A Global Platform for Monitoring Marine Litter and Informing Action

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Background and context

Marine litter is “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment”. All the world's oceans and seas, even in remote areas far from human contact, contain marine litter due to its transboundary nature. The continuous growth in the amount of solid waste thrown away and the slow rate of degradation of most items are together leading to a gradual increase in marine litter found at sea, on the sea floor and coastal shores. It has become an economic, environmental, human health and aesthetic problem posing a complex and multi-dimensional challenge.

Marine plastics are of particular interest due to the fact that in the last 50 years, plastic production has increased more than 22-fold while the global recycling rate of plastics in 2015 was only an estimated 9% (Geyer et al., 2017). This rise in plastic production and unmanaged plastic waste has resulted a growing threat to marine environments with an estimated 5-13 million tons of plastic from land-based sources ending up in marine environments annually (Jambeck et al., 2015).

The UN Sustainable Development Goals recognize the importance of marine plastics through a target related to marine litter (SDG target 14.1) and in four UN Environment Assembly resolutions (from UNEA-1 in 2014, UNEA-2 in 2016, UNEA-3 in 2017 and UNEA-4 in 2019). However, there are large gaps in knowledge in terms of understanding marine litter and microplastics: a reliable figure for the volume of plastics entering the ocean, the accumulated volume of plastics in the marine environment, mapping of the source and sink location of plastics, and basic data on microplastics are currently lacking. There is a need to use existing data from remote sensing, citizen science, and in situ monitoring to better understand marine litter and microplastics; however, much of the research in this field is at an initial stage and only data related to beach litter is available in many regions (UN Environment, 2018).

Sustainable Development with Goal 14, Target 14.1 recognizes the consistent need for monitoring and reporting of marine litter: *“by 2025, prevent and significantly reduce marine pollution of all kinds (…)”*. This target provides a deadline for progress on reducing marine litter and further informed by SDG indicator 14.1.1b, *“plastic debris.”* UN Environment is proposing four core sub-indicators for SDG 14.1.1b:

1) Plastic debris washed/deposited on beaches or shorelines (beach litter)

2) Floating plastic debris and debris in the water column

3) Plastic debris on the seafloor/seabed

4) Plastic ingested by biota (e.g. sea birds) (optional).

Despite the growing interest in monitoring the above areas, there is a wide range of non-comparable monitoring approaches that limits the development of indicators and spatial or temporal assessments (Galgani, Hanke & Maes, 2015). The focus of this paper is on the monitoring of marine litter, not on the sources and pathways of marine litter. This is only one part of the picture as these measures only capture the accumulation of plastics and do not cover marine litter more broadly, do not cover microplastics, and do not cover the sources and pathways for marine litter. In order to effectively monitor, manage, and avoid the generation of marine litter, there is a need to consider the following:

- ***Plastic flow:*** How marine litter moves in the marine environment in a way that allows tracking the origin of plastic pollution is
- ***Life-cycle approach:*** Monitoring should encompass not only the amounts of plastic already in the ocean, but quantify flows and stocks of plastic across the life cycle of plastic-using products. This requires a holistic approach assessing production and use / consumption practices across the life cycle of products.
- ***Waste management practices:*** Leakages in the waste management system, illegal dumping, and leakages in the recycling process are a leading contributor to marine litter. The SDGs capture waste management as an important contributor to marine litter.
- ***Plastic in waterways:*** There is a lack of information on how plastic and microplastics move through rivers, sewage systems and other waterways to end up in the marine environment.
- ***Plastic types:*** There is a need to track plastics and microplastics by type of plastic, including plastic related e-waste and chemicals (and toxicity) in plastics. It is not possible to get a complete picture of marine litter without information on what can be recycled and what has chemicals.
- ***Consumer awareness:*** Communication of information and data must builds public awareness so that consumers can make informed decisions.
- ***Microplastics:*** Understanding the sources of microplastics and the impact of microplastics on human health is a priority.
- ***Trade-offs:*** Understanding when a specific alternative to a plastic product is better or worse than the use of plastics is a challenge. Life Cycle Assessment (LCA) is the tool best suited for such purpose, although it still does not incorporate indicators for the impacts of marine litter. Without considering LCA results alongside marine litter indicators, it is difficult to provide policy advice that would result in benefits and not costs to human health and the environment.

Marine litter observation is currently very sparse, and as a result, there is a knowledge gap about the biological and physical process that transport plastics through marine ecosystems and potentially to humans (Katija et al. 2017). Therefore, any quantitative approach to integrating source and dispersion/accumulation dynamics must take a multidisciplinary approach combining forward or inverse hydrodynamic or dispersion models with multisource Earth observation data.

While standardized methods for monitoring marine litter will greatly improve the understanding of the marine litter, development and reporting of indicators will require integrated and comparable data. Currently, peer-reviewed journals and databases hosted by NGOs and government authorities hold much of the data on marine litter. As suggested by Galgani, et al. (2015) and Maximenko et al. (2019), a joint international database would facilitate the collection of data for marine litter indicators and improve standardization and comparability. Such a database would also support policy decisions related to the reduction of marine litter and support analysis of the efficacy of mitigation efforts.

This paper outlines a concept for the development of a global data platform for marine litter including the vision, feasibility, potential structure and funding needed. This paper will further discussions on developing a long-term project in support of such a platform that could be hosted on the UNEP World Environment Situation Room. This paper is organized into eight sections:

Section 1 provides a summary of existing and developing monitoring technology.

Section 2 provides a summary of existing marine litter databases and major published datasets.

Section 3 explores indicators for monitoring marine litter.

Section 4: explores life cycle indicators for plastic litter and linkages with other monitoring initiatives across the plastics value chain

Section 5 provides a summary of existing and developing platforms of relevance.

Section 6 outlines the proposed features of a global platform for monitoring marine litter and informing action, next steps and required resources.

Section 7 outlines a proposed pilot project for the development of marine litter in a digital ecosystem for the environment.

Section 8 provides insights into aspirational, future developments.

Section 1: Monitoring technologies

There is a need for regular and standardized monitoring of marine litter in order to understand long-term changes in marine litter and for the successful development and implementation of mitigation strategies. The diverse nature, sources and impacts of marine litter require a wide range of technologies and methods for monitoring. Recent efforts to compile information on existing methodologies and recommend standardized methodologies for global monitoring include the Joint Group of Experts on the Environmental Aspects of Marine Environmental Protection (GESAMP) Guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean (GESAMP, 2019) and the Global Manual on Ocean Statistics (UN Environment, 2018).

One challenge for implementing and further developing monitoring methodologies for marine litter is an understanding of the existing technologies for monitoring marine litter. This section summarizes technologies for the monitoring of marine litter and describes how to use these technologies to collect the necessary data for a global view of marine litter. For an overview of the observing system technologies required for the development of a future integrated marine debris observing system, see Maximenko et. al. (2019).

For this paper, we have grouped technologies based on applicability to the size classes recommended in the GESAMP 2019 methodology (Table 1). In addition, we have assigned technology readiness levels (Table 2) based on the National Oceanic and Atmospheric Administration (NOAA) policy on research and development transitions to support prioritization of data standardization and integration. Readiness levels are defined by NOAA as "a systematic project metric/measurement system that supports assessments of the maturity of research and development projects from research to operation, application, commercial product or service, or other use and allows the consistent comparison of maturity between different types of research and development projects" (NOAA, 2017).

Table 1. Size categories for routine marine litter monitoring (GESAMP, 2019)

Size Category	Size Range
Mega	> 1 m
Macro	25 mm - 1 m
Meso	5-25 mm
Micro	<5 mm

Table 2. Technology readiness levels (NOAA, 2017)

Readiness Level	Readiness Level Defined
1	Basic research and/or development principles observed and reported
2	Formulation of concept for operations, application,

	commercialization or other uses for societal benefits
3	Proof-of-concept (viability established)
4	Validation of system, process, product, service or tool in laboratory or other experimental environment
5	Validation of system, process, product, service or tool in relevant environment
6	Validation of system, process, service, or tool in relevant environment (potential demonstrated)
7	Prototype demonstrated in an operational or other relevant environment (functionally demonstrated in pseudo real world environment)
8	System, process, product, service, or tool completed and “mission qualified” through test and demonstration in operational or other relevant end-to-end environment (functionality demonstrated)
9	System, process, product, service or tool approved for deployment and use in decision making (transition complete)

Human observers

Visual human observation is the most wide spread and technically simplistic way to collect data about marine litter. Human observers monitor beach/shoreline litter, floating litter, water column litter, seabed/seafloor litter, marine litter ingestion/entanglement and sources of marine litter. Human observation is most appropriate for macro- and mega-litter based on what is consistently visible to the naked eye (GESAMP, 2019).

Protocols and guidelines for monitoring beach/shoreline litter with visual observations vary widely by organization (UN Environment, 2016, Arctic Council, 2015; European Commission JRC, 2013; Opfer et al., 2012; Cheshire et al., 2009; NOWPAP CEARAC, 2007). For litter on the beach/shoreline surface, analysis is typically done through done through visual transects and counting collected items from beach cleanup efforts. Some organizations employ apps to facilitate data entry and reporting (e.g., NOAA Marine Debris Tracker App[1], European Environment Agency’s Marine LitterWatch App[2], Ocean Conservancy’s Clean Swell App[3]).

Human observers typically monitor floating litter using transects from ships. While different methods are used, visual surveys from ships for floating marine litter have been used for almost 50 years and is an important source of data (GESAMP, 2019). These observations are generally limited to mega- and macro-litter. Human observations of water column litter, and the analysis of

[1]https://marinedebris.noaa.gov/partnerships/marine-debris-tracker

[2]https://play.google.com/store/apps/details?id=com.litterwatch&hl=en_US

[3]https://www.coastalcleanupdata.org/#download

meso-litter, require collection of materials with net tows. Observers sort items by type and size and analyze items by count and/or weight (GESAMP, 2019; Lebreton et al., 2018).

Underwater visual surveys by SCUBA divers can monitor and collect marine litter in shallow waters. Distance and transect sampling is commonly used to measure marine litter density (Galgani et al., 2013; Spengler, 2008; Buckland, 2001). This method is limited in its depth typically to 20-30 m at most, requires SCUBA equipment and skilled observers, and is most appropriate for macro-litter. In addition to professional surveyors, recreational divers also play a role in surveys. For example, divers through Project AWARE's Dive Against Debris program are encouraged to collect and report marine litter found underwater, and they are directed to collect and observe at the same locations when they do for further data validation (GESAMP 2019).

Visual reporting of abandoned, lost, or otherwise discarded fishing gear is an important part of monitoring entanglement and entanglement risk. Overall, monitoring entanglement has a straightforward observational methodology, where it is important to note the size, location, impacted species or habitat, as well the type of litter when reporting on entanglement (GESAMP 2019). Networks for reporting of entanglement and litter with entanglement risk include the NOAA SOS Whale Network[4] and the International Association of Geophysical Contractors Marine Debris and Ghost Net Initiative[5]. For example, in a study on pollution incidents reported by observers on-board fishing vessels in the Western and Central Pacific Ocean, 71 - 80% percent of the incidents reported were documented as waste dumped overboard, and only 13 -17 % as abandoned, lost or dumped fishing gear, depending on the type of vessel (Richardson et al. 2017). Increased observer coverage and data collection on-board ships such as fishing vessels may provide essential information. Extending such observations to other vessels would provide more information about the quantities and types of pollution caused by shipping. Reporting pollution incidents on-board using navigation logs would continue to be an appropriate form for use by an expanded, cross-fleet observer program that is quality controlled and standardized to Global information Systems (IMO, GOOS, etc.).

Human observation of the sources of marine litter include monitoring floating riverine inputs and leakage from waste sites. In Europe, the Riverine Litter Observation Network[6] uses human observation of floating macro litter on the river surface. An added challenge to visual observations of floating litter in riverine environments include surface water speed and turbulence (González-Fernández & Hanke, 2017). In order to establish and estimate the link between land-based waste management and losses of waste into the marine environment, human observers are used to conduct terrestrial litter surveys of inland, riverine and coastal areas (Schuyler et al., 2018).

Data collected from human observers has been tested and used extensively for analysis in regions including the North-East Atlantic, Baltic Sea and United States (Hardesty et al., 2017;

[4] https://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/disentanglement_network.html

[5] https://www.iagc.org/ghost-net-contact-form.html

[6] https://mcc.jrc.ec.europa.eu/main/dev.py?N=simple&O=394&titre_page=RIMMEL%2520observation%2520Network

OSPAR, 2017; European Commmission JRC, 2013). However, since standardized global protocol/process for collecting data using human observations has not yet been implemented, we have assigned human observers a readiness level of 8.

Readiness Level: Human Observers

8: System, process, product, service or tool completed and “mission qualified” through test and demonstration in operational or other relevant end-to-end environment (functionality demonstrated)

Microscopy

Meso- and micro-litter analyses use microscopy, which has applications for the monitoring of beach/shoreline litter, floating litter, water column litter, seabed/seafloor litter, marine litter ingestion and sources of marine litter. Sample collection for beach/shoreline litter is typically done by collecting sediment with a spoon, spoon trowel or sediment core and passing the sample through various sieves depending on the size class of interest (GESAMP, 2019). Floating/water column samples require filtration either after the samples are collected or using in situ filtration equipment (Choy et al., 2019; GESAMP, 2019). Samples for ingestion are typically taken from dead organisms or from items associated with live animals such as regurgitated pellets, scat and nesting materials (GESAMP, 2019). In addition, submersible microscopes (e.g. holographic (4deep) or cytometric) can autonomously measure micro-plastics in typical outflow areas. The use of digital holographic microscopy, matched with the continuous advancements in deep learning techniques, can provide new opportunities for the use of coherent imaging systems in many areas, including potentially microplastics pollution analysis (Rivenson et. al., 2019)

Microplastics are often subject to microscopic analysis. Methods for sample preparation and analysis vary widely based on sample type (e.g. water sample, sediment sample, ingested sample) and microscopy type (e.g. light microscopy, electron microscopy, etc.). Prior to analysis, microplastics undergo a chemical digestion to remove all organic matter from samples. Chemical digestion methods, along with their advantages and disadvantages, are broken down into three general categories: oxidative, acidic, alkaline/basic and enzymatic (Table 3).

Table 3. Advantages and disadvantages for extracting and purifying microplastics in organic matrices (GESAMP, 2019)

Purification Method	Advantages	Disadvantages
Oxidative Digestion	• Inexpensive	• Temperature needs to be controlled • Several applications may be needed
Acid Digestion	• Rapid (24 hr)	• Can attack some polymers
Alkaline Digestion	• Effective • Minimal damage to most polymers	• Damages cellulose acetate
Enzymatic Digestion	• Effective • Minimal damage to most	• Time-consuming (several days)

	polymers	

Methods for extraction of ingested litter from samples vary widely (Courtene-Jones et al., 2019; GESAMP, 2019; van Franeker et al., 2011; Zhao et al., 2016) and need a standardized approach to ensure consistency.

Another challenge for analysis of marine litter by microscopy is the potential for sample contamination. Careful procedures to avoid sample contamination during analysis are being implemented in research studies such as burning off contaminants from glassware, pre-filtering of reagents through glass fiber filters, handling of samples in laminar flow hoods and analysis of blanks to estimate potential contamination (GESAMP, 2019; Wesch et al., 2017; Zhao et al., 2016).

Analysis by light microscopy typically consists of counting microplastics and characterizing their color, shape and sizes (Vandermeersch et al., 2015). Scanning electron microscopy can provide additional detail about the surface texture of particles but is only viable for analysis of small quantities of samples do to the intensive processing and analysis required (GESAMP, 2019). Overall, various microscopic approaches have trade-offs in terms of precision and accuracy of material identification with some methods potentially underestimating microplastics pollution due to false positives (Zarfl, 2019). As protocols for cleanly and accurately collecting, processing and analyzing samples for microscopy are still being researched, we have assigned a readiness level of 3 to light microscopy.

Readiness Level: Microscopy

3: Proof-of-concept (viability established).

Weighing

Technology for calculating the mass of marine litter is frequently used for the analysis of macro, meso- and micro-litter beach/shoreline litter, floating litter, water column litter, seabed/seafloor litter, marine litter ingestion/entanglement and sources of marine litter (Lebreton et al. 2018; Lebreton et al., 2017; NOAA Marine Debris Program, 2015). Mega-debris is difficult to weigh, compounded by the fact marine life heavily colonize mega-debris such as fishing nets. Challenges for accurately weighing larger items include sand or debris entangled in the item and consistency in properly drying samples (GESAMP, 2019). Technologies for weighing macro- and meso-litter tend to be simple including scales and drying ovens (Ryan et al., 2014).

Accurate mass (or gravimetric analysis) of micro-plastic requires proper sorting, extraction and sample purification as outlined in the light microscopy section. Consistency in mass measurements have shown to be consistent across labs when the same method is applied for analysis (NOAA Marine Debris Program, 2015). One critical aspect to consider for mass calculation is that most methods for microplastics analysis include an density separation step where settled solids are discarded and only floating solids are analyzed (GESAMP, 2019; NOAA Marine Debris Program, 2015). One consideration regarding this approach is that scanning electron microscopy images have shown microplastics to have extensive fouling by microbial communities (Zettler et al., 2013) which can cause plastic debris to sink (Andrady, 2011).

Accordingly, following proper steps prior to analysis of the weight of micro-litter will ensure that biofouling does not result in an underestimate.

As standardized approaches to removing sand, biofouling and water residue from samples have not been implemented and methods often vary widely or are not specifically reported, we have assigned a technology readiness level of 3 to weighing marine litter.

Readiness Level: Weighing Litter

3: Proof-of-concept (viability established).

Spectroscopy

Spectroscopy, the analysis of absorption or scattering of light, allows for the discrimination between organic and inorganic particles as well as various types of plastics as these materials produce different spectral signals (Lenz et al., 2015). While the waste management and recycling industries have utilized near-infrared spectroscopy to identify plastics since 1998, the utilization of spectroscopy for analysis of marine litter is fairly recent (Choy et al., 2019; Yu et al., 2019; Zhu et al., 2019; Zulkifley et al., 2014).

The focus of spectroscopy techniques such as Fourier Transform Mass Spectroscopy (FTIR) and Laser Raman Spectroscopy have been on the analysis of microplastics in the marine environment (Choy et al., 2019; GESAMP, 2019; Yu et al., 2019). New spectroscopic approaches such as staining and semi- or fully-automated spectroscopic analysis are currently under development (GESAMP, 2019). As sample collection, treatment and analysis methods are still in the research and development phase for the identification of marine plastics by spectroscopy, we have assigned a readiness level of 1 to spectroscopy.

Readiness Level: Spectroscopy

1: Basic research and/or development principles observed and reported.

Mass Spectronomy

Mass spectronomy measures the mass to charge ratio of ions in a sample, providing information about chemical composition. Mass spectronomy technologies used for analysis of microplastic particles include thermal extraction and desorption gas chromatography mass spectrometry (TED-GC-MS) and pyrolysis gas chromatography mass spectrometry (Py-GCMS). These technologies require the thermal degradation of plastics, separation of degradation products through chromatography, and analysis of the products with mass spectronomy (GESAMP, 2019; Dumichen et al., 2017) . Other forms of mass spectronomy identify chemicals associated with plastic samples (GESAMP, 2019; Kuhn et al., 2018). For example, inductively coupled plasma spectroscopy (ICP-MS) can identify metals associated with plastics, which can provide information about hazardous metals associated with microplastics (Kuhn et al., 2018). As the application of mass spectronomy to the analysis of marine litter is still in the research and development phase, we have assigned a readiness level of 1 to mass spectronomy.

Readiness Level: Mass Spectronomy

1: Basic research and/or development principles observed and reported.

Visual Imagery and Video

Ship-based cameras, unmanned aerial vehicles (UAVs), balloons, high altitude pseudo satellites (HAPS), remotely piloted aircraft systems (RPAS) and satellites collect visual imagery. Fixed-wing drones are increasing the distance and duration of drone flights. Blimps have the advantage of longer stable flights. Model studies should guide the use of both drones and blimps, as they are limited in terms of timing and spatial coverage.

The use of small aircraft, drones, unmanned aerial vehicles (UAVs), balloons, and satellites are promising for the analysis of beach litter as well as sea surface litter. The advantages of aerial technologies include access to imagery from difficult to access beaches, more rapid, complete beach coverage, and high-resolution imagery. Aerial imagery can be processed manually or automatically using machine learning tools that are currently in development (Deidun et al., 2018; Martin et al., 2018; Moy et al., 2018). The various aerial technologies have strengths and weaknesses based on cost and coverage. For example, UAVs offer ultra-high resolution imagery but are prohibited to fly over people, limiting survey locations (Moy et al., 2018). Validation of results using ground measurements is an important component for the development of these technologies and further tests are necessary to understand the limitations and appropriate applications of aerial technologies for monitoring of beach litter (Deidun et al., 2018; Moy et al., 2018).

Photographing marine litter using a camera fixed to the bow or mast of a vessel is an emerging approach for monitoring floating marine litter. High-resolution cameras or other sensors (e.g. Lidar) mounted on ships can increase the observations on the floating litter and with the use of AI, provide in situ observation in real time. Further testing is necessary to validate the consistency of these sensors. In addition to ship-based cameras, autonomously operated vehicles (AOVs) have the potential to monitor of surface/subsurface marine litter at sea. For example, Wave Gliders that use wave energy for propulsion often have video cameras that can be used for marine litter quantification (Galgani et al., 2013).

