Towards a Regional Assessment on Marine Litter in the East Asian Seas

(Cambodia, Malaysia, the Philippines, Thailand and Viet Nam)

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This work has been supported by COBSEA participating countries and partner organisations who have engaged in the regional and national training of trainers on Monitoring and Assessment of Marine Litter and data sampling, which has enabled the creation of this assessment.

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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

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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
IGM – COBSEA Intergovernmental Meeting
NGO - Non-governmental organization
RAP MALI - Regional Action Plan on Marine Litter
SEA Circular – Reducing Marine Litter and Addressing the Management of Plastic Value Chain in Southeast Asia, UN Environment Programme (UNEP)
UNEP - The United Nations Environment Programme
WGML - COBSEA Working Group on Marine Litter

Contents

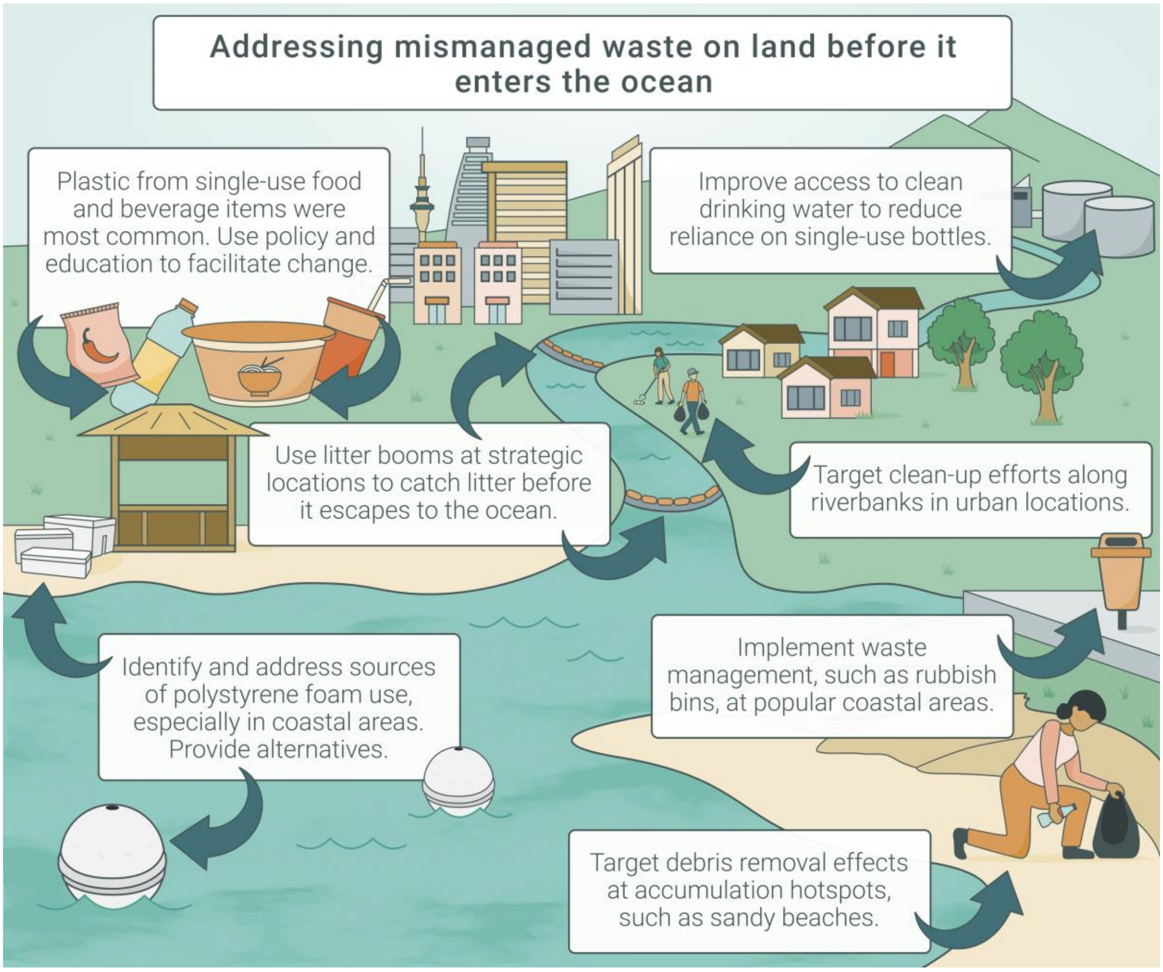
1 Summary

Debris in the environment is a transboundary problem that impacts people and ecosystems. The East Asian Seas Region was identified as a global region with disproportionately high litter leakage from land-based sources to the environment; however, these estimations often are generated by statistical models based that lack empirical 'on-the-ground' data about waste leakage to the environment, including different habitats and land-uses. As part of the 24th IGM of the Coordinating Body on the Seas of East Asia, participating countries adopted a Regional Action Plan on Marine Litter in 2019. The goal of this RAP was to guide actions on marine litter within the region. This assessment builds on existing efforts, supporting countries to have in place a reliable snapshot of mismanaged plastic of plastic in selected areas in Cambodia, Malaysia, the Philippines, Thailand and Viet Nam. By taking a consistent approach within the participating countries, there is a demonstrated focus on consolidation, coordination and cooperation among countries within the region. Regional assessments necessarily rely upon collaboration, consistency and agreement among participating countries, such that data collection is streamlined and harmonised to ensure both interoperability and comparisons among sites, countries and within the region.

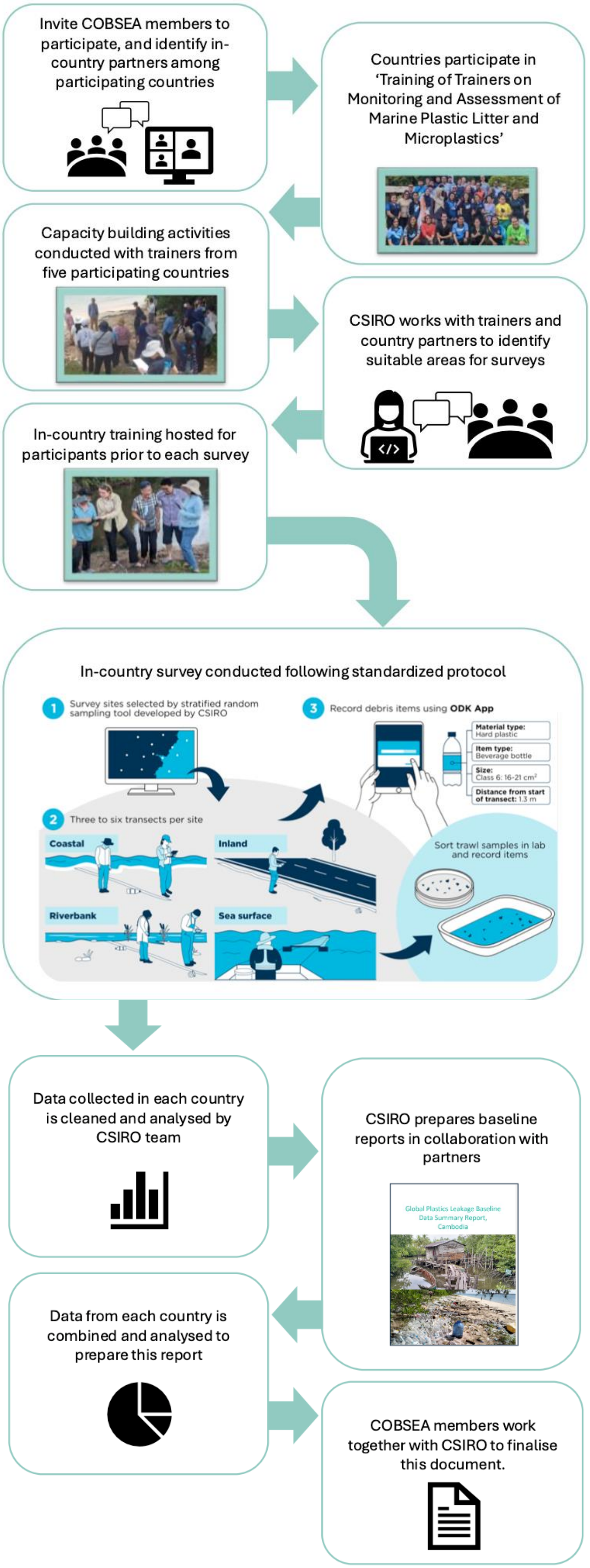
The assessment is the first of its kind providing harmonized on- the-ground evidence at the regional level. A total of 1501 transects were surveyed across the 5 countries. This constituted 540 transects at inland locations, 430 transects along riverbanks, 369 transects along coastlines, and 135 sea surface trawls conducted by boat. Debris density varied among countries, with Thailand having the highest average debris density across inland, river, and coastlines (4.11 items per m^2), followed by Cambodia (4.06 items per m^2), Viet Nam (3.54 items per m^2), Philippines (2.35 items per m^2), and Malaysia (1.29 items per m^2). Debris density patterns varied among compartments examined but was highest at coastal sites across the region. Specifically, Cambodia had the highest debris density along coastlines (10.56 items per m^2), followed by Thailand (9.75 items per m^2), Philippines (2.53 items per m^2), Malaysia (2.5 items per m^2), and Viet Nam (2.31 items per m^2). For rivers, Viet Nam had the highest debris density (5.74 items per m^2), followed by Thailand (5.68 items per m^2), Philippines (3.55 items per m^2), Cambodia (1 items per m^2), and Malaysia (0.92 items per m^2). For inland, Viet Nam had the highest debris density (2.59 items per m^2), followed by Philippines (1.52 items per m^2), Thailand (1.18 items per m^2), Cambodia (0.93 items per m^2), and Malaysia (0.74 items per m^2). The most common whole items encountered in the region were single use items, such as food wrappers and labels, and plastic bottles. While the most common fragmented item found across the region was polystyrene foam. This assessment allows countries in the region to address sources, causes and drivers of pollution based on robust evidence, and include recommended actions to prevent, manage, and track pollution effectively.

2 Recommendations and opportunities in brief

Most items detected originate from mismanaged waste on land. Addressing waste mismanagement at the source (land) before it gets to sea is an effective approach to reduced debris in the river and coastal environment. Polystyrene foam fragments are the single most common item recorded within the region, but their source remains unclear. Collectively, the most common whole items are associated with plastic bottles – predominantly beverage bottles, including bottled water. This provides an opportunity to target reduction, and programs such as container deposit schemes. We note that access to clean drinking water is an important social and health issue that is driving the environmental issue of plastic bottles in the environment. There was an over-representation of single-use plastic items associated with food and beverage industry generally, as well as cigarettes and plastic bags. To make the biggest reductions on litter entering the environment, these could be the items to start with. Targeting cleanup efforts along riverbanks in urban areas and/or putting litter booms at strategic locations in key rivers could be an effective strategy to reduce the amount of debris being transported to the ocean. Debris removal efforts at sandy beaches could be more effective at removing a greater amount of debris compared to boulder/cobble/mud coastal areas. Furthermore, improving waste management (e.g. rubbish bins) at popular coastal areas, such as sandy beaches, may help to reduce local littering. Focusing policy, education efforts, and waste management in populated areas and areas with low economic product may help to have an increased relative impact to combat local litter.



A conceptual overview of the process in developing this regional assessment.



3 Background

3.1 Litter in the East Asian Seas region

Pollution of the world's environment 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 & Andrady, 2019), which is reflected in the growing amount of 'marine litter', predominantly plastic, on the ocean's surface (Wilcox 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 is used interchangeably with 'marine debris' by many entities.

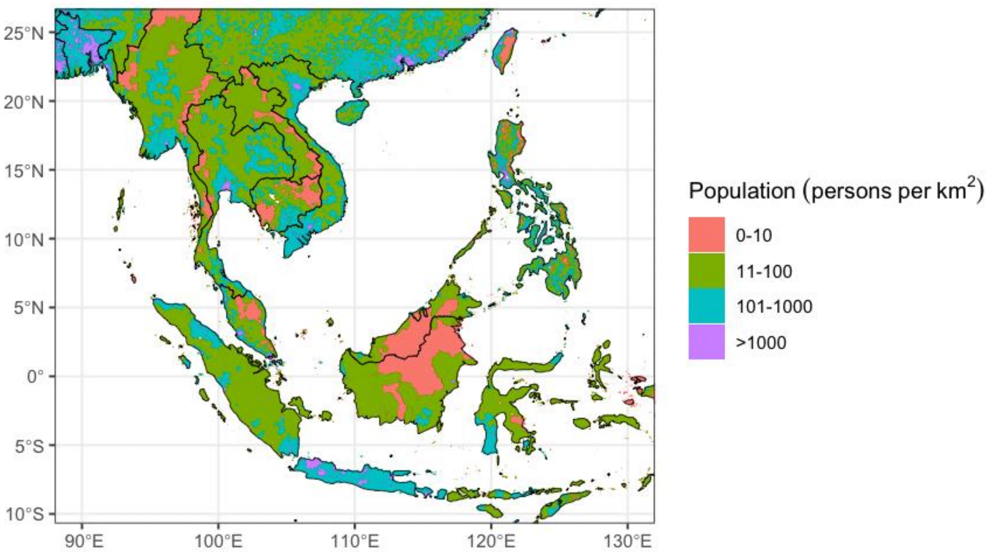
In 2016, more than 10% of the global production of plastic waste, approximately 19 to 23 million metric tons, was estimated to have entered aquatic ecosystems (Borrelle et al., 2020). This waste negatively impacts wildlife health (Roman et al., 2019; Wilcox et al., 2018), poses a hazard to marine logistics and transport, and is potentially a human health issue (Wright & 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 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 & 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, Schuyler et al. 2022). Quantifying and measuring the extent and change of this complex environmental problem is forefront to identifying plastic sources and sinks and implementing effective solutions. Instituting monitoring programmes at national and regional scales is an important component of solving the global plastic pollution crisis.

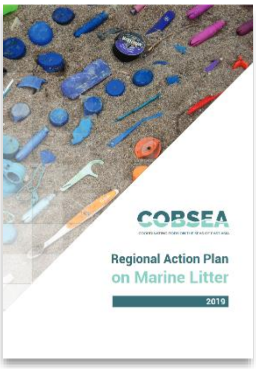
Plastic being surveyed in mangroves beside a large river, Phang-Nga, Thailand (CSIRO)

The East Asian Seas region was identified as a global region with disproportionately high leakage of litter from land-based sources to the environment (Jambeck et al., 2015; Lebreton & Andrady, 2019; Lebreton et al., 2017; Meijer et al., 2021). However, these estimations are generated by statistical models leaning on data such as population density close to the coastline or waterways and gross domestic product (GDP), in combination with estimates of mismanage waste. Many of these earlier estimations lack empirical 'on-the-ground' data about waste leakage to the environment from Asia. Though statistical models are a valuable stopgap to preface likely plastic leakage situations in data poor situations, ground-truthing these models with empirical data becomes increasingly important as decision-makers seek to act on scientifically sound information. In the East Asia context, ground-truthing is all the more important since some of the parameters that underpin these early models, such as human population density , have since been found not to correlate as strongly with litter leakage as originally believed (Schuyler et al., 2022; Schuyler et al., 2021).



Population density (persons per km^2) in south-east Asia, 2015, sourced from NASA's socioeconomic data and applications centre (SEDAC).

3.2 The COBSEA Regional Action Plan on Marine Litter



This assessment on marine litter status and trends is developed in line with the **Regional Action Plan on Marine Litter (RAP MALI)**, which was revised and adopted in 2019 at the Twenty-fourth Intergovernmental Meeting (IGM 24) of the Coordinating Body on the Seas of East Asia (COBSEA). 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*."

To address monitoring priorities and capacity needs in the region, COBSEA partnered with CSIRO to develop the *Regional Guidance on Harmonized National Marine Litter Monitoring Programmes*: Monitoring Efforts and Recommendations for National Marine Litter Monitoring Programmes (Appendix A), which was adopted by part one of the Twenty-fifth Intergovernmental Meeting (IGM 25) in 2021.

Appendix 2 of the RAP MALI identifies priority activities toward implementation of the Action Plan, including "*3.2.4. Prepare regional reports on marine litter and microplastic and delivery against* Sustainable Development Goal target 14.1, and other relevant Goals and targets, based *on National Marine Litter and Microplastic Monitoring Programmes*." Accordingly, the biennial workplan for implementation of the RAP MALI 2021-2022 includes the development of a plan for a regional-level assessment, to guide activities to strengthen monitoring under the biennial workplan 2023-2024.

3.3 The Purpose of this Assessment

The COBSEA RAP MALI envisages possible periodic regional reports on marine litter, building on national monitoring efforts, to track progress against the Action Plan, SDG 14.1, and relevant UNEA resolutions (RAP MALI Action 3.2.4). This activity entails scoping needs of member states and steps toward developing a regional assessment report in the future, in close consultation with COBSEA WGML and its Expert Group on Monitoring, as well as the COBSEA Secretariat, UNEP Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA) and the Global Partnership on Plastic Pollution and Marine Litter (GPML). This ultimately led to the preparation of this document, the Regional Assessment of Marine Litter in the East Asian Seas (Cambodia, Malaysia, the Philippines, Thailand and Viet Nam).

As advised by IGM 25, a regional assessment must be informed by robust national baseline data. Building on recommendations provided by the Fourth Meeting of the COBSEA WGML, the regional assessment will use survey data collected at the national level. The aim is to provide an assessment of marine litter status and trends in the region to inform coherent decision making in the region, in line with the RAP MALI, as well as appropriate action towards an anticipated international instrument on plastic pollution. The regional assessment encompasses the East Asian Seas region, including harmonized data from participating COBSEA countries, using data collected by COBSEA and CSIRO with in-kind funding to complement SEA Circular efforts. This assessment is the first of its kind providing harmonized on- the-ground evidence at the regional level.

4 Preparing national baselines of litter in the East Asian Seas region

4.1 Aim, scope and value of developing baselines

The development of the regional assessment of marine litter in East Asian Seas is based on national baseline reports developed with support from COBSEA and CSIRO and existing monitoring efforts in participating countries. The aim of the regional assessment is to provide key information on leakage of plastic litter into the marine environment to inform decision making across COBSEA participating countries. COBSEA participating countries –Cambodia, People's Republic of China, Indonesia, Republic of Korea, Malaysia, the Philippines, Thailand, Singapore and Viet Nam, collectively cover a diverse geography across more than 12,850,000 km^2 of land area, spanning both hemispheres from tropical monsoon to temperate continental climates. Given the large area, numerous countries, different systems of government, numerous languages, and enormous diversity of litter involved, a well-planned and large-scale survey was needed to deliver a scientifically-sound assessment of marine litter status and trends in the region.

To deliver this goal, the regional assessment uses data that was:
1. Collected using scientific best practice, fulfilling the five tenets of designing national and regional scale marine litter monitoring programmes, and
2. Collected consistently among participating countries.

Five tenets for marine litter monitoring programmes from the Regional Guidance on Harmonized National Marine Litter Monitoring Programmes: Monitoring Efforts and Recommendations for National Marine Litter Monitoring Programmes:

The five tenets for designing national and regional scale marine litter monitoring programmes:
1. Clear delineated and repeatable methods.
2. Quantification and reporting findings in a way that is harmonized 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.

4.2 Technical assistance and capacity building

Technical assistance was provided to COBSEA countries for developing and strengthening national marine litter monitoring programmes in line with *Regional Guidance on Harmonized National Marine Litter Monitoring Programmes*: Monitoring Efforts and Recommendations for National Marine Litter Monitoring Programmes and international guidelines, and corresponding to national monitoring needs and capacities. At the regional level, this included training for trainers on monitoring methods and approaches (detailed information provided in Table 1). Training was provided to build capacity of national focal agencies and other relevant local and national government entities on marine litter monitoring methods, approaches, and quality standards to meet national needs in line with *Regional Guidance on Harmonized National Marine Litter Monitoring Programmes*: Monitoring Efforts and Recommendations for National Marine Litter Monitoring Programmes and international guidelines. Engaging with and training participants from local partner institutions, including universities and civil society groups, has built capacity across the region. Training encompassed not only measuring, and mapping plastic pollution in their environment, but leadership, situational awareness and building capacity to support the continuation of coastal and ocean health monitoring. Training included all visible sized plastics, from the largest items to microplastics visible to the human eye.

Table 1. Outline of technical assistance provided at national level to Cambodia, Malaysia, the Philippines, Thailand and Viet Nam for developing harmonized national marine litter monitoring programmes, after each participated in the Regional Training of Trainers on Monitoring and Assessment of Marine Plastic Litter and Microplastics', in July 2022.

Country	Technical Partner	Survey area	Technical assistance and capacity building activities
Cambodia	Fauna & Flora, Cambodia Programme	Sihanouk province	CSIRO provided technical assistance to Fauna & Flora to conduct a national training in Cambodia in 12 – 14 October 2022, after which Fauna & Flora conducted the 'Cambodia national baseline assessment survey' across the coastline region encompassing four provinces (Preah Sihanouk, Koh Kong, Kompot and Kep) and two neighbouring provinces (Kompong Speu and Takeo) from 14 – 27 October 2022. Representatives from Fauna & Flora Cambodia Programme and Cambodia Ministry of Environment received face-to-face technical training through peer-to-peer learning exercises during the regional Training of Trainers in July 2022 in Phuket, Thailand.
Malaysia	Ministry of Natural Resources and Environmental Sustainability (NRES), Maritime Institute of Malaysia (MIMA)	Kuala Terengganu and Kelantan	CSIRO provided technical assistance to NRES and MIMA to conduct remote training in Malaysia for the 'National Training of Trainer Monitoring and Assessment of Marine Plastic Litter and Microplastics' 28 November – 2 December 2022. This was followed by a national baseline survey with NRES, MIMA and Universiti Malaysia Terengganu (UMT) conducted across Kuala Terengganu and Pasir Putih and Bachok, Kelantan on 21 – 26 April 2024.
Philippines	Davao del Sur State College (DSSC)	Davao region	CSIRO provided technical assistance to DSSC to conduct institutional training in the Davao, Mindanao, Philippines for participants from Davao Del Sur State College from 17 – 18 October 2022 in Davao, Mindanao, Philippines. For the Philippines National Survey "Marine Litter Monitoring Training and Assessment in the Philippines", surveys commenced in September 2022 and were completed in December 2022.
Thailand	Department of Marine and Coastal Resources (DMCR) and other government agencies	Phuket and Phang Nga province	CSIRO provided face-to-face technical assistance and capacity building during national baseline survey as part of the Regional Training of Trainers on Monitoring and Assessment of Marine Plastic Litter and Microplastics, Thailand from 25 July to 3 August 2022. This course included 29 Thai participants. Most participants were from DMCR, also included Pollution Control Department, Department of Fisheries and others.
Viet Nam	Viet Nam Association of Seas and Islands (VASI) and Greenhub	Mekong Delta	Trainers from the non-governmental organisation Greenhub hosted a capacity building 'Marine Litter Monitoring Training and Litter Assessment in Hanoi, Viet Nam' from 28 October to 17 November 2022 in Hanoi, Viet Nam. This activity was followed by 'Capacity building and Establishing a Baseline of Marine Litter in the Mekong Delta of Viet Nam' from 31 July to 11 August 2023 for capacity building and to undertake baseline survey of marine litter in in the Mekong River basin of Viet Nam, led by VASI and supported by Greenhub, with in-person technical assistance from CSIRO.

