Hyperspectral reflectance dataset of pristine, weathered and biofouled plastics

Giulia Leone[1,2,4,5, *], Ana I. Catarino[1], Liesbeth De Keukelaere[3], Mattias Bossaer[1], Els Knaeps[3§] Gert Everaert[1§]

[1]Flanders Marine Institute (VLIZ), Oostende, Belgium
[2]Ghent University, Research Group Aquatic Ecology, Ghent, Belgium
[3]Flemish Institute for Technological Research (VITO), Belgium
[4] Research Institute for Nature and Forest, Aquatic Management (INBO), Brussels, Belgium
[5] Research Foundation – Flanders (FWO), Brussels, Belgium
§ Shared senior co-authorship

[*]*Correspondence to*: Giulia Leone (giulia.leone@ugent.be)

Abstract

This work presents a hyperspectral reflectance dataset of macroplastic samples acquired using Analytical Spectral Devices (ASD) FieldSpec 4. Samples analysed consisted of pristine, artificially weathered and biofouled plastic items and plastic debris samples collected in the docks of the Port of Antwerp and in the river Scheldt near Temse Bridge (Belgium). The hyperspectral signal of each sample was measured in controlled dry conditions in an optical calibration facility at the Flemish Institute for Technological Research, and, for a subset of plastics, under wet and submerged conditions in a silo tank at Flanders Hydraulics. The wet and submerged hyperspectral signals were measured in a mesocosm setting that mimicked environmentally relevant concentrations of freshwater microalgae and of suspended sediment. The ASD was equipped with an 8° field of view at the calibration facility, and a 1° field of view was used in the mesocosm setting. The dataset obtained complies with the Findability, Accessibility, Interoperability, and Reuse (FAIR) principles and is available in the open-access repository Marine Data Archive (https://doi.org/10.14284/530, Leone et al., 2021).

1 Introduction

The spectral reflectance measurements, collected in the framework of the Plastic Flux for Innovation and Business Opportunities in Flanders (PLUXIN) project, contribute to the current knowledge on the detection of plastics using remote sensing techniques.

In recent years, focus has been placed on the detection of plastic litter using remote sensing techniques such as optical sensors on satellites, aircrafts, and drones (Garaba and Dierssen, 2018; Martínez-Vicente et al., 2019). With the increasing demand of these technologies, it is crucial to generate knowledge on the diagnostic spectral properties of not only pristine, but also weathered and biofouled plastics (Moshtaghi et al., 2021) that are representative of the variety of environmental plastics.

Currently the spectral reflectance of dry plastics is known, and is already applied in the field of material recycling (Moroni et al., 2015), but it is restricted to items assessed for dry measurements. To be able to identify plastic litter in aquatic environments such as rivers, harbours, and oceans, we require the acquisition of the spectral features when plastics are either wet or submerged (Moshtaghi et al., 2021), as water absorbs the light in both the near (NIR) and shortwave infrared (SWIR). In addition, other water constituents such as sediment or algae, could further impact the reflected signal of plastic items (Moshtaghi et al., 2021).

To date, only a limited number of high-quality datasets consisting of hyperspectral measurements of wet and submerged plastic litter, have been published in open-access repositories (e.g., Garaba and Dierssen, 2018, Garaba and Dierssen, 2020; Knaeps et al., 2021). As plastics in our environment are so diverse in polymer type, colour, transparency, thickness, state (pristine, bio fouled, weathered, wrinkled) and wetness (dry, wet, submerged), it is critical to generate, within the scientific community, substantiated data sets which represents plastics in many different facets. The collected spectra can serve as reference or endmember spectra in future Remote Sensing plastic detection techniques and help to understand the complexity of plastic detection through spectral analysis. It is recognized that not all possible scenarios can be measured in an experimental way, therefore the dataset can further be used to compare with and complement numerical simulations. The dataset described in the current paper aims at complementing the existing datasets by adding new information about the hyperspectral reflectance of pristine plastic items, harvested plastic litter, and artificially weathered and biofouled plastic samples. In addition, the dataset reports the optical features of plastics acquired in various water turbidity conditions obtained by adding sediment or algae to the water, at selected concentrations.

The dry spectral reflectance of plastic specimens, consisting of different polymers, was measured using an Analytical Spectral Device (ASD) FieldSpec 4. For a selection of these samples, the spectral reflectance was also collected in wet and submerged settings.

