From detection to action:

The Role of Remote Sensing in Shaping Marine Plastic Litter Policies and Innovations

Results and Recommendations from the Plastic Litter & Remote Sensing Discovery Programme

Authors

A report prepared for the Smart Sustainable Plastic Packaging Challenge

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Contents

Disclaimer

The findings and recommendations represented in this document were produced following an online survey and series of workshops involving independent stakeholders (Industry, NGOs, Academic/Research, Gov & Other) and the recommendations are a representation of their discussions and views.

Foreword

Confronted with the alarming reality of plastic pollution, up to 8.8 million metric tons of waste annually is estimated to enter our oceans, the threat to our ecosystems, wildlife, and health is undeniable.

The adage "you can't manage what you can't measure" holds particularly true in this context. To safeguard our planet, oceans, and health, the deployment of remote sensing and earth observation technologies is crucial. These geospatial technologies play a pivotal role in realising the 2030 Agenda, the Paris Agreement, and the Sustainable Development Goals, forming a cornerstone in the battle against the triple planetary crisis of climate change, biodiversity loss, and pollution.

We need not only more data from remote sensing technologies but also better data infrastructure and analytical frameworks to transform it into actionable intelligence. Data should lead to action, and in the face of today's complex, multifaceted global plastic litter challenge, the "Plastic Litter and Remote Sensing Discovery Programme" aims not only to understand the role of remote sensing in the measurement, tracking, and monitoring of plastic litter but also explores how these insights can shape plastic litter policies and innovations.

Through the findings of this report, we hope to scale up solutions, inform actions, expand existing programmes, strengthen the ecosystems of innovation, and develop new initiatives to unlock transformative actions on the ground. The Plastic Litter and Remote Sensing Discovery Programme, an initiative funded by UKRI's Smart Sustainable Plastic Packaging Challenge, delivered by Innovate UK, and supported by partners such as Innovate UK Business Connect, the Satellite Applications Catapult, and the Arribada Initiative, embodies our urgent and critical response to this crisis.

The findings and recommendations highlighted in this report are a testament to the extraordinary expertise, passion, and commitment of everyone involved, particularly those who engaged in our workshops and surveys.

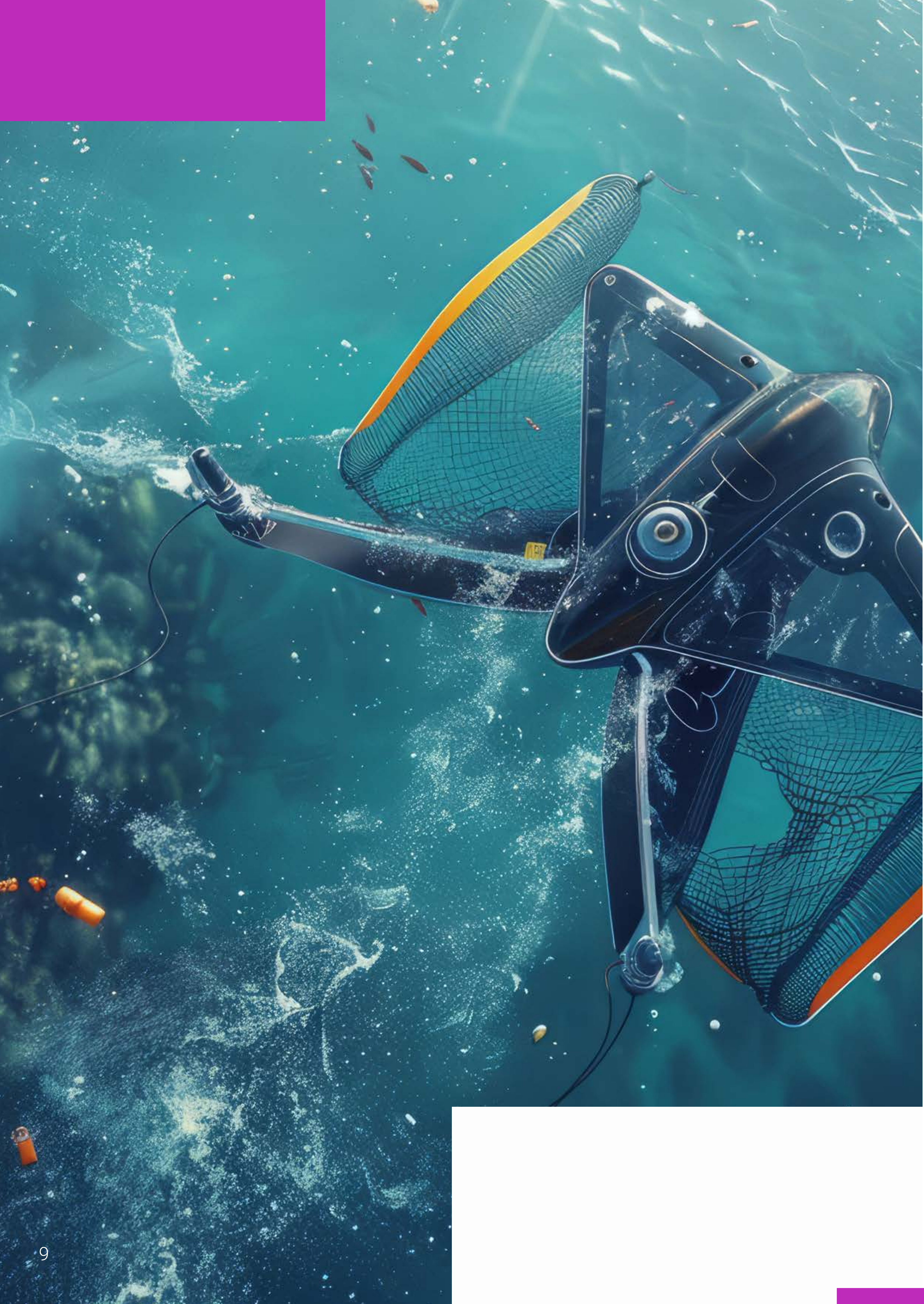
Their contributions have not only enhanced our understanding but also opened doors for significant advancements in this field. We extend our deepest gratitude to all the individuals and organisations whose collaborative efforts have been crucial in propelling this project forward, providing invaluable insights that have refined our approach to leveraging remote sensing data and technologies for policy development and market growth.

Finally, heartfelt appreciation is extended to the dedicated team whose relentless efforts have been instrumental in rolling out the programme, collecting data, analysing inputs, and compiling this report.

With gratitude,

Luca Budello

**Knowledge Transfer Manager,
Geospatial Innovate UK Business Connect**



Executive Summary

Data gathered through remote sensing has begun to play a role in identifying and monitoring plastic litter. However, organisations trying to mitigate the plastic litter problem are hesitant to rely on data and results from remote sensing studies. Encouraging the wide-scale adoption of remote sensing studies necessitates a careful evaluation of remote sensing technology capabilities, specific end-user needs and funding considerations. Innovate UK, the Arribada Initiative, and the Satellite Applications Catapult (SAC) conducted a series of scoping activities to gather valuable insights into the use of remote sensing for plastic litter monitoring and its integration into policymaking and industry practices.

We conducted an online survey and facilitated two workshops with academics, industry, government officials, and NGOs. We also consulted companies and performed a limited literature review to explore the commercial potential of using remote sensing to detect and monitor plastic litter. Although quantifying the economic scope remains challenging, the findings indicate a growing market potential for remote sensing applications in plastic litter management.

Results from the scoping activities showed that, while current remote sensing technology has the capacity to detect plastic litter, especially in large aggregations, several limitations exist:

1. The low spatial resolution of satellite sensors can make it difficult to consistently detect smaller litter items, often registering them as sub-pixel spectral signatures.
2. The diversity in plastic litter characteristics e.g., colour, shape, and polymer composition further complicate litter detection, especially when weathering alters hyperspectral signatures.
3. There is currently no single sensor capable of consistently and accurately monitoring plastic litter in all marine environments.
4. There is a shortage of vital, in-situ, validated observations of marine plastic to ground truth remote sensing interpretations and any existing ground truthing observations have numerous uncertainties.
5. The remote-sensing and plastic litter community is currently fragmented and has no method of standardisation, making it difficult to compare studies or interpret their data together within a regional or global context.
6. Ultimately, participants voiced that these limitations often prevent remote-sensing study results from being applied to policies that support monitoring, regulation, and solutions for plastic litter.

The scoping participants consented that scaling the use of remote sensing technologies for monitoring, measuring, and tracking plastic litter hinges on fostering a functional market. Such a market would accelerate product adoption and overcome technical obstacles that currently undermine trust. To achieve this, participants suggested:

1. The sector must adopt a standardised framework, supported by policy incentivising and managing the reduction of plastic waste akin to the carbon credit market.
2. Introduce mandatory reporting regulations and introduce new market instruments like carbon offsets to stimulate demand for new products, spur innovation, and catalyse industry investment.
3. Creating new policies that enforce ESG-compliant transparency, coupled with financial incentives, can empower voluntary industry actions and effectively address the varied challenges associated with the adoption of remote sensing for plastic litter monitoring.

The scoping activity participants highlighted several opportunities to address the plastic litter issue through the improvement of remote sensing technology capabilities. With more investment, these technologies have the potential to substantially contribute to evidence-based policy decisions and offer scalable solutions for efficiently monitoring plastic litter. Participant suggestions included:

1. Identifying sources of plastic litter into the marine environment.
2. Investigating the relationship between extreme weather events and plastic litter discharges.
3. Understanding landfill and river run-off positioning to avoid leakage into the environment.

However, participants noted that achieving these objectives requires higher resolution data with improved spatial, spectral, and temporal capabilities, which can feed into predictive models to help policymakers take proactive measures. Finally, they suggested that a suitable future system utilising remote sensing technologies could help verify the effectiveness of implemented policies and build a more holistic picture of plastic litter's impact on the marine environment.

Based on the scoping activity outcomes and to support the innovation and adoption of remote sensing for plastic litter detection and monitoring, we outline a roadmap that aims to accelerate the development of technologies across varying TRLs, fostering a supportive environment for market readiness and collaboration. Our recommendations, in line with Innovate UK portfolio of products, aim to leverage existing products to support the remote sensing sector's growth.

Our suggested two-tiered funding framework comprises a 'Kick Starter' for early-stage feasibility and proof of concept and a 'Major Projects' for market demonstrator and scaling commercial solutions. Adopting tested frameworks like the Contracts for Innovation in collaboration with DEFRA, or other interested public sector partners, can help to stimulate academia-industry partnerships and leverage public sector procurement, driving both policy evolution and market-led innovation.

This cohesive strategy not only enhances the UK's environmental monitoring capabilities by remote sensing but also positions UK plc as a leader in the global mitigation of plastic pollution, leveraging cutting-edge technology. In anticipation of policy shifts like the UN Global Plastics Treaty, investing in such innovation programmes will place UK plc at the forefront of an emergent new global market. This strategic position promises competitive advantages, economic expansion, and the advancement of high-skilled job sectors, potentially contributing to the levelling up agenda. With a commitment to environmental stewardship and the potential to shape international policies, the UK is poised to foster a legacy of sustainable economic development and global innovation leadership.

Introduction

Remote Sensing and Plastic Litter Monitoring

Remote sensing (RS) is the leading technique for collecting high-quality, standardised optical imagery at a global scale (*Bierman et al., 2020*). The three main remote sensing platforms for identifying marine plastic debris are waterborne proximal spectrometers, such as autonomous underwater vehicles (AUV), airborne craft, including unmanned aerial vehicles (UAVs), and spaceborne satellites. In addition, near-shore debris can be monitored using in situ, vessel-based photographs (*Papachristopoulou et al., 2020*), ground-based photographs, video footage and digital camera photographs (*Kataoka et al., 2012*). In this report, we define "remote sensing" as 'the method of obtaining information about objects or areas from a distance, typically from satellites, drones and other airborne and waterborne platforms'. We also define "plastic litter" as 'plastic products that have been discarded, disposed of, or abandoned'.

The use of satellite remote sensing to detect plastic in different environments is relatively new and has a variety of challenges. These challenges are attributed to limitations in available data's temporal, spatial, and spectral characteristics. However, spaceborne data acquisition is advancing rapidly due to its global spatial coverage, frequent and consistent observations, high spatial resolution, available range of sensors (including multispectral and hyperspectral data), improved accessibility, and ability to integrate with other data sources. This report will primarily focus on the use of space-based sensors, owing to their ability to provide consistent global data across large geographic areas.

Plastic detection often relies on nuanced spectral characteristics, which may require more spectral bands for accurate identification. A trade-off is required to strike a balance between spatial and spectral resolution when selecting remote sensing platforms for plastic litter identification. While satellites like Landsat 8 offer free and open access to 9 spectral bands, a moderate 30-metre spatial resolution, 16-day temporal resolution, and global coverage, they may lack the spectral sensitivity needed to precisely identify plastic (*Bierman et al., 2020*).

Landsat data have previously been used to analyse the heat generation in landfills compared to the immediate surroundings (*Gill et al., 2019*) and has been used for the spatial estimation of agricultural plastic waste by satellite images (*Lanorte et al., 2017*). Commercial satellites, like SkySat and RapidEye, offer fine spatial resolutions between sub-metre to 5 metres, but are limited to between 3 and 5 spectral bands and the data can be expensive to obtain (*Bierman et al., 2020*). As such, they too may lack the spectral sensitivity needed to precisely identify plastic. Currently, researchers and practitioners must carefully evaluate their project objectives and prioritise either spatial or spectral characteristics to meet their specific plastic detection needs. Advances in remote sensing technology continue to offer solutions for improving plastic detection and monitoring, enabling more effective environmental conservation efforts.