4.3 Sampling habitats/compartments

The GESAMP report (see Appendix A) specifies four major habitats/compartments for marine litter monitoring. These are ‘Shorelines and coastal environments’, ‘Rivers and waterways’, ‘Oceans’ (including the sea surface, water column and seafloor), and ‘Biota’. To add to these compartments of marine litter, we add the compartment ‘inland’, as this regional action plan also seeks to understand the sources of mismanaged waste in the environment, the majority of which are land-based. In this plan, we do not focus on biota, instead focusing on four primary environmental habitats and compartments; inland, rivers and waterways, coastlines and oceans, with a focus on sea surface.

Different habitats/compartments include (left to right) inland, rivers, coastline and the sea surface.

Each of these habitats/compartments provide different information about the sources and sinks of marine litter. For example, inland habitats represent locally deposited litter (dumping, littering and otherwise inappropriately disposed). Rivers represent litter that is lost locally, but also litter transported from upstream sources. Coastlines represent a standing stock of litter that was directly deposited on the coastline (littering), debris that has arrived locally from nearby rivers and waterways, having washed onto the beach, as well as debris that has arrived from the ocean, potentially deposited from elsewhere. The sea surface represents floating debris from sea-based sources (such as lost fishing gear), as well as debris that has made its way from land to the ocean, and floating debris that has been residing in the ocean and is approaching the land, where it may be deposited on land.

Inland	River	Coastal	Trawl
			

Sampling (left to right) inland, river, coastal and the sea surface compartments, using the CSIRO method, with each area offering different information about the types, sources and sinks of litter leakage.

For robust information about the sources, sinks and pathways contributing to what types of and where we find mismanaged waste in the environment, it is beneficial to sample in each of the different habitats/compartments across each of the countries within the region. The benefit of including different compartments in this regional approach is it aids in identifying regional sources and sinks of marine litter, with respect to neighbouring countries.

A conceptual overview of the four compartments sampled. We recommend sampling all four compartments for a robust picture of regional sources and sinks of litter in the environment.

4.4 The right sites: a statistically robust site selection strategy

Best practice in designing surveys

Most surveys and monitoring programmes are designed solely or primarily to assess the location or sites where the data was collected. However, if you want to ask questions about the debris likely in locations that you have not surveyed, sites need to be selected in a way that captures variation in a manner that is stratified across the different sources of variation. For example, sites with different population densities, different land uses, and different levels or types of infrastructure. Once the sources of variation have been identified, to select sites in a scientifically robust approach, you need consider:

Balanced survey design to account for potential variables **between sites** including:

- Stratification of sites across strata
- Randomisation of sites across locations

And the sampling hierarchy **within each site** including:

- Replication within sites
- Stratification within sites
- Randomisation within sites

With site selection incorporating stratification, randomisation and replication, best practices suggest the search and survey methodology will include control of or account for survey effort and detection probability to reduce biases and variation introduced by different numbers of people searching for different lengths of time or using different search strategies.

Stratification of sites

Previous analysis of global litter patterns have shown that the types and densities of litter are heterogenous both on land and at sea, and this variation is heavily correlated with socioeconomics (Hardesty et al., 2021; Schuyler et al., 2022; Schuyler et al., 2021). East Asia covers a diverse range of socioeconomic characteristics from high to low wealth regions, dense infrastructure to rural and natural areas, diverse land-uses, and geographic features spanning wet tropics to dry continental habitat. Therefore, to make robust predictions in each of these environments, sites containing a diverse range of each of these features need to be considered in selecting representative sites to survey.

To capture this variation across the region, we recommend that sites sampled span:

- A representative range of land-uses from the urban to the rural and natural
- A representative range of population densities and amounts of infrastructure from high to low
- A representative range of distances from transport infrastructure including road and railway
- A representative range of distances from the coastline and waterways.

The CSIRO protocol includes inland site selection that includes a randomised, stratified method clustering the distance from the coast, the distance from roads, the distance from rivers the land-use, the population density, distance from railway. For each of these where there is a nearby river, it

is paired with a river site that is no more than a specified distance apart (for practical purposes).

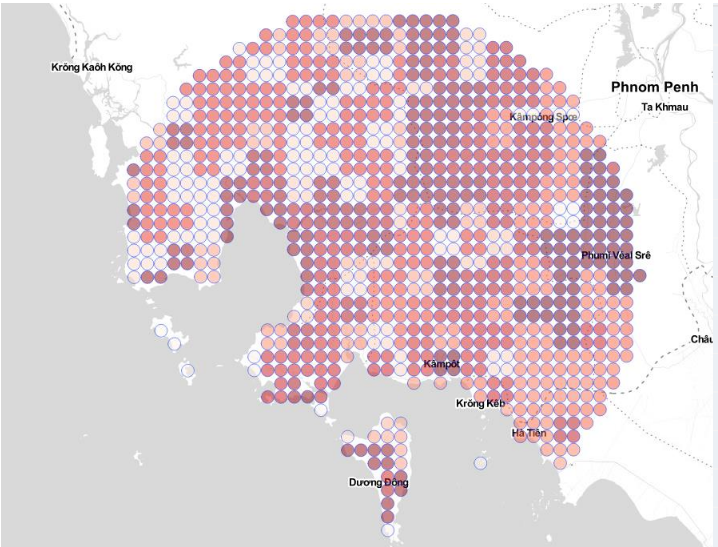
Representative, stratified and randomised sampling is not all sunshine and sandy beaches! Sampling a representative range of land-uses to reduce sampling biases sometimes means getting your hands (and feet!) dirty, as demonstrated here sampling a very muddy coastal site in Viet Nam's Mekong Delta.

Stratification, randomisation and replication

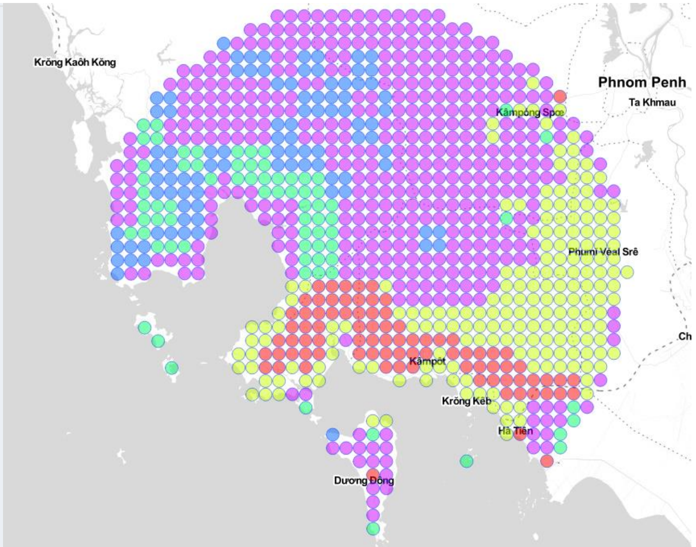
Once site stratification has been factored into the site selection process, randomisation and replication are the next steps for statistically robust site selection. Randomisation entails a selection process where any individual site has an equal probability of selection. Randomisation is used to reduce human biases in the choice of survey sites, to avoid bias.

Replication entails the selection of several sites with the same characteristics to understand the variation among the stratified sites with the same characteristics. The number of replicates required for statistical robustness depends on the variation present. The more variation there is, the more replicates required to have an adequate number of samples. However, as a rule of thumb, most scientists aim to work with at least 15-30 replicates per category.

All possible river sites within 100km of Sihanoukville, Cambodia, with 35 stratified river sites randomly selected from the range of possibilities.



	1	2	3	4	5
	0	0	6	0	0
Dense settlements	0	6	0	0	0
Irrigated villages	0	2	1	0	1
Populated forests	0	0	0	84	0
Populated irrigated cropland	12	0	5	0	21
Populated rainfed cropland	1	4	5	0	43
Rainfed mosaic villages	1	11	1	0	6
Rainfed villages	19	66	4	0	31
Remote croplands	10	3	17	0	109
Remote forests	0	0	0	10	0
Residential irrigated cropland	33	31	13	0	100
Residential rainfed mosaic	7	4	21	0	122
Rice Villages	1	61	0	0	4



Example of stratification of 12 different land uses, across a 5x5km grid, within 100km of Sihanoukville, Cambodia, statistically sorted into five clusters. We also include other characteristics of each grid cell such as population, infrastructure and other geographic features across the survey area. The image in the middle shows each of the 12 land uses and which cluster it was allocated to, with the location of groups of different land uses in each cluster.

4.5 Towards establishing national baselines on marine litter

Technical assistance was provided by CSIRO to identify sources and accumulation zones for marine litter. At the national level, this entailed organizing country-specific workshops to adapt and apply relevant methodologies to address data gaps and implementing baseline assessments with national stakeholders and partners. From 2022, CSIRO worked closely with technical partners and agencies to provide on-site and/or remote support for randomised and stratified site selection. These formed the basis for national baseline surveys, including the use of a dedicated digital application for data collection developed by CSIRO to ensure robust data entry in the field. National baseline data collection efforts and associated reports were developed and validated in consultation with multiple agencies and participating organisations. National baseline of marine litter monitoring should involve government agencies of participating countries and can be adjusted in accordance with respective national circumstances.

CSIRO provided both on-site (top, Thailand) and remote (bottom, Cambodia) support for building capacity to measure and monitor marine litter.

4.6 On-ground data collection efforts

This assessment has reiterated the importance of on-ground data collection to ground-truth global estimations of litter leakage. Here we demonstrate the steps to support harmonised, on-ground data collection through development of national capacity, supported by technological resources.

4.6.1 Development of national capacity

Regional Training of Trainers

Development and delivery of a national capacity training for litter monitoring was a pre-requisite for undertaking this harmonised litter monitoring programme. The 'Training of Trainers on Monitoring and Assessment of Marine Plastic Litter and Microplastics' was organized by COBSEA and CSIRO, with the assistance of the Department of Marine and Coastal Resources (DMCR) under the SEA Circular project (Table 1). The training is based on the Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean developed by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) and in line with *Regional Guidance on Harmonized National Marine Litter Monitoring Programmes*: Monitoring Efforts and Recommendations for National Marine Litter Monitoring Programmes developed by COBSEA and CSIRO. The training programme was delivered by four technical partners from CSIRO. Members from five COBSEA participating countries attended the training, and have taken these skills to their respective countries, establishing **national nodes of expertise** across the East Asia region.

The main goal of the training was to enable course participants to establish/design a programme to monitor and assess the distribution and abundance of plastic litter to support national monitoring programmes. Training was conducted in a way that suits each country's individual needs, while harmonizing within the East Asia region, where possible.

Training national trainers from five countries in coastal survey methodology during the Regional Training of Trainers on Monitoring and Assessment of Marine Plastic Litter and Microplastics in Phuket, July 2022.

Building capacity of in-country experts

The goal of the Regional Training of Trainers on Monitoring and Assessment of Marine Plastic Litter and Microplastics was building capacity for the development of in-country experts. Over two weeks, we implemented a detailed training and capacity building programme, combining classroom theory and outdoor practical sessions with guidance on how to conduct the four survey types: coastal, inland, river and trawl sampling. In addition, training included classroom and theory sessions covering site selection learning, limitations and opportunities for monitoring, harmonisation of different survey types, understanding bias in data collection, sampling microplastics, best practices for clean-ups, and the difference between designed surveys and clean-ups, as well as limitations of each. Learning sessions also included a focus on technology and plastics (artificial intelligence/machine learning, sensor technologies, automated sampling approaches, remote sensing, and other up and coming technology approaches. The second week enabled participants to put their learning into practice. In addition to practical training on the survey methodology, participants were trained in the use of a google group to access the survey sites, and an electronic application for data collection and entry.

This training successfully built the capacity for the participants to use this knowledge to implement national training within their home countries with limited remote support from CSIRO. This included both those countries that have substantial experience, as well as those with little prior experience in marine litter monitoring.

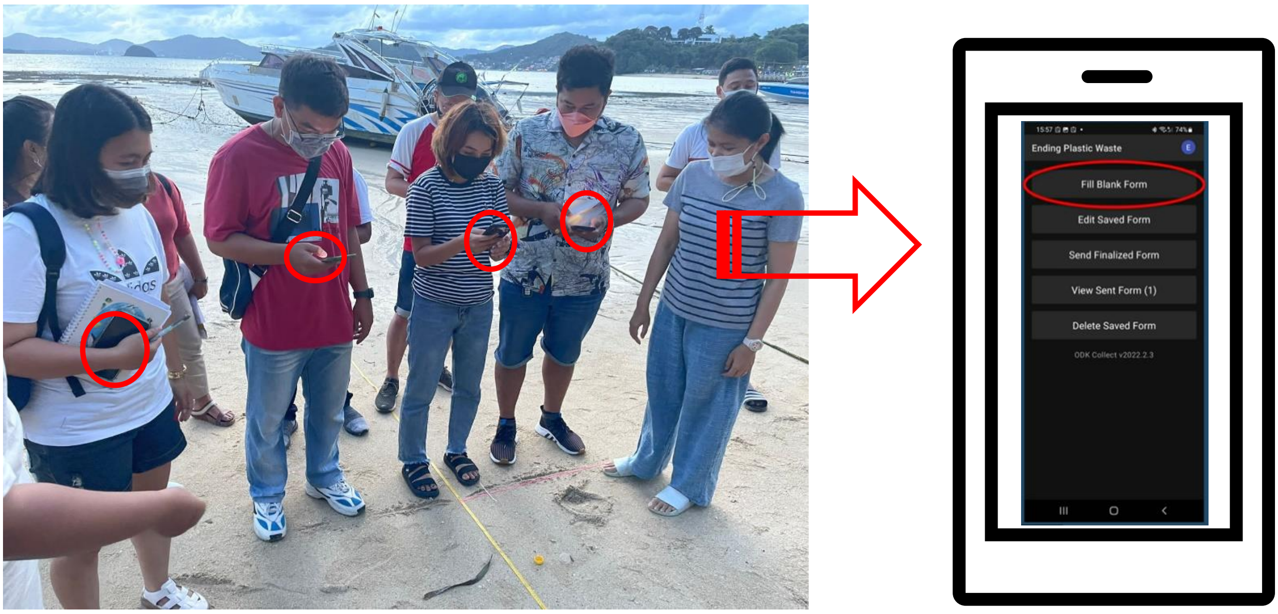
National expertise built through Fauna & Flora, Cambodia, enabled Cambodia's first national baseline survey of litter to be conducted. Here the national experts are teaching local participants how to conduct a litter survey at a river site in Phnom Penh using an agreed upon methodology.

4.6.2 Resources to support on-ground data collection

COBSEA and CSIRO have worked together to develop a suite of resources to make surveying easier and more accessible for participants, and accessible across a variety of languages. Ultimately, the aim is that participants can readily find their pre-selected sites, navigate to the site, access instructional videos (if more information is needed), conduct the survey and enter their data on android phones or tablets. In cases where sites are not accessible (e.g. private property; fences; mangrove forest), the instructional handbook provides guidance to surveyors on to choose alternative sites.

The ODK phone app for data entry (available in multiple languages) minimises the potential for errors in the data recording process. By using fixed survey forms on the app, surveyors are guided through the survey and data entry process. Surveyors also have the opportunity to review and, if necessary, correct any mistakes made during data entry. For example, a common mistake is that a transect is allocated an incorrect number (e.g. transect 2 instead of 1), but is easily rectified upon review. Upon completion of the survey, CSIRO reviewed the entered data and conducted quality control to ensure that entered data was robust and correct to be included in the regional assessment. In this assessment, we only included data from sites that had the required minimum of three transects.

COBSEA and CSIRO have collaborated to develop 30 short, instructional videos that will be translated into a variety of languages, covering a range of topics including “Why do we survey”, “Overview of survey methods”, “Safety” as well as what to do when faced with unusual situations, such as sea walls on coastal surveys.



The ODK data entry portal/platform for capturing data which works on Android devices. This is an easy-to-use app-like tool that you can use on your mobile phone or tablet. You simply go to your app store and search for ODK Collect.

4.7 Steps to transform national baselines into a regional assessment

4.7.1 Modelling regional marine litter status

A stratified, randomised and replicated sampling approach applied across a broad variety of socioeconomic and geographic indicators enables one to understand the factors that contribute to debris in the environment. CSIRO's Global Plastics Leakage Baseline method has been applied across twenty countries and counting. A variety of international datasets that are publicly available provide global layers of socioeconomic and geographic data that can be used in this modelling.

Socioeconomic parameters

Socioeconomic parameters such as national wealth, population, infrastructure and socioeconomic status of the local area have been shown or suggested to correlate with littering across multiple studies (Alisha et al., 2020; Hardesty et al., 2017; Jambeck et al., 2018; Lebreton et al., 2017). A variety of national and multijurisdictional organisations collate global socioeconomic layers that can be used to map these variables and compare sites where litter surveys have taken place. Examples include:

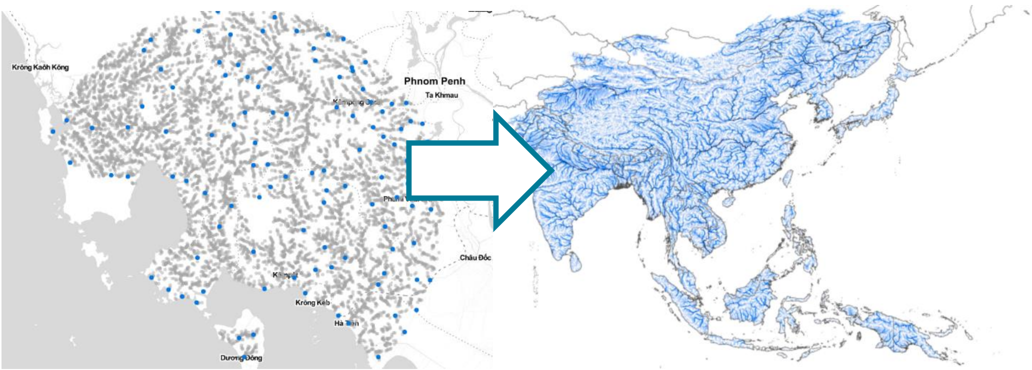
- The World Bank, which collates information on gross and regional national income (The World Bank, 2019)
- UNISDR Global Exposure Datasets, which collates information on Population and Built Environment (UNISDR, 2015).
- NASA's Earth Observation group, which collates information on the intensity of lighting at night (Earth Observation Group, 2019)

Geographic parameters

Geographic variables such as land cover and distance from features including coastlines, rivers, and roads are correlated with the littered loads of different items. Global layers of geographic variables include:

- Global land cover type data, separated into different types of land use and vegetation cover (MODIS Terra+Aqua Land Cover Type) .
- Socioeconomic Data and Applications Center (SEDAC), which collates data on global roads from the nearest road (Socioeconomic Data and Applications Center (SEDAC), 2010)
- U.S Geological survey, which has collated data on global rivers (U.S. Geological Survey, 2019).

Lighting at night is a socioeconomic indicator that serves as a proxy for population, wealth and infrastructure. This view of East Asia at night is a composite image assembled from data acquired by the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite over nine days in April 2012 and thirteen days in October 2012 and is sourced from the NASA Earth Observatory.



Location of and distance of sites from rivers are a geographic parameter associated with litter density. In this example, we show river sites surveyed in Cambodia, overlayed on a global layer of rivers collated by U.S Geological Survey (USGS).

Relationship between litter and socioeconomic and geographic parameters

Broadly, this extensive global sampling programme demonstrates that there are many commonalities among countries that drive litter loads within countries across the region. However, there is some variation or trends that occur in specific countries due to specific cultural factors, underscoring the benefit of sampling as broadly as possible, particularly when trying to develop a regional assessment. There are a variety of site, socioeconomic and geographic variables that, so far, appear to be influential in predicting litter across Asia, and will likely be important to consider. Data showing the relationship between how different features of inland, river and coastline environments correspond the debris loads within each country, and regionally, underpin the information necessary to conduct a regional assessment.

5 Baseline data in this regional assessment

5.1 A summary of baseline data collection

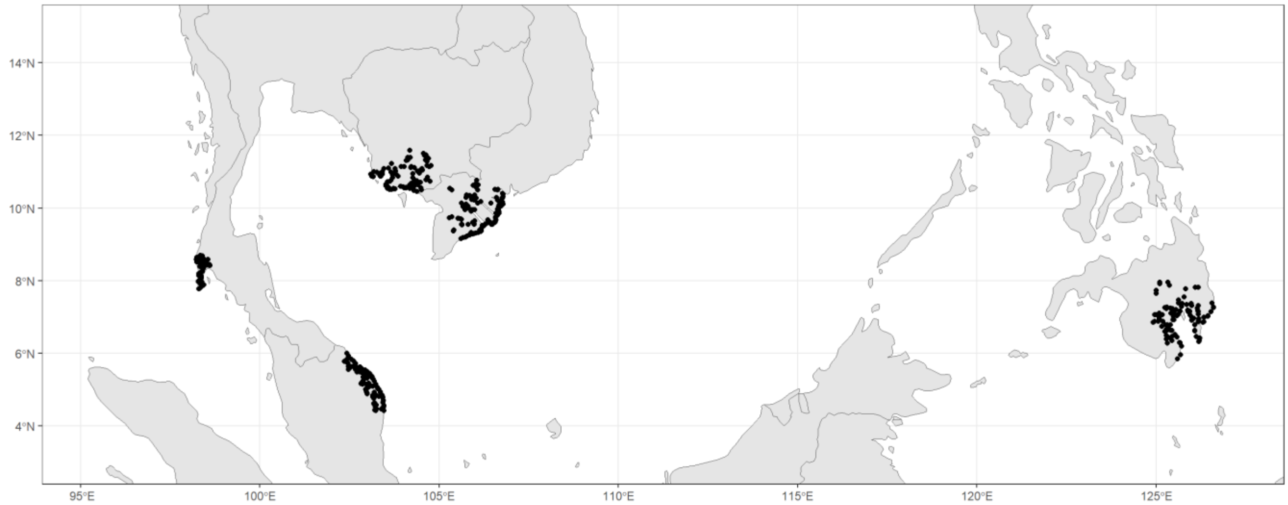
A total of 1339 transects were surveyed across 5 countries. This constituted 540 transects at inland locations, 430 transects along riverbanks, 369 transects along coastlines, and 135 sea surface trawls conducted by boat. Land-based transects constituted 33,262 m^2 of surveyed area across the five countries. Surface trawls are conducted by boat, and an estimated area of 86,251 m^2 was surveyed for floating plastic debris using surface trawl nets. Debris density surveyed at each of these transect and trawl locations was used to inform this regional assessment.

Table summarising the total number of transects surveyed at each country, and within each ecosystem type (inland, river, coast, and ocean). Note that trawls for Cambodia were completed during January 2024.

			Transect Type				
Country	**City or Region**	**Date**	**Inland**	**River**	**Coast**	**Trawl**	**Total**
Cambodia	Preah Sihanouk, Koh Kong, Kompot, Kep, Kompong Speu & Takeo	October 2022	95	94	90	27	**306**
Malaysia	Kuala Terengganu	April 2024	106	113	84	27	**330**
Philippines	Davao	July 2022	129	75	99	27	**330**
Thailand	Phuket	July 2022	78	52	27	27	**184**
Viet Nam	Mekong Delta	August 2023	132	96	69	27	**324**
		Total	**540**	**430**	**369**	**135**	**1474**

Table summarising the total area (m^2) surveyed by transects at each country, and within each ecosystem type (inland, river, coast, and ocean).

