environments

Pollution of the world's oceans by plastic and other anthropogenic solid waste is a global, transboundary problem. Plastic production, and the consequent loss of plastic solid waste to the environment, is growing through time (Lebreton and Andrady 2019), which is reflected in the growing amount of 'marine litter', predominantly plastic, on the ocean's surface (Wilcox, Hardesty et al. 2020). The United Nations Environment Program (UNEP) defines 'marine litter' as ***“any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment”*** and the focus of this review is on plastic marine litter, though the term maybe used interchangeably with 'marine debris' by some entities.

In 2016, more than 10% of the global production of plastic waste, approximately 19 to 23 million metric tons, was estimated to have entered aquatic ecosystems (Borrelle, Ringma et al. 2020). Plastic in marine and aquatic environments is more than an eyesore. This waste negatively impacts wildlife health (Wilcox, Puckridge et al. 2018, Roman, Hardesty et al. 2019), poses a hazard to marine logistics and transport, and is potentially a human health issue (Wright and Kelly 2017). Despite increasing global awareness of plastic pollution and rising multijurisdictional momentum seeking and effecting changes at local and national levels, there remain significant challenges to developing meaningful solutions at broader scales.



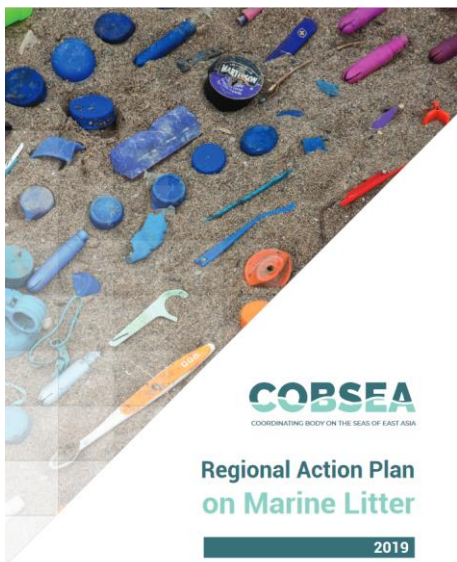
©Sustainable Coastlines

Mismanaged plastic waste is predicted to increase over the coming decades in quantities that far exceed the current mitigation efforts (Borrelle, Ringma et al. 2020). Countries within the Asia region, in particular, are forecast to be disproportionate sources of this plastic waste entering the ocean through rivers in the coming years (Lebreton and Andrady 2019). To address the risk that mismanaged plastic waste poses to aquatic systems, the first step is quantifying and understanding the nature of the pollution problem. Mismanaged waste in the marine environment is heterogeneous and transboundary by nature, driven by both socioeconomic and geographic factors (Hardesty et al., 2021). Quantifying and measuring the extent and change in this heterogeneous environmental problem is forefront to answering applied research questions, identifying plastic sources and sinks and implementing effective solutions. Instituting pollution monitoring programmes at regional scales is an important approach to solving the global plastic pollution crisis.

1.2 The Coordinating Body on the Seas of East Asia (COBSEA)

The Coordinating Body on the Seas of East Asia (COBSEA) is a regional intergovernmental mechanism and one of 18 Regional Seas programmes. It is the decision-making body for the East Asian Seas Action Plan, bringing together nine countries – **Cambodia, China, Indonesia, Republic of Korea, Malaysia, the Philippines, Thailand, Singapore and Viet Nam** – in protection and sustainable development of the marine and coastal environment. COBSEA focuses on marine pollution, ecosystem-based marine and coastal planning and management, and ocean governance.



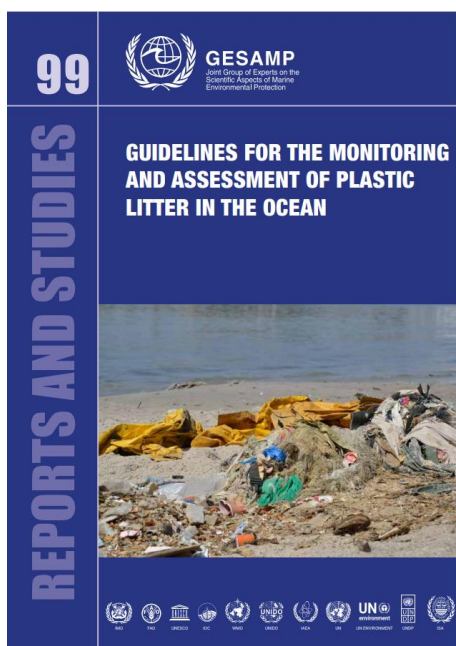


In 2019, the 24th Intergovernmental Meeting of the Coordinating Body on the Seas of East Asia (COBSEA) revised and adopted the **2019 Regional Action Plan on Marine Litter (RAP MALI)**. The RAP MALI guides coordinated action in the East Asian Seas region toward preventing and reducing marine litter from land-based sources and from sea-based sources, strengthening monitoring and assessment of marine litter, and creating enabling conditions for implementation. The RAP MALI has the explicit objective to *“improve monitoring and assessment of marine litter and its impacts for a science-based approach”*. There are two key reports integral to COBSEA meeting these objectives. The first is the GESAMP report, which outlines guidelines for scientific best practice in marine debris monitoring. The second is the Regional Guidance on Harmonized National Marine Litter Monitoring Programmes report, which

was commissioned by COBSEA to inventories current marine litter monitoring efforts in Asia, identify successes, gaps and make recommendations.

2 Key reports: Guidelines for the Monitoring and Assessment of Plastic litter in the Ocean (GESAMP) and Regional Guidance on Harmonized National Marine Litter Monitoring Programmes

2.1 The GESAMP report

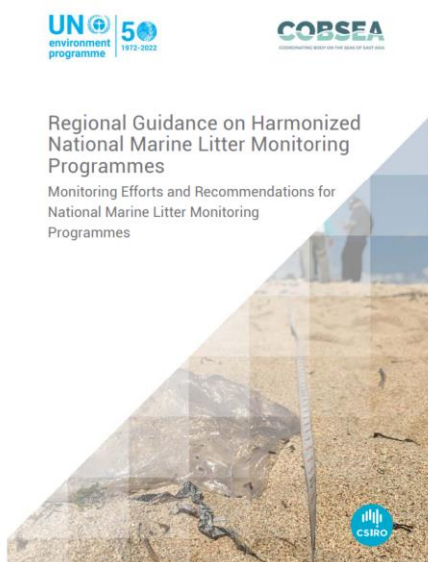


In 2019, the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, a group of independent scientific experts that provides advice to the United Nations system on scientific aspects of marine environmental protection, tabled the “*Guidelines for the monitoring and assessment of plastic litter in the ocean*” or GESAMP report (pictured on the right).

The principal purpose of the GESAMP report is to provide recommendations, advice and practical guidance, for establishing programmes to monitor and assess the distribution and abundance of plastic litter, also referred to as plastic debris, in the ocean. It is a product of the GESAMP Working Group (WG40) on ‘*Sources, fate and effects of plastics and microplastics in the marine environment*’, co-led by the Intergovernmental Commission on Oceanography (IOC-UNESCO) and the United Nations Environment Programme

(UNEP). The report was prepared by 19 independent experts from 14 countries, with financial support from a number of agencies and national governments.

2.2 The Regional Guidance on Harmonized National Marine Litter Monitoring Programmes report



In 2021, to identify existing monitoring programmes and knowledge gaps, COBSEA participating countries provided information on monitoring efforts within their respective countries. From this consultation exercise, the “*Regional Guidance on Harmonized National Marine Litter Monitoring Programmes*” report was developed (pictured on the right). Firstly, an inventory of these regional monitoring efforts were compiled in a monitoring inventory based on the information provided. Secondly, existing programmes and efforts were reviewed in view of the five survey design suggestions in line with international guidance (such as the GESAMP report). Finally, this report summarises the successes, gaps and opportunities in current monitoring efforts; detailing what is

done well (successes), where gaps remain for further development, and the opportunities to improve and harmonize approaches. Findings were shared with COBSEA participating countries and the WGML to provide additional input and validate compiled information to inform further discussion of joint objectives, core indicators, harmonized approaches and quality standards.

2.3 What is the Marine Debris Monitoring Methods Handbook, Part I (this handbook)?

The Marine Debris Monitoring Methods Handbook, Part 1 (this handbook) seeks to provide information to participants in COBSEA participating countries about the different monitoring approaches that are taken in international marine litter monitoring programs. The objective of this handbook is to provide a menu of options that have been rolled out at national and multinational/regional scales to monitor marine litter, to provide guidance on best-practice in marine litter monitoring approaches for regional-scale marine litter monitoring.

This handbook covers:

- A brief introduction to what marine litter monitoring is and why people monitor litter; including examining different habitat types, use of citizen science marine litter surveys, science-based best practice approaches to marine litter monitoring and different marine litter size classes.
- Different approaches to marine litter monitoring methods, including clean-ups, different survey types, and new and emerging technologies.
- A short introduction to some of the globally widespread marine litter monitoring programmes.
- An evaluation of the suitability of different global litter clean-up and survey programmes for establishing baselines and monitoring changes through time
- Best practice recommendations for monitoring programmes to aid decision-making for regional assessment in COBSEA partner countries.
- A brief introduction to new and emerging technologies to aid marine litter monitoring programmes.

Part I What is Marine Litter Monitoring?

Part I of the handbook introduces different types of marine litter survey and monitoring methodologies. This section highlights key facets to consider when designing marine litter surveys or monitoring programmes to guide future monitoring and survey efforts.



3 What is marine litter monitoring?



“Marine litter monitoring”, as adapted from The United Nations Environment Programmes’ Evaluation Manual (2008) definition of monitoring, is the regular collection and analysis and distribution of information for the surveillance of plastic and other anthropogenic litter in marine, coastal and aquatic environments.

These data, when analysed, can aid in identifying marine litter baselines, changes, the progress or limitations of interventions or management

activities as early as possible, allowing governing bodies, project managers and communities to implement or adjust management as needed. Monitoring is a continuing process throughout time or throughout the implementation of a project or management plan and may extend beyond completion. Single or “one-off” data collection efforts, or ‘surveys’ do not constitute monitoring, though a single survey is the first step towards a monitoring program. A collection of one-off survey efforts, if appropriately harmonised, can feed into one national programme or source inventory.

4 Why monitor or survey marine litter?

Having an answer and specific outcome in mind and an answer to this question is the premier consideration for designing a marine litter monitoring program. All the details are secondary and knowing why you are conducting this survey needs to sit at the top of the hierarchy when designing a monitoring program. Ensuring you have identified your focal questions is if key consideration when developing, designing and implementing a monitoring program.

Some common reasons for embarking on marine litter monitoring programmes include:

- Looking at the changes in quantity and composition of marine litter through time.
- Facilitate decision making with respect to marine litter.
- Understanding whether there are problem litter items in your local region.
- Understanding the sources and sinks of marine litter in your region.
- Understanding how marine litter in your local area compares to other areas.

The information gained from monitoring programs is usually gathered for [the purpose of informing policy decisions to reduce marine litter in the area](#). The reduction of marine litter is a goal sought to improve quality of life for humans and wildlife, for example:

- Maintaining a beautiful environment. Marine litter can be an eyesore and reduces the economic and perceived intrinsic value of an area.
- Protecting the environment.
- Safeguarding human health.
- Conservation of wildlife.

However, all marine litter surveys are not equal in the quality of data that they can provide to fulfil the above goals. **Survey design** is a key component in developing a **quality data set**. It is useful to consider design at a number of levels, when embarking on a new, or modifying an existing marine litter program. Marine litter monitoring programmes can be ongoing programs, or one-off surveys, often with a specific goal in mind. These two approaches are designed in very similar ways, but there are some key differences between the two. It is important to understand that one-off surveys often form the basis for ongoing monitoring programmes, and that both survey types are valuable and informative to programme managers and policy makers.

4.1 Marine litter monitoring programmes

Marine litter monitoring programmes are conducted on an on-going basis. Marine litter monitoring programmes are the most useful type of survey to monitor changes through time and responses to policy change, given that they often provide a long-term information about debris in the programme area. Marine litter monitoring programmes are typically funded by government, non-government organisation or private entity that has access to ongoing funding. Sometimes there is a specific policy-related goal associated with such monitoring programmes, others are designed to prioritise environmental health through the removal of litter, while others are designed to foster community spirit. Ongoing litter monitoring programmes may be conducted monthly, six-monthly, annually, or even bi-annually. Timing may be flexible to adapt to seasonal conditions (such as pre- and post-monsoon season) which may be variable.

4.2 One-off marine litter survey programmes

Marine litter surveys typically occur just once, or several times across a fixed duration, and are usually designed with an end goal in mind. For example, a survey designed around a research question, such as the amount of litter in a particular waterway, or to test the effectiveness of a policy change, such as a grocery bag ban. While one-off surveys do not constitute a monitoring programme, a collection of one-off survey efforts, if appropriately harmonised, can feed into one national programme or source inventory, and are included as valuable resources in this handbook.

Many university studies and research programs are one-off marine litter survey programs, though these programmes might involve multiple surveys throughout a fixed period. Funding to undertake litter surveys may be linked to a particular outcome. Though one-off surveys are often not the best tool to examine long-term time trends, they are ideal for situations where there are resources available for a particular goal. The data from one-off surveys can provide useful snapshots of litter in a habitat or region; and longer-term litter monitoring programmes may be instigated by the results of one-off surveys.

One-off litter surveys often form the basis for ongoing monitoring programmes and can provide valuable snapshots of litter in time and space. This information can feed in and form the basis for evidence-based decision making.

5 Habitats /compartments

There are **four major habitats or compartments** that are most frequently considered for monitoring. These include coastal environments, rivers and waterways, oceans (sea surface, water column and seafloor) and biota. Inland habitats, both natural, built environment and refuse collection facilities are also surveyed for litter and solid waste. As this handbook focuses on marine litter monitoring, we focus on the marine and aquatic rather than the inland habitats. There are four main habitats for monitoring marine litter quantity and change through time identified by GESAMP (Kershaw, Turra et al. 2019): shoreline, seawater, seafloor and biota. We expand on these categories to include aquatic waterway environments.

5.1 Shorelines and coastal environments

Coastal environments are a habitat type that captures the transition from terrestrial landscape to ocean. Marine litter in coastal environments tends to include a mix of locally deposited (littered) debris that has been dropped directly into the coast or has been transported from a nearby land-based source via wind or rain, mismanaged waste that has arrived from nearby via local river input, and mismanaged waste that may have been transported from far away by oceanic processes such as currents and onshore wind. **Coastal environments are popular regions to conduct land-based surveys because coastal environments are often valued for their recreational value**. Many coastal environments include beaches of various substrate types, and small islands may be considered entirely coastal with respect to their habitat type. Manual clean-ups, sometimes including citizen scientists or volunteers, are the most popular way that coastal monitoring programs or surveys are conducted. However, a range of other techniques also exist, such as beach-sweeping of sandy beaches and remote sensing surveys, such as the use of video footage taken by unmanned aerial vehicle (UAV / drone).

5.2 Rivers and waterways

Rivers are another popular habitat for implementing and carrying out survey programs, as **they reflect items that are locally deposited from the nearby human population and are rarely confounded by items that arrive via ocean transport**. The quantity of litter that flows down a river is generally strongly linked to rainfall, with more litter being transported with rainfall events, and less litter being flushed or transported when the weather is dry. River monitoring programs will optimally consider and include information about the weather at the time of the survey, whether significant rainfall has occurred before the survey, and the time since the last major rainfall event. Manual clean-ups of the edges of rivers and waterways, sometimes including citizen scientists or volunteers, are the most popular way that river and waterway monitoring programs or surveys are conducted. Other monitoring or survey methods include the use of booms to capture litter as it is transported down the river, autonomous infrastructure or similar that picks up trash, and remote sensing, such as video recording devices placed on the underside of bridges and other infrastructure.

5.3 Oceans (sea surface, water column and seafloor)

Oceanic surveys may look at the sea surface, water column or the seafloor. Ocean plastic usually arrives from inhabited landmasses, where marine litter is transported to the ocean via rivers or from the coast. Marine litter can also arrive in the ocean through direct deposition of mismanaged waste from boats, including both intentional deposition such as dumping at sea of land-based waste and waste from ships, or accidentally through items falling off ships or fishing gear becoming lost/derelict. [Marine litter in the ocean may be more sparsely dispersed, compared to coastal and river environments, but can accumulate in high densities in some regions near to the coast, on the seafloor in submarine canyons, as well as in oceanic gyres or accumulating areas.](#) The North Pacific subtropical gyre is famously referred to as the “*Great Pacific Garbage Patch*” for its high density of buoyant marine litter, with an estimated 1.8 trillion items, weighing an estimated 79 thousand tonnes, floating in an area of 1.6 million km² (Lebreton, Slat et al. 2018). Surface trawling, such as using a manta net, is a popular method for sampling the sea surface for buoyant debris. Seafloor surveys often occur by manual counts and clean-ups conducted by divers, seafloor sampling through dredges and core sampling, and through remote sensing, such as photographs and video footages taken by both manned and unmanned underwater vehicles. Sampling of the oceanic water column is the least common method of marine litter survey as it is a difficult and expensive means of sampling. Not surprisingly, very little is known about marine litter in the water column.