The Sentinel-2A and 2B Earth Observation satellites, launched by the European Space Agency (ESA) in 2015 and 2017, have substantially enhanced resolution capabilities, making it possible to identify macroplastics from low-earth orbit (*Bierman et al., 2020; Sasaki et al., 2022*). The Sentinel-2 satellites are equipped with a 12-band multi-spectral instrument (MSI) sensor, initially designed for terrestrial applications, and offer global coverage of coastal waters with revisit times every 2 to 5 days. Moreover, their high spatial resolution of up to 10 metres enables the detection of relatively small features and objects within the marine environment, such as river plumes, boats, and patches of macroalgae.

Additionally, the spatial and spectral resolution of Sentinel-2 is adequate to differentiate macroplastics from natural sources of floating debris and even from seawater itself. Despite these advances, remote sensing continues to have challenges. For example, reliably detecting small plastic particles or microplastics is beyond the limitations of today's sensor technology.

It is still difficult to classify plastic materials and distinguish them from natural debris. Image quality and analysis can also be affected by atmospheric and water conditions such as cloud cover or water turbidity. There are also limitations with the regions covered by today's satellites, with typically only coastal waters being captured, leaving vast swathes of the ocean being un-imaged at a suitable resolution and cadence. Several hyperspectral satellite constellations are planned for 2023 – 2025 that could provide many more spectral bands. Companies HySpecIQ, Pixxel and Xplore are planning sensors that can achieve 5 metre (or better) resolution, which could greatly improve the classification of plastic materials in a marine environment.

To gather information on how remote sensing is used to understand, monitor, and mitigate plastic litter and how remote sensing studies may inform policies about plastic litter mitigation, we conducted a series of scoping activities with academic remote sensing researchers, companies using remote sensing to monitor plastic debris, and policymakers. We gathered this information through an online survey and a series of workshops revolving around three pillars:

(1) innovation,

(2) policy, and

(3) intervention.

This report captures the discussions and recommendations that resulted from the scoping activities.

Potential Market Opportunities

Between 1.1 MT and 8.8 MT of mismanaged plastic litter enter our oceans annually (*Jambeck et al., 2015, Lau et al., 2020*) and, without intervention, those values could increase by an order of magnitude by 2025 (*Jambeck et al., 2015*). It is estimated that this marine plastic pollution has already resulted in an economic loss of between GBP £4.9 to £15.6 billion for over 87 coastal countries (*Deloitte, 2019*). Efforts such as marine debris clean-up programmes, mechanical cleanup of the floating plastics, and voluntary buy-back programmes have cost between GBP £1.1 billion – £17.32 billion, inclusive of the European Union's annual spend of GBP £511 million on the coastal clean-up of its territory (*CBD High-Level Panel., 2014*).

Despite the high economic loss and plastic litter clean-up costs, we haven't fully studied the plastic litter cycle from upstream sources of plastic to their eventual downstream aggregations (*Bank et al., 2021*). Numerous uncertainties still exist around detecting and monitoring plastic litter, partly due to methodological inconsistencies in sampling, analyses, and reporting. It is also currently challenging to combine data across large spatiotemporal scales (*Lau et al., 2020*). An earth-system-level plastic observation system, in which remote sensing techniques could play a key part, could help us understand the plastic litter cycle and mitigate the amount of marine plastic litter (*Bank et al., 2021*).

The growing issue of plastic litter is garnering more legislative and policy support. However, for policy to be effective, it's crucial that policymakers identify the fundamental problems and desired goals related to plastic litter. This could be achieved by focusing on a limited, simplified set of indicators (*Alpizar et al., 2020*). Remote sensing could provide valuable data and insights informing the knowledge gaps required to guide policy decisions and implement mitigation (*Bank et al., 2021*).

In response to this climate, several companies have recently launched commercial services to identify, monitor, and/or track marine plastic litter with remote sensing methods (SkyflowX, Plastic-i, Argans, Pixalytics, Vito Remote Sensing). While this new market could aid plastic clean-up and policy-making efforts, quantifying the market value is difficult because it is an emerging market with little to no historical revenue information and lacks clear market customers. Furthermore, many companies operating in this space are mission-focused, tackling the plastic litter problem as a core part of their ethos and envisioning the creation of a functioning market to foster sustainable economic growth.

Nascent market analyses by recently started companies (pers comm) revealed that the few known customers may be reluctant to adopt remote sensing commercial services for several reasons:

- Among the potential market customers, plastic clean-up is currently prioritised over plastic detection and monitoring.
- Clean-up organisations may lack the budget for more expensive remote sensing services.
- Regulatory agencies are hesitant to trust the results from remote sensing technology.

Despite these market challenges, the European Union (EU) has recently supported programmes that emphasise plastic litter detection and monitoring such as LifeLema, The Marless Project, and Preventing Plastic Pollution. Additionally, new legislation and regulations such as the UN Plastic Treaty, the EU Marine Strategy Framework Directive, the EU Plastics Strategy, alongside initiatives like the UN sponsored Global Partnership on Plastic Pollution and Marine Litter (GPML) Digital Platform are creating a growing need for enhanced plastic detection and monitoring, an area where remote-sensing methods can be particularly effective over large geographies.

These actions suggest that market opportunities for remote sensing in plastic litter monitoring may be increasing even if the market opportunity cannot yet be quantified.

Methodology

Survey

Between 14th June - 5th September 2023, we conducted an online survey. We identified potential participants for this survey using Innovate UK, Arribada Initiative, and SAC existing contacts and a comprehensive literature review of published articles on remote sensing and plastic litter.

We searched ISI Web of Knowledge, Scopus and Google Scholar for the terms plastic pollution, plastic litter, and marine debris in conjunction with remote sensing, satellite, drone, UAV, and sentinel. We targeted researchers who use remote sensing to understand plastic litter, companies who use remote sensing to monitor plastic litter, and those who create policies around plastic litter mitigation (for a list, see Appendix A). We employed respondent-driven sampling to reach an appropriate number of respondents while avoiding potential sampling biases (*Newing, 2011*).

Our survey had 12 questions with both open and closed responses. We have provided the survey questions in Appendix B. The survey clearly defined 'remote sensing' and 'plastic litter' as used in this scoping study. We categorised the open-response questions about challenges and priority actions using an inductive approach. We identified summary themes in the answers to open-response questions by directly examining the data (*Elo & Kyngäs, 2008*) instead of having predefined categories.

Workshops

We facilitated two workshops to gather information from experts on how remote sensing is used to detect, understand, and monitor plastic litter and how that information may inform policies about plastic litter mitigation. Additionally, we also aimed to identify the current challenges surrounding remote sensing techniques for plastic litter studies and using study results to inform policy. The recording of the workshop is available to the public at vimeo.com/846600857/e4fb6f9b3c

Workshop 1

Workshop 1 was held on 18th July 2023. A total of 153 people registered for the workshop and 79 attended. Demographics of attendees were UK and globally based with participants from India, Germany, Portugal, Turkey, Belgium, UAE, Maldives, Malawi, Spain, Brazil, Democratic Republic of the Congo, Vietnam, Greece and the Maldives. This diversity in participation enabled a rich exchange of insights and experiences and a global view of initiatives and policies.

Registrants interested but unable to join the workshop on the day included delegates from USA, Costa Rica, South Africa, Kenya, Finland, Nigeria, Romania, Iran, China, Togo, Switzerland, Mauritius, Nicaragua, Japan and Ghana.

The workshop aimed to address critical questions related to plastic litter and our three pillars of Innovation, Policy, and Intervention. During the workshop, chosen experts from academia, industry, and policy presented case studies (see Appendix C for two highlighted case studies). They then participated in panel discussions driven by responses to a live survey given to all the workshop attendees. We used the online interactive presentation software Mentimeter to coordinate the live survey and record all responses (14 questions; see Appendix D). We also captured experts' responses and insights during the panel discussions through comprehensive notetaking. We noted question and answer responses from all the workshop participants using live chats and 'chat box', which were active throughout the workshop.

Workshop 2

Workshop 2 was conducted on 19th September 2023. A total of 31 people registered and 24 attended. This workshop entailed more in-depth explorations of remote sensing techniques and challenges with a carefully curated group of participants who had previously attended Workshop 1. Themes discussed in the Workshop 2 were based on the major themes we identified as arising during the survey and Workshop 1. For this workshop, we used an online collaborative whiteboard called 'Miroboard' that allows multiple users to work together in real time on a virtual canvas. Using this platform, we asked the participants a series of questions and they responded by free-writing answers. We then grouped the answers into similar themes and held full-group discussions about those themes and identified issues. For this report, we pulled data and information from the participants' Miroboard responses and comprehensive notes we took during the discussions. We have provided images of the Miroboard in Appendix E.

Survey Results

Respondents

There were 60 respondents to our 12-question survey. Researchers were the largest proportion of respondents (47%, n=60). Other respondents were stakeholders from industry, NGOs, government and other organisations. Most respondents focused their work on the UK (Fig. 1a) or globally (Fig. 1b). The remaining respondents focused their work on other countries, with 13 different countries mentioned in total.

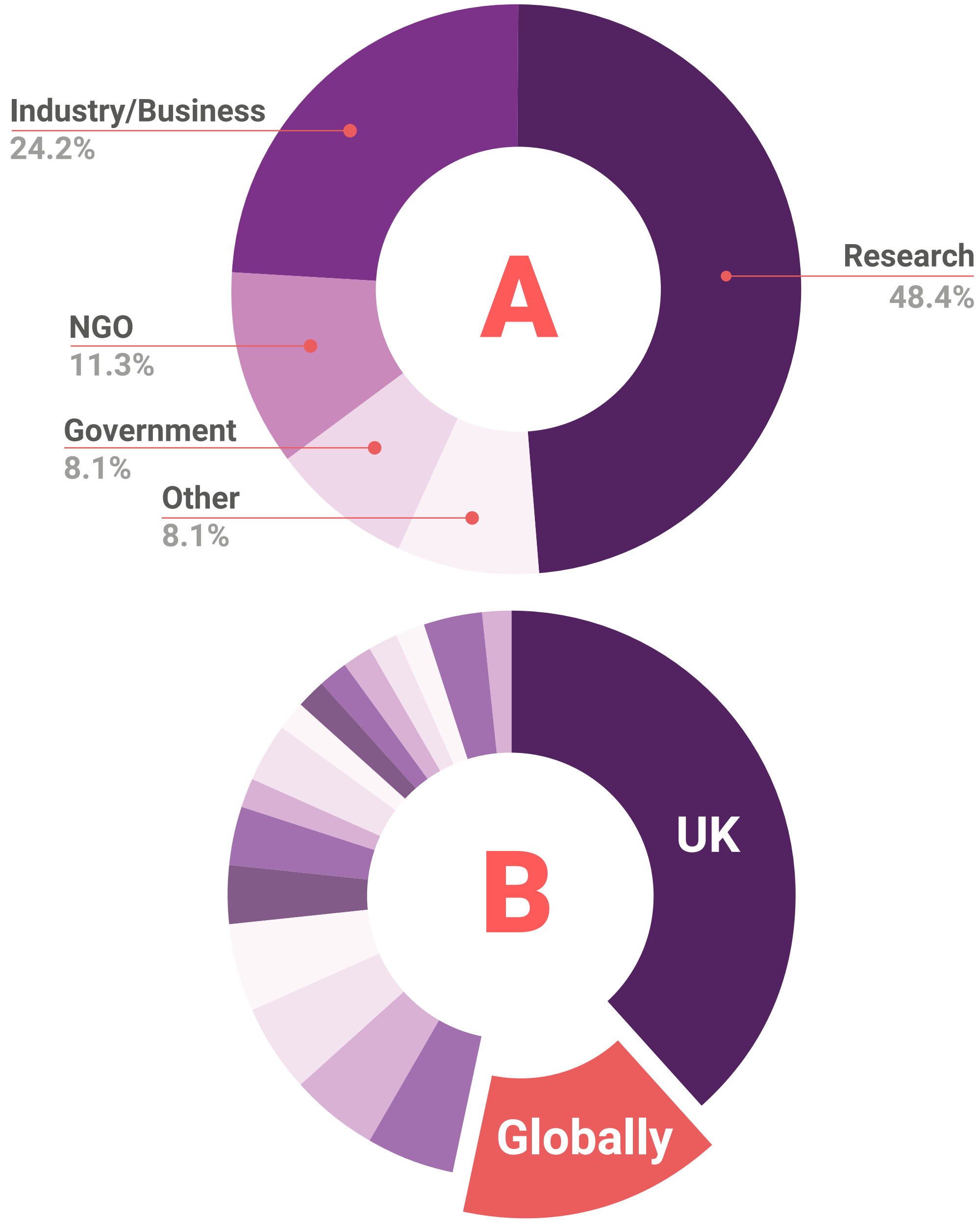


Figure 1
a) The field of work respondents are in (e.g., researcher, industry, government),
b) The country in which respondents' work was based or the country it primarily affected. (n=60).

A large proportion of respondents focused on either 'Product/Service' development (25%, n=60) or 'Technology' (25%, n=60; Fig. 2). However, most respondents stated that they worked within 'other' fields. When asked to describe "other", their responses included:

1. Machine Learning Algorithms.
2. Policy development.
3. Integrating remote sensing into local ecological knowledge and oceanographic models to inform businesses, communities, or government.
4. Manufacturing carbon-negative products from plastic packaging waste.
5. Finding correlations and collaborations.