The presented data can be used to generate insights on the spectral properties of plastic litter and how these features change when plastics are exposed to natural agents or different depths. The dataset was compiled following the FAIR (Findable, Accessible, Interoperable, Reusable; go-fair.org) principles and it is publicly available at https://doi.org/10.14284/530 (Leone et al., 2021).

2. Data collection

Data collection consisted of measuring the spectral reflectance of different plastic specimens using the ASD. The measurements were conducted in two different settings: at an optical calibration facility located at the Flemish Institute for Technological Research (Mol, Belgium), and at a silo tank at the Flanders Hydraulics Research facility (Antwerp, Belgium). The spectral reflectance of each plastic specimen was collected at least 5 times ("pseudo-replicates") within 1 minute. These pseudo-replicates are measurements taken by slightly changing the position of the plastic sample. Therefore, very homogeneous plastics will have less variation in the pseudo-replicates' reflectance.

2.1 Plastic specimens

We aimed to collect the spectral reflectance of plastic items as representative as possible of commonly found plastics in the environment (LI et al., 2016), and to provide additional information on their reflectance when exposed to natural agents such as sunlight (UV radiation) or biofilm growth. To do so, we have selected and analysed a total of 10 polymer types. The selected polymers were Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), and two types of Polyethylene terephthalate (PET), crystalline and amorphous, Fluorocarbon, Thermoplastic elastomer, Polyvinyl chloride (PVC), Nylon 6 (PA6) and Paraffin (Table 1; Table 1S). In addition, we have further artificially weathered and biofouled a selection of 6 plastic polymer types. The polymer discrimination was based on the available information from the supplier or marked on the plastic itself (e.g., plastic bottle or bags with an identifiable polymer tag). In addition, for a set of samples, we confirmed the polymer type using a micro-Fourier Transform

Infrared Spectroscopy (µFTIR, PerkinElmer, FTIR spectrometer Frontier). The percentage of matching score with a library was recorded and it is reported in the dataset. Table 1 provides an overview of measured plastic types within this study and compared to existing datasets. This dataset adds additional information of plastic spectral reflectance of similar polymers to what is already available in the literature, allowing comparison, but also novel conditions and treatments (Table 1).

Table 1. Comparison of polymers and conditions analyzed in this dataset and in the literature. (D = Dry; W = Wet: S = Submerged; PE = polyethylene, PP = polypropylene, PS = polystyrene, PET = Polyethylene terephthalate, PVC = Polyvinyl chloride, PA6, PA 6.6. = Polyamide 6 and 66, LD-PE = low density polyethylene, FEB = fluorinated ethylene propylene Teflon, ABS = terpolymer lustran 752, PMMA = polymethyl methacrylate)

Polymer type	**This dataset**			**Knaeps et al., 2022**			**Garaba and Dierssen, 2018**			**Garaba and Dierssen, 2020**		
-	**D**	**W**	**S**	**D**	**W**	**S**	**D**	**W**	**S**	**D**	**W**	**S**
Pristine Sample												
PE	X	X	X	-	-	-	-	-	-	-	-	-
PP	X	X	X	X	X	X	X	-	-	X	-	-
PS	X	X	X	-	-	-	X	-	-	X	-	-
PET amorphous	X	X	X	-	-	-	-	-	-	-	-	-
PET crystalline	X	X	X	-	-	-	-	-	-	-	-	-
PET unspecified	X	-	-	X	-	-	X	-	-	X	-	-
PVC	X	-	-	-	-	-	X	-	-	X	-	-
Thermoplastic elastomer	X	-	-	-	-	-	-	-	-	-	-	-
PA6 and PA 6.6	X	-	-	-	-	-	X	-	-	X	-	-
Paraffin	X	-	-	-	-	-	-	-	-	-	-	-
LD-PE	X	-	-	X	-	-	X	-	-	X	-	-
Polyester	-	-	-	X	-	-	-	-	-	-	-	-
FEB	-	-	-	-	-	-	X	-	-	X		-
ABS	-	-	-	-	-	-	X	-	-	X	-	-
Merlon	-	-	-	-	-	-	X	-	-	X	-	-
PMMA	-	-	-	-	-	-	X	-	-	X	-	-
Non specified polymers	-	-	-	X	X	X	-	-	-	-	-	-
Environmentally weathered and biofouled samples												
PE	X	X	X	-	-	-	-	-	-	-	-	-
PP	X	X	X	-	-	-	-	-	-	-	-	-
PS	X	-	-	-	-	-	-	-	-	-	-	-
PET unspecified	X	X	X	-	-	-	-	-	-	-	-	-
Fluorocarbon	X	-	-	-	-	-	-	-	-	-	-	-
Paraffin	X	-	-	-	-	-	-	-	-	-	-	-
Non specified polymers	-	-	-	X	-	-	X	X	-	X	X	-