5.4 Biota

Many marine and coastal species eat and become entangled in marine litter. [Surveying biota can be a useful way to sample marine litter for environmental monitoring purposes, human health purposes \(as in the case for edible species\) and for wildlife conservation and animal welfare.](#) Edible biota such as the blue mussel, *Mytilus edulis*, and small fish such as the anchovy, *Engraulis sp.*, and sardine, *Sardina sp.* And *Sardinops sp.* are common survey species for ingested marine debris (Renzi, Specchiulli et al. 2019, Pennino, Bachiller et al. 2020). Commercially harvested species of edible bivalves and small fish are often selected as they are abundant in the environment, commonly eaten, and single animals have a low monetary value. Stomach samples from edible species are often sub-sampled from intentional harvests for human consumption for the purpose of marine litter survey or monitoring programmes. When monitoring biota that are known to interact with plastic but are threatened, such as marine mammals, sea turtles and seabirds, individuals are typically opportunistically collected if found deceased. Opportunistic collection methods include those that are caught as by-catch in fisheries, and those that naturally wash up dead on the beach. Plastic can also be monitored in the waste products of some wild animals, for example, by collecting the scats of sea lions and cetaceans or the regurgitated pellets (boluses) of seabirds.



6 Use of citizen science marine litter surveys

Citizen science surveys are often utilized with the intention of collecting data at minimal cost across broad geographic and temporal ranges (Dickinson, Zuckerberg et al. 2010). For marine litter, citizen science surveys have been found to be as robust as more formal scientific surveys and equally accurate at identifying litter types (van der Velde, Milton et al. 2017), though there is a detection bias against small items (Loizidou, Loizides et al. 2018). One caveat concerning the representativeness of citizen science clean-ups compared to designed surveys is that citizens typically target easily accessible, 'dirty' and accessible areas (Hardesty, Wilcox et al. 2017). Targeting sites in this manner makes it difficult to extrapolate beyond areas that have been surveyed or cleaned, in contrast to taking a designed-based approach (Hardesty, Wilcox et al. 2017). Despite these caveats, citizen science surveys provide valuable and accessible broad-scale data.



PADI AWARE's "Dive Against Debris" programme is a well-known and respected citizen science marine litter survey programme that engages PADI scuba divers to surveys seafloor habitats.

7 Best-practice for marine litter monitoring programmes

7.1 Scientific best practice for survey design

From the globally accepted guidelines of the GESAMP 2019 report and recommendations from the 2021 Regional Guidance on Harmonized National Marine Litter Monitoring Programmes report, we present five science-based, best practice suggestions for marine litter monitoring.

The five tenets for designing national and regional scale marine litter monitoring programmes (e.g., establishing baselines and monitoring changes through time):

1. Clearly defined and repeatable methods.
2. Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible.
3. Representative capture of variation within each habitat to avoid sampling bias.
4. Accounting for data collection effort.
5. Representation of different habitats.

Clearly defined and repeatable methods

Repeatability and reproducibility are a challenge for all scientific disciplines and monitoring programmes. This is also challenge for marine litter monitoring, where questions such as “*when*” “*where*” and “*how*” can completely change how a survey is conducted and the results derived from the surveys. When, where and how are especially important in long-term monitoring programmes to be sure that the results found are real and not artefacts of a survey conducted in a different place (even small distance differences can affect the litter found in complex and heterogenous habitats), at a different time (monsoon vs dry season, before or after a big celebration or clean-up) or using a different search method (vehicle survey vs foot, walking vs hands-and knees). Controlling for detection probability by specifying the searching methodology. For example, the methodology may specify searching by walking in a straight line or transect (rather than random searching) or searching while standing (rather than on hands-and-knees).

Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories

There are many different methods by which marine litter monitoring programmes quantify and report their findings. The usefulness of a study is ultimately determined by the quality of this reporting. The ability to ‘harmonise’ and to directly compare findings between different efforts and glean policy-relevant information from these studies/programmes is key for designing effective and successful monitoring programmes.

Representative capture of variation within each habitat to avoid sampling bias

Biases can be easily introduced by not representatively capturing within-habitat variation. Often sampling biases are not intentional, but small differences in the way a survey is conducted can lead

to very large differences in results. Biases can be introduced by lack of randomised or representative site-selection, for example, concentrating marine monitoring on the dirtiest beach along a coastline, or even just surveying solely the litter-dense strandline of a site rather than across the entire area to gain a more accurate, representative sample. Therefore, surveys are best designed in such a way that the monitoring programme representatively samples within and across each habitat type. The best way to representatively capture variation is to sample the entire habitat. However, this is rarely feasible, and sample areas within the habitat are often selected.

Best practice for site selection includes:

- Stratification of the survey sites to representatively capture variation.
- Randomisation of survey sites, accounting for stratification.
- Within-site replication.

When the entire habitat/site cannot be surveyed, best-practice survey design incorporates these approaches to representatively capture of variation within each habitat and avoid sampling bias.

Account for survey / data collection effort

Variation in survey effort can mislead results and undermine an entire programme if survey effort is not controlled or accounted for.

Measures of data collection effort may include:

- The number of people that carried out the survey,
- The size of the survey area,
- How long people spent searching for litter (Hardesty, Wilcox et al. 2016).

Combined, this information can help discern the probability of surveyors detecting the litter that is present.

Sampling effort does not need to be completely consistent on every survey, but effort does need to be accounted for, and quantified in survey design and execution. This is so that changes detected can be confidently distinguished as real, and not an artefact of sampling bias. By quantifying sources of survey effort, such as the number of people, area surveyed and survey duration, statistical standardisation methods can be applied to the results to reduce or account for sampling biases. Standardisation methods takes this information into account to get a 'true' representation of the amount of litter at each site.





Representation of different habitats

Different types of habitats accumulate different types and quantities of litter (Roman, Hardesty et al. 2020). To representatively account for the inventory of litter in the marine environment, different habitats must be sampled according to the objectives of the monitoring programme. There are four main habitats for monitoring marine litter quantity and change through time, as highlighted by the GESAMP working group: shoreline, seawater, seafloor and biota (Kershaw, Turra et al. 2019).

7.2 Size of marine debris items and litter surveys

Size of marine debris items

Anthropogenic litter in all habitats/compartments comes in a range of sizes, from the microscopic to the very large. When describing the size of items, the most studies group items in the visible size range into ‘mega’ (items >1m), ‘macro’ (items 25mm – 1m), ‘meso’ (items 5mm – 25mm) and ‘micro’ (items 0.1µm – 5mm). Smaller than micro are ‘nano’ sized items (items 0.001 – 0.1µm), for which very little has been studied with respect to aquatic environments. Nano particles are therefore not further discussed in this report. ‘Meso’ and ‘micro’-sized items are often broken-down pieces of larger items that have been fragmented by photo-degradation and mechanical degradation of wind and water. Many survey approaches target plastics across just one or two of these size ranges and planning which size range is applicable is integral to choosing the appropriate monitoring approach.

Size	Micro	Meso	Macro	Mega
Dimension	<5mm	5mm – 25mm	25mm – 1m	>1m
Item examples	Microfibres, nurdles / plastic pellets, small plastic fragments, plastic microbeads.	Torn food wrapper, plastic fragment from larger item, cap from small container.	Food wrappers, plastic bags, plastic bottles, take-out container, disposable cutlery.	Tarpaulin, fishing net, agricultural sheeting, woven polypropylene sack, drum.
				

Surveys focusing on meso-plastics and macro-plastics

Meso, macro and mega anthropogenic debris is easy to see along the banks of watercourses. Tangled in riverside, vegetation, in rocks on riverbanks, and trailing across infrastructure such as pipework, dam walls and support piers of bridges, such mismanaged waste creates an eyesore in these natural aquatic systems. For this reason, many of the worlds’ debris survey programs focus on these larger sized items, as specialized equipment and laboratory facilities are not necessary to count or monitor them. [Although commonly observed in this environmental snagging context, macro and mega sized litter tends to be less numerically common than meso and micro-sized litter in inland and aquatic habitats](#) (Blettler, Ulla et al. 2017), especially in the sediment and water column. Plastic tends to dominate anthropogenic litter in aquatic and marine environments (Bruge, Barreau et al. 2018, van Emmerik and Schwarz 2020). Food wrappers (mainly polypropylene and polystyrene), smoking-related items, bags (high- and low-density polyethylene), bottles (polyethylene terephthalate), and disposable polystyrene food containers (expanded polystyrene) are common macro-sized items in inland and freshwater systems (Blettler, Ulla et al. 2017, Bruge, Barreau et al. 2018). [Macro and mega sized items can break down into meso and micro sized items with exposure to the environment, with one item sometimes fragmenting into hundreds or](#)

thousands of smaller ones given enough time and exposure to the elements. Therefore, removing these larger items from the environment can prevent the future release of thousands of microplastics, as larger items become degraded.

Surveys focusing on microplastics

Microplastic items range from visible size range, that can be surveyed by eye, to fragments that are difficult, or too small to accurately see and count. For this reason, [surveys that focus on microplastics typically require trained professional surveyors, and specialized equipment and facilities to capture](#). Where surveys specifically seek to find micro-sized litter, the presence of microplastics and microfibers are widespread, particularly fibers. Microplastics are especially common in aquatic systems, and are ubiquitous in wetlands throughout the world (Kumar, Sharma et al. 2021). Rivers can contain high levels of microplastics, especially where there is input of untreated wastewater (Woodward, Li et al. 2021). The presence of microfibers reflects input into the environment, and more microfibers are expected in heavily urbanized areas compared to remote areas. Across the world, urban areas tend to have greater loads of microplastic in aquatic environments than rural areas. For example, in India, urban rivers have twice the density of microplastics compared to rural rivers (0.4 microplastic particles/L in urban Chennai, 0.2 microplastic particles/L in a rural river near Munnar).

One of the significant challenges affecting quantification of smaller microplastics is the contamination of samples by microplastics generated by the clothing and equipment of surveyors.

It is imperative that studies focusing on microplastics have comprehensive contamination controls. Another challenge of microplastic surveys is distinguishing plastic from natural objects. Fourier-Transform Infrared Spectroscopy (FTIR) is a popular technique used to distinguish synthetic from natural objects. FTIR works by obtaining an infrared spectrum of absorption or emission of a solid, liquid or gas. Currently, much work that focuses on or counts microfibers does not discern between whether those fibers are synthetic or from natural materials.

Microplastic surveys and contamination

A major challenge of surveys that focus on microplastic is avoiding contamination. Clothing of surveyors can shed fibres, and research equipment too may create contamination through damage and chips. It is imperative to have quality contamination protocols in place when conducting microplastic surveys and analysis. A low-cost approach to avoiding (or quantifying contamination is wearing a single color and fiber type when in the lab, so that at least if contamination occurs it can be detected (e.g. orange wool only).

Part II Approaches to marine litter monitoring

Part II introduces different types of marine litter monitoring, including traditional methods such as manual clean-ups and designed litter surveys.



8 Different methods for monitoring marine litter

Different countries around the world count litter and quantify change through a variety of different methods. Among commonly used methods are litter clean-ups and designed surveys. **Clean-ups are used where the removal of litter from the environment is the primary goal and are often undertaken by non-professionals. Designed surveys are often undertaken by professionals or trained participants, include quadrat surveys, transect surveys (including strandline surveys), and volume-based surveys (including sediment surveys and water sampling).** In this section, we address different environmental survey programmes. The information included is current to the time that this report was compiled. We recognise that survey protocols change through time and recommend that readers check organisation's website for the most up-to-date information about survey protocols. This section is not inclusive of biota monitoring, which has its own unique set of methodologies, advantages and disadvantages depending on the approaches and species utilised.

9 Clean-ups

9.1 Summary of 'clean-up' approaches to environmental monitoring

Much of the world's marine debris data comes from clean-up activities. **Clean-up programs generally are co-ordinated by a group which organises to remove and dispose of litter that has accumulated in a chosen area.** Sometimes a tally of items removed for data collection is also carried out. This differs from municipal waste removal services or waste picking, where no data on the types of litter collected is recorded. Clean-ups can occur in any habitat, but are most popular on beaches, in inland areas, or on the seafloor in coastal dive locations. Clean-up programmes operate at different scales, from local to international.

Examples of clean-up programmes operating at different scales include:

- Individuals removing litter from an area that they feel a sense of duty or custodianship over
- Small community group-level clean ups of single beaches, parklands, small islands or rivers, usually administered by a small group of community members. For example, *"Keep Main Beach Clean"*.
- Clean ups of larger areas such as larger islands, stretches of coastline, national parks or along rivers, often coordinated by a larger community organisation or local government
- National clean ups administered by larger organisations. For example, *"Clean up Australia Day"*, an annual nation-wide clean up organised by the non-government organisation *"Keep America Beautiful"* in the United States of America.
- International clean-up programmes, administered by large non-government organisations. For example, the *'International Coastal Clean-up'*, administered by the non-governmental organisation *'Ocean Conservancy'*.

Internationally renowned clean-up programmes

Many of the world's best known marine debris surveys and monitoring programmes take a clean-up approach. Examples include the '**International Coastal Clean-up**', administered by the international NGO 'Ocean Conservancy', and the '**Dive Against Debris**' programme, administered by scuba-diving interest NGO, PADI AWARE. Using the power of volunteers, these clean-ups have been conducted across 150 and 120 countries, respectively, worldwide.

Clean-up surveys are one of the most common approaches to marine litter surveying worldwide and are often organised by citizen scientists and community groups. **Clean-ups are popular because removing litter from the environment as part of a co-ordinated group effort makes most socially conscious people feel good that their direct action is helping the environment.** Often, but not always, the priority of clean-ups is awareness raising, along with removing litter and/or community engagement as the primary goal, while the recording of data is a secondary or tertiary goal. Because the recording of data is not the primary goal, the data collected from clean-up programmes varies in quality, and not all data generated by clean-up programmes are suitable for robust environmental monitoring. Here we outline some of the benefits and disadvantages to clean-up approaches to litter monitoring.

9.2 Benefits of 'clean-up' activities as a monitoring approach

From a monitoring programme managers perspective, the main benefits of clean-up programmes, in addition to removing litter from the environment, is that they are popular with the community, and provide a simple approach to engage members of the public with the environmental issue of litter in their local area. Typically, less financial and expert human resource investment is required to generate a lot of data in a clean-up programme, compared to monitoring programmes undertaken by paid professionals or contractors. With thousands of communities and citizen science groups conducting millions of clean-ups around the world and diligently recording items collected, the datasets generated cover nearly every country in the world at a small fraction of the cost that would be required to send trained teams to clean up these locations.

To summarise, the benefits of clean-up approaches to litter monitoring are:

- **Removing litter** from the environment
- **Cheaper** to conduct than designed and professional surveys if they engage volunteer labour
- **Engaging the community** in preserving their local environment
- **Raising awareness** of local-scale litter issues, and potentially fostering behaviour change

However, there are caveats about the data collected through clean-up programmes.

9.3 Disadvantages of the ‘clean-up’ approach to litter monitoring

There are three main disadvantages to the clean-up approach to litter monitoring. The first is that there are generally strong biases in the sites or areas selected for clean-ups, with community organisations often prioritising locations that accumulate a lot of litter (‘dirty’ locations), and/or sites with high recreational and societal value, such as well-loved beaches, national parks and holiday locations chosen. Because of this values-based motivation for site-selection, it is rare that stratified or representative sampling is applied to community clean-ups. When this clean-up is used for robust analysis, this can lead to the quantity of litter in an area being over-estimated or under-estimated. The second disadvantage is that clean-up approaches rarely sample the target location evenly and hence the within-site representation is highly variable. For example, if the clean-up site is a beach, clean-up participants may walk along the strandline only, and prioritise removing larger and easier-to-see items. This means that the survey data can be biased as it misses litter types that accumulate higher on the beach or in the backshore, and/or is missing smaller items and microplastics, including fragments. Furthermore, as more participants join, a larger area may be included, though not all the area may be ‘cleaned’ or ‘surveyed’ equivalently. A third disadvantage to clean-up approaches to marine litter monitoring is that volunteers may not accurately gauge survey effort with respect to their clean-up, nor accurately fill in survey sheets. It is common that volunteers prioritise the removal of litter over the collection of data, meaning that errors in counts of the individual items, or the mass of items (especially when wet or sandy/soiled items are collected) is common. By example, in a site clean-up with numerous members, volunteers may roam and search in a non-standardised manner, searching for different lengths of time, covering a variable distance of ground. In such clean-ups, and some stretches of ground will be searched more than once by numerous participants, while other areas might not be searched at all, especially in a large site. For this reason, it is difficult to avoid biases and accurately quantify search effort in community clean-ups.

To summarise, the disadvantages of clean-up approaches to litter monitoring are:

- **Bias in the choices of sites cleaned**, favouring dirty sites or sites with high recreational/social value, therefore representativeness, stratification and replication between sites is rare.
- **Sites are generally sampled unevenly**, leading to compromised within-site representation and stratification, with a bias towards collecting larger litter items.
- **Accurate data collection is not always prioritised**, leading to errors in item counts, variation in recording of item categories, and mass of items, particularly when items are wet or sandy/soiled.

Despite these disadvantages, there are approaches that those overseeing clean-ups as part of monitoring efforts can take to reduce the chance of biases and errors. We detail some of these best practice approaches below.