Remotely operated vehicles (ROVs), such as submarines or manned submarines, can view seabed litter plastic or take core or surface samples to detect presence of microplastics and other litter (Woodall et al., 2014). ROVs are often preferable for litter surveys on continental slopes, uneven terrain, or the deep seafloor. Litter can accumulate in certain locations on the seafloor such as coastal canyons, as well as areas with steep slopes, rocky bottoms, or ocean trenches. These areas would specifically benefit and often necessitate the use of ROVs to observe and/or collect marine litter. Video cameras can record high-resolution images while other light devices such as lasers can measure transect areas, object size and distances on the seafloor. Proposed learning algorithms aimed at more successful vision detection of litter will be useful in exploring and mapping litter by autonomous underwater vehicles. While ROVs have proven useful, the high cost of operation as well as the specific skill set required for both operation and observation remain a limitation.

There are various technologies to estimate riverine sources directly with varying levels of effort, scale and accuracy. Drone or field surveys of river mouths can assess accumulated plastic. DRONET[7] is developing a standard methodology for drone-based surveys of plastic.

Visual imagery and video are used in relevant environments but do need standardization. Accordingly, we have assigned a readiness level of 5 to the analysis of marine litter by visual imagery and video.

> **Readiness Level: Visual Imagery and Video**
>
> **6:** Validation of system, process, service or tool in relevant environment (potential demonstrated).

Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) provides high-resolution image of the radar reflectivity of an observed scene. SAR has potential to provide information about expected locations of marine litter and detect mega-litter on the water's surface but is sensitive to parameters such as surface roughness. Waves (surface and internal), winds, currents, upwelling and several other oceanographic phenomena influence surface roughness. Interestingly SAR is also sensitive to presence of substances that can dampen the surface waves, such as oil spills, algal blooms or any other substances influencing the water surface tension and often defined surfactants.

Two main mechanisms could lead to the detection of plastics on water surface: a) detection of large plastic debris and b) detection of microplastics or small concentration of plastic pieces in the water column.

a) Plastic debris: SAR can detect large metallic objects on the sea surface; however, it is still unknown if large concentration of plastic debris can produce changes in pixel brightness (i.e. increase or decrease backscattering). In an experiment by Topouzelis & Papakonstantinou (2019), Sentinel-1 detected large squares of plastic bottles but not detect all experimental squares.

b) Microplastics: Plastic in the ocean is heavily colonised by microbes that produce substances and biofilms (surfactants). Marino et al. (2019) showed that surfactants such as sea-slicks and biofilms were visible on Sentinel-1 images as dark curved stripes. They hypothesized these "stripes" occur because of the microbial colonisation of micro-plastics. Additionally, ocean colour images showed very low chlorophyll-*a* concentrations, which suggests these features were not produced by algal blooms. These signatures present dependency on a range of winds, appearing at wind speeds up to $10 ms^{-1}$.

[7] https://www.theplastictide.com/blog-1/2018/4/22/launching-the-marine-litter-dronet

As the use of SAR for marine litter, monitoring is still in the research and development phase, we have assigned a readiness level of 1 to SAR.

Readiness Level: Synthetic Aperture Radar

1: Basic research and/or development principles observed and reported.

Multispectral and Hyperspectral imaging

Satellite remote sensing of beach litter and sea surface litter is currently in the research and development phase, primarily repurposing missions that were not originally designed for litter monitoring. Satellite imagery relevant for remote sensing of beach litter includes visual imagery and spectral analysis. Commercial satellite imagery is the primary technology of relevance when detecting litter on beaches and rivers, given the very high-resolution needed to discern this litter. For spectral analysis, research activities to map the spectral signatures of marine plastics are underway and show promise for potential characterization of marine litter on beaches (Acuna-Ruz et al., 2018; Garaba & Dierssen, 2018). Preliminary studies have shown the synergetic use of satellite images and UAVs to detect floating litter (Topouzelis et al, 2019). Current high-resolution satellite sensors can monitor floating mega litters. Statistical indicators and density heat maps can be derived in accordance to predefined requirements. Future satellite sensors may show improved functionality for measuring marine litter on beaches but these concepts are still in development. Given the current state of technology and applications research, we have assigned a technology readiness level of 1 for satellite remote sensing of beach and sea surface litter.

Multi-spectral satellite remote sensing of plastic in the water column is currently only possible for larger elements on or close to the water surface, and under good atmospheric conditions (no clouds). The Copernicus Sentinel 2 constellation is likely to be the most valuable existing mission with freely available data and relatively high-resolution (10m GSD) spectral radiometry with global coverage. Commercial higher (i.e. very high-resolution) satellite data are available for purchase but have low temporal resolution. In all cases, cloud cover and sea surface conditions affect the detection of debris no matter the resolution. An initial assessment of observation requirements for measuring marine plastic debris from space can inform further sensor development (Martínez-Vicente et al, 2019).

As the plastic elements sink or decompose, the likelihood of detection with remote sensing methods decreases significantly. There are some promising methods for looking at anomalies or particular signatures to identify ocean plastic. For example, ESA’s Sentinel-3 satellite has an ocean color imager that is potentially detecting unique signatures or large agglomerations of plastic. However, this sensor only images at 300 m resolution, and even with a revisit rate of almost every 2 days, it will not detect most plastic of interest. Commercially available hyperspectral sensors such as HyMap may be more suited for detecting plastics (Garaba et al., 2018; Goddijn-Murphy et al., 2018).

As multispectral and hyperspectral imaging is still in the research and development phase, we have assigned a readiness level of 1.

Readiness Level: Multispectral and Hyperspectral imaging

1: Basic research and/or development principles observed and reported.

GPS tags and transmitters

Debris tagged with GPS tags and transmitters can provide direct tracking of floating marine items. Compiling trajectories of marine litter can reconstruct the path of plastic from source to fate. Argo tracking sensors, or GPS devices, can track debris but remain too expensive to implement widely. The upcoming Kineis constellation from CLS[8,9], or a low-tech solution such as PandaSat[10] proposed by WWF, could provide more affordable solutions in 2021. Large floating plastic debris is tagged and tracked using satellite trackers deployed from vessels in the Pacific[2]. However, these do come with the caveat of introducing electrical trash into the environment. For areas close to shore, cheaper, accurate IoT (internet of things) technology can be deployed using conventional 3G networks, or Lora systems to provide better coverage where mobile data is lacking. Deployment of Iridium satellite connectivity is prohibitively expensive. Accordingly, the use of GPS tags and transmitters to monitor the trajectory of marine litter have been assigned a readiness level of 1.

Readiness Level: GPS tags and transmitters

1: Basic research and/or development principles observed and reported.

HF Coastal Ocean Radar

The primary product of HF Coastal Ocean Radar (HFR) is mapping of surface currents within 200km of the shore, and some systems produce maps of significant wave height to about one-third of the range for currents. The spatial and temporal resolutions vary in the range 300m – 20km, and 5min – 3hour respectively, depending on the operating frequency and whether the system is based on a wide aperture (for high resolution) or a compact configuration. Wind directions are observed, and U10 wind speeds are derived from the significant wave height measurements. HFR systems are located on land and usually run continuously, producing data with latency times of the order of minutes to data hubs and archives.

HFR is useful for mitigating the effects of plastics in the ocean in three ways.

[8] https://mcc.jrc.ec.europa.eu/main/dev.py?N=simple&O=394&titre_page=RIMMEL%2520observation%2520Network

[9] https://www.cls.fr/en/kineis-unique-constellation/

[10] https://space-science.wwf.de/project/pandasat/

a) The 2D field of surface current vectors can be analysed to identify locations and properties of meso-scale eddies in coastal waters, and convergences in the surface field where down-welling occurs to concentrate surface debris. The advantage of 24/7/365 data is that it can be used for time scales of tidal effects up to seasonal variability.

b) The high-resolution configurations provide Langrangian Tracking of parcels of surface water and provide insights into horizontal diffusion and Coherent Lagrangian Structures that set boundaries to surface drifters.

c) Maps of wind speed and directions improve the tracking of floating objects.

HFR installations are generally in areas of environmental or social concern where direct measurements are useful, but realistically HFR installations are sparse and their main use will most likely be to provide insights into accumulation dynamics, and to validate dynamical models.

> **Readiness Level: HF Coastal Ocean Radar**
>
> 1: Basic research and/or development principles observed and reported.

Modeling

The abundance of litter in the marine environment has steadily increased over the last few decades and recent studies have showed relatively high concentrations of microplastics particles (particles up to 5 mm) in coastal sediments (Browne et al., 2011). By various means (e.g. transport accidents, inappropriate disposal of packing materials as well as microplastics beads used in cosmetics), different types of plastics enter the water column, with serious ecological implications for marine organisms, such as fatal entanglement in macro plastics or the ingestion of microplastics by fish and birds (Leslie et al., 2011). With these concerns in mind, many questions arise: Which areas probably have the highest concentrations of plastic litter (hotspots)? What are the transport routes of plastic litter in the water bodies and in which areas do they end up? How are different types and sizes of plastic behaving? The fate of the plastics in the marine environment is also uncertain: they might accumulate or degrade due to fragmentation and microbiological decay. To address these issues, it is essential to develop an integrated approach that highlights the role of transport and fate models to provide the means to include different processes and investigate their relative contribution.

High-resolution hydrodynamic models are considered critical to resolving the key marine litter questions as they offer a platform that can integrate (and give much greater value to) the very sparsely available observation data (Martinez-Vicente et. al., 2019). An analogous example is the assimilation of the relatively sparse Argo float data into the Mercator global forecast, greatly improving the performance and reliability of the model (e.g. Turpin et. al., 2016). There are certainly technical hurdles e.g. establishing common currency, metrics and uncertainties between specific observation types and models; establishing the necessary sub-mesoscale global nests of models required for appropriate simulation of litter dispersion and accumulation (D'Asaro et al

2018). The combination of high-resolution numerical simulations and sparse observations will certainly play a major role in better understanding global dispersion and accumulation.

Numerical modeling of beach litter primarily aims to forecast litter accumulation on beaches to support cleanup efforts and identify potential hot spots (Granado et al., 2019; Haarr et al., 2019; Yoon et al., 2010). One challenge for predicting beach litter accumulation is the fine resolution required, ranging from a few 100 m to 1 km, which can be limiting for forecasting along shorelines that lack high resolution data and oceanographic models (Critchell & Lambrechts, 2016). Combining local and regional high-resolution circulation models with satellite-observed surface debris could provide a basis for forecasts of beaching events. This approach is discussed for forecasting beaching of *Sargassum* and could be used for marine debris. Research efforts to develop and improve beach litter forecasts through new techniques, such as machine learning and GIS-based tools, are underway but are still in the research and development phase (Aydin & Butler, 2019; Critchell et al., 2015; Critchell & Lambrechts, 2016; Granado et al., 2019; Yoon et al., 2010).

A very important auxiliary input for modeling the trajectories of plastics in the ocean are ocean surface currents. The output of regional and global Ocean General Circulation Models (OGCM) can map and predict past and future trajectories of marine plastic. This can assist in identifying sources and accumulation locations (van Sebille et al., 2012). The data used to generate these models include wind speed and direction, mapped sea level anomaly (MSLA), and sea surface temperature, which are available almost daily. These models can be fine-tuned using data from buoys, or GPS tracked plastic pieces (GESAMP, 2019; van der Mheen et al., 2019). The TOPIOS project (http://topios.org/), among others, is developing three-dimensional modeling of marine plastic. To improve the knowledge regarding the distribution and possible accumulation zones of marine plastic litter in the North Sea and within the CleanSea project, microplastics transport is simulated with a hydrodynamic-based particle tracking model. The model calculates how the position of microplastic particles evolves in time from their release until the end of the simulation. The settling velocity of the plastic particles in the water system is dependent on the ambient conditions (temperature/salinity) as well as on the particle characteristics (density/size/shape). The developed model is generic and can be extended to other European regional seas.(http://cleansea.eu) (Stuparu et al., 2015).

Modeling is a promising approach to improve the existing knowledge regarding the litter dynamics in marine environments and obtain new insights in areas where information is lacking (Thompson et al., 2009). For example, the data regarding the abundance of plastic litter on the seabed is very limited. Also, it is assumed that substantial quantities of plastic litter has accumulated in the natural environment due to the continued input of marine litter over the last decades; however, the location of possible accumulation areas is not well delimited. The modelling approach provides a link between the source and the fate of microplastics. By describing microplastics pathways, an overview of estimated accumulation areas is possible and can be a helpful tool for guided monitoring and data collection campaigns.

As modelling of marine litter is still in the research and development phase, we have assigned a readiness level of 1.

Readiness Level: Modelling

1: Basic research and/or development principles observed and reported.

Table 4. Summary of technology for marine litter monitoring

Technology	Readiness Level	Size Class	Application Area	Pros	Cons
Human eye	8	Mega- and macro-litter	• Beach/shoreline litter • Floating/water column litter • Ingestion of marine litter/entanglement • Sources of marine litter	• Advanced technology not required • Can be implemented by citizen science volunteers • Well-developed methods and studies exist	• Depends on regular sampling and commitment of human resources • Dependent on human error • Resource and time intensive • Requires global agreement and implementation of comparable methods
Weight	3	Mega-, macro-litter and micro-litter	• Beach/shoreline litter • Floating/water column litter • Ingestion of marine litter/entanglement • Sources of marine litter	• Allows for relatively quick and simple analysis of beach litter quantities • Can be linked with voluntary beach clean-up efforts	• Beach litter water content, sand and biofouling can bias results • Presence of light weight items such as Styrofoam and wrappers may lead to underestimates of beach litter severity
Microscopy	3	Meso- and micro-litter	• Beach/shoreline litter • Floating/water column litter • Ingestion of marine litter/entanglement • Sources of marine litter	• Provides information about smaller classes of litter • Provides important information about ingestion	• Sample collection and analysis has risk for contamination • Sample preparation and analysis varies and requires agreement and implementation of comparable methods • Time consuming • Human error in identifying material types

Spectroscopy	1	Meso- and micro-litter	• Beach/shoreline litter • Floating/water column litter • Ingestion of marine litter/entanglement • Sources of marine litter	• Provides information about types of plastics in a sample • Can provide information about the fate and breakdown of litter	• Time consuming and expensive • Consistent sample preparation methods not agreed upon • Limited number of samples can be analysed
Mass Spectronomy	1	Micro-litter	• Beach/shoreline litter • Floating/water column litter • Ingestion of marine litter/entanglement • Sources of marine litter	• Provides information about chemicals associated with litter (such as contaminants)	• Time consuming and expensive • Limited number of samples can be analysed
Visual Imagery and Video	6	Mega- and Macro-litter	• Beach/shoreline litter • Floating litter • Ingestion of marine litter/entanglement • Sources of marine litter	• Simple and affordable technology • Variety of systems available including cameras attached to air planes, drones, and submersibles • Access to hard to reach beaches	• Limited to large debris items • Image processing can be time consuming
Hyperspectral Imaging	1	Macro-litter	• Beach/shoreline litter • Floating litter • Sources of marine litter	• Ability to survey large areas in short periods of time by using satellites, planes or drones • Access to hard to reach beaches	• Regulatory issues can restrict areas of operation of airborne platforms • Limited to large debris items • Imagery can be limited by weather conditions • Image processing can be challenging and time consuming • Further research and

					validation required
Synthetic Aperture Radar	1	Mega-litter	• Beach/shoreline litter • Floating litter • Sources of marine litter	• Ability to survey large areas in short periods of time by using satellites, planes or drones • New sensors and processing tools are in development • Can be used to identify convergent zones where marine litter accumulation is likely	• Most high resolution data is commercial • Limited to large debris items • Processing data is resource intensive
GPS tags and transmitters	1	Mega- and macro litter	• Floating/water column litter	• Can provide information about pathways of marine litter • Data can improve modelling and source identification efforts	• Iridium satellite connectivity is prohibitively expensive to be deployed into the sea • Introduces electronic litter into the marine environment
HF Coastal Ocean Radar	1	Mega-litter	• Floating/water column litter	• HFR installations are generally in areas of environmental or social concern where direct measurements are useful • Provide insights into horizontal diffusions	• HFR installations are sparse
Modelling	1	Mega, Maco-, Meso- and Micro-litter	• Beach/shoreline litter • Floating/water column litter • Ingestion of marine litter/entanglement • Sources of marine litter	• Predictive ability can support identification beach litter hot spots in areas lacking on the ground data • New processing technologies such as machine learning and GIS-based tools show promise	• Many oceanographic models are not at a high enough resolution to predict beach litter • Running of models can be resource intensive, requiring high levels of computing resources • Additional research and

					testing required before models can be used for decision making

Section 2: Existing marine litter databases and major datasets

In order to make accurate recommendations about how to effectively develop a global monitoring platform and inform action for marine litter, it is important to understand what existing platforms and data are available. In the past two decades, there has been a steady increase in the amount of data, reports, and studies related to marine litter. In the past five years alone, the level of information and work focused on marine litter and subsequent areas of interest has spiked. Through expert input, the areas of interest within marine litter include: marine litter found in the water column, marine litter ingestion and entanglement, marine litter on the seabed/seafloor, marine litter on beaches and shorelines, sources of marine litter, waste management, the plastic life cycle and microplastics. Figure 1 shows an analysis based on a Web of Science Search that highlights the trends of marine litter research over the past 20 years.

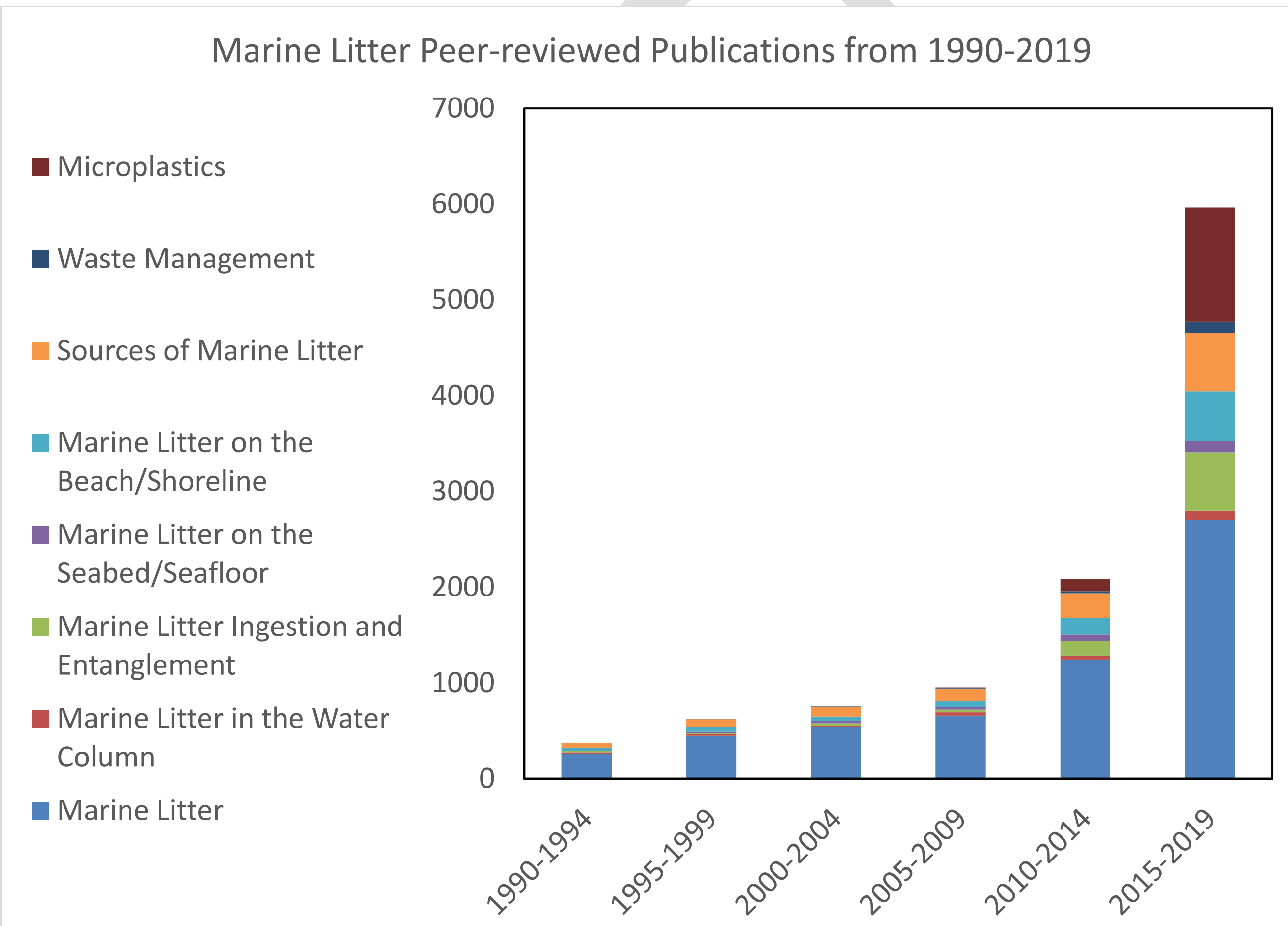

Figure 1. Research articles published about marine litter and sub categories of marine litter: beach litter, ingestion and entanglement, seabed and seafloor, water column, and sources of marine litter. Data was collected using a Web of Science search and analysis from 1990-2019.

