ESA Discovery and Preparation – OSIP

Campaign on Remote Sensing of Plastic Marine Litter

# HyperDrone

## Executive Summary Report

Date 24th October 2022

Ref.: HD-ESR-2022

ESA contract no. 4000113163/20/NL/GLC


PML | Plymouth Marine Laboratory

SAMS Scottish Association for Marine Science

# 1 HyperDrone: Introduction

Development of instruments and algorithms for remote sensing of plastics need standardised global in-situ observations. Compared to aquatic environments, dry shores are more accessible to frequent in situ observations. As part of the **HyperDrone** project, funded by the Discovery Element of the European Space Agency's Basic Activities, we aimed to develop a standardised indicator for in-situ radiometric detection of plastic debris with the view to be deployed globally on different platforms. Plymouth Marine Laboratory (PML), with the support of the NERC Field Spectroscopy Facility and the Scottish Association for Marine Science (SAMS), undertook field campaigns collecting radiometric data using handheld spectrometer and hyperspectral images from sensors mounted on Remotely Piloted Aircraft Systems (RPAS). To make a robust dataset, the dataset was collected along the shore in real environmental conditions and uncertainty budgets were tailored for those acquisitions. This will in turn ensure best results for designing bespoke theoretical instruments for the remote sensing of plastics. The data collected will be made freely available along with the uncertainty budgets to encourage other researchers to test their methods or design new sensors.

Plastic targets were deployed along with field hyperspectral spectrometers (the Spectra Vista Corp) in hand-held mode and hyperspectral sensors mounted on drones (including the Headwall co-aligned SWIR VNIR imager and the BaySpec OCI-F) flying at different altitudes. Spectra from different plastic types and non-litter plastic materials were collected in distinctive cases: rocky shore and sandy beach. This work provides guidance on sensor requirements as well as model signal unmixing for retrieval of mixed plastic pixel coverage for subpixel detection.

HyperDrone has worked towards three major objectives:

**-O1:** Build a standardised dataset of plastic spectra for remote sensing.

**-O2:** Develop radiometric proxies for plastic debris detection in the shore zone.

**-O3:** Assessment of new instrument requirements for plastic detection (e.g. Ground Sampling Distance, bandwidths, thresholds for subpixel detection) on the basis of the processed data.

***Figure 1:*** *Left: Headwall (larger) and BaySpec (smaller) hyperspectral sensors mounted in RPAS at Oban Airport. Right: target deployment on the shore and SVC being operated.*

# 2 Methodology: Field campaigns overview

As part of HyperDrone, three field campaigns were carried out to collect data necessary to meet the objectives of this project. The three field campaigns can be classified by the year when they took place:

**-2020 Dataset:** dry-run field campaign at Tyninghame beach (UK) on the 29th of September 2020

**-2021 Dataset:** main field campaign at Oban airport shore on the 26th of July 2021.

**-2022 Dataset:** SAMS field campaign at Oban airport on the 27th of July 2022.

To collect the different datasets, the following hyperspectral sensors were used:

a) The HR-1024i spectrometer from the Spectra Vista Corp. (**SVC**) covering the range 350-2500nm.
b) The hyperspectral **Headwall** co-aligned imager covering the VNIR and SWIR region (450-2500nm) mounted on a RPAS platform and collecting LiDAR data for direct geo-rectification via the manufacturer software.
c) **BaySpec** OCI-F hyperspectral sensor, operating in the range 900-1700 nm

A total of 14 plastic targets with different compositions were deployed during low tide at Tyninghame beach (Scotland, UK with latitude, longitude = 56.014, -2.590) on the 29th of September 2020. Targets were arranged in a zig zag pattern to reduce the effects of pixel bleeding.


***Figure 2:*** *True colour photo taken using a DJI Mavic 2 drone on the 29th September 2020 HyperDrone field campaign. The targets have been numbered for identification.*

The targets spectra were collected along with non-plastic materials (sand, rock and seaweed) by using the SVC and Headwall instrument at different altitudes (30 m, 60 m, 90 m and 120 m). For each plastic target, several in situ spectral readings were taken with the SVC spectrometer. The reflectance is calculated directly by the sensor's software by taking a reference measurement from a calibrated Spectralon panel immediately before each acquisition of the signal from the target.

