

Reproducibility and Readiness Levels in Plastic Monitoring

Author list: Stefano Aliani¹, Amy Lusher², Francois Galgani³, Dorte Herzke⁴, Vladimir Nikiforov⁴, Sebastian Pimpke⁵, Lisa Roscher⁵, Vitor Hugo da Silva⁶, Jakob Strand⁶, Giuseppe Suaria¹, David Vanavermaete⁷, Katrien Verlé⁷, Bavo de Witte⁷, Bert van Bavel²

¹ CNR-ISMAR, La Spezia, Italy. email:stefano.aliani@ismar.cnr.it

² NIVA, Oslo, Norway

³ IFREMER, Unit RMPF, Tahiti, French Polinesia

⁴ NILU, Tromsø, Norway

⁵ AWI, Helgoland, Germany

⁶ Aarhus University, Aarhus, Denmark

⁷ ILVO, Merelbeke, Belgium

Standfirst

Flexible decision-making tools are needed to support action plans for plastics and other pollutants. Reproducible Analytical Pipelines (RAPs) and technological readiness levels (TRLs) will enable systematic validation and global harmonization of plastic pollution monitoring methods.

Plastic pollution is a wicked problem¹ that spans all environmental compartments, with different magnitudes in space and time. A Global Plastic Treaty is under preparation² with the ambitious goal of producing a set of legally binding tools aimed at stopping or reducing the flow of plastics into the environment. Policymakers and scientists are looking forward to endorsing monitoring plans based upon ready-to-deploy methods for different analytical scenarios. However, plastic monitoring is facing a reproducibility crisis³. Despite attempts to define monitoring guidelines, there are still no widely accepted monitoring frameworks. Tools and protocols have been developed to quantify plastic pollution, but these methods often provide incomparable results, even if applied to the same environmental matrix⁴.

To promote and accelerate the adoption of best monitoring practices, a flexible method-validation framework based on reproducibility, replicability, and repeatability⁵ is urgently required. In this Comment, we propose the application of RAPs and TRLs as a tool to support policy and technical decisions about plastic monitoring.

Reproducible Analytical Pipelines

RAPs are a set of automated processes used to identify best practices needed to assure that coding pipelines and data processing are standardized, quality controlled and reproducible. The concept was first introduced to manage workflows in software engineering and it is now widely applied to streamline industrial processes⁶. RAPs are especially helpful for multilevel workflows (like many plastic monitoring methods), providing modularity as a possible solution⁷.

At present, each plastic monitoring guideline is traditionally considered a unique, solid and complete path dedicated to a single matrix and particle size. Moving forwards, we advocate

framing these work- flows as modular RAPs, where any methodological step is separately evaluated and then implemented, saving money and time compared with evaluating a full pipeline.

Plastic monitoring can be divided into six modules in the RAP: survey design, sample collection, sample preparation, analytical detection, quantification, and data reporting (Fig. 1a). Important information can be extracted when every step in a RAP is investigated separately. For instance, scientists or policymakers can decide if a single step in the RAP (such as the use of analytical instruments to confirm the polymeric identity of particles) is mature enough to be implemented in all monitoring guidelines that share it. If the method is not mature, further testing and validation can be recommended.

To support this decision-making, it is important to use a robust and synthetic approach to assess the maturity of each step of a plastic monitoring RAP (that is, how much a technology is ready to fulfil the expected tasks). Although rarely applied to environmental science ⁸, we suggest using TRLs — developed by NASA to evaluate if a space technology was ready for deployment or needed further development⁹— for this assessment.

Technological Readiness Level

The TRL scale classifies technology or methods into basic research (TRLs 1–3), applied research (TRLs 4–5), in development (TRLs 6–8) and implementation (TRL 9) phases (Fig. 1b). Where a technology falls on the scale is usually assessed by experts' opinions. In plastic research and monitoring, TRL can be based on the functionality, reliability, usability, efficiency, maintainability, accessibility, cost, and portability of a method. These aspects could be ranked and assessed using a SWOT (strengths, weaknesses, opportunities, and threats) approach. The outputs of these systematic assessments should be freely available to relevant stakeholders, deposited in suitable open-access repositories (such as the GPML digital platform, and repeated and updated on a regular basis. This information will support informed decision-making, but before implementation, scientific, technical, logistical, environmental, and ethical constraints must be considered¹⁰.

Merging RAPs and TRLs

The TRL approach could be simply applied to entire full plastics monitoring guidelines; however, we argue that if applied singularly to each step in a RAP, it has the potential to greatly improve and accelerate the selection, evaluation, and adoption of large-scale plastic monitoring programmes. For instance, no methodological standards exist for microplastic sampling in the air (for example, using active versus passive samplers, measuring dry versus wet deposition, and appropriate sampling volume and duration). Therefore, air sampling-related modules would have a TRL <3, as they are still at a basic research level and not yet ready for monitoring recommendation. Conversely, analysis of samples with Fourier transform infrared (FTIR) spectroscopy is not dependent on the sampling method or matrix, and is commonly used for plastic polymer identification. FTIR would have a TRL of 9 and could be recommended for air monitoring guidelines. Overall, the low TRL of the sampling module prevents the definition of a full standard pipeline for monitoring microplastics in the air, but breaking the method down into the RAP and applying TRLs demonstrates that more widely accepted and optimised sampling protocols should be still developed.