As research and data about marine litter has become more readily available to global audiences, databases house these large repositories of data to make them useful to decision makers (managers, policy makers, etc.) and the scientific community. After seeking input from groups, research teams, private, and public sector organizations worldwide, we have compiled an extensive, though not complete, summary of available marine litter databases and datasets.

The live results of the inventory can be viewed here.

This inventory highlights the specific areas of interest the data covers, the data management protocols of the data, collection and analysis methods, region(s) the data covers, and any other relevant information.

Based on primary survey results obtained from 27 databases and datasets, the vast majority of the databases contained information regarding beach and shoreline, followed by seafloor/seabed, water column, sources of marine plastic, and plastic ingested by biota. A number of the beach or shoreline monitoring databases work in conjunction with citizen science groups to collect litter data. Projects and programs from governmental bodies, NGOs, private enterprises, research institutions and universities from across the world are working to solve the marine litter crisis. Listed below (Figure 2) are a few examples of marine litter databases ranging in scope, institutional goals and litter area of interest.

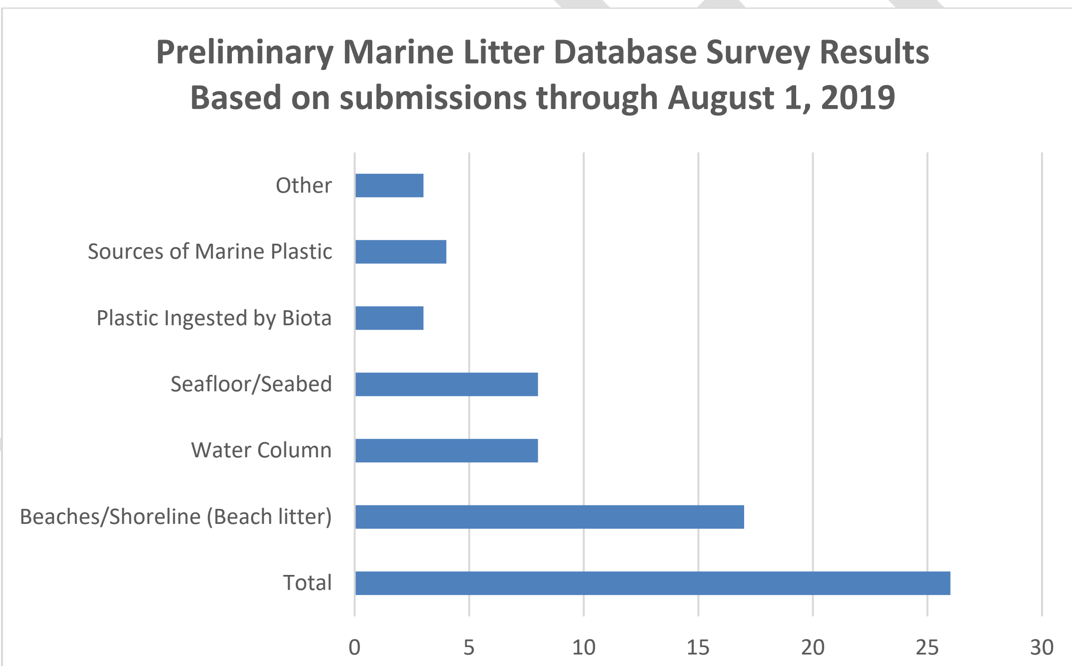

Figure 2. Results of the survey conducted for this paper about marine litter databases and datasets. Participants provided information about their main areas of focus of data collection and analyses were in regards to marine litter.

The **NOAA Marine Debris Monitoring and Assessment Project** (MDMAP, Figure 3) run by the NOAA Marine Debris Program focuses its efforts on beach litter collection and counting. The database collects their data with the help of citizen science efforts from partner organizations and volunteers conducting shoreline surveys. The database accepts data from shoreline surveys using the NOAA protocol from anywhere in the world, but most of the data is collected from the US Coastal Zone, and predominantly the west coast. The MDMAP collects data for debris larger than 2.5 cm in the longest dimension. Within the database, both flux accumulation/flux data and standing/concentration data are available, both collected using surveys of specified areas of the shoreline. NOAA staff publish data after review and verification. Anyone can request access to the database, wherein NOAA approves requests and then all verified data is reportable/downloadable.

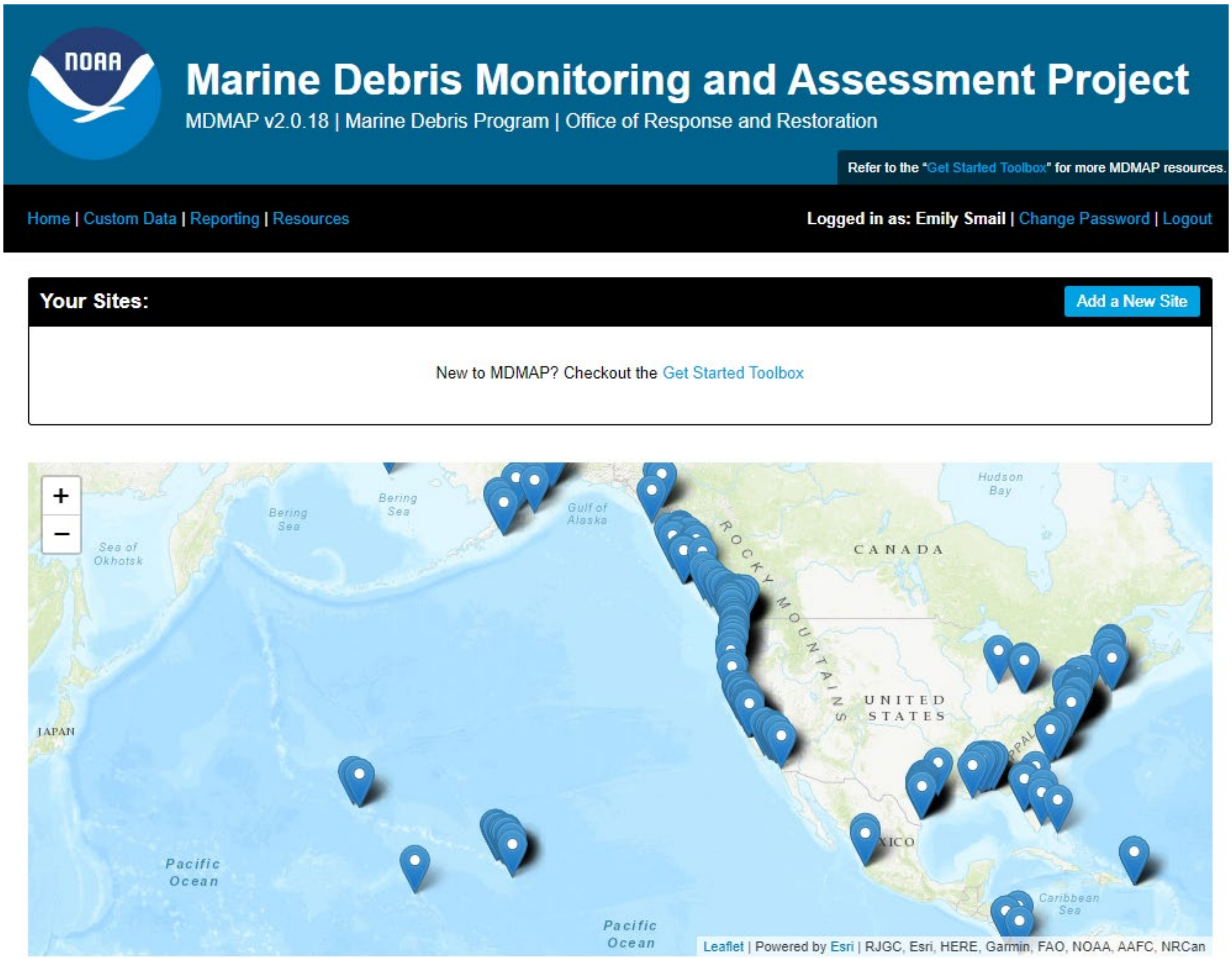

Figure 3. The [Marine Debris Monitoring and Assessment Project Database] (MDAMP v.2.0.18, viewed on November 20, 2019).

Marine LitterWatch (Figure 4)**,** operated by the European Environment Agency,focuses on litter on the coastline of most of Europe in order to "strengthen Europe's knowledge base and provide support to European policy making." The database includes a total count and itemized breakdown of all items collected/observed. Additionally, information on the specific locations sampled include total cleanups, average amount collected per cleanups, and the organization who aided with the cleanups Marine LitterWatch functions as a mobile application for volunteer organizations and Regional Seas programs in Europe to participate in cleanups. The application is used to survey a given area of clean up based on specific items broken into categories of plastic, cloth/textile, and glass/ceramics with sub-sections within those categories. At present, the Marine LitterWatch data represents the effort made by the communities collecting it and is therefore illustrative of the amount and type of items found on the surveyed beaches. Additional handling is required for using this data for further statistical purposes. The datasets are also not quality checked or monitored once the data is input into the survey. The EEA wide policy on data management, access, and sharing, is open, free, readily available access to data. https://www.eea.europa.eu/legal/eea-data-policy/data-policy

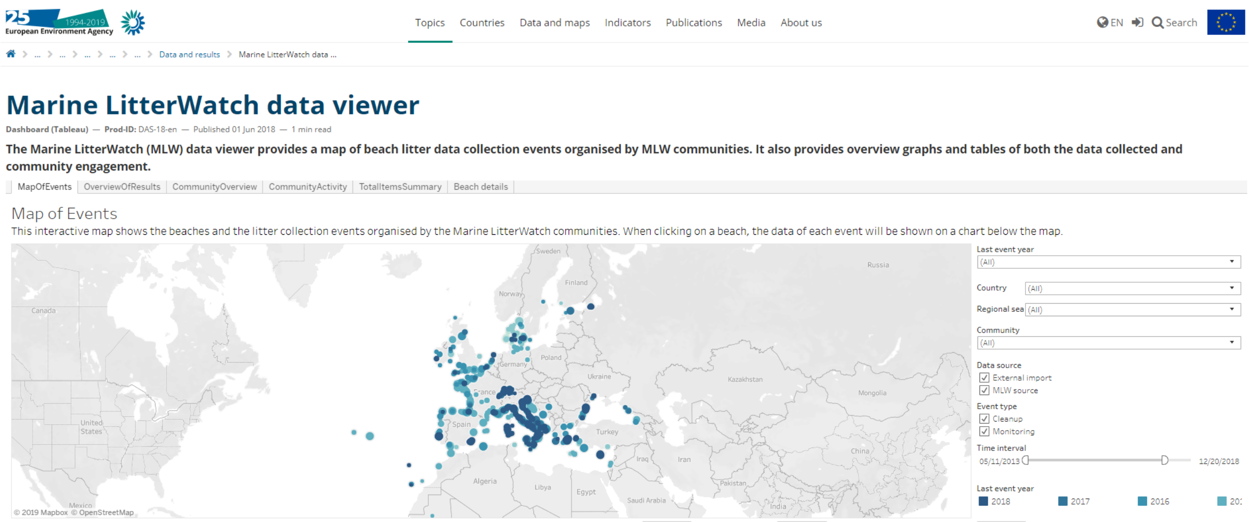

Figure 4. The Marine LitterWatch Data Viewer (viewed on November 20, 2019).

The Deep-Sea Debris Database (Figure 5), operated the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), is a composite of filmed and photographed debris found on the seafloor off the coast of Japan and the Pacific. The images include location, date observed, type of debris (plastic, glass, rubber, cloth, etc.) attributes, whether organisms were interacting or near the debris, the characteristic of the sediment, as well as the location depth of the debris. The database has a total quantity of debris observed broken down by type of debris. Cameras deployed below the surface of the water to the seabed film a specified area to observe debris. The raw data and images are available on the database. Some of the data are labeled and protected as intellectual property, but otherwise the data is open and available for others to use. In regards to the ownership of the data, the data and samples collected with JAMSTEC facilities and equipment belong to JAMSTEC. Organizations, institutes and researchers for scientific and educational purposes can use data and samples managed by JAMSTEC. They promote the use of their data to help industrial and society. Data used by industry may be charged, but all other scientific and educational use of data will be free charge.

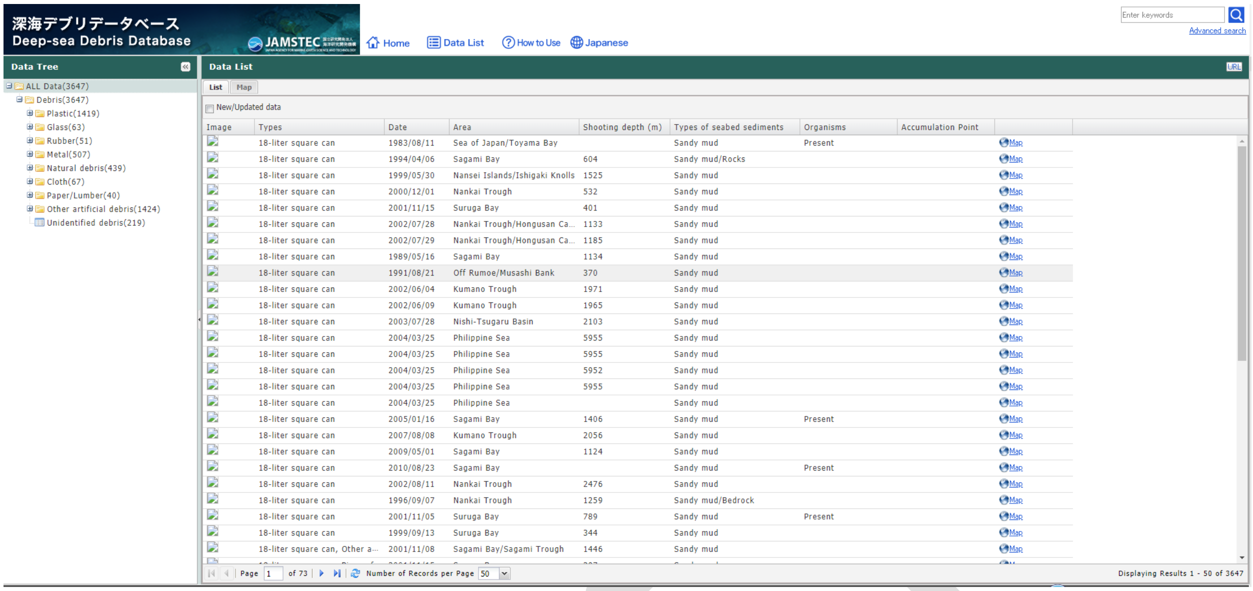

Figure 5. The Deep-sea Debris Database (viewed on November 20, 2019)

The Coastal Observation and Seabird Survey Team (COASST) is a part of the University of Washington and focuses on beach litter, ingested litter, as well as sources of this litter in parts of Washington and Oregon, USA (Figure 6). This database provides information on counts and item-specific characteristics (item type, color, material, size, loops, floppiness, brands, logos, languages, shininess, biofouling, weathering, intactness etc.) of items observed during standardized beach surveys following specific protocols for sampling debris between 2.5mm and 2.5cm; 2.5cm and 50cm; and greater than 50cm, respectively. To collect this information, trained citizen scientist volunteers collect data following the standard protocols developed by COASST. "By collaborating with coastal residents, natural resource management agencies and environmental organizations, COASST works to translate long-term monitoring into effective marine conservation solutions and responsible marine stewardship." The raw data from collections are unpublished but are available upon request. The team requires a data use agreement to establish terms of use and the data is quality analyzed and controlled by the team. Additionally post-processing procedures ensure the validity of the data.

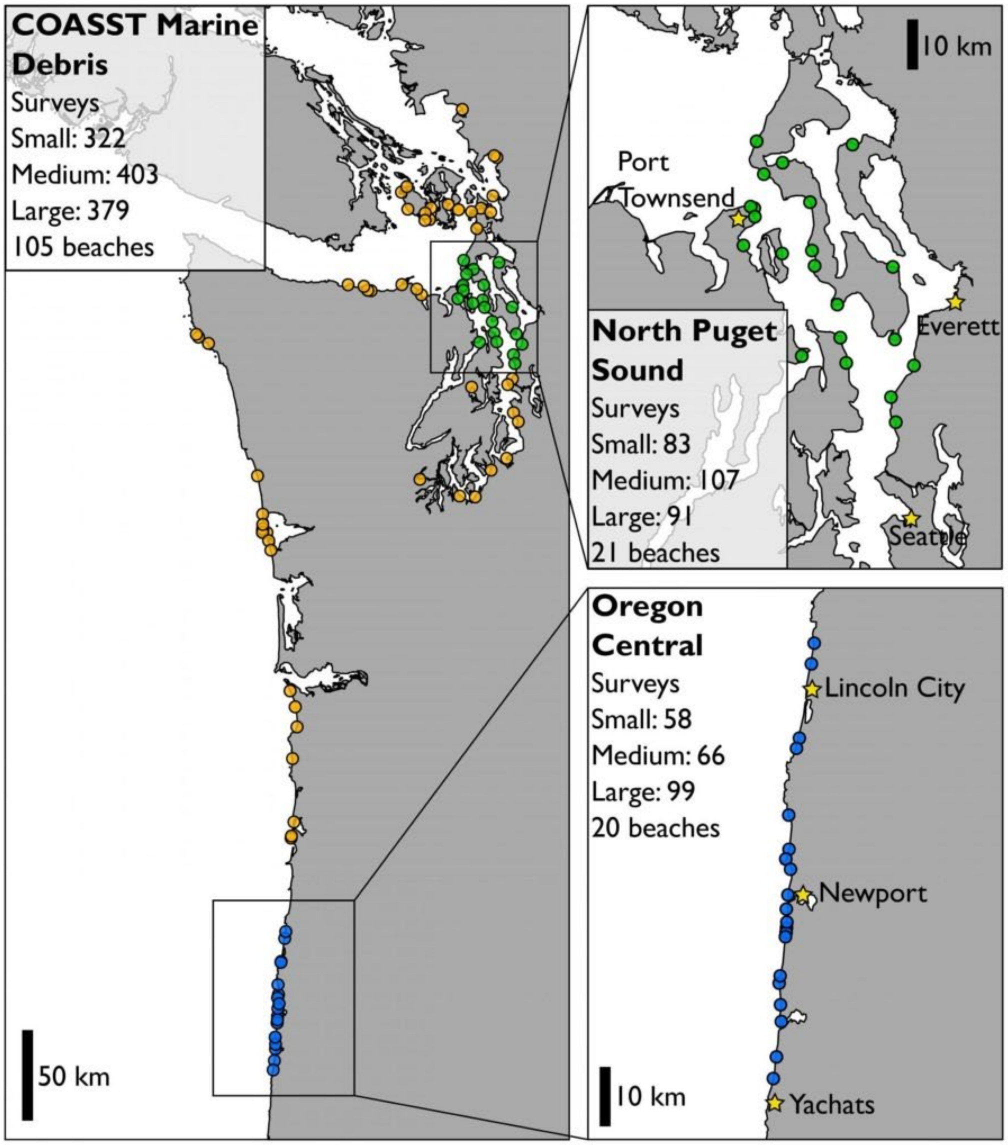

Figure 6. Map showing the locations of data collected for the COASST program as of 2018 (Image credit: Hillary Burgess).

The European Marine Observation and Data Network (EMODnet Chemistry) Marine Litter Database (https://www.emodnet-chemistry.eu/marinelitter) is part of EMODnet Chemistry, one of the seven thematic portals of EMODnet[11] (Figure 7). EMODnet Chemistry is operated at a European scale through a network of National Oceanographic Data Centers and monitoring agencies coordinated by OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale), an internationally oriented public research institution in Italy. The Marine Litter Database (Molina Jack et al., 2019) offers the first pan-European data on marine litter, namely beach litter (Addamo et al., 2018; European Commission, 2018), floating microlitter in the water column and litter on

[11] www.emodnet.eu

the seafloor from fishing trawls. National and regional marine monitoring programmes from across European member states and bordering countries (e.g. Ukraine, Russia, Georgia and Montenegro) assemble the data. The database is a strong collaboration with the Joint Research Centre (JRC) of the European Commission to ensure it compiles data requested by the European Commission's Marine Strategy Framework Directive (MSFD) and by the Regional Sea Conventions. It builds on existing databases, mainly OSPAR/MCS for beach litter in NE Atlantic and ICES DATRAS for sea floor litter in NE Atlantic and Baltic Sea. Additionally, it hosts litter data from wider monitoring and observing programmes, including scientific research, citizen science and specific initiatives like samples collected from racing yachts, in partnership with the Volvo Ocean Race. The database includes data quantities and types of beach litter, sea floor litter and floating micro-litter. The online EMODnet Chemistry platform offers a products viewer and access service where marine litter geospatial data can be discovered, viewed and visualized as pan-European map layers. Datasets are available for download together with metadata to describe the data collection and acknowledge the original data collector. Generally, there are no restrictions to access or reuse of the raw data available in the database (https://emodnet-chemistry.maris.nl/search), and where specific access requirements exist e.g. for particular countries, this is specified in the database.

