ESA Discovery and Preparation – OSIP

Campaign on Remote Sensing of Plastic Marine Litter

SPOTS: Spectral properties of submerged and biofouled marine plastic litter

Executive Summary

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1 Introduction

1.1 Background

Plastic litter is a growing threat to the natural environment. The exponential rise of plastic production and mismanaged plastic waste generates a continuous increase in plastic material in rivers and oceans. Over recent years, remote sensing has become an emerging and promising method for the global quantification and monitoring of plastic debris. Hyperspectral and multispectral sensing are among the most promising remote sensing technologies for detecting plastics. Several studies have been performed, demonstrating the feasibility of hyperspectral or multispectral detection of plastics. However, there is a limited understanding of the detectability of plastics under suboptimal conditions. These conditions mean lighting, submersion of the plastic object, and biofouling or degradation of the plastics.

1.2 Project summary

The main goal of the project *Spectral properties of submerged and biofouled marine plastic litter* (SPOTS) is to investigate the effects of biofouling and submersion on the spectral reflectance of floating plastic litter. We aim to explore spectral reflectance changes under controlled conditions, creating a standardized set of plastic samples and exposing them to water and biofouling. Secondly, we explore the possibilities of detection in the field by measuring an artificial submerged target. The effect of submersion was measured under controlled conditions in an indoor lab at ZfMars-ICBM Wilhelmshaven, Germany. The field trials were conducted offshore at Tsamakia Beach in Lesvos, Greece. Finally, plastic samples with a biofilm were created at the Center for Marine Debris Research on Oʻahu, Hawaiʻi, The United States, and spectral reflectance scans for the biofouled plastics were carried out on a nearby private property.

1.3 Objectives

The main objectives of SPOTS were:

- to create a standard set of plastic samples, also to be distributed to other researchers for observation with different instrumentation,
- to establish a spectral reflectance library (in the 280 nm – 2500 nm spectral range) of submerged and biofouled virgin and marine-harvested plastic litter samples,
- to obtain insight into the (combined) effect of biofouling and submersion on the spectral reflectance of plastic through controlled lab measurements,
- to test the feasibility of hyperspectral detection of plastics in the field through field tests using a UAV-mounted hyperspectral sensor,
- to explore linear regression models for the prediction of submersion depth and polymer types from hyperspectral reflectance data, and
- to provide the newly obtained spectral reflectance library as an open-access dataset.

2 Measurements design, instrumentation, and execution

A general principle of the study design for SPOTS was to utilize standardized reference virgin plastics used throughout the different measurements of this project. In addition, the team distributed the standard samples. These plastic panels were made of high-density polyethylene (HDPE), polypropylene (PP), polyamide/nylon (PA6), polyethylene terephthalate (PET), rigid polystyrene foam (XPS Styrodur), and polyvinyl chloride (PVC). The materials were produced in three different thicknesses: 1, 5, and 10 mm thick, generating 18 different types of samples.

2.1 Indoor lab measurements

The indoor lab measurements took place in August-September 2021 at the *Institut für Chemie und Biologie des Meeres* (ICBM) in Wilhelmshaven. The team commissioned a customized 1 m^3 IBC container, painted black and equipped with a custom-built mount designed to hold a camera, a spectroradiometer, and samples at adjustable heights. A glass window fixated thin and film-like samples to prevent buckling or buoyancy effects. The setup lighting consisted of two Arrilite 575 OSRAM halogen tungsten lamps, while the room was darkened to mitigate stray light. Figure 1 shows the tank setup, with the design seen left and the as-built setup seen right.

Twenty-three plastic samples, including the 'standard' plastics, were scanned, at 22 water depth configurations, down to 70 cm deep. The team used a spectral evolution SR-3501 spectroradiometer (280 – 2500 nm) and a SPECIM-IQ (400 – 1000 nm) snapshot hyperspectral camera to record each sample. For irregular samples, a NIKON Coolpix 16 MP camera took true color reference photographs. Figure 2 presents an overview of all the samples. FFigure 3 shows the measurement setup equipped with the SPECIM IQ camera.