Artificially biofouled samples												
PE	X	X	X	-	-	-	-	-	-	-	-	-
PP	X	X	X	-	-	-	-	-	-	-	-	-
PS	X	X	X	-	-	-	-	-	-	-	-	-
PET amorphous	X	X	X	-	-	-	-	-	-	-	-	-
PET crystalline	X	X	X	-	-	-	-	-	-	-	-	-
PVC	X	-	-	-	-	-	-	-	-	-	-	-
Artificially weathered samples												
PE	X	X	X	-	-	-	-	-	-	-	-	-
PP	X	X	X	-	-	-	-	-	-	-	-	-
PS	X	X	X	-	-	-	-	-	-	-	-	-
PET amorphous	X	X	X	-	-	-	-	-	-	-	-	-
PET crystalline	X	X	X	-	-	-	-	-	-	-	-	-
PVC	X	-	-	-	-	-	-	-	-	-	-	-

2.2.1 Pristine plastic specimens

To enhance the physio-chemical properties of an end plastic product, plastic manufacturers often incorporate additive substances into the pristine polymer (Garaba et al., 2021). Additives included in plastics, such as coloured plastics, may be influencing the spectra (Garaba et al., 2021). Thus, to avoid confounding measurements, sheets of 6 x 6 cm were obtained from a commercial supplier (Carat, Germany, https://www.carat-lab.com) as pure pristine plastic polymers without any additional additive for the following polymers: PP, PE, PS, PET amorphous, PET crystalline. In addition, no colour or stains were added to the commercial plastics, and as such, these selected samples were transparent or white. The other pristine plastic samples were either purchased from a local shop (Oostende, Belgium), or obtained from other institutes (Marine Remote Sensing Group, University of the Aegean in Plastic Litter Projects (2021 and 2022), The Ocean Cleanup).

2.1.2 Weathered plastics

To mimic the effect of solar radiation on plastic items in the environment, pristine plastics without additives were exposed to UV radiation in an Atlas SunTest CPS+ weathering chamber, simulating one solar year in central Europe (Gewert et al., 2018) (Table 2). Prior to the treatment, plastic specimens were cut, using a hot knife, into 2 x 10 cm sheets in order to fit them into closed Quartz cuvettes. Although UV exposure in a laboratory cannot perfectly mimic environmental conditions, to reproduce them as accurately as possible we have tested different treatments for weathering conditions: i.e., dry UV exposure, seawater UV exposure (35 psu) and dark controls (dry and wet), and each treatment consisted of a set of three independent replicates for each polymer type (Table 4).

Table 2. Parameters of the UV chamber, used in artificial weathering experiments

UV irradiation W / m^2	Black Stand Temperature (BST) °C	Chamber Temperature (CHT) °C	Test durations h
60	50	30 - 35	917

2.1.3 Biofouled plastics

To test the effects of biofilm attached to the surface of plastic items on their spectral reflectance, we induced biofilm growth on the two surfaces of pristine samples. Since surface roughness can affect biofilm growth and its survival (Rodriguez, D., B. Einarsson, 2012), one of the two surfaces of the commercial plastic specimens, was manually treated for approximately 10 seconds with sandpaper (grain size 80) to create a rougher surface compared to the smooth and untouched one. An aquarium was filled with unfiltered seawater collected from the port of Ostend (Belgium), which was renewed every two weeks, kept at 20 °C, and aerated with an air pump. Plastic specimens were suspended in the aquarium with paper clippers and rope (Fig. 1) to allow the biofilm to form on all of the surfaces.

Figure 1. Aquarium set-up for biofilm growth on pristine plastic specimens. Picture taken by Giulia Leone

2.1.4 Field plastic items

Plastic specimens were collected from the Port of Antwerp and in the Scheldt River, near Temse Bridge (Belgium) and are naturally exposed to weathering and biofouling and are, compare to pristine polymers, non-homogeneous. The plastic coming from the river Scheldt were collected by a plastic collector installed by the Belgian company Dredging, Environmental and Marine Engineering NV (DEME) Environmental Contractors (DEC) on behalf of Vlaamse Waterweg (the Flemish authority responsible for waterways in Flanders, Belgium).