9.4 Best-practices in the 'clean-up' approach to monitoring mismanaged waste

Some of the disadvantages of clean-up approaches to litter surveys can be overcome with careful planning and attention to detail. For example, biases in site selection can be overcome by a representative and stratified site pre-selection system for community clean-ups. Within-site representativeness and stratification can be improved by training clean-up co-ordinators in techniques to overcome these disadvantages. For example, clean-up coordinators may want to split their volunteer group evenly across the site, providing bounded, representative sub-sites across the broader site, asking each team to evenly cover these sub-sites, rather than letting volunteers roam widely to clean.

A major problem of clean-ups is poor quality control in data recording, meaning that the results of entire clean-up programmes cannot be included if key data is missing, or inaccurately recorded. Data recording can be improved by site-coordinator training, and by discussing and demonstrating the importance of good data collection techniques before the clean-up begins. For survey effort data, this might include providing volunteers with equipment, such as tape measures and stop watches, to accurately record the distance/area surveyed, and the time spent undertaking the survey.

One common pitfall of clean-up data is the lack of recording zero counts. Often, recorders may leave zero counts blank. When the data is analysed, those performing the analysis will not know whether blank records are zero, or 'forgotten', and depending on the objective of the survey, these omissions may mean that data from the entire survey cannot be used. Accuracy of data collection and counting can be improved by having one or two data recorders whose sole responsibility is to record the data, and ensure accuracy and good practice among the team, including filling in every blank cell, and recording of all zeros. Electronic forms can help this problem, as electronic forms and data cards can be programmed with constraints that do not enable participants to leave the cell blank. Another technique to ensure accurate counts (though this takes more time), is to collect all litter from the survey into a bag or box, and sort and count together at the end of the clean-up session.

To summarise, some steps that can be added for best practice to clean-up approaches to litter monitoring are:

- **Pre-selection of a representative and stratified suite of sites** for volunteer coordinators to choose from can reduce biases such as targeting of locations that may introduce data biases
- **Training clean-up coordinators** in the importance of within-site replication, stratification and representativeness, and attention to survey effort, so they can manage their team in such a way to avoid within-site biases. Examples might include splitting a site into sub-sites, and allocating specific team members to different, bounded sub-sites.
- **Attention to accurate data-recording.** This includes making sure that the clean-up participants count carefully, and do not leave blank spaces when recording data. For accurate measuring of survey effort, clean up coordinators may want to provide the team with equipment such as measuring tapes and stop watches to accurately record survey effort.
- **Electronic data entry forms** can reduce the instance of volunteers incorrectly entering data and leaving blank spaces, as electronic forms can be constrained to disallow blanks.

Clean-ups can be a valuable approach to data collection, if a few extra steps are taken to ensure best practice to avoid some of the biases inherent to clean-up approaches.

Avoiding blank data cells, and the importance of zeros

A common error in data collection in general, and volunteer collected data specifically is failing to complete data forms in their entirety. People often leave blank cells (failing to record zero items or other important information). When survey data is analysed, the presence of a single blank cell in an important category can mean that the entire survey cannot be used. For example, a blank cell in survey effort entries, such as the distance/area surveyed, number of surveyors or the time taken, means that data analysts cannot distinguish whether low or high litter counts are due to hot/cold spots, or because there was high or low survey effort driving the trends. Zero counts of items are often left blank in data forms. When this happens, the data analyst cannot know whether no data was recorded because no litter of that type was found, or because the data recorder forgot to write in that cell. Attention to not leaving blank cells, and filling in zeros where no litter was found, can help make the best use of data collected.

10 Designed surveys

10.1 Summary of the 'clean-up' approach to litter monitoring

Designed surveys are intended specifically to quantify, catalogue, and monitor mismanaged waste and marine litter in the environment. Designed surveys are usually undertaken by scientists, environmental officers, contractors and other trained professionals. Though debris may be removed from the environment during a designed survey, designed surveys differ from clean-up activities in a number of ways. The gathering of robust, reliable information is a primary goal of the survey, rather than the immediate removal of litter itself. There are numerous types of designed surveys that are used in environmental sciences generally. In this section we summarise the main approaches, and discuss the benefits, disadvantages, and best-practice of the most popular designed survey approaches for marine litter monitoring, including:

- Quadrat surveys
- Transect and area-based surveys (including strandline and trawl surveys)
- Volume-based surveys (including water and sediment sampling).

This section serves as just a brief introduction to the main concepts of each survey method. Each individual designed survey programme often has its own specific guidelines and protocols, which may differ from the general information provided in this handbook.



11 Quadrats

11.1 Summary of the quadrat survey approach to litter monitoring



Quadrat surveys are a designed survey where a square or rectangular area, called a quadrat, is placed on the ground in numerous locations within a site, and all items of interest within the quadrat are counted. Quadrat surveys may focus on the surface of a substrate, but can also include core samples, and can be carried out on land or on the seafloor. Quadrat sampling approaches are popular in many natural sciences because they enable a physically bounded method by which to sample a chaotic

natural system, providing robust, reliable and defensible data that can be readily extrapolated into non-sampled sites.

11.2 Benefits of the quadrat survey approach to litter monitoring

Quadrat surveys have many advantages over clean-ups, in part due to their bounded nature and the increased rigor of the survey approach. The clearly defined edges of a quadrat mean that sampling effort and area is tightly constrained, and there is less likely to be variation in the data/results that are driven by factors relating to surveyor effort and *how* the survey was conducted (these problems are common in clean-ups) rather than variation due to the characteristics of the marine litter itself. **Quadrat surveys make for straightforward calculations of marine litter density at a site**, and ready comparison between sites.

To summarise, the benefits of quadrat approaches to litter monitoring include:

- **Bounded area sampling** means that items within quadrats are not likely to be missed
- **Survey effort and area is constrained**, making for more accurate analysis and extrapolation

However, there are caveats about the data collected through quadrat sampling.

11.3 Challenges associated with the quadrat survey approach to litter monitoring

Quadrat placement, if randomised without including the habitat variation that may be present within the broader survey area, can miss important details. For example, across a larger site, randomised quadrats may not include an important debris-accumulation area, such as a drainage channel in a larger agricultural site. Individual quadrats within a site can also have large variations in the amount of debris between quadrats, which is reasonable due to the highly variable nature of

debris accumulation in the environment. If there is significant variation in litter between quadrats, then extrapolation and among site comparisons may be less accurate than desirable.

To summarise, the disadvantages of quadrat approaches to litter monitoring are:

- **True representativeness and randomisation may be difficult**, and without good randomising methodology, surveyors can be biased towards placing quadrats on debris-dense areas within the survey site
- Quadrat placement **can miss important details** that occupy a small proportion of the survey site, especially if representativeness is not factored into the randomising method.
- Depending on the diversity of the counted object (in this case, litter) within the site, many transect squares may be needed. Highly diverse sites might have more variation within a site than between sites, making **comparison between sites difficult**.

Despite these disadvantages, there are approaches that those overseeing quadrat surveys as part of monitoring efforts can take to reduce the chance of biases and errors. We detail some of these best practice approaches below.

11.4 Best-practice in the quadrat survey approach to litter monitoring

To improve the data from quadrat surveys, the site selection must be properly randomised. For example, a quadrat survey of a beach is not random if all the quadrats are placed on the strandline. Furthermore, the randomisation method must be structured in a way that variable compartments within the site are stratified to properly represent the site. If a site is large, power analysis may be required to determine the minimum number of quadrats that are required to be sampled for a statistically robust and appropriately representative survey.

To summarise, some steps that can be added to ensure best practices to quadrat approaches to litter monitoring are:

- Ensure a **true randomisation approach** to reduce the chance of surveyor-introduced biases
- Factor in a level of **site representativeness to apply across the randomisation technique**, so that important features occupying a small proportion of the total site are not overlooked
- For highly diverse or variable sites, **statistical techniques such as power sampling** may be required to determine the minimum number of quadrats required to conduct between-site comparisons.

With careful consideration, quadrat surveys can be a valuable approach to data collection.

12 Transect surveys

12.1 Summary of the transect survey approach to monitoring mismanaged waste



Transect surveys are a designed survey whereby a measuring device is used to ensure the entire area surveyed is recorded appropriately. Typically, a tape measure or similar device is placed on the ground in a straight line, for a fixed distance, within a site. The surveyors walk along the measure, called the 'transect line', and count all items of interest within a fixed distance (such as 1 or 5 or 10 m) from the tape measure. Transect surveys tend to focus on the top of the land type. Transects may be used at inland, along coastal and riverbed sites, or on the sea surface, but can also be used on the seafloor. Sea surface transects differ from land-based transect surveys because they ideally involve towing a trawl net with a fixed mouth width (and of a particular mesh dimension). Trawl surveys are conducted by

travelling a predetermined distance and/or for a set time at a fixed speed in a moving vessel, an approach known as surface trawl sampling. Like quadrat sampling, transect sampling approaches are common in many natural and agricultural sciences, because they enable a physically bounded method by which to sample a chaotic natural system, providing robust scientific data that can be readily extrapolated into non-sampled sites.

Among transect surveys of coastal and river habitats, there are two common approaches:

- I. **Transects that run parallel** (the same direction as) the coastline/riverbank, often along the strandline/debris line (the line where anthropogenic litter and vegetation debris accumulates). This is often called a **strandline survey**.
- II. **Transects that run perpendicular** (at a 90° angle to) the coastline/riverbank, often starting at the waterline and ending at, or beyond the backshore vegetation or top of the riverbank.

Here we discuss both types of transect surveys, and the differences between them.

12.2 Benefits of the transect survey approach to litter monitoring

Transect surveys have many of the benefits of a quadrat survey, in that the bounded nature means there is less likely to be variation in the data/results that are driven by factors relating to surveyor effort. Like quadrat surveys, transect surveys are useful for calculations of marine litter density at a site, though this is contingent on where the transect line is placed, and the ready comparison between sites (a challenge for all survey types). Because they encompass larger survey areas than do quadrats, they may better capture small-scale differences that quadrat surveys might miss. Transects are also an efficient means of sampling across a variety of strata at a site, and as such are economical and robust, if sites and transects are selected appropriately.

To summarise, the benefits of transect approaches to litter monitoring are:

- **Bounded sub-sampling** means that items within transects are not likely to be missed
- **Survey effort and area is constrained**, making for more accurate analysis and extrapolation
- Because transects span longer distances than quadrats, they are more likely **detecting important features that take up a small proportion of the total area of the site**, that might otherwise be missed
- They are a **cost effective and robust** means of sampling across a larger geographic expanse than area-based surveys or clean ups.
- Because transects can encompass multiple land use types within a site, they may **better allow for robust analysis and comparisons** compared with other survey approaches.

However, there are caveats about the data collected through transect approaches.

12.3 Disadvantages of the transect survey approach to litter monitoring

There are some disadvantages of transect approaches to litter monitoring, but these mainly relate to the physical space of the transect. The first disadvantage is that there can be confusion about whether items at the edge of the boundary fall inside or outside of the transect. This differs to quadrats, where the edge of the quadrat provides a clear boundary. Features of the landscape, such as trees, shrubs, embankments, erosion and changes in height of the ground can impede laying a transect in a straight line. Sometimes obstacles such as shrubs can completely cover a transect line, making it difficult to properly survey the ground under the obstacle, and/or impacting on the calculation of distance/area surveyed.

Further to these general disadvantages, strandline surveys have some unique disadvantages. The first disadvantage is that the debris load caught in a strandline changes with wind and water intrusion: this can be twice a day in the case of a beach strandline (due to tidal fluxes), or when it rains for a river strandline. Furthermore, the data that results from debris surveyed in a strandline can only be compared to other strandlines and cannot be extrapolated to other parts of the site, nor is it ideal to compare among strandlines if a number of additional factors are not taken into account. Strandlines are debris accumulating areas and as such will over-represent debris if extrapolated to other areas more broadly (non-strandline areas). Hence, it is not appropriate to apply to hotspot or change through time monitoring due to how heavily impacted this type of data is and its structural biases.

To summarise, the disadvantages of transect approaches to litter monitoring are:

- Without clear boundaries like a quadrat survey, there may be **uncertainty as to which items lay within or outside of the boundaries** of the transect
- For trawl samples, if the water is moving, **it can be challenging to determine how much water is moving** through the trawl net, without the use of a flow meter

- **Features of the landscape**, such as trees, bushes, waterways and changes in height of the ground, **can impede the transect line**
- Without careful placement, the transect **surveys may not be representative of the sub-habitats within the site**

Unique disadvantages of strandline transect approaches to litter monitoring are:

- **Marine litter loads along strandlines changes rapidly**, and debris can be deposited or moved on tides and with rainfall events.
- **Strandline debris data cannot be readily extrapolated** to determine the debris load at the site or habitat at large.
- **Debris data collected at strandlines can only readily be compared to other strandlines**, generating a dataset that has limited applicability and transferability for other sites.
- **Strandline surveys provide an overestimate of debris load**, as by definition these surveys take place at accumulating areas.

Despite these disadvantages, there are approaches to conducting transect surveys as part of monitoring efforts that can reduce bias and errors. We detail some of these best practice approaches below.

12.4 Best-practices in the transect survey approach to litter monitoring

To reduce these disadvantages, applying stratified and representative design approaches to transect placement is a best practice. The use of measurement aids, such as rulers or a string of the width of the transect, can be used to distinguish which items are inside or outside the transect boundary. At each site, because one is not exhaustively surveying and recording information for a large area, conduct multiple transects within a site (a minimum of three ensures analysis can include an average and variability measures). For trawl samples, aids such as flow meters can help quantify the water moving through the trawl net. We further recommend conducting transects perpendicular to the coastline and river, moving from the water's edge away from it at 90 degrees. This allows one to sample across the full representation of the site, rather than biasing towards a particular area.

To summarise, some steps that can be added for best practice to transect surveys for monitoring include:

- **Use of measurement aids**, such as a ruler, to determine whether items near the transect boundary are within or outside of the transect.
- **Apply stratification and representativeness within the site** to ensure sub-habitats are captured.
- For coastline and river surveys, **conduct transects running from the water's edge perpendicular to the coastline/river**.

- **Carry out multiple transects (minimum of 3)** at each survey site to ensure representation of the amounts and types of debris at that site and striking the balance between cost, efficiency and representativeness.

With best-practices implemented, transect surveys are a valuable and cost-effective approach to litter and mismanaged-waste monitoring.



13 Volume-based surveys (sediment sampling and water sampling)

13.1 Summary of the volume survey approach to litter monitoring



Volume surveys are a designed survey, where a fixed volume of a substrate, typically sediment (sediment sample) or water (water sample) is collected to measure the plastic contained per unit of volume. For aquatic and marine habitats, sediment provides an indication of non-buoyant items (those that do not float), while surface or subsurface water samples target buoyant and neutrally buoyant items (floating items or those that are the same density as the water).

Sediment surveys have become an increasingly popular method especially for sampling microplastics. Sediment surveys are popular on beaches, in estuaries and riverbeds, but have been conducted across a variety of environments, including on the deep ocean floor. Sediment sampling typically involves using a bucket, grabbing device or corer to take a volume of sediment, and quantifying the plastics within the sample. Sediment samples are useful because they reveal litter items that are not just visible and sitting on top of the sediment, but those that are buried. Hidden items that are buried in the sediment are a particularly important component of the pollution of high-energy locations, such as beaches with big waves. They can also provide a view through time, with deeper cores providing information of older (past) environmental debris compared to surface sediment which is more recent.

Water sampling targets litter and fragments that are both accumulated and in transit (or flux) in the water column. Water sampling is popular especially in rivers and is increasingly being used (grab samples) in ocean environments. Water sampling is typically done by filling a container (typically a bottle or bucket) with water from a fixed depth, to quantify the number of items, typically microplastics, within the volume of water. Water sampling is an important method for understanding the loads of plastic present in water bodies, as water columns, especially in remote parts of the ocean, are among the least understood areas with respect to plastic pollution.

13.2 Benefits of the volume-based survey approach to litter monitoring

The benefit of sediment and water sampling is that they account for unseen items – those hidden in the sediment or water column. The methodology of taking a fixed volume of water or sediment from a site works similarly to a quadrat sample for quantifying plastic on the ground surface due to their bounded nature. The clearly defined edges of the container used mean that sampling effort and volume is tightly constrained. Because of this, volume-based surveys make for straightforward calculations of marine litter density at a site, and ready comparison between sites. Furthermore, the sampling approach is quite to carry out, with respect to field time. The effort required comes in the sample processing time.

To summarise, the benefits of volume-based survey approaches to litter monitoring are:

- **Fixed volumes of water and sediment** means that items within containers are not likely to be missed.
- **Survey effort and area is constrained**, making for more accurate analysis, extrapolation, and direct comparison between sites.
- **Relatively quick to do in the field** (unless sampling in the depths of water from a vessel or unmanned autonomous vehicle).

However, there are caveats about the data collected through sediment surveys.

13.3 Disadvantages of the volume-based survey approach to litter monitoring

One notable disadvantage for volume sampling is that it is only most useful for smaller items, such as microplastics and smaller mesoplastics. Prohibitively large volumes of sediment and water would be required to sample macroplastics and this approach is not undertaken with an eye to sampling large items (to the authors' knowledge). Volume sampling, if randomised without factoring within-site habitat variation, can miss important details and, as with other compartments, the high level of variability means multiple samples will yield a more accurate picture of anthropogenic debris. For example, across a larger site, randomised volume measurements may not land on an important debris-accumulation area, such as an underwater feature such as a sink hole or channel. Debris variability is also quite high even at local scales from sediment sampling (Barrett, Chase et al. 2020). If there are significant between-sample variations, then extrapolation and making between-site comparisons is a challenge. Hence, taking multiple samples is important, as is true for any other sampling or survey approach. Another disadvantage is volume-based surveys have a limited ability to detect plastic in relatively 'clean' or lightly contaminated environments, without significant volumes of water and/or sediment being taken. Distinguishing between the absence of plastic, and low amounts of litter, can be challenging with volume-based approaches.