The way forward

TRLs and RAPs are not new ideas; indeed, they are widely used in industry and TRL is a key policy tool of the European Union (Commission Decision C (2017)7124). Applying them to plastic research could aid expert groups, such as those related to the European Commission's Joint Research Centre or to the Marine Strategy Framework Directive Technical Group on Marine Litter, and other international bodies (AMAP, HELCOM, ICES, JAMSTEC, NOAA, OSPAR, UNEP), in harmonizing monitoring protocols. Moreover, this integrated framework allows researchers to better advise governments and policymakers. The United Nations Plastic Treaty can also benefit from this concept if TRLs and RAPs are used to implement effective monitoring plans needed to assess the efficacy of mitigation actions. Assigning TRLs to RAPs will ultimately improve the reliability and replicability of global plastic monitoring efforts by highlighting methods that do — and do not — work. Such work will support the development of best practices to monitor and assess plastic pollution on a global scale.

Fig 1

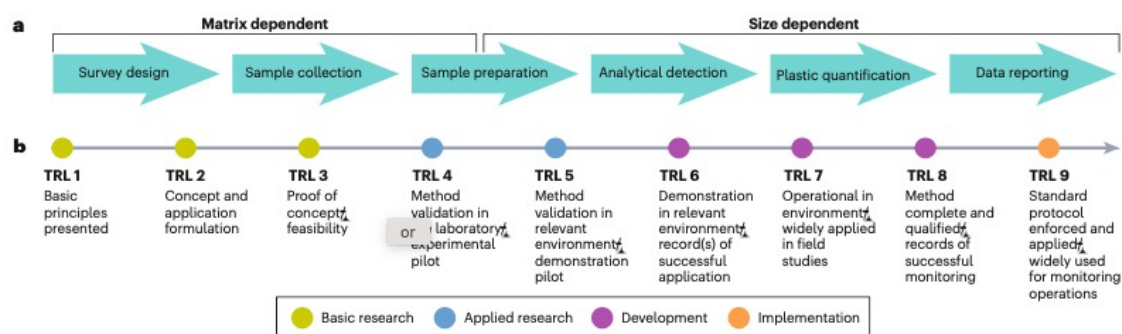


Fig. 1 - RAPs and TRLs in plastic monitoring. **a**, The six fundamental steps common for every size and matrix that form the Reproducible Analytical Pipelines (RAPs) for plastic analysis and monitoring. Survey design, sample collection and preparation depend on the sampling matrix. Analytical detection, quantification and data reporting are particle-size-dependent. **b**, The status of a RAP can be assessed against the nine technological readiness levels (TRLs). If the TRL of a module is >6 the step is mature for large-scale deployment. A step with a TRL <3 is not suitable for monitoring plans and needs further work in research and development.

References.

1. Wagner, M. in *Microplastic in the Environment: Pattern and Process* (Ed. Bank, M. S.) 333–352 (Springer International Publishing, 2022).
2. *Assembly of the United Nations Environment Programme, End Plastic Pollution: Towards an International Legally Binding Instrument* (UNEP, 2022); <https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/41841/INC1REPORTADVANCEFINAL.pdf?sequence=1>.
3. Baker, M. 1,500 scientists lift the lid on reproducibility. *Nature* **533**, 452–454 (2016).
4. Cowger, W. et al. Reporting guidelines to increase the reproducibility and comparability of research on microplastics. *Appl. Spectrosc.* **74**, 1066–1077 (2020).
5. Plessner, H. E. Reproducibility vs. replicability: a brief history of a confused terminology. *Front. Neuroinform.* **11**, 76 (2018).

6. Tanca, A. et al. A straightforward and efficient analytical pipeline for metaproteome characterization. *Microbiome* **2**, 49 (2014).
7. Schapiro, D. et al. MCMICRO: a scalable, modular image-processing pipeline for multiplexed tissue imaging. *Nat. Methods* **19**, 311–315 (2022).
8. White, R. et al. Technology development for the early detection of plant pests: a framework for assessing Technology Readiness Levels (TRLs) in environmental science. *J. Plant Dis. Prot.* **29**, 1249–1261 (2022).
9. Héder, M. From NASA to EU: the evolution of the TRL scale in Public Sector Innovation. *Innov. J.* **22**, 1–23 (2017).
10. *Defining the Most Representative Species for IMAP Candidate Indicator 24*(UNEP,2018); https://www.rac-spa.org/sites/default/files/doc_marine_litter/imap_eng_web.pdf.

Acknowledgments

This publication is part of a project that has received funding from the European Union's Horizon 2020 Coordination and Support Action programme under grant agreement 101003805 (EUROqCHARM). This output reflects only the author's view and the European Union cannot be held responsible for any use that may be made of the information contained therein.

Competing interest

The authors declare no competing interests.