A second field campaign was carried out on the 26th of July 2021 at Oban Airport. A total of 15 different plastic targets were deployed and their hyperspectral signature was collected in a similar manner with the same instruments. For each dataset, uncertainty errors were estimated for each sensor.


***Figure 3:*** *Small inset (top left) shows Oban Airport shore. Larger image shows orthorectified near true colour Headwall data collected at 90 m altitude on the 26th of July 2021 over the Oban Airport shore.*

For the 2022 field campaign, only the BaySpec OCI-F "Hyperspectral Imager" was used to collect data at low altitudes over a subset of plastics targets that included EPS, HDPE and PP. As the Bayspec is more affordable than the Headwall sensor, the goal was to assess if the quality was good enough to detect plastics using the less pronounced SWIR absorption features at 1210 nm.

# 3 Data analysis

The analysis of the SVC data collected highlighted that most of the plastic types have a strong absorption feature around 1730 nm and some of them have a secondary weaker absorption feature around 1215 nm (see figure 4).

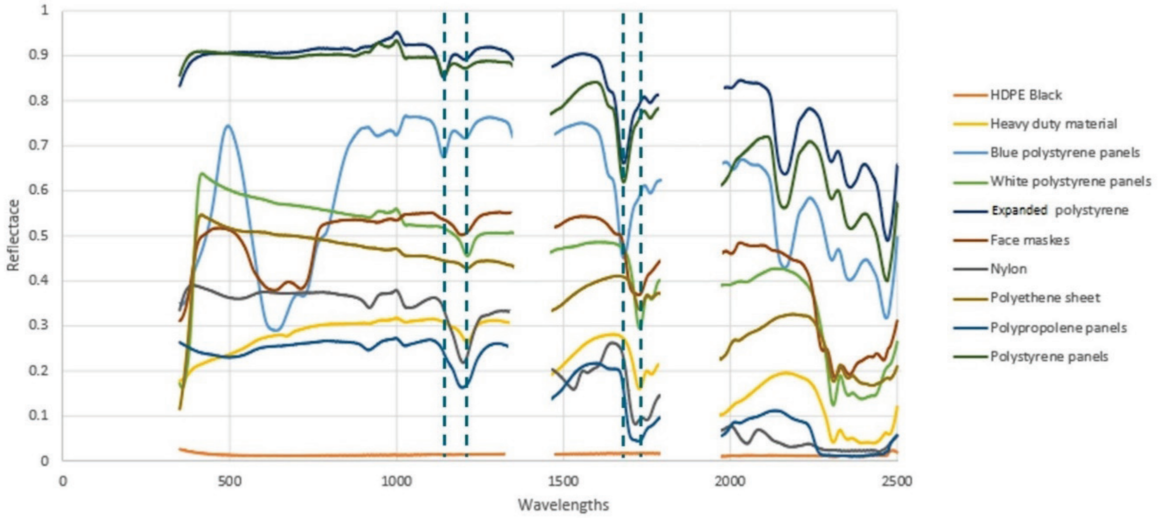


***Figure 4:*** *Mean reflectance of targets deployed in the 2020 HyperDrone campaign as captured by the SVC instrument. All plastic types show absorption in the SWIR. The strongest absorption is around 1730 nm for most materials (some around 1680 nm) and a second absorption around 1215 or 1200 nm.*

This is in accordance with scientific publications[1]. In all cases, the absorption features of some plastic materials can be slightly displaced from the centre wavelength (either 1732 or 1215 nm respectively) but still within the vicinity as it is, for example, present for EPS materials at 1680 nm. For all materials, the plastic absorption is stronger in the region 1640-1740 nm than around 1215 nm, with the former therefore preferred for the radiometric detection of plastic materials. Figure 4 also highlights that specific materials have stronger absorption features making them more likely to be detected.