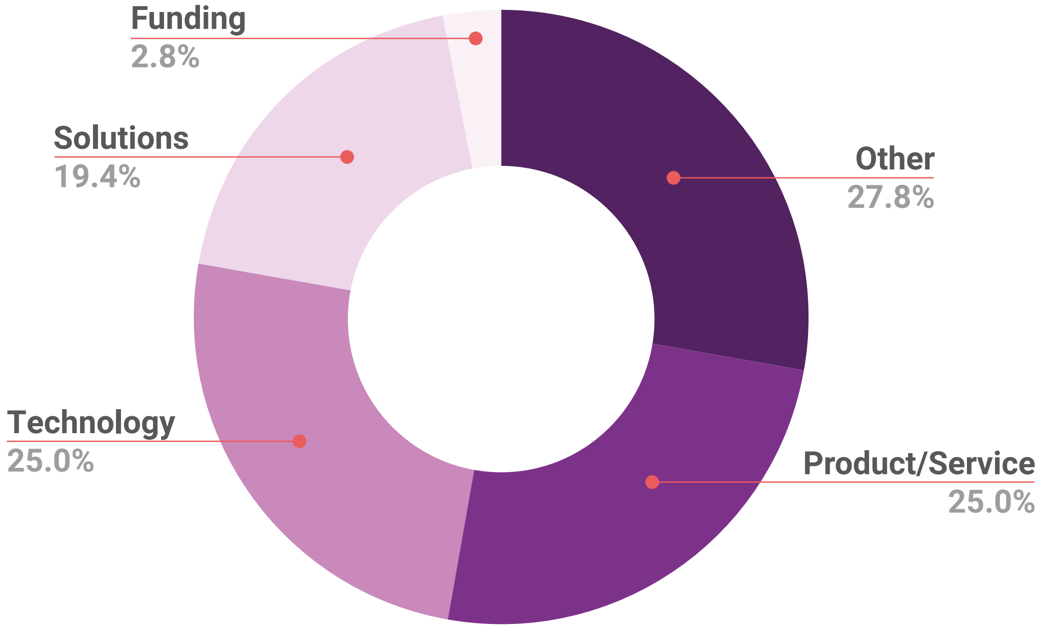


Figure 2
The respondents focus of work (n=60)

When asked in an open-response question which remote sensing techniques or data analysis methods the respondents used or are developed, they responded:

1. AI and Deep Learning Models (highest proportion answer).
2. Image and data analysis development.
3. Environmental monitoring.
4. Using RFID (Radio Frequency Identification) for remote sensing.
5. Spectral classification and spectral similarity analysis.
6. IR spectroscopy/mixing.
7. Python, ML, SQL.
8. Thermal Infrared Sensing.

Stakeholder Groups

Respondents were asked for which stakeholders they create or investigate guidance, ideas, actions, or policies focused on plastic pollution and remote sensing techniques ("yes/no" questions, n=60). Participants were allowed to select more than one category. The highest proportion of the group responded with academia and research (63%; n=38), followed by industry (50%; n=30), government (42%; n=25) and NGOs (30%; n=18; Fig. 3).

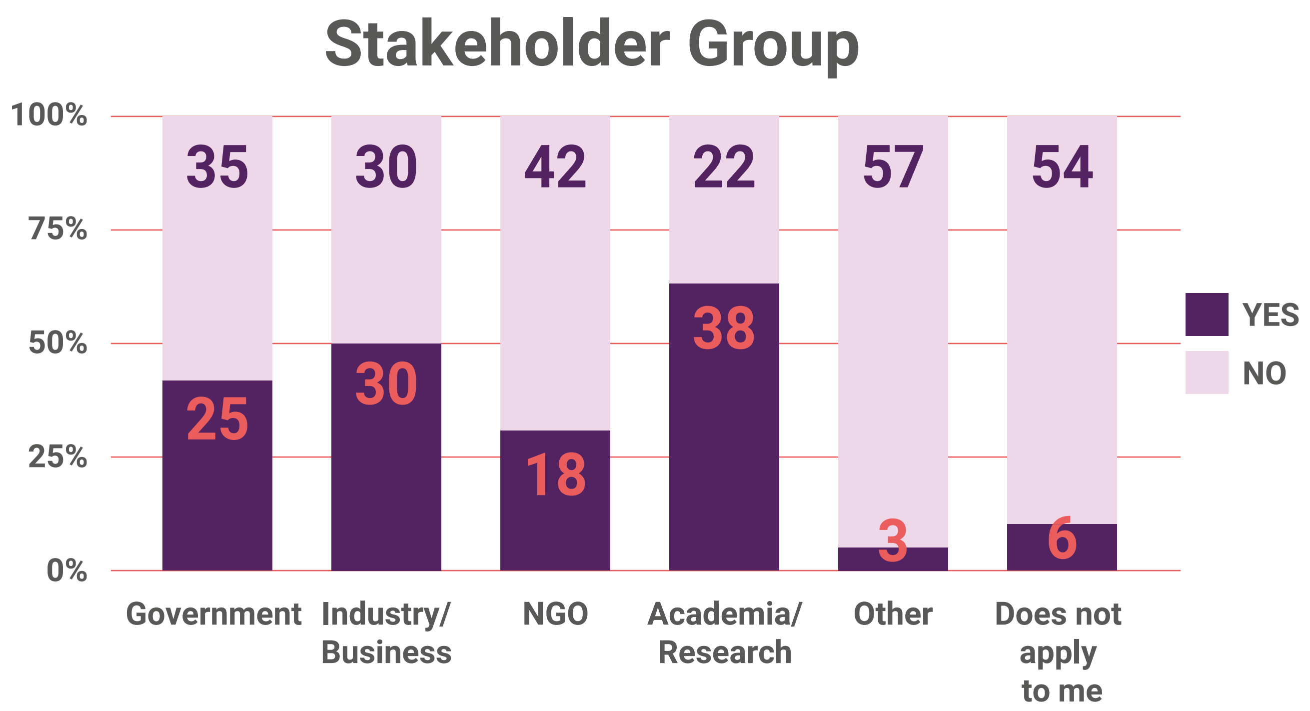
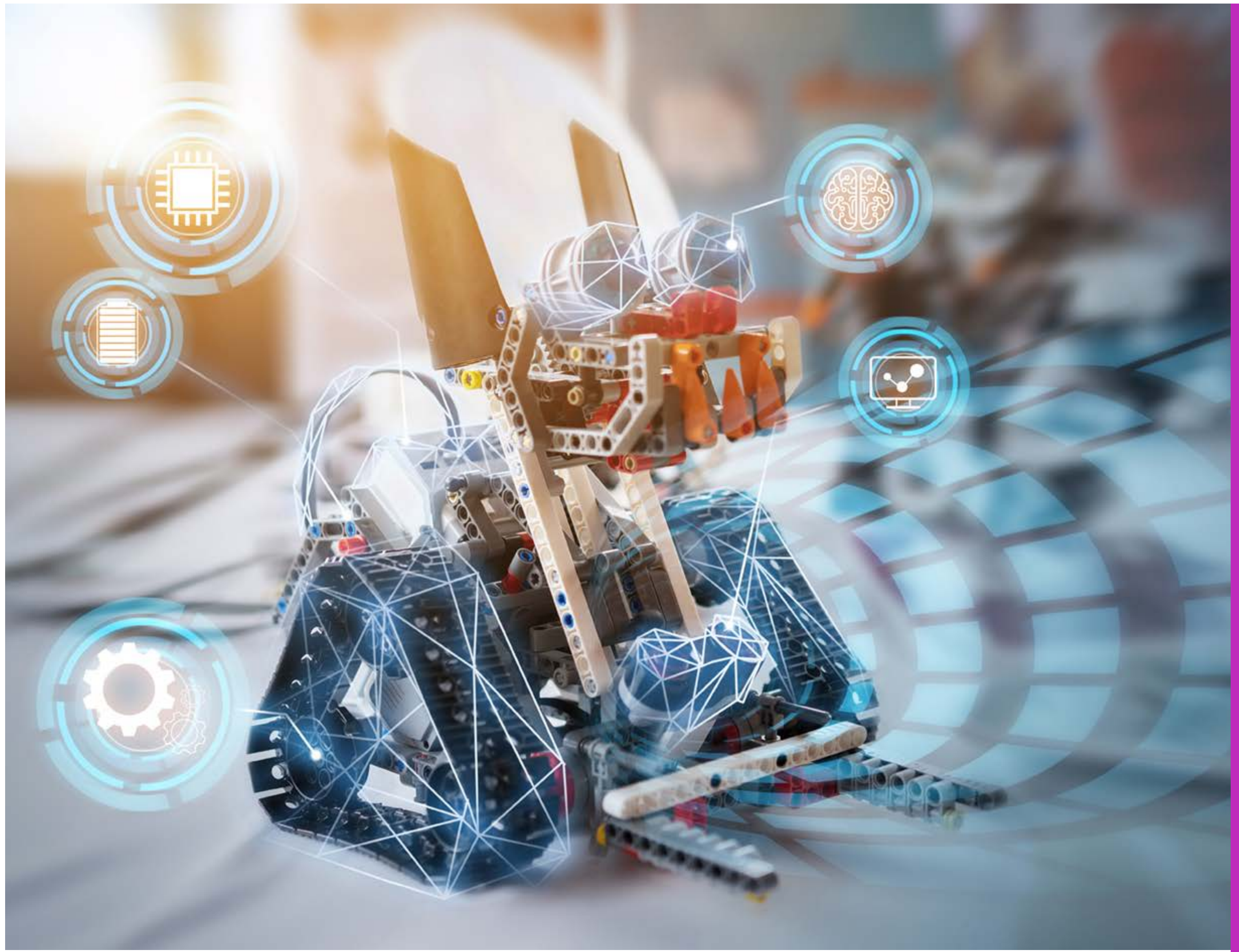


Figure 3
Stakeholder respondents create or investigate guidance with (n=60).



We believe the focus on academia/research suggests a strong emphasis on generating knowledge and understanding the fundamental aspects of remote sensing for plastic pollution detection. Additionally, the focus may be because remote sensing is an emerging field primarily made of researchers looking to generate knowledge. This could be a positive sign that scientific understanding is advancing to solve plastic litter problems.

However, while academia plays a crucial role in generating knowledge, industry, government, and NGOs often play vital roles in implementing that knowledge through policies and actions. A gap in knowledge transfer and lack of communication between all stakeholder sectors may impact research being translated into real-world solutions.

Fortunately, the number of participants from government and industry may indicate a growing focus among stakeholders on applying technology to address and solve environmental challenges.

Funding Interventions

When asked where funding should be prioritised ("yes/no" questions, n=60), respondents primarily selected new technology (62%; n=37) and awareness (52%; n=31; Fig. 4). Note that the respondents were allowed to choose more than one category. The high number of participants selecting 'new technology' could reflect the high number of academic attendees who may be most interested in R&D. However, the responses for feasibility studies (42%; n=25), policy/action (38%; n=23), and new products (38%; n=23) highlighted that a substantial proportion of respondents understood the practical applications of remote sensing technology and were seeking solutions for both policy formulation and product innovation.

The participants' focus on funding new technology implies that they believe R&D can improve the efficacy of remote sensing techniques for plastic pollution detection.

However, since several participants' answers also focused on applying the results of remote sensing studies, we believe that a comprehensive approach to solving plastic litter problems is required. This approach should encompass considerations beyond R&D, such as the necessity for policy development, product creation, and feasibility studies.

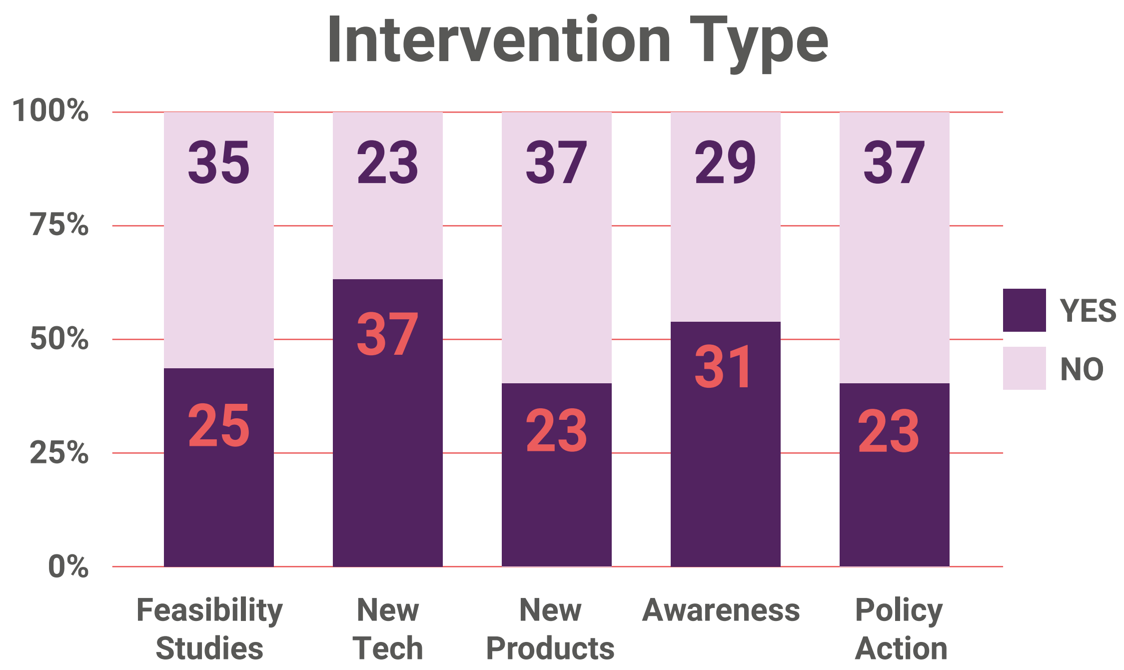


Figure 4
Respondents prioritisation for funding interventions (n=60)

Challenges

With an open-response question, we asked participants what they thought were the current top three challenges to working in their area of remote sensing and plastic litter. Our qualitative analysis of the responses found seven main themes: technical method development, data & equipment accessibility, data resolution & spatial scales, ground truthing, plastic litter characterisation issues, policy use, finance (see Fig. 5 & Challenges Themes.)

