Report on the SPARSE Workshop 2025

Surface Plastic Remote Sensing – A Way Forward for the Detection of Marine Litter and Floating Matter

Santa Chiara Lab, University of Siena – 28–30 May 2025

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The SPARSE Workshop 2025 brought together leading researchers and experts to discuss the current state and future directions of remote sensing technologies for detecting plastic pollution across marine, freshwater, riverine, polar, and terrestrial environments in water proximity. Over three days, the workshop featured 5 keynote lectures, 19 oral presentations, a poster session, and breakout sessions highlighting advances in satellite, aerial, in-situ, and modelling approaches supporting global plastic pollution monitoring and outlining perspectives. Remote sensing of plastic litter is an emerging field characterized by rapid methodological innovation but also by significant scientific challenges, as the difficulty of spectrally distinguishing plastics from natural floating materials, the limited sensitivity of current sensors, and the need for standardized validation and interoperability across observation systems. A detailed workshop programme as well as the Book of Abstracts is attached to the present report.

A. Oral and poster presentations

The workshop was organized around three main topics in oral and poster presentations:

- Topic 1 – State of the Art in Remote Sensing of Floating Plastics
- Topic 2 – Land-to-Sea Fluxes and Accumulation Zones
- Topic 3 – Remote and *in-situ* Measurements

In Topic 1 "State of the Art in Remote Sensing of Floating Plastics", presentations focused on these main aspects:

1.1. Spectral characterization and algorithm design
1.2. Calibration, Validation, and Controlled Experiments
1.3. Windrows as Key Remote Sensing Targets

1.1 Spectral Detection and Algorithm Development

Several presentations in this sub-topic showcased progress in spectral characterization and algorithm design:

- Spectral discrimination of floating matter emphasized the challenge of distinguishing plastics from seaweed, driftwood, and organic materials within mixed pixels, advocating combined use of multispectral and hyperspectral data.
- Evaluation of plastic indices in freshwater demonstrated that common indices detect floating debris effectively but cannot reliably differentiate plastics from other materials in complex inland waters.
- Machine learning approaches achieved strong performance using U-Net models and augmented spectral libraries, though false positives—often due to biological features such as *Noctiluca* blooms—remain a major obstacle.
- Hyperspectral fluorescence LIDAR showed promising results for identifying specific plastic types even when submerged in surface layers.

1.2 Calibration, Validation, and Controlled Experiments

A recurring theme was the essential role of controlled environments for sensor calibration:

- The Plastic Litter Project provided a multi-year infrastructure for calibration using artificial targets, exploring detection limits, biofouling effects, and multi-platform synergies.

- Prisma, Sentinel-2, and WorldView fusion (REACT project) enhanced detection capabilities using spectral unmixing and machine learning.
- Experiments deploying plastic targets in lakes and coastal zones helped quantify the detectability limits of SAR, multispectral, and hyperspectral sensors.

1.3 Windrows as Key Remote Sensing Targets

Windrows—elongated, submesoscale lines of convergence—were a central topic:

- Cózar's keynote and related studies highlighted windrows' role as high-density plastic hotspots.
- Ground-truthing campaigns confirmed orders-of-magnitude increases in plastic concentrations within windrows compared to surrounding waters.
- Despite their ephemeral nature, windrows represent one of the most promising proxies for space-based detection of plastic litter.

In Topic 2 "Land-to-Sea Fluxes and Accumulation Zones", presentations focused on these aspects:

1.1. Riverine and Coastal Monitoring
1.2. Modeling Transport Pathways

2.1 Riverine and Coastal Monitoring

Several contributions addressed rivers as major vectors of marine plastics:

- The UPSTREAM project developed UAV-based and satellite-based monitoring of riverbanks and surface litter along the Danube, identifying hotspots using AI-enhanced detection.
- Studies in the Arno River revealed stable macroplastic hotspots along banks and unexpected downstream decreases in microplastics, suggesting anthropogenic structures shape sediment retention.
- Asia-Pacific plume fronts showed that plume frontal zones can concentrate plastics by factors up to 500, underscoring the importance of front-resolving remote sensing approaches.