2.2 Spectral measurements of plastic items

The spectral reflectance measurements of plastic specimens were performed using an Analytical Spectral Device (ASD) Field-Spec4 (Table 3). The reflectance was automatically derived and normalized to a 99% Labsphere Spectralon® Lambertian panel. In the silo tank, the Spectralon panel was positioned on the holder of the adjustable arm, at the same distance from the ASD field of view as the dry plastic specimen.

Table 3. Hyperspectral-radiometer specifications used in the two locations of the study, calibration facility and water silo tank ASD: Analytical Spectral Device; VNIR: visible-near infrared; SWIR: shortwave infrared

	ASD specifications in the calibration facility	ASD specifications in the tank
Spectral range (nm)	350 - 2500	350 - 2500
Spectral resolution (nm)	VNIR: ca. 3 nm SWIR: 10 - 12 nm	VNIR: ca. 3 nm SWIR: 10 - 12 nm
Scans per measurements	30	10
Replicate measurements	5	5
Foreoptic field of view	8°	1°

3 Experimental set-ups

Following the procedure described by Knaeps et al., 2021, we measured the spectral reflectance of the different plastic samples at two different facilities: 1) Measurements done in dry conditions were performed at the optical calibration laboratory of the Flemish Institute for Technological Research (VITO), Belgium; 2) the series of wet and submerged measurements were acquired in a mesocosm setting, with experiments being performed in a conical shaped silo tank at the Flanders Hydraulics Research facility in Antwerp, Belgium. In both laboratory and silo tank set-ups (Fig. 2), we have attached a laser pen to the ASD pistol grip to ensure that, at all times, the fibre optics of the ASD were pointing at the plastic samples.

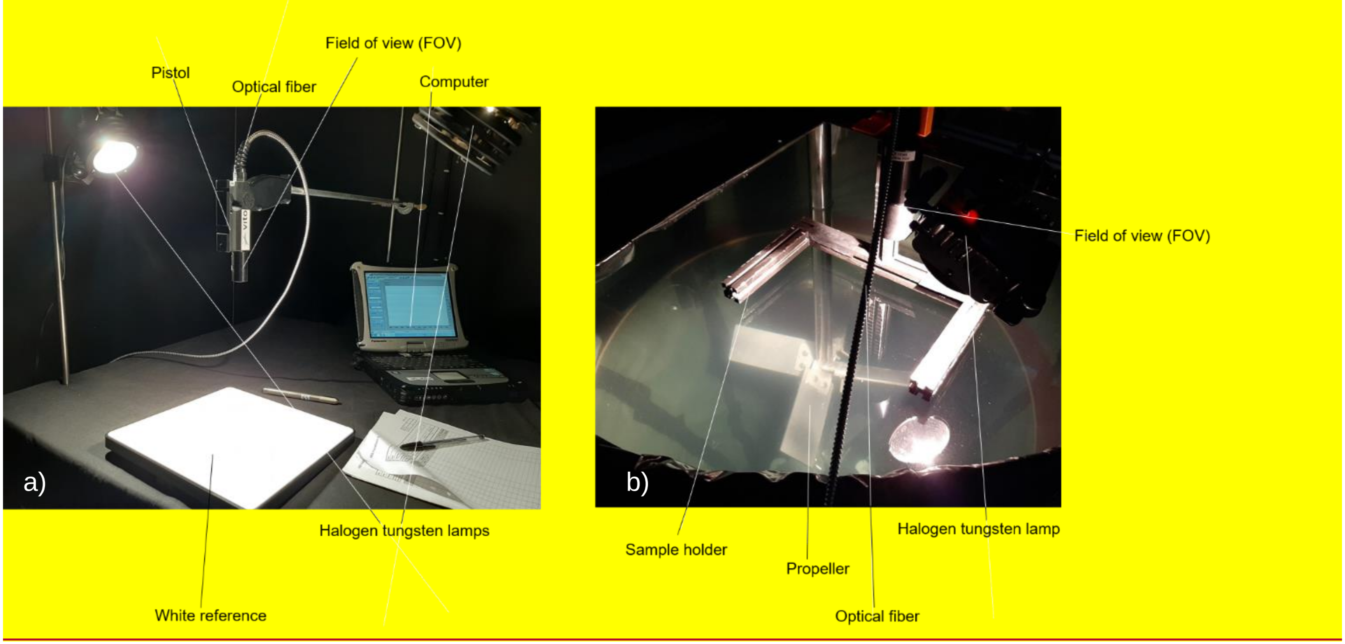

Figure 2. Experimental set-up. a) laboratory set-up; b) silo tank set-up. Pictures taken by Giulia Leone

3.1 Laboratory set-up

All the plastic specimens were measured in the optical calibration facility (VITO, Belgium). This laboratory consisted of a dark room where a desk equipped with two halogen tungsten lamps and a holder for the ASD field of view, allowed us to collect the measurements.