Technical method development

A number of respondents highlighted challenges with data collection and analysis method development. They noted that the absence of method standardisation often hampers comparing the results of remote sensing studies and inhibits global data compilation. They also reported that effective processing of remotely-sensed data was an issue. As data availability increases, its processing and interpretation become more complex, demanding advanced statistical and machine-learning models. Additional problems they reported were a lack of information and data synergy with results and processing tools spread across several, and often independent, platforms.

Data & equipment accessibility

Some respondents see the lack of open-access data as a barrier to developing advanced computer-based data analysis techniques. Access to alternative data resources and a lack of equipment accessibility, i.e., high-resolution satellite data resources or equipment to capture hyperspectral data, especially in the infrared bands, are currently lacking. A few participants reported experiencing government permit restrictions on remote sensing as well as restrictions on sharing information with researchers from other countries.

Data resolution & spatial scales

Respondents also reported that the low resolution of remotely-sensed data creates challenges in monitoring plastic pollution. At current spatial resolutions, a lot of marine litter (ML) is too small to be consistently detected by satellite sensors, unless it is within large accumulations. This is because much of marine litter is small compared to the satellite instrument's pixel size, and so is only detecting a sub-pixel spectral signature. Specifically, some noted that metre-scale resolution with daily coverage could help train and test new analytical methodologies.

Ground truthing

Many respondents noted a real need for more in-situ, validated observations of floating marine litter, or ground truthing. Ground truthing is important to understand the uncertainties around the currently collected data and the accuracy of remotely-sensed data interpretations.

Despite having some open access data sets, respondents said that there are problems labelling plastic litter and current ground truth "plastic-litter" information has numerous uncertainties. This is exasperated with a lack of extensive sets of training data for ML. One noted example was that, because optical satellites cannot take pictures through clouds, radar satellites are deployed to take the same pictures of the same locations. However, the optical and radar images are not acquired at the same time, adding a further issue when it comes to ground truthing data.

Plastic characterisation issues

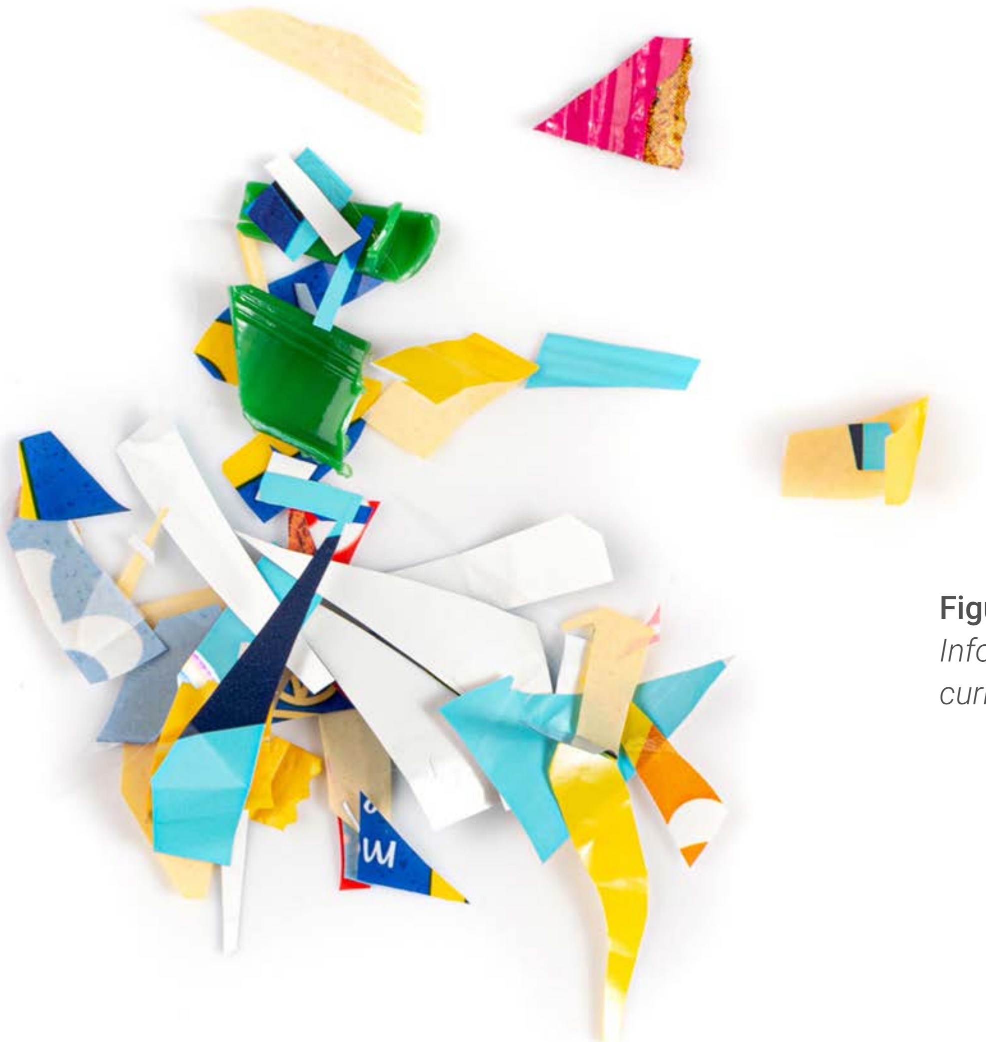
Numerous respondents reported challenges with the ability to detect a range of plastic characteristics e.g., colour, shape, and composition. Firstly, microplastic-sized particles are not currently detectable using remote sensing. Furthermore, it is difficult to identify a piece of litter's type of plastic polymer using spectral data at VNIR, SWIR and TIR wavelengths. Finally, weathering alters plastic litter signatures and makes correct detection challenging, due to changed hyperspectral signatures. Overall, there is not one sensor that can monitor plastic litter in all marine environments.

Policy use

Respondents reported that getting governmental bodies and regulatory agencies to use remote sensing technologies is an issue because in practice these institutions are very concerned by remote sensing techniques being used to find waste crime and litter.

Finance

Apart from direct issues of using remote sensing data for plastic pollution, respondents also identified finding financing to develop cost-effective ways to implement plastic litter identification, the expense of purchasing or developing specific technologies and finding paying end-users for commercial products as challenges. Others reported difficulty getting government and regulatory agencies to support funding pitches or to participate in pilot/funded projects.



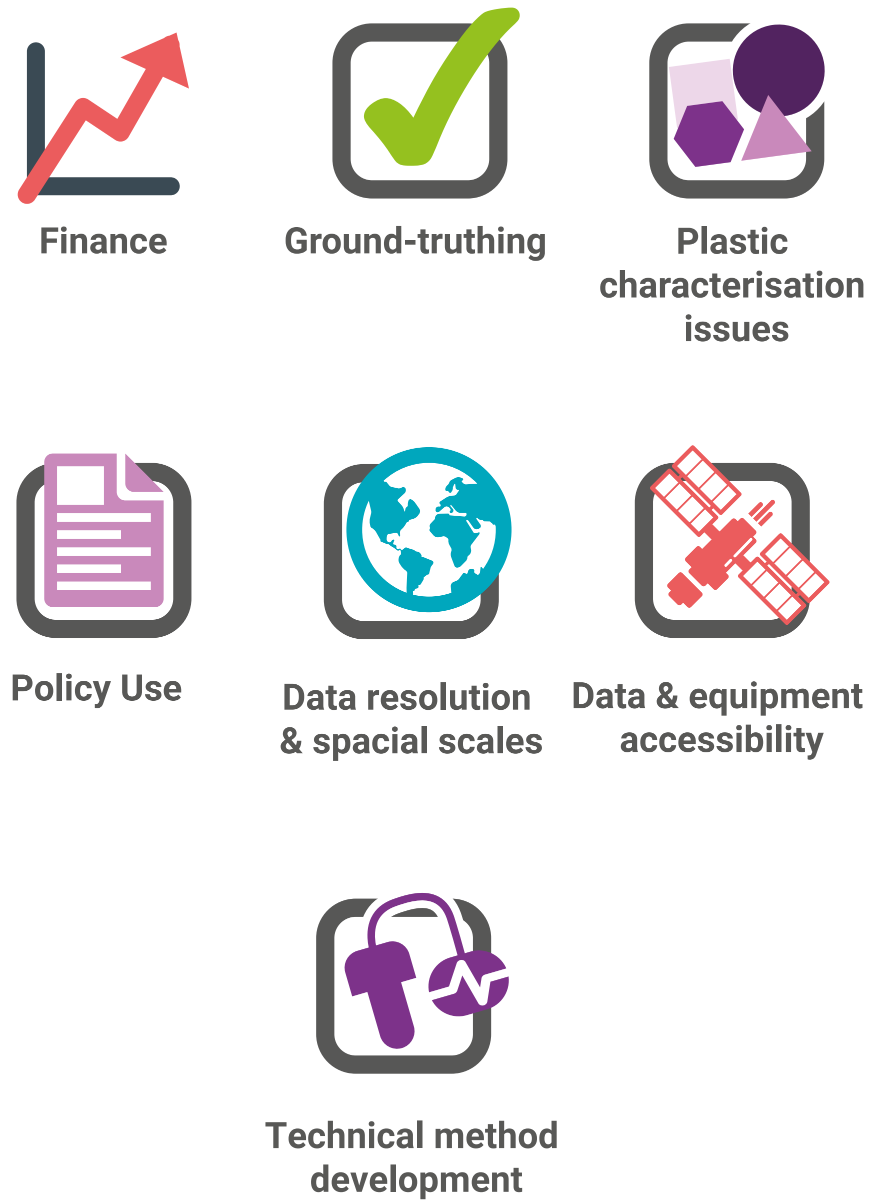


Figure 5
Infographic of the seven main emerging themes from survey participants responses about the current challenges to working in their area of remote sensing and plastic litter.

Challenges themes

Main emerging themes from survey participants responses about the current challenges to working in their area of remote sensing and plastic litter with challenge theme described and directly related quotes from respondents.

Technical method development

Challenges described

Lack of method standardisation

Tracking plastic pollution

Lack of collaboration between different stakeholders

Effectiveness of process post separation and analysis

Only surface mapping capabilities available

Quotes from respondents

“The absence of standardised methods to identify, quantify, and classify marine plastic litter in satellite images hampers comparisons of studies and global data compilation.”

“Adopting appropriate long-range communication for tracking plastic.”

“Lack of policy and directions from the field researchers for people working on algorithm and software developing.”

“As data availability increases, its processing and interpretation become more complex, demanding advanced statistical and machine learning models.”

“Sub-surface (i.e., water) detection.”

Data & equipment accessibility

Challenges described

Restrictions on data availability

Lack of open access data

Equipment accessibility

Quotes from respondents

“Government permits and restrictions on remote sensing as well as restrictions on sharing information with researchers from foreign countries.”

“Lack of open access data to develop advanced computer vision techniques.”

“Limited access to alternative data resources & equipment, i.e., high-resolution satellite data resources & equipment to capture hyperspectral data, especially in the infrared bands.”

Data resolution & spatial scales

Challenges described

Imagery resolution

Identification over different spatial scales

Quotes from respondents

“Plastic litter, except for large accumulations, is small compared to the satellite instrument’s pixel size and so we are detecting a sub-pixel spectral signature.”

“Remote identification of plastic litter at different spatial scales.”

Ground truthing

Challenges described

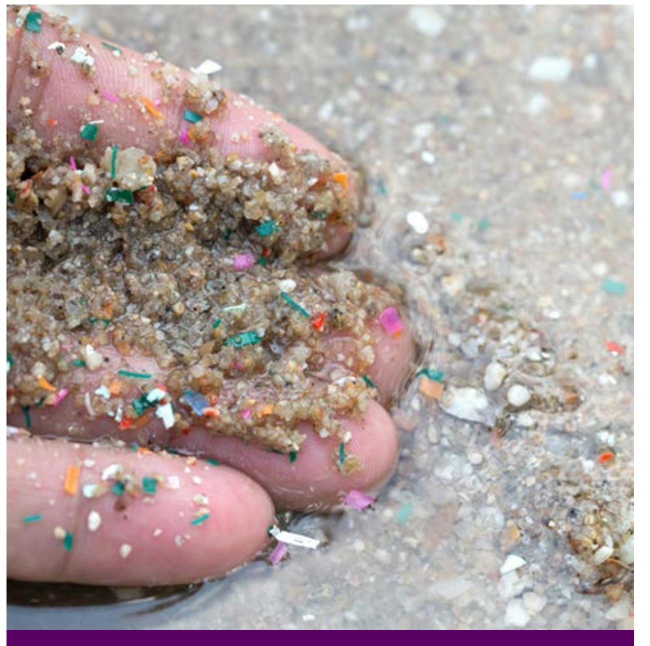
In-situ data for validation

Labelling uncertainties

Quotes from respondents

“In-situ validated observations of actual floating marine litter concentrations, available satellite characteristics.”