		Transect Type				
Country	**City or Region**	**Inland**	**River**	**Coast**	**Trawl**	**Total (m2)**
Cambodia	Preah Sihanouk, Koh Kong, Kompot, Kep, Kompong, Speu & Takeo	2375	1066	1440	12,584	17,465
Malaysia	Kuala Terengganu	2650	2030	4686	16,130	25,496
Philippines	Davao	3225	982	2622	11,579	18,408
Thailand	Phuket	1950	716	868	20,231	23,765
Viet Nam	Mekong Delta	3300	1144	4226	25,727	34,397
	Total	**13,500**	**5,938**	**13,842**	**86,251**	**119,531**



Map of the survey sites that contribute the baseline data utilised in this regional assessment, containing surveys from Cambodia, Malaysia, Thailand, Philippines and Viet Nam.

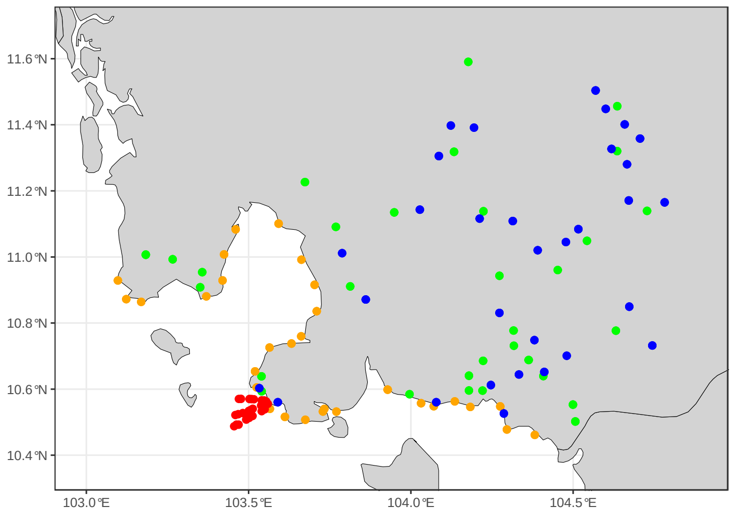
The national survey programme that contributed to this regional assessment was conducted between 2022 and 2024 and kicked off with the 'Training of Trainers on Monitoring and Assessment of Marine Plastic Litter and Microplastics' was held from Monday 25th – Friday 30th July 2022 at the Phuket Marine Biological Center in Phuket, Thailand. In this photo are participants from the five countries, who later led each of their respective countries national baseline surveys with support from CSIRO, plus CSIRO trainers upon completion of this initial training programme.

5.2 Baseline data collection: Cambodia

The 'Marine Litter Monitoring Training and Assessment in Cambodia' was held from Wednesday 12th – Friday 14th October 2022 in Phnom Penh, Cambodia, and was organized by Fauna & Flora Cambodia, COBSEA and CSIRO under the SEA Circular project. The training was based on the Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean developed by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) and in line with *Regional Guidance on Harmonized National Marine Litter Monitoring Programmes*: Monitoring Efforts and Recommendations for National Marine Litter Monitoring Programmes developed by COBSEA and CSIRO. The training programme was delivered face-to-face, in Khmer language by, Mr Majel Kong (Fauna & Flora), assisted by Mr Enrico Barilli (Fauna & Flora) and Mr Phalla Sou from Ministry of Environment (MoE) and technical partners from CSIRO with remote support led by Mr. TJ Lawson. This followed on from the face-to-face capacity building activities provided to Mr Enrico Barilli (Fauna & Flora), Mr Majel Kong (Fauna & Flora), assisted by Mr Phalla Sou (MoE) on Monday 25th – Friday 30th July 2022 at in Phuket, Thailand.

Following the Marine Litter Monitoring Training and Assessment in Cambodia, the Cambodia national baseline assessment survey was conducted from Sunday 16th – Thursday 27th October 2022, led by Mr Majel Kong and Mr Enrico Barilli, assisted by Mr Phalla Sou from MoE and remotely supported by the technical assistance of CSIRO staff. The survey group was made up of 16 Cambodian participants and one non-Cambodian participant, including two Fauna & Flora staff, four MoE representatives from the departments of Solid Waste Management and Water Quality management and 11 contracted surveyors.

The survey area included the metropolitan and regional areas around Sihanoukville. We selected a region roughly 410 km long from the Vietnamese border to Kiri Sakor. The inland and river sites surveyed extended inland past Kampong Speu in the east. A total of 14,425 debris items were detected and recorded across the 93 coastal, river and inland sites surveyed. Trawl surveys were conducted separately by Fauna & Flora and MoE representatives in January 2024 due to weather and logistical challenges.



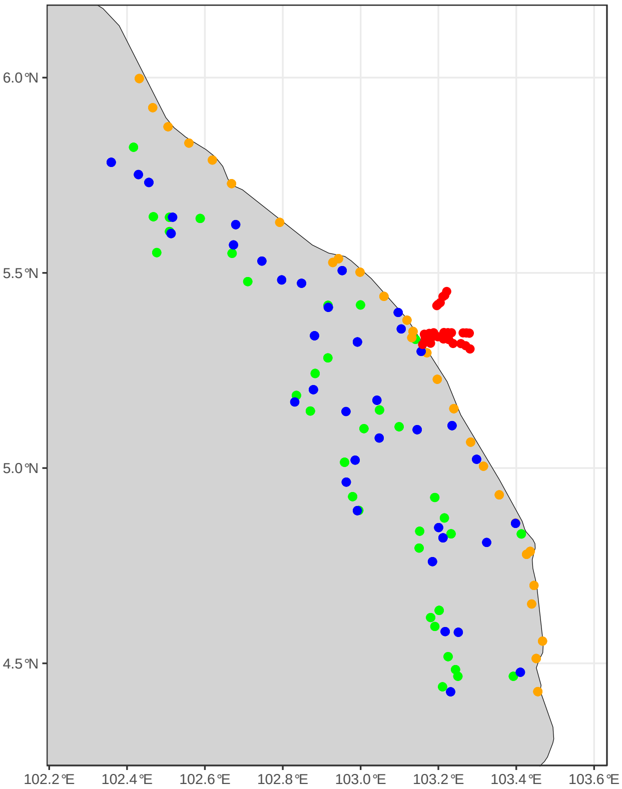
Map of inland (green), river (blue), coast (orange) sites surveyed in Cambodia in October 2022, and trawls (red) conducted in Cambodia in January 2024.

5.3 Baseline data collection: Malaysia

Training in Malaysia commenced with a half day remote training session led by CSIRO's team on Monday 15 April 2024. Face to face training was delivered by CSIRO staff Sunday and Monday 21 and 22 April, 2024. Surface trawl sample training and data collection taking place on Tuesday 23 April, with samples processed on Friday 26 April. The CSIRO team was supported by Puteri Arlis Tsharina Jazlan 'Arif from the Maritime Institute of Malaysia (MIMA) and Nor Effahazira Binti Mohamad Khairudin of the Ministry of Natural Resources and Environmental Sustainability (NRES).

In total, fourteen organisations were involved in the training and survey work (including CSIRO and Singapore government staff). Participants were trained on how to collect, record, report, and make decisions regarding debris items, site selection characteristics, and other key factors required for consistency in data collection for the different survey methods (coastal, inland, and river). Following the training period, we divided into six teams to carry out fieldwork safely and securely over the chosen study region. The group successfully completed surveys at a total of 100 land-based sites between 21 and 26 April, 2024 and surface trawls were completed at 27 stations.

The survey area included the metropolitan and regional areas surrounding Kuala Terengganu. We selected a region roughly 200 km long from Pasir Puteh, Kelantan in the north to Kemasik, Trenegganu in the South. Inland and river sites were surveyed to Kenyir lake in the west. A total of 15,936 debris items were recorded across 28 coastal, 35 inland and 37 river sites.

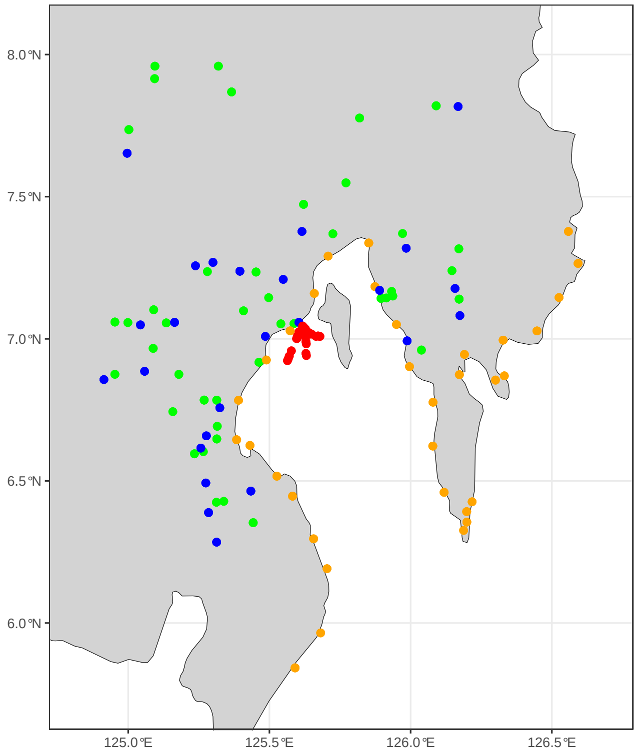


Map of inland (green), river (blue), coast (orange) sites surveyed, and trawls (red) conducted in Malaysia.

5.4 Baseline data collection: The Philippines

Training for the Philippines National Survey "Marine Litter Monitoring Training and Assessment in the Philippines" was led by Mr James Phil Flores and Mr Harold Fuentes for participants from Davao Del Sur State College from Monday 12th – Tuesday 13th September 2022 in Davao, Mindanao, Philippines, followed by a national baseline survey programme in Mindanao, Philippines. The survey took place across several dates from Tuesday 13th September to Friday 11th November. The DSSC training was joined by different faculty members and selected students of Davao del State College (DSSC). Members of a non-government organization that focuses on conservation of marine areas (CLAMS) also joined the event. Mr Harold Fuentes and Mr James Phil Flores led the training in a face-to-face capacity, after having received comprehensive training at the 'Regional Training of Trainers on Monitoring and Assessment of Marine Plastic Litter and Microplastics, Thailand 2022'. These participants will also join the baseline survey headed by DSSC. The overview of the project was given by TJ Lawson of CSIRO. The training began with classroom theory sessions. After the classroom theory sessions, the group undertook a field demonstration / practical session led face-to-face by Mr James Phil Flores and Mr Harold (Ron) Fuentes from Davao Del Sur State College (DSSC).

The baseline survey area included the metropolitan and regional areas surrounding Davao, Mindanao in the Philippines. This region was chosen as the partner institution, DSSC, was based in this region and were able to assemble a team and conduct surveys within a reasonable timeframe. We selected a region roughly 100 km radius around Davao city, covering much of the Davao region. The inland and river sites surveyed extended inland from the south-eastern coast of Mindanao into the very center of Mindanao Island, including the area around the inland Valencia city to the north-west of the study region. A total of 11,076 debris items were detected and recorded across the 90 sites, including coastal, river and inland sites surveyed. Trawl surveys were conducted separately and found 1406 items over 27 trawls.



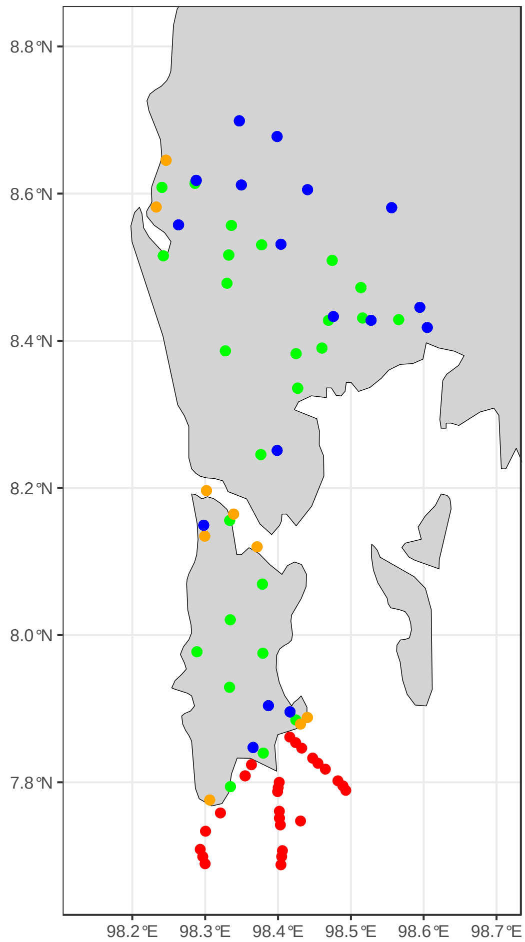
Map of inland (green), river (blue), coast (orange) sites surveyed, and trawls (red) conducted in the Philippines.

5.5 Baseline data collection: Thailand

The 'Training of Trainers on Monitoring and Assessment of Marine Plastic Litter and Microplastics' was held from Monday 25th – Friday 30th July 2022 at the Phuket Marine Biological Center in Phuket, Thailand, and was organized by COBSEA and CSIRO, with the assistance of the Department of Marine and Coastal Resources (DMCR) under the SEA Circular project. The training was based on the Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean developed by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) and in line with *Regional Guidance on Harmonized National Marine Litter Monitoring Programmes*: Monitoring Efforts and Recommendations for National Marine Litter Monitoring Programmes developed by COBSEA and CSIRO. The training programme was delivered by four technical partners from CSIRO. The CSIRO team was led by Dr Denise Hardesty, and included Dr. Lauren Roman, Mr. TJ Lawson and Ms. Justine Barrett. Following the Regional Training of Trainers on Monitoring and Assessment of Marine Plastic Litter and Microplastics, the Thailand national baseline assessment survey was conducted from Monday 1st – Friday 5th August 2022, supported by the technical assistance of CSIRO staff for the first three days (Mon 1st – 3rd August), and completed by the DMCR team. Technical partners from Cambodia, Malaysia, Philippines and Viet Nam were invited to observe the survey for applied learning to assist in effective replication in their respective countries.

The group was made up of 29 Thai participants, mostly Department of Marine and Coastal Resources (DMCR), but also included staff from the Pollution Control Department. In addition, personnel from the Ministry of Natural Resources and Environment, Department of Fisheries, Prince of Songkla University, Burapha University, Phuket Rajabhat University and Southeast Asian Fisheries Development Centre (SEAFDEC), attended across the two weeks. In addition to the Thai participants, 11 participants from other COBSEA countries attended for capacity building and peer-to-peer learning. This included participants from Cambodia, Malaysia, the Philippines and Viet Nam.

The baseline assessment survey area included the metropolitan and regional areas surrounding Phuket, and parts of Phang-Nga province. We selected a region roughly 340 km long from the southern tip of Phuket to Kapong in the north. A total of 149,659 debris items were detected and recorded across the 76 sites surveyed. Unfortunately, due to technological issues in the field (such as monsoon rain damaging electronics and some surveys not being properly uploaded), the data from some surveys was not able to be uploaded and used for analysis. Trawl surveys reported a further 5276 items across 27 tows.

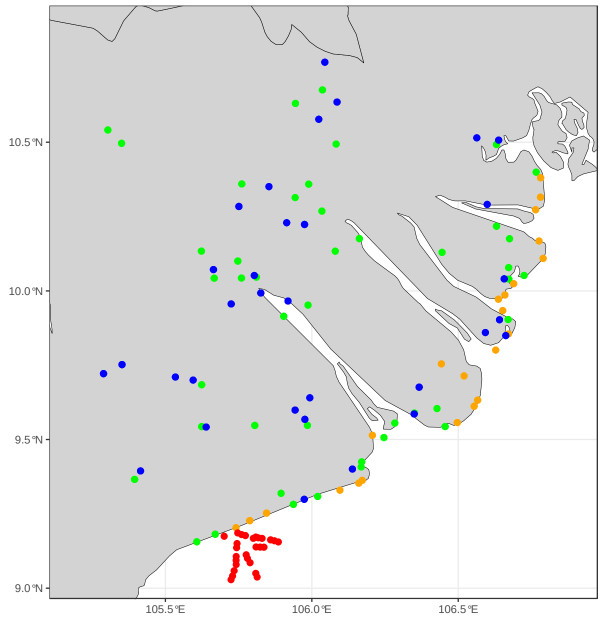


Map of inland (green), river (blue), coast (orange) sites surveyed, and trawls (red) conducted in Thailand.

5.6 Baseline data collection: Viet Nam

Capacity building and Establishing a Baseline of Marine Litter in the Mekong Delta of Viet Nam was undertaken from July to August 2023, following on from COBSEA supported capacity building activities during 2022. A classroom theory session on Marine Litter Monitoring Training and Assessment in Viet Nam was conducted in Bạc Liêu across three days from Monday 31st July to Wednesday 2nd August 2023 for participants from both Viet Nam's central government and provincial government and a second accelerated training was held on Thursday 4th and Friday 5th for students from Bạc Liêu University. Following this, a baseline assessment of litter in the Mekong delta of Viet Nam was conducted from Thursday 3rd August – Friday 11th August 2023, led by Mr. Trần Văn Hùng, Dept. of Science, Technology and International relation, the Viet Nam Agency of Seas and Islands, Ministry of Natural Resources and Environment (MONRE), and Nguyễn Văn Công, Greenhub and supported by the face-to-face technical assistance of CSIRO including Dr Lauren Roman, Mr TJ Lawson and Ms Ruby Jones.

The group was made up of 20 participants from Viet Nam government, both central government Ministry of Natural Resources and Environment (MoNRE) and provincial government from the 16 provinces in which surveys were undertaken, two experienced participants (assisting as trainers) from the non-government organization (NGO) Greenhub, and 18 students and two staff from Bạc Liêu University. The baseline assessment survey area included the metropolitan and regional areas in the Mekong Delta, including 13 provinces/cities in the Mekong Delta region. A total of 19 861 debris items were detected and recorded across the 99 sites surveyed across coasts, rivers and inland. Trawl surveys reported a further 653 items across 27 tows.



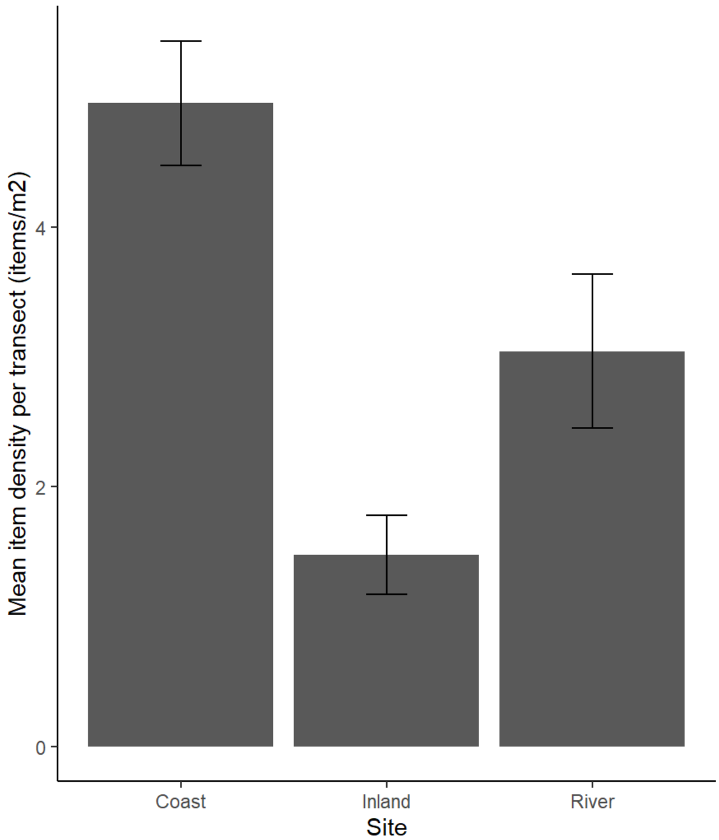
Map of inland (green), river (blue), coast (orange) sites surveyed, and trawls (red) conducted in Viet Nam.

6 Regional assessment of total litter loads

6.1 Debris density across the region

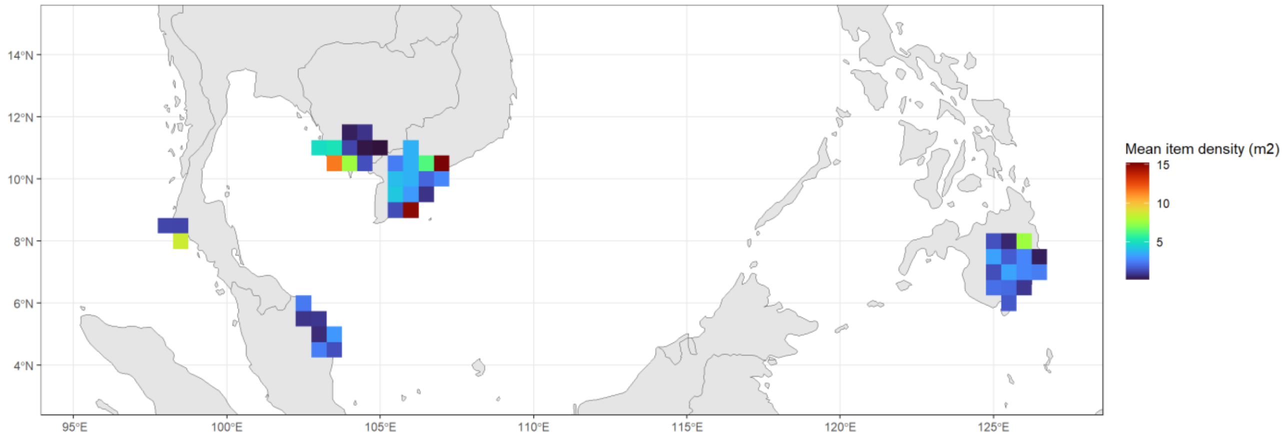
Across the region 1339 transects were conducted. These included 369 coastal transects, 430 river transects and 540 inland transects. However, we removed one transect at one coastal site from this dataset where we believe a subsampling error occurred. This occurred at a coastal site at Phuket Thailand where 131,156 items were recorded, predominantly polystyrene foam fragments. While such counts are not unheard of in the region (and have been recorded during surveys conducted using the same methodology in the Republic of Korea), in this instance we have removed this transect from all further summary statistics and analysis. We have retained and analysed the remaining two transects for that coast site, and all other transects across all site types as part of this regional assessment (except for Chapter 9 where the entire site was excluded from analysis).

The highest debris loads across the region, measured by debris density (items per m^2), occurred on coastlines, which overall had an average of 5.0±0.5 items/m^2 across the region's coastlines (n = 368 transects). This was followed by river sites, 3.0±0.6 items/m^2 (n = 430 transects) and inland, which averaged 3.0±0.6 items/m^2 (n = 540 transects). The most debris found on any transect occurred at an inland agricultural site at Xom Van Lang, Viet Nam, where 3,800 items were recorded. The highest density of debris occurred at a river site in Ban Ku Ku, Phuket, Thailand where 206.6 items/m^2 were recorded. Debris density was not universally high across the region, and zero items were found in 114 transects across Cambodia (n = 53 transects), Malaysia (n = 31 transects), Philippines (n = 5 transects), Thailand (n = 21 transects) and Viet Nam (n = 4 transects). This included three coastal transects, 48 river transects and 63 inland transects.