3.1 Silo tank set-up

The water silo tank (Diameter 2m, Depth 3m), at the Flanders Hydraulics Research (Belgium), was equipped with a controlled mixer with a double pitch blade impeller that permitted the mixing of the water to obtain suspensions of sediment or algae. No information about the rpm was available on the metal impeller at the water tank. We attached a tailor-made aluminium frame to the water tank for the mounting of spectroradiometer detector and light, together with a plexiglass sample holder to lower the plastic specimens in the tank and measure their spectral reflectance at different water depths. The plexiglass was cut to fit the plastic samples which were held by black plastic paper clips. In the current study, we acquired data using a single lamp attached to the frame, with an angle of 40 degrees. To reduce undesired stray light, a dark environment was created with black plastic cover around the experimental set-up and in addition black plastic bags were held against the tank by means of wooden rings with weights and waterproof tape. In the tank, samples attached to the plexiglass sample holder were first measured at dry conditions, just above the water level and then carefully lowered in the water at fixed depths. The water level above the sample was measured with a ruler and the chosen depths were: 1 cm, 2 cm, 4 cm and 8 cm. After the submersion, the plastic was measured again above the water level as wetted sample. The same steps were performed in clear and turbid water.

3.1.1 Water with added sediment

Natural sediment was collected using a manual Van Veen grab by the Flanders Marine Institute (VLIZ) during a sampling campaign as part of the PLUXIN project, in Nieuwpoort (Belgium). The sediment was transported to the laboratory (VLIZ), placed into a metal container, and dried in the oven for 4 days at 60 °C, and was afterwards manually crushed using a mortar, and stored in the dark until further use. To add the crushed sediment into the tank, before any measurements, the tank metal impeller was activated for a one and a half minute to allow the sediment to stay in suspension in the water. This action was repeated approximately every 30 minutes to maintain the sediment in suspension. The actual concentration of sediment added in the tank was measured by Flanders Hydraulics. The suspended sediment concentration (SSC) was determined gravimetrically, after filtration of the sample through a filter with a pore size of 0.45 µm and drying at a temperature of 105 °C. The results showed a low concentration of sediment of 4 mg / L and a higher concentration of 16 mg / L.

3.1.2 Water with added microalgae

To evaluated how the readings of spectral reflectance of plastic specimens can be affected by turbidity in the water due to microalgae suspension, measurements were performed using two concentrations of freshwater *Pseudokirchneriella subcapitata*. The concentrations were selected to mimic the natural conditions of spring and late summer seasonal concentration of green algae for a Western European River (Ibelings et al., 1998). The nominal concentrations of microalgae were 1500 cells / mL and 3000 cell / mL. The microalgae *P. subcapitata* was cultured at the Research unit “Health” at VITO, and the stock solution of 8,18 * 10^6 algae / mL was kept for 11 days in a cold room and in dark before being used in the experimental set-up. After poring 450 mL of stock solution, before any measurements, the metal impeller was activated for a one and a half minute to allow the algae to suspend into the water. This action was repeated approximately every 30 minutes to maintain the algae in suspension. To obtain a higher concentration of algae that would mimic a nominal concentration of 3000 cells / mL, other 450 mL of stock solution were then added into the tank.

4. Data description

In this study we created a dataset with the spectral reflectance of ten plastic polymers undergone to two treatments (i.e., artificial weathering and artificial biofouling) in addition to field collected samples and pristine plastics (Table 4). All data included in the presented dataset were curated before submission and consist of the raw reflectance data of the samples. A metadata section, included in the dataset, explains the data, adding additional and essential information. For instance, information on the polymer type, µFTIR results with the corresponding library matching score, origin of the sample, date and time of collection. The sample code was created following the naming convention of Knaeps et al., 2021. To ensure that end users can correctly interpret each section of the metadata, a README file is available together with the dataset. From the presented dataset it is possible to visually show the spectral reflectance of different plastic polymer and compare the different conditions experimentally tested (Fig 1S; Fig2S). For instance, it is possible to derive the effect of weathering and biofouling on the spectral reflectance of a polymer when compared with the same pristine one.