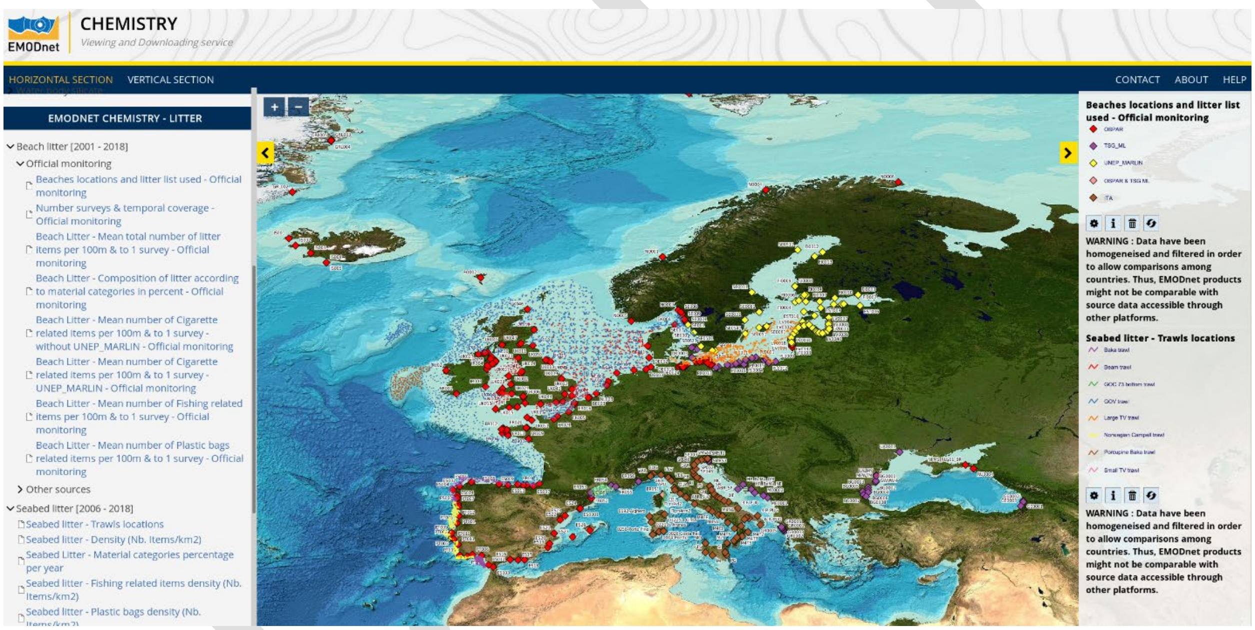

Figure 7. The [EMODNET Chemistry – Litter viewing and downloading service.](#) Map showing the location of beaches (legenda specify the different reference lists used to describe litter items) and seafloor litter surveys (legenda specify the different sampling gears used during the surveys) (viewed on November 25, 2019).

The Australian Marine Debris Database is organized by an Australian NGO called the Tangaroa Blue Foundation as part of the Australian Marine Debris Initiative (Figure 8). This database collects information on beach litter primarily on the Australian Coast with some data also available from the Asia Pacific and Oceania region. 140 categories based on material type and name are used to describe debris. To collect data, volunteers perform beach clean-ups of coastal areas on both land (beaches) and sea (near-shore surface levels). Volunteers count an itemize litter based on the specifications. Reports include approximate weight of litter and length of area of cleanup as well as optional photographs. Data are vetted before approval. The database has an open access policy that allows community groups, schools and partner organizations to generate a specific set of data reports to assist in identifying marine debris trends and creating local source reduction plans. Acknowledgement of both the Australian Marine Debris Initiative and the data contributor is mandatory for any public use of the data for any purpose. This information is available by emailing info@tangaroablue.org with both the location and date of the data requested. Additionally, there is a data management system in place – submitted data queues in holding folder for vetting before acceptance into the database.

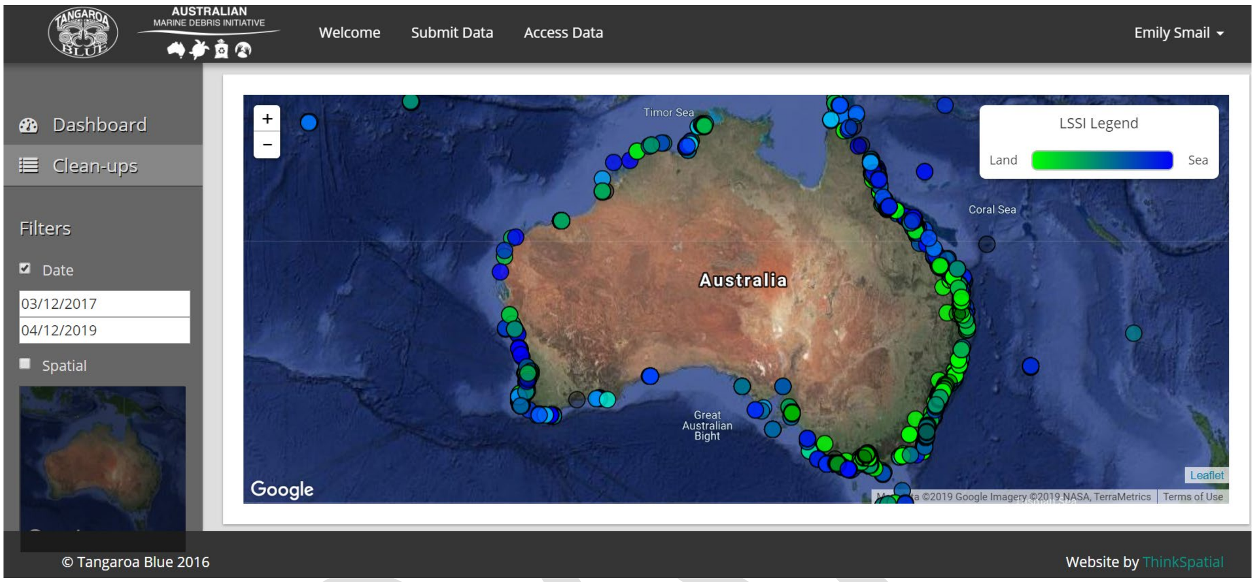

Figure 8. The Australian Marine Debris Initiative Database (viewed on December 3, 2019)

The TIDES (Trash information and Data for Education and Solutions) database, operated by the Ocean Conservancy, focuses on cataloguing and collecting litter found on beaches, shorelines and in the water column (Figure 9). This database contains information on the total mass of trash collected, the total number of trash bags filled, the total distance of area covered. An itemized list of total trash collected broken down by most likely to find items, fishing gear, packaging materials, and other items such as personal hygiene products, smaller trash items (less than 2.5 cm) and items of local concern. The public can collect data and report debris as land based trash, underwater, or trash collected by watercraft. The main form of collection of information comes from annual international cleanup events and a mobile app called Clean Swell are used to collect and itemize trash found near and in bodies of water. Groups or individuals collect trash and tally the total number of specific items found as well as the overall mass of the total trash. The data is recorded to the TIDES database and publicly available, though there is no specific database/dataset management protocol, but site-specific datasets are available and archived from past years data collected.

Figure 9. The [Trash information and Data for Education and Solutions Database] (viewed on December 3, 2019)

Litterbase is a global portal organized by the Alfred-Wegener-Institut Helmholtz-Zentrum für Polar and Meeresforschung (Figure 10). This portal has information on litter present on beaches/shorelines, the water column, the seafloor, ingested plastics scoping across oceans, rivers, lakes, and other inland waters. In the portal, information can be found regarding: quantitative geo-referenced data on aquatic and terrestrial debris; microplastics and nanoplastics from the peer-reviewed literature; quantitative geo-referenced data on effects of marine debris; microplastics and nanoplastics on aquatic and terrestrial biota from the peer-reviewed literature (field studies); and reports of impacts of marine debris, microplastics and nanoplastics on aquatic and terrestrial biota from the peer-reviewed literature (laboratory studies, species list).

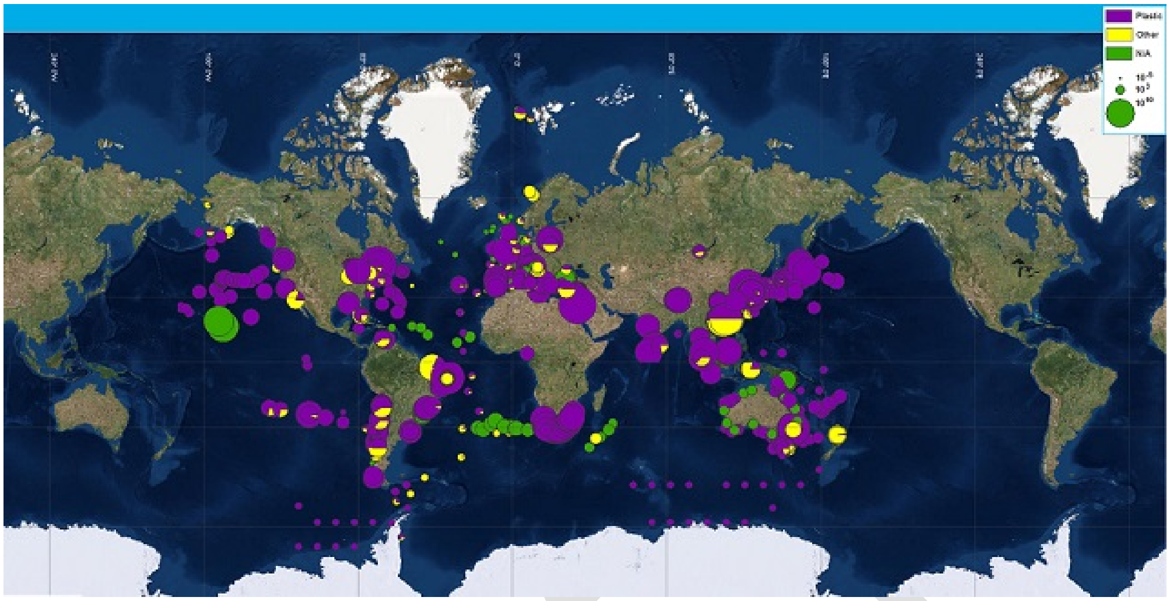

Figure 10. [Global map of litter distribution in Litterbase](Image source: https://www.maritime-executive.com/article/ocean-litter-portal-established)

The Global Ghost Gear Initiative: Data Portal is organized by the Global Ghost Gear Initiative of the Ocean Conservancy (Figure 11). This initiative works to find fishing gear that has been lost, abandoned, or otherwise discarded. This initiative works with global partners including the fishing industry, private sector, NGOs, academia, and governing bodies. The data portal has data from the US coasts, the European Coasts and the Asia-Oceania Pacific region. In the data portal, information about different types of "ghost gear" is available including found nets, lines, pots and traps. Total counts and location, dates, gear class. The data is collected using volunteers and partners that upload data to their mobile application "GGGI Ghost Gear Reporter." Bulk upload is available on their website as well. Additionally, all data is available on the data portal, and specific measurements are available upon request as well.

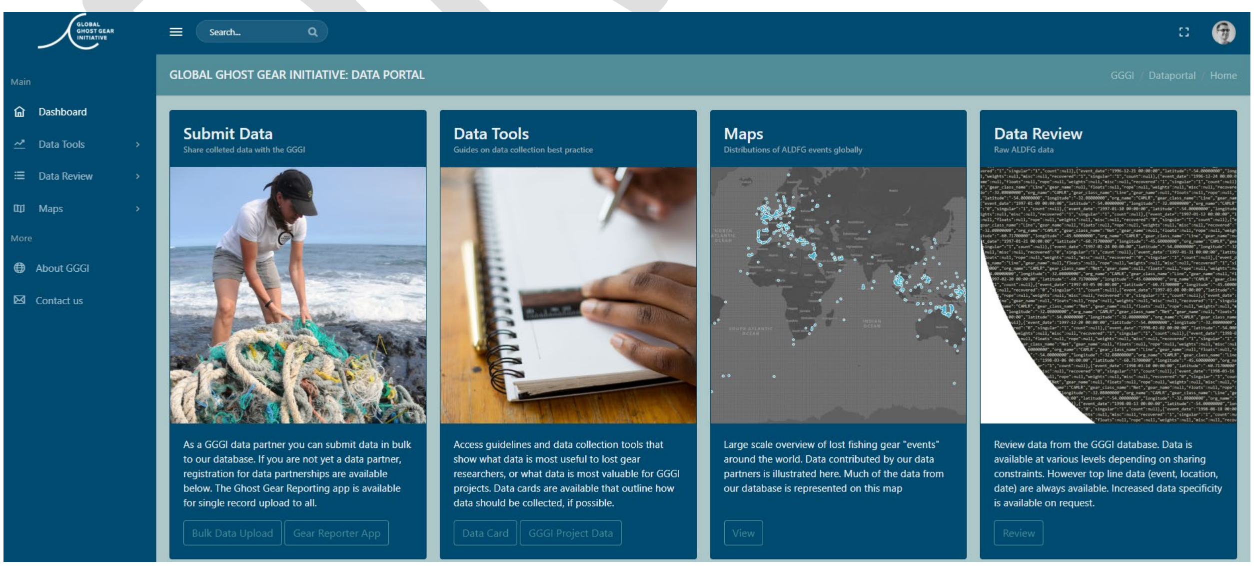

Figure 11. The [Global Ghost Gear Initiative Data Portal](viewed on December 3, 2019).

Section 3: Indicators and Applications of Technologies

Marine litter indicators address the following:

1. What is the abundance, distribution and composition of marine litter, and are these attributes changing over time (Ryan et al., 2009)?

2. What are socioeconomic drivers of marine litter, and are they changing over time?

3. What is the flow of marine litter, and how is this changing over time?

4. What are the impacts of marine litter, and are they changing over time (Ryan et al., 2009)?

In this section, we review existing and developing indicators to address these questions as well as proposed indicators for reporting on SDG 14.

Indicators for abundance, distribution and composition of marine litter

Indicators for the abundance, distribution and composition of marine litter have been developed for beach/shoreline litter, floating/water column litter and seafloor litter (GESAMP, 2019; UN Environment, 2018). These indicators seek to provide a measure of the state of marine litter in the environment (GESAMP, 2019).

Beach/shoreline litter

Various methods that take into consideration types, quantities, distribution and fluxes produce beach litter indicators. Some studies record numbers of various types of marine litter while others look at the mass of litter with some studies looking at both (Galgani et al., 2015; Galgani, Hanke, et al., 2013). Beach litter indicators can be used to focus mitigation measures and evaluate the effectiveness of legislation and regulations by providing information on the amounts, trends and sources of marine litter (OSPAR, 2010). Beach litter indicators are the most developed and common indicators and have been used extensively for analysis in regions including the North-East Atlantic, Baltic Sea and United States (European Commission JRC, 2013; Hardesty et al., 2017 ; OSPAR, 2017). Although there are many existing initiatives related to beach litter collection and monitoring, there are inconsistencies in the methodologies used across these initiatives, which impairs comparability and global analysis.

Focusing on distribution, the GESAMP report highlights the importance of understanding the physiology of a shoreline. The dynamic nature of shorelines, due to both oceanographic and meteorological factors, such as tides, waves and currents, and winds and rain, are dominant in determining how marine litter will end up on beaches. Additionally, the nature of the shoreline, specifically the surface structure and slope, will determine what type of litter remains on the beach and where that litter is located over space and time. Ekman transport, a process in which on and offshore winds will blow floating litter onto or off of the shoreline which causes pronounced currents both on and offshore, is highlighted as a means of understanding the flux process between floating and shoreline litter.

Tourism and increased human activity is a good indicator of beach litter quantities. Seasonal increases of visitors to the beach will lead to increased quantities and types of litter load to an area. Conversely, high levels of human activity can also indicate lower levels of specific larger types of litter due to organized beach sweeps (Opfer et al., 2012; Ryan et al., 2009). Using temporal, geographical, and oceanographic metrics for indicators of when beach litter will in high quantities and when certain types of litter will be present is an effective way to know when to conduct monitoring activities.

Floating and water column

Ocean circulation, material density, degradation, and biofouling are a few factors that influence the distribution of marine litter on the surface and throughout the water column. The composition of marine litter in the water column ranges from large items such as abandoned, lost, discarded fishing gear (ALDFG) to microplastics (GESAMP, 2019). Indicators for floating and water column debris are essential for knowing what sampling strategy to adapt when monitoring marine debris. In a sort of circuitous route, the indicator needed to identify marine litter quantity and distribution floating on the surface or in the water column, depends on what type of material you are trying to monitor or sample.

Generally, there are a few primary indicators that can be used to determine where marine litter will be in the open waters, how much will be there, and the type. As with beach or shoreline litter, temporal variations play a big factor in indicating the location and distribution of litter, including tidal conditions, short-term wind and rain events, and seasonal extremes or anomalies. There are also specific types of litter or plastic that are more or less dense than water. Depending on the structure, make up and size of the litter, the distribution and composition of litter within the water column is slightly more straightforward to determine; for example, polystyrene will sink while polyethylene and polypropylene polymers will presumably float (GESAMP, 2016). Understanding shipping and fishing pathways and monitoring may also be a useful indicator as to where to find marine debris, especially debris in the water column. Most of the debris found in the ocean are land-based, but there is still a significant portion of debris entering the water from sources at sea (NOWPAP CEARAC, 2007). Very high-resolution satellite images, UAV data and ship-mounted cameras can indicate mega-litter conglomerates on the sea surface.

Seafloor

From shallow areas near reefs, to deep trenches, litter is all across the seafloor. Indicators for monitoring sea floor litter are a more nuanced than indicators for beach litter or floating and water column litter, because the sea floor is a sink for marine litter (Galgani et al. 2000, Pham et al. 2014, Woodall et al. 2014, GESAMP 2019). There are two dominant non-naturally occurring indicators of potential seafloor litter. The first is proximity of maritime activities, such as fisheries, aquaculture, shipping, construction, energy extraction and recreational activities (Pham et al. 2013, Loulad et al. 2017). The second is shore-based leakage or run off points, like major river deltas, populated and industrialized coastlines and coastal tourism. Though not all seafloor litter is macro in scale (there is a significant issue of microplastics in sediments), a key indicator of type of litter found on the seafloor is the physical characteristics of litter, especially density and size.

While time and seasonal trends are hard to use as indicators, especially concerning quantity, due to the lack of baseline studies and observations of seafloor litter, environmental factors of the seafloor may be a key indication of the possible presence of litter. Water depth, seafloor topography, surface and deep-water currents may be an indicator of distribution (GESAMP 2019).

Socioeconomic drivers of monitoring marine litter

Indicators of marine litter from costal sources include urban development, population proximity to the ocean, and economic status. Urban development linked to marine litter include transportation infrastructure and storm water drains. Coastal roads increase beach access resulting in a greater number of beach users and visitors, which can result in coastal debris deposition (Willis et al. 2017, UNEP 2017, Glanville and Chang 2015). Locations where activities are transitory, such as parking lots or shopping malls, can also accumulate litter (Hardesty et al. 2016). Storm water drains are a link between urban run-off and marine litter. They also transport microplastics that come from washing clothes made with synthetic materials (Browne et al. 2011). The number of storm water drains is a potential indicator as it positively correlates with the abundance of marine litter, even when controlling for population density (Willis et al. 2017).

The relationship among a population size, its distance from the coastline, and the abundance of marine litter is dependent on the geographic scale of the indicator. Remote and uninhabited islands can accumulate large quantities of marine debris, which reflects global issues with marine litter and not a singular point source (Lavers et al. 2019). At regional scales, the abundance of marine litter scales positively with population size (Hardesty et al. 2016, Browne et al. 2011). Even isolated sites located in regions with large populations have high litter deposition (Hardesty et al. 2017). In some locations, local community environmental stewards actively remove litter or reduce litter deposits by influencing beachgoer behavior (Hardesty et al. 2017). The interplay between societal norms and local policies influence both litter accumulation and stewardship Communities can place pressure on the government to provide and maintain municipal waste removal services, which are scarce in disadvantaged communities (Hardesty et al. 2016, Cordova et al. 2019). Governments can also take a proactive approach by banning major sources of marine litter. For example, Bandung, Indonesia is the only Indonesian city that bans Styrofoam food packaging, and is the largest source of marine litter in Indonesia (Cordova et al. 2019).

Economic status determines waste production and the resulting marine litter. Low and middle-income countries generate less plastic waste per-capita than high-income countries (Jambeck et al. 2015). However, low and middle-income countries have less infrastructure and financial resources for proper waste management (Brooks et al. 2018). GDP can serve as an indicator as mismanaged waste has high potential to become marine litter. Since the 1980’s, high-income countries have been major exporters of plastic waste to low and middle-income countries, which places further strain on countries with limited capacity for proper waste management (Brooks et al. 2018). This issue is more apparent in the wake of the 2017 Chinese import ban of nonindustrial plastic waste (Brooks et al. 2018). In countries like Australia, biosecurity laws prevent litter imports, thereby making debris removal from remote islands logistically difficult and expensive (Lavers et al. 2019).

Indicators for the flow of marine litter

Spatial distribution of floating litter, along with current, tidal, and riverine information can be a useful source indicator for input of litter into this marine environment. This may allow for important evidence about the pathway and input zone, which is useful to determine the potency of the source as well as the efficacy of any management practices in place. The use of specific items as indicators of sources or pathway of marine input is a useful practice, such as items from industrial or fishing vessels.