The highest debris loads recorded across the region occurred on coastlines (n = 368 transects, 5.0±0.5 items/m^2), followed by riverbanks (n = 430 transects, 3.0±0.6 items/m^2) and inland (n = 540 transects, 3.0±0.6 items/m^2).

When we compiled all the surveys into 0.5 degree or latitude and longitude grid cells, corresponding to an approximately 55km x 55km, the highest item densities occurred at 10.5°N, 107°E (n = 12 transects, 15.2±12.5 items/ m^2) and 9°N, 106°E (n = 3 transects, 15.2±12.5 items/ m^2), at the northern and southern extent of the coastlines of the Mekong Delta in Viet Nam. However, it is possible that debris loads in the Mekong Delta are underestimated due to accessibility issues resulting from extensive mangrove forest, discussed later in this report.

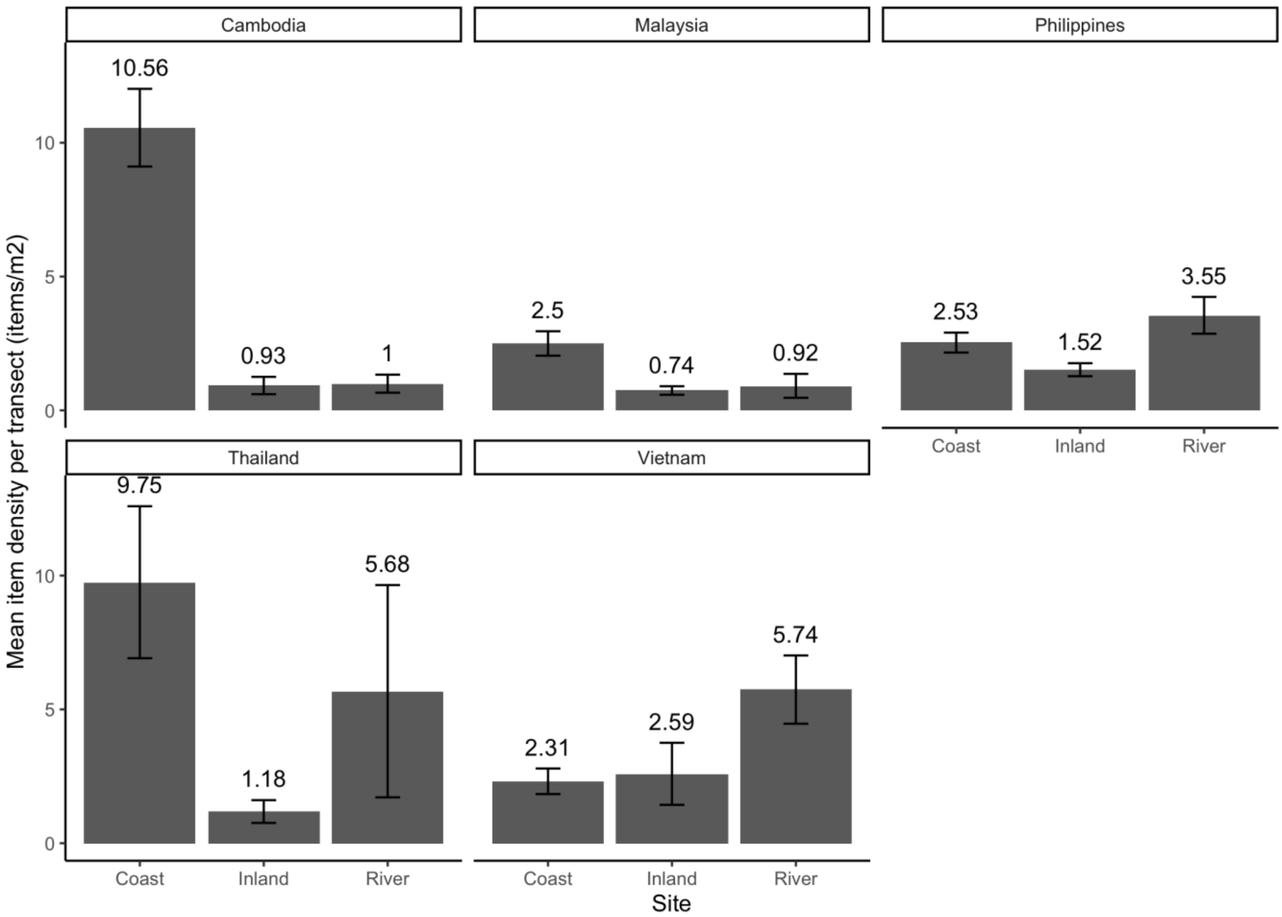


Debris density varied markedly across the region. The highest pooled item densities occurred at 10.5°N, 107°E (n = 12 transects, 15.2±12.5 items/ m2) and 9°N, 106°E (n = 3 transects, 15.2±12.5 items/ m2). This map shows the average number of items recorded per metre squared recorded across transect types in each 0.5° tile (corresponding to an approximately 55km x 55km grid cell).

The team learning how to accurately survey litter along riverbanks in Viet Nam, including learning to notice the smallest items from a standing survey position.

6.2 Debris density per site type across the region

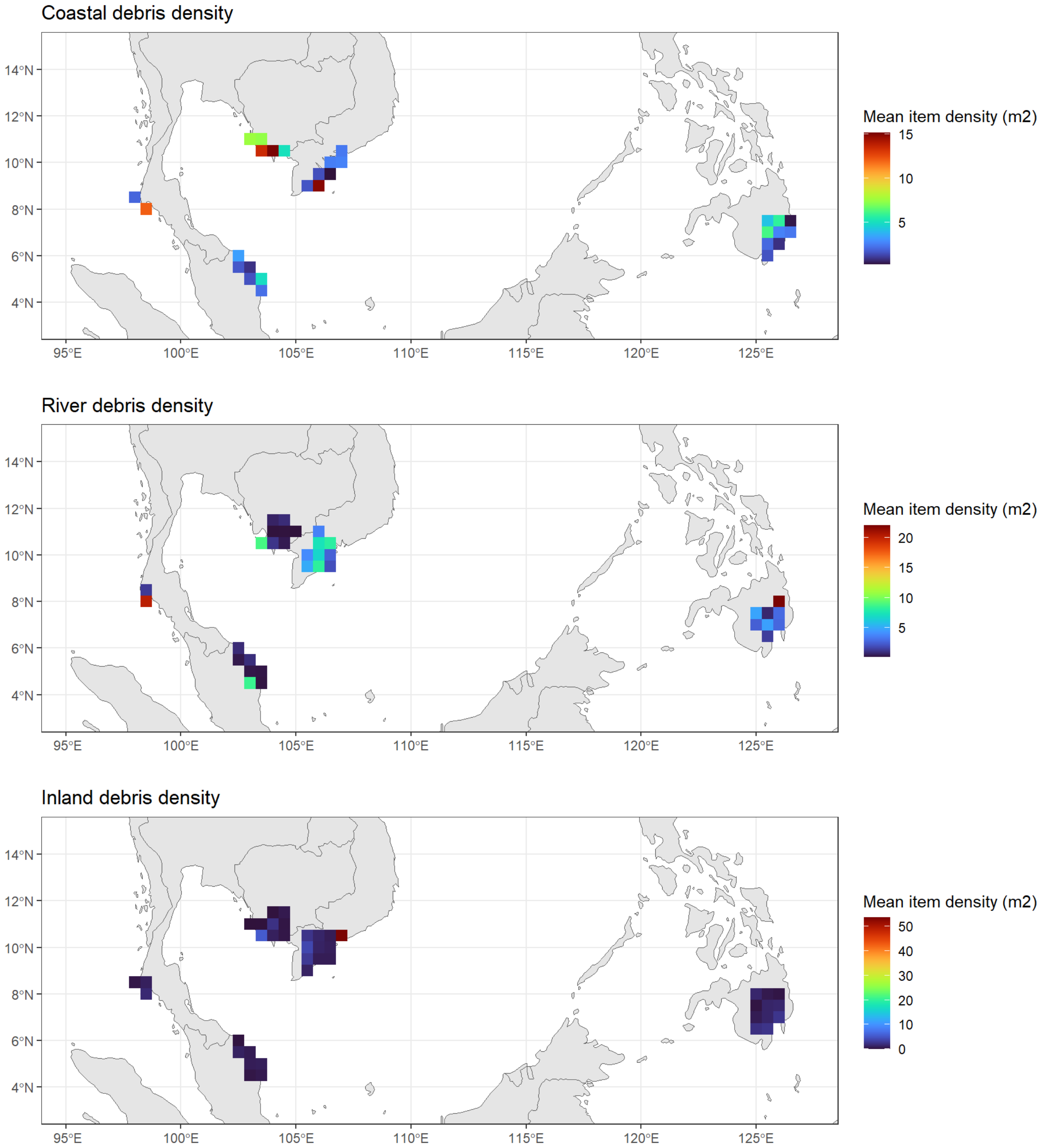
Debris density by site type varied across the region. Coastal environments had the highest litter densities in Cambodia (10.6±1.5 items/m^2), Malaysia (2.5±0.5 items/m^2) and Thailand (9.8±2.8 items/m^2). However, rivers had the highest debris densities in Philippines (3.6±0.7 items/m^2) and Viet Nam (5.7±1.3 items/m^2). Inland sites had the lowest debris densities in all countries, except for Viet Nam, where the densities of inland debris density (2.6±1.2 items/m^2) exceeded that of coastal debris (2.3±0.5 items/m^2). However, our teams on the ground observations suggest that this might be because of access issues to many of the coastal sites in the Mekong Delta, which were blocked by mangrove forests, and that coastal site that were able to be accessed for surveys were over-represented by seawall sites, that tend to have lower loads of trapped debris compared to natural coastlines.



Debris density (items per square meter) was higher along the coast compared to inland and river areas, but only in Cambodia, Malaysia, and Thailand. In Philippines and Viet Nam, the density of debris was higher along riverbanks compared to inland and coastal regions. Numbers above error bars are the mean value to facilitate comparison.

Hotspots for coastal, river and inland debris occurred heterogeneously across the region. Coastal debris hotspots occurred in several coastal locations in the Gulf of Thailand, and where this water body meets the South China Sea, spanning coastlines in Cambodia and Viet Nam, debris densities averaged 13-15 items/m^2 of coastline. River debris hotspots occurred heterogeneously, with the two most polluted pooled river hotspots occurring in Mindanao, Philippines at 8°N, 126°E (n = 3 transects, 22.1±8.0 items/ m^2) and Phuket, Thailand at 8°N, 98.5°E (n = 12 transects, 20.3±17.0 items/ m^2), more than double the pooled density of other locations.

Inland hotspots for debris density showed much lower density values than coastal and river sites. The highest value was strongly influenced by one site in Viet Nam at 10.5°N, 107°E (n = 3 transects, 53.5±49.3 items/ m^2). The remaining inland locations all had debris densities lower than 5.4±4.6 items/ m^2), with more than half (n = 22) having less than one item per square metre.



Debris density varied markedly across the region, and by site type. These maps show the average number of items recorded per metre squared recorded across transect types in each 0.5° tile (corresponding to an approximately 55km x 55km grid cell).

7 Regional assessment of debris on land

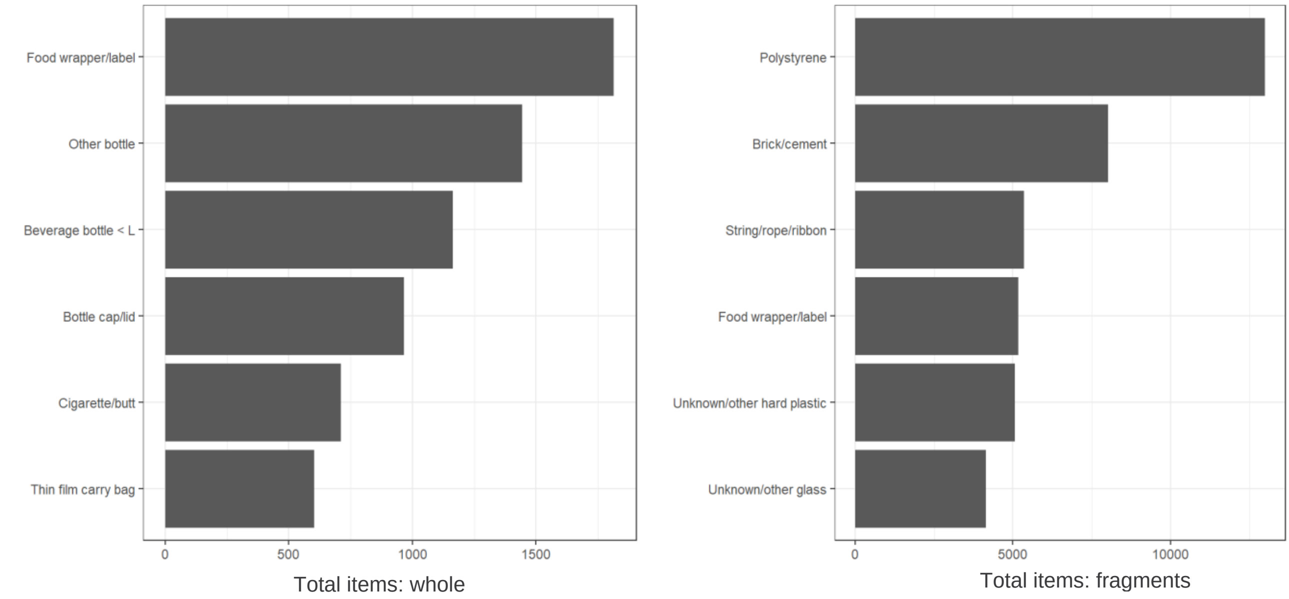
7.1 Items across the region

The most common litter items encountered across the region are reported in this section. Note that the values presented here are raw counts of items and are not weighted for country or site type. Whole items were not as commonly recorded as were fragments of items across the region, a finding that has been seen in 20 countries where CSIRO's Team has facilitated surveys. This generally reflects the propensity of whole items to become weathered and break into numerous fragments as they are exposed to sunlight (photodegradation) and mechanical degradation (e.g., wave action in coastal environments, physical damage inland such as being driven over by vehicles). Here we present the most common six items encountered across the national baseline surveys.

The most common whole items encountered in the region were food wrappers and labels (n = 1,815, 15.3%), followed by other plastic bottles, a category including plastic bottles that were not beverage bottles (but included bottles of drinking water) (n = 1443, 12.1%), beverage bottles <1L (n = 1164, 9.8%), bottle caps and lids (n = 965, 8.1%), cigarette butts (n = 710, 6.0%) and plastic thin film carry bags (n = 603, 5.1%). This highlights that the most abundant items are all single use items, five of which are single-use plastics and most associated with eating and drinking, and one with smoking. The single most common item is plastic food packaging, half of the six most common whole items found across the region are single use plastic bottles or their associated lids.

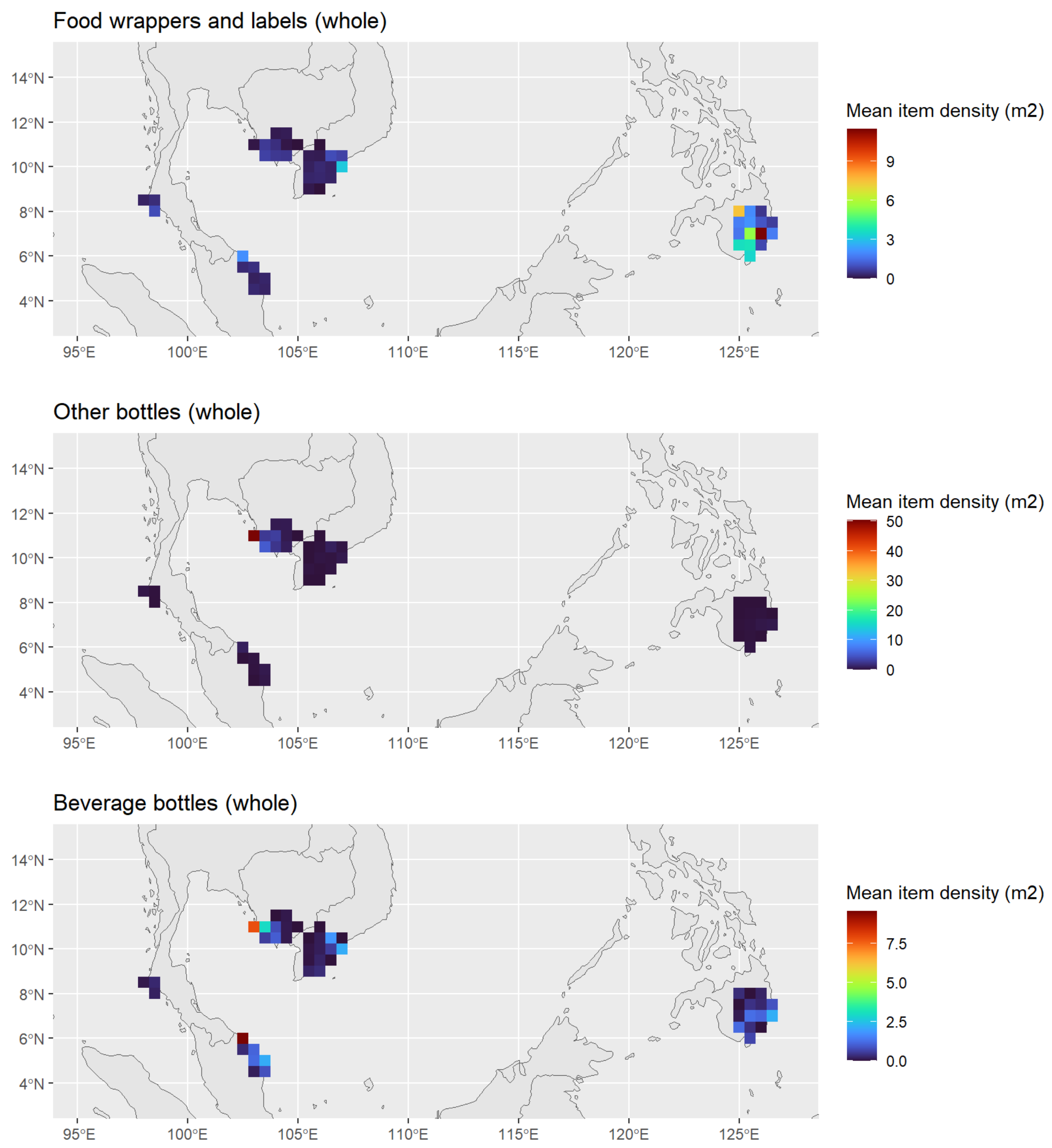
The most common fragmented item found across the region was polystyrene foam (n = 12,981, 20.0%), followed by bricks / cement (n = 8015, 12.3%), string/rope/ribbon (n = 5344, 8.2%), food wrappers and labels (n = 5169, 8.0%), unknown or other hard plastic (n = 5057, 7.8%) and other / unknown glass (n = 4142, 6.4%). Interestingly, of these only food wrappers appear in the top six list of most common items, showing that these items originate from whole items that are readily fragmented and may not remain whole for long (such as polystyrene, sting/rope, hard plastic and glass), or are intentionally fragmented (likely brick and cement as part of construction).

Food wrappers and labels occurred among the top six most common whole and fragmented items regionally.

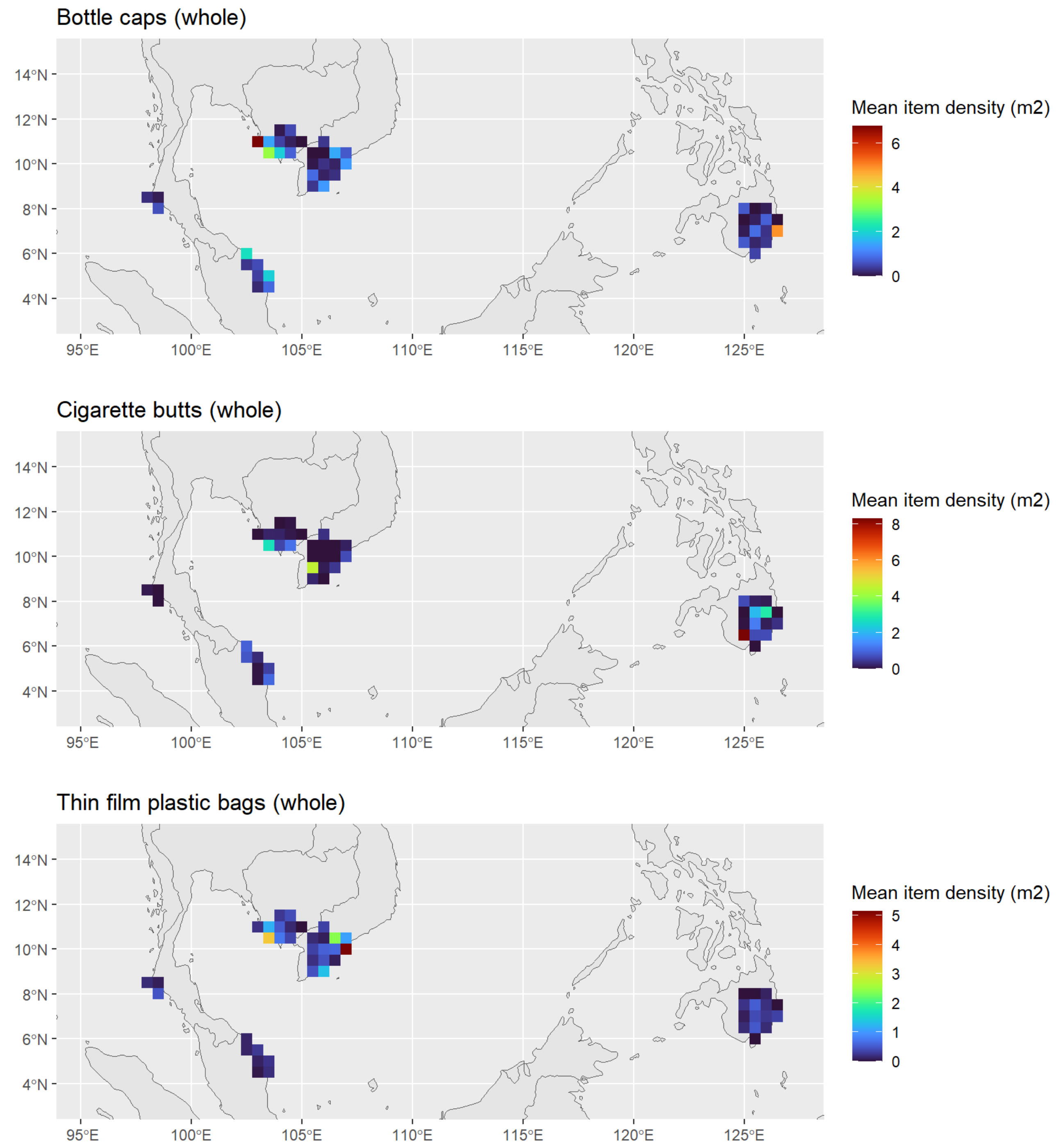


Most common six whole and fragmented items encountered in the region.

