Abstract

Unlocking the Potential of Spectral Signature Unmixing and Machine Learning for Detecting Plastic Marine Litter: Insights from the REACT Project

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The ESA-funded REACT project aimed to develop a proof-of-concept for remotely sensing marine plastic litter. The project utilised image fusion techniques with multispectral (MS) (i.e., Sentinel-2, WorldView 2/3) and hyperspectral (HS) (i.e., PRISMA) satellite data in controlled real-world experiments and then, on the fused images, it employed two different approaches: one based on Spectral Signature Unmixing (SSU) and the other on Machine Learning (ML) methodologies.

The primary objectives were to assess the detection capabilities of current and future satellite imagery and remote sensing tools for plastic litter, understand the impact of atmospheric and acquisition conditions on the spectral properties of plastics, develop adaptive indices insensitive to biases induced by sunglint, explore data fusion methods to increase the detectability of marine plastic litter and investigate SSU and ML algorithms for plastic detection. The project outputted abundance maps and probability maps of marine plastic litter, representing the fraction and probability of plastic presence in each pixel.

The key user of the REACT project was the Environmental Prevention and Protection Agency of the Puglia Region in Italy, which is the responsible authority for monitoring marine litter in compliance with the European Marine Strategy Framework Directive (2008/56/EC).

The controlled experiments utilised 12 floating plastic targets of varying sizes and materials. Spectroradiometer measurements were taken during these experiments, and the targets were placed both offshore and onshore during satellite data collection campaigns on the Greek island of Lesvos.

Different methods of pansharpening HS images were evaluated, with component substitution methods yielding the best results. Furthermore, the evaluation of fusion methods for MS images showed that the CNMF method outperformed and significantly enhanced the capability of Sentinel-2 imagery to detect marine plastic targets.

The endmember spectra of plastic materials showed similar to the water spectral signatures but higher radiance values, particularly at 1000nm in the pan-sharpened HS images. SSU applied on pansharpened HS images was able to detect offshore plastic targets, with certain limitations because plastic targets and shallow waters spectra were not separable in the HS images. The endmember spectra of plastic materials were adequately discriminated from those of water in the fused MS images, showing high reflectance values at 865 nm and 1614 nm.

The study proposed three plastic indexes based on radiance differences in the VNIR region to discriminate plastic targets from water. These indexes were successfully applied to the pan-sharpened images, resulting in the detection of offshore plastic targets.

A combination of unsupervised (K-Means) and supervised (LGBM) methodologies was employed for ML-based detection. Despite the limited dataset, ML algorithms showed promising results in detecting floating objects offshore, reducing false positives and improving accuracy with increased training data.

Two probability maps were produced based on available data: one from pan-sharpened HS data using supervised and unsupervised methods and the other from the fused MS data using the K-means method. These probability maps can provide valuable information for monitoring plans, determining optimal monitoring station locations, and modelling dispersion.