To summarise, the disadvantages of volume-sampling approaches to litter monitoring are:

- Volume sampling methods are **useful for microplastics and smaller mesoplastic**, depending on the size of the mouth of the sampling container. However, **volume sampling is rarely a useful technique for macroplastics** unless very large volumes of sediment or water can be collected.
- **Local heterogeneity is high, so multiple samples are required.**
- Insufficient sampling across the strata can result in **missing debris if it only occurs in a small proportion of the survey site.**
- **Difficulty in detecting plastic in clean / lightly contaminated environments** is a concern as large volumes of water and/or sediment may be required to detect debris in low density areas.

Despite these disadvantages, there are approaches that those organising volume surveys as part of monitoring efforts can take to reduce bias and the chance of errors. We detail some of these best practice approaches below.

The Regional Research Inventory and volume-based surveys of microplastics in East Asia

A science-policy team, led by researchers from the National University of Singapore with support from UNEP, COBSEA, SEA circular and the government of Sweden, have recently compiled an inventory of peer-reviewed science and humanities research publications on marine plastics. This database is called the 'Regional Research Inventory' and is available online. Volume-based surveys to quantify microplastics in seawater and sediment are among the most common type of environmental sampling survey conducted by universities in the ASEAN+3 nations at the time of compiling this handbook. The Regional Research Inventory has aimed to harmonise the units of reporting for findings, where possible, and is useful for comparing microplastics per volume of substrate across different countries and habitats in East Asia.

13.4 Best-practices in volume-based survey approaches to litter monitoring

To improve the data from volume surveys, sites selected will ideally be chosen using a stratified random sampling approach. If there is a high diversity of features within the site (such as an uneven seafloor), the randomisation method will ideally be structured in a way that variable compartments within the site are stratified to as fully represent the site as possible. We suggest multiple samples (replicates, minimum of 3) are taken at each site. If a site is large, power analysis may be required to determine the minimum number of volume samples that are required to be samples for a statistically robust survey.

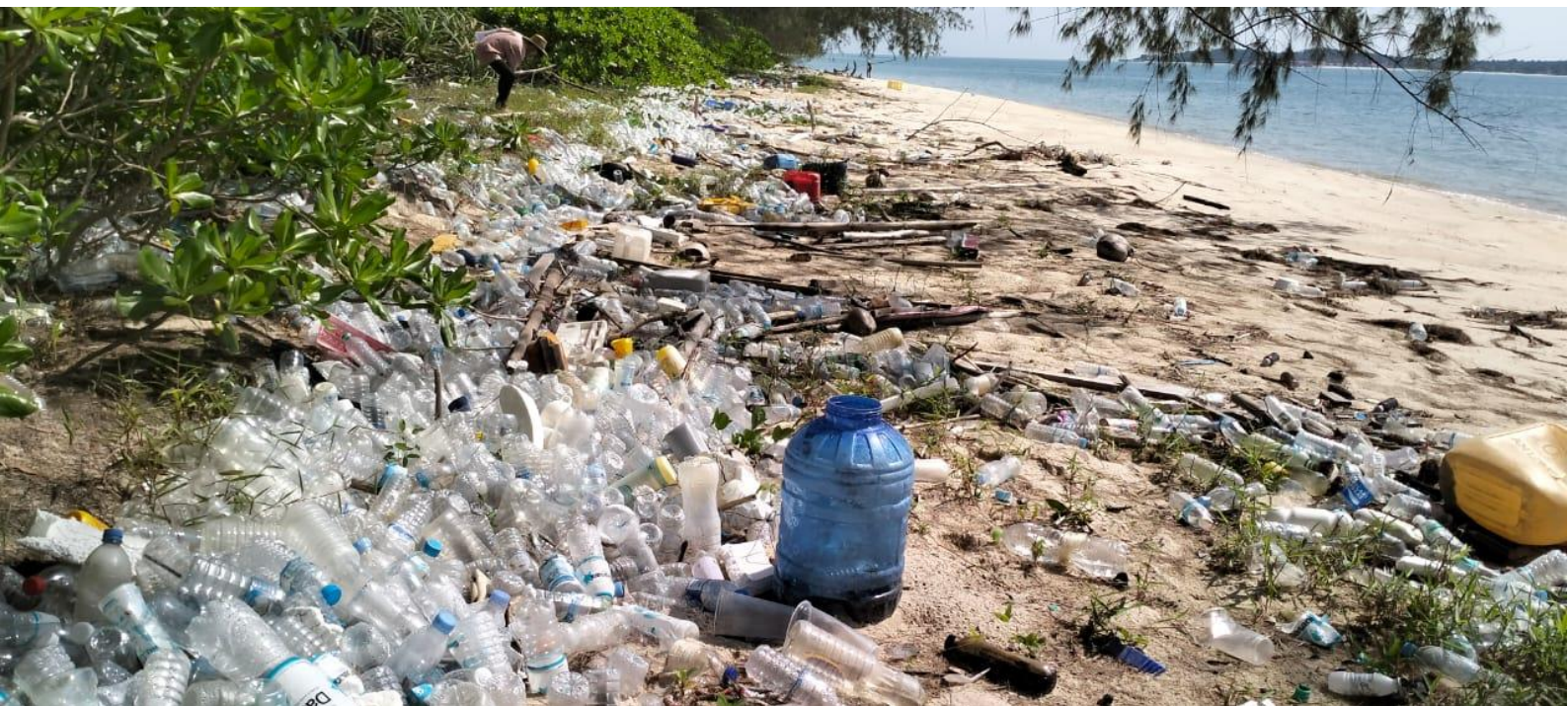
To summarise, some steps that can be added for best practice to volume approaches to litter monitoring are:

- **Ensure a true randomisation** approach to ensure sampling is representative across the site.
- **Factor in a level of site representativeness** to apply across the randomisation technique, so that important features occupying a small proportion of the total site are not overlooked.
- For highly diverse or variable sites, **statistical techniques such as power analysis may be useful** to determine the minimum number of samples required to conduct between-site comparisons, especially in regions with variable amounts of plastic, and in clean / lightly contaminated environments.

With careful best-practice survey design, volume-based surveys can be a valuable approach to data collection, especially for microplastics.

Brand audits

Brand audits are a secondary type of information that is often collected as an “add-on” to other marine litter surveys – both clean-ups and designed surveys. However, brand audits are increasingly carried out with the specific goal of identifying major brands associated with products/waste observed in the environment. Brand audits provide detailed information about the companies that originally produce the items that are polluting the area surveyed. As a stand-alone source of data, brand audits may not provide enough information to be able to show important trends such as debris density or changes through time. However, when combined with traditional survey approaches, brand audits may provide a valuable new source of information about corporate responsibility for plastic pollution. We recommend performing brand-audits in concert with survey designs that are already representative and stratified. Taking this approach adds value to already well-designed surveys.



Part III Global marine litter monitoring programmes

Part III of this handbook describes several of the well-known marine litter monitoring programmes undertaken across the world. The goal of this section is to evaluate the suitability of different programmes for establishing baselines and monitoring changes through time.



14 Examples of global marine litter monitoring programmes

There are hundreds if not thousands of litter monitoring programmes globally, including programmes run by governments, NGOs, universities and community groups, occurring across multiple habitat types in countries around the world. Among these are eight large, multijurisdictional programmes, the larger of which have been adopted across more than 100 countries globally. These surveys are undertaken by a combination of citizen science surveys and professional surveys, or a combination thereof. **The aim of this section is to evaluate the suitability of different programmes for establishing baselines and monitoring changes through time, utilizing the five tenets for designing national and regional scale marine litter monitoring programmes.** It is key to understand that each of these protocols is designed with a different goal or purpose in mind, and not all protocols are fit-for-purpose for all survey and marine litter monitoring objectives. Though we summarise each approach through the lens of the five tenets for designing national and regional scale marine litter monitoring programmes (e.g., establishing baselines and monitoring changes through time), we acknowledge that different programs have goals and outcomes that may not be measured against these criteria. For example, the focus of community clean-ups may lean more heavily on mass of litter removed or number of people engaged, a measure not captured by the five tenets. Other programmes may focus on presence of microplastics, on fast survey completion time, or on linking litter presence with harm to wildlife, as other examples of outcomes not addressed by the five tenets. Here we summarise approaches of eight well-known examples, with the information that was available at the time of report compiling.



14.1 Ocean Conservancy International Coast Cleanup (ICC)

AT A GLANCE...	
OCEAN CONSERVANCY INTERNATIONAL COAST CLEANUP (ICC)	
Programme type	Clean-up
Survey approach	Not prescriptive
Clearly defined and repeatable methods	NO
Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible	YES
Representative capture of variation within each habitat to avoid sampling bias.	NO
Accounting for data collection effort	NO
Representation of different habitats	YES

The Ocean Conservancy is a United States of America based NGO that advocates for environmental issues affecting the ocean. The Ocean Conservancy began the 'International Coastal Cleanup' programme more than 30 years ago. This volunteer-led coastal marine litter survey and clean-up programme has been run in more than 150 countries. Ocean Conservancy ICC programme surveys coastline and rivers and waterways habitat.

Ocean conservancy's clean-up locations are chosen by volunteers participating in the clean-up. Although their data card asks for information such as the location, distance cleaned, and the number of adult and child participants, the entry of this information is not required for form submission. Ocean Conservancies ICC has been adapted into national monitoring in some countries, for example the annual International Coastal clean-up Singapore, which conducts clean ups and reports on surveys across the country.



VOLUNTEER OCEAN TRASH DATA FORM



Ocean and waterway trash ranks as one of the most serious pollution problems choking our planet. Far more than an eyesore, a rising tide of marine debris threatens human health, wildlife, communities and economies around the world. The ocean faces many challenges, but trash should not be one of them. Ocean trash is entirely preventable, and data you collect are part of the solution. The International Coastal Cleanup is the world's largest volunteer effort on behalf of ocean and waterway health.

HERE IS HOW IT WORKS:



SITE INFORMATION:

Cleanup Site Name:

State or Province: Zone or County:

Country: Nearest Crossroad or Landmark:

NUMBER OF VOLUNTEERS WORKING ON THIS CARD:

adults:

children (under 12):

MOST UNUSUAL ITEM COLLECTED:

TYPE OF CLEANUP:

Land: Underwater: Watercraft:

Please return this form to your area coordinator. If you are unable to do so, please mail or email it to:

Ocean Conservancy
Attn: International Coastal Cleanup
1300 19th Street, NW, 8th Floor
Washington, DC 20036
cleanup@oceanconservancy.org

Trash Free Seas: www.oceanconservancy.org/cleanup
Be a Green Boater: www.oceanconservancy.org/do-your-part/green-boating
Sponsors: www.oceanconservancy.org/cleanupsponsors



TRASH COLLECTED

Citizen scientist: Pick up all trash and record all items you find below. No matter how small the items, the data you collect are important for Trash Free Seas.®

EXAMPLE:

Plastic Bags: = 8

TOTAL #

Please DO NOT use words or check marks. Only **numbers** are useful data.

MOST LIKELY TO FIND ITEMS:

Cigarette Butts:	=	Beverage Bottles (Plastic):	=
Food Wrappers (candy, chips, etc.):	=	Beverage Bottles (Glass):	=
Take Out/Away Containers (Plastic):	=	Beverage Cans:	=
Take Out/Away Containers (Foam):	=	Grocery Bags (Plastic):	=
Bottle Caps (Plastic):	=	Other Plastic Bags:	=
Bottle Caps (Metal):	=	Paper Bags:	=
Lids (Plastic):	=	Cups & Plates (Paper):	=
Straws/Stirrers:	=	Cups & Plates (Plastic):	=
Forks, Knives, Spoons:	=	Cups & Plates (Foam):	=

FISHING GEAR:

Fishing Buoys, Pots & Traps:	=
Fishing Net & Pieces:	=
Fishing Line (1 yard/meter = 1 piece):	=
Rope (1 yard/meter = 1 piece):	=

OTHER TRASH:

Appliances (refrigerators, washers, etc.):	=
Balloons:	=
Cigar Tips:	=
Cigarette Lighters:	=
Construction Materials:	=
Fireworks:	=
Tires:	=

PACKAGING MATERIALS:

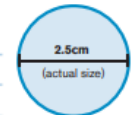
6-Pack Holders	=
Other Plastic/Foam Packaging:	=
Other Plastic Bottles (oil, bleach, etc.):	=
Strapping Bands:	=
Tobacco Packaging/Wrap:	=

PERSONAL HYGIENE:

Condoms:	=
Diapers:	=
Syringes:	=
Tampons/Tampon Applicators:	=

TINY TRASH LESS THAN 2.5CM:

Foam Pieces	=
Glass Pieces	=
Plastic Pieces	=



DEAD/INJURED ANIMAL	STATUS	ENTANGLED	TYPE OF ENTANGLEMENT ITEM
	Dead or Injured	Yes or No	

ITEMS OF LOCAL CONCERN:

1. 2. 3.

CLEANUP SUMMARY (circle units)

Number of Trash Bags Filled: Weight of Trash Collected: lbs/kgs Distance Cleaned: miles/km

14.2 Clean-coast index (CCI)

AT A GLANCE...	
CLEAN-COAST INDEX (CCI)	
Programme type	Designed survey
Survey approach	Transect
Clearly defined and repeatable methods	YES
Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible	NO
Representative capture of variation within each habitat to avoid sampling bias.	PARTIAL
Accounting for data collection effort	NO
Representation of different habitats	Shoreline only

The Clean Coast Index (CCI) was developed by Israel's Ministry of Environmental Protection's Marine and Coastal Division to objectively evaluate the degree of cleanliness at beaches. The approach aimed to provide transparent and timely information on the state of these beaches, which allows the ministry to take action against those authorities that are not fulfilling their legal duties to maintain beach cleanliness. The CCI provides a rapid approach methodology that has become popular among governments and other environmental managers globally and has since been rolled out to quickly assess beach cleanliness for management purposes in numerous jurisdictions. Its popularity is because this approach is quick and easy, though at the cost of limited information provided.

The CCI takes a transect approach, with multiple transects taken within the same habitat compartment, and then the total litter across the transects is divided across the total area surveyed, to generate an index


that is delineated into a measure of beach cleanliness, from 0-2 (very clean) to 20+ (extremely dirty).

The CCI provides a clearly defined and repeatable method, however it does not categorise litter in a way that is harmonizable with other programs, nor does it account for collection effort. Surveyors are instructed to conduct transects in the same habitat compartment (for example, separating sandy coastlines with rocky coastlines), but does not provide specific guidance for representative capture.


$$\frac{\text{Total plastic parts counted in } Z \text{ lines}}{Z \times 2[\text{m}] \times \text{beach width} [\text{m}]} = \text{Plastic parts} / \text{m}^2.$$

- 0-2: very clean—no litter is seen
- 2-5: clean—no litter is seen over a large area
- 5-10: moderate—a few pieces of litter can be detected
- 10-20: dirty—a lot of debris on the shore
- 20 +: extremely dirty—most of the beach is covered with plastic debris.

Coast index	Very clean	Clean	Moderate	Dirty	Extremely dirty
Numeric index	0-2	2-5	5-10	10-20	20+



Available online at www.sciencedirect.com
ScienceDirect
Ocean & Coastal Management 50 (2007) 352–362
www.elsevier.com/locate/ocecoaman



Clean-coast index—A new approach for beach cleanliness assessment

Ronen Alkalay*, Galia Pasternak, Alon Zask

The Ministry of the Environment, Marine and Coastal Environment Division, P.O.B. 811, Haifa 31007, Israel

Available online 18 December 2006

Abstract

A clean-coast index (CCI) was developed and is suggested as a tool for evaluation of the actual coast cleanliness. It measures plastic debris as a beach cleanliness indicator, in an easy way precluding bias by the assessor. Furthermore, the CCI is the measuring tool of the "Clean Coast" program—a new, long-term approach for cleaner beaches by various activities such as an increase in the public awareness. The CCI was proved to be a useful tool for measuring progress and the success of activities such as education campaigns, media coverage and enforcement actions.

© 2006 Elsevier Ltd. All rights reserved.

1. Introduction

Marine litter is a growing environmental problem worldwide [1]. It is threatening marine and coastal wildlife [2–8] as well as causing loss of coastline aesthetic quality [9,10]. It has a negative impact on the economy and on health [11–13]. Marine litter is defined as "solid materials of human origin that are discarded at sea or reach the sea through waterways or domestic and industrial outfall" [14].

There are two sources of marine litter: sea-borne and land based—such as industrial wastes and litter originating from human activity on the beach [13,15]. According to the US Department of Commerce and the US Navy, approximately 80% of litter is washed off the land, blown by winds, or intentionally dumped from shore [16]. According to their 2004 cleanup report, over 60% of all debris found during the cleanup originated from recreational activities.

*Corresponding author.
E-mail address: ronene@environment.gov.il (R. Alkalay).