2.2 Modelling Transport Pathways

Modelling advances were highlighted as crucial for integrating multi-source observations:

- The Integrated Marine Debris Observing System emphasized numerical models as essential tools to fill observational gaps and predict debris movement during extreme events.
- The OPAT (Ocean Plastic Alert and Tracking) system combined satellite detection with 48-hour drift forecasts, offering near-real-time tracking for emergency responses and cleanup operations.
- Multi-platform fusion studies demonstrated the value of harmonizing UAV, satellite, and in-situ data to track leakage from source to sink.

In Topic 3 "Remote and In-Situ Measurements", the following themes were addressed:

3.1. From Microplastics to Macroplastics
3.2. From Seabed to Space – A Multi-Compartment View
3.3. Emerging Technologies and Future Satellite Missions

3.1 From Microplastics to Macroplastics

Research spanned all size classes:

- Simulations of microplastic optical signatures showed that detection from Sentinel-3 OLCI is theoretically possible in oligotrophic waters for concentrations ≥ 2–10 mg/m³, primarily in blue-green wavelengths.
- Deep-sea studies using sediment cores and sea-ice sampling provided essential baselines for long-term monitoring and highlighted the potential for remote sensing proxies in polar environments.

3.2 From Seabed to Space – A Multi-Compartment View

The SSPIRIT project promoted integration across aquatic compartments, combining:

- Aerial multispectral surveys
- Underwater acoustic and optical sensors
- Satellite observations
- Predictive modelling

with the goal of delivering a comprehensive, multi-layer remote sensing strategy for debris detection.

3.3 Emerging Technologies and Future Satellite Missions

A major discussion point concerned the next generation of sensors:

- NASA's perspective (Lorenzoni et al.) outlined investments in new spectral libraries, next-generation satellites, and technologies such as imaging spectroscopy, polarimetry, and active optical approaches.
- Future hyperspectral missions (e.g., Sentinel-2 NG, PRISMA 2nd Gen, Landsat Next) are expected to significantly improve detection limits for both plastics and co-occurring floating matter.

B. Breakout Sessions

Fundamental discussions were held during the breakout sessions, an essential component of the workshop's structure aimed at facilitating the discussion and outlining the way forward, individuating knowledge gaps and how to set up collaborations to fill in these gaps. The SPARSE breakout sessions explored key challenges and priorities in advancing remote sensing capabilities for detecting, identifying, and characterizing marine litter and other aquatic floating matter. These took place during the whole workshop duration and were organized into the following four topics:

1. *Data availability, access, and databases' harmonization; intercomparison of processes and techniques, and data uncertainties*
2. *Technology requirements for effective space-based measurements to identify, characterize, quantify and track marine litter and potential extensions to other floating matter;*
3. *New proxies and processes as remote sensing target to help monitoring marine litter, e.g. windrows;*
4. *Remote sensing of plastic in inland water bodies and coasts, including harmonization of low altitude monitoring.*

Across all four thematic topics, participants emphasized the need for harmonized data, improved validation, interdisciplinary cooperation, and development of robust operational frameworks to support both science and policy.

1. Data Availability, Access, and Harmonisation

Participants highlighted a strong need for round robin exercises using current and future algorithms to assess performance across shared datasets. The community lacks high quality, open access, well documented training data, especially direct ground-based field observations, which are essential for AI based algorithms. Tailored datasets covering blooms, pumice, sea snot, Sargassum, plastics, and other floating matter were identified as a priority. Resources like OceanScan and the IOCCG Task Force database were cited as key repositories. Better documentation, including atmospheric correction methods, litter composition, and uncertainty estimates, is crucial. Leveraging Analysis Ready Data and very high-resolution imagery from ESA Third Party Missions was encouraged.

2. Technology Requirements for Space Based Monitoring

Current satellite studies can detect floating matter but cannot reliably distinguish plastics from natural debris. Progress requires carefully balancing spatial, spectral, and signal to noise trade-offs, with a particular emphasis on adding narrow SWIR spectral channels. A phased approach was suggested: first separate chlorophyll containing from non-chlorophyll materials, then refine unmixing techniques and simulations. Challenges such as biofouling and plastic aging require further study. Joint experiments, improved data integration across sensors, and rigorous accuracy assessments were identified as core steps forward.