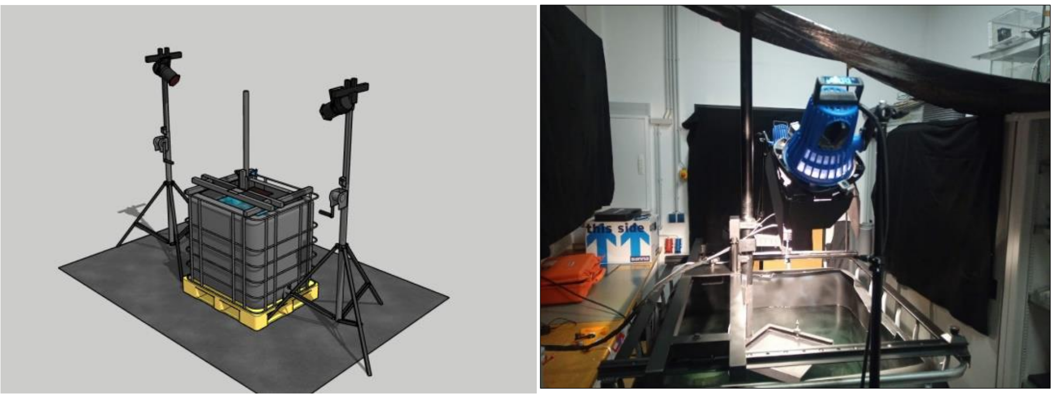


Figure 1: The measurements tank, as designed (left) and built and positioned (right) in the lab: dark fabric around the tank and a dark material overhead, reduce stray light. The normal office lighting was switched off during the scans.