0964-5691/\$-see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ocecoaman.2006.10.002

14.4 PADI AWARE Dive Against Debris

AT A GLANCE...	
PADI AWARE DIVE AGAINST DEBRIS	
Programme type	Clean-up
Survey approach	Not prescriptive
Clearly defined and repeatable methods	NO
Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible	YES
Representative capture of variation within each habitat to avoid sampling bias.	NO
Accounting for data collection effort	PARTIAL
Representation of different habitats	Ocean and lake only

PADI AWARE (Formerly Project AWARE) Dive Against Debris programme is a seafloor citizen-science marine litter survey and clean-up programme, launched in 2011. Since the programme’s inception, Dive Against Debris has been undertaken in 120 countries around the world, **reporting over 1.6 million pieces of litter.**

PADI AWARE Dive Against Debris programme allows volunteers to choose their dive sites to conduct debris surveys/clean-ups, **this programme has a much stronger focus on scientific survey technique than many other programmes.** PADI AWARE requires extensive meta data to be collected, both about the dive site itself, but also about the surveyors, enabling search effort to be calculated for their surveys. Though the PADI AWARE Dive Against Debris programme is a clean-up primarily, it does have many of the elements of a designed survey, such as attention to accounting

for data collection effort. With a few minor additions, PADI AWARE’s clean-up survey can be readily adapted for ocean and lake marine litter monitoring programmes.



Dive Against Debris®

Data Card

Dive Against Debris is the collection and survey of underwater marine debris. Only report debris you find and remove from the bottom. Survey leaders should record all debris divers collect for the same survey dive on one Data Card. Report your data via the PADI AWARE app or online at <https://www.padi.com/aware/dive-against-debris>. See the *Dive Against Debris® Survey Guide* for instructions on using this form.

Survey Date (DD/MM/YYYY)	Survey Site Name	Organization/Dive Center
--------------------------	------------------	--------------------------

Survey Site Location (nearest landmark to help verify location i.e. adjacent road name, nearest city/town, state/province, country)	Number of Participants
---	------------------------

Survey Site GPS Coordinates <small>(Set your GPS Map Datum to WGS84)</small>	Latitude <small>(Take your readings in decimal degrees)</small>	Longitude <small>(Take your readings in decimal degrees)</small>	Survey Duration (in minutes)
---	--	---	------------------------------

Survey Depth Range <input type="checkbox"/> metres <input type="checkbox"/> feet max _____ min _____	Area Surveyed <input type="checkbox"/> m ² <input type="checkbox"/> ft ²	Total Weight of All Debris Collected <input type="checkbox"/> kg <input type="checkbox"/> lbs Estimated: _____ or Measured: _____	OR <input type="checkbox"/> Our Survey Site Was Free Of Debris
--	---	--	---

Survey Leader Name	Survey Leader email
--------------------	---------------------

Dominant Substrate (check one) <input type="checkbox"/> Sand <input type="checkbox"/> Coral <input type="checkbox"/> Silt <input type="checkbox"/> Gravel <input type="checkbox"/> Rock <small>(please describe)</small>	Ecosystem (check one) <input type="checkbox"/> Coral reef <input type="checkbox"/> Rocky reef <input type="checkbox"/> Kelp <input type="checkbox"/> Mangroves <input type="checkbox"/> Seagrass <input type="checkbox"/> Other <small>(please describe)</small>	Waves (check one) <input type="checkbox"/> Calm (0-0.1 m/0-4 in) <input type="checkbox"/> Smooth (0.1-0.5 m/4-19 in) <input type="checkbox"/> Slight (0.5-1.25 m/19 in-4 ft) <input type="checkbox"/> Moderate (greater than 1.25 m/4 ft)
---	--	--

Weather Conditions from Previous Week	Did You Find Entangled Animals? Identify animal(s) found: Identify entangling debris item: Number of different species entangled: _____ Number of animals found: Dead _____ Injured _____ Released unharmed _____
---------------------------------------	---

Are you aware of an event that could have contributed to the debris you have documented? <input type="checkbox"/> Yes <input type="checkbox"/> No If so, describe and provide verification – link to the news, etc.

Items of Local Concern List the top three debris items you consider a problem in your location and explain why
--

What is the most unusual item found?	Photos included <input type="checkbox"/> Entangled animals, marine debris impacts, items you can't identify, items you did not remove, etc. See the <i>Survey Guide</i> for more info.
---	---

Count all debris items as one, regardless of size. See **Too Small to Count?** in the *Dive Against Debris® Survey Guide* for counting large quantities of small pieces. List debris items under the main material of construction. List items that do not fit into a category here:

Other Debris Items (Identify Material)	Tally (Illl I = 6)



Plastic Materials	Tally
01. bags: grocery/retail (plastic)	
02. bags: trash (plastic)	
03. bait containers/packaging	
04. balloons	
05. balls	
06. baskets, crates	
07. beverage bottles: less than 2 litres (plastic)	
08. beverage bottles: 2 litres or more (plastic)	
09. bottles: bleach, cleaner	
10. bottles: oil/lube	
11. buckets, drums & jerry cans: 2 litres or more	
12. buoys & floats (plastic & foamed)	
13. caps & lids (plastic)	
14. carpet (synthetic)	
15. cigarette filters	
16. cigarette lighters	
17. cigar tips	
18. containers: fast food, lunch boxes & similar	
19. cotton bud sticks	
20. cups, plates, forks, knives, spoons (plastic)	
21. diapers/nappies	
22. fishing: line	
23. fishing: lures, rods/poles	
24. fishing: nets & pieces of nets	
25. fishing: traps & pots	
26. foam insulation & packaging	
27. food wrappers (plastic)	
28. furnishings (plastic)	
29. gloves (latex)	
30. light sticks/cyalumes	
31. mesh bags: fruit, vegetable, shellfish	
32. pipes (plastic/PVC)	
33. rope (plastic/nylon)	
34. scuba & snorkel gear, masks, snorkels, fins	
35. sheeting: tarpaulin, plastic sheets, palette wrap	
36. six-pack rings, ring carriers	
37. strapping bands (plastic)	
38. straws, stirrers	
39. syringes (plastic)	
40. tampon applicators	
41. tobacco packaging & wrappers	
42. toothbrushes	
43. plastic fragments	
Glass & Ceramic Materials	
44. beverage bottles (glass)	
45. buoys (glass)	
46. cups, plates, tableware, dishes (glass & ceramic)	
47. fluorescent light tubes	
48. jars: food (glass)	
49. light globes: bulbs, etc	
50. syringes (glass)	
51. glass & ceramic fragments	

Metal Materials	Tally
52. aerosol/spray cans	
53. appliances: household	
54. batteries: AA, AAA, C & D, 6V, 9V, etc	
55. batteries: car or boat	
56. beverage cans (aluminium)	
57. cans: food, juice, other (tin)	
58. caps & lids (metal)	
59. cars & car parts	
60. cups, plates, tableware, dishes (metal)	
61. drums: 55 gallon	
62. fishing: sinkers, lures, hooks	
63. fishing: traps & pots	
64. forks, knives, spoons (cutlery)	
65. gas bottles/cylinder, drums: more than 4 litres	
66. pipes & rebar	
67. pull tabs: beverages	
68. scuba weights	
69. strapping bands (metal)	
70. wire, wire mesh, barbed wire	
71. wrappers (foil/metal)	
72. metal fragments	
Rubber Materials	
73. condoms	
74. gloves (rubber)	
75. inner-tubes & rubber sheets	
76. rubber bands	
77. tires/tyres	
78. rubber fragments	
Wood Materials	
79. fishing: traps & pots	
80. furnishings (wood)	
81. lumber (processed or cut/milled wood)	
82. pallets	
83. wood fragments	
Cloth Materials	
84. bags (burlap/hessian)	
85. bags (cloth)	
86. gloves (cloth)	
87. rope & string (cloth)	
88. towels, rags	
89. cloth fragments	
Paper/Cardboard Materials	
90. bags (paper)	
91. cardboard: packaging & cartons	
92. paper: books, newspapers, magazines, etc	
93. paper/cardboard fragments	
Mixed Materials	
94. bricks, cinderblocks, chunks of cement	
95. clothing	
96. computer equipment & other electronic devices	
97. fireworks	
98. shoes, flip flops, sandals, tennis, etc	
99. tampons	
100. toys	

Having trouble identifying a debris item? Refer to the **PADI AWARE App** for images of all debris items.

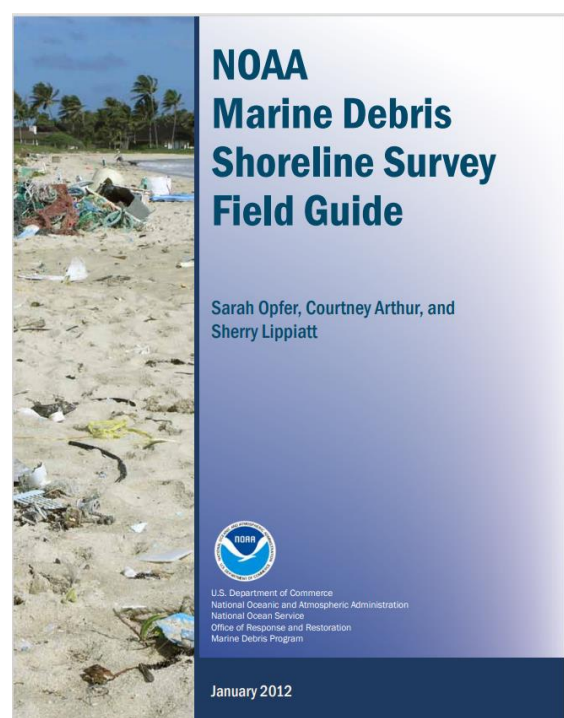
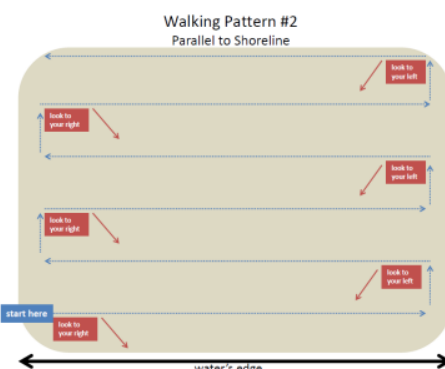
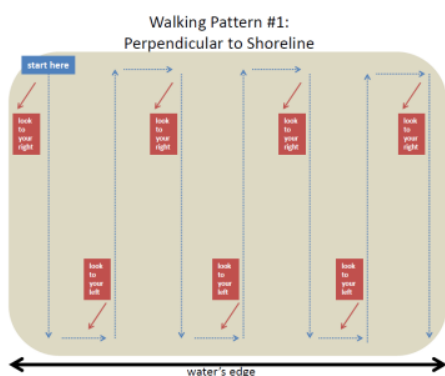
14.5 National Oceanic and Atmospheric Administration (NOAA) Standing Stock Surveys

AT A GLANCE...	
NOAA STANDING STOCK SURVEY	
Programme type	Designed survey
Survey approach	Transect
Clearly defined and repeatable methods	YES
Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible	YES
Representative capture of variation within each habitat to avoid sampling bias.	YES
Accounting for data collection effort	PARTIAL
Representation of different habitats	Shoreline only

NOAA's monthly Marine Debris Monitoring and Assessment Project (MDMAP) is part of the United States of America's NOAA Marine Debris Program. **The NOAA standing stock survey programme uses a transect approach and focuses on shorelines habitat and is applied broadly across numerous jurisdictions in the United States of America and internationally.** NOAA MDMAP serves as a template for many international monitoring programmes.

Though focusing on shorelines only, the NOAA standing stock surveys account for most of the tenets for designing national and regional scale marine litter monitoring programmes. NOAA standing stock surveys have clearly defined methods, even describing how surveyors must walk, and carefully incorporates replication and randomisation within sites, providing a randomisation tool for surveyors. This survey approach also controls for number of surveyors (survey effort) and the probability of

detection but does not measure the amount of time that a survey takes for data collection effort. Because only a limited type of beaches are surveyed, it is difficult to extrapolate beyond beaches with similar characteristics to those actually surveyed.





NOAA Marine Debris Monitoring and Assessment Project

Survey Coversheet

Complete ONE per survey

Record data at <https://mdmap.orr.noaa.gov>

SITE NAME: _____
Name used for the 100-meter site in the MDMAP database

DATE: _____
MM/DD/YYYY

PARTICIPANT INFORMATION:
Name of all participants (include email if you wish to receive MDMAP updates from NOAA)

TOTAL SURVEY DURATION: _____
Include travel time to/from the site. HH:MM

K-12 GROUP? yes
Is the team a student group? no

TEAM COUNT: _____
The total number of participants involved in the survey

FIRST TIMERS: _____
For how many participants is it their first MDMAP survey?

RECREATORS:
Upon arrival, how many people are in the 100-meter site?

WEATHER NOW:
(Check one)

- 0-10
- 11-50
- 51-100
- >100

- sunny
- partly cloudy
- mostly cloudy
- light rain/precip
- heavy precip

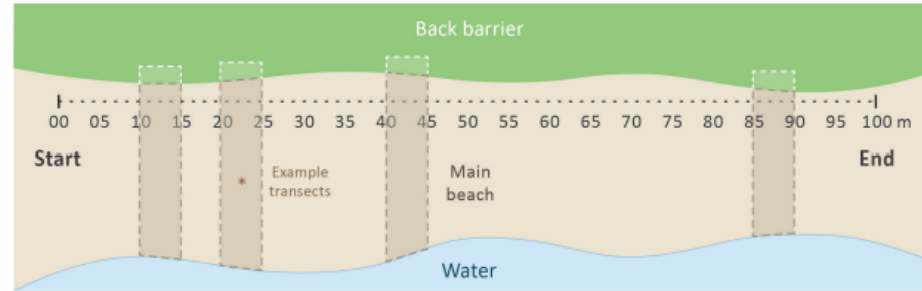
DRAIN INPUT: yes
Is there a storm drain, pipe, or channeled input within the 100-meter survey site? no

TRASH CANS:
Are trash cans present or not? If present, what condition are they in? (Check one)

- present and overflowing
- present and NOT overflowing
- not present

DEBRIS REMOVAL: all/most
Was debris removed from the 100-meter site (not just the survey transects)? some none

SURVEY PHOTOS:
List timestamp, photo number, or other information to keep track of photos from the survey.



SURVEY QUICK REFERENCE

Before beginning, refer to the Monitoring Toolbox and Survey Guide at <https://marinedebris.noaa.gov/monitoring-toolbox>

Before you go:

- Select FOUR random transect start points
- Check the weather and tides (aim for a low or outgoing tide)
- Confirm that you have all datasheets, survey supplies, and safety gear

At the survey site:

- Estimate the number of recreators within the 100-meter site as you arrive
- Record the survey coversheet data
- From the site start, use a measuring wheel or meter tape to find and mark the start of each of the four transects with a flag or other marker

For each transect:

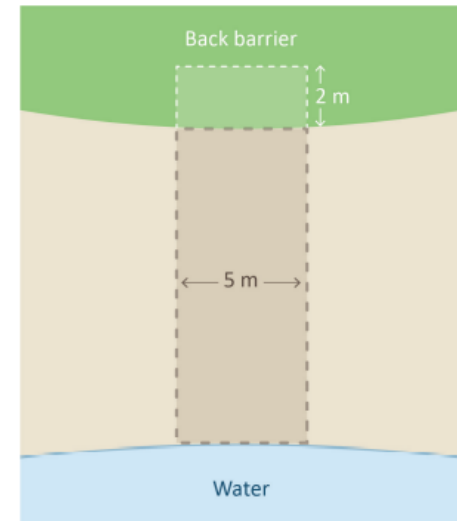
- Complete a transect datasheet (front and back)
- The search should be conducted by no more than two people walking the perimeter of the 5-meter transect and looking in
- Count and categorize debris that is at least 2.5 centimeters (bottle cap or larger) - smaller items can be described in the "notes"
- Record items 2 meters into the "back barrier" separately from the "main beach" (see diagram to right)

Before leaving:

- Note the total survey duration on the *Survey Coversheet*
- Note where and how much debris was removed within the 100-meter site on the *Survey Coversheet* and *Transect Survey Forms*
- Gather all supplies

When a new person joins the team:

- They should shadow transect set-up and search, and conduct a "consistency check" for debris categorization before collecting data independently



Example of a survey transect.

Reminders:

- Fragments are unidentifiable broken items larger than 2.5 centimeters
- Material selection should be based on what is predominant on the surface of the item
- Surveys can be paired with beach cleanups, but wait until after data collection is completed

We recommend photos of:

- All the debris laid out with a ruler for scale (one photo per transect) if debris is removed
- Close-ups of any unidentifiable, interesting, or difficult to categorize items
- Items that are too large to remove, as you found them
- Include a ruler for scale!