The major land-based sources of marine plastic include landfills, floodwaters, industrial outfalls, discharge from storm water drains, untreated municipal sewerage, and littering of beaches and coastal areas from tourism and other activities. Existing databases, social media and public documents can provide information on these sources.

The integrated information and model system would provide a basis for risk assessments. For example, a candidate for assessing the risk of seafood contamination from ocean plastics is the functional dependency network analysis (Pinto & Garvey, 2013), which this model system would support. Likewise, the model system would facilitate cost-benefit analyses for mitigation means.

This integrated system also would allow for a scenario-based exploration of possible futures. After careful validation and calibration, this model could assess future trajectories for ocean plastics based on scenarios of plastic production, waste management, recycling and reuse practices, as well as efforts to remove plastics from the ocean. Desirable futures can identify transformative policies needed to ensure such futures.

Plastic debris in rivers, including the mouths of rivers and estuaries

Main sources of marine litter entering the ocean through rivers are due to improperly managed plastic waste, including failed recycling, inadequate sewage systems, and inadequate disposal (Jambeck et al., 2015). A combination of an intensive 2-week in situ sampling program with hydrological data showed that the Saigon River, Vietnam, carried macro-plastic loads at least four times higher than previously estimated (Van Emmerik, 2018). This underlines the importance of case studies in those rivers that knowingly contribute significantly to the flow of plastic into the ocean. The Ocean Cleanup initiative (https://theoceancleanup.com/rivers/) is working with governments to prevent plastic from entering the world's oceans from rivers from 1000 of the most polluting rivers, all over the world, by 2025.

Sediment outflows at river mouths, indicative and correlated with land-based sources of pollution might be a potential indicator for plastic debris. Sediment samples in estuaries could also provide information on plastic contents, potentially given time variability over the last five to seven decades.

In addition to estimates of plastics at river mouths and in estuaries, it is important to map the input of plastic into the rivers. Variables such as watershed population, sources of waste and leakages into the environment, management practices, and runoff would be important auxiliary data to harvest from existing sources.

Marine litter debris from ocean activities (shipping, fishing, mining)

Many sea-based activities contribute to marine debris. Important contributions come from fishing and aquaculture, shipping (e.g., transport, tourism), dredged material, offshore mining and extraction, sewage sludge and illegal dumping at sea. As most sea-based sources of plastic come from ship presence or traffic, the comprehensive available Automatic Identification System (AIS) data provides a database of valuable information about ships and their movements. While various free sources of AIS data exist online, these are limited in scope. The full database is available for purchase. Based on this full database, pattern recognition and matching algorithms could be used to match hotspots of marine litter with ship presence, taking into account the trajectories of these hotspots based on ocean currents. This would allow determination of ship size, type, and flag country to identify the most likely polluters.

Knowing where the most important fishing areas are at any given one point in time (e.g. Global Fishing Watch, https://globalfishingwatch.org) would help to detect major potential sources and locations of ghost gear.

A key convention for the International Maritime Organisation (IMO) is the International Convention for the Safety of Life at Sea (SOLAS). Regulation 19 of Chapter V of SOLAS - carriage requirements for shipborne navigational systems and equipment – lists the navigational equipment to be carried on-board ships in accordance to ship type. All ships are required to carry AIS, which must be able to provide information about the ship to other ships and to coastal authorities automatically. More specifically, regulation 19 of SOLAS Chapter V requires AIS to be installed on-board all ships which are of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size.

This means that AIS cannot necessarily track many fishing vessels. However, it is mandatory for all fishing vessels engaged in commercial activities to broadcast their positions via encrypted satellite communication every 2 hours. This system, known as Vessel Management System (VMS) monitors national fishing fleets and foreign vessels fishing within national waters is available only to national governments authorities and groups that share access. By engaging national authorities as well as FAO, VMS data at global level can track, monitor, model and evaluate the sources and locations of fisheries ghost gears.

Aquaculture is also a known source of lost fishing gear and apparatus. High-resolution imagery can reliably detect the locations of these activities (Trujilo et al., 2012).

The Marine Environment Protection Committee (MEPC) of the International Maritime Organisation (IMO) has agreed an Action Plan (IMO, 2018) to address Marine Litter from ships (including from fishing vessels). Building on the existing policy and regulatory frameworks such as the MARPOL Convention (MARPOL, 1973) and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the London Convention and Protocol for short, LCP, 1972), the action plan introduces new supporting measures to address the issue of marine litter from ships. The Global Platform can feed into the Action Plan and respond to the requirements of this Action Plan.

Marine litter from coastal disasters

The modern built environment includes a large fraction of plastic material. In 2015, 72 million tons of plastic went into building and construction (with an average use time of 35 years) (Parker 2018). Considering the migration of the global population, a large fraction of this is located in the coastal zone or in flood zones and thus exposed to hydro-meteorological hazards. This rapidly increasing exposure of the built environment to floods and storms has increased the likelihood of plastic and other debris entering the ocean. The likely increase of the frequency and intensity of hydro-meteorological hazards due to modern climate change further exacerbates this risk.

It is urgent to compile information on the amount of marine debris resulting from coastal disasters. Databases compiled by insurances, real-estate companies and municipalities could be harvested to estimate and map the plastic integrated the built environment. Overlaying this information with disaster assessment would provide a basis to quantify the amount of plastic and other debris washed into the ocean during major hazardous events.

Primary Microplastics

Microplastics in the environment are categorized as primary and secondary microplastics. Boucher and Damien (2017) define primary and secondary microplastics as follows:

- **Primary microplastics** are plastics directly released into the environment in the form of small particulates. They can be a voluntary addition to products such as scrubbing agents in toiletries and cosmetics (e.g. shower gels). They can also originate from the abrasion of large plastic objects during manufacturing, use or maintenance such as the erosion of tires when driving or of the abrasion of synthetic textiles during washing.

- **Secondary microplastics** are microplastics originating from the degradation of larger plastic items into smaller plastic fragments once exposed to marine environment. This happens through photodegradation and other weathering processes of mismanaged waste such as discarded plastic bags or from unintentional losses such as fishing nets.

Indicators of marine microplastics pollution includes emission estimates of primary microplastics. Primary microplastics include tire dust/particles, road markings, synthetic textiles, maritime coatings, personal care products, plastic pellets and artificial turf (Boucher & Damien, 2017; Wang et al., 2019). Emission estimates can then be linked into estimates of microplastics entering the aquatic environment through various pathways (e.g. domestic sewage, road runoff, wind, adjacent waters) (Burton, 2017; Lassen et al., 2015; Verschoor et al., 2016).

For example, a recent study by Wang et al. (2019) utilized this process to estimate the contributions of various items to primary microplastics emissions and estimate the amounts entering aquatic environments in mainland China (Figure 12).

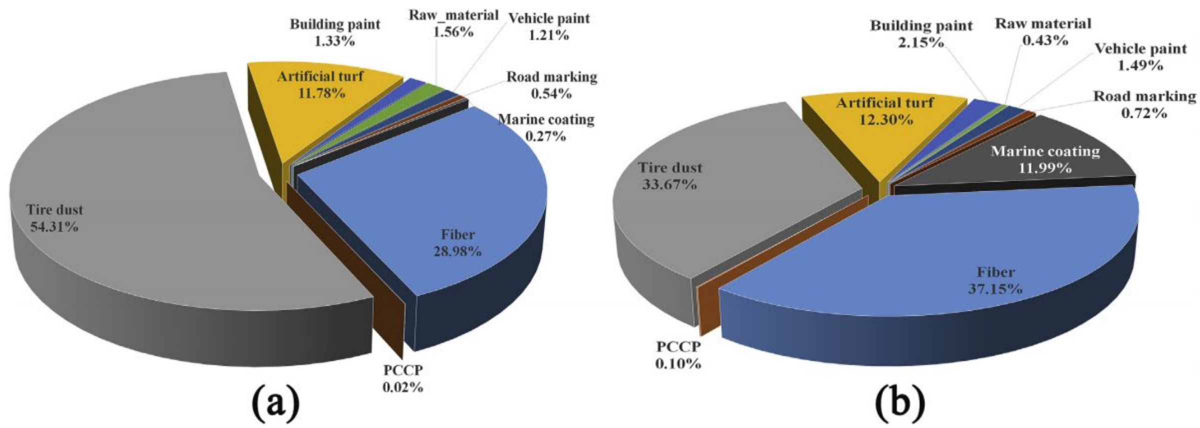

Figure 12. Contribution of various sources to total primary microplastics emissions (a) and the amounts entering the aquatic environment (b) in mainland China in 2015. Source: Wang et al., 2019.

These estimates can be validated by the analysis of microplastics in known sources, such as storm water, and the marine environment (Sutton et al., 2019) though additional analysis and research is needed before primary microplastics emissions can be routinely used as indicators.

Indicators for impacts of marine litter

Biological Impacts

Marine organisms regularly interact with litter deposited into the ocean. Whether there are filter feeders incidentally consuming microplastics, birds nesting on floating debris on the ocean surface or beach, larger fish eating litter that travels upwards through the different trophic levels, or coral reef habitats being disturbed by litter on the ocean floor, litter and debris impact myriad marine biota through a number of different means. Monitoring how, where, why, and when organisms interact with litter is crucial for the safety and wellbeing of the oceans.

Biological and classical indicators play a pivotal role in the monitoring of marine litter. Because not all litter will be collected or counted, the biological indicators act as a way to measure the impact marine debris is having on the environment and serves as a way to assess the impact of a specific measure or policy set in place. For example, the INDICIT II project has found an effective biological indicator should be “accurate, sensitive, reliable and easy to use for all the stakeholders in order to be applied to a large geographic area.” Sea turtles, crustaceans and fish are useful indicators because they tend to ingest of become entangled in marine debris, have a large spatial distribution, and use all ecological marine components from the seabed to sea surface[12].

Entanglement and ingestion are two biological indicators that will provide information about the interactions between organisms and marine debris. Monitoring entangled organisms can indicate changes in the abundance of debris responsible for entanglements[7]. Entanglement also serves an indicator for the harm caused by the incorporation of marine debris into nests of breeding birds[6]. While it occurs less frequently than ingestion, using a consistent monitoring approach could potentially allow entanglement to be an indicator for the success of mitigation efforts.[13] In addition, the presence of plastic items in nests can be an indicator of the amount of litter in the natural environment near their nesting areas as well as a risk for entanglement[6].

Ingestion of marine debris can be useful as an indicator for a number of different things. The first is that, plastic content of a bird stomach can determine regional differences in the abundance of marine debris. Comparing plastic loads of birds in different regions can act as a way to show where more pollution is acting as both a source and a sink[7]. Using stomach contents of fulmars, the OSPAR Commission developed an indicator to demonstrate the changes in quantities of floating debris in the North Sea as well as the impact it has on biota[3].

The CleanSea Project developed a series of considerations to make when selecting or implementing an organism as a bio-indicator (as opposed to collecting samples from naturally available species) that would aid in both consistency and accuracy. As with experiments, selection should be based on a site-by-site, case by case basis. The general guidelines provided for selection are as follows: region specific indicator species; non-threatened or protected species; species that can be kept in cases for easy field deployment or retrieval (such as bi-valves); invertebrate species (require less training and handling than vertebrate species); perform sampling in a cost-effective manner by synergies with pre-existing programs; species which when measure are directly linked to impact and effects (more difficult to achieve); species that are directly linked to measure and could be used to evaluate progress towards targets and effectiveness of mitigation activities (Ryan et al., 2009). The use of these guidelines for selection of a bio-indicator, while not comprehensive and fully incorporating all debris, can be a useful starting point.

Fossi, et al, developed a more general approach to indicator selection of sentinel species as indicators. This study surveyed reports of marine species impacted by debris in the Mediterranean Sea, specifically species that had ingested debris. Based on their findings, they determined six key criteria to consider when selecting an indicator based on ecological and biological data. The first was background information, including biological and ecological characteristics of the species as well as the knowledge of the non-affected species to be able to generate a point of comparison. The second was habitat information of the species, including both the habitat and home range of the species (sessile, motile, depth, travel, migration). The third was trophic information and feeding behavior, specifically the feeding mechanic and behavior knowledge in order to select a wide range of levels of the food scale. The fourth was spatial distribution of species, which is

[12] https://indicit-europa.eu/cms/wp-content/uploads/2018/09/Protocole_v7_hd.pdf

[13] https://mcc.jrc.ec.europa.eu/documents/201702074014.pdf

important because of the spread of debris both across the surface and seabed and throughout the water column. The fifth was commercial importance and conservation status, which may allow for a measure of potential transfer of plastic from seafood to humans. Additionally, it is important to monitor species of concern and how marine litter affects them. The sixth recommendation was to note the documented ingestion of marine litter based on the statistics and data available (Fossi et al., 2018). As with the CleanSea Project, the criteria of selection represent a basis of guidelines, not all the information needed will be readily available, and not all species used will be the all-telling indicator. With all data collection though, having a consistent basis of how to sample and prepare data will have a number of long term benefits, namely the ability to accurately compare data from across different regions of the world.

Economic Impacts

Various industries are both the source of and are vulnerable to economic losses from marine litter. The economic consequences of marine litter can be immediate, as in the case of repairing fishing gear, or long term, due to lasting changes in ecosystem function. Marine litter poses hazards to human health; therefore understanding the welfare risks can incentivize marine litter mitigation efforts.

Fisheries

The fishing industry is a source of marine litter, but it also incurs direct and indirect costs from marine litter. Direct costs include repairing or replacing lost or damaged gear, time spent clearing litter from nets, reduced catch due to contamination, and rescue services (Mouat et al. 2010). A case study from the Shetland Islands revealed that direct costs of marine litter to the Scottish fishing industry is between $15.5 million and 17.2 million, or 5% of overall revenues annually (Mouat et al. 2010). The estimated direct cost of marine litter to the EU fishing industry is $81.9 million (UNEP 2017). Indirect costs of marine litter come from derelict fishing gear, or lost fisheries equipment such as trawl nets, gill nets, traps, or pots (National Resource Council 2008). A phenomenon known as “ghost fishing” occurs when derelict fishing gear continues to capture marine life after the equipment is lost (Newman et al. 2015). This can reduce potential harvest and have long-term impacts on fisheries sustainability (UNEP 2017, Matsouka et al. 2005). For example, derelict crab pots in Puget Sound, Washington, cause an estimated 4.5% harvest loss in *Cancer magister* landings, or $744,000 annually (Antonelis et al. 2011).

Marine litter can have economic impacts on the fishing industry by harming marine life, resulting in negative public perception of seafood safety. Stomach, gills, and tissues of fish and bivalves contain microplastics and are reflective of plastic use by local human populations (Barboza et al. 2018, Rochman et al. 2015). Ingested microplastics can affect the growth rate or mortality of marine life by blocking feeding appendages or altering hormone levels (Wright et al. 2015). It is unclear how microplastics and their associated chemicals transfer up the food chain (Smith et al. 2018). Seafood contamination by plastics, or the perception of it, can reduce consumer demand, which leads to economic loss throughout the fishing industry.

Tourism

Beach users place aesthetic value on recreational spaces and are deterred from coastlines they perceive as having too much litter. This can negatively impact coastal communities that rely on visitors for revenue, such as the UK, which generates between $7.6 billion to 12 billion from coastal tourism annually (Mourat et al. 2010). After heavy rainfall on Goeje Island, South Korea, a large pulse of marine litter resulted in 500,000 fewer visitors to the island (Jang et al. 2014). Without tourists to spend money on food and lodging, Goeje Island lost an estimated $25.2 million to $31.7 million in 2011. A garbage and medical waste spill on the New Jersey shore caused an estimated 22% drop in beach visitation and a total loss of $1.4 billion (Tyrell 1992). Based on public questionnaires, in Cape Peninsula, South Africa, 40% of foreign tourists and 60% of domestic tourists would avoid visiting if there were more than 10 litter items per square meter (Balance et al. 2000). Along the coast of Paraná, Brazil, 85% of users would avoid visiting beaches with more than 15 items per square meter, which would cost up to $8.5 million in lost revenue (Krelling et al. 2017).

Beach cleaning can generate revenue by attracting visitors. Using a travel cost model by Leggettt et al. (2014), in Orange County, California, a 75% reduction in marine litter would generate $53 million. However, beach cleaning comes at a cost. In coastal cities along Oregon and California, beach cleanup, street sweeping, storm water capture devices, storm drain cleaning and maintenance, public education, and losses from tourism costs between $9.5 million to $10 million, depending on population size (Stickel et al. 2012). Coastal municipalities in the UK spend $19.7 million annually on marine litter removal and $11.4 million annually in Belgium and the Netherlands combined (Mouat et al. 2010). The amount spent on these efforts in each municipality depends on the touristic value of their beaches. Voluntary stewardship programs also play an important role in removing marine litter and raising public awareness of coastal issues. 5 coastal stewardship organizations in the UK used $14,525 for program support such as cleaning supplies, liability insurance, and transportation to waste management facilities. However, program costs often do not account for the time donated by volunteers. In the UK, 8,809 volunteers contributed the equivalent of $143,673 of their time based on the British minimum wage (Mouat et al. 2010).

Ecosystem services

Marine ecosystem services are valued at $18.1 trillion (Costanza et al. 1997). Marine litter threatens the three components of ecosystem services: provisioning (e.g. food and materials), regulatory (e.g. climate regulation and diseases control), and cultural services (e.g. recreation and heritage) (Beaumont et al. 2019), which have vast economic costs to various sectors as reviewed above. Invasive species can have a detrimental impact on biodiversity and disrupt ecological processes, which in turn affect ecosystem services. Marine litter can serve as a raft for transporting invasive species long distances to areas they do not naturally occur (Rech et al. 2016), which would necessitate the economic costs of eradication and monitoring of invasive species. For example, the eradication and monitoring of the introduced carpet sea squirt (*Didemnum vexillum*) in Wales cost $733,208 over 10 years (Newman et al. 2015). Without this intervention, this introduction costs an estimated $9.4 million to the local mussel fishery (Newman et al. 2015). In the north Pacific, the folliculinid ciliate (*Halofolliculina* spp.), responsible for skeletal eroding band disease in corals, was found on plastic debris (Goldstein et al. 2014). Their original distribution was in the South Pacific and Indian Ocean, but their presence in the North Pacific and the accumulation of plastic debris in the Hawaiian Islands suggests that marine litter facilitated the transport of the ciliate (Goldstein et al. 2014). Coral diseases can cause changes to the diversity and abundance of marine life, which can have economic costs associated with tourism and fishery activities.

Human health

Health care costs of marine litter depend on the severity of acute and chronic medical conditions. Maritime collisions with large litter or entanglement can lead to injury or death, and the litter created from these accidents can persist as hazards to people at sea (Newman et al. 2015). Medical and hygiene waste threaten water quality, and exposure to contaminated seawater can result in infections (Tyrell 1992). Injury claims in New Zealand costs thousands of dollars, with injuries primarily due to punctures (Campbell et al. 2019). Children are the demographic most vulnerable to marine litter related injuries as they are unaware of potential hazards (Campbell et al. 2019).

Toxins associated with marine litter pose a threat to bodily functions. Contaminants from agricultural and industrial run off, such as polychlorinated biphenyls (PCBs) and dichlorodiphenylchloroethane (DDT), and bisphenol A (BPA), are linked to organ damage, hormonal disruption, and reproductive abnormalities (Center for Disease Control). The chemical composition of plastic polymers facilitates the accumulation of contaminants, causing litter to be orders of magnitude more toxic than the surrounding seawater (Galloway 2015). Pollutants absorbed in lower trophic levels can propagate throughout a food web (Ross and Birnbaum 2003). Current research suggests that toxin bioacculumation is dependent on contaminant type, dosage, and prior exposure (Lohmann 2017).

Marine litter can serve as a vector for diseases (Lamb et al. 2018, Barnes 2002). Plastic litter harbors its own “plastisphere”, or a microbial community that is different from the surrounding seawater (Zettler et al. 2013). *Vibrio* strains of bacteria responsible for infectious diseases are in the plastsphere, suggesting that marine and human life can be susceptible to infections and the spread of diseases can be far reaching (Zettler et al. 2013).

Indicators for SDG reporting

The existing internationally agreed GESAMP guidelines determine the agreed indicators for reporting on marine plastic litter under SDG Target 14.1.1b. Sub-indicators beach litter, floating plastic and plastic in the sea column, plastic on the sea floor and additional option indicators included in the approved methodology (Table 5, UN Environment 2019). Indicators are categorized into three levels:

Level 1: Global indicators

- Plastic patches greater than 10 meters (for Areas Beyond National Jurisdiction or Total Oceans)
- Beach litter originating from national land-based sources

Level 2: National indicators

- Beach litter count per km2 of coastline (surveys and citizen science data)
- Floating plastic debris density (visual observation, manta trawls)
- Water column plastic density (demersal trawls)
- Seafloor litter density (benthic trawls (e.g. fish survey trawls), divers, video/camera tows, submersibles, remotely operated vehicles)

Level 3: Supplementary indicators

- Beach litter microplastics (beach samples)
- Floating microplastics (manta trawls, e.g. Continuous Plankton Recorder)

- Water column microplastics (demersal plankton trawls)
- Seafloor litter microplastics (sediment samples)
- Plastic ingestion by biota (e.g. birds, turtles, fish)
- Plastic litter in nests
- Entanglement (e.g. marine mammals, birds)
- Plastic pollution potential (based on the use and landfilling of plastics)
- River litter
- Other parameters related to plastic consumption and recycling
- Health indicators (human health and ecosystem health)

Table 5. Monitoring parameters for marine plastic litter to track progress against SDG Target 14.1 (UN Environment, 2019).

