State-of-the-art technologies for monitoring plastic seafloor litter

"The current monitoring programme is value for money as it provides a lot of data as part of an existing monitoring programme, however as it is opportunistic there are limitations and evidence gaps. A better understanding of the seafloor environment, as a major sink of marine litter is still needed."
~Quality Status Report 2023, OSPAR

In recent decades, the increasing levels of plastic in the World's oceans has drawn significant public attention and raised concerns about the impacts this might be having on the marine environment, marine organisms and human health. This has resulted in marine litter, and especially plastic litter, being high on the political agenda. A large proportion of this plastic accumulates at the bottom of the ocean, resulting in a need to monitor and quantify seafloor litter. The monitoring of litter in marine environments is a fundamental part of the wider state of environmental reporting, and a key component of ecological risk assessments, which are ideally based on realistic exposure conditions. Marine litter is a transboundary problem and international cooperation and coordination are crucial to monitor and reduce marine pollution. On a global level, marine litter is included under the UN Sustainable Development Goal 14 'Life Below Water' and Challenge 1 of the UN Decade of Ocean Science for Sustainable Development 'Understand and beat marine pollution'. Since the 2010s, frameworks such as the International Council for the Exploration of the Sea (ICES), the Regional Seas Conventions (e.g. Oslo Paris Convention; OSPAR) and the European Union Marine Strategy Framework Directive (MSFD) have been quantifying and monitoring seafloor litter using beam trawl hauls, revealing the first insights into the prevalence distribution patterns, transport routes and accumulation zones of plastic litter.

Benthic trawl surveys are a practical way to monitor seafloor litter because they are already coordinated by ICES for fish stock assessments, but are a destructive sampling technique that has been subject to discussion and criticism for many years. In line with the Biodiversity Strategy 2030, the European Commission has the intention of implementing restrictions to limit bottom trawling in EU waters, supporting the transition to more selective and less damaging fishing techniques. It has subsequently put forward a legislative proposal to phase out bottom trawling by 2030. In addition, a catch-based assessment of seafloor litter comes with a number of other drawbacks, e.g. limited to locations for fishing, focus on shallow waters, no monitoring in marine protected areas (MPAs), uncertainty when comparing different trawls with different mesh sizes, etc.

In light of all these drawbacks, scientists have been seeking new and innovative ways to detect and quantify plastic litter present on the seafloor and in the lower layer of the water column. These approaches include elements of autonomous detection (in situ detection without human interference), which can enable swift observations of marine litter, allowing the quick analysis of evolutionary patterns of litter distribution, as well as better policy alignment. The need for innovation in monitoring and observation activities for seafloor litter was also raised by the ICES Working Group on Marine Litter (ICES WGML) and explicitly mentioned in the OSPAR Quality Status Report, which is endorsed by 15 Governments and the European Union. Furthermore, the following focal points can be identified when screening the literature:

- There is a clear gap in the available scientific literature and knowledge for sustainably and accurately monitoring plastic seafloor litter at an international level;

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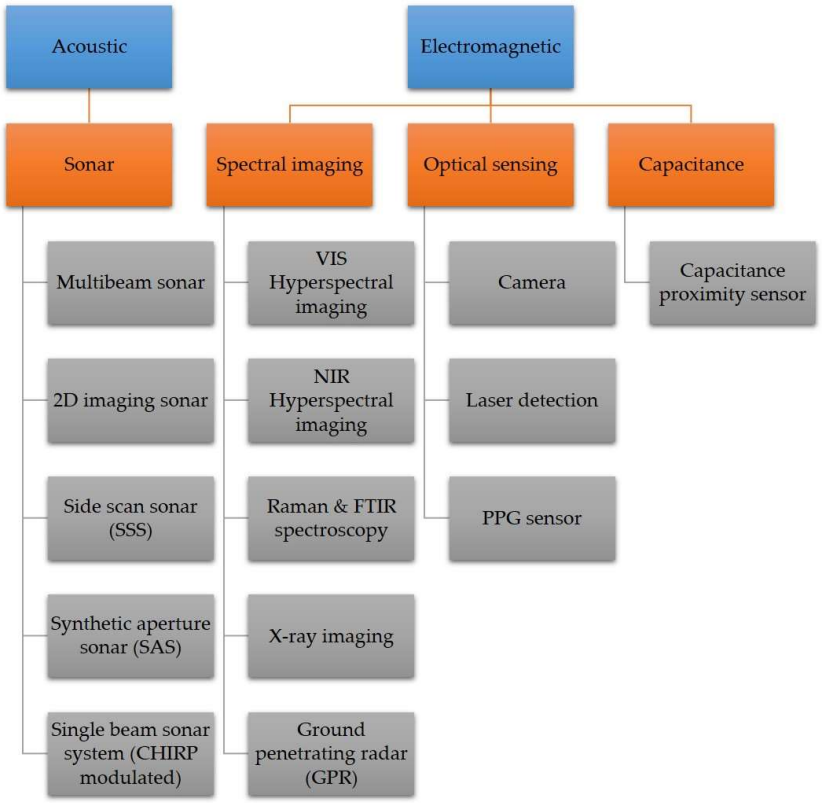
- There is currently no off-the-shelf in situ detection technique that is operational for systematic seafloor monitoring of plastic litter in diverse marine environments that provides sufficient details to meet the required objectives for exposure, effects, and risks assessment of seafloor plastic litter;
- With the increased interest and desire to efficiently and effectively sample and monitor seafloor litter, it is necessary to compare the different available approaches to allow researchers and regulators to identify the most suitable techniques for use in research or monitoring.