We suggest that users of this dataset perform splice correction on the data using Python or any suitable software. This processing step will lead to the obtention of spectra that do not present radiometric steps at the joints of the detectors. In addition, pseudo-replicates of each plastic sample were taken, and therefore we advise that users calculate the mean of these measurements to obtain a single spectrum for each observed item (Fig 4).

Table 4. Overview of the polymer and treatment performed during the study (SSC: suspended sediment concentration)

Treatment	Polymer tested	Origin/Supplier	State of samples	Condition of the water in the tank
• Pristine • Artificially dry weathered • Artificially seawater weathered • Artificially biofouled on pristine surface • Artificially biofouled on rough surface • Field	• PS • PE • PP • PET amorphous • PET crystalline • PVC • Extruded polystyrene • Thermoplastic elastomer • Fluorocarbon • Paraffin	• Carat • The Ocean Cleanup • Shop • Port of Antwerp • Scheldt • VITO • Marine Remote Sensing Group	• Dry • Wet • Submerged	• Clear water, no turbidity • Algae: 1.Nominal conc. 3000 cells/ml 2.Nominal conc. 1500 cells/ml • Sediment: 1.SSC 4mg/L 2.SSC 16mg/L

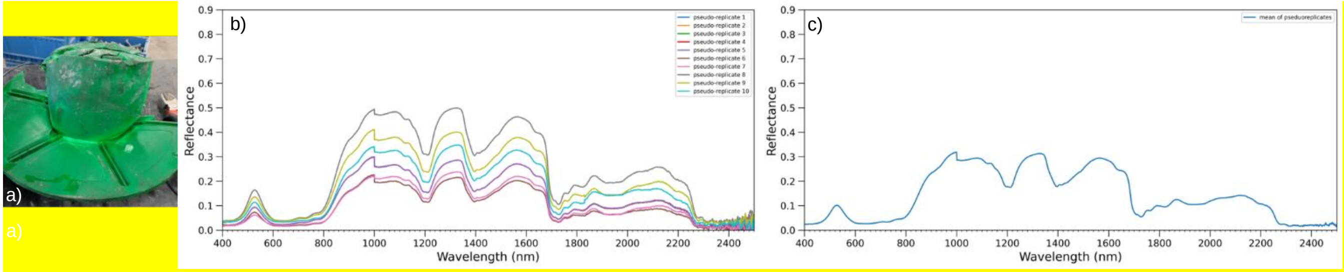

Figure 4. Spectra of field sample and figure of the object from which the spectra were obtained (a). Spectrum (b) shows the pseudo-replicates of the low homogeneous field samples. Spectrum (c) is the mean of all the pseudo-replicates. No splice correction was applied.

5. Data availability

The data are available in the open access repository Marine Data Archive at https://doi.org/10.14284/530 (Leone et al., 2021)

6. Conclusions

The use of remote sensing technologies can be used in the detection, observation and monitoring of marine plastic pollution. However, due to a lack of knowledge of the optical features of environmental plastics, small steps can be made in designing algorithms to appropriately detecting plastic pollution. The presented hyperspectral dataset is a step forward in the knowledge of the optical features of plastic litter when exposed to natural agents such as UV radiations or the growth of biofilm. In addition, from the data presented it is possible to investigate the effects that biofouling and weathering have on different polymers. Lastly, the conditions in which a plastic polymer is (i.e., dry, wet or submerged with different turbidity) are also described and assessed in the presented dataset. Therefore, we anticipate that this dataset will contribute to the definition of optical spectral bands and assist in the development of algorithms for the observation, monitoring and discrimination of plastics in a (semi-) operational environment.

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Credit author statement

Giulia Leone: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition, Data curation, Investigation. **Ana I. Catarino:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Liesbeth De Keukelaere:** Conceptualization, Writing – review & editing. **Mattias Bossaer:** Investigation, Methodology, Writing – review & editing. **Els Knaeps:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition. **Gert Everaert:** Conceptualization, Methodology, Funding acquisition, Supervision, Writing – review & editing

Competing interests

The authors declare that they have no conflict of interest.

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