Monitoring parameters (and methods)	Level 1	Level 2	Level 3
Plastic patches greater than 10 meters*	X		
Beach litter originating from national land-based sources	X		
Beach litter (beach surveys)		X	
Floating plastics (visual observation, manta trawls)		X	
Water column plastics (demersal trawls)		X	
Seafloor litter (benthic trawls (e.g. fish survey trawls), divers, video/camera tows, submersibles, remotely operated vehicles)		X	
Beach litter microplastics (beach samples)			X
Floating microplastics (manta trawls, e.g. Continuous Plankton Recorder)			X
Water column microplastics (demersal plankton trawls)			X
Seafloor litter microplastics (sediment samples)			X
Plastic ingestion by biota (e.g. birds, turtles, fish)			X
Plastic litter in nests			X
Entanglement (e.g. marine mammals, birds)			X
Plastic pollution potential (based on the use and landfilling of plastics)			X

River litter	**X**
Other parameters related to plastic consumption and recycling	**X**
Health indicators (human health and ecosystem health)	**X**

** This indicator is most useful for areas beyond national jurisdiction or total ocean area, not for national monitoring.*

These indicators are marked as levels 1, 2 or 3, level 1 being global data or globally modelled, level 2 including national monitoring and level 3 describing supplementary/recommended indicators.

Section 4: Monitoring the plastics value chain

Monitoring marine litter is essential for our understanding of the situation; however, simply measuring the problem is not enough to inform policy. A complete life-cycle approach to the way plastic is produced, used in products and eventually becomes waste is important for understanding the sources and management options to the global problem of marine litter, as well as issues related to waste in terrestrial and freshwater environments. A life-cycle approach includes all the stages from raw material (essentially oil and gas) extraction, processing, design and manufacture of plastic products, their use, and finally end-of-life waste management practices[14] (UNEP 2012), as well as how waste ends up in the natural environment, and how waste flows through river and other water pathways. This approach also pushes the assessment towards all sorts of environmental impacts generated by the use of resources (land, water, minerals, biomass…) and generation of emissions (greenhouse gas emissions, toxic emissions, nutrient pollution, etc.) and potentially including plastic litter) along the life cycle of production and consumption systems. In this way, life cycle approaches provide the systems perspective required to assess how plastic is used for which products, enabling comparisons with alternatives: ways of using plastic (e.g. in reusable vs. disposable products) or products made from alternative materials. UNEP (2018) and Ryberg et al. (2019) follow such a life cycle approach in mapping the global losses of plastic across its main value chains, differentiating among polymer types, application, macroplastics and microplastics, etc.

According to these studies, approximately 6.2Mt of macro-plastics and 3.0 Mt of microplastics were lost to the environment in 2015 (Figure 13). Figure 14 on the overview of the plastic value chain shows amounts annually produced, used in different sectors and eventually disposed of (end-of-life stage). The figure shows total masses of plastics lost to environment (marine, freshwater, and terrestrial compartments) per life cycle stage.[15] Across the plastics life cycle, the largest losses of plastics occur in the use and end of life (EoL) stages, which account for ca. 36% and 55% of total plastics losses to the environment, respectively. Losses during plastics production are relatively small and account for 0.25% of total plastic losses. In general, about 90% of microplastics losses from the use stage, about 77% of macro-plastics losses are from the EoL stage, and 13% of macro-plastics losses stem from littering. Figure 15 shows the plastic losses to the environment distributed by geographical regions, macro- and microplastics, and loss sources.

[14] See e.g. https://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/

[15] The mass of plastics produced is not equal to the mass of plastics disposed of due to plastic service lifetime extending beyond the year of production. Accordingly, a fraction of the plastic wastes disposed of in 2015 were produced in the years before 2015.

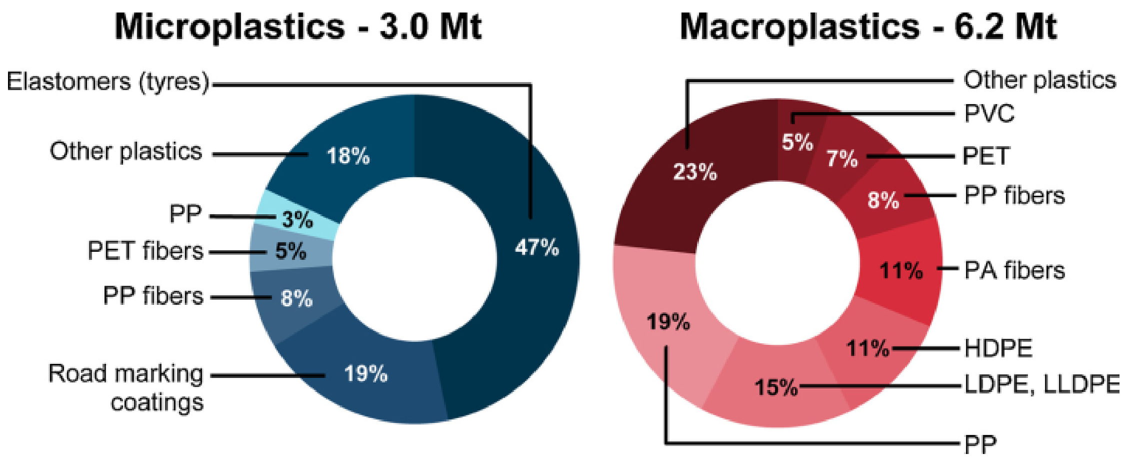

Figure 13. Losses of microplastics and macroplastics to the environment (marine, freshwater, and terrestrial compartments) by polymers and plastic applications (when exact plastic (or polymer) types cannot be identified). Source: Ryberg et al. (2019)

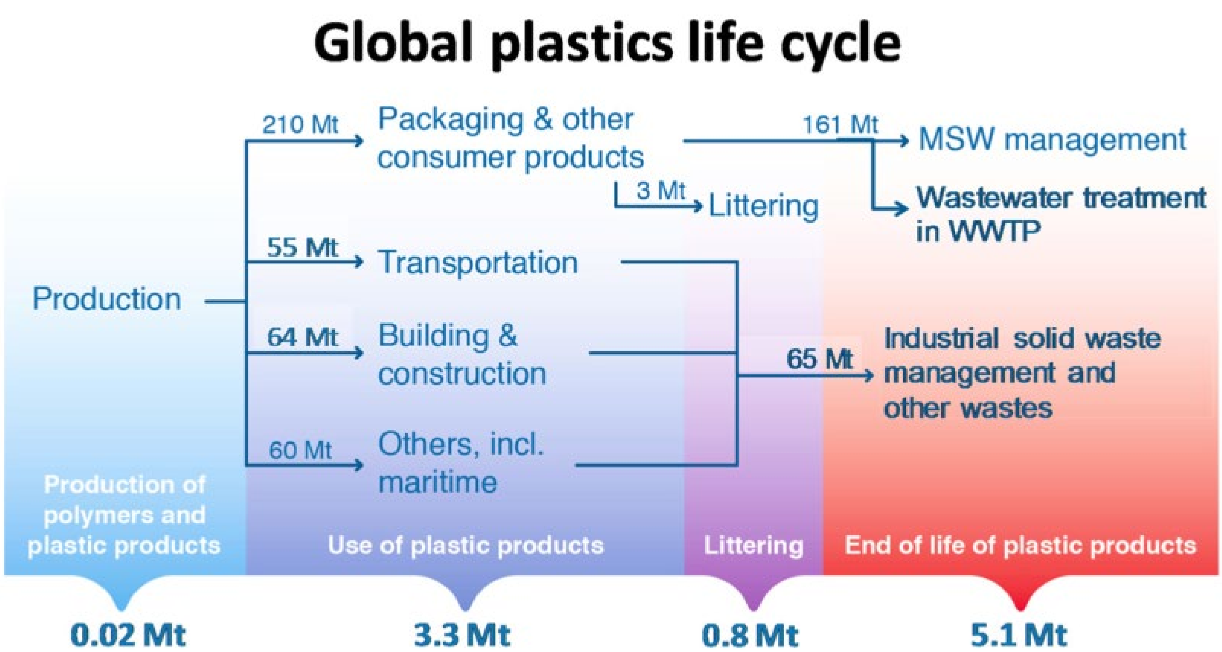

Figure 14. Global plastic life cycle value chain estimated losses to the environment for the year 2015. Source: Ryberg et al. (2019)

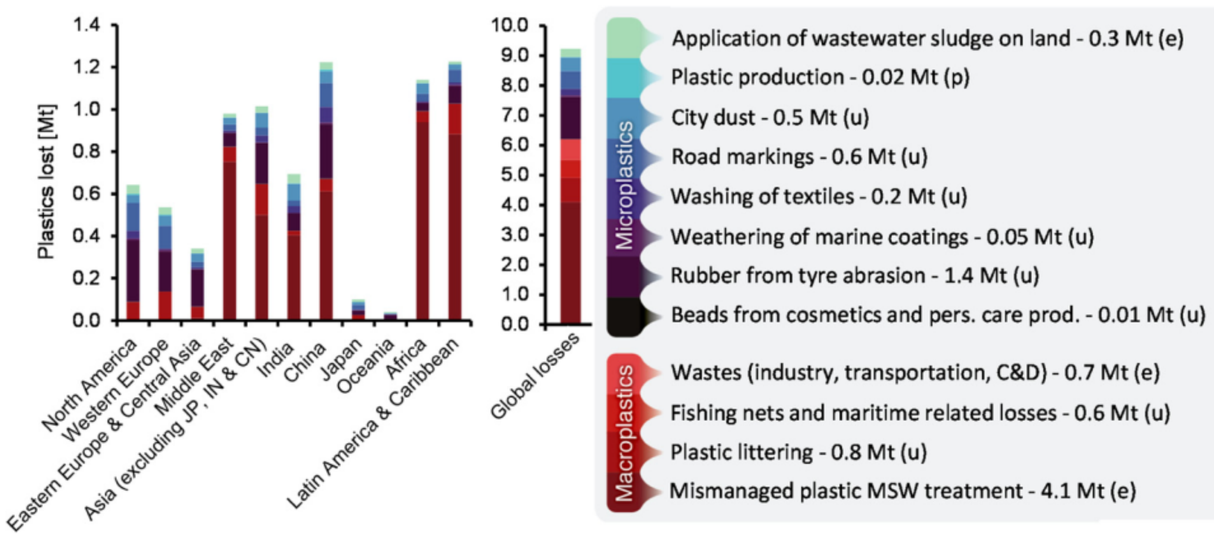

Figure 15. Losses of macroplastics and microplastics to the environment (all marine, freshwater, and terrestrial compartments combined) characterized according to region and loss sources. Losses from maritime activities like fishing or shipping, and losses from building industry and the transportation sector could not be assigned to specific regions and are only indicated in the global estimates. (p) is loss during production stage, (u) is loss during use stage, (e) is loss during end-of-life stage. Source: Ryberg et al. (2019)

As shown above, life cycle-based studies provide a systems perspective of how plastics are manufactured and how they flow through the economic sector until their final destination. The geographical resolution of such approaches depends strongly on the source of data and data collection approach. Two main monitoring approaches can be distinguished: top-down and bottom up.

Top-down approaches mainly rely on reported trading databases on manufactured amounts, imports, exports and reported waste management data. Their system boundaries are often confined at country level. SDG indicators under SDG 12 fall under this category. The challenge of such approaches is to reduce the geographical resolution beyond country level. In such cases, life cycle-based studies can provide valuable information on the origin (i.e. country) of estimated plastic amounts present in the marine environment, however, they struggle to allocate those amounts to specific cities or to come up with a clear understanding of which disruptions in the waste management system are causing this pollution.

Bottom-up approaches collect primary data, mainly at city level, with special focus on getting a deep understanding of the value and service chains of plastic materials. SDG indicators under 11 fall under this category. The advantage of such approaches is that they can provide information on the source of marine plastic litter (i.e. city). Furthermore, they provide valuable information on possible policy and infrastructure interventions to reducing plastic waste emissions to terrestrial environments, lakes and rivers and harmful waste burning practices due to the in-depth understanding of the disruptions in the municipal solid waste management (MSWM) system.

Both approaches are mutually complementary and can be used for triangulation.

The complexity of a life-cycle approach, with thousands of interrelated processes spanning sectors and country borders, requires that significant parts of the system be modelled (rather than directly measured or monitored). Such modelling requires reliable databases of key "check points" in the system, such as production volumes; amount of waste generated and collected; final destination of discarded plastic (collection for recycling; amount effectively recycled; fraction incinerated with / without energy recovery; landfill; dump / environment / litter); amount of recyclate re-entering the system in the transformation stage.

A life-cycle approach directly links with a number of additional SDG targets and indicators (table 6):

- 8.4.1 and 12.2.1 on domestic material consumption and material footprint relates to how much raw materials are used by an economy and includes plastic production information;
- 11.6.1 and 12.5.1 on municipal solid waste management and recycling, respectively;
- 6.3.1 and 6.3.2 on pollution in wastewater and freshwater.

Table 6. SDG Targets and Indicators Related to a Life-cycle Approach.

Goal 6: Ensure availability and sustainable management of waste and sanitation for all		
Target		*Indicator*
6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.1: Proportion of wastewater safely treated
		6.3.2: Proportion of bodies of water with good ambient water quality
Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all		
Target		*Indicator*
8.4	Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable	8.4.1 Material footprint, material footprint per capita, and material footprint per GDP
		8.4.2 Domestic material consumption, domestic material consumption per capita,

	consumption and production, with developed countries taking the lead	and domestic material consumption per GDP
Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable		
Target		*Indicator*
11.6	By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.6.1 Percentage of urban solid waste regularly collected and with adequate final discharge with regard to the total waste generated by the city
Goal 12: Ensure sustainable consumption and production patterns		
Target		*Indicator*
12.2	By 2030, achieve the sustainable management and efficient use of natural resources	12.2.1 Material footprint, material footprint per capita, and material footprint per GDP
		12.2.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP
12.4	By 2020, achieve environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment	12.4.1 Number of parties to international multilateral environmental agreements on hazardous and other chemicals and waste that meet their commitments and obligations in transmitting information as required by each relevant agreement
		12.4.2 Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment (including e-waste)
12.5	By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	12.5.1 National recycling rate, tons of material recycled

UN Environment is collaborating with the International Union for the Conservation of Nature (IUCN) IUCN in developing a national guidance on plastic pollution hot spotting and shaping action. This guidance will provide countries with a systemic methodology based on life cycle approach, to help identify hotspots related to the most relevant plastic polymers, products, sectors and regionalities. Under this guidance, measuring the leakage occurred at each life cycle stage and their associated impacts will identifying hotspots from value chain. For example, high amount of plastic product production, high littering rate, low waste collection rate in rural areas and insufficient recycling capacity across the country are also potential key hotspots along the value chain. Built on comprehensive hotspot analysis, the guidance will further help identify key intervention areas and instruments tailored to the local context to enable actions at relevant life cycle stages.

Waste Management

The adequate collection and disposal of municipal solid waste (MSW) is a global challenge, particularly impacting low- and middle-income countries. According to current estimates, 2 billion people worldwide have no access to waste collection services, and environmentally unsound practices manage 3 billion people's waste (Wilson et al., 2015). This has severe impacts both on human health and on the environment, with plastic pollution and particularly marine litter being a direct consequence.

Oceans are a major sink of this unmanaged plastic in the environment, with about 80% of marine litter believed to derive from land-based sources (Eunomia, 2016). As shown before, this is largely because of a lack of waste collection infrastructure and poor waste management practices (Ryberg et al., 2019).

To solve the marine litter problem, an important part of the solution relies on understanding the MSWM systems and practices and identify the high priority areas to intervene.

In contrast to the holistic life cycle based methodologies, different monitoring tools and methodologies focus on one part of the life cycle of plastics: they put the spotlight on understanding MSWM systems and the plastic leakage occurring from them. In other words, such initiatives highlight the priority of closing the tap of pollution.

Getting a clear picture and numbers of the extent of undesired waste management practices in cities (e.g. open burning, illegal dumping, etc.), the amounts of uncollected waste together with amounts of plastics leaking from the different physical elements of MSWM systems, opens the possibility for the formation of concrete policy and infrastructure interventions.

SDG 11.6.1 is a reference methodology on this topic. This indicator looks at the proportion of MSW collected out of total MSW generated and the proportion of MSW managed in controlled facilities out of total MSW generated. The inclusion of an additional third sub-indicator on the quantity of plastic leakage into the environment is under discussion. For the calculation of this leakage amount the Waste Flow Diagram (GIZ 2020) methodology would be used, which consists of a rapid and observation based assessment for mapping waste flows and quantifying plastic leakage in cities. Other tools are also being prepared such as the ISWA Plastic Pollution Calculator.

Effective indicators for waste management are an important measure on the impact waste creates on the marine environment. Waste management indicators look at production of solid waste, sewage treatment, tourist activities (ASEAN, 2007; Prabhakaran, 2013; Tanguay et al., 2012; WTO, 2003). . A recent study by Prabhakaran (2013) summarized indicators related to marine waste management (Table 5).

Indicators for the various life cycle stages of plastics (and other components of litter) can provide important information about the current and projected status of marine litter. These indicators can also provide information to industry and policy makers regarding material selection and regulation. For example, comparison between plastic and aluminum containers in the United States from 1960 – 2017 demonstrates a contrast between plastic and steel containers in terms of dominance in the market, recycling and disposal (Figure 16).

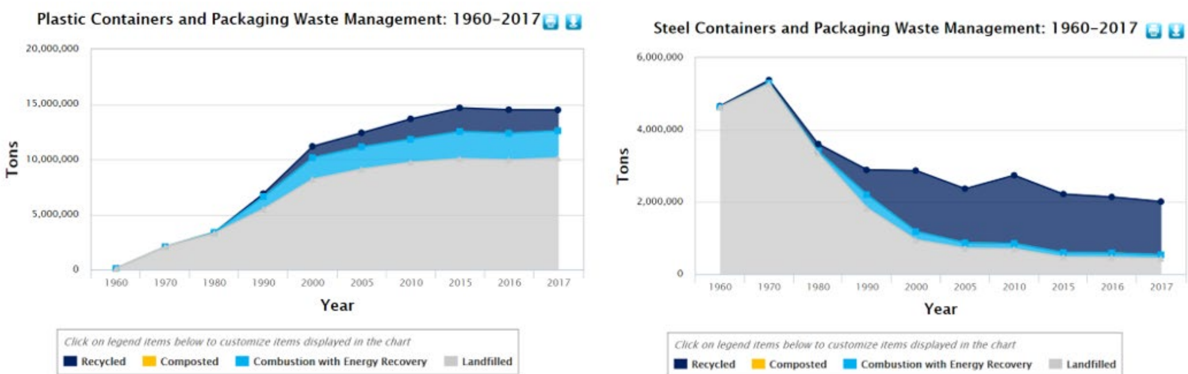

Figure 16. Plastic and Steel Containers and Packaging Waste Management in the Untied States from 1960 – 2017[16].

Indicators specifically related to marine litter include analysis of improperly disposed litter that subsequently leaks into the marine environment as well as indicators for the residence time of litter in the marine environment.

[16] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/containers-and-packaging-product-specific-data#PlasticC&P

Section 5: Existing and Developing Global Data Platforms

One challenge regarding ocean data is the proliferation of databases and portals. Recognizing this challenge, several global efforts are in development to create aggregated platforms that search and/or harvest data from multiple databases and repositories. This section provides summaries of existing and developing platforms that could host or be leveraged (e.g. support a portion of the platform or supply data) to a global marine litter platform.

Global Earth Observation System of System (GEOSS) Platform

The Group on Earth Observations (GEO) is a partnership of more than 100 national governments and in excess of 100 Participating Organizations that envisions "*a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations*" (GEO, 2005). The GEO community is creating a Global Earth Observation System of Systems (GEOSS) to better integrate observing systems and share data by connecting existing infrastructures using common standards.[17]

The GEOSS Platform[18] proactively links existing and planned observing systems around the world and supports the development of new systems where there are gaps. The GEOSS Platform promotes the use of common technical standards in order to combine data from thousands of different instruments into coherent data sets. The GEOSS Platform (Figure 17) is a brokering infrastructure. The GEO Discovery and Access Broker (GEO DAB) is the primary mechanism to discover and access all data and information. The GEO DAB implements the necessary mediation and harmonization services through Application Program Interfaces (APIs). These APIs allow data providers to share resources without having to make major changes to their technology or standards.

Presently, the GEOSS Platform brokers more than 150 autonomous data catalogs and information systems, useful for the different GEO Societal Benefit Areas including data from: CAFF, Data.gov, Data.uk, EEA, GBIF, Iris, JRC Open Data catalog, NASA, NCAR, NOAA, OCHA HDX, RCMRD, UNEP, UNOSAT, USGS, Web Energy Services, WMO WIS, Esri Living Atlas of the World, and many more. Data providers are constantly being added and brokered, according to user needs, and it would be possible to add and broker marine litter data from a variety of sources.