“Despite having some open access data sets, labelling has problems and having ground truth ‘plastic-litter’ information has some uncertainties.”



Plastic characterisation issues

Challenges described

Microplastic detection

Identification of differing particle composition e.g., colour, polymer

Quotes from respondents

“Detecting microplastics in the ocean is tough because of their small size and diverse optical properties, which hinder remote sensing.”

“Differentiation of different types of plastic litter using spectral data at VNIR, SWIR and TIR wavelengths.”

“Existing radar detection techniques are unsuitable for detecting plastics.”

Policy use

Challenges described

Use of remote sensing data by governmental bodies

Embedding remote sensing technology by government

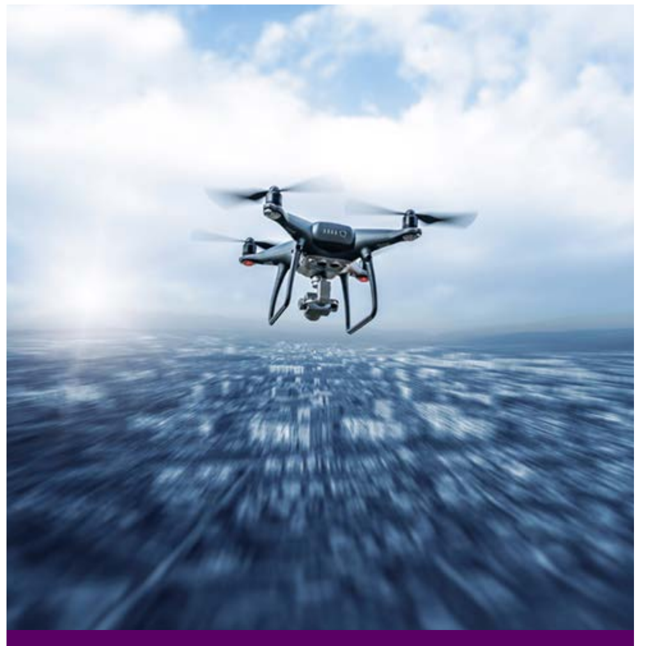
Collaboration

Quotes from respondents

“Governmental bodies and regulatory agencies are keen to be tackling problems, but in practice they are very concerned by remote sensing techniques being used to find waste crime and litter...”

“Positioning the use of it to key stakeholders.”

“Profession isolation. Very few people are working on developing or utilising remote sensing for mapping plastics, of the few, there are very limited (if any) opportunities in the form of conferences or workshops to allow sharing of knowledge and experiences.”



Finance

Challenges described

Developing cost-effective implementation

Expensive of specific technologies

Lack of funding or paying customers

Quotes from respondents

“Ensure that EO missions are affordable, which in turn means that the Space data is available.”

“Cost of UAV sensors in specific wavelengths.”

“Getting Government and regulatory agency support in pitching for funding and participating in pilot/funded projects (even at no cost) e.g., looking at data collected.”

Priority Actions

With an open-response question, we asked participants what they thought were the current top three priority actions, interventions, or innovations that would help improve their area of work and help understand or mitigate plastic litter problems. Our qualitative analysis of the responses found seven main themes: method standardisation, technical developments, analytic developments, identifying sources of plastic litter, collaboration, behavioural changes, funding & investment (see Fig. 6 & Priority Actions Themes.)

Method standardisation

Respondents suggested a push towards method standardisation with specific protocols and more data sharing. The recommended further investments in studies that explore and standardise data acquisition procedures and protocols for marine litter mapping. Respondents thought that the industry being accountable for developing tools with standard protocols would be a more attractive data collection strategy. Other suggestions include performing a critical review of all published papers to review the current state of the field.

Technical developments

There were numerous suggestions for technical developments and enhancement of remote sensing technologies. For example, working on the capabilities of operational UAV hyperspectral remote sensing, high-resolution SAR (Synthetic Aperture Radars) imaging in real-world locations, hyperspectral thermal wavelength sensors and making commercial remote sensing data available to researchers. Also, others suggested a satellite mission dedicated to plastic litter with appropriate sensor resolutions and more feasibility studies.

Analytic developments

Priority action suggestions for analytic developments included using new machine learning and modelling developments to increase data analysis efficiency. Using these techniques will also help to develop robust machine-learning algorithms to differentiate plastic litter from other litter. Actions that will aid this will be creating synthetic data to self-train machine-learning models, evaluating those models using real data and working on developments of proxy approaches for mapping plastics using lower-resolution optical imagery.

Identifying sources of plastic litter

Respondents also identified specific ways that remote sensing could aid in highlighting geographic regions as sources of plastic pollution. For example, remote sensing could map entire marine systems from source to sink or to identify areas of high plastic litter dumping. Remotely-sensed data could be coupled with other disciplines, like oceanographic modelling, to investigate whether there is a relationship between weather events and plastic litter discharge peaks (e.g. from river to marine coastal environment). Probabilistic oceanographic modelling could predict where litter is likely to be carried or identify marine features particularly susceptible to accumulations of litter.

Behavioural changes

Respondents gave numerous suggestions of how remote sensing could be used to encourage behavioural change. Plastic litter detection needs to be combined with action so that the knowledge is used to improve the current situation. For example, remote sensing could support plastic collection and recycling that could feed into the creation of a circular economy for plastics. Public awareness could be increased by encouraging citizen science programmes that validate plastic litter presence and ground truth remote sensing studies.

Funding & investment

Respondents identified funding and investment in research and innovation in developing cost-effective techniques and systems for remote sensing. To be able to achieve this, the community needs to direct public sector funding to the key leverage points that will have the largest positive outcome for the marine environment as well as identifying the best use cases that achieve the creation of impactful business cases. This can then be used to scale and build commercially viable solutions such as circular economy models. Respondents also thought that strong investment is needed in integrating remote sensing data with stakeholder/community knowledge.

Collaboration

A major theme emerging from suggested priority actions was further collaboration between stakeholders. Respondents spoke about feeling isolated within the field (e.g., 'profession isolation') they strongly encouraged knowledge exchange programmes, such as visits or workshops, to develop technical capacity, sharing of knowledge and experiences and reduce professional isolation.

Better communication is needed to bridge the gap between research and practical applications which are essential to effectively address plastic litter. Other respondents thought that effective collaboration could help develop actionable policies that are based on academic research. Respondents thought that policymakers should commit to supporting and utilising remote sensing technology and actively promote its possibilities.

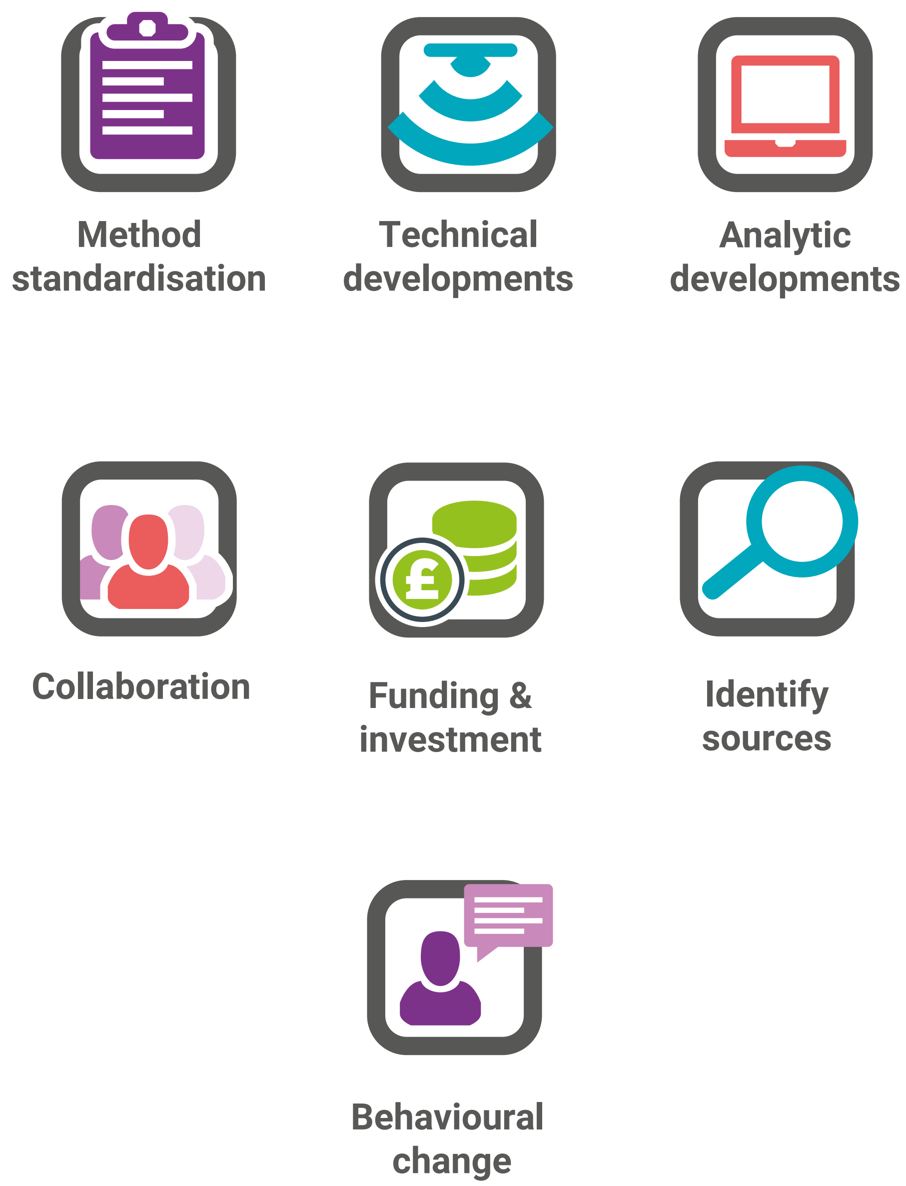


Figure 6

Infographic of the seven main emerging themes from survey participants responses about the priority actions, interventions, or innovations that would help improve their area of work and help understand or mitigate plastic litter problems.

Priority Actions Themes

Main emerging themes from survey participants responses about priority actions, interventions, or innovations that would help improve their area of work and help understand or mitigate plastic litter problems with priority action themes described and directly related quotes from respondents.

Method Standardisation

Priority Actions described

Specific protocols for promoting standardisation.

Better data sharing.

Quotes from respondents

"Invest in studies that explore and standardise data acquisition procedures."

"Less restrictions on data sharing for research purposes."

Technical developments

Priority Actions described

Enhancement of remote sensing technologies.

Increase access to technologies.

Demonstrate capabilities for detection.

Dedicated satellite mission.

Quotes from respondents

"Development of; operational UAV hyperspectral remote sensing capability, hyperspectral thermal wavelength sensors & satellite-based sensors capable of resolving plastic litter."

"Develop new sensors or make available commercial remote sensing data available to researchers."

"More access to very high-resolution SAR imaging over real-world locations of either test targets of plastic, or either, real world cases of plastic pollution."

"Demonstrate the capabilities of EO technologies for detection of plastic and mitigation by identifying source waste sites."

"Satellites only provide one source of data, and so we need to combine EO with other technologies to support the detection and mapping of plastic litter."

"Development of a satellite mission focused on plastic litter pollution with appropriate sensor resolutions (more feasibility studies like Marlise)."

Analytic developments

Priority Actions described

Increased utilisation of algorithms and modelling.

Continued development of analytical approaches.

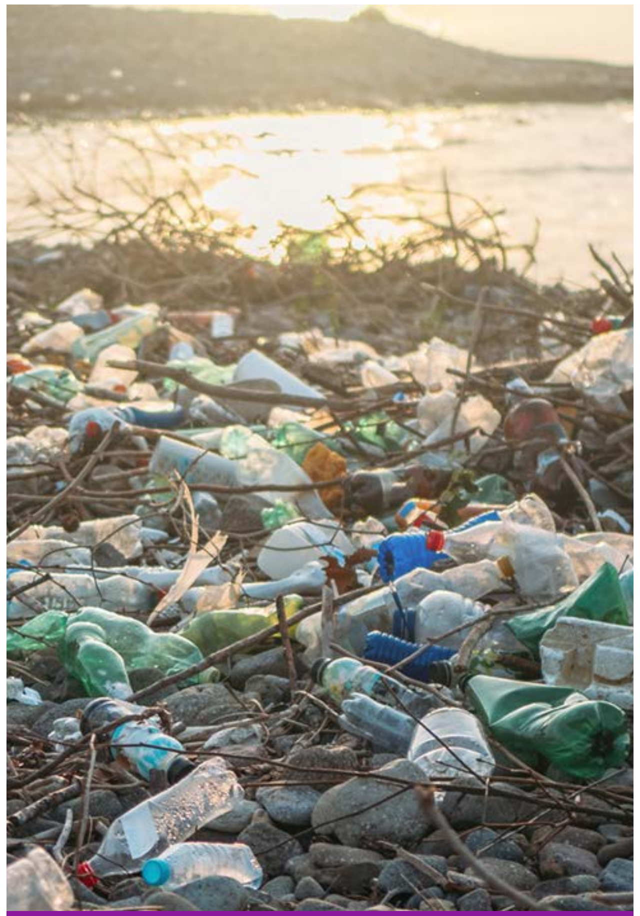
Quotes from respondents

"Create synthetic data to self-train the model and evaluate it in real data."