14.6 OSPAR guidelines – Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area

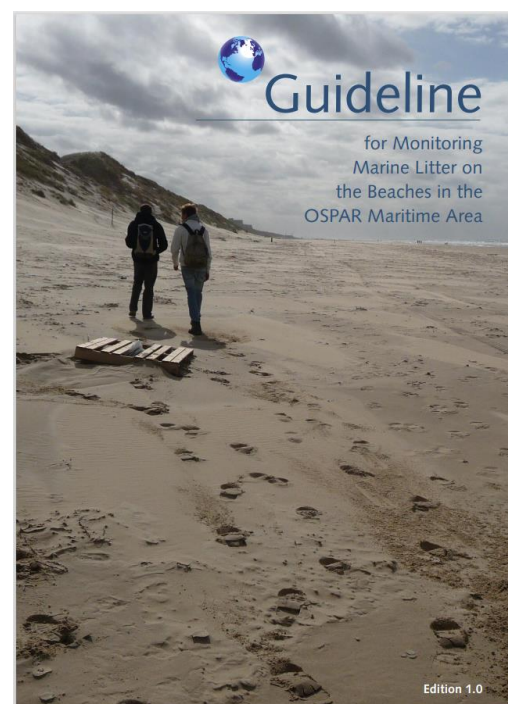
AT A GLANCE...	
NOAA STANDING STOCK SURVEY	
Programme type	Designed survey
Survey approach	Transect
Clearly defined and repeatable methods	YES
Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible	YES
Representative capture of variation within each habitat to avoid sampling bias.	NO
Accounting for data collection effort	NO
Representation of different habitats	Shoreline only

The OSPAR guidelines are a designed marine litter monitoring protocol, taking a transect approach for beaches in Europe that border the North-East Atlantic Ocean.

OSPAR is the mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic. It is an intergovernmental partnership of European countries bordering the Northeast Atlantic Ocean, and includes Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

The OSPAR guidelines provide information to survey shorelines only and have built in a recommendation to survey four times per year, once in each winter, spring, summer and autumn, corresponding the main seasons experienced in Europe. The OSPAR guidelines show photographs of litter categories, which are broadly harmonizable with other major international litter survey categories and recommend training of surveyors to better ensure comparability between surveys.

The OSPAR guidelines take a transect approach, with transects being conducted parallel to the shoreline. This approach recommends two transects, the first of 100m in length, recording all litter items, and a second of 1km in length recording just macro and mega sized litter items 50cm or larger. The OSPAR guidelines also monitor biota and have a sister protocol for marine litter interactions among fauna encountered.

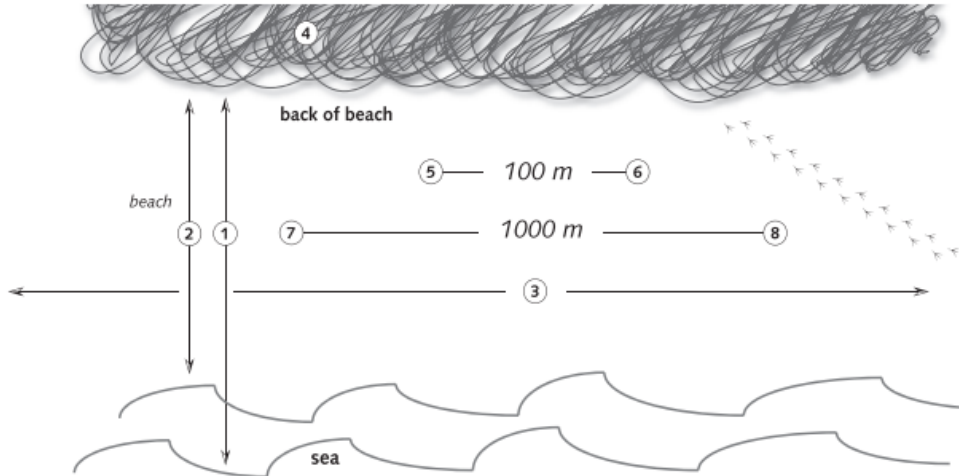


OSPAR Marine Litter Beach Questionnaire

Name of beach:

OSPAR beach ID:

Country: to be filled in by national coordinators



- ① Beach width at mean low spring tide: (m) ② Beach width at mean high spring tide: (m)
 ③ Total length of beach: (m) ④ Back of beach (example dunes):
- ⑤ GPS coordinates start 100 m:
 ⑥ GPS coordinates end 100 m:
 ⑦ GPS coordinates start 1 km:
 ⑧ GPS coordinates end 1 km:

Coordinate system used: Date position measured:/...../..... (d/m/y)

Prevailing currents off the beach*: N E S W Prevailing winds*: N E S W

When you look from the beach to the sea, what direction is the beach facing*: N E S W

Type of beach material (% coverage): (e.g. sand 60%, pebbles 40%)

Beach topography: (e.g. slope 20%)

Are there any objects in the sea (e.g. a pier) that influence the currents:

Major beach usage (local people, swimming and sunbathing, fishing, surfing, sailing etc):

1. seasonal or whole year round:
 2. seasonal or whole year round:
 3. seasonal or whole year round:

Access to the beach: Vehicle Pedestrian Boats

*you may tick one or two boxes

OSPAR Marine Litter Monitoring Survey Form

100 metre area

OSPAR ID	Unep ID	Items	Total
<i>Plastic • Polystyrene</i>			
1		4/6-pack yokes	
2		Bags (e.g. shopping)	
3		Small plastic bags, e.g., freezer bags	
112		Plastic bag ends	
4		Drinks (bottles, containers and drums)	
5		Cleaner (bottles, containers and drums)	
6		Food containers incl. fast food containers	
7		Cosmetics (bottles & containers e.g. sun lotion, shampoo, shower gel, deodorant)	
8		Engine oil containers and drums <50 cm	
9		Engine oil containers and drums > 50 cm	
10		Jerry cans (square plastic containers with handle)	
11		Injection gun containers	
12		Other bottles, containers and drums	
13		Crates	
14		Car parts	
15		Caps/lids	
16		Cigarette lighters	
17		Pens	
18		Combs/hair brushes	
19		Crisp/sweet packets and lolly sticks	
20		Toys & party poppers	
21		Cups	
22		Cutlery/trays/straws	
23		Fertiliser/animal feed bags	
24		Mesh vegetable bags	
25		Gloves (typical washing up gloves)	
113		Gloves (industrial/professional gloves)	
26		Crab/lobster pots	
114		Lobster and fish tags	
27		Octopus pots	
28		Oyster nets or mussel bags including plastic stoppers	

14.7 APEC Marine Environmental Training and Education Center (AMETEC) protocol

AT A GLANCE...	
AMETEC PROTOCOL	
Programme type	Designed survey
Survey approach	Quadrat & volume (sediment)
Clearly defined and repeatable methods	YES
Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible	YES
Representative capture of variation within each habitat to avoid sampling bias.	PARTIAL
Accounting for data collection effort	PARTIAL
Representation of different habitats	Shoreline only

The APEC (Asia-Pacific Economic Cooperation) Marine Environmental Training and Education Center (AMETEC) protocol was developed in 2013 through a collaboration between Korea Institute for Ocean Science and Technology (KIOST) and Our Seas of East Asia Network (OSEAN). It is based on the 2009 UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter. The AMETEC protocol is a designed survey programme that aims to monitor plastics on beaches in the visible size range using a quadrat sampling method, followed by microplastics using a volume-based beach sediment sampling method. It has been carried out across numerous countries in the Asia-Pacific region, including the Republic of Korea, Taiwan, Thailand and Vietnam. The AMETEC protocol is also designed to account for monsoon and non-monsoon seasons, a seasonal variable linked with flushing debris from land to sea that is unique to the world's tropical/sub-tropical latitudes.

Quadrat placement according to the survey design accounts for variation in litter loads along across the tide-range of the beach, demonstrating some within-

habitat capture, but the protocol is not designed capture variation between sub-habitats, such as boulders, pebbles, slabs or other types of non-sandy coastal habitats. Because the AMETEC protocol uses a quadrat survey followed by a volume-based survey, accounting for data collection / survey effort is naturally constrained. However, because the number of surveyors nor survey time recorded, survey effort is not fully accounted for.



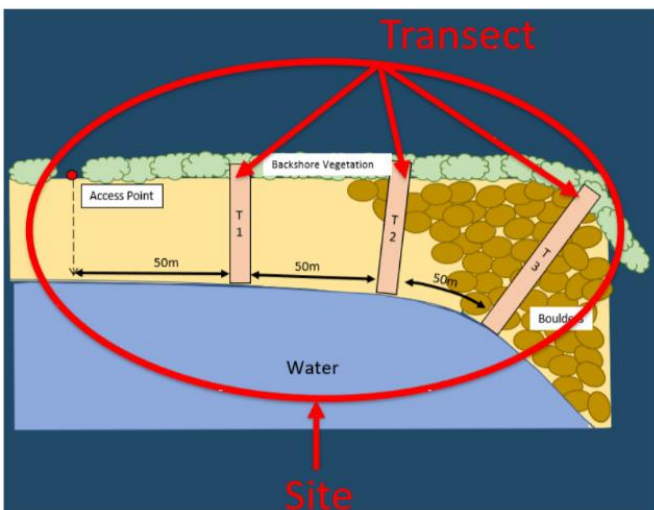
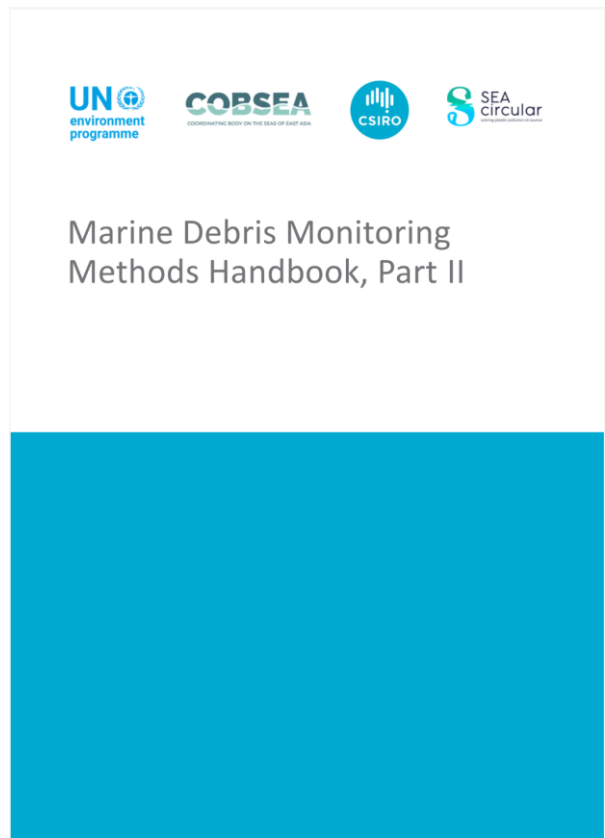
The AMETEC protocol involves two stages to its marine litter survey methodology, the first takes a quadrat approach and the second takes a volume-based sediment survey approach.

14.8 CSIRO Global Leakage Baseline Project (GLBP)

AT A GLANCE...	
CSIRO GLOBAL LEAKAGE BASELINE	
Programme type	Designed survey
Survey approach	Transect
Clearly defined and repeatable methods	YES
Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible	YES
Representative capture of variation within each habitat to avoid sampling bias.	YES
Accounting for data collection effort	YES
Representation of different habitats	YES

The CSIRO Global Plastic Leakage Baseline Project (GLBP) aims to use field sampling and mathematical modelling to document the distribution of plastic in the ocean, on the coast and in the nearshore environment. CSIRO's GLBP survey programme uses a transect approach, and comprehensively captures multiple habitats, including coastlines, rivers and waterways, sea surface and inland habitats at each surveyed site. The protocol requires a minimum of three transects to be carried at each survey location, to ensure representation across strata. Surveys also take place across multiple habitats/land use types to ensure representation across the environment and so that predictions can be made of debris load, type and density across broader geographic scales. The approach has been used in more than 20 countries around the world to establish baselines and support ongoing monitoring and is used to support National Plans of Action on Plastic for countries and regions globally. The CSIRO GLBP has recently developed an app and online training resources to support the delivery of this program in numerous languages.

There is a comprehensive explanation of the CSIRO Global Leakage Baseline Project methodology in the Marine Debris Monitoring Methods Handbook, Part II.



14.9 Survey design in global marine litter monitoring programmes

The eight listed global marine litter monitoring programmes, Ocean Conservancy ICC, Project AWARE Dive against Debris, NOAA standing stock surveys, #BreakFreeFromPlastic Brand Audit and CSIRO Global Plastic Leakage Baseline Project each take different approaches to survey design. Here we summarise survey design and sampling bias in each of these programmes.

Table 1 shows that multijurisdictional litter clean-up and survey programmes vary in their standard form for a science-based approach.

Table 1 Survey design in multijurisdictional global marine litter monitoring programmes

SURVEY DESIGN	OCEAN CONSERVANCY INTERNATIONAL COAST CLEANUP (ICC)	CLEAN COAST INDEX (CCI)	#BREAKFREEFROMPLASTIC BRAND AUDIT **	PROJECT AWARE DIVE AGAINST DEBRIS	NOAA STANDING STOCK SURVEY	OSPAR GUIDELINE	AMETEC PROTOCOL	CSIRO GLOBAL PLASTIC LEAKAGE BASELINE PROJECT
Clearly defined and repeatable methods	NO	YES	NO	NO	YES	YES	YES	YES
Quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible*	YES	NO	NO	YES	YES	YES	YES	YES
Representative capture of variation within each habitat to avoid sampling bias.	NO	PARTIAL	NO	NO	YES	NO	PARTIAL	YES
Accounting for data collection effort	NO	NO	YES	PARTIAL	PARTIAL	NO	PARTIAL	YES
Representation of different habitats	YES	Shoreline only	YES	Ocean and lake only	Shoreline only	Shoreline only	Shoreline only	YES

* Though these surveys have different item lists, many of the common items use policy-relevant categories, and are reported in a way that is possible to harmonise most items with other programs

**This only applies if the #BreakFreeFromPlastic Brand audit approach is used as a standalone survey

Part IV Best practice recommendations for adapting existing monitoring programmes

In part IV, we provide recommendations for improving best practice of existing monitoring programmes for the goal of establishing baselines and monitoring changes in litter through space and time.



15 Recommendations for improving best practice and increasing scientific rigor in existing monitoring programmes

15.1 Recommendation overview

If your goal is to evaluate the suitability of different existing programmes for establishing marine litter baselines and monitoring changes through time in your country or region, this section provides specific guidance and recommendations for the programmes outlined in Part II.

Most of the eight well-known examples of global marine litter monitoring programmes adopt the majority of the five tenets for designing national and regional scale marine litter monitoring programmes. With a few modifications, each of these programmes can be adapted for establishing baselines and monitoring changes through time. We recommend COBSEA partner countries to capitalise on the opportunities already provided by existing programmes by using scientific best practice **to adapt the five tenets to current programmes**. By leveraging the successes of existent programmes, and patching the gaps, harmonisation of COBSEA monitoring programmes can be achieved through making small changes to existing efforts, following examples already implemented by some countries. Overarchingly, we recommend improving attention to reporting of survey effort across all monitoring programmes and, where possible and appropriate, align data sheet reporting categories for comparability between survey types and among countries within the region. This is particularly the case for programmes that are already widespread in the region, for example, the clean-up activities Ocean Conservancy's International Coastal Cleanup and Project AWARE's Dive Against Debris. Such examples can be guided in such a way that can provide useful monitoring information by including stratification, randomisation, and replication. To better sample under-represented habitats using a method that meets the five tenets for designing national and regional scale marine litter monitoring programmes, we recommend the adoption and expansion of survey programmes that are already established in the region, such as the CSIRO GLBP programme.

The five tenets for designing national and regional scale marine litter monitoring programmes (e.g., establishing baselines and monitoring changes through time):

1. Clearly defined and repeatable methods.
2. Quantification of data and reporting of findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible.
3. Representative capture of variation within each habitat type/strata to avoid sampling bias.
4. Account for data collection effort.
5. Representation of different habitats.

15.2 Attention to quantification and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible

Quantification of data and reporting findings in a way that is harmonised with other surveys and uses policy-relevant categories, as best possible, is something that most programmes already strive for. This is particularly so for common items such as plastic bags, bottles, cups, food packaging, utensils, ropes, fishing gear and cigarette butts. Two programmes that record much broader categories that do not delineate specific items are the CCI and #Breakfreefromplastic brand audit.

We recommend that each survey/monitoring programme, at a minimum, report:

1. **That if using the CCI, individual items are recorded** in a way that is harmonised other surveys and uses policy-relevant categories. This extra time spent could greatly improve the utility and value of this data.
2. **The #Breakfreefromplastic brand audit is conducted as a secondary information source alongside a programme or approach that meets the five tenets** and where items are quantification and reported in a way that is harmonised with other surveys and uses policy-relevant categories

Adapting these measures to quantify and report findings in a way that is consistent with other surveys efforts in the region will greatly aid multijurisdictional harmonisation efforts.

15.3 Attention to representative capture of variation within each habitat to avoid sampling bias.

Most sites are not homogenous. For example, even a coastline that is mostly sandy beach might include a beach entrance section, a section near a car park, a modification such as a seawall or a section that is rocky or vegetated. Furthermore, beaches may be coves or headlands (which have different accumulation characteristics) and some may include a waterway outlet such as a drain or natural waterway. Also, the coastline will face different directions and/or experience different prevailing winds, depending on season, geography and other factors.

Few survey programmes give detailed attention to representative capture of variation within each habitat to avoid sampling bias. Those that do this well are CSIRO's GLBP or NOAA's Standing Stock Surveys. These programmes randomisation and stratification methodology can serve as a template to adapt other programmes and introduce site randomisation and stratification. The CCI and AMETEC protocol partially stratify within their sites, but the methodology is less comprehensive. Small adjustments and adaptations can greatly improve the representativeness of the data generated by other programmes.