3. Proxies and Processes for Remote Sensing of Marine Litter

Proxies such as Total Suspended Matter, chlorophyll a, floating matter, and sub mesoscale features remain the most feasible satellite indicators of marine litter but require significant validation. Ground-based field campaigns are essential to assess proxy reliability, reduce false positives, and understand environmental drivers (winds, sea state, glint). Proxies should be tied to regional knowledge to improve interpretation. Modelling efforts can help explore frequency and dynamics of litter events, though forecasting remains limited by insufficient qualitative data. Participants stressed the need for standardized spectral reference libraries, FAIR compliant validation datasets, and indicators tailored to policy and monitoring programs.

4. Remote Sensing of Plastics in Inland Waters and Coasts

A diverse group addressed the need to harmonize methods for nanoplastic, microplastics and megaplastics observations, integrating in situ, drone, and satellite techniques. Basic reporting guidelines (units, categories) are needed, acknowledging that remote sensing cannot mirror manual litter classifications. Monitoring leakage pathways, particularly from landfills, was considered feasible with UAVs and satellite imagery, provided that simultaneous ground measurements are gathered for calibration. It was acknowledged that inland waters present unique challenges due to vegetation and dynamic topography. The group also underscored the importance of incorporating toxicity assessments and socio-economic metrics to better link plastic pollution with human and environmental impacts.

C. Conclusions

The SPARSE Workshop 2025 demonstrated significant scientific progress in remote sensing of plastic litter and floating matter, driven by innovations in spectral analysis, machine learning, modelling, and multi-sensor integration. Across sessions and breakout discussions, several challenges were identified:

- Spectral ambiguity between plastics and natural materials.
- Need for standardized datasets, especially ground-truth acquisitions for validation, with clear guidelines (e.g. for preferred units).
- False positives, particularly in productive coastal waters.
- Scaling from controlled experiments to operational monitoring in dynamic environments.
- Integration of data from multiple platforms—UAVs, satellites, ships, models—into consistent operational pipelines.
- Monitoring in extreme environments, including polar regions and urban areas.

While these challenges remain, especially around spectral discrimination, validation, and operational scalability, the field is rapidly advancing toward systematic, global monitoring capabilities. The workshop reinforced the necessity for international coordination for ground-truthing, shared datasets, continued sensor development, and cross-disciplinary collaboration to achieve operational remote sensing solutions that support environmental policy, mitigation strategies, and long-term sustainability goals.

SPARSE WORKSHOP Surface Plastic Remote Sensing

a way forward for the detection
of marine litter and floating matter

Daily Programme

28-30 May 2025
Santa Chiara Lab, University of Siena
Italy

Organisation

Scientific Committee

- Luisa Galgani – University of Siena (Italy)
- Liselotte Tinel – IMT-Nord Europe (France)
- Stefano Aliani –National Research Council – Institute of Marine Sciences (Italy)
- Paolo Corradi – European Space Agency (The Netherlands)
- Sophie Hebden – ESA-Future Earth (UK)

Local Organizing Committee

- Luisa Galgani – University of Siena (Italy)
- Amedeo Boldrini – University of Siena (Italy)
- Alessio Polvani – University of Siena (Italy)

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Day 1, 28/5/25

	10:00 – 13:00	*Registration Santa Chiara Lab & badge pick-up*
	14:00 – 14:30	Welcome & Institutional greetings
Topic 1: State of the Art	14:30 – 15:00	*Keynote talk:* A. Cózar, "Marine litter windrows: how could they boost remote monitoring of ocean pollution?", Abstract nr. 8
	15:00 – 15:15	K. Topouzelis, "The Plastic Litter Project: advancing remote sensing for marine litter detection through calibration and validation experiments", Abstract nr. 23
	15:15 – 15:30	S. Livens, "From seabed to space: a comprehensive approach to plastic litter monitoring", Abstract nr. 14
	15:30 – 15:45	C. Atuhaire, "Evaluating the effectiveness of plastic indices in detecting floating plastic litter in freshwater environments", Abstract nr. 4
	15:45 – 16:00	R. De Vries, "Mapping macroplastics at scale: calibration and multi-year global analysis from the Automated Debris Imaging System (ADIS)", Abstract nr. 10
	16:00 – 16:15	A. Valente, "Detection of floating macroplastic aggregations in Sentinel-2 satellite imagery: machine learning models, open-source pipeline, and real-world applications", Abstract nr. 24
	16:15 – 16:30	M. Balsi, "Experimentation of real-time plastic litter detection in the environment", Abstract nr. 5
	16:30 – 18:00	***Breakout Sessions 1***
	18:00 – 18:30	***Breakout Sessions report to the Auditorium***
	18:30 – 19:30	*Icebreaker buffet served at Santa Chiara Lab & Poster Session*