The GEOSS Platform is testing evolved capabilities implementing a series of scenarios that illustrate its potential to support access and use of *Data and Knowledge* as a possible contribution to the implementation of a results-oriented GEOSS. It shows how the GEOSS Platform could potentially provide value to different categories of users, including Earth scientists and policy makers, in finding, producing and analyzing information, ultimately supporting the process of knowledge acquisition by the final consumers.

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[17] http://www.earthobservations.org/geo_community.php

[18] http://www.earthobservations.org/gci.php

The demonstrated GEOSS Platform capabilities enable:

- Harmonized discovery and access of data, information and knowledge from heterogeneous distributed sources
- Analytical comparison of resources
- Value added products generation and sharing
- Knowledge building through mediated collaboration (registration of models, algorithms, data; curation of relations between data, services and publications).

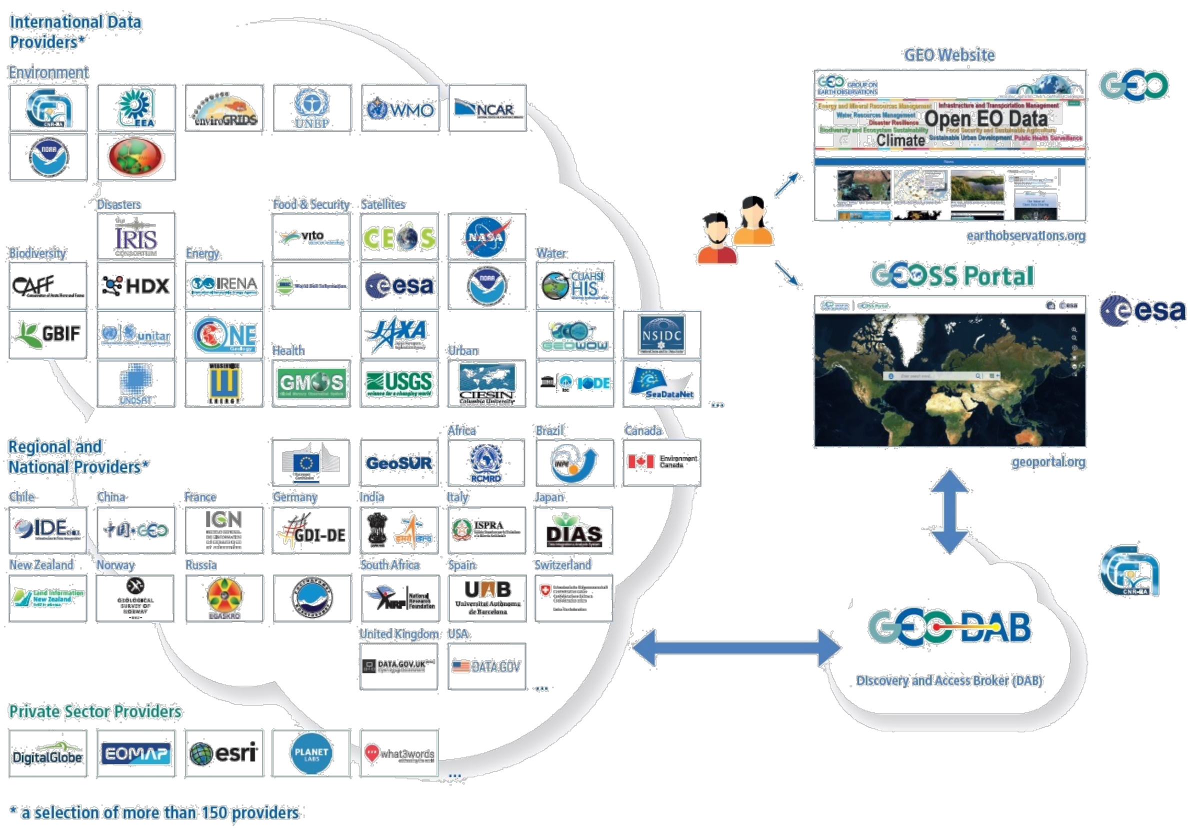

Figure 17. Components of the GEOSS Platform.

The GEOSS Portal currently offers a single access point for searching for and identifying available data sources. The GEOSS Infrastructure will evolve through 2020 – 2022 to include the development of GEO Community Portals, or “hubs” (DeLoatch, 2019). The development of a GEO Marine Litter Community Portal is a possibility.

Ocean Data Information System (ODIS)

The programme "International Oceanographic Data and Information Exchange" (IODE)[19] of the "Intergovernmental Oceanographic Commission" (IOC) of UNESCO serves to enhance marine research, exploitation and development, by facilitating the exchange of oceanographic data and information between participating Member States, and by meeting the needs of users for data and information products.

IODE currently supports several marine data and information products and repositories including the Ocean Biogeographic Information System (OBIS)[20] (a data system for biodiversity and biogeographic data and information on marine life and the Ocean Data Portal[21] (a data system that collects, integrates and manages physio-chemical data). IODE also has a number of distributed National Oceanographic Data Centres (NODCs) and Associate Data Unites (AUDs) that work to support data and information management in member states[22].

Currently IOC data is not accessible through a single portal or platform leading to the recommendation from a 2016 external audit of IOC and its activities for IODE to implement a universal marine data and information system. In response to audit recommendation, IODE produced a concept paper for the development of an Ocean Data and Information System (ODIS) that would improve the accessibility and interoperability of existing data and information linked to and not linked to the IOC. A concept paper outlines a conceptual architecture for the system (Figure 18), as well as, an implementation plan and a Cost Benefit Analysis (Spears et al., 2017).

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[19] https://www.iode.org/

[20] http://www.iobis.org/

[21] http://www.oceandataportal.org/

[22] https://www.iode.org/index.php?option=com_content&view=article&id=61&Itemid=100057

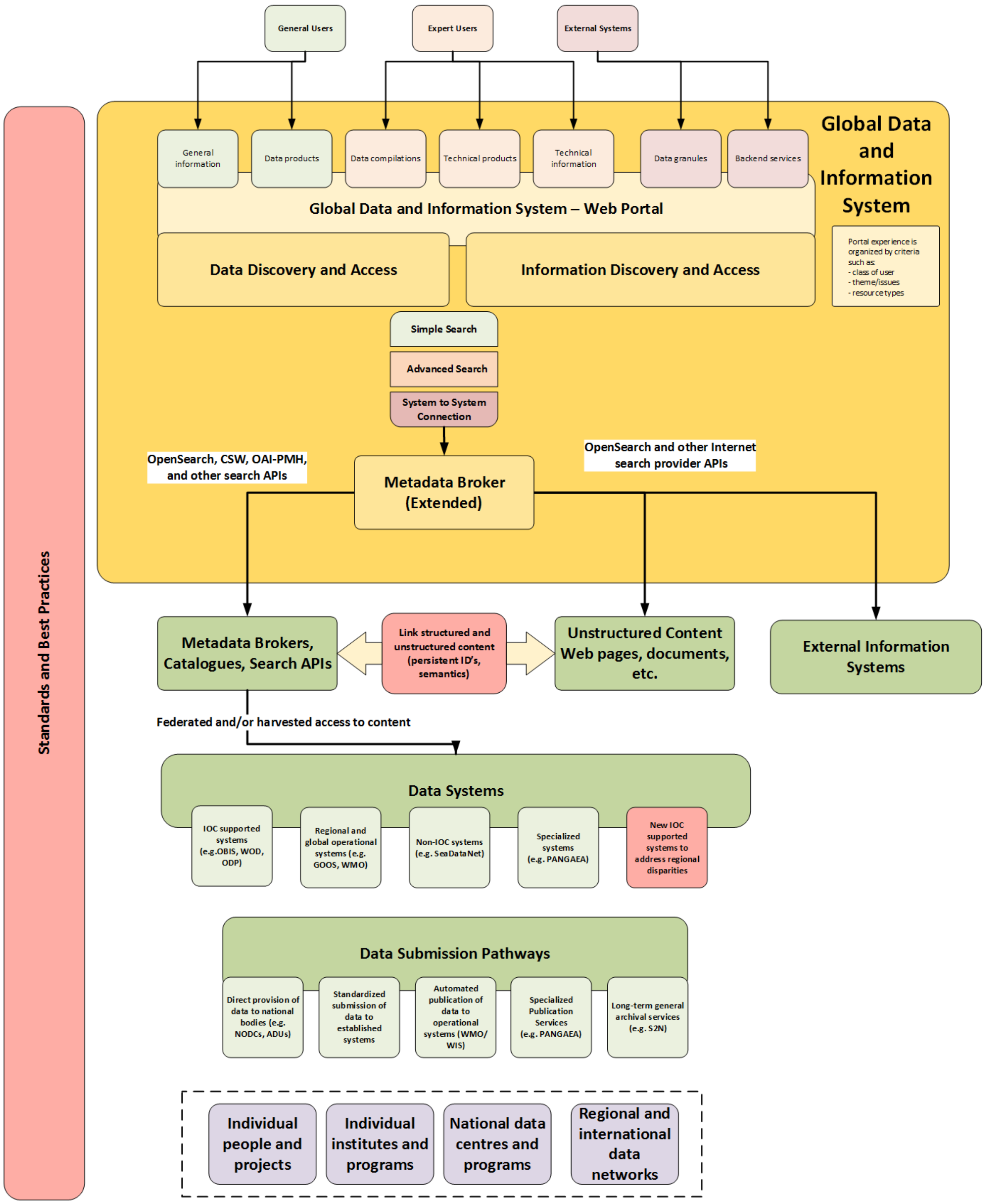

Figure 18. The Conceptual Architecture of ODIS (Spears et al., 2017)

At the thirtieth session of the IOC-UNESCO assembly, IODE was invited to prepare a fully detailed and costed project proposal for ODIS for submission to the IOC Executive Council at its 53rd session in 2020 (IOC-UNESCO, 2019). With funding, it is possible that ODIS could support access to global marine litter data.

Ocean Data Platform

The Ocean Data Foundation[23] is a not-for-profit foundation funded by the Resources Group, the philanthropic foundation of Norwegian businessperson Kjell Inge Røkke. The Ocean Data Platform, an initiative of the ODF, is an open and collaborative data platform that harnesses the power of data liberation and data contextualization for the public, industry, academia, science, policymakers and governments. The platform strives to connect data, people & technology to drive sustainable ocean governance and blue economy.

The platform is planned to function as an open collaboration with existing data providers and knowledge hubs for ocean data[24]. The ODP currently is developing selected key use cases around which it will build the platform. Depending on the development timeline and functionality of the Ocean Data Platform, it is possible that this platform could support access to global marine litter data.

European Marine Data and Observation Network (EMODnet)

EMODnet is a long-term flagship initiative of the EU (funded by the European Commission Directorate-General for Maritime Affairs and Fisheries, Figure 19). EMODnet has mandate and goal to deliver open access to aggregated and standardized marine data and data products across seven thematic areas, namely bathymetry, biology, chemistry, geology, human activities, physics and seabed habitats. It offers a broad range and wealth of in situ data, in addition to combined data products with satellite-derived data (e.g. bathymetry). Products range from a Digital Terrain Model for high-resolution Bathymetry to Seabed Habitat Maps (following EUNIS classification), Vessel Density Maps (monthly composites) and the marine litter maps of the Marine Litter Database. EMODnet delivers this in collaboration with other key marine data initiatives including the Copernicus Space programme (and Copernicus Marine Service) and the Data Collection Framework (fisheries). EMODnet has an increasingly international user community. In addition, through its Data Ingestion service and international collaborations EMODnet increasingly offers a wider coverage of datasets, including beyond Europe. EMODnet Chemistry is one of the seven thematic portals of EMODnet and provides access to a broad range of chemical data spanning chlorophyll to dissolved gases and pollutants, including marine litter. Data products are also available for eutrophication, contaminants and marine litter across six European sea and bordering ocean regions. For marine litter, data are assembled, standardized and aggregated from multiple gear types and the collected litter data follows the data policy defined by data originators. For restricted data, the relevant National Oceanographic Data Center facilitates a negotiation process between the user and the data originator. When data are used, acknowledgement of the data source is requested. EMODnet Chemistry provides access to the litter datasets through a dedicated discovery and access service (https://emodnet-chemistry.maris.nl/search) allowing to search by the available parameters (space, time, matrix, group of variables, discovery parameter, data distributor and country). In addition, the aggregated datasets are described in the product catalogue (https://www.emodnet-

[23] www.oceandata.earth

[24] https://www.revocean.org/platform/oceandata/

chemistry.eu/products/catalogue) providing also information on the unique persistent identifier (DOI). Data products as concentration and composition of litter items, of cigarette and fishing related items and plastic bags along the European coasts, density and composition of litter in the seafloor are available through the viewing service and through the product catalogue service.

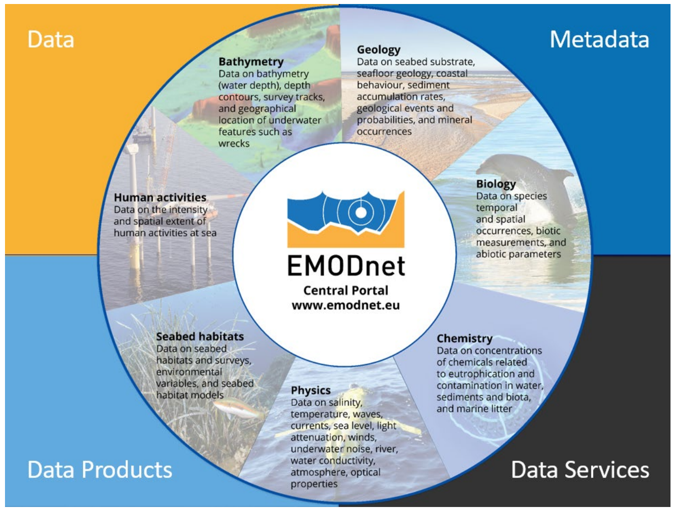

Figure 19. EMODnet open access marine data, metadata and data products across seven thematic areas. Data and web services offer unique ways to discover, visualize, download and work with marine data.

The Living Atlas of the World

Living Atlas of the World[25] is currently the world's largest GIS digital library that includes a rich set of thousands of ready-to-use online data layers and maps, as well as related capabilities (e.g., geocoding, routing, geoenrichment) (Figure 20). Desktop, server, mobile, and/or web mapping applications can access all assets. The content is hosted by Esri but the mostly open-access contributions are from scores of partners from government, NGOs, academia, and the private sector, representing the top 1% of ArcGIS Online's[26] 11 million public items, accessed by 1.6 million users daily, and with 4.5 billion map tile requests monthly. The Living Atlas is useful and reliable for hundreds of topics (e.g., Oceans Chapter of the Atlas)[27], including ocean conservation, coastal and marine spatial planning, ocean resource management and marine litter surveys.

[25] https://livingatlas.arcgis.com/en/

[26] http://www.arcgis.com/home

[27] https://livingatlas.arcgis.com/en/browse/#d=2&q=oceans&categories=Environment:0110000000

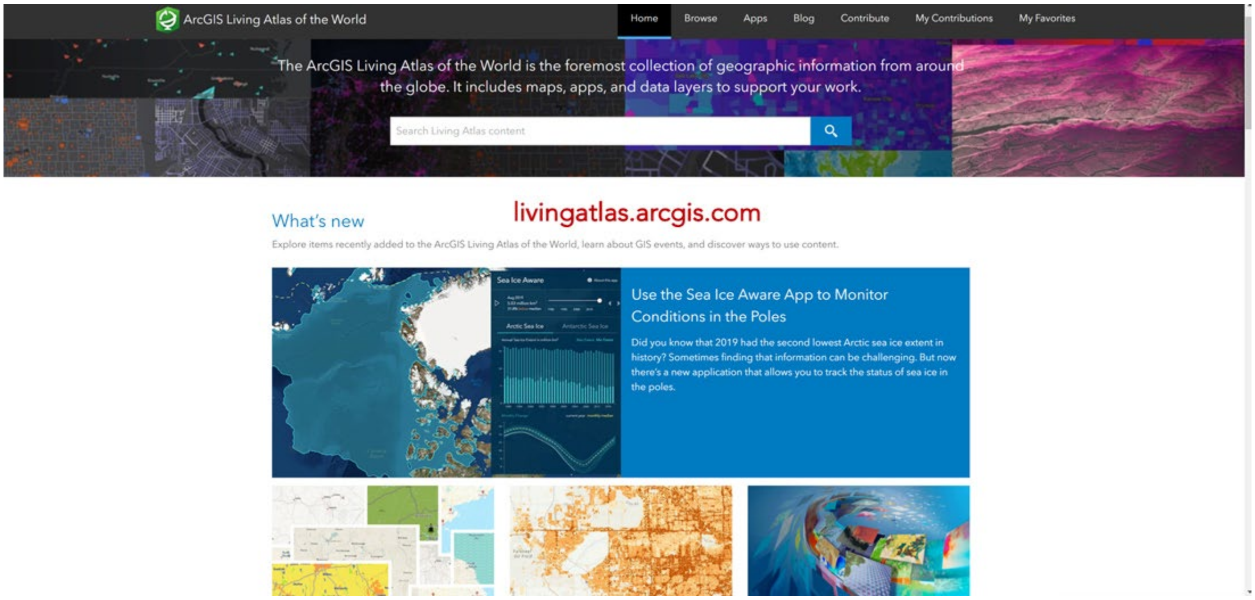

Figure 20. The Living Atlas of the World includes over 7000 ready-to-use datasets, maps and apps for empowering many environmental data systems. Partners with and contributors to the Atlas include NOAA, the Marine Conservation Institute, the European Space Agency, NatureServe, GRID-Arendal, and the UN Environment Programme World Conservation Monitoring Centre.

Resource Watch

The Resource Watch[28] platform, hosted by the World Resources Institute (WRI), is a free, open data visualization platform that includes more than 200 data sets on topics ranging from climate change to agriculture. Data in the platform are curated by WRI experts and extracted from peer reviewed and verified sources. Resource Watch data visualization functionalities include the ability to overlay data sets, create dashboards, and download data from the original source.

Earth Challenge 2020

In recognition of the 50th anniversary of Earth Day on April 22, 2020, a consortium of partners led by the Woodrow Wilson International Center for Scholars, Earth Day Network, and U.S. Department of State are launching Earth Challenge 2020 as the world's largest coordinated citizen science campaign. Earth Challenge 2020 initially focuses on six research areas, including plastics pollution, and seeks to harmonize existing citizen science data through an open, API-enabled platform and enable new data collection through a mobile application. While the project will launch in April 2020 with a global outreach campaign, the ultimate goal of this initiative is to create a long-lasting infrastructure for supporting interoperable citizen science data. Initially, the project seeks to harmonize and make available a subset of citizen science data on beach/ shoreline litter collected through NOAA's Marine Debris Tracker App, EEA's Marine LitterWatch

[28] https://resourcewatch.org/

App, Ocean Conservancy’s Clean Swell App, and the Earth Challenge 2020 app. Earth Challenge 2020 data will be discoverable through GEO DAB, and accessible through GEOSS.

Section 6: Proposed Features of a Global Platform and Required Resources

As noted in Section 3 – marine litter data is diverse and widespread. The lack of standardized marine litter parameters, data criteria, and observation methods, as well as methods for extracting information and knowledge from the available data, currently limits the understanding of sources, transportation trajectories, global distribution, fate, and impacts of marine liter. Likewise, in all societal sectors, those addressing the challenges of mitigating marine litter need a wide range of information and knowledge. Knowledge needs change – sometimes rapidly – as new threats emerge or the extent of environmental impact is revealed; thus, linking relevant marine litter data and science to societal decision and policy-making poses challenges to current approaches.

To build a useful Global Platform for Marine Litter, some key questions need to be addressed:

1. Usability — Who is it for?
2. Accessibility — Who can access it?
3. Capacity — Are users equipped?
4. Political buy-in — Is there wider support?
5. Governance — Are there frameworks and policies in place?
6. Sustainability — What are the sources for long-term thinking and funding?

For the Global Platform to be a useful tool, stakeholders must coalesce priorities in terms of the necessary policy drivers and needed corresponding information and knowledge products. This white paper provides insights on the high-level legislative frameworks, monitoring techniques and observational datasets, existing databases, algorithmic and analytic elements, and existing indicators and their technical readiness level, as well as examples of existing data management and visualization platforms. The Global Platform for Marine Litter will need to integrate these components and offer relevant insights to its users.

Challenges to integrating and extracting information from data include:

- distributed datasets
- different observation methods, protocols, and standards
- disparate temporal and geospatial scales
- lack of metadata standards
- indeterminate data quality
- inconsistent or poorly documented data policies (including open data policies)

Desired Features of the Global Platform

Data Ingestion Portal

A relevant part of marine litter data (beach, seafloor, floating, etc.) is regularly monitored at national, regional, or higher level in the EU. Nevertheless, much marine litter data still is available only in peer-reviewed literature or grey literature. To encourage publication of data in openly available databases, a data ingestion portal should be included (e.g., EMODnet Data Ingestion https://www.emodnet-ingestion.eu/). For data upload, ingestion tracking, storage, and transformation this component includes commonly agreed specifications for data, metadata, models, schema, and templates.