To improve stratification and randomisation within sites, especially large sites, we recommend dividing sites into areas that represent different features. For example, a 6km coastline might contain 4km of wide sandy beach, and half of which is remote, a 1km seawall and 1km of vegetation. In a site of this variety, we recommend (if the resources are available) a minimum of three surveys/clean-ups, one for the sandy beach section, one that occurs by the seawall, and the third in the vegetated section. By stratifying and randomising clean-ups within-sites, the survey data

captures within-site variation in marine litter that may occur due to the types of terrain and onshore forcing, for better information about local marine litter situations.

Most survey programmes are conducted on sandy beaches near populated regions. To improve randomisation of the site location for designed surveys, **we recommend applying randomisation and stratification methods**. Some programmes include such methodologies, including CSIRO’s GLBP or NOAA’s Standing Stock Surveys, that can serve as a template for other programmes. **For clean-ups, randomised and stratified design can be introduced prior to the start of surveys via a “suggest sites” or pre-selection of sites be nominated by the local organisations responsible for clean-ups**. By nominating or pre-selecting habitat types before the clean-up date, representation of different types of sites (sandy beaches, rocky beaches, mangroves, riverbanks, river deltas and other site types), nearby and distant from populated areas, can be selected to more broadly represent the habitat(s) within the area.

This approach can be applied to seafloor surveys too, as the seafloor is also not homogeneous. For example, a dive site may contain seafloor of different depths, different surfaces (rock, coral, mud, sand), different organisms (sponges, hard and soft corals, algae/seaweeds, kelp gardens, seagrass). To improve stratification and randomisation within sites, especially large sites, **we recommend dividing sites into areas or zones that contain these different features**. For example, a coral reef dive site may contain a mixture of coral structures spread across sand. In such a site, clean-ups could be split into coral seafloor clean-ups and sandy seafloor surveys/clean-ups if it is not feasible to carry out the activity across the entire area. By stratifying and randomising clean-ups within-sites, the survey data captures the type of within-site variation in marine litter that may occur due to the types of terrain and forcing, such as ocean currents

15.4 Representation of different habitats.

Representation of different habitats provides a wider-lens view of the marine debris situation in a location, such as sources and sinks/accumulation points, as well as flux of litter between habitats and compartments. However, this section is brief as representation of different habitats is not possible for all survey programmes, with most focusing on just on one or two habitats / compartments. Harmonisation of methods between programmes generally is important when considering that most methods focus on just one habitat or compartment, so marine litter can be appropriately compared for a holistic and system-scale view of marine litter as it cycles from source to sink. A more holistic understanding provides scientifically sound evidence to policy makers who seek to make solutions based on sound evidence.



15.5 Accounting for data collection effort.

Data collection effort is comprised of two main components that can affect data, the survey effort and the detection probability of different types of items. In general, designed surveys account either wholly or partially for data collection effort through prescriptive methodologies. Clean-up approaches, however, rely on volunteer labour and are rarely prescriptive.

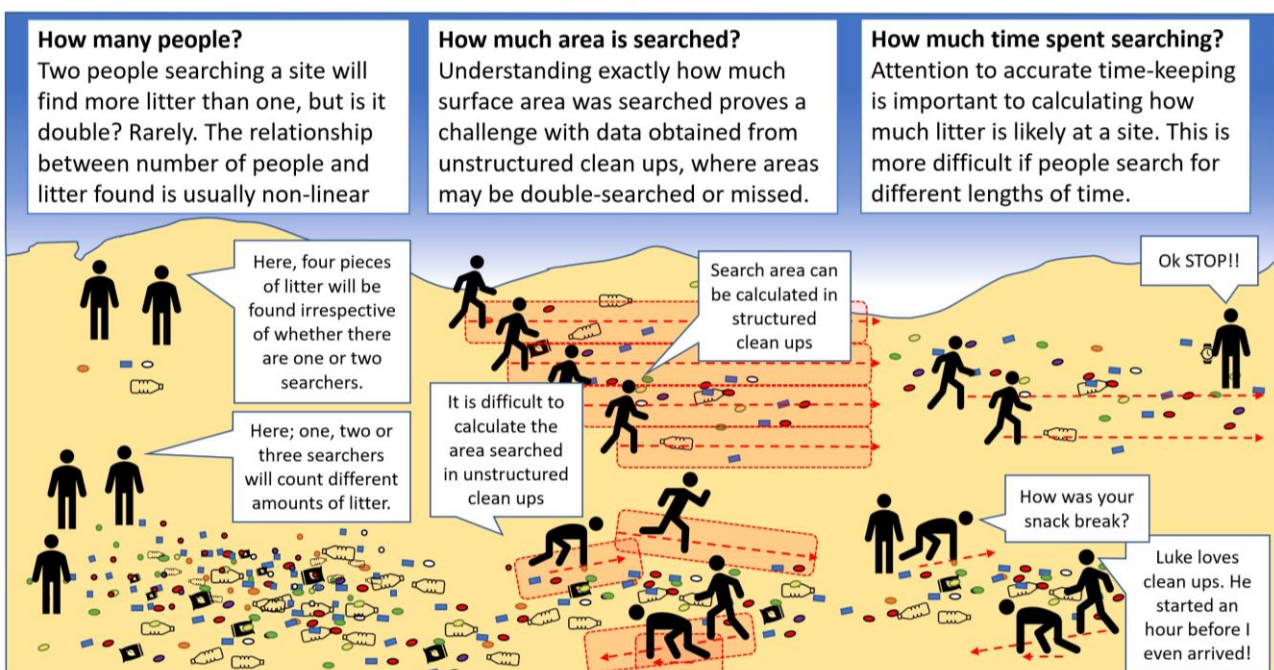
15.5.1 Recommendations to improve survey effort

We recommend attention to reporting survey effort. This is important across all monitoring approaches. Many of the one-off and ongoing programmes already include at least one measure of survey effort, however these effort mechanisms are not consistent nor are results always standardised with attention to differing survey effort, leading to different results. Specific information to record includes start and stop time of survey activity, area surveyed and how many people surveyed within the area.

We recommend that each survey/monitoring programme, at a minimum, report:

1. **The number of surveyors.** How many people are undertaking this survey?
2. **The area (m² or km²) surveyed, volume surveyed if a volume-based survey (cm³ or m³) or length of the survey (m or km).** A squared or cubic measurement is preferred over a linear measurement, where possible.
3. **The duration of the survey,** including start and end time.

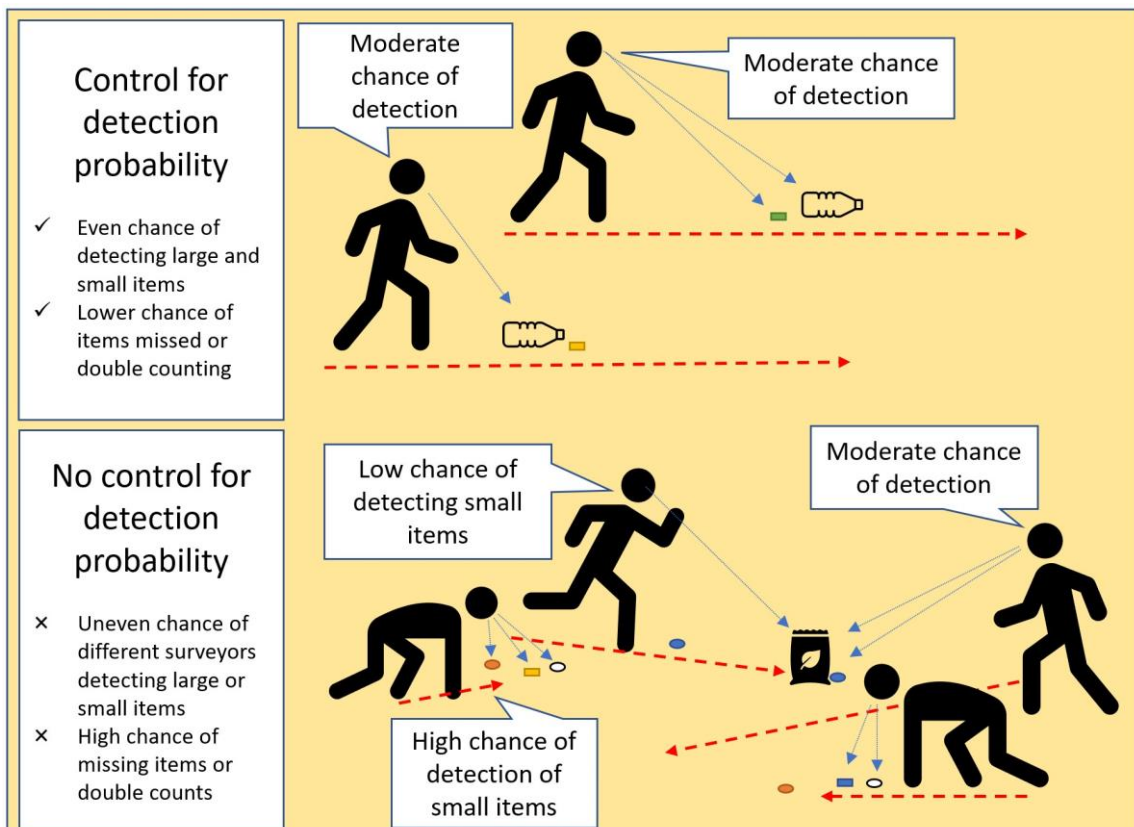
The inclusion of these three measures of effort across surveys will mean that even in situations where data collection effort cannot be controlled, it can be statistically accounted for during data analysis.



15.5.2 Recommendations to standardise detection probability

The probability of surveyors detecting debris that is present, especially small items, is variable for surveys approaches that are not prescriptive about *how* surveyors should search. Clean-ups, for example, are rarely prescriptive and clean-up programme attracts a variety of individuals who might search and survey in different ways. For example, some will walk briskly, chatting with friends, some will diligently search on hands and knees, looking under rocks and vegetation, and everything in between. Within the site, search effort may not be constant. At a beach site, people may be more likely to walk along the wet sand or strandline, than to venture into dunes or coastal vegetation. At a river site, people may be more inclined to search immediately along a muddy or wet riverbank. Multiple participants may search along the same stretch within the survey site while other areas within the site are neglected or missed. **We recommend that prior to surveys being conducted, survey teams agree on a search methodology and divide participants' effort so that search is evenly spread along the site.**

Some survey types are inherently more difficult to control for data collection effort and the probability of detection than others. For example, for seafloor surveys, due to the nature of scuba diving, survey effort and detection depend on dive conditions such as visibility and the strength of currents. However, some divers may search more diligently than others, looking under rocks and in vegetation, while others might opt for visually searching while swimming at a distance above the seafloor. It is also possible, with pairs of divers, that some areas within the dive site are searched by multiple people while others are missed, leading to uneven search effort and detection probability. **We recommend that prior to surveys being conducted, the team agrees on a search methodology and divides participants' effort so that their search is evenly spread throughout the site.**



Part V New and emerging technologies for marine litter monitoring programmes

In part V, we provide an overview of some of the new and emerging technologies in the marine litter monitoring space

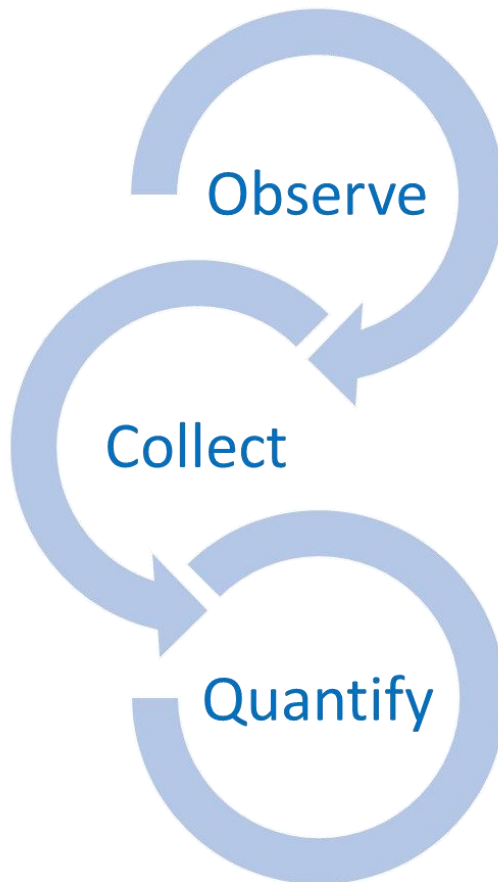


16 New and emerging technologies

16.1 Summary of new and emerging technologies in litter monitoring

Traditional marine litter surveys are time consuming, expensive, and sometimes hazardous to human health. To reduce or avoid some of the risks associated with traditional surveys, there is increasing attention and resources are devoting to the development of new and emerging technologies that can aid marine litter monitoring. New and emerging technologies are being developed for three different time-consuming aspects of marine litter monitoring:

- I. New technologies to **observe** litter in the environment. Examples include satellites, UAV/drones and remote cameras/sensors to take photographs of litter in the environment, and social media initiatives to encourage people to voluntarily take photographs of litter they see.
- II. New technologies to **collect** litter in the environment. Examples include the vast variety of litter or pollutant traps.
- III. New technologies to **quantify** litter in the environment. Examples often hinge in artificial intelligence and machine learning processes to recognise patterns in the data collected (for example, recognising images of marine litter in a photograph of a shoreline).



New technologies to observe, collect, and quantify environmental litter can provide valuable opportunities to add value to marine littering problems. However, no single new technology is a panacea to fix all problems that exist with traditional methods, nor can one method address all research or monitoring questions. Here we briefly describe some of the opportunities and challenges of the different new and emerging technologies for marine litter monitoring. Please note that this section is meant as a brief introduction. It is not a comprehensive assessment of the different methods nor is it exhaustive across all emerging technologies and tools.

16.2 Remote sensing (Aerial footage and photography): Satellite and drone surveys



Remote sensing through the use of aerial footage and photography, such as satellite photography and the use of unmanned aerial vehicles (UAVs), colloquially called ‘drones’, are popular emerging technologies to observe litter in the environment. Remote sensing enables the user to capture images/footage quickly and efficiently over large areas for satellites, and distances up to a few kilometres for drones. The advantage of satellites is that vast areas can be surveyed,

and that you can elect the resolution that you seek from the company that offers the satellite photography service. Costs can be prohibitive for fine scale resolution, however.

The advantages of drones as a tool to survey litter are that they can carry a video recording device and take fast but quality video footage from a bird’s eye view of the study area. This useful tool saves humans surveyors from carrying out laborious manual visual surveys, which is especially valuable in difficult or dangerous terrain, such as where there are wetlands, mud, extreme temperatures, water courses, dangerous animals, thick vegetation or difficult access to sites. Drones can be a useful complement to traditional methods, especially in situations where there are sites with some of the difficulties described. Aerial footage is also very useful for detecting very large litter items in the macro and mega size range. However, there are some significant disadvantages of using drones as the sole method of marine litter monitoring, without a parallel traditional process for marine litter monitoring.

The main disadvantages of remote sensing surveys are:

- Satellite photography services **can be very expensive**, and some UAVs are expensive to buy, and drone pilots can be expensive to hire for taking footage
- The resolution of the **images and video captured may be only suitable for larger items** – small items often cannot be seen, and items that are not brightly coloured may be difficult to distinguish from the background environment.
- **Items may be obscured or hidden under vegetation.**
- Drone surveys in many jurisdictions **require a trained and licensed drone pilot** to operate the drone, and **drone flying is not permitted in some locations**, such as close to airports.

- Drone footage and satellite imagery **can generate a very large amount of data that may require extensive digital management** or human effort to process.
- The satellite imagery and drone footage **needs a secondary method to count the items observed**, either by someone watching the footage and manually counting, or with artificial intelligence / machine learning (discussed later).

Despite these challenges, satellite imagery and drone surveys are a useful tool in some monitoring scenarios, for example, monitoring the presence of large litter items or detecting and counting informal dump sites (see box below). Currently, many of the disadvantages of satellite images and drones as a monitoring tool are due to technological limitations, both due to the drones themselves, as well as the technology currently available to process the footage taken. As satellite, drone, video and pattern recognition technology improves, technology that supports aerial photography may play a much larger role in the future of waste leakage and marine litter monitoring programmes.

Global Plastics Watch – an example of remote sensing to **observe** marine litter

Global Plastic Watch (GPW) is a digital platform that maps the world’s plastic pollution in near real-time using a unique combination of satellite imagery and artificial intelligence (<https://globalplasticwatch.org/>). GPW was developed by the Minderoo Foundation No Plastic Waste initiative, in partnership with Earthrise Media. GPW uses freely available data from the European Space Agency, GPW detects plastic waste sites on land and monitors them over time.

The benefits of remote sensing initiatives, including the GPW, is that they can identify waste sites to enable site clean-ups and better enforcement of laws against dumping, provide risk indicators for existing plastic waste sites such as proximity to water or communities, highlight priority areas for investment in waste and recycling infrastructure, and demonstrate visible progress towards waste management targets.



16.3 Mounted cameras as a monitoring tool



Mounted camera surveys may be used to record and observe litter in the environment. Cameras may be mounted at a fixed location facing an area that litter passes in rivers or other aquatic environments for monitoring purposes. A fixed location may be a structure above a waterway, such as the underside of a bridge (see photo to left) and/or in the mouth of a stormwater drain. Cameras can also be

mounted on ships or other vehicles to document mismanaged waste in the environment.