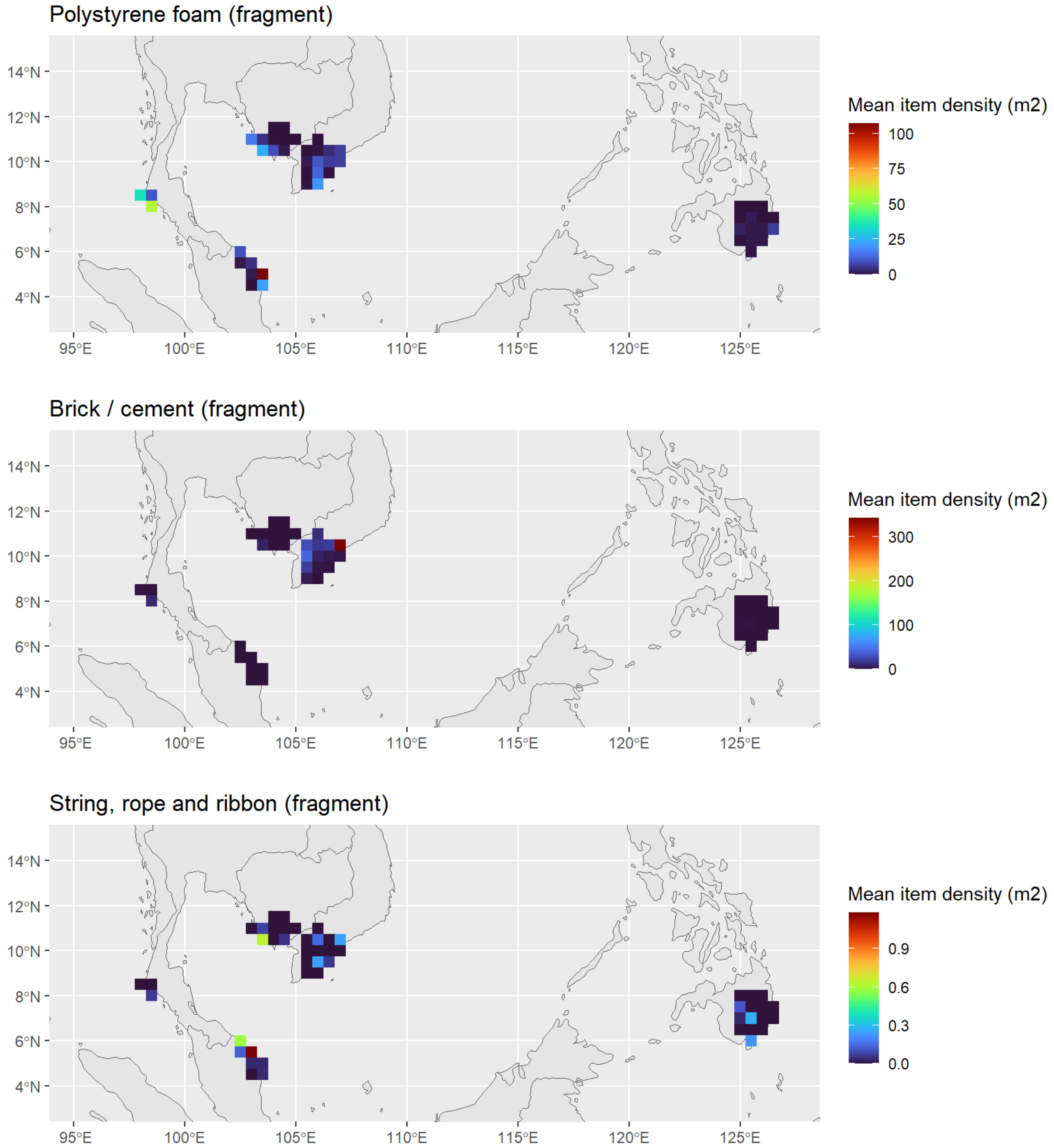
When items are examined across the region, though most item hotspots are heterogeneously distributed, there are national patterns in their distribution that can be observed for some items. For example, food wrappers and labels, both whole and fragmented, are very abundant in the Philippines. Bottles (both beverage and other) and bottle caps have dense hotspots in Cambodia, though Malaysia has the highest density of beverage bottles in the region. Polystyrene foam has hotspots across the four countries on the south-east Asian mainland but is less common in the Philippines than in the other four countries surveyed.



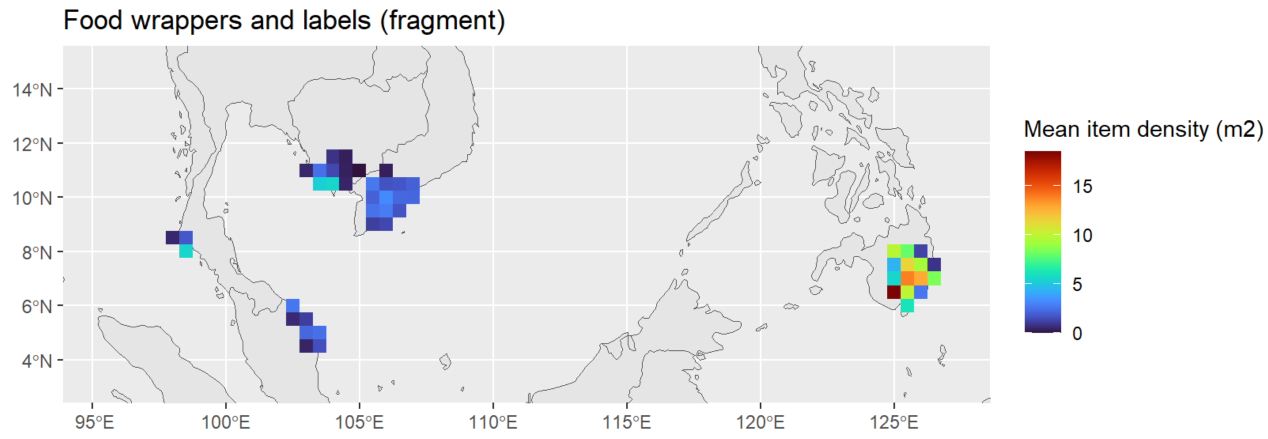
Top three most common of the top six whole items in region in each 0.5° tile (corresponding to an approximately 55km x 55km grid cell).

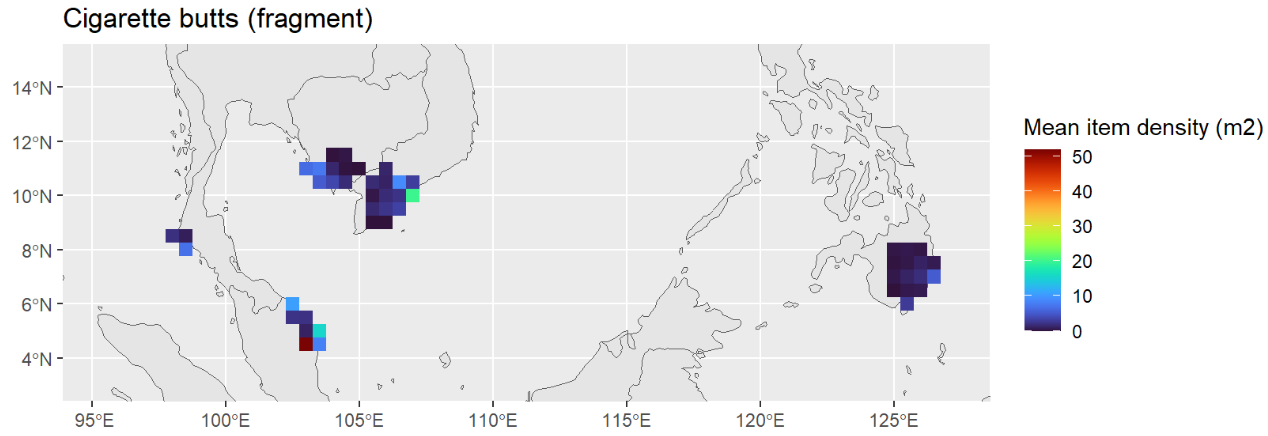


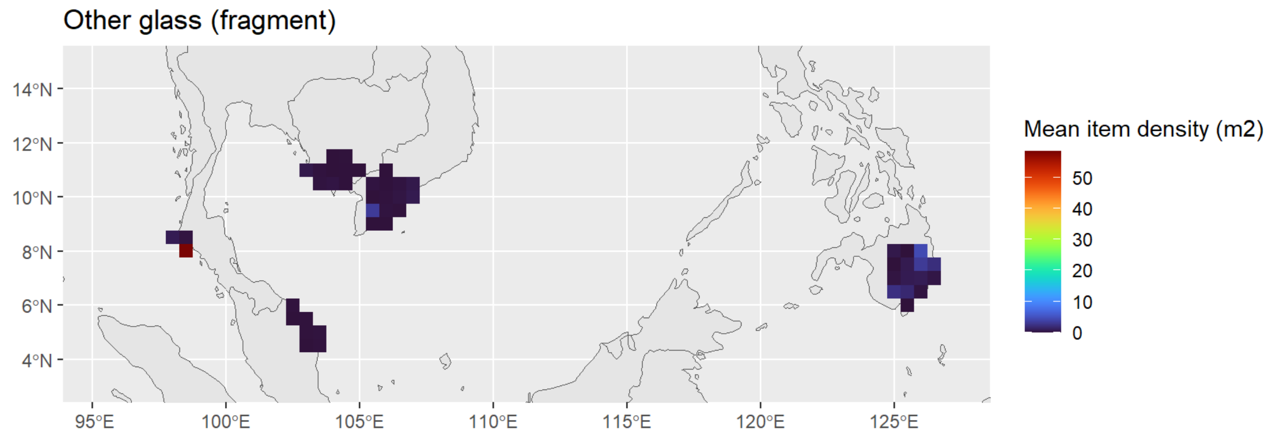
Top four, five and six most common whole items in region in each 0.5° tile (corresponding to an approximately 55km x 55km grid cell).



Top three most common of the top six items fragments in region in each 0.5° tile (corresponding to an approximately 55km x 55km grid cell).







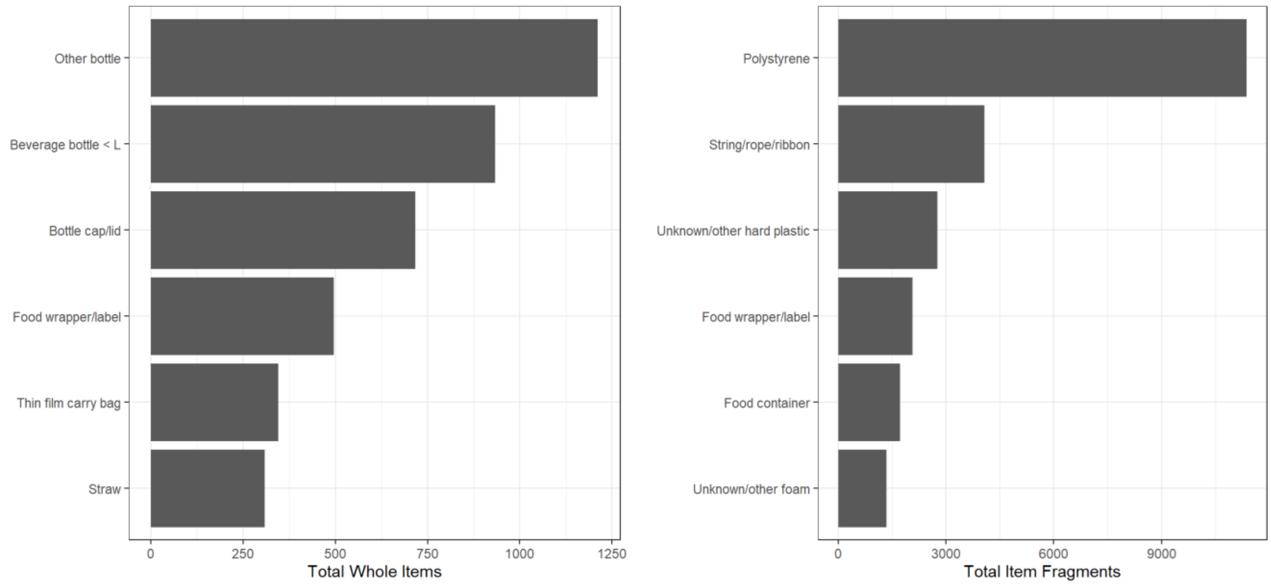
Top four, five and six most common items fragments in region in each 0.5° tile (corresponding to an approximately 55km x 55km grid cell).

7.2 Items per site type across the region

When litter loads are examined across site types, most items overlap with those that were identified as the six most common overall in the region, though the order of their abundance differs.

Among coastal sites across all countries, five of the six most common whole items were also the most common whole items regionally (cigarette butts did not occur among the top six most common but were ranked 10th). Plastic straws, which did not occur among the regional top six (straws were the 8th most common whole item overall) were the 6th most common whole item on coasts. Among fragmented items, four of the six most common fragments regionally also occurred in the top six item fragments on coasts. These included polystyrene, string/rope/ribbon, other hard plastic and food wrappers. Two additional items were among the top six on coasts, food container fragments (ranked 5th on coasts, ranked 7th regionally) and unknown/other foam fragments (ranked 6th on coasts, though not among the top 10 regionally).

In many cases, the transport potential of different items, such as their buoyancy (relating to transport in water and by heavy rain, e.g. beverage bottles), windage (tendency to be readily moved by wind, e.g. polystyrene) or capacity to snag in the environment (e.g. string/rope/ribbon) related to which items occurred among the top six most common in different sites. The items that are common on coasts, both whole and fragmented are overrepresented by lightweight, buoyant items that are readily transported down waterways and beached by wind and wave action on coastlines and in the backshore. For example, items such as bottles and foam (polystyrene and other) often protrude fully or partially from the sea surface when drifting and are readily moved by wind across the water's surface. Polystyrene foam fragments dominated beached litter across the region. All other beached litter items, except for other foam fragments, were dominated by a variety of single-use plastics, mostly relating to food and beverages. Thin film bags were commonly observed to be associated with transporting food and beverages.

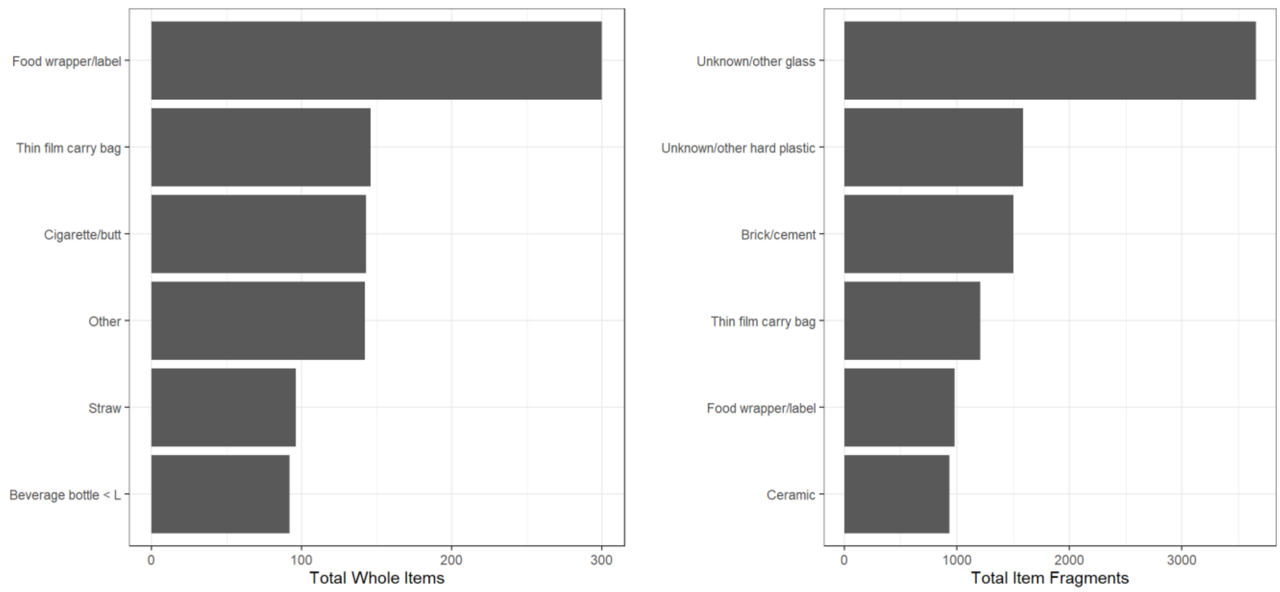


Six most common whole and fragmented items encountered on coastlines in the region. Note that these are raw counts only and not weighted by country.

Among river sites, four of the six most common whole items were also the most common whole items regionally. Interestingly, other bottles and bottle caps did not appear among the top six items in rivers. We posit this is because buoyant items likely rapidly transit downstream once they enter waterways, especially given the regular heavy rainfall experienced in South-east Asia. Hence, such items may be less likely to spend a long time snagged or residing on the riverbank. Other items, which is a broad category capturing a myriad of item types that do not fit other categories were the fourth most common whole item type in rivers. Plastic straws, which did not occur among the regional top six (straws were the 8th most common whole item overall) were the 5th most common whole item on rivers banks.

Among fragmented items, four of the six most common fragments regionally also occurred in the top six item fragments on coasts. These were other glass, other hard plastic, brick/cement and food wrappers and labels. We note that up to three of these items are not buoyant (hard plastic fragments buoyancy depends on the polymer type), and that soft plastics such as food wrappers are readily snagged in riverside vegetation or partially buried in riverbank substrates. The additional two additional items among the top six fragments along rivers included thin film carry bags (ranked 4th in rivers, ranked 7th regionally) and ceramic (ranked 6th in rivers and 10th regionally).

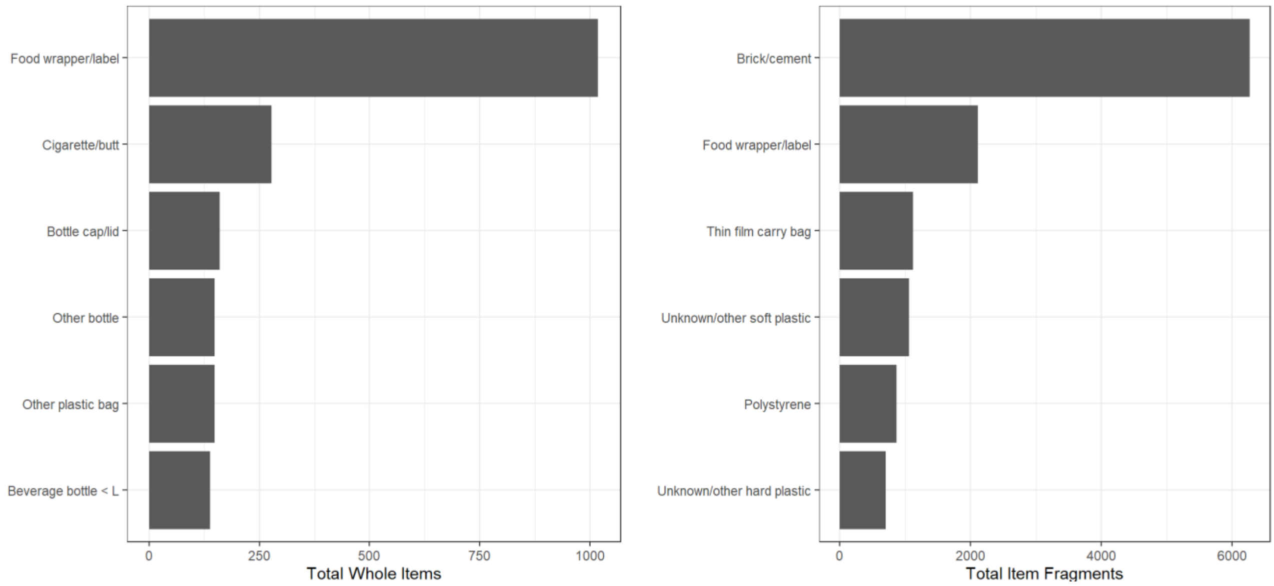
The items that were most common in river surveys were over-represented by negatively buoyant (sinking) items and those that tend to snag (such as ceramic and thin film bags, respectively). We posit that this is because the items more likely to be encountered in riverbank surveys are those that are more resistant to being moved downstream following heavy rain or flooding, which would include sinking items (plastic polymers that are denser than water, brick, cement and ceramic) and those that become tangled or entrapped in riverbank vegetation, substrate or mud (plastic bags, food wrappers and labels). Highly buoyant items were less well represented, likely because they transit downstream, especially after rainfall events. As these surveys count items on the riverbank, results may differ from items encountered in surveys of the river water.



Six most common whole and fragmented items encountered on riverbanks in the region. Note that these are raw counts only and not weighted by country.

Among inland sites, five of the six most common whole items were also among the most common whole items regionally. This included food wrappers and labels, cigarette butts, bottle caps, other bottles and beverage bottles. However, thin film carry bags were not among the top six (though it ranked 7th), instead other plastic bags was the 5th most common inland item recorded across all five countries. Among fragmented items, four of the six most common fragments regionally also occurred in the top six item fragments inland. These were brick/cement, food wrappers and labels, polystyrene and other hard plastic. The items that did not occur in the regional top six fragments included thin film carry bag fragments (ranked 3rd inland and ranked 7th regionally) and fragments of other plastic bags (ranked 5th inland though not among the most ten common items regionally). From our on-ground observations during surveys, these other plastic bag fragments were predominately woven polypropylene bags/sacks, which readily fragment. Most woven polypropylene sacks that we observed were cement bags, rice bags or livestock feed.

The items that were most common in inland surveys tightly correlated with the most common items regionally, especially for whole items. We suggest that the strong overlap between inland items and the top six most common items regionally is that most debris recorded across these surveys have their origins on land as mismanaged waste. Most of these items were single-use plastics, associated with food and drink. Cigarettes were also highly represented and have previously been found to be the single most common land-based item in a global survey (Hardesty et al., 2021). This is due to a global cultural phenomenon whereby cigarette butts are extinguished / disposed on the ground. An exception to this is other bags (predominantly woven polypropylene bags), which were often seen in degraded condition indicating re-use. However, this led to pollution by fragments of woven polypropylene pollution as the bags degraded. Managing items before they enter waterways presents an opportunity to reduce the input of plastic waste to the environment at its source.



The six most common whole and fragmented items inland on coastlines in the region. Note that these are raw counts only and not weighted by country.

The overlap in the top six common whole items between regional and site levels. The top six items globally occur also in the top six among most site types.

Whole items – top six most common regionally and across site types				
	Regional	Coastal	River	Inland
Food wrapper / label	1st	4th	1st	1st
Other bottles	2nd	1st		4th
Beverage bottle	3rd	2nd	6th	6th
Bottle cap	4th	3rd		3rd
Cigarette butt	5th		3rd	2nd
Thin film carry bag	6th	5th	2nd	
Straw		6th	5th	
Other			4th	
Other plastic bag				5th

The overlap in the top six common item fragments between regional and site levels. The top six items globally occur also in the top six among most site types.