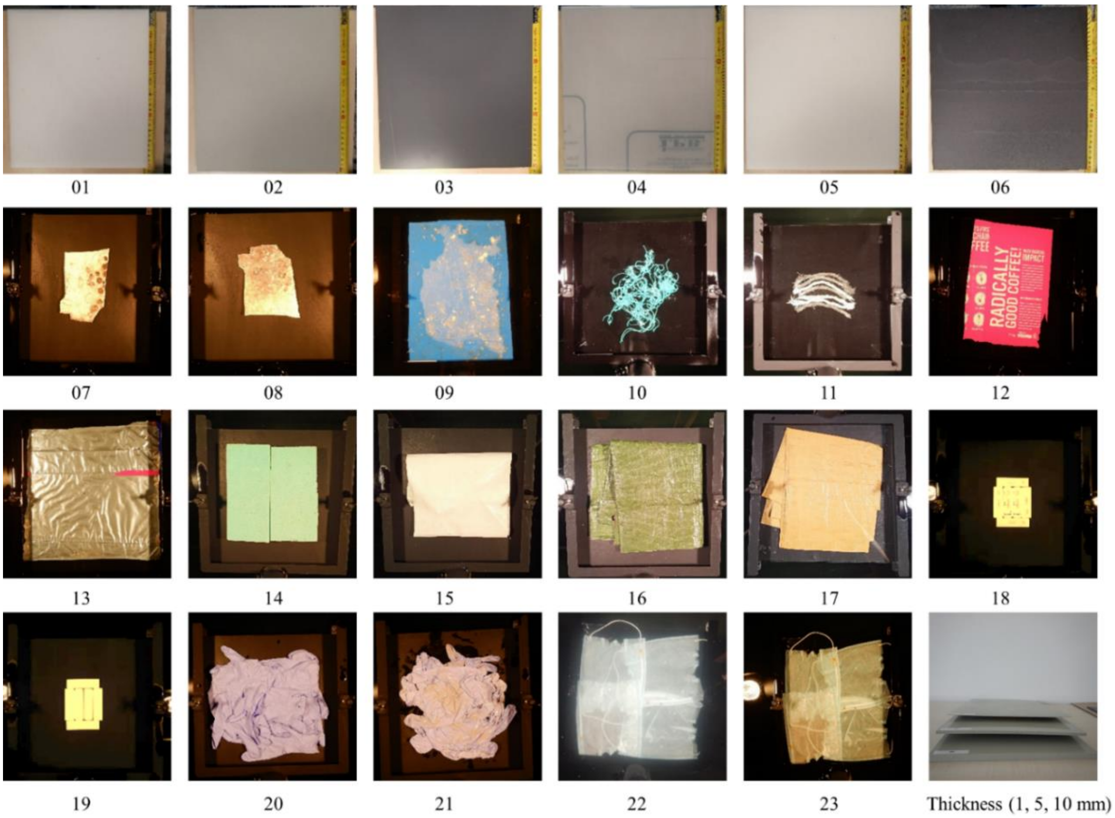


Figure 2: Overview of the plastic samples measured from August to September 2021 during the reflectance measurement campaign. 01 – 06 are the standard reference plastics, observed in three different thicknesses. 07 – 11 are weathered plastics obtained from the Great Pacific Garbage Patch. 12 & 13 are multilayer packaging, and 14 – 17 are commonly used materials in construction: thermal insulation foam and plastic tarps. Finally, several COVID-19-related items were scanned: Rapid Antigen Tests (18/19 for front and back), medical gloves (20 clean, 21 weathered), and facemasks (22 clean and 23, weathered).

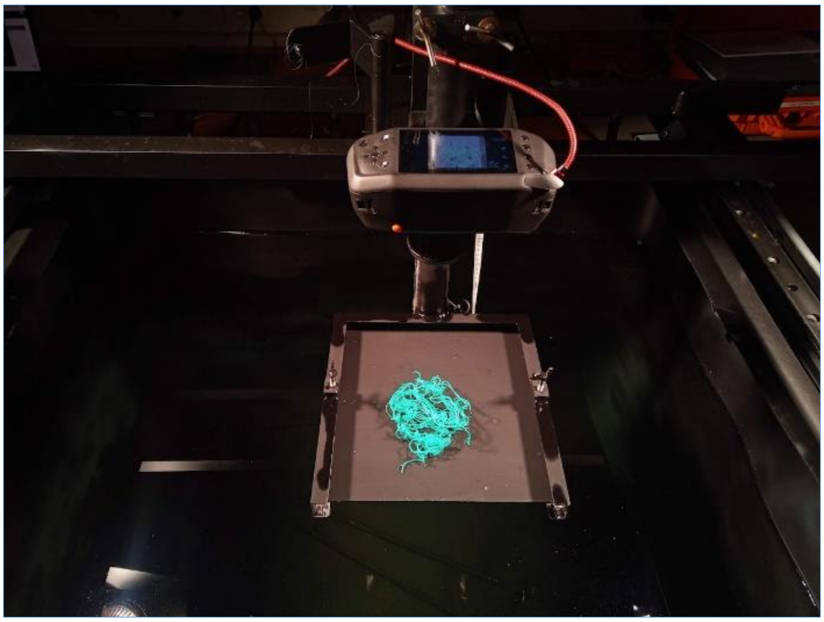


Figure 3: Scanning ocean plastic (net) using the Specim IQ hyperspectral camera.

2.2 Outdoor lab biofouling measurements

The team collected the final measurements from 12 to 16 September 2022 on Oʻahu, Hawaiʻi, USA. These measurements were focused on biofouled plastic samples. Although biofouling is ubiquitous in aquatic environments, replicating it is a non-trivial process and requires a delicate balance of environmental parameters. The biofilm is fragile and quickly disintegrates and decomposes when left out of the water.

In collaboration with Hawaiʻi Pacific University and the Center for Marine Debris Research, the standard plastic samples were left to accumulate biofilm in a seawater tank for three months. Additionally, sensors attached to the tank measured environmental parameters relevant to biofilm growth: water temperature, air temperature, dissolved oxygen, and photosynthetically active radiation (PAR).

As the measurement campaign took place at a different location, the samples were submerged in an adjacent tidal canal to conserve the biofilm layer during the experiment. Figure 4 presents an example of a biofouled plastic sample. The setup used the same instrumentation as the indoor lab measurement, but the main difference is that the outdoor scans used natural sunlight for illumination.