Different approaches using the hyperspectral data for detecting plastics were tested including Multilayer Perceptron neural network classifier (MLP) with good results. However, the nature of plastic absorption features makes it possible to simply find a combination of spectral indices (such as NDVI) built around the centre of the of the SWIR absorption features at 1730 nm and 1680 nm. Plastic materials can be therefore highlighted with a ratio around those wavelengths via simple thresholding as long as their value is higher than non-plastic materials (e.g. rocks, sand, seaweed). This method has the advantage to require a multispectral (and non-hyperspectral) input, consequently being more suitable to a potential application to data from satellite or airborne sensors. Non-plastic materials such

[1] S. P. Garaba and Heidi M. Dierssen. An airborne remote sensing case study of synthetic hydrocarbon detection using short wave infrared absorption features identified from marine-harvested macro- and microplastics. Remote Sensing of Environment, 205:224 – 235, 2018.

as seaweed and vegetation can also be identified using different spectral indices, such as NDVI, and be masked out. By using this approach, the Plymouth Marine Laboratory developed an algorithm for the remote sensing of plastics over land. An example is illustrated in Figure 5.

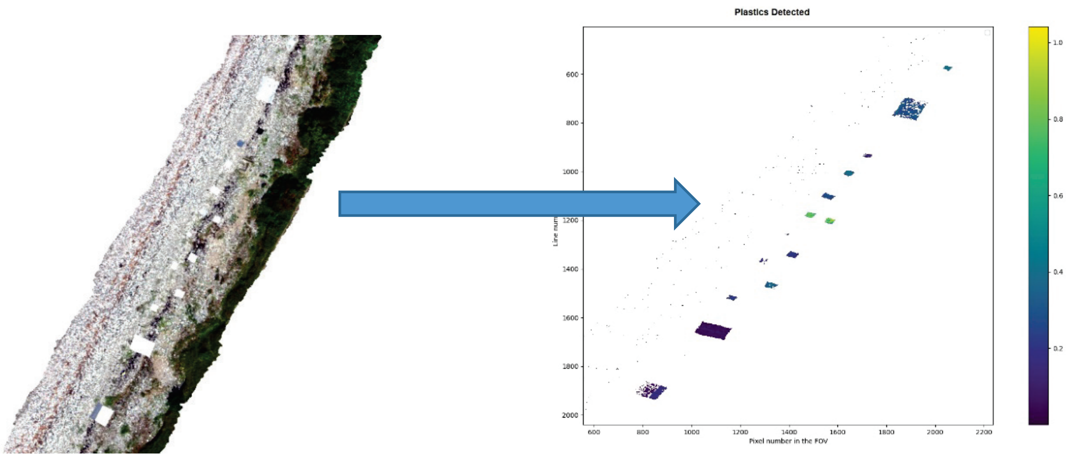


***Figure 5:*** *Left: visible image of the targets deployed on the shore, Right: algorithm output showing the detected targets.*

Based on this algorithm and the datasets (including uncertainty budgets), HyperDrone also estimated the limit of **subpixel detection** and **bandwidths** needed for a theoretical multispectral sensor for plastic litter detection.