"Develop robust algorithms to differentiate plastic litter from other litter."

"Investing in ML and Big Data analytics."

"Development of proxy approaches for mapping plastics using lower-resolution optical imagery."



Identify sources of plastic litter

Priority Actions described

Mapping sink to source dynamics.

Identify specific geographic areas.

Quotes from respondents

"Monitoring platform to identify sources of high plastic litter and areas where they are getting dumped."

"Better investigations into understanding why some areas have significant levels of plastic litter."

Collaboration

Priority Actions described

Collaboration between stakeholders.

Integration in policy.

Knowledge Exchange.

Quotes from respondents

"Collaboration with technology partners to innovate a device to monitor and recycle plastic litter & particle tracking modellers and surveyors in the field."

"Encourage collaborations and exchange visits. In addition, creating unique funding opportunities."

"Develop policy that uses RS data about litter (i.e., work out what the aims of the policy should be...)."

"Government/regulatory agency commitment to participate in projects."

"Creation of deliberate knowledge-sharing programmes in the form of training to allow the development of the technical capacity."

Behavioural change

Priority Actions described

Raise public awareness.

Detection combined with action/ solutions.

Quotes from respondents

"More engagement of citizens in science, through the contribution in validation by plastic litter spotting."

"Quotas on plastic production and especially single use items through legislative measures, infrastructure and systems to move away from single use items), investments in developing countries' economies."

"Review of the full circular economy plastics cycle w/ a biodiversity lens. For example, a 20% reduction of plastic."

Funding & investment

Priority Actions described

Funding for cost-effective techniques.

Focus innovation.

Investment in integrating community knowledge.

Quotes from respondents

"A value chain needs to be built so there is funding for all aspects of the chain and the overall solution is commercially viable."

"Fund fundamental research into development of instruments and techniques to detect litter."

"Satellite missions dedicated to marine plastic litter observations."

"Government making certain forms of data available free to research (or subsidise its purchase)."

Workshop Results

Workshop 1 – Summary

Workshop one was structured around three core themes for using remote sensing to detect plastic pollution: Innovation, Policy, and Intervention. The workshop drew participants (n=79) from a variety of sectors, with a substantial representation from Industry/Business, constituting 44% of the total participants. The academic and research community also played a prominent role, with 36% of participants, followed by the NGO sector (10%), government entities (5%) and other sectors (5%). The workshop included presentations, case studies, and a live survey. Below we summarise the key findings and insights from workshop participants' discussions.

Technological Innovation

During the workshop, participants focused on the growing need for improvements to current remote sensing technologies. Such challenges included the quality and capabilities of both sensors and technology; 44% of respondents (n=36) in the live survey said this was the main barrier in the quality of their results.

Additionally, participants discussed that current methodologies sometimes lead to 'false positive' plastic litter detections, which can affect result reliability. Participants also discussed the need to enhance the accuracy of machine learning algorithms that identify plastic litter and the need for validation data (particularly for floating debris).

The standardisation of spectral libraries was also recognised as a complex task. This underlines the necessity for advancements in sensor technology and data analysis techniques to improve the accuracy of plastic litter detection.

Furthermore, workshop participants highlighted that there is a requirement to have dedicated satellite technology specifically tailored for the marine environment for remote sensing plastic litter detection. This is due to current satellites being primarily designed and optimised for terrestrial applications. When tasked with monitoring ocean environments, these satellites can encounter problems that can impede results, such as limited spatial resolution (hindering their ability to capture detailed data in dynamic marine environments), spectral capabilities to accurately detect different materials, inconsistent pass frequency and poor weather conditions.

Workshop participants explored alternative solutions, including using satellites like Prisma. However, it became apparent that even with these alternatives, acquiring high-resolution hyperspectral data within the 10-30 metre range would remain a challenge.

Funding

Participants held diverse opinions regarding where funding should be allocated for the mitigation of plastic litter. There was no single dominant approach, which highlighted the multi-faceted nature of the problem. When participants were asked in a live survey where funding needs to be allocated to help mitigate plastic litter using remote sensing, the responses were evenly distributed across key categories. Sixteen percent of participants (n=19) favoured each of the following categories: monitoring and data collection, technology development, data access, product and service improvement, and policy development. However, at several points in the workshop, participant discussion highlighted the requirement to improve innovation and product development. Another challenge that emerged was focussed on securing the necessary funding for these initiatives.

Industry stakeholders also shared their struggles in accessing specific regulatory bodies and crucial data necessary for sustainability-related innovations. It was discussed that having access to this information can ensure that industry products or initiatives align with environmental standards and regulations. Without access to this data, industry stakeholders may find it challenging to make informed decisions for product development. These financial hurdles highlight the importance of fostering collaboration between the public and private sectors to fund research and development efforts.

End-User Engagement and Target Market

Industry experts were unsure about the exact stakeholder groups who would use and benefit from their remote sensing technologies aimed at monitoring plastic litter. They found it challenging to clearly define and understand their target audience.

This uncertainty could create obstacles in tailoring products to effectively meet the needs of the end customers. Industry experts also raised concerns about the adoption of their products by the intended users; for example, ensuring that the technology is not only effective but also user-friendly.

Participants commented that effective communication and collaboration between product developers and end-users to understand their specific needs, preferences, and challenges would address these challenges. This collaboration could help refine product features, user interfaces, and implementation processes to ensure that the technology is user-friendly and aligns with the requirements of those who will use it.

Collaboration and Multi-Stakeholder Approach

Collaboration between various sectors, including NGOs, governments, and other stakeholders, was considered important for developing remote sensing capabilities and understanding. Additionally, there was a recognition of the need for online forums, apps, and further workshops for stakeholders to collaborate and share data and insight; for example, workshops for policymakers and those in research and innovation to discuss in depth how they can assist each other was voted at 42% in favour (n=19). Collaboration with colleagues outside the UK was emphasised, as it brought diverse perspectives and resources to the table.

In the context of presenting remote sensing data for policy and guidance, diverse opinions emerged. In the live survey, participants (n=19) suggested various audiences, with national government departments (37%) being seen as central actors in policy formulation. Industries engaged in plastic waste management or reduction (32%) were also identified as key recipients of data. This was followed by international organisations such as the UN Convention on Plastic Pollution (21%) and local councils & regional policymakers (10%).

Workshop 2 – “Deep-dives”

Workshop 2 consisted of an in-depth exploration of themes that were most strongly emphasised by workshop 1 participants and survey respondents. We invited a small group of research, technology development, and policymaking experts to participate in focused conversations and “deep-dives” into challenges and priority actions with the three pillars of Innovation, Policy and Intervention.

Innovation

Ground truthing

Workshop participants suggested that ground truthing effectiveness and feasibility could be increased using citizen science and collaborating with organisations to collect in-situ data on vessels regularly passing through areas where data is needed. Numerous ideas came from participants for mounting standard camera systems on vessels/ships. Cameras are already present on some fishing vessels to monitor fish stocks. Using those cameras, it may be possible to monitor any plastic litter coming up with the fish catches.

Participants also suggested that such projects could be an alternative income stream for fishers once their fishing quotas have been reached. Participants emphasised that, to aid with satellite ground truthing, data collected by fishers should be geotagged, timestamped and combined with physical plastic samples. Getting agreements from fishers to have their locations tracked would be necessary.

Alternatively, one participant mentioned autonomous, rather than manned, vessels have been demonstrated for use for such data-gathering exercises. Furthermore, participants suggested that data collection gaps could be addressed via engaging with citizen science. A popular idea was using cruise ships or recreational sailing vessels to collect data in areas where in-situ validation data is lacking. The data collected by citizen scientists could be processed with machine learning or AI before going into databases (with specific DOIs) accessible to stakeholders needing ground truthing data. Citizen science programmes could also mitigate the expense of in-situ data collection.

Data Analytical Methods

The most promising analytical developments participants mentioned were machine learning, spectral detection and the combination of existing modelling techniques. When using machine learning software to analyse remote sensing data for plastic litter, it was noted that having automatic inputs and a user-friendly interface could ensure that those other than experts benefit from this technology.

In terms of spectral detection, participants mentioned advances in infrared sensing which could help better detect black plastic pieces. However, they stated that the most effective advances would come from looking at plastic with a multiple-sensor approach, such as combining optical image analysis with LIDAR (Light Detection and Ranging) or fluid lensing techniques. With a multi-sensor approach, researchers could produce new and refined plastic litter proxies and better correlate them with real plastic litter.

Combining data from multiple sensors could also improve the detection of bio-fouled plastic, which historically has been challenging. Satellite imagery could also be combined with existing oceanographic models on current/tides/waves to pinpoint potential plastic litter aggregations, produce risk maps and trace plastic litter back to its source. Participants did mention that this would need a discussion around the infrastructure needed to fuse these different data types into cohesive datasets. Moving forward, this could be very useful in creating new and well-informed policies (e.g. UN Plastics Treaty).

Standardisation

Participants discussed the importance of distinguishing clearly between "harmonising" and "standardising" remote sensing-based data collection or analytical protocols. In the academic research sector, one participant emphasised that complete standardisation is not always beneficial because having a diverse range of methodologies could advance or create a suite of viable interpretations.

However, even if data collection and analysis protocols are not standardised, it would be critical that the different approaches are comparable. Harmonising, rather than standardising, protocols could preserve method diversity while allowing research studies to be compared across organisations. The ability to compare studies could enhance stakeholders' trust in study results.

Other participants noted that there needs to be a compromise on the scale of total standardisation vs harmonisation. For example, effective standardisation should include standardising training data and validation methods for ML models. Indeed, standard formatting for Machine Learning Training datasets is already in development and there is a call to establish a minimum, quantifiable level of uncertainty that would be deemed acceptable. Participants suggested that the remote sensing community could use standards from other sectors as templates.

Further to this, participants also discussed that data infrastructure should be federated and connected to a platform via an API to ensure quality and ease of sharing between different organisations. For example, participants pointed to Digital Twins of the Ocean as a good example because it has developed standard data inputs and outputs that are easily transferable to different models.

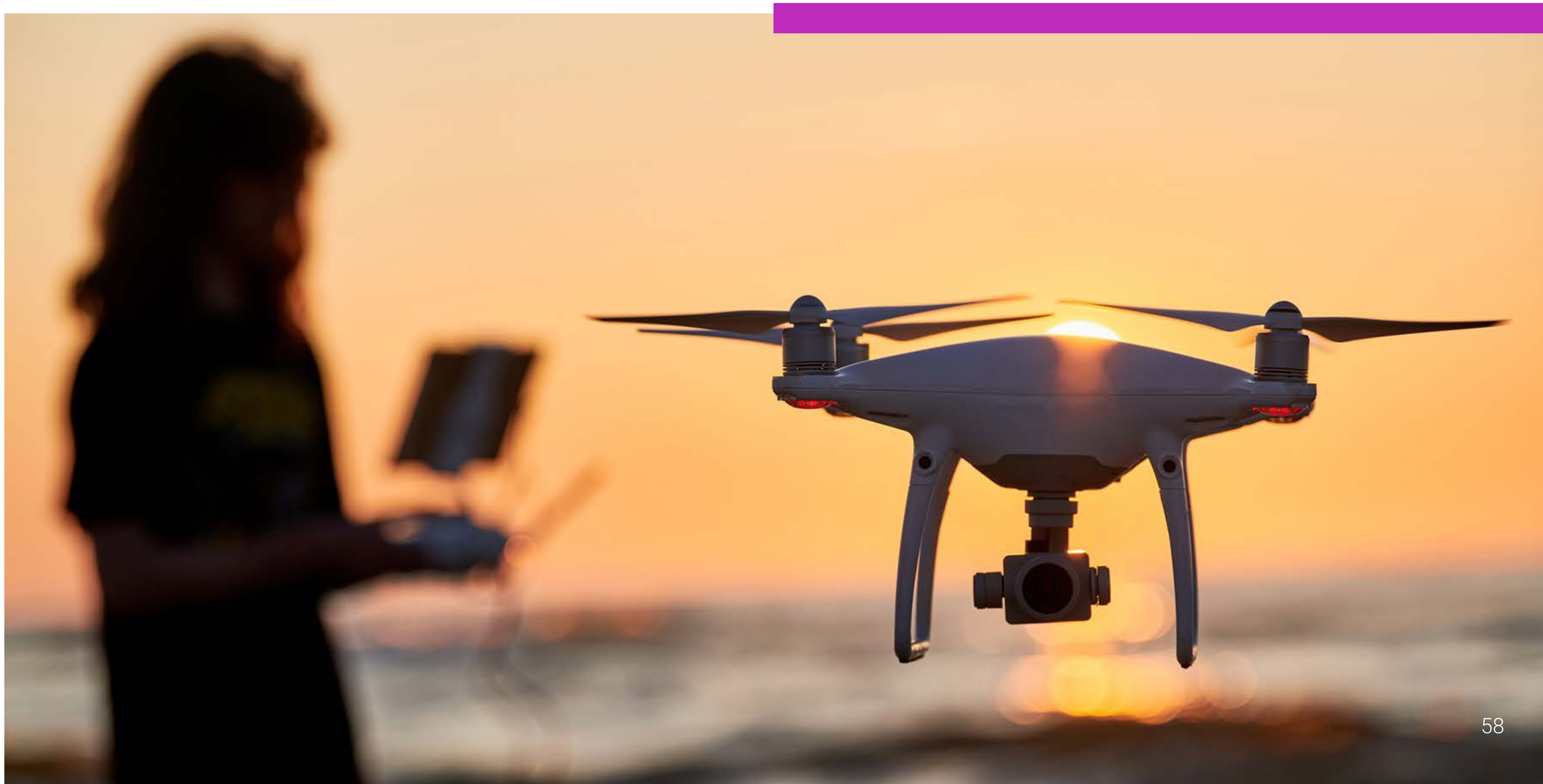
Policy

Policy needs

There was a strong consensus among participants that the remote sensing industry and academia fields have the potential to positively aid policy making by measuring the impact of policy changes and providing actionable data for evidence-based policy decisions. Remote sensing could potentially predict plastic accumulation zones or events. Within a UK context, drone surveys could complement in-situ surveys in habitats that are challenging to monitor, such as the intertidal zone. With further innovation into spectral and shape analysis these surveys could be a scalable solution for efficient monitoring.