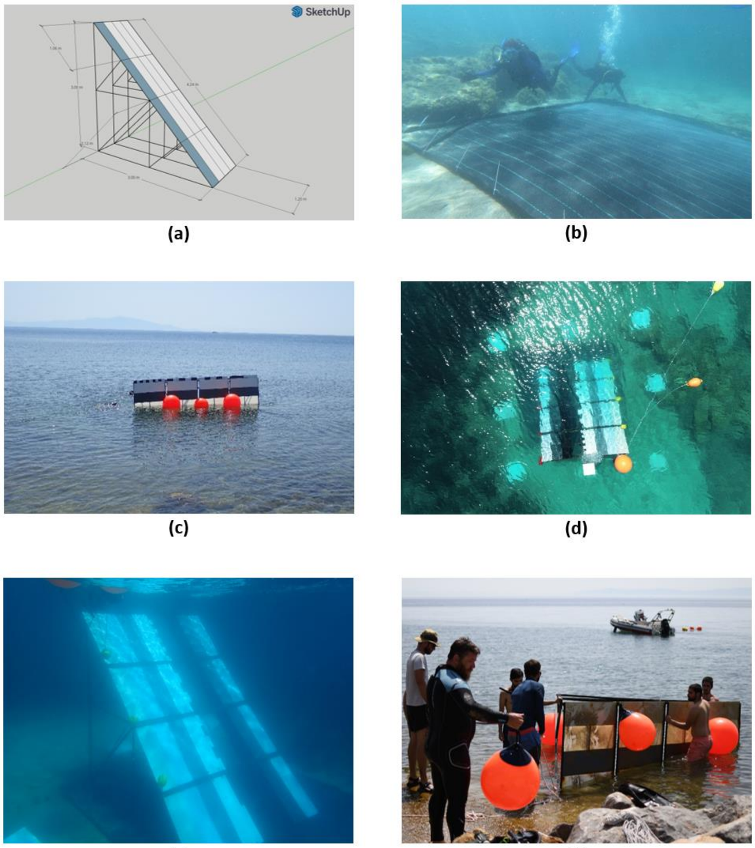
Figure 4: Close-up of the measurement setup using a similar clamping setup as the indoor lab measurements. The spectroradiometer lens is visible at the top of the image, pointing perpendicular to the biofouled sample.

2.3 Field measurements

The field measurements were conducted by the Department of Marine Sciences at the University of the Aegean from 25 May to 18 June 2021 in Mytilini, Greece. The Marine Remote Sensing Group built a unique artificial plastic target for the scope of this study. Figure 5 overviews the different stages of the artificial target's construction and deployment. In addition to the six standard reference plastic types, the team added two additional types of plastic: LDPE and white PS. A sloped construction fixated eight strips of plastics positioned at a gradually increasing depth from 0 to 3 meters.

A modified DJI S1000 UAV carried a Bayspec OCI-F hyperspectral pushbroom scanner (400 – 1000 nm) and scanned the artificial target from its side. The team made repetitive flights spread out over the entire measurement date range. In total, the team performed 41 flights.

Each flight's data was processed into a hypercube, a raster image in which every pixel contains a spectral signature—a DJI Phantom 4 collected RGB pictures, which were combined into orthophotos by photogrammetric processing.



(a) (b)

(c) (d)

(e) (f)

Figure 5: Impressions of the field test artificial target: (a) Technical draft of one half of the target, (b) Dark background being deployed by the team of divers, (c) the target being deployed using flotation balloons, (d) close-up top view of the target just after deployment, (e) the submerged target, just after deployment, (f) the target being decommissioned after three weeks. Biofouling is visible on the target.

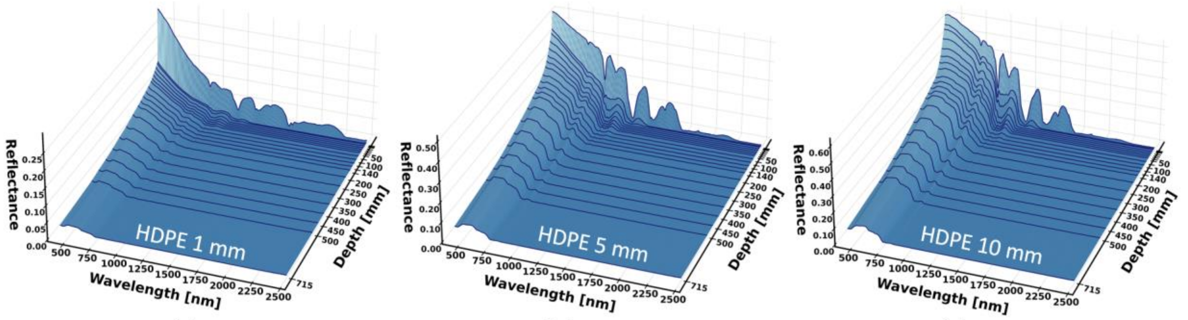
3 Processing and results

The spectral reflectance data from the indoor and outdoor lab measurements were processed, refined, and visualized using a unique set of scripts in Python 3.8. These scripts allow efficient management and querying using a (local) PostgreSQL database. Comparing the data across different water depths and material thicknesses showed that many absorption features will attenuate when underwater. The comparison also differentiated the strength of this decline between varying materials and thicknesses. Figure 6 shows an example of the decrease of spectral reflectance with increasing water depth and varying material thickness.