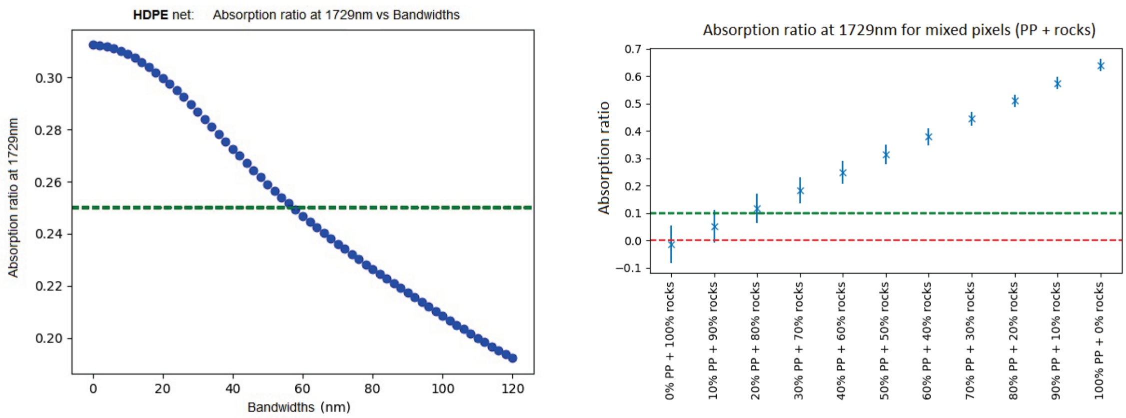


***Figure 6:*** *Plot on the left shows the response of a spectral index built to reflect the absorption feature at 1730 nm for HDPE net with different bandwidths. Plot on the right shows the response of mixed pixels of PP and rocks in different percentages (with fixed bandwidth native to SVC, approx. 5 nm)*

From this analysis, it was estimated that the **bandwidth for sensors that include a band at 1729 nm should be 50 nm or narrower** (accounting for the error bar of approx. 0.1 not included in left plot for simplicity)**.** And for the best case, **subpixel detection** of plastic litter over land is possible if:

a) at least 10-40 % of a rocky or sand pixel is covered by plastics with high absorption at 1729 nm or
b) at least 40 % over seaweed.

In order to give an idea of the limits of SNR needed for a bespoken sensor for the remote sensing of plastics, white noise was introduced in the mean reflectance of the target for different SNR ratios. If we consider SNR as a ration between the reflectance (R) received by the instrument and the noise in the signal, we can simply find the noise levels $\sigma$ for a fixed SNR as: $\sigma = R/SNR$

Therefore, the reflectance measured by the sensor with a given noise fixed by its SNR would be $R' = R \mp \sigma$. This assumes that the noise of the SNR of the instrument is measured for reflectance rather than radiance which means that assumes that the atmospheric effects are already being accounted for in the SNR. Using that reasoning, the response of the worst-case scenario for a few plastic targets and backgrounds has been simulated using the mean reflectance of different plastic targets that have more pronounced absorption features.

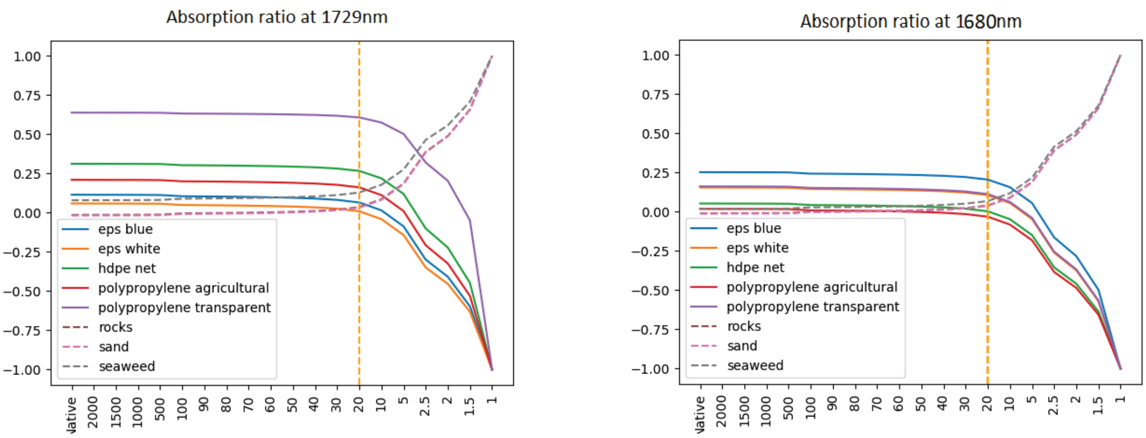


***Figure 7:*** *Simulations of expected indices response for different materials for a theoretical instrument with different SNR.*

For SNR lower than 20, non plastic materials score values as high as the plastic materials making impossible to differentiate those. Moreover, there is very little impact in the reflectance reading as long as the SNR values are larger than 100.