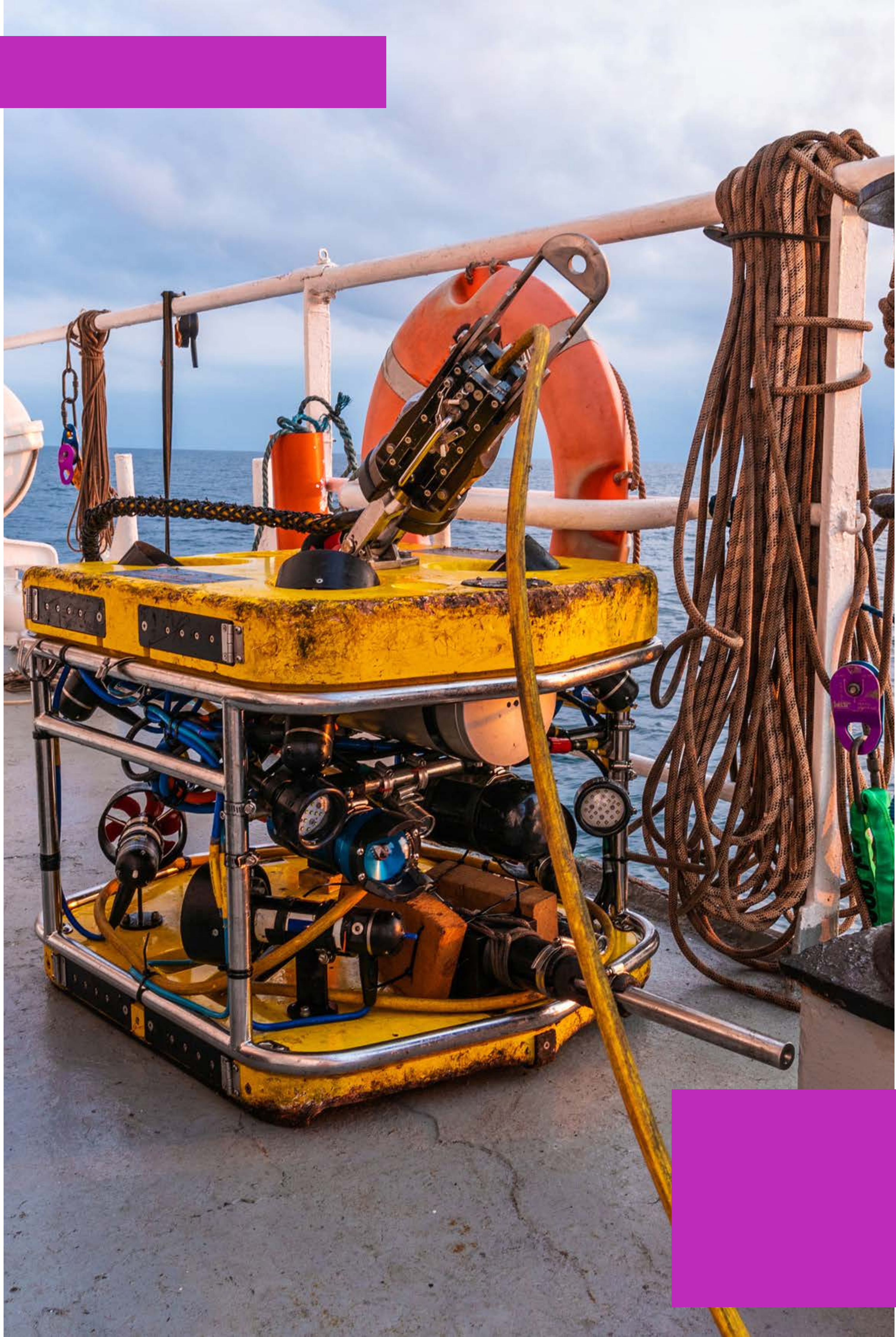
Other initiatives that are using satellite imagery to search for plastic aggregations in coastal zones could help locate accumulations of plastic litter before it disperses. Another policy need is to understand the impact of plastic litters' presence on different species. Participants felt like remote sensing technology is transferable to biological components of the ecosystem and training algorithms can identify plastic but also potentially other important parameters. Integrating both information on plastic litter and the ecosystem can build a more holistic picture of potential impact which will lead to greater understanding.

A suitable future system utilising remote sensing technology to aid policy will have to work in a standard way to fulfil verification reporting needs, as has been seen with carbon credits previously. However, to achieve this, current assumptions about remote sensing technology and the data it collects e.g., high costs, not trustworthy or too complicated to use, need to be addressed.



Within an international context, remote sensing techniques could aid policy in reporting on future UN Plastic treaty obligations and the UK can contribute to a global vision of the plastic litter issue e.g., floating debris from satellite is a recognised UN SDG indicator 14.1.1. Therefore, there should be an aim to reflect global policy.

However, historically, despite investment into this field, there has been strong resistance to incorporate and uptake remote sensing data into policy. Participants from industry and academia felt that these remote sensing techniques must not be viewed as a substitute but as complementary to more traditional monitoring methodologies.



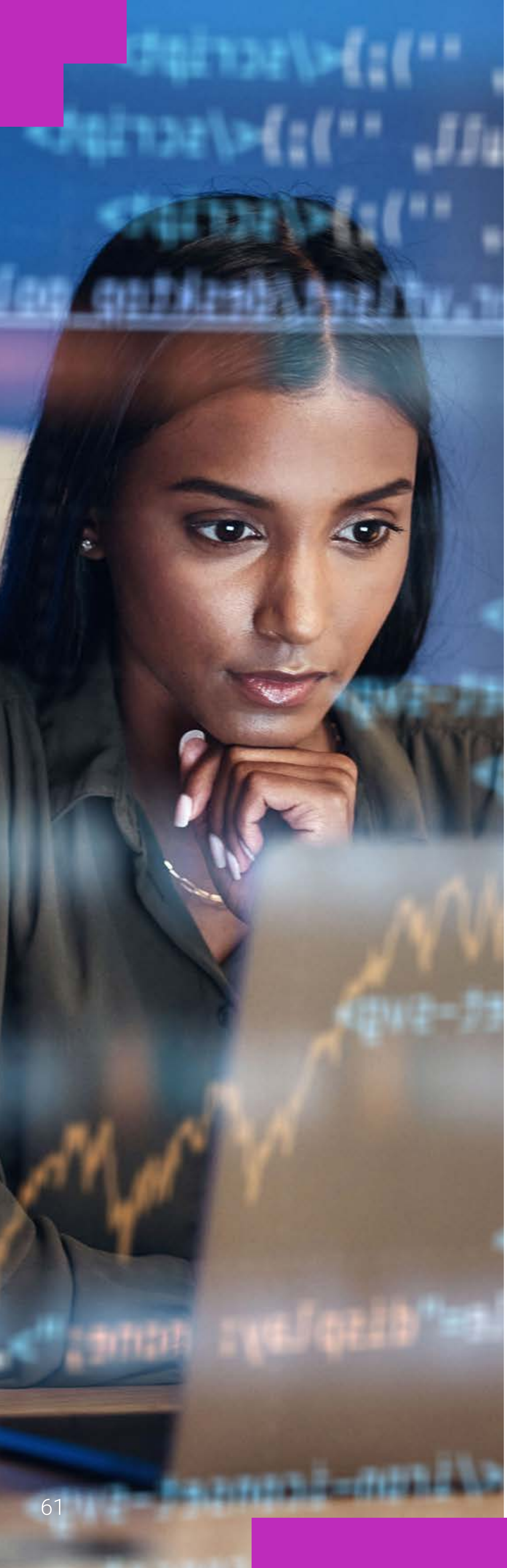
Technology use to support policy

Participants thought of several ways that remote sensing technologies could provide opportunities to better support policy and plastic litter monitoring on the ocean surface (e.g., imagery to look at aggregations or river runoff sources) and floor (remote sensing using underwater cameras). One idea was that future work into satellite detection and earth observation data could feed into predictive models that anticipate changes in oceanic conditions, helping policymakers act proactively. For example, promoting policies for the reduction of leakage of certain single-use plastic items from hotspot source locations. However, participants stressed that to achieve this, current capabilities in spatial, spectral, and temporal resolution must be increased.

Some members of the workshop strongly advocated that a new satellite mission would be a good opportunity to test a multi spectral sensor detecting wavelengths attuned specifically to plastic. They also discussed that analysis of the improved imagery could be used to inform policy makers about issues such as river runoff and landfill placements.

Participants highlighted some important requirements for other sectors to be able to support policy activities. Firstly, if innovators had advanced notice of policy makers reporting metrics, innovators could make changes aligned with these specific measures. Secondly, there needs to be clear and consistent lines of communication between innovators, academics, and policy makers. Finally, policy makers should consider how well innovators could access and understand policy documents.

Suggestions to policy makers were to create an easily digestible format for important documentation so companies or academics can create technology and scientific research that is aligned with higher level requirements. To help with this, the sector could take inspiration from existing models to stimulate innovation to support policy, such as a series of feasibility studies with open calls to translate policy document requirements into easily understandable challenge approaches.



Intervention

Collaboration and Trust

Participants noted three main lines of action to encourage collaboration whilst maintaining trust between industry, academia and policy making stakeholders.

Firstly, participants placed a high importance on clear, transparent, and efficient communication, to facilitate diverse approaches in remote sensing applications to mitigate the issue of plastic litter. Also clear communication and definition of certain terms (e.g., Artificial Intelligence) by industry and academic experts when trying to increase user adoption, as sometimes, in the workshop participants' experience, the use of certain terms can create nervousness around the uptake of products and services. To improve this, it will be important for companies to provide a clear description of uncertainties on measurements and explain how those measurements were produced using remote sensing techniques and analysis.

However, it is also paramount that this should be done without the companies feeling like they are compromising their unique IP. When done in balance this will aid in building trust in the reliability of results for users of the products.

The second aspect that participants discussed was the importance of a community/consortium-based approach. These "community-led" programmes would work to build trust and confidence across multiple disciplines. Then, with multiple entities working together on next steps, everyone involved would mutually benefit.

A good example of a community approach is the open-geospatial consortium (OGC) where private organisations are included, everyone has governance in the system and different stakeholders work on differing elements. The current community in the remote sensing and plastic litter field is very fragmented and it would be very beneficial to create a unifying view in the long term.

However, before creation, it will be important to look for existing remote sensing groups (e.g., Geoblue for use of remote sensing within the marine environment) with which plastic-litter-based topics could be engaged. Engaging in existing groups would help combat engagement fatigue as key stakeholders may already be members of relevant consortiums. Some international-level scientific task forces exist for marine litter (e.g., UNEP partnership on marine litter) but nothing yet exists like this for remote sensing. These marine litter groups could provide good connections or examples for the remote sensing community to follow.

Finally, collaboration could help build trust in data from remote sensing and the processes used to gain data-driven intelligence.

Participants suggested several ways in which this could be done. For instance, creating a data management infrastructure and drafting data sharing agreements would facilitate efficient data sharing. This could allow for intercomparison activities between different data analytic parties which have proved to be very useful for gaining an understanding of diverse approaches in other earth observation applications. Participants suggested holding workshops centred around trust between machine-learning algorithm developers and data users, such as policy makers.

Another strongly supported suggestion was the community innovators and academics coming together and applying different data analysis techniques to an agreed upon dataset(s) and reviewing the outputs. This all could be done blind/independently but would show the current diversity of the outputs, what the community agrees/disagrees with, and a way forward to understand how to improve techniques. When considering collaboration with partners from different sectors (e.g., industry and research) it will be important to acknowledge desired end goals (e.g., peer-reviewed publications vs. system establishment and long-term datasets) and make sure everyone is benefiting from combined project goals.

Discussion

Below, we provide an overview of the key insights and considerations that we derived from analysing the outputs from the scoping activities. We believe these highlight valuable perspectives on the challenges and opportunities surrounding remote sensing and plastic litter mitigation that could inform forward actions.