The biofilm on biofouled plastic samples influences spectral reflectance in the visible (400 – 700 nm) spectral domain. The effect of biofouling on NIR and SWIR spectral reflectance is minimal, and the spectral reflectance shape is still very similar to virgin plastic in this domain. Figure 7 shows an example of this for a 10 mm PP plate.

The field test data was processed from pushbroom data into hypercube data using Bayspec software. A customized python script was used for the co-registration of the hypercube and the RGB orthomosaic data (Figure 8). The hypercube spectral reflectance data exhibited unexpected spectral features. To address this issue, additional hyperspectral measurements of several parts of the offshore artificial target were made to recalibrate the hypercube data. This recalibration has improved the overall quality of the hypercube dataset. However, several unexpected effects are still present, indicating the difficulties of push-broom hyperspectral data acquisition over water, which contains waves and sun glint.

A comprehensive effort was made to find a standard best linear regression model to predict plastic depth irrespective of the six different types of plastics based on a pair of wavelengths using a log-ratio linear regression method. The team found that the predictive quality of linear regression models is limited when the plastic type is unknown. It is recommended to explore more advanced regression models for simultaneous estimation of plastic type and water depth.



(a) (b) (c)

Figure 6: 3d visualization of spectral reflectance vs. depth for HDPE, at 1 mm (a), 5 mm (b), and 10 mm (c) thickness.

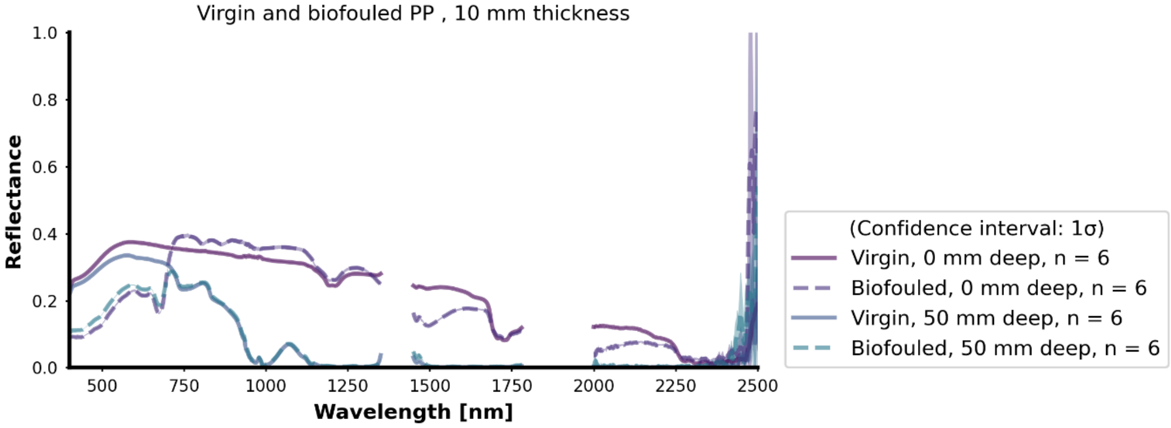


Figure 7: 10 mm thickness PP, virgin (solid lines) and biofouled (dashed lines). The main difference occurs in the visible spectrum (400 – 700 nm), which is relatively dark. Apparently, the biofilm does not influence the spectral features.