However, multispectral sensors that cover the range 1200-1600 nm are usually more affordable than those covering 1200-2500 nm due to the cooling systems required at these higher wavelengths. As noted before, the SWIR spectral absorption features of plastic are less pronounced in that region (1200-1600 nm) and therefore a multispectral analysis based on that region is expected to be more affected by noise. Using the BaySpec data collected in 2022 (Figure 7), an analysis was carried out by the Scottish Association for Marine Science to assess the feasibility of detecting plastics with airborne sensors around 1215nm. In this case, the method of Analysis of Variance (ANOVA) was selected to fit a hyperbolic sinusoidal curve on the SWIR spectral feature to assess the possibility to discriminate plastic from non-plastic materials. By using the empirical function:

$$R(\lambda) = R_{scale}.sech^2\left(\frac{\lambda - \lambda_0}{\lambda_{scale}}\right) + R_0$$

where *R(λ)* is the known ratio data as a function of known wavelength, $\lambda$. The function has four tunable parameters: $R_0$ is the average ratio away from the absorption "dip" or lowest point. $R_{scale}$ is a scaling of the $sech^2$ curve, and gives the **depth** of the 'absorption dip' below $R_0$ . $\lambda_{scale}$ gives a measure of the **width** of the dip (wavelength distance from curve minimum to the point where the dip is 40% below $R_0$ , or roughly the "half-depth half-width") and $\lambda_0$ the wavelength of the **point of the minimum**.

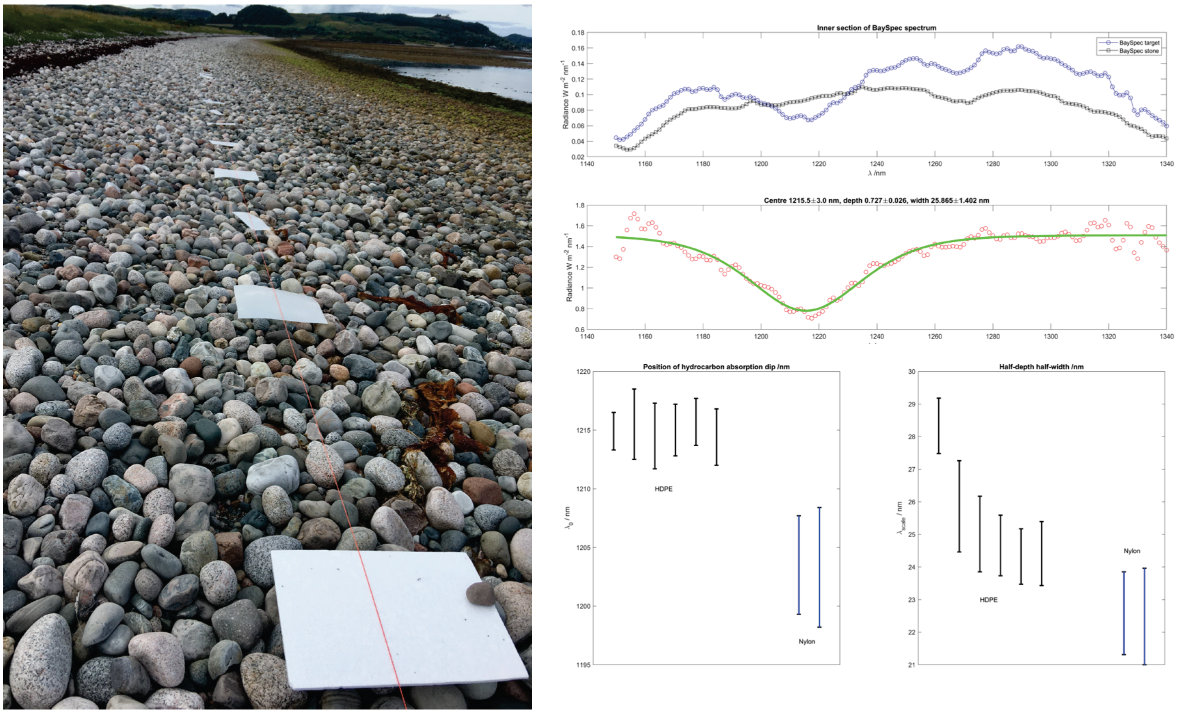


***Figure 8:*** *Image on the left shows plastic targets deployed at Oban airport in 2022. Top right plot shows the mean radiance of the rocky background and of the HDPE target as measured by the BaySpec. Bottom right plot* shows $\lambda_0$ and $\lambda_{scale}$ presented as error bars, and indicates the detected difference between HDPE and Nylon.