It is also possible to have underwater fixed cameras for monitoring items within the water column. Mounted camera approaches have many of the same advantages and disadvantages of aerial photography, and we will not repeat the above list here. However, one key topic to keep in mind is the resolution of images. It is worth a brief reminder about the benefits of standardising survey effort.

One main difference between aerial photography/footage and mounted camera surveys is image resolution – fixed cameras monitor litter in the environment at a smaller scale, usually a single small section of a river or stormwater drain. Fixed cameras that are above rivers and storm water drains can usually see mesoplastic sized items and larger but are unlikely to capture microplastic sized items, depending on the resolution and pixels of the camera. Some fixed cameras that are close to or submerged in the water can detect microplastics.

Many fixed cameras are programmed to photograph or record either continuously, or at fixed time intervals. Because both the time and area surveyed is fixed, fixed cameras make excellent options for litter monitoring of the environments for which they are designed. That said, aerial footage surveys can be standardised for effort (time, distance and area surveyed) as well.

16.4 Sensor technologies

Sensor technologies are increasing employed to measure and monitor waste. These technologies are not solely focused on measuring litter already in the environment, as battery powered waste level sensors are used in ‘smart bin’ applications and in reverse vending machines. Here, the fullness of trash cans or rubbish bins is measured, and sensors may be linked to a cloud server or Internet of Things (IOT) for communication. Sensors are also being used to identify and detect objects and item types in reverse vending machines, allowing a user to deposit an item and receive a credit or cash for those items that attract. In addition, sensor technologies are in development for measuring waste and fullness levels



in storm water drains and gross pollutant traps. This will allow improved waste management at the local level, prior to overflows resulting in litter being lost back into the environment.

Sensor technologies are often used in environmental monitoring across an array of applications (temperature, pressure, humidity, water quality, etc.). Sensors are also used in waste management facilities to identify and sort different types of plastic and other material types into those which can and cannot be recycled, etc.

Each of these applications facilitates the automatization such that an individual human is not required for measurement, also allowing for data collection which can be useful for management and policy purposes.

16.5 Pollutant traps as a means of monitoring waste in the environment



Pollutant traps are a class of physical structures that are designed to passively collect waste that has entered the environment. Debris is flushed into the trap by water and wind. These can include the wide variety of gross pollutant traps that is incorporated into city stormwater infrastructure as well as nets, cages and booms that are placed across rivers and waterways to capture litter. Pollutant traps can also be placed in the ocean, for example, ‘sea bins’ that are placed in some ports and harbours, as well as engineering solutions such as booms that sweep the ocean for floating plastic (such as the boat-towed open ocean boom designed by The Ocean Cleanup). Pollutant traps perform a beneficial service by gathering litter in the environment, which can then be emptied from the trap.

Litter collected by pollutant traps can also be identified, categorized and quantified to survey the types of litter entering this environment. The advantages of collecting litter this way is a useful method to passively sample the environment. However, because freshwater pollutant traps rely on rainfall to flush debris into them, and on cleaning to empty them, standardising for ‘survey effort’ is more complicated than for designed surveys. Several factors that must be considered if using surveys of pollutant traps for monitoring, including:

- Time since last rainfall, and amount of rainfall (especially if there has been a high rainfall event)
- Time since last clean of trap
- Catchment area from which the water flushes litter
- Capacity of the trap
- Size of items that the trap can collect (e.g., mesh size)
- Maintenance status of the trap – is it in good working order?

- Traps collect non-debris too and can get filled with sediment and vegetation (land-based) and pumice and wood (sea-based).
- How full is the trap – for many trap types, as the trap fills, the function and ability to capture litter decreases

Measuring the litter accumulated in pollutant traps can provide a useful method to passively sample debris in the environment, though each trap type requires specific considerations, including the above, to ensure the monitoring programme considers sampling effort. Without standardising sampling effort (such as the amount of water that has passed through the trap), comparisons between sites and through time will not be reliable, as you are likely to be measuring the influence of an environmental factor and not real change. For example, changes in litter are likely to be confounded by the amount of rainfall or amount of sediment in the bottom of the trap. Standardisation is easier for some pollutant trap types than others (for example, litter collected in a sea bin, checked at standard time intervals, is easier to standardise than a municipal gross pollutant trap). Pollutant traps can be a useful aid for monitoring mismanaged waste in the environment.

16.6 Social media as a monitoring tool

Social media is a useful new technology to make connections and gather data. However, information that comes from social media is very heavily driven by social factors, such as how many people visit a site. Social media surveys provide useful information about occurrence/presence data (for example, the presence of marine debris in birds' nests), however, we do not recommend using social media-based surveys for marine litter monitoring. **Social media derived information is not recommended as a foundation for a national monitoring program**, though it can be useful for raising awareness and identifying hot spots for litter in the environment. Overall, **social media does not account for the five tenets for designing national and regional scale marine litter monitoring programmes**, such as accounting for surveyor effort, representative capture of variation within or between each habitat to avoid sampling bias, among other pitfalls.

16.7 Automated survey tools/autonomous devices

Numerous private companies are bringing automated tools to market that have been explicitly designed to observe, collect and quantify debris in the environment. Technology is

developed and sold by companies that do not typically prescribe how users design they survey or data collection. This falls outside the purview of the developers. However, there is ample room for users to apply survey methods adhering to the five tenets for designing

national and regional scale marine litter monitoring programmes, utilising new technologies. For example, portable, automated depth samplers (pictured) are offered by numerous companies, as an automated method to collect volume-based water samples at pre-selected depths from ocean and freshwater environments. Companies also offer pre-trained AI tools for quantifying the debris collected by their tools. Ocean diagnostics is one of many new companies offering automated survey tools specifically designed for the observation, collection and quantification of marine litter, and this company offers tools that both collect litter, provide paired automated machine-learning based plastic counting and classifying tools, and laboratory services.



SATURNA – an example of an automated tool to quantify marine litter

Saturna is a standardized imaging and illumination device that is pioneered by the company Ocean Diagnostics. This device plugs in to your computer and syncs with the company's web-based analysis data portal and uses AI to perform rapidly characterize and quantify visible plastic particles. This is one example of an automated tool offered by private companies to collect a robust set of size, colour and categorical metrics for visible microplastic samples like those collected from trawl nets, beach quadrat samples and other monitoring approaches.



16.8 Artificial intelligence and machine learning (ML)



Machine learning (ML) is a type of artificial intelligence in computing, which aims to understand and build methods that 'learn' material that the program is shown, based on pattern recognition. For marine litter, ML is typically used to observe and/or quantify objects. In brief, a selection of training data is provided for the program to recognise specific patterns. Machine learning algorithms build a model

based on sample data, known as training data, to make predictions or decisions without being explicitly programmed to do so. For a marine litter detection algorithm, training data might include a selection of photographs of a plastic bottle in the ocean, with the explicit intention to train a model so that when the program/algorithm is later presented 'test data' photos of the ocean with and without plastic bottles, the model can distinguish between photos that contain plastic bottles, and those that do not. Properly trained, machine learning algorithms have the potential to save thousands of people hours (or more) reviewing, identifying, and categorising data. For example, tens of thousands of images such as those that might result from a camera mounted under a bridge, pointed at a river taking a photo every five minutes, may only contain a small number of images of litter floating down the river. An algorithm can be trained to recognise which images do or do not have litter in them, saving someone a great deal of time and money manually looking through these photos. There is a seemingly limitless potential for benefits from machine learning, however, there are also caveats and challenges.

Whilst there have been multiple attempts to use ML for detecting anthropogenic pollution in both riverine and general environments, these attempts have not been wholly successful thus far. This is due to a variety of factors ranging from the complex nature of the domain (there is a huge variation in objects and background) to the lack of support for continuing technology development beyond the proof-of-concept phase. The primary caveat of machine learning for environmental monitoring is that producing and training machine learning models that can do what you want them to and do it reliably with a small degree of error, takes considerable forward planning, and is very time intensive and costly. Training ML programs should not be entered into blindly, and those seeking to take this path would benefit from defining a clearly articulated/bounded set of problems that you want the computer to solve and a realistic view of the capabilities of this technology. It is also relevant to account for the amount and type of training available to train your models, and whether the training data has a clear overlap in patterns with your test data. There is a common saying in machine learning "rubbish in, rubbish out", which means that if you give your model poor training data, then the end product will be less useful than it otherwise could be. In summary, the more complicated the task, the more difficult it is to build a model, the more training data is required, and the less accurate a model is likely to be. As an example, a model that recognises a uniform, clean and non-crushed coca cola can on a plain background and seldom-changing background, such as white beach sand, will be fairly easy to train. However, a model that attempts to quantify and

categorise many types of litter, in many different states of cleanness, age, whole and fragmented, on a changeable background such as drone footage taken along a river, will be difficult to train.

Some of the disadvantages with machine learning for marine litter monitoring are that often, the type of problem that people want the model to answer is very difficult to train for and may not be realistic with the current state of technology, without a limitless budget and team of the world's best computer engineers. Counting cans from a particular manufacturer on a white sandy beach is a problem that might be straightforward to train a model for, but is unlikely to be encountered in real life. Many of the real-life applications that are sorely wanted, such as counting and identifying different types of litter along a dirty vegetated river, are often prohibitively difficult to train a model for, and fall outside of the capabilities and resources of most organisations that survey and monitor marine litter.

Another disadvantage of machine learning is that a set of training data for one scenario does not always easily transfer for another. Therefore, resources may be allocated to solving one problem, and then when the next problem comes along, a new model and an additional set of training data is needed. For example, a model trained to identify plastic bottles in a river might not be able to detect plastic bottles in the ocean. Or a model that is trained to detect floating plastic in the sea may not be able to distinguish between plastic and light reflecting off the sea surface, or a model trained to detect litter in a river, may not be able to distinguish between litter and leaves, and likely cannot be transferred to another river.

To summarise, even though there is limitless potential for ML approaches to monitoring mismanaged waste in the environment, and specific, well-defined and bounded research problems that machine learning is well-suited to, the technology still has a long way to come for many of the types of problems that marine litter monitoring organisations seek to answer. We suggest that those who want to use machine learning for marine litter monitoring seek the advice of software engineers familiar with training these types of models as the first step in their journey of embracing this powerful technology for marine litter monitoring.

“Rubbish in, rubbish out” - opportunities and pitfalls of machine learning approaches to litter detection

Machine learning techniques are being increasingly applied to a whole suite of problems that seek to take advantage of a computers capabilities to be trained for pattern recognition, including the detection of litter in photographs and footage. However, machine learning is complicated, and without clearly defined questions with firm boundaries, results can vary. The saying “rubbish in, rubbish out”, is common to machine learning, and means that if you give your model poor training data, then the end product model will be bad at its job. We suggest that those who want to use machine learning for marine litter monitoring seek the advice of experienced software engineers who are familiar with machine learning as the first step in their journal of embracing this powerful technology for marine litter monitoring.

16.9 Summary

There are a litany of new technologies emerging to bring automation into the observation, collection and quantification of marine litter for survey and monitoring purposes. However, no single technology is a silver bullet solution to marine litter monitoring, and each needs to be applied by carefully balancing the advantages and disadvantages of the different technologies. Regardless of what technologies are used, knowing the specific question you aim to answer and following best-practice advice and the five tenets for designing national and regional scale marine litter monitoring programmes will provide the most accurate information for marine litter monitoring.



17 References

- Barrett, J., Z. Chase, J. Zhang, M. M. B. Holl, K. Willis, A. Williams, B. D. Hardesty and C. Wilcox (2020). "Microplastic pollution in deep-sea sediments from the Great Australian Bight." Frontiers in Marine Science: 808.
- Blettler, M. C. M., M. A. Ulla, A. P. Rabuffetti and N. Garello (2017). "Plastic pollution in freshwater ecosystems: macro-, meso-, and microplastic debris in a floodplain lake." Environmental Monitoring and Assessment **189**(11): 581.
- Borrelle, S. B., J. Ringma, K. L. Law, C. C. Monnahan, L. Lebreton, A. McGivern, E. Murphy, J. Jambeck, G. H. Leonard, M. A. Hilleary, M. Eriksen, H. P. Possingham, H. De Frond, L. R. Gerber, B. Polidoro, A. Tahir, M. Bernard, N. Mallos, M. Barnes and C. M. Rochman (2020). "Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution." Science **369**(6510): 1515-1518.
- Bruge, A., C. Barreau, J. Carlot, H. Collin, C. Moreno and P. Maison (2018). "Monitoring litter inputs from the Adour River (Southwest France) to the marine environment." Journal of Marine Science and Engineering **6**(1): 24.
- Dickinson, J. L., B. Zuckerberg and D. N. Bontar (2010). Citizen science as an ecological research tool: Challenges and benefits. Annual Review of Ecology, Evolution, and Systematics. **41**: 149-172.
- Hardesty, B. D., C. Wilcox, Q. Schuyler, T. Lawson and K. Opie (2016). Developing a baseline estimate of amounts, types, sources and distribution of coastal litter – an analysis of US marine debris data. A final report for Ocean Conservancy and the National Oceanic and Atmospheric Administration of the United States.
- Hardesty, B. D., C. Wilcox, Q. Schuyler, T. Lawson and K. Opie (2017). Developing a baseline estimate of amounts, types, sources and distribution of coastal litter – an analysis of US marine debris data. Version 1.2., Commonwealth Scientific and Industrial Research Organisation.
- Kershaw, P., A. Turra and F. Galgani (2019). "Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean-GESAMP Reports and Studies No. 99." GESAMP Reports and Studies.
- Kumar, R., P. Sharma and S. Bandyopadhyay (2021). "Evidence of microplastics in wetlands: Extraction and quantification in Freshwater and coastal ecosystems." Journal of Water Process Engineering **40**: 101966.
- Lebreton, L. and A. Andrady (2019). "Future scenarios of global plastic waste generation and disposal." Palgrave Communications **5**(1).
- Lebreton, L., B. Slat, F. Ferrari, B. Sainte-Rose, J. Aitken, R. Marthouse, S. Hajbane, S. Cunsolo, A. Schwarz, A. Levivier, K. Noble, P. Debeljak, H. Maral, R. Schoeneich-Argent, R. Brambini and J. Reisser (2018). "Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic." Scientific Reports **8**(1): 4666.
- Loizidou, X. I., M. I. Loizides and D. L. Orthodoxou (2018). "Persistent marine litter: small plastics and cigarette butts remain on beaches after organized beach cleanups." Environmental Monitoring and Assessment **190**(7).
- Pennino, M. G., E. Bachiller, E. Lloret-Lloret, M. Albo-Puigserver, A. Esteban, A. Jadaud, J. M. Bellido and M. Coll (2020). "Ingestion of microplastics and occurrence of parasite association in Mediterranean anchovy and sardine." Marine Pollution Bulletin **158**: 111399.
- Renzi, M., A. Specchiulli, A. Blašković, C. Manzo, G. Mancinelli and L. Cilenti (2019). "Marine litter in stomach content of small pelagic fishes from the Adriatic Sea: sardines (*Sardina pilchardus*) and anchovies (*Engraulis encrasicolus*)." Environmental Science and Pollution Research **26**(3): 2771-2781.
- Roman, L., B. D. Hardesty, M. A. Hindell and C. Wilcox (2019). "A quantitative analysis linking seabird mortality and marine debris ingestion." Scientific Reports **9**(1).

Roman, L., B. D. Hardesty, G. H. Leonard, H. Pragnell-Raasch, N. Mallos, I. Campbell and C. Wilcox (2020). "A global assessment of the relationship between anthropogenic debris on land and the seafloor." Environmental Pollution: 114663.

van der Velde, T., D. A. Milton, T. J. Lawson, C. Wilcox, M. Lansdell, G. Davis, G. Perkins and B. D. Hardesty (2017). "Comparison of marine debris data collected by researchers and citizen scientists: Is citizen science data worth the effort?" Biological Conservation **208**: 127-138.

van Emmerik, T. and A. Schwarz (2020). "Plastic debris in rivers." Wiley Interdisciplinary Reviews: Water **7**(1): e1398.

Wilcox, C., B. D. Hardesty and K. L. Law (2020). "Abundance of Floating Plastic Particles Is Increasing in the Western North Atlantic Ocean." Environmental Science & Technology **54**(2): 790-796.

Wilcox, C., M. Puckridge, Q. A. Schuyler, K. Townsend and B. D. Hardesty (2018). "A quantitative analysis linking sea turtle mortality and plastic debris ingestion." Scientific Reports **8**(1).

Woodward, J., J. Li, J. Rothwell and R. Hurley (2021). "Acute riverine microplastic contamination due to avoidable releases of untreated wastewater." Nature Sustainability: 1-10.

Wright, S. L. and F. J. Kelly (2017). "Plastic and Human Health: A Micro Issue?" Environmental Science & Technology **51**(12): 6634-6647.



As Australia's national science agency and innovation catalyst, CSIRO is solving the greatest challenges through innovative science and technology.

CSIRO. Unlocking a better future for everyone.

Contact us

1300 363 400

+61 3 9545 2176

csiroenquiries@csiro.au

csiro.au

For further information

CSIRO Oceans and Atmosphere

Britta Denise Hardesty

+61 3 6232 5276

Denise.hardesty@csiro.au

<https://research.csiro.au/marinedebris/>