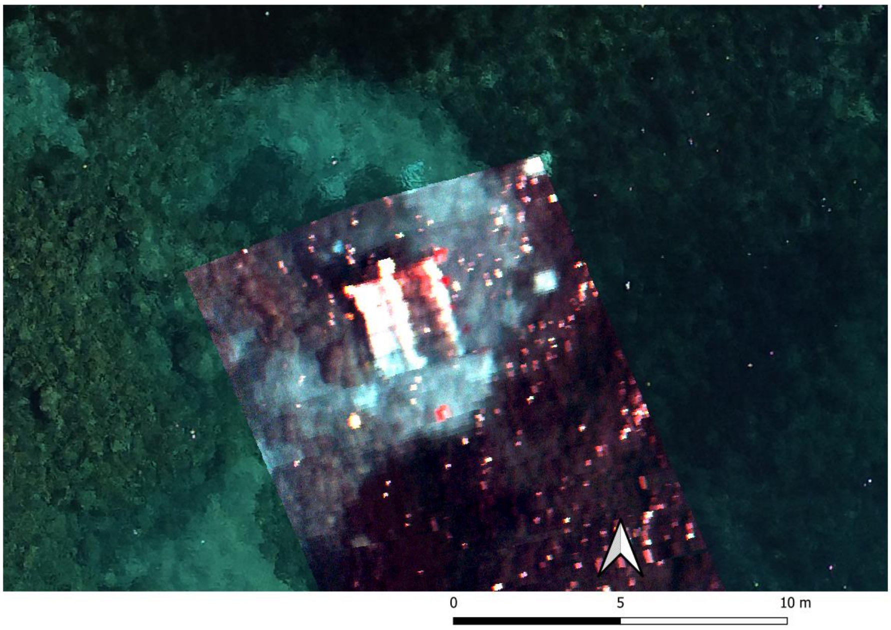


Figure 8: Hypercube (foreground), visualized with the true-color bands, co-registered and overlaid with true-color orthomosaic background. The artificial target is visible in the middle of the image, with several buoys (red and yellow). The orthomosaic results from the photogrammetric adjustment of several snapshot images, while the hypercube is composed by joining the pushbroom sensor data line-by-line.

4 Conclusions and recommendations

All planned measurements were completed, and the studies established high-quality spectral reflectance reference libraries. All datasets have been extensively quality-controlled and analyzed with a focus on obtaining, refining, and testing a preliminary regression model that could potentially describe spectral reflectance as a function of water depth and material polymer type. The team is nearing the completion of two separate manuscripts and publishing open-access datasets based on the field and lab test data. The presented initial findings in this report are preliminary and will be further/extensively analysed to validate as well as verify our current understanding of the dataset. In brief, the following main conclusions can be distilled:

Biofilm does not impact the diagnostic absorption features of tested plastic reflectance

Attenuation of reflectance is mainly observed in the visible spectrum (<750 nm), but diagnostic absorption features are not impacted by the biofilm available for this study. The team does recommend exploring further spectral reflectance measurements of thicker biofilms and assessing the quantitative effects of biofouling on measured signals. For transparent plastics (PET), the biofilm increases the spectral reflectance magnitude for all wavelengths.

The water depth impacts key spectral features, especially in the SWIR spectrum (> 1000 nm), as expected.

The spectral reflectance magnitude and shape are impacted by water absorption even at the shallowest depth evaluated (5 mm) from the UV to SWIR. Consequently, aquatic remote sensing methods that aim to explore SWIR absorption features are limited to floating plastic waste.

The precision of plastic depth estimation is limited when the polymer type is unknown.

The team has tested a Stumpf[1] regression model to estimate plastic depth. A generic parameter set was chosen based on the six standard sample types. However, the preliminary predictive performance of this model was poor, i.e., with errors of up to 100%. This linear regression model does not perform correctly without knowing the polymer type. The team recommends further exploration of combined scalar/logistic models to optimize for both polymer type and water depth. Additionally, the team sees potential in applying linear prediction models, assuming the most abundant plastic type.

Other material properties play a role in the detectability of plastics by hyperspectral sensors.

The material's thickness and apparent color can each influence the spectral reflectance magnitude and be a decisive factor for its detectability in noisy environments (i.e., with sun glint or sea foam) or when the plastic surface cover fraction is low.

Detailed spectral reflectance library

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[1] Stumpf, R. P., Holderied, K., & Sinclair, M. (2003). Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnology and Oceanography, 48(1 II), 547–556. https://doi.org/10.4319/lo.2003.48.1_part_2.0547

This study has delivered a detailed spectral reflectance reference library, which explores the effects of polymer type, material thickness, biofouling, and water depth. The team expects that this dataset, when published open access, can be used to enrich existing spectral reflectance reference libraries. The dataset can motivate further scientific research on how remote sensing of biofouled and submerged plastics can be improved or achieved.