Day 2, 29/5/25

Topic 2: Land to sea fluxes & accumulation zones of plastic and floating matter	08:30 – 09:00	*Keynote talk:* S. Aliani, "Plastics on the ocean's surface", Abstract nr. 2
	09:00 – 09:15	N. Deschand, "Floating litter detection from satellite images combined with numerical drift solutions of the advanced Ocean Plastic Alert and Tracking System (OPAT)", Abstract nr. 9
	09:15 – 09:30	S. Liubartseva, "Modeling plays a crucial role in the integrated marine debris observing system", Abstract nr. 13
	09:30 – 09:45	F. Serafino, "X-Band radar data analysis for detection of small garbage islands", Abstract nr. 21
	09:45 – 10:00	D. Papageorgiou, "Integrating UAV and high-resolution satellite imagery for riverine litter monitoring: A case study from the UPSTREAM Horizon project", Abstract nr. 18
	10:00 – 10:15	M. Polcari, "Satellite-based detection of plastic pollution: an experiment in Massaciuccoli Lake, Central Italy", Abstract nr. 19
	10:15 – 10:30	B. Kulkarni, "Plastic pollution in coastal water of Mumbai (west coast of India)", Abstract nr. 12
	10:30 – 11:00	*Coffee break & Poster Session*
	11:00 – 12:30	***Breakout Sessions 2***
	12:30 – 13:30	*Lunch served at Santa Chiara Lab & Poster Session*
Topic 3: Remote and	13:30 – 14:00	*Keynote talk:* V. Martinez Vicente, "Detection of floating marine litter from remote sensing in the marine environment: what can we do next?", Abstract nr. 16

In-situ measurements state-of-the-art	14:00 – 14:30	*Keynote talk:* L. Lorenzoni, "Marine debris detection from space: what is here today, and what is next – a perspective from NASA", Abstract nr. 15
	14:30 – 14:45	C. Hu, "On the logic of remote detection of plastic litter in the aquatic environments: a revisit", Abstract nr. 11
	14:45 – 15:00	G. Ceriola, "Advancing remote sensing and AI for marine and land-based debris detection: insights from the REACT and SPOTTED projects", Abstract nr. 1
	15:00 – 15:15	V. Raimondi, "Hyperspectral fluorescence LIDAR remote sensing of plastic litter in aquatic environment", Abstract nr. 20
	15:15 – 15:30	S. Cheatham, "Simulating the satellite remote sensing reflectance signal of marine microplastics using measurements of spectral and angular scattering properties", Abstract nr. 6
	15:30 – 15:45	M. Mancini, "From Macro- to Microplastics: a lesson learned from the Arno River (Italy)", Poster nr. 10
	15:45 – 17:00	*Coffee break & Poster Session*
	17:00 – 18:30	***Breakout Sessions 3***
	19:30	*Social Dinner at Spadaforte restaurant, Piazza del Campo 13, 53100 Siena*

Day 3, 30/5/25

Topic 3: Remote and In-situ measurements state-of-the-art	08:30 – 09:00	*Keynote talk:* M. Arias, "Finding marine litter from space: spectral detection and discrimination of floating matter", Abstract nr. 3
	09:00 – 09:15	I. Corsi, "Plastic pollution in the polar environments: towards effective monitoring tools to quantify and map the human plastic footprint", Abstract nr. 7
	09:15 – 09:30	G. Suaria, "Ground truthing of litter windrows in the Northern Adriatic Sea: preliminary results from the PoPlast2021 cruise", Abstract nr. 22
	09:30 – 10:00	*Coffee break & group picture*
	10:00 – 12:30	***Breakout Sessions 4*** – finalize the work and the statements
	12:30 – 13:30	*Lunch served at Santa Chiara Lab*
	13:30 – 16:00	Open Panel Discussion: all breakout sessions rapporteurs and leads report in the auditorium and closing remarks open to the academic community. Panel Leads: V. Raimondi, S. Garaba, K. Topouzelis, M. Arias
	16:00	*End of the workshop*