Data Brokering Functionality

The use of brokering services (such as the GEOSS platform) provides data discovery and access for existing data and is currently distributed across a variety of databases. A brokering service is a requirement of the Global Platform.

Knowledge resource repository

The Global Platform requires a central digital archive providing access to codified knowledge and featuring replicable open-science workflows for using marine litter data to extract knowledge supporting policies and policy development. This repository links and provides access to:

- Legislative frameworks, action plans, etc.
- List and roles of stakeholders
- Indicators, targets, etc.
- Research papers describing methods;
- Monitoring methodologies and algorithms;
- Datasets available (*in situ*, satellite, airborne, citizen science); and
- Results and scenarios for verification.

Data Processing and Analysis

The Global Platform requires computing resources and tools for processing and analysis to extract “knowledge”, such as change detection, trend analysis, etc., to inform policymakers on topics such as marine litter sources and the impact of policies

Data Visualization

“The Global Platform needs viewing and publishing services for displaying aggregated and disaggregated datasets, maps, and indicators.

Standardization and Interoperability

As described in Section 3, marine litter data are acquired employing different monitoring methods with multiple protocols and standards having disparate temporal and geospatial scales, distinct quality levels, and contrasting technology readiness levels. Therefore, it is critical for the Global Platform to adopt consistent methodological standards and ensure data consistency to enable the comparison of indicators at different scales and between regions.

This consistency includes the standardization of marine litter terms and common vocabularies (semantics). For example, the SeaDataNet pan-European infrastructure for ocean and marine data management identifies common terminologies, metadata attributes, data schemes and models to uniformly populate the EU EMODnet Chemistry marine litter database (Addamo *et al.*, 2018; Molina Jack *et al*., 2019) to implement the Marine Strategy Framework Directive (MSFD) (European Union, 2008).

The EMODnet Chemistry experience in integrating heterogeneous data sources (collection, standardization, quality control and sharing) began in 2009 with data related to eutrophication and contaminants (MFSD Descriptors 5, 8 and 9). The Chemistry consortium has experience in managing physical and chemical oceanographic data and information, thanks to the activities carried out during the SeaDataNet project. In recent years, this experience has expanded in response to the request to manage marine litter data (MFSD Descriptor 10).

Since the beginning, the management plan for marine litter data has been to adopt consolidated data formats, when available, and adapting them as needed. Following this approach, three specific methods for microliter on the beach, seafloor and water surface have been adopted, using the best available reference documents to develop a tailor-made approach at the European scale (Martín Míguez *et al*., 2019).

The ingestion of the litter datasets have been challenging due to the complexity of the information and the heterogeneity of the source data. One of the key elements of the success in the data ingestion was the interaction with data originators. The consortium established a communication with data originators (direct or through contacts from the Regional Sea Conventions) that allowed to set up a feedback quality loop done in contact with data originators. This step was crucial to clarify doubts on reported data and to detect potential duplicates and errors in datasets (or part of them).

For beach litter, the ingestion of EEA Marine Litter Watch (MLW) datasets is still ongoing. EEA MLW collects data both from official monitoring and from citizen science. Data from citizen science represents a really interesting and relevant source of marine litter data due to its wide distribution (bottom-up approach). However, datasets collected with MLW app, have a strong heterogeneity in metadata and data quality. Data from monitoring activities or from citizen science vary in quality. For example, for single citizen surveys, it is not mandatory to specify the identity of the data originator, therefore the feedback quality loop regularly done with known originator is not possible through traditional methods such as expert review. Additionally, the identification of surveyed beaches is very relevant for the consolidated monitoring in order to have time-series data on the same place. Instead, for citizen science data the focus is on survey location, aside from the beach where this survey has been performed. As a result, the identification of the surveyed beaches along the time can be difficult. An on-line beach catalog or an OGC layer providing information (coordinates and metadata) on the surveyed beaches can help in the integration of official monitoring data and citizen science apps, and identify areas to prioritize for repeated sampling to promote the collection of time-sensitive data.

The use of citizen science data can be very useful, especially where monitoring programs are scarce or even not in place. However, it is necessary to implement tools that ensure a minimum quality of data. One promising area for future work is cross-validating citizen science data and small aircraft data. A second is the use of machine learning (ML) to identify different types of marine debris photographed by citizen science volunteers as an alternative, or complement, to expert-based data validation techniques.

Despite all the efforts to harmonize and integrate the available information, the production of data products able to summarize and highlight specific features is not an easy task. Due to the complexity and heterogeneity of the surveyed data, their integration is sometimes not possible.

As an example, the use of different gears (nets with different characteristics) for seafloor litter sampling leads to non-comparable data, due to the differences in the sampling efficiency of the nets. Any efforts to harmonize and integrate data must also consider data policies, including use conditions and requirements such as (in the case of citizen science) attribution to a citizen science volunteer.

Open Platform

To build a customer-centric and user defined Global Data Platform there will be a need to move from pre-defined data products to content-as-a-service model. Cloud computing and data analyses between different spatial and non-spatial data is imperative in order to bring together spatial Earth observation data, socio-economic data to generate knowledge and information (e.g. indicators) which respond to policy needs. This will require an open, collaborative and federated platform, where data producers can host, manage and share their own data locally. The platform must provide open standard interfaces so that information can be exchanged and services can be accessed from existing national/regional platforms and systems.

The Global Data Platform will need to tackle a number of challenges to continuously gather, curate, keep updated, and disseminate actionable information to become indispensable for decision making.

- Usability: The platform must be demand-driven and user-oriented. If the objective is to develop a platform (Knowledge Hub) with highest readiness level: 9 - System, process, product, service or tool approved for deployment and use in decision making (transition complete), it is critical to involve key users in the earliest stages of the design. We have to avoid the risk to implement yet another technology-driven, supply-side data delivery platform not responding to users need.
- Data vs Knowledge: The platform should be result-oriented, providing clear and objective guidance to decision makers. Raw data must be transformed into actionable knowledge to drive decisions, policymaking, and mitigation actions. Assimilative numerical models, intelligent algorithms, remote sensing and advanced visualization tools may help contextualize the information and help the development of operational monitoring systems (Atwood et al., 2019). In addition, indicators be must cross-referenced with socio-economic data and provide scenarios for decision-makers to respond to the challenges of adapting to and coping with these impacts. Indicators must be contextualized in order to be used operationally in the decision-making process.
- A Platform for decision makers: The platform needs to deliver more than quantitative data. Policy makers primarily adapt or adopt tested and tried policies and "do not target plastic waste once it has entered the environment; instead they aim to reduce the quantity of plastic production and use, before it is likely to enter the environment. In contrast, waste abatement outreach programs and infrastructure commonly target plastic waste before and after it has entered the environment. These strategies try to prevent and remove plastic waste from entering the environment and prevent coastal deposition" (Willis et al., 2018). It would be very useful for decision makers to have linked to the core monitoring areas examples of successful policies, regulations, awareness/abatement campaigns and strategies to prevent and reduce plastic pollution in general, and marine plastic, in particular.

- One platform for different countries: Decision makers need to have correct insights at the right scale, however the requirements linked with these insights might vary between countries. The platform must therefore be configurable and scalable in order for countries to be able to upload and analyze national data and compare it to broader global context. As identified by UN Environment (Jensen et al., 2019a; Jensen et al., 2019b), this is necessary condition if the platform is to generate the correct insights at the right scale, deliver these at the right time and in the right format in order to influence decision-making.
- A platform with different applications. As additional stakeholders are considered, the initial requirements of the database content should incorporate data to develop less mature observation techniques, such as remote sensing (Section 1, Table 4). Design of specific parts of the Global Data Platform could focus on cross validating the simultaneous observations using different techniques. For instance, in order to progress with remote sensing applications, part of the dataset should match simultaneous satellite observations. This practice is common for ground truth and development purposes for ocean color satellites (e.g. NASA SeaBASS). This can be supported through standardized and quality controlled datasets of marine plastics concentrations in combination with additional radiometric measurements.

From Open Data to Open Science

It is widely accepted that the benefits from adopting an open data policy include supporting broad economic benefits and growth, enhancing social welfare, growing research and innovation opportunities, facilitating knowledge sharing and effective governance and policy making (CODATA & Uhlir, 2015). Not all governments have however established national Open Data regulations/policies to enable agencies to share Earth observation datasets nationally, regionally and internationally.

Adopting an open data and open access policy is not sufficient on its own; it is important to provide a platform to maximise the “reproducibility spectrum”, where data, code, analysis procedures, best practices, and literature, are shared and replicable. In addition, a data policy following the FAIR (Findable, Accessible, Interoperable and Reusable) principles, will support the development of solutions which are co-designed between research institutions, societal groups, government agencies, third sector and industry. These elements will guarantee the implementation of an open science platform where users are empowered and knowledge is reproducible. Reliable access to open data is also a necessary requirement for any platform that seeks to support ongoing monitoring and assessment, including monitoring progress against the SDGs.

Tanhua et al. (2019), outline how these principles apply to ocean data and discuss why ocean science is an essential foundation for the development of new services made possible with big data technologies.

Partnerships

Partnerships – public-private partnerships are a critical success factor for the implementation of the Global Platform. When planning the next steps of this project we must make sure that all potential stakeholders are included. This encompasses end users to identify and understand (not assume) their requirements, plus observation and monitoring; data management; big-data analysis and analytics (including AI); computing and geospatial infrastructure, social science and policy communities.

Some technological partners could include:

- The Environmental Systems Research Institute (Esri; https://www.Esri.com/en-us/about/science/initiatives/ocean-science)
- The AI for Earth initiative (https://www.microsoft.com/en-us/ai/ai-for-earth)
- Google Earth

One example of such a public private partnership used to make progress on an SDG indicator is the Water Related Platform[29]. This is a free platform bringing together the European Commission Joint Research Centre's expertise in satellite data and data analysis, Google's cloud computing and artificial intelligence and UN Environment's scientific knowledge. Another example is GEO Blue Planet's partnership with Esri in support of SDG 14.1.1's eutrophication methodology for summarizing chlorophyll-*a* over time in four pilot areas worldwide[30] (Smail et al. 2019). Still another is Earth Challenge 2020, which integrates data from public sector agencies (NOAA and EEA) with NGO data, and makes integrated data accessible through Esri's ArcGIS platform. These examples demonstrate both the necessity of public private partnerships, and early indicators of collaboration that could be built on and expanded in a larger, coordinated effort.

[29] https://ec.europa.eu/jrc/en/science-update/monitoring-our-blue-planet-first-sdg-indicator-platform-launched-google-jrc-and-un-environment

[30] https://storymaps.arcgis.com/stories/37cadf2878e64cd9b34df62baa732b4c

Section 7: Marine Litter in a Digital Ecosystem for the Environment – Thought on A Pilot Project

Section 4 emphasizes the proliferation of data and knowledge platforms that aim at enhanced data integration and improved access to knowledge derived from data. Most of these platforms take a thematic approach or target specific user groups. Adding another traditional platform that aims to serve the users who have knowledge needs related to marine litter would increase the proliferation. It is very unlikely that adding more of the same will meet the urgent and rapidly changing needs in the Anthropocene. Considering that the future of humanity and many other species depends on a well-informed stewardship of the planet, it appears mandatory to make an effort to exploit the wealth of the ever-increasing global data resource utilizing leading edge technologies, approaches and concepts.

A fundamentally different alternative approach has been proposed by Campbell and Jensen (2019a,b). A "global digital ecosystem for the environment" would utilize the rapid development of new technologies and methodologies to create an ecosystem of active species interacting with each other and users (Figure 21). However, a "healthy" ecosystem has a broad diversity of active species that interact with each other and evolve over time. Developing the concept of an ecosystem that integrates data, information derived from the data and knowledge co-created in a collaboration of human agents with the data and information requires to identity the species that live in this ecosystem. Similar to a biological ecosystem, it is fundamental to recognize the keystone species that are central to the functioning of the ecosystem and that determine the nature of this system.

To some extent, the World Wide Web is an ecosystem in which a large diversity of Web-species interact with each other, compete, benefit from each other, and evolve independently over time. The digital ecosystem for the environment would have to exhibit similar characteristics in order to be an ecosystem. The current perception of the world of data, however, does not provide for this. In general, data are perceived as passive objects that need to be discovered, accessed, and processed in order to extract information. Progress towards a digital ecosystem would require a fundamental transition from this current perception of data to a new perception of data as active subjects (Plag and Jules-Plag, 2019). In this perception, data subjects can interact with other data subjects and human agents to provide access to the information embedded in the data.

Figure 21. Digital elements that could facilitate a digital ecosystem for the environment. From Campbell and Jensen (2019a).

In the following, we provide initial thoughts on a pilot project designing and implementing a digital ecosystem focusing on marine litter. This proposal for the Marine Litter Digital Ecosystem (MLDE) should be further developed in a participatory approach including the relevant communities. It is recommended to prepare a white paper that further develops the thoughts provided.

Initial Thoughts on the Marine Litter Digital Ecosystem

The species in the Marine Litter Digital Ecosystem (MLDE) fall into at least four main domains:

1. **Data collection**: digital (software) agents that collect new data and generate a flow to those species that represent data products;

2. **Data representation**: digital agents that represent data objects and can provide information extracted from these objects, as well as, give access to the data in the objects and receive feedback on data;
3. **Tool representation**: digital agents that give access to models and data processing tools; and
4. **Knowledge representatives**: digital agents that represent knowledge created by interaction of human and digital agents.

Thus, the taxonomy of the MLDE would have to include at least the four domains "data collection" (DCD), "data representation" (DRD), "tool representation" (TRD) and "knowledge representation" (KRD). The domain of "best practices" (BPD) should also be considered. Each of these domains will have classes that consist of a number of families. Each family comprises a number species.

In the data collection domain (DCD), the classes are defined based on the complexity of the "sensors" that provide the data stream or data streams. Individual sensors providing a stream of observations constitute the most basic species. There is considerable diversity ranging from sensors of physical conditions (e.g., temperature, humidity, displacements,

The agents in the DCD are often linked to sensors or provide means for the reporting of data through crowd sourcing or the harvesting of data from existing sources. Agents in the DRD that represent data objects can represent a range of objects from collections of raw data to information extracted from data, including complex indicators for the environment or synthetic data and information based on models. If they are asked to provide information that requires data processing, these agents can interact with the agents in the TRD representing tools for processing. They would have the full information related to the data object each of them represent ranging from the actual data, the full metadata, information on quality, usability, former uses including – to the extent legally allowed – former users, processing tools, and feedback from other users.

Agents in the KRD representing knowledge have semantic capabilities to answers questions from human agents. The knowledge they represent is a collaboration of relevant groups of societal agents, including scientists, policy makers and other relevant stakeholders.

While most of the agents in the DCD could be reflective agents, the agents in the other domains would have to be learning agents that combine model-based, goal-based and utility-based agents. In particular the agents in the DRD and LRD would need semantic capabilities.

A first implementation of the MLDE could utilize the infrastructure available through the Web. The standardized protocol for the communication between the different agents would require a major development within the framework provided by the Web.

Section 8: Future Developments

In the discussion paper "The Case for a Digital Ecosystem for the Environment", UN Environment (Jensen & Campbell, 2019a) makes a compelling case on not only how data, technology and innovation can transform the collection and management of environmental data, but also how they can critically enable conditions for better governance.

As reported by the UN Secretary General's Independent Expert Advisory Group on a Data Revolution for Sustainable Development,[31] without high quality geospatial data, the task of designing, monitoring, and evaluating effective policies to achieve the Sustainable Development Goals (SDGs) is almost impossible. For SDG14.1.1, and in particular the marine litter indicator, new data management technologies, artificial intelligence, cloud computing and cloud storage of information, together with increased volume of accessible geospatial data, are making it possible to manage, share, process and analyse large volumes of data in near real time as well democratizing access to the data itself.

The digital ecosystem proposed by UN Environment would comprise of the following four main components: *(1)* data; *(2)* infrastructure; *(3)* algorithms and analytics; and *(4)* insights and applications. The Global Platform would therefore need to transform data using an underlying infrastructure combined with algorithms and analytics (see for example artificial intelligence) into insights and applications that are used by stakeholders (National Statistics Offices, decision makers, environmental managers, researchers, public & private organisations, citizens, etc.).

As reported by Joppa et al. (2019), to address the challenge of harnessing computing power and provide actionable solutions for climate change, we need to make use of the three catalysts of our information age – ubiquity of data, advances in algorithms and access to scalable computing infrastructure – and apply them to our sustainability challenges. Hence, a Global Platform must be ambitious from a technological perspective and make sure to leverage the data, infrastructure and algorithms and analytics components, to address the insights and applications as set by the end-users.

Use of Artificial Intelligence

As mentioned in Section 1, the use of machine learning and deep learning as part of artificial intelligence (AI) to detect marine litter in the aquatic environment (at the surface and in the water column) is becoming increasingly relevant.

Fulton et al. (2014) have evaluated a number of deep learning algorithms performing the task of visually detecting marine litter, with the objective of exploring, mapping and extracting debris using autonomous underwater vehicles (AUVs). Balas et al. (2004) have applied artificial intelligence techniques of neural network and fuzzy systems to determine beach litter grading based on litter surveys. Kylili et al. (2019) have shown the added value of deep learning techniques in

[31] A world that counts: Mobilising the Data Revolution for Sustainable Development. http://www.undatarevolution.org/wp-content/uploads/2014/11/A-World-That-Counts.pdf.

automatically identifying and determining the amount of floating marine litter, with a success rate of approximately 86%. Schulz and Matthies (2014) found artificial neural networks eligible to deliver reliable predictions of marine litter in the southern North Sea with relatively low computational effort and little input of information. Toro (2019) proposes the use of deep neural networks to survey and detect marine debris at the bottom of the water column from Forward Looking Sonar (FLS) images. The automatic detection and quantification of small microplastics particles (20-1000μm) through fluorence microsocopy and image analysis is helping to address the difference in marine litter fraction spatial distribution between surface and water column (Erni-Cassola et al., 2017).

These artificial intelligence based solutions provide fast, scalable, and potentially cost effective automatic methods for identifying and evaluating marine litter. As more and more remotely sensed observational data is available from autonomous underwater vehicles (AUV) and remote platform aerial systems (RPAS) in forms of videos and imagery, machine learning provides a solid, sustainable and trustworthy alternative to the standard visual-census approach, from both a time and classification perspective (Martin et. al, 2018; Moy et. al., 2018).

Integrated Marine Debris Observing System

While there is an existing wealth of data available, observations of marine litter sources, composition, pathways and distributions in the ocean are sparse and inaccurate. For example, total amounts of plastic, and other man-made debris in the ocean and on the shore, temporal trends, degradation processes, vertical fluxes and tie scales are largely unknown (Maximenko & Corradi, 2019). There is a need to develop a long-term observation platform, which is able to provide the necessary monitoring data for mitigating the impacts of marine litter on the ecosystem.

Two years after the Paris Climate Agreement, the world's nations mobilized their efforts to tackle climate change. Space Agencies and other key stakeholders recognized the need to implement a Space Climate Observatory (SCO[32]). Along these lines, there is a need to mobilize those stakeholders committed to making meaningful advances, that the development of an Integrated Marine Debris Observing System (IMDOS) is critical. Investing in new dedicated space and in-situ programmes, federating existing national and regional databases and coordinating all leading actors, will offer unified access to a vast majority of marine debris data (acquired from space and in-situ), which can deliver indicators and decision-support tools (integrating other sources of data) via a Global Platform for Monitoring Marine Litter and Informing Action.

New Approaches for monitoring harm caused by marine litter

Transoceanic rafting is the transport of biota on litter items and a fundamental feature of marine evolutionary biogeography and ecology (Carlton et al., 2017). It has become a new problem because of the recent proliferation of floating particles, which are mostly plastics. Trillions of both micro and macro-plastics at the surface, and sunk debris are all potential carriers of marine organisms, with advantages for plastic as a transport mechanism in its longevity at sea, its surface properties favoring attachment and a passive and low speed dispersion. Hundreds of

[32] https://www.spaceclimateobservatory.org/presenting-sco/?lang=en

different species, from bacteria to larger invertebrates, representing more than 380 taxa, settle on plastics, also on deep-sea litter, acting as new habitats. In addition to the alteration the composition of ecosystems and the possible changes in genetic diversity (Werner et al., 2016; Carlton et al. 2017), some of them may be at risk like Harmful algal blooms related dinoflagellates, pathogens to fish and human and invasive species (Werner et al., 2016; GESAMP, 2020).

To date, there is no systematic record of the settling of species on marine litter, from microorganisms to large invertebrates, planktonic or benthic. Because of the risk associated to their transport, collection of data on rafted organisms, their possible toxicity and mode of invasion has become critical. In a recent G7 workshop (G7, 2019), it has been concluded that monitoring should include more knowledge on the microbiology and other species that can present a risk (invasive, harmful algae, pathogens species) by colonization of plastics, and are subject to transport on plastics. Sharing data through a dedicated plastics database collecting information on the colonization of plastics is a priority that will provide historical records, evaluate trends and support risk assessments. A future strategy involves exploring the various options, including the generation of a new database or establishing links with existing databases on invasive species, on a global scale (GISP, http://issg.org/database/welcome/) or at regional level (EASIN, https://easin.jrc.ec.europa.eu/easin), and also considering the possible support of existing database on marine litter (ICES/PICES, RSCs,EMODNET, etc.).

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