This highlights that plastic litter could be detected using spectral features around 1215 nm by processing hyperspectral data. In addition, considering that the absorption feature is not as deep as the one centred at 1730 nm, the sensor will need higher spatial resolution and/or higher SNR. Therefore, this method is better suited for small aircrafts or RPAS flying at lower altitudes.

# 4 HyperDrone conclusions and discussions

**HyperDrone** has succeeded in creating a **robust hyperspectral dataset collected with both in-situ handheld instrument and imagers flown on RPAS at different altitudes** in **real light conditions** and with **error estimations** (associated to each sensor: SVC and Headwall). The **dataset and error estimations will be made freely available.** We believe they represent a valuable resource for other researchers to develop and test their own methodologies for plastic detection over land or design new sensors.

This research has developed further proof that although most plastic types have absorption features in the SWIR, not all plastic types are equally likely to be differentiated as plastic using only absorption features in the SWIR (see Figure 4). **Most plastics show deep absorption features around 1730 nm**, while this absorption feature is shifted on **EPS targets to around 1680 nm**. Most plastics also have another absorption feature around the 1215 nm wavelength but it is weaker and will consequently need detectors with a higher signal to noise ratio to reduce uncertainty in the data and limit the number of false positives.

Following the analysis of this project, we recommend that **a theoretical instrument for the remote sensing of plastic on the shore should include a band centred at 1730 nm** to be able to discriminate plastics from other common materials such as rocks, sand and algae. This ensures that many types of plastic materials will be detected, and **ideally the new sensor should also include another band at 1680 nm to be able to detect EPS litter as well**. Analysis of the **SNR** showed that those bands should have a **SNR of 100 or larger**.

We have proposed different methodologies for the remote sensing of plastics by exploiting the mentioned SWIR absorption features, including Artificial Intelligence (AI). While a Multilayer Perceptron neural network classifier (MLP) was developed for hyperspectral data, it is also possible to detect certain plastic types by training AI-models with spectral indexed based on **multispectral radiometry**. HyperDrone has also developed a simple logic for a **radiometric algorithm for plastic litter detection based around normalised difference indices using the wavelength 1610 nm, 1680 nm and 1730 nm** in combination with other indices (like NDVI) to mask non-plastic materials (Figure 5**)**. This method gave good results when detecting the plastic observed by the Headwall data. The thresholds needed to identify plastic polymers have been identified thanks to the uncertainties associated with the datasets collected. It is expected that this proxy for radiometric plastic detection can be tweaked for different backgrounds and areas of interest accounting for different soil types by including different spectral indices for new regions.

Moreover, it has been estimated that the required **width for the spectral bands centred at 1729 nm and 1680 nm should be no more than 50 nm** in a theoretical sensor designed for plastic detection**.** Based on the algorithm proposed and the error estimations, we also have highlighted that it is possible to perform **subpixel detection for specific plastic types with deeper SWIR absorption features**. It was estimated that for those plastic types with stronger absorptions in the SWIR, **at least 30%-40% of a pixel should be covered by plastic over a background of sand or seaweed or rocks** in order to provide detection with higher confidence via the developed algorithm. This means that at satellite level, considering to have a sensor with the same characteristic of the SVC and a GSD of 10 m x 10 m, we will theoretically need at least 40 $m^2$ covered by plastics within the pixel for the detection. However, for aircraft mounted sensors such as the hyperspectral Specim Fenix1K with 0.4 m ground resolution at 500 m altitude, it should be possible to detect larger individual plastic debris. **Similarly, hyperspectral or multispectral sensors with acquisition bands centred at the wavelengths indicated above could be deployed on RPAS platforms to provide a monitoring service for the remote sensing of plastics along the shores or inland based purely on a radiometric analysis.**