To address these gaps, this study evaluates which existing technologies are eligible for future in situ meso- and macroplastic litter (>5 mm) detection on the seafloor and the hyperbenthic area (<1 m above seafloor). The current state of the different technologies was benchmarked against the envisaged final product to determine the main steps toward innovation. A set of objectives to describe the final product were introduced and a Technological Readiness Level (TRL) was defined for each technique in the context of plastic litter detection based on the suggested scale by Aliani et al. (2023). Four objectives, underpinned by the expert judgment of the ICES WGML, were set up that matched the expectations of the desired technology for seafloor plastic litter detection: (i) identification and differentiation of plastic litter, (ii) spatial coverage of detection techniques, (iii) detection size range of detection techniques and (iv) artificial intelligence for plastic detection. Furthermore, the compatibility of each technique with operating platforms (e.g. USV, AUV, ROV, ships and towed systems) was determined. This study provides the following results:

- Fourteen technologies that are potentially suitable for in situ plastic detection in marine environments were identified in this systematic review based on 101 scientific publications (see figure below);
- Most of these technologies are currently at low-middle TRLs, requiring several more development, testing and commercialisation steps before they can be applied effectively in marine field conditions and achieve a level of identification and quantification that is comparable to the existing seafloor litter monitoring programs;
- Sonar systems (e.g. 2D imaging sonars) and optical sensing systems (e.g. camera) have the highest TRL for in situ meso- and macroplastic detection. Synthetic Aperture Sonars (SAS) has been shown to be the most promising for seafloor plastic detection given its differentiation possibilities, along with the broad detection size range and spatial coverage;
- Spectral imaging and capacitance systems look promising at the proof-of-concept level, but currently lack validation in an operational environment;
- For technologies targeting micro- and mesoplastics, further research is urgently needed;
- Detection methods are region-specific in terms of applicability. Therefore, a decision tool to define the most suitable method for different scenarios was developed;
- This study enables determination and comparison of the different state-of-the-art detection techniques.

It is anticipated that the compilation of information in this study, in combination with the proposed decision framework would be helpful in identifying the optimal monitoring system design worldwide for seafloor litter. While a TRL scale has many advantages, there is an additional need for a comparability assessment between the different technologies to ensure that the resulting monitoring data is fit for purpose and sufficiently comparable across studies utilising different analysis approaches. To enable the comparison of data generated by these different technologies as they develop further, there is a need for harmonisation of the categories of seafloor litter items and units. These technologies, alone or in combination, have the potential to contribute to the establishment of more robust global environmental indicators and monitoring programs for plastic pollution. The monitoring, research and regulatory communities need to view such technologies as the future for marine litter monitoring and already start to develop a road map for their harmonisation, validation, approval and inclusion in official monitoring programs.



Acknowledgements:
Matthias Sandra (VLIZ), Lisa I. Devriese (VLIZ), Andy M. Booth (SINTEF), Bavo De Witte (ILVO), Gert Everaert (VLIZ), Jesus Gago (IEO), Francois Galgani (Ifremer), Kobus Langedock (VLIZ), Amy Lusher (NIVA), Thomas Maes (GRID-Arendal), Hans Pirlet (VLIZ), Josie Russell (Cefas), Christopher K. Pham (OKEANOS)

Systematic review article:
Sandra, M.; Devriese, L.I.; Booth, A.M.; De Witte, B.; Everaert, G.; Gago, J.; Galgani, F.; Langedock, K.; Lusher, A.; Maes, T.; Pirlet, H.; Russell, J.; Pham, C.K. (2023). A systematic review of state-of-the-art technologies for monitoring plastic seafloor litter. *Journal of Ocean Engineering and Science*

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