Collaboration and Trust

The number and nature of survey responses and workshop discussions about significant fragmentation within the community of remote-sensing innovators highlight the pressing need for a more interconnected ecosystem. It is evident that fostering collaboration demands a concerted effort. Participants unanimously agree that a community-led programme is essential to build trust and confidence across multiple disciplines. Improved communication channels, particularly between industry and policymakers, are necessary, especially when addressing uncertainties surrounding remote-sensing study results.

At the heart of the issue lies the need to build trust and confidence across a diverse array of disciplines. Remote sensing technology intersects with various sectors, from academia to industry and policymaking. To harness its full potential, it is imperative to bridge the divides that have hindered seamless collaboration. Using the scoping activity results, we identify the follow principal issues:

- **Trust in Data Quality:** Many respondents expressed concerns about the reliability of the data due to the absence of standardised practices.
- **Trust in Output Quality:** Another common issue is a lack of confidence in the quality of the outputs derived from remote sensing, with a particular focus on openly addressing uncertainties. This scepticism stems from the absence of well-established and widely acknowledged processes for validating results, grounded in rigorous methodologies.
- **Trust in Policy Outcomes:** Trust in the outcomes of policy actions is essential to provide the necessary certainty for the development of new or existing markets.
- **Trust in Data Partnerships**: Many respondents hesitate to engage in partnerships involving the sharing of proprietary data and the intellectual property generated through such collaborations.

The critical challenge of establishing trust and confidence in remote sensing technology necessitates standardised practices, rigorous methodologies, and transparent processes, all of which are vital to unlocking the full potential of remote sensing for addressing plastic litter. To address this challenge, participants have emphasised the need for knowledge-sharing and collaboration, advocating for dedicated platforms like conferences, workshops, and online forums to share experiences, co-create solutions, and foster collaboration. In this context they all recognised the importance of improved communication in addressing the uncertainties inherent in data, processes, and building collaborations.

> **This plastic community seems fragmented, and we need to build trust so we can create a unifying view that is not case based.** WORKSHOP PARTICIPANT

> **Encourage collaborations and exchange visits.**
> SURVEY PARTICIPANT

> **A key point is naturally quantifying the uncertainties on the results (from remote sensing data analysis) you give. In the carbon market, the downfall is that it hasn't been done historically. This feeds into the recent trust issues in that industry. We need to be clear on the initial observations you're (industry or academia) making and be clear about the methods you are using without giving away proprietary ideas and communicating uncertainty.** WORKSHOP PARTICIPANT

User Adoption

Our scoping activities revealed that applied remote sensing data could not only create economic value but also contribute reliable source information to facilitate informed plastic litter mitigation decision-making within policy and industry. However, given the fragmentation across the ecosystem, there are a lack of holistic approaches that help bridge the gap between research and commercialisation efforts. From the scoping activities, we identify:

- **Diverse Innovation Requirements:** Participants have highlighted the distinctive innovation needs within the community. Academic stakeholders are primarily focused on the development of new technologies and data science methodologies, while industry stakeholders are more concerned with addressing market challenges, product development, and creating opportunities for commercialisation.
- **Regulation as a Market Driver:** Regulatory measures have the potential to provide the necessary certainty and shape new markets. Understanding how regulatory bodies make decisions could stimulate the development of products aligned with the requirements for policy formulation and enforcement. Hence address a market at the other end.
- **Industry's Commercial Focus:** Industry stakeholders appear to prioritise customer acquisition through commercialisation activities over relying on public sector funding, indicating a strong market-driven approach.
- **Supporting the Entire Value Chain:** Key advice that has emerged is the need to provide comprehensive support across the entire value chain. This support should encompass early-stage research and development, all the way to commercialisation and financing. A holistic approach holds the potential to establish a market ecosystem akin to that of carbon credits, thereby facilitating innovation and sector growth.

To address these challenges, participants have highlighted the need to address the fragmentation in the ecosystem, which is the main challenge in bridging the research-commercialisation gap.

Key insights from participants stress the importance of addressing the diverse needs of innovators focused on low Technology Readiness Level (TRL) technologies versus those with high TRL innovation, leveraging regulation for market development, prioritising industry's commercial focus, and providing comprehensive support along the value chain, all of which are crucial for advancing remote sensing in plastic litter management.

> A value chain needs to be built so there is funding for all aspects of the chain and the overall solution is commercially viable.
>
> SURVEY PARTICIPANT

> We want to see a marketplace evolving around plastic like that exists around carbon.
>
> WORKSHOP PARTICIPANT

> We need to involve in-situ people like policy makers to communicate what types of data are needed vs what scientists are producing.
>
> WORKSHOP PARTICIPANT

Resource sharing

In response to the participants' clear expression of the need for an open-access data infrastructure within the remote sensing and plastic litter community, it becomes evident that collaborative efforts are essential. If diverse stakeholders, such as industry and academics, were to engage in data-sharing agreements, it would represent a significant stride toward understanding the existing remote sensing data landscape for monitoring plastic litter and identifying critical gaps. Developing a curated and open-access data infrastructure would support innovation, while data sharing and licensing agreements would help build trust and enhance collaboration across data providers. In this way, the community can enhance the interoperability of remote sensing data, empowering new technology and software applications to effectively harness the wealth of remote sensing information.

However, it is essential to address the questions that emerged during the workshop discussions, particularly concerning the extent and types of data that companies are willing to share, the quality of shared data, including machine learning training data, full algorithms, interoperability of different data types, and the trustworthiness of outputs for decision-making.

The suggestion to establish a community-led task force to tackle technical challenges related to data standards, licensing, sharing, and interoperability would go a long way in producing quick outputs and feedback loops. These considerations underscore the need for thoughtful collaboration to maximise the potential of remote sensing technologies in plastic litter monitoring.

> We must not think in isolated spaces, but if we are thinking of a whole line from research to policy, we need some kind of large-scale structure that can be shared between stakeholders and effectively managed.
>
> WORKSHOP PARTICIPANT

> Digital twins of the ocean are already trying to create data standards so scientists' data outputs could be compatible with these larger models. WORKSHOP PARTICIPANT

Ground truthing & citizen science

A significant emerging concern from our scoping activities is ground truthing and the need for more in-situ, validated observations to comprehend data uncertainties and the accuracy of remotely-sensed data interpretations. Many participants suggested equipping vessels with high-resolution cameras to collect in-situ data (e.g., 'ships of opportunity'), particularly when location data is included (e.g., timestamped and geotagged) to aid in collecting robust in-situ data for the validation of remote sensing data and improve overall trust within the results.

Ground truthing and remotely sensed data could then potentially be combined with other biodiversity impacts measures to allow for the assessment of ecological impacts of plastic litter. This wider application of such data collection would also be beneficial for policy makers. Furthermore, integrating citizen science programmes could alleviate the expenses associated with collecting in-situ data for ground truthing. This therefore has the potential to engage a wide range of marine sectors with remote sensing for plastic litter i.e., tourism, leisure, operational real estate, and transport.

> I've heard of people using cameras on vessels to look at what is at sea. Any ships could be equipped with cameras. This could give more data. WORKSHOP PARTICIPANT

> More engagement of citizens in science, through the contribution in validation by plastic litter spotting. SURVEY PARTICIPANT

> Data recording on vessels is great, but we must make sure the collected data is geotagged and timestamped.
> WORKSHOP PARTICIPANT

Data standards

Within the scope of our scoping activities, participants consistently underscored the challenges associated with crafting robust data standards and processes to enhance data quality and facilitate interoperability. This is a crucial component for data sharing, cross-source data analysis, robust data science, and the crucial establishment of trust in analytical outputs.

From the response by the participants in both workshops and surveys, one way to tackle this challenge is to establish standards for specific application of remote sensing data that encompasses machine learning model training data, validation data, and ground truthing data. To effectively address these requirements, participants suggested developing initiatives centred on data intercomparison.

Furthermore, in our pursuit of developing a thriving market for plastic litter monitoring, where remote sensing plays a pivotal role in informing industry and shaping policies, it is imperative that we not only address challenges related to data standards but also standardise processes that are accepted as a source of truth. For example, the carbon market applies, albeit with varied success, the Monitoring, Reporting and Verification (MRV) method which first emerged in the monitoring of deforestation for REDD+ projects.

Similar standards if applied in the monitoring of plastic litter would enhance trust in the process with the potential of opening new markets and aid policy. As one workshop respondent stated, *"We want to see a marketplace evolving around plastic like that which exists around carbon."*

> Standardising the format of data (remotely-sensed or ground truthing data) rather than techniques. That could help us compare and share results. It also helps with effectiveness.
> WORKSHOP PARTICIPANT

> Create synthetic data to self-train the model and evaluate it in real data.
> SURVEY PARTICIPANT

> Invest in studies that explore and standardise data acquisition procedures.
> WORKSHOP PARTICIPANT

Findings

Building a Road Map for Actions by Prioritising Interventions

To construct a cogent and effective roadmap for scaling up the use of remote sensing technologies to monitor and mitigate plastic litter, it is imperative to prioritise interventions that strengthen the core of technological innovation, propel market creation, and strengthen the ecosystem.

The rationale behind these priorities is twofold: to catalyse the progression of emerging technologies across various Technology Readiness Levels (TRLs) and to create a supportive environment for market receptivity, collaborative innovation, and trust in the outputs of this technology. Thus, the goals of this innovation roadmap are:

1. Strengthening the foundation of innovation.
2. Supporting product development and access to markets.
3. Encourage cohesion of the innovation ecosystem.

We provide a flowchart for these ideas in Figure 7 and more detailed findings in Appendix F.

1. Strengthening the Foundation of Innovation

At the foundational level, interventions are selected to transition innovative concepts through the lower TRLs, where the risk of failure is highest and the need for structured support and early-stage funding is most critical. The incubation of new technologies, particularly in the data science domain, and technology knowledge transfer from universities to industries should be encouraged through access to funding and collaborations to ensure that innovative ideas are nurtured and developed into viable technologies.

- **Early-Stage Innovation Funding/ Competitions:** Allocate grants for research in novel remote sensing technologies, specifically for plastic litter detection, with a focus on proof-of-concept and initial concept validation (TRL 3-5 stages).
- **Incubating Ideas Through Design Thinking:** Empower the community interested in remote sensing and plastic litter to identify opportunities, communicate ideas clearly, and manage risks while constantly rethinking their strategies.
- **Collaborative Efforts:** Promote collaborative projects through funding and innovation competitions, encouraging academia-industry partnerships.

Alignment with products across the Innovate UK family

- **Design Foundations:** The Design Foundations grant funding programme is aimed at helping businesses engage with customers, end-users, or wider stakeholders through early-stage, people and planet centred design research to identify high-value innovation opportunities and generate more innovative products, services and business models.
- **Ignite Lab:** Powered by the Design Foundation programme, Ignite Labs is a new programme managed by Innovate UK Business Connect and done in collaboration with the Satellite Applications Catapult to support design thinking on challenge-led innovation. This is useful to provide a cross sector ecosystem to develop common and shared foundation on which to build innovative activities.
- **Launchpads:** Innovate UK Launchpads is a programme aimed at supporting emerging clusters of Small and Medium-Sized Enterprises (SMEs) in the UK. This programme could support strengthening cooperation in geographically dispersed clusters.
- **Feasibility Studies:** Fund collaborative feasibility studies to tackle TRL 3-5 or other type of challenges that requires collaborative efforts. For example, the "Net Zero Mobility: Feasibility studies for optimal data exchange" aims to support the sharing and exchange of data. A critical limitation found in our study.
- **Knowledge Transfer Partnerships (KTPs):** KTPs are designed to build long-lasting and mutually beneficial collaborations between academia and industry.

2. Supporting Product Development and Access to Markets

As these technologies mature, the focus shifts towards bridging the gap between technological advancement and market-ready solutions. Here, the focus shifts from experimenting with new technologies to understanding the 'problem to solve'.

Developing use cases and testing technologies in market conditions can support productisation and commercialisation opportunities. In this context, market-led innovations, through challenge-led approaches and public-private partnerships, should be prioritised to ensure that the advanced technologies are market-relevant, scalable, and trustworthy.

- **Challenge-Led Initiatives:** Use challenge-led approaches for higher TRL (6-9) innovations to create market-relevant products. These challenges need to have a champion or be developed in collaboration with either a public sector organisation or end user.
- **Public-Private Partnerships:** Encourage collaborations between public and private sectors to catalyse match funding, leverage investments and support procurement.
- **Commercialisation Support:** Drive commercialisation through dedicated programme of activities, investment strategies and incubation.

Alignment with products across the Innovate UK family

- **Innovation Exchange (IE):** Innovation Exchange is a cross-sector programme managed by Innovate UK Business Connect to support innovation transfer by matching industry challenges to innovative companies from other sectors. Previous IE have also included collaborations with the Department for International Trade to support the Indian government in using technology for safer public space operation.
- **Contracts for Innovation:** Innovate UK Contracts for Innovation (formerly known as the Small Business Research Initiative or SBRI) helps public sector organisations to solve complex challenges by running a competitive funding opportunity, to develop and adopt new solutions and technologies. Innovate UK could work in collaboration with DEFRA to develop feasibility studies for challenge-led pre-procurement innovation. Examples of programmes like this include the IUK/Geospatial Commission's SBRI: Geospatial data to solve transport challenges and the 'SBRI - Unlocking Space for Business' in collaboration with the UK Space Agency.
- **Investor Partnerships:** Innovate UK Investor Partnerships aim is to stimulate research and development in micro, small, and medium-sized enterprises, while accelerating equity investment into those companies so that they can grow more rapidly through innovation.
- **Space Commercialisation Engine:** The engine