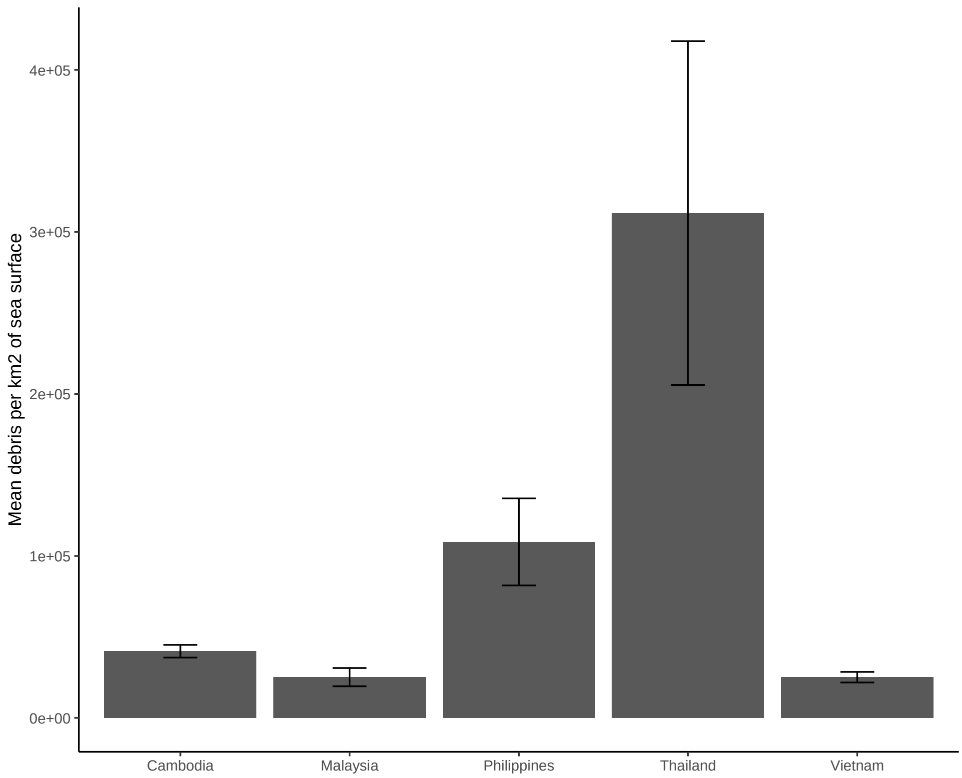
Fragment items – top six most common regionally and across site types				
	Regional	Coastal	River	Inland
Polystyrene	1st	1st		5th
Brick/cement	2nd		3rd	1st
String/rope/ribbon	3rd	2nd		
Food wrapper / label	4th	4th	5th	2nd
Other hard plastic	5th	3rd	2nd	6th
Other glass	6th		1st	
Food container		5th		
Other foam		6th		
Thin film carry bag			4th	3rd
Ceramic			6th	
Other soft plastic				4th

8 Regional assessment of floating debris at sea

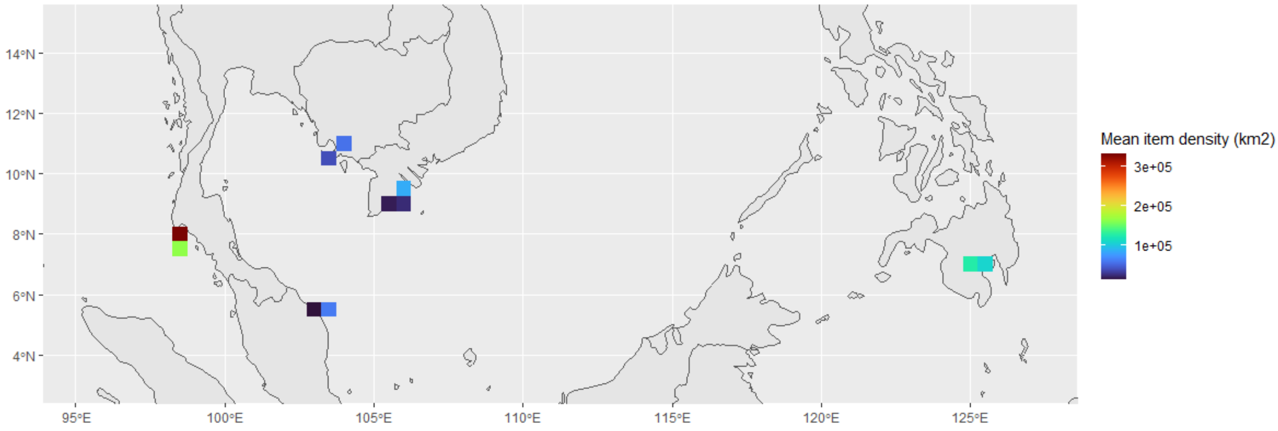
8.1 Debris density across the region

Debris density at sea varied across the region. In each country, 27 tows were conducted, (Cambodia n = 514 items, Malaysia n = 367 items, Philippines n = 1406 items, Thailand n = 5276 items and Viet Nam n = 653 items). The total sea surface area surveyed covered 86,251m^2 in which 8216 items were recorded and collected. When converted to debris density, the sea surface in Phang Nga Bay, off Phuket, Thailand had the highest density of items (311,680.2±106,115.0 items/km^2), followed by Davao Gulf, off Davao, Philippines (108,652.6±18,815.4 items/km^2), Gulf of Thailand, off Sihanoukville, Cambodia (41,166.2±3,971.4 items/km^2), Malaysia (25,165.0±5,638.9 items/km^2) and South China Sea, off Bạc Liêu, Viet Nam (25,124.0±3,260.0 items/km^2).

The average debris count in Phang Nga Bay was nearly triple the density of the next highest debris count. We note that the trawl surveys were conducted early during Thailand's monsoon season, with heavy rains occurring soon before the dates that trawls were conducted. We recommend that future trawl surveys are conducted during the dry season. It is noteworthy that the second highest debris densities occurred Davao Gulf, Philippines, where the trawl samples were conducted within the gulf. The lower densities sampled in other countries occurred in open water bodies.



The highest at-sea debris loads recorded across the region occurred the sea off Thailand had the highest density of items (311,680.2±106,115.0 items/km2), followed by Philippines (108,652.6±18,815.4 items/km2), Cambodia (41,166.2±3,971.4 items/km2), Malaysia (25,165.0±5,638.9 items/km2) and Viet Nam (25,124.0±3,260.0 items/km2).



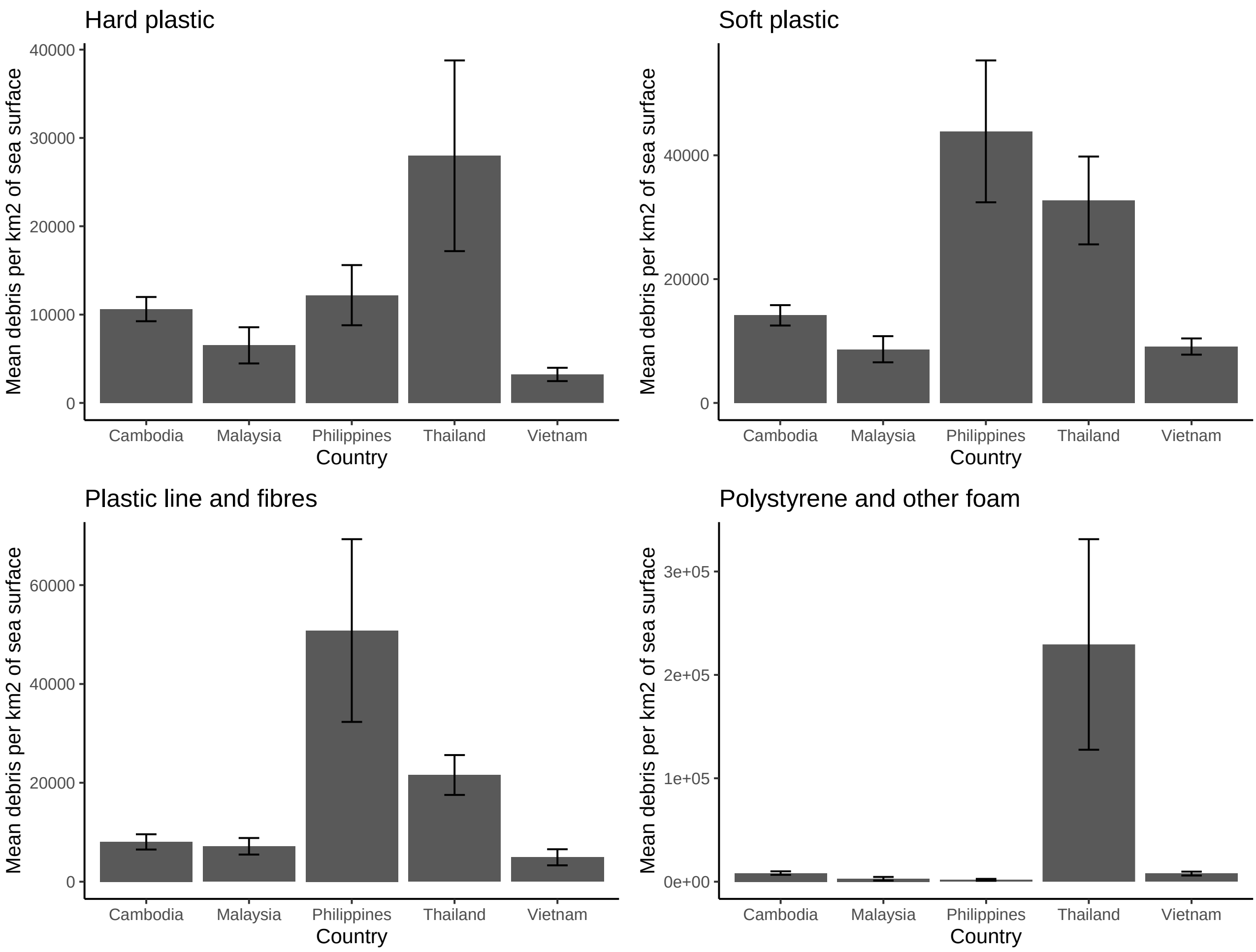
The highest debris densities occurred in two enclosed bays: the Phang Nga Bay, off Phuket in Thailand and Davao Gulf, off Davao in the Philippines. The lower densities occurred in open water bodies. Debris densities are shown in 0.5° tiles, corresponding to an approximately 55km x 55km grid cell.

8.2 At-sea items across the region

Given that only a few item types float at sea, the trawl surveys are constrained to four item types: hard plastic, soft plastic (includes food wrappers, plastic bags etc.). plastic line and fibres (including plastic rope) and polystyrene and other foams. The most common litter items encountered across the region are reported in this section. The most common item encountered in trawl surveys was polystyrene and other foams (predominantly polystyrene, n = 4085), followed by soft plastic (mostly indistinguishable soft fragments, though distinguishable items included food wrappers and plastic bag fragments, n = 1717), plastic lines and fibres (much of this was fragments of rope, n = 1416) followed by hard plastic (mostly indistinguishable hard fragments, n = 998). Note that these are raw counts of items and are not weighted for country or the amount of water that passed through each tow net. For the remainder of this section on trawl sampling, these results are standardised to items per km^2 of sea surface so that the item densities can be compared between countries.

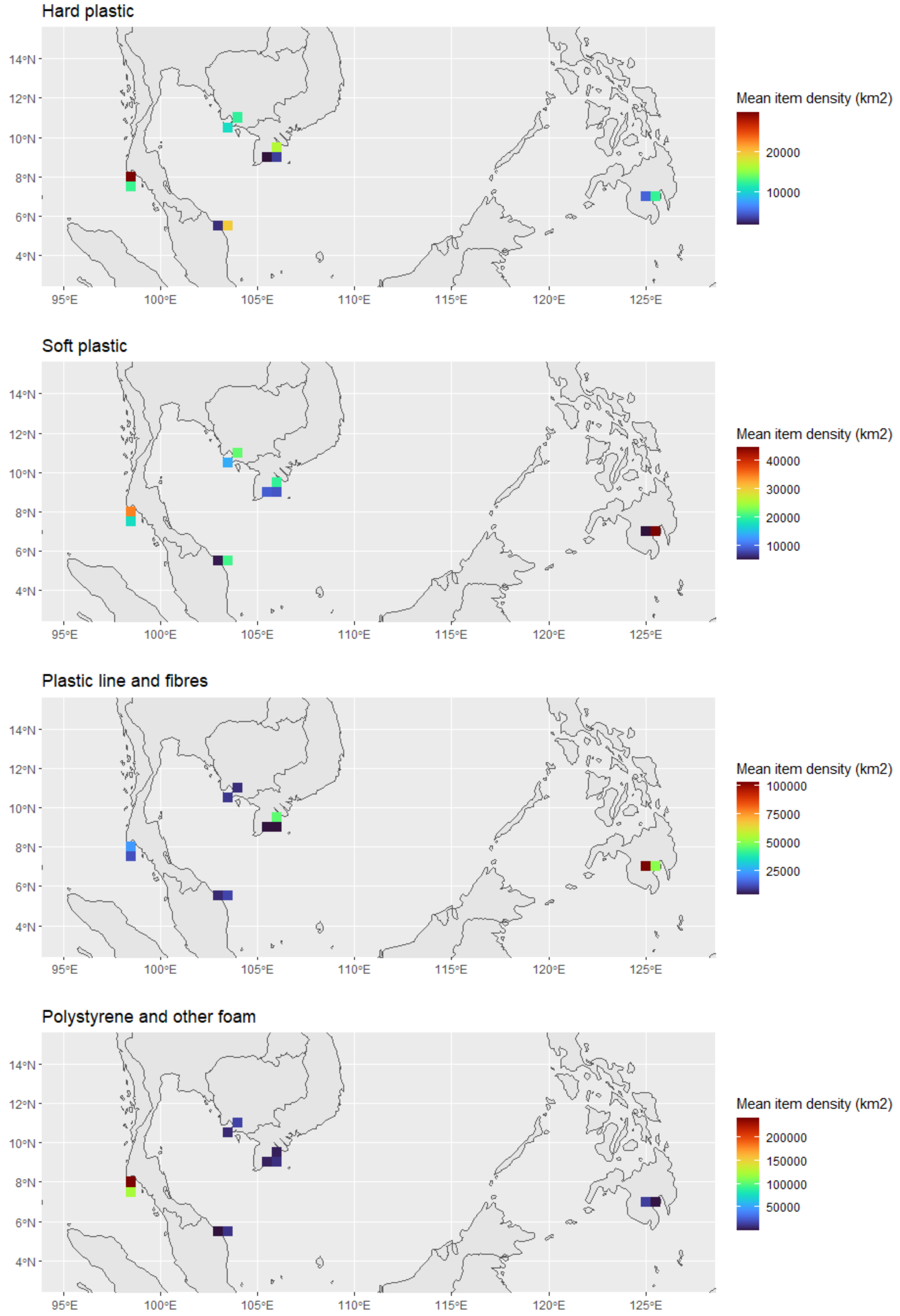
Preparing a standardised manta tow net used for sea surface trawl sampling.

The amount and type of debris somewhat varied by area, though some areas contained similar densities of floating items of a particular type. For example, Thailand had much higher densities of floating polystyrene foam and hard plastic than other countries, and Philippines has much higher densities of soft plastic, and plastic lines and fibre than other countries. The relative proportions of floating plastic lines and fibres was similar off Cambodia, Malaysia and Viet Nam, held similar sea surface densities of most items, though Cambodia was usually the higher of the three across all four item types.



Polystyrene was the most abundant item encountered at sea in the region, followed by soft plastic and plastic lines and fibres. Hard plastic was the least common item found in the trawl nets.

Participants emptying the cod end of a manta trawl net during trawl sampling off Davao in the Philippines.



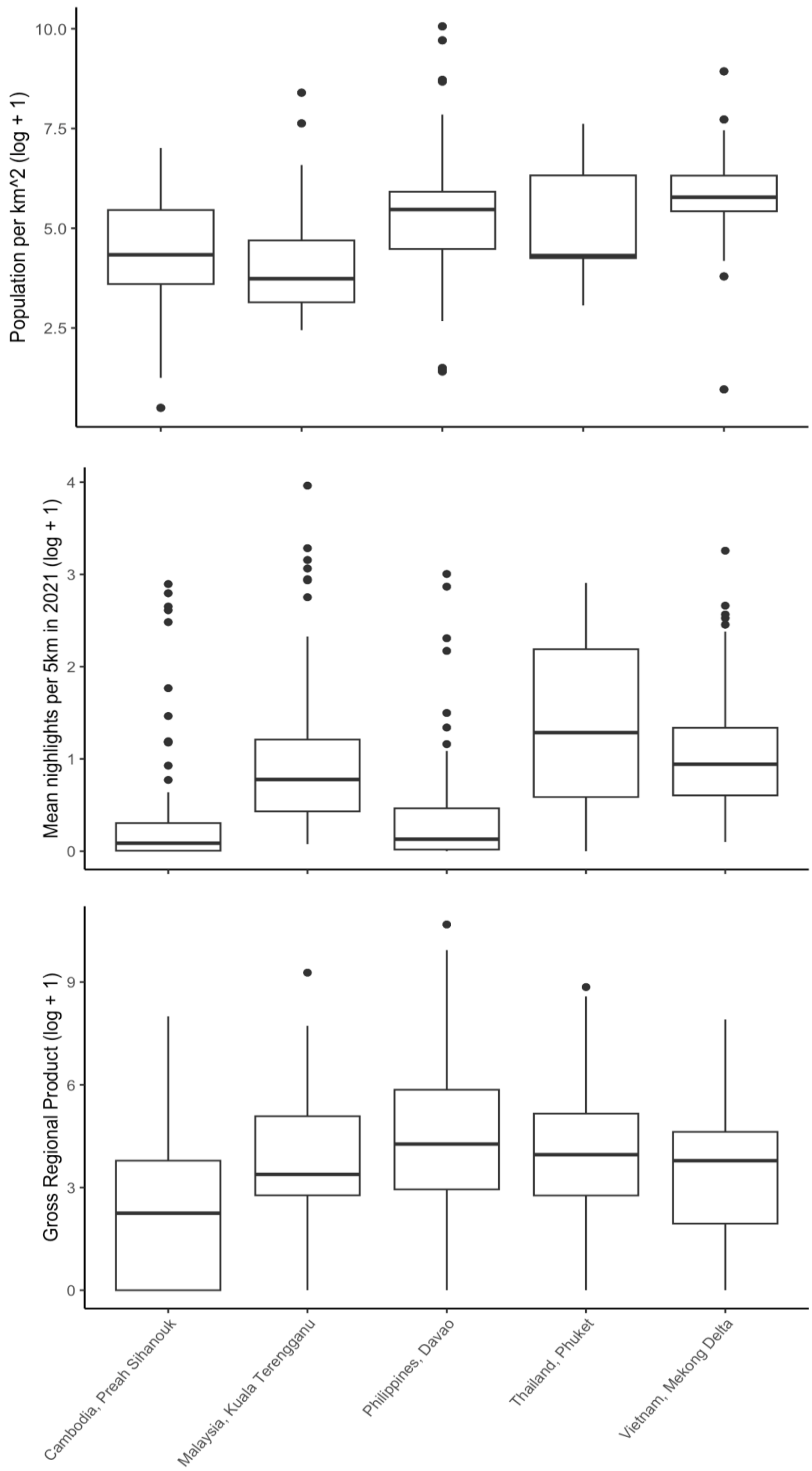
The different types of marine litter varied by location. Note that semi enclosed bays had higher counts.

9 Understanding patterns of debris in the region

To design effective interventions and prevent mismanaged waste from entering the sea, it is important to understand what is driving the distribution of debris. Based on previous work, we investigated several different factors that could influence debris distribution. At each survey site, we collected information on the local conditions, such as the number of visible humans, the slope of the land, whether dumping had occurred, the height of the vegetation, the percent of the transect that was bare ground, and the type of land-use (e.g. residential, agricultural, natural etc.).We also integrated information from globally available GIS layers, including the local population density, land use type, distance to the nearest road, and distance to the nearest river. We also used proxies for socio-economic status, including night lights within a 5 km radius of the site, and the Gross Regional Product (WorldBank) as an indication of the regional economy.

These covariates were included in a statistical model to determine which factors are most strongly correlated with debris amounts in the survey sites. We used debris data from all five countries considered in this report, except for data from 3 sites that were considered outliers for the purposes of analysis. These included one inland site from Viet Nam (site ID VICTI30), one river site from Thailand (site id THPHR11), and one coastal site from Thailand (site ID THPHC01). To be able to directly compare the covariates and determine how certain factors influence debris density, we calculated the effect size. Terms with a positive effect size have a positive correlation with the amount of debris, while terms with a negative effect size are negatively correlated with the amount of debris. The higher the absolute value of the effect size, whether positive or negative, the more that covariate explains the variability in the debris found.

Factors that influence debris density in the environment vary depending on whether locations are inland, along riverbanks, or along the coastline. As such, we have examined the inland, river, and coastal surveys conducted in each country separately. We have also considered each country as a covariate within the model to account social, cultural, and other differences among countries that can influence debris density.



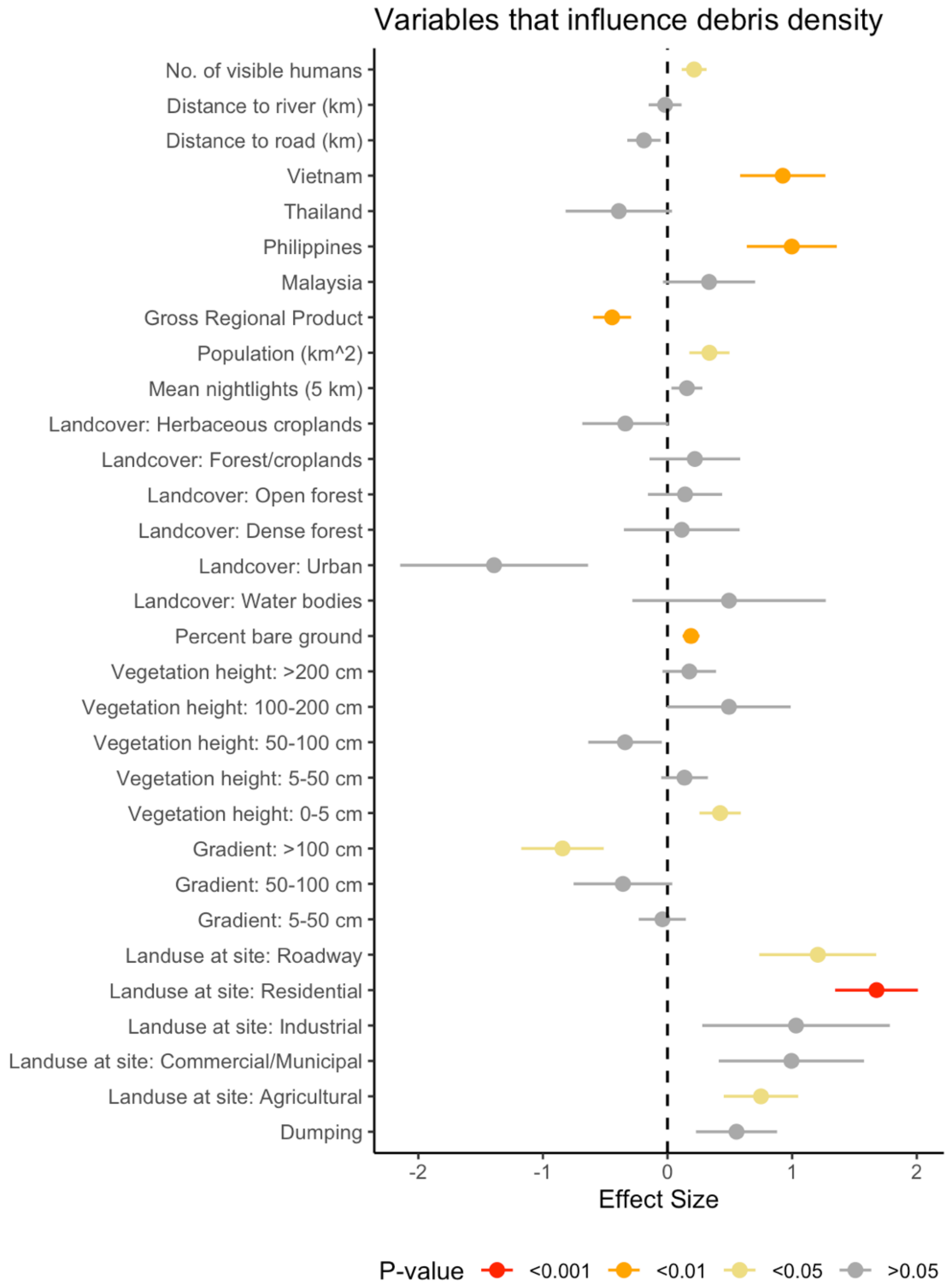
Boxplot showing the distribution of three socio-economic covariates used in modelling: Population per km^2; mean 2021 nightlights per 5 km^2; Gross Regional Product. Each are presented on a log scale to facilitate visualization.

9.1 Inland debris

The inland debris density model fit the data very well, explaining 62% of the data from 519 transects across the five countries included in the regional analysis. At inland sites, the model describing debris density indicated that debris density was lowest in natural/parkland land-use areas compared to residential, agricultural, and roadway land-use areas. Debris density was also driven by the regional population and economy, with debris increasing in areas with more people and less economic output.

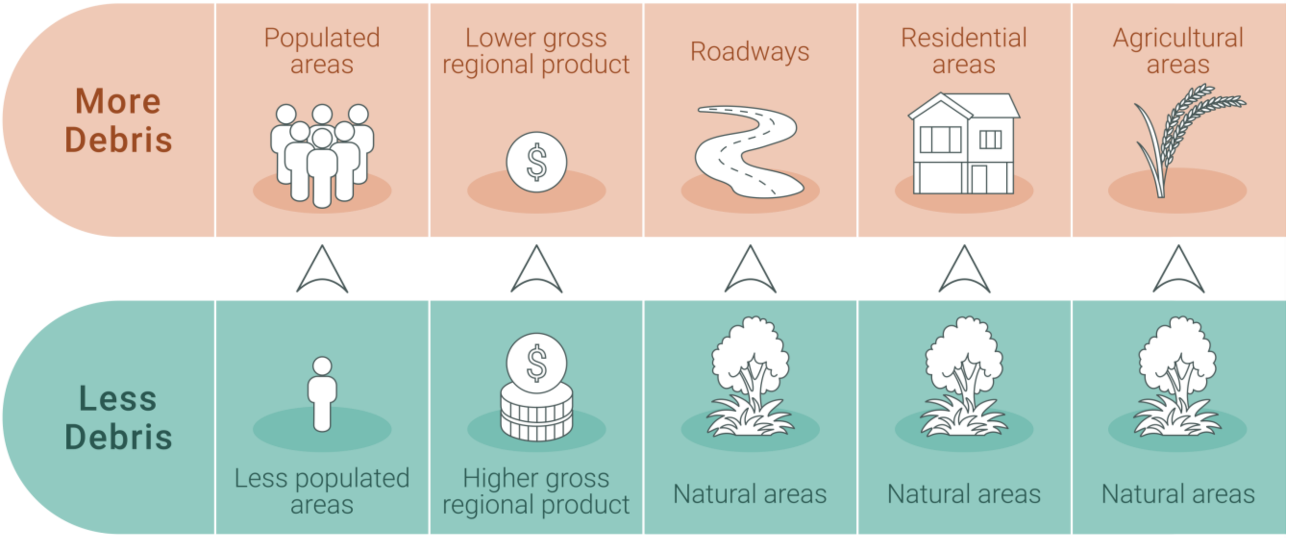
At the transect level, local factors were also important in describing the amount of debris. For example, transects with steep gradients had less debris, presumably due to debris less likely to accumulate in steep areas. Debris was also more common in areas with no vegetation and higher proportions of bare ground. This may reflect debris in urban areas (e.g. concrete, roads, paved surfaces), as well as the fact that debris is easier to see with the human eye when there is no vegetation. Debris density was also found to be higher in areas where dumping had been noted by the survey team, although this relationship was not statistically significant.

Photo of an example inland transect: a palm plantation in Malaysia (site MALKTI32). Of the 328 items recorded at this site, 226 of them were classified as insulation/stuffing fragments.



Effect sizes for each variable that describes debris density at inland sites. Colour represents the significance levels, lines are the standard error for each item, and points are the model coefficient estimates. Categorical variables are compared to a reference level: Land use reference is natural/parkland, landcover reference is natural herbaceous, vegetation height reference is no vegetation, gradient reference is flat, country reference is Cambodia. For example, Viet Nam has significantly higher inland debris density than Cambodia. Residential land use areas have significantly higher debris that natural/parkland land use areas.

Significant factors describing the density of debris
INLAND



Some of the main covariates that explain debris density at inland sites.

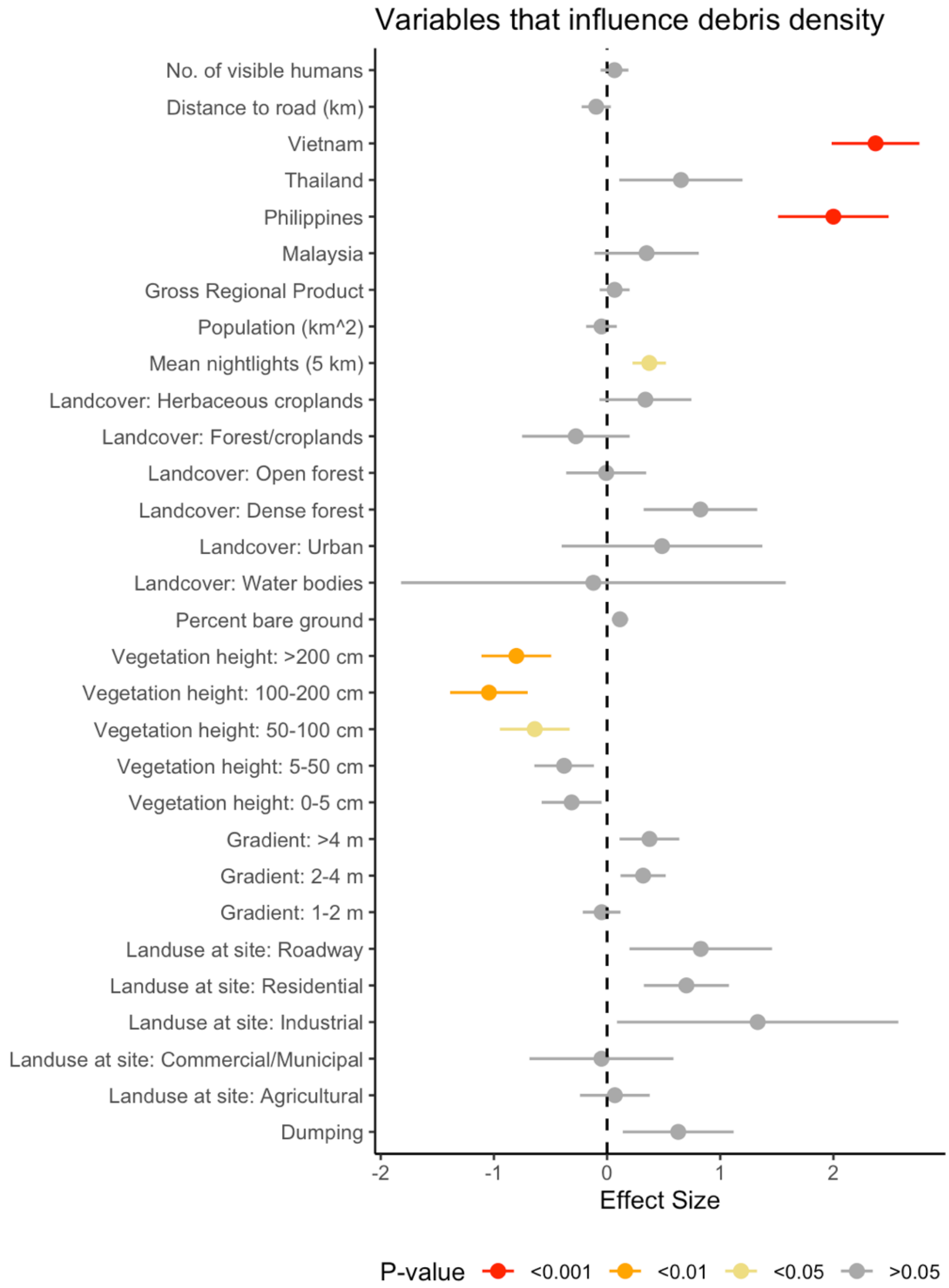
Participants walking to an inland site in a coastal residential area in Cambodia.

9.2 River debris

The river debris density model fit the data well, explaining 73% of the data from 411 transects across the region. Across all five countries, debris density along rivers was significantly higher in areas that were more developed, as indicated by the amount of night lights in a 5 km area. Debris density in rivers was not correlated with population or Gross Regional Product, as was seen for inland sites, nor did it correlate with socioeconomics. River debris density also varied significantly between countries, with Viet Nam and Philippines having significantly more debris along rivers compared to Cambodia, Malaysia, and Thailand.

At each transect surveyed, the local vegetation height on the riverbank were also important in describing the amount of debris. Debris density was significantly lower at transects with vegetation > 50cm (waist high) compared to no vegetation. Debris density was also found to be higher in areas where dumping had been noted by the survey team, although this relationship was not significant.

Litter can become trapped in the vegetation along riverbanks. Here a participant finds a whole plastic bag, among other items, in the thick riverbank vegetation in a river survey in Phuket, Thailand.



Effect sizes for each variable that describes debris density at river sites. Colour represents the significance levels, lines are the standard error for each item, and points are the model coefficient estimates. Categorical variables are compared to a reference level: Land use reference is natural/parkland, landcover reference is natural herbaceous, vegetation height reference is no vegetation, gradient reference is flat, country reference is Cambodia. For example, Viet Nam has significantly higher debris density in rivers than Cambodia.

Significant factors describing the density of debris
RIVERBANKS

Some of the main covariates that explain debris density at river sites.

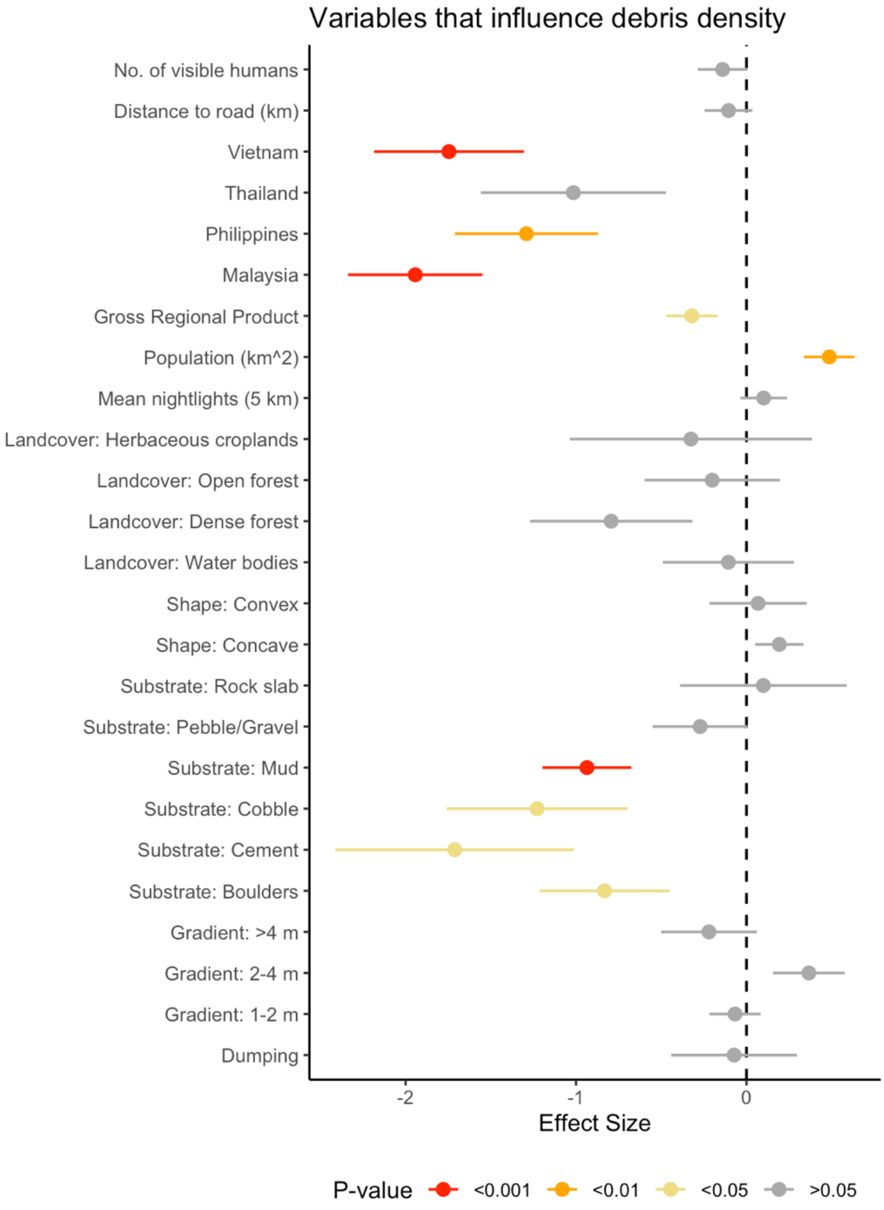
River sites with no vegetation had more debris than those that were vegetated.

9.3 Coastal debris

The coast debris density model fit the data very well, explaining 79% of the data from 281 transects across the region. At coastal sites, debris density was driven by the regional population and economy, with debris increasing in areas with more people and less economic output (as measured by gross regional product). This is a similar result to the findings from inland sites across the region. Substrate at coastal sites was also an important element that related to density of debris. Debris density was significantly lower in mud, cobble, cement, and boulder substrates compared to sandy coastal sites. Coastal debris density also varied significantly between countries, with Cambodia having higher coastal debris than all the other countries. This relationship was significant with Viet Nam, Philippines, and Malaysia but not Thailand.

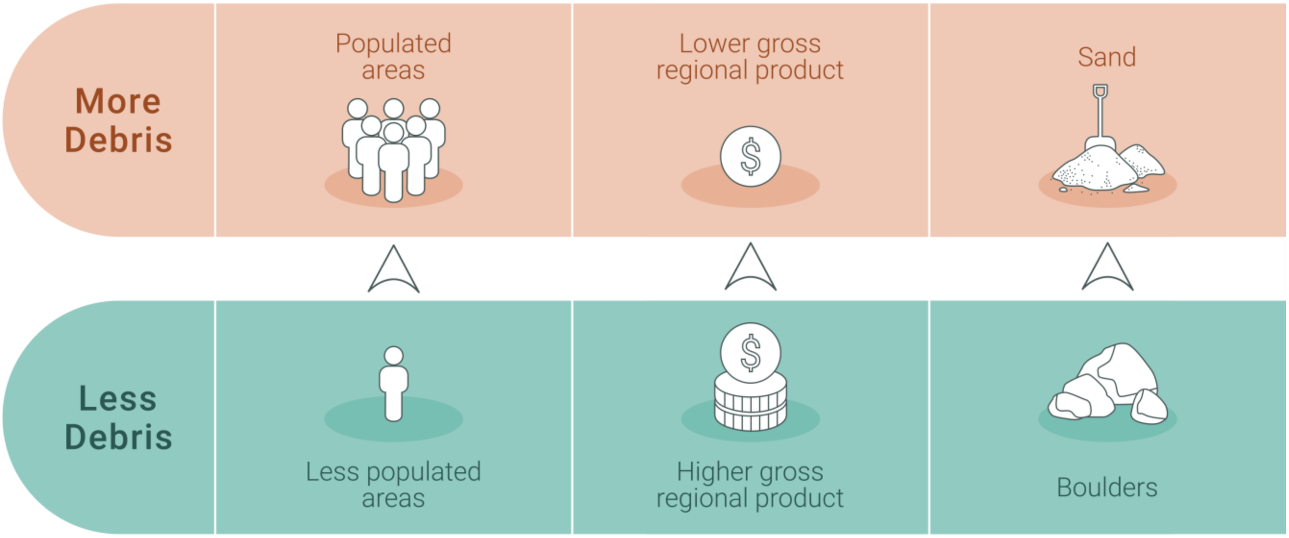
Coastal sites contained some of the highest debris densities of all sites in the East Asia region.

Sandy coastal sites had more litter, on average, than those with boulder or rock slab shorelines.



Effect sizes for each variable that describes debris density at coastal sites. Colour represents the significance levels, lines are the standard error for each item, and points are the model coefficient estimates. Categorical variables are compared to a reference level: Landcover reference is Natural Herbaceous, gradient reference is flat, substrate reference is sand, country reference is Cambodia. For example, Viet Nam has significantly higher debris density in rivers than Cambodia.

Significant factors describing the density of debris
COASTS



Some of the main covariates that significantly explain debris density at coastal sites.

Food and beverage related litter, as well as bags of domestic waste, were often recorded next to roadways at inland sites in Cambodia, whist zero debris counts were not unusual in natural area inland sites such as those in forest, scrub and other remote areas far from towns and sealed roadways.

10 Region-wide patterns

10.1 Regional similarities in litter throughout East Asia

There were a number of similarities in the patterns of litter accumulation in the East Asia region. Three distinct region-wide similarities included:

1. The density of litter was highest at coastal sites.
2. Fragments of polystyrene foam were the single most abundant item across the East Asian mainland.
3. Single-use plastic litter associated with food and beverages dominated litter loads across inland, river, and coastal compartments.

However, we also found that some patterns differed between the Philippines and the other four countries, discussed here briefly.

High litter density at coastal sites

Debris density being highest at coastal sites was a region-wide pattern, the only countries where this didn't hold true was for the Philippines and Viet Nam. For the Philippines, we believe that the data collected and presented here accurately reflects the situation. Litter patterns in the Philippines were uniquely different to the other four countries, discussed in further detail in the following "differences" section. However, for Viet Nam, we believe this finding is likely not representative of the area and influenced by the accessibility of coastal sites due to mangrove forests in the Mekong Delta, explored later in this section.

Litter trapped in mangrove backshore at a coastal site in Cambodia.

High loads of plastic litter accumulate in coastal sites due to a combination of three primary mechanisms: littering, urban runoff from coastal watersheds/rivers and onshore transport of debris from the existing reservoir of materials in offshore marine waters (Willis et al., 2017). Rivers are also a significant transmission source of debris from the land to the ocean, with an estimated 1.15–2.41 million tonnes of plastic waste estimated to enter the ocean from rivers annually (Lebreton et al., 2017), of which a proportion becomes deposited on coastlines. Debris deposited on the coast significantly increases with proximity to urban areas (Hardesty et al., 2017). Monsoon rains are well-recognised to transfer plastic across compartments from inland, through waterways and into the ocean in equatorial coastal regions (Jong et al., 2022), representing the processes also likely occurring in this region. For example, recent research has found that plastic abundance in sea surface trawls conducted in the wet season is significantly higher than those reported in the dry season in the Gulf of Thailand (Nakano et al., 2024). Heavy seasonal rains flushing land-based litter from inland sources, through waterways and into the sea, is likely the reason why higher debris loads were recorded on coastlines than inland and river environments in four of the five countries reported on during this effort.

As previously mentioned, we believe that the coastal debris density reported for the Mekong delta in Viet Nam is likely an underestimate of true litter loads. Briefly, many coastal sites in Viet Nam's Mekong Delta were not able to be accessed due extensive mangrove forest covering kilometres between the backshore and the water's edge. Furthermore, the tidal range in this area could also vary 1-2km in these environments. Surveyors observed very high densities of debris trapped within these mangrove forests, however these could not be surveyed due to access, compromising the representativeness of coastal surveys for quantifying litter in this dominant coastline type. Where coastal sites were able to be surveyed, these occurred mostly to the far north of the delta, and included a high proportion of seawall sites, which are known to trap less litter than other backshore types.

Mangrove environments are well recognised as unique but understudied traps for anthropogenic marine debris in coastal environments, because the structure of mangrove roots trap debris (Luo et al., 2021; Martin et al., 2019). Due to the difficulty of access, mangroves are an understudied coastal habitat for plastic pollution compared to other coastline types, and there is a lack of studies using standardised methodologies and reporting categories comparing mangroves with other coastline types (Luo et al., 2021). Where previous studies have compared litter loads between mangroves and sandy beaches (recognised to trap more debris than other coastal substrate types in this report), it was found that there is a higher mass of plastic items in mangroves than beaches, and that they particularly trap large objects (Martin et al., 2019). Therefore, we posit that it's likely that the coastal litter loads reported for the Mekong Delta in this study are underestimated, and real coastal debris loads, were we able to access these mangrove coastal sites, are likely much higher than reported here.

Trying to access coastal sites proved a challenge in the Mekong Delta region of Viet Nam, where extensive mangrove forests prevented access to many natural coastal sites. Furthermore, the tide in the Mekong Delta left many kilometres of silt to reach the water's edge at low tides. The authors observed large amounts of debris trapped within these mangrove forests, which was difficult to account for in this survey due to accessibility, and consequently, coastal debris loads are probably underestimated in the Mekong Delta

An abundance of polystyrene foam fragments

Fragments of polystyrene foam were the single most abundant item recorded throughout the surveys; a pattern detected in all countries except for the Philippines (discussed later in the regional differences section). Polystyrene foam was predominately found in coastal environments, but also was abundant in sea surface trawls. While polystyrene foam did occur inland, it was only the 5th most common item, suggesting that the origin of these items may be sea based or close to coasts, with a small fraction of the total foam originating from inland sources. The overwhelming abundance of polystyrene foam as a common item in surveys, especially in coastal surveys, reflects the results of other studies conducted using CSIRO methodology in Asia, where polystyrene foam was also the single most abundant item recorded in the Republic of Korea (CSIRO Marine Debris and OSEAN teams, 2021) and a previous survey of Hai Phong in Viet Nam (CSIRO Marine Debris Team and GreenHub, 2021). Ultimately, these findings suggest that polystyrene litter is a region-wide problem.

Polystyrene pieces are generated from the fragmentation of larger polystyrene foam items. Polystyrene foam is ubiquitous in Asia for both transporting goods in boxes, protecting fragile items in packaging, in floats used for fishing and in some areas, and as a base for floating structures. Because polystyrene fragments recorded in these surveys are heavily fragmented, it is not usually possible to determine the original item or source. Given their abundance, we note that polystyrene presents an opportunity for debris reduction and/or mitigation measures.

Dominance of single-use plastic associated with food and beverages

One significant pattern that emerged across all five countries in the region was the dominance of single-use plastic items associated with food and beverages. This pattern transcended country and compartment, with this group of items dominating inland, rivers and coasts throughout the region. Within the broader trend of single-use plastic associated with food and beverage, two specific items stood out. Food wrappers and labels, and plastic bottles (and their caps). Specifically,

1. Food wrappers and labels were among the most common whole and fragmented items regionally.
2. Plastic bottles and their caps were among the most common whole items in all environments throughout the region.

Single-use plastics, especially those associated with the food and beverage industry, are well recognised to be among the most common debris items found in marine environments worldwide (Hardesty et al., 2021; Roman et al., 2020). At a global scale, food wrappers are recognised as the third most common item recorded in coastline clean-up activities worldwide from data collected across 86 countries, beverage bottles the fourth most common, and bottlecaps the fifth (Roman et al., 2020). Though this trend occurred across the region, it was particularly pronounced in some countries. Specifically, food wrappers and labels dominated debris in the Philippines, being the top most common item in this country, a trend previously highlighted through a global analysis where the Philippines was identified as having the highest densities of food wrappers in coastal environments in the world (Hardesty et al., 2021). This study reported that the Siargao Islands in the Philippines had the highest density of food wrappers in the world, with an estimated 1,348 food wrappers/km along the coastline (Hardesty et al., 2021). This finding is likely attributable to local cultural practices in the Philippines that favour single-use packaging for affordability and convenience. Specifically, Filipinos have the "tingi" culture where products are taken and used in smaller quantities and hence, are sold in the immediate quantity needed. However, this practice of selling items in single use sachets is not unique to the Philippines and can be found throughout Asia. In Cambodia, though bottled water was categorised as "other bottle" rather than "beverage bottle" it was the most common whole item recorded, potentially highlighting a country-specific issue with access to potable water. Previous studies examine debris in coastal areas worldwide found that plastic bottle litter, encompassing both bottled water and sweet or carbonated drinks, is found in high densities across the worlds tropics (Hardesty et al., 2021). In these respects, the patterns we found in the East Asia region through this multijurisdictional survey effort support that the items dominating litter in Asia do not differ substantially from globally abundant items. None the less, the densities of these items found in the surveyed countries in Asia are significant and highlight the need for regional collaboration to reduce litter entering the environment.

Differences in the distribution and types of litter items in the Philippines compared to the four other countries

Philippines differed to the four other countries in numerous ways, including where debris was distributed (higher densities along rivers rather than coastlines) and the types of debris that were most abundant (less polystyrene foam and more soft plastic food packaging in all land-based site types and at sea). From a management perspective, this means that the Philippines may require specific management actions to target local litter patterns.

That we found higher litter densities in rivers than on coastlines does not necessarily reflect that Philippine rivers are unusually littered regionally, but rather that litter may be less likely to become beached on coasts compared to the other survey areas. For example, we found that though the Philippines had its highest litter densities in rivers, the average river litter density was not higher than other countries in the region. The coastlines surveyed, except those directly bordering the semi-enclosed Davao Gulf, face the Philippine Sea where physical ocean drivers may transport debris offshore into the North Pacific Ocean. This differed from many of the other survey locations where coastlines were not open to as extensive of an open water body. In fact, Philippines had the fewest beached items of all countries surveyed. Debris beached on coastlines, as highlighted earlier, accumulates due to a combination of littering, urban runoff and onshore transport of debris from the existing reservoir of debris floating offshore in marine waters (Willis et al., 2017). Therefore, a detailed investigation of oceanographic forcing (ocean currents, prevailing wind direction) would provide stronger insights into the accumulation patterns of debris on coastlines throughout the region.

Though riverbanks in the Philippines had higher litter densities than coastlines, these litter densities were within the range of riverbank litter densities throughout the region.

The types of debris found in the Philippines was uniquely different to the remaining four countries. Specifically, less polystyrene foam occurred compared to other areas. The reason for this is not currently known. As mentioned previously, the Philippines had higher densities of food wrappers than other locations, attributable to the “tingi” culture where products are used and sold in smaller quantities. Though this also occurs elsewhere throughout the region, given its widespread practice in the Philippines, addressing plastic waste generated by tingi is a unique management opportunity to reduce the single most abundant plastic items polluting the natural environment in the country.

Food and beverage associated litter caught among water hyacinth along an urban riverbank in Viet Nam.

10.2 Socioeconomic and land use patterns across the region

Overall, we found that socioeconomic variables and land use types played a role in describing debris loads across the region. However, the relative role of these variables varied across compartments. In general, we found that areas that were more populated, had smaller economic output, and more intensive land uses had higher debris density.

Environmental debris is a function of both socioeconomic and local landscape factors

We found debris in the environment was related to both broadscale socioeconomic factors as well as fine-scale transect-level factors, such as debris varying between paved or vegetated surfaces. Despite the vast degree of local scale variability at each transect, the fact that socioeconomic and land use factors were still significant in describing debris density is an important result. Specifically, population, economic output, and land use all describe general patterns in debris density across the region. This is consistent with previous published works that highlight the role of these same factors in litter distribution in other counties outside of south-east Asia (Schuyler et al., 2022; Schuyler et al., 2021). This result also points to the value of conducting a robust survey design that can account for such diverse local and non-local factors. While our assessment also found that debris varied among countries in this assessment, by only examining one city per country it is difficult to understand whether debris density patterns relate to inter- or intra-country dynamics. Future integration of additional surveys in other locations and countries will help to improve models and our understanding of the drivers of debris in the environment in south-east Asia.

The influence of socioeconomic factors varied between inland, rivers, and coasts

In this regional assessment, the relative role of socioeconomic factors and land use types varied between the compartments (inland, river, coast) examined. Inland sites have the most variation in surveyed land use types compared to rivers and coastal sites, due to the way that humans occupy and use inland spaces. As such, we see that debris density is higher in areas with more intensive humans uses, such as closer to roads, and in residential and agricultural land use types. Similarly, debris along riverbanks was higher in more urban areas compared to natural areas, and higher along riverbanks with no vegetation. Interestingly, population density and economic production were not important in describing debris density along riverbanks. This pattern likely reflects a spatial scale component, where urban areas were indicated by the average intensity of lighting at night over 5 square kilometres, compared to the more local scale population density at 1 square kilometre. We expect debris along riverbanks to reflect the general land use of a broader catchment area, as debris will accumulate in/near rivers due to local weather effects (e.g. rainfall runoff) and thus the broadscale nightlights factor was more effective at describing debris patterns along rivers.

In coastal sites in the region, we also found that debris density related to the way in which humans likely use coastal areas. Debris along coastlines is a function of local sources (e.g. littering) as well as debris that has arrived from the ocean and been deposited on the shoreline. Thus, our results showing sandy beaches in populated areas had higher debris indicates that much of this debris likely arises from local sources, and not only from ocean deposition. Given our results, it is likely that efforts to mitigate local sources of mismanaged waste at coastal sandy beaches will have a demonstrable effect. However given that we also observed high loads of debris on remote coastlines, managing upstream land-based sources of litter and litter lost at sea would also be important actions to reduce plastic in the East Asian Seas.

The data collected here contributes to a world first, statistically robust, global baseline study of how much waste is lost to the environment. By using the same methodology and building capacity for individuals in multiple countries around the world, we can move towards eventually making predictions about not only local, but also national, regional and global debris losses into the environment. Additionally, we can continue to look at differences in amounts of debris across coastal, inland and riverine areas between countries to identify the drivers that may be similar or different amongst surveyed regions. With a robust, comparable baseline of information gathered in multiple major metropolitan centres around the world, we will have the data in hand to evaluate policy effectiveness and change through on-ground activities at local, national and international scales.

10.3 Comparison with previous estimates of mismanaged waste

The East Asian Seas region is recognised for having high levels of litter leakage from land-based sources (Jambeck et al., 2015; Lebreton & Andrady, 2019; Lebreton et al., 2017; Meijer et al., 2021). Initial estimates of this leakage relied heavily on statistical models based on factors such as population density close to the coastline or waterways and gross domestic product (GDP), but these estimations lacked empirical data. It is important to ground-truth these models with empirical data that has been sampled on a robust and repeatable way. According to Jambeck et al., 2015, the five countries considered in this assessment were ranked, from most mismanaged plastic waste to least, were: Philippines, Viet Nam, Thailand, Malaysia, and Cambodia. Of this ranking, all countries except Cambodia were considered in the top 20 countries globally for high levels of mismanaged waste. However, using empirical data sampled by national baseline surveys and compared within this report, the ranking of countries, from highest average debris density across inland, rivers, and coasts, to least, is: Thailand (4.11 items per m^2), Cambodia (4.06 items per m^2), Viet Nam (3.54 items per m^2), Philippines (2.35 items per m^2), and Malaysia (1.29 items per m^2). This ranking varied among environmental compartments sampled across the region. Specifically, Cambodia had the highest debris density along coastlines (10.56 items per m^2), followed by Thailand (9.75 items per m^2), Philippines (2.53 items per m^2), Malaysia (2.5 items per m^2), and Viet Nam (2.31 items per m^2). For rivers, Viet Nam had the highest debris density (5.74 items per m^2), followed by Thailand (5.68 items per m^2), Philippines (3.55 items per m^2), Cambodia (1 items per m^2), and Malaysia (0.92 items per m^2). For inland, Viet Nam had the highest debris density (2.59 items per m^2), followed by Philippines (1.52 items per m^2), Thailand (1.18 items per m^2), Cambodia (0.93 items per m^2), and Malaysia (0.74 items per m^2). This ranking comparison points to the value of surveying the amount and types of debris leaked into the environment, as more detailed empirical information can be used in determining a national baseline of litter and for comparison across the region. It also highlights the importance of the validation process of data from other methodologies and models applied in the same countries and geographical boundaries.

10.4 Opportunities for targeted actions

- Most items detected originate from mismanaged waste on land. Addressing waste mismanagement at the source (land) before it gets to sea is an effective approach to reduced debris in the river and coastal environment.
- Polystyrene foam fragments were the single most common item recorded within the region. These appear mostly on coastlines and their source was not clear, although both local land and sea sources are likely. Interestingly, polystyrene was less common in the Philippines so it might be worth investigating whether there are different practices in the Philippines compared to the other four countries.
- Collectively, the most common whole items are associated with plastic bottles – predominantly beverage bottles, including bottled water. This provides an opportunity to target reduction, and programs such as container deposit schemes to reduce plastic bottles entering the environment have been successful in other parts of the world. Bottled water was well represented regionally, though water bottle counts were particularly high in Cambodia. We note that access to clean drinking water is an important social and health issue that is driving the environmental issue of plastic bottles in the environment.
- There was an over-representation of single-use plastic items associated with food and beverage industry generally, as well as cigarettes and plastic bags. To make the biggest reductions on litter entering the environment, these could be the items to start with. For example, food wrappers are a potential area of intervention given how common they were regionally, but especially in the Philippines. Additionally, single use plastic bags are another potential area of intervention given their frequency. We have observed that plastic bag bans, when coupled with enforcement, can quickly result in a visible change in plastic bag litter. Kenya is one country where this change has been readily observed. In other countries, there are many efforts to reduce single-use plastic bags use, including outright banning of these items.
- Targeting cleanup efforts along rivers in urban areas and/or putting litter booms at strategic locations in key rivers could be an effective strategy to reduce the amount of debris being transported to the ocean. Additionally, periodic cleaning before monsoonal rains may help to prevent litter being flushed downstream. Improving waste disposal systems in urban areas would also be effective to dissuade illegal dumping of waste into rivers (which was observed during the surveys). Clean-up programs that focus efforts on reducing debris along riverbanks could be particularly helpful in reducing downstream litter in waterways.
- Debris removal efforts at sandy beaches could be more effective at removing a greater amount of debris compared to boulder/cobble/mud coastal areas. Furthermore, improving waste management (e.g. rubbish bins) at popular coastal areas, such as sandy beaches, may help to reduce local littering.
- Focusing policy, education efforts, and waste management in populated areas and areas with low economic product may help to have an increased relative impact to combat local litter.

10.5 Opportunities to expand surveys

The data collected here contributes to a world first, statistically robust, global baseline study of how much waste is lost to the environment. By using the same methodology and building capacity for individuals in multiple COBSEA countries, we can look at differences in debris across coastal, inland and riverine areas between countries to identify the drivers that may be similar or different amongst surveyed regions. With a robust, comparable baseline of information gathered in multiple major metropolitan centres around the world, we will have the data in hand to evaluate policy effectiveness and change through on-ground activities at local, national and international scales.

The national baseline estimates of marine litter examined in this regional assessment forms the necessary foundation for establishing and conducting national monitoring programs. Our results showcase how variable debris in the environment is, and that it is a function of both local factors (e.g. substrate type; vegetation height) and non-local factors (e.g. population, development, land cover). Only one survey per country makes it difficult to understand whether debris density patterns are related to inter- or intra-country dynamics. The integration of additional surveys in other locations and countries will help to improve models and our understanding of the drivers of debris in the environment. Additionally, focusing on maintaining or increasing the number of inland strata surveyed will further help understand the drivers and patterns of how debris enters the environment. Future efforts to examine additional cities and COBSEA countries will help to provide additional context on marine litter patterns for the region. Future iterations of such reporting mechanisms can include data from additional countries on an opt-in basis.

11 Limitations and factors not accounted for

11.1 Recommended timing of surveys.

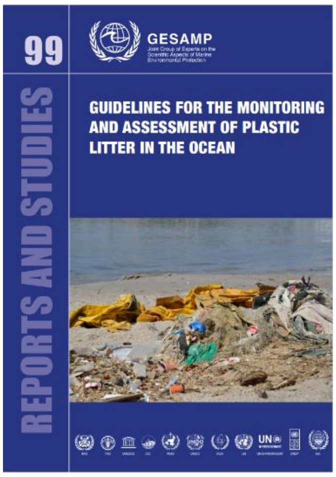
Weather patterns in Asia are heavily influenced by seasonal monsoons, which bring wind and rain to the continent. Given the annual deluge of rain arriving with somewhat predictable timing, these monsoons weather patterns are important to factor into monitoring programmes. This is because the movement of water has the potential to flush litter from inland areas into waterways, and then downstream into the ocean. Whether surveys occur before, during or after monsoons is likely to influence and bias the litter loads counted in each habitat. For ongoing litter monitoring, **we recommend monitoring twice a year - once in the non-monsoon and once after the first flush of the monsoon** to accurately account for the influence on litter loads.

11.2 Accounting for at-sea sources of litter

One of the benefits of samplings different compartments – inland, river, coast and trawl, is that this approach can distinguish between litter that has been generated domestically in recent times (inland and river), and that which has arrived from the sea – both from at-sea sources such as fishing, as well as from legacy plastics floating in the ocean (Willis et al., 2017). A number of sea surface currents may direct floating marine litter onshore onto coastlines across East Asia, and factoring these into calculations can aid in disentangling which litter items types found on beaches are derived from local mismanagement, and which have been brought to the countries' shorelines by ocean currents (Chassignet et al., 2021; van Sebille et al., 2020).

Appendix A Relevant Reports

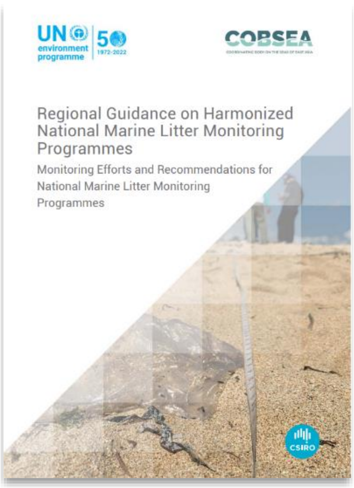
A.1 The GESAMP report



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.

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 several agencies and national governments.

A.2 COBSEA Regional Guidance on Harmonized National Marine Litter Monitoring Programmes: Monitoring Efforts and Recommendations for National Marine Litter Monitoring Programmes



Part one of IGM 25 in 2021 adopted *Regional Guidance on Harmonized National Marine Litter Monitoring Programmes*: Monitoring Efforts and Recommendations for National Marine Litter Monitoring Programmes to guide strengthening and harmonizing monitoring efforts in the region. The document responds to existing monitoring efforts and capacities in participating countries and provides targeted recommendations for monitoring methods, data standards and core objectives to strengthen national monitoring programmes. Recommendations are both regionally appropriate and in line with globally established guidelines, methods, and quality standards to promote data comparability for transboundary cooperation. The document was based on a regional inventory of existing monitoring efforts which were reviewed against five survey design suggestions in line with international guidance. The document summarized successes, gaps and opportunities to improve and harmonize approaches and inform joint objectives, core indicators, and quality standards.

References

Alisha, F., Davlasheridze, M., & Mykoniatis, N. (2020). Socioeconomic drivers of marine debris in North America. *Marine Environmental Research*, *160*, 105042.

Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G. H., Hilleary, M. A., Eriksen, M., Possingham, H. P., De Frond, H., Gerber, L. R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., & Rochman, C. M. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science*, *369*(6510), 1515-1518. https://doi.org/10.1126/science.aba3656

Chassignet, E. P., Xu, X., & Zavala-Romero, O. (2021). Tracking marine litter with a global ocean model: where does it go? Where does it come from? *Frontiers in Marine Science*, *8*, 667591.

CSIRO Marine Debris and OSEAN teams. (2021). *Global Plastic Leakage Baseline Data Summary Report, Yeongsan, South Korea.* .

CSIRO Marine Debris Team and GreenHub. (2021). *Global Plastic Leakage Baseline Data Summary Report, Viet Nam*.

Earth Observation Group, N. N. C. f. E. I. N. (2019). 2015 Nighttime Light Composite. In (Vol. Version 1 VIIRS Day/Night Band Nighttime Lights): National Oceanic and Atmospheric Association

Hardesty, B. D., Lawson, T. J., van der Velde, T., Lansdell, M., & Wilcox, C. (2017). Estimating quantities and sources of marine debris at a continental scale [Article]. *Frontiers in Ecology and the Environment*, *15*(1), 18-25. https://doi.org/10.1002/fee.1447

Hardesty, B. D., Roman, L., Leonard, G. H., Mallos, N., Pragnell-Raasch, H., Campbell, I., & Wilcox, C. (2021). Socioeconomics effects on global hotspots of common debris items on land and the seafloor. *Global Environmental Change*, *71*, 102360.

Jambeck, J., Hardesty, B. D., Brooks, A. L., Friend, T., Teleki, K., Fabres, J., Beaudoin, Y., Bamba, A., Francis, J., & Ribbink, A. J. (2018). Challenges and emerging solutions to the land-based plastic waste issue in Africa. *Marine Policy*, *96*, 256-263.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean [Article]. *Science*, *347*(6223), 768-771. https://doi.org/10.1126/science.1260352

Jong, M.-C., Tong, X., Li, J., Xu, Z., Chng, S. H. Q., He, Y., & Gin, K. Y.-H. (2022). Microplastics in equatorial coasts: Pollution hotspots and spatiotemporal variations associated with tropical monsoons. *Journal of Hazardous Materials*, *424*, 127626.

Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal [Article]. *Palgrave Communications*, *5*(1), Article 6. https://doi.org/10.1057/s41599-018-0212-7

Lebreton, L. C. M., Van Der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans [Article]. *Nature Communications*, *8*, Article 15611. https://doi.org/10.1038/ncomms15611

Luo, Y. Y., Not, C., & Cannicci, S. (2021). Mangroves as unique but understudied traps for anthropogenic marine debris: a review of present information and the way forward. *Environmental Pollution*, *271*, 116291.

Martin, C., Almahasheer, H., & Duarte, C. M. (2019). Mangrove forests as traps for marine litter. *Environmental Pollution*, *247*, 499-508.

Meijer, L. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Science Advances*, *7*(18), eaaz5803.
Nakano, H., Alfonso, M. B., Jandang, S., Phinchan, N., Chavanich, S., Viyakarn, V., & Isobe, A. (2024). Influence of monsoon seasonality and tidal cycle on microplastics presence and distribution in the Upper Gulf of Thailand. *Science of The Total Environment*, *920*, 170787.
Roman, L., Hardesty, B. D., Hindell, M. A., & Wilcox, C. (2019). A quantitative analysis linking seabird mortality and marine debris ingestion [Article]. *Scientific reports*, *9*(1), Article 3202. https://doi.org/10.1038/s41598-018-36585-9
Roman, L., Hardesty, B. D., Leonard, G. H., Pragnell-Raasch, H., Mallos, N., Campbell, I., & Wilcox, C. (2020). A global assessment of the relationship between anthropogenic debris on land and the seafloor. *Environmental Pollution*, 114663.
Schuyler, Q., Hardesty, B. D., Lawson, T., & Wilcox, C. (2022). Environmental context and socio-economic status drive plastic pollution in Australian cities. *Environmental Research Letters*, *17*(4), 045013.
Schuyler, Q., Wilcox, C., Lawson, T., Ranatunga, R., Hu, C.-S., & Hardesty, B. D. (2021). Human population density is a poor predictor of debris in the environment. *Frontiers in Environmental Science*, 133.
Socioeconomic Data and Applications Center (SEDAC). (2010). Global roads open access data set (gROADS). In: NASA Earth Observing System Data and Information System (EOSDIS)
The World Bank. (2019). *World Bank Open Data*. https://data.worldbank.org/
U.S. Geological Survey. (2019). HydroSHEDS 15sec SHAPE: River Network. In: U.S. Department of the Interior.
UNISDR. (2015). *Global exposure datasets- Population and built environment* (Global Assessment Report on Disaster Risk Reduction, Issue.
van Sebille, E., Aliani, S., Law, K. L., Maximenko, N., Alsina, J. M., Bagaev, A., Bergmann, M., Chapron, B., Chubarenko, I., & Cózar, A. (2020). The physical oceanography of the transport of floating marine debris. *Environmental Research Letters*, *15*(2), 023003.
Wilcox, C., Hardesty, B. D., & Law, K. L. (2020). Abundance of Floating Plastic Particles Is Increasing in the Western North Atlantic Ocean. *Environmental Science & Technology*, *54*(2), 790-796. https://doi.org/10.1021/acs.est.9b04812
Wilcox, C., Puckridge, M., Schuyler, Q. A., Townsend, K., & Hardesty, B. D. (2018). A quantitative analysis linking sea turtle mortality and plastic debris ingestion [Article]. *Scientific reports*, *8*(1), Article 12536. https://doi.org/10.1038/s41598-018-30038-z
Willis, K., Denise Hardesty, B., Kriwoken, L., & Wilcox, C. (2017). Differentiating littering, urban runoff and marine transport as sources of marine debris in coastal and estuarine environments [Article]. *Scientific reports*, *7*, Article 44479. https://doi.org/10.1038/srep44479
Wright, S. L., & Kelly, F. J. (2017). Plastic and Human Health: A Micro Issue? *Environmental Science & Technology*, *51*(12), 6634-6647. https://doi.org/10.1021/acs.est.7b00423

The Coordinating Body on the Seas of East Asia is dedicated to protecting the coastal and marine environment of the East Asian Seas for a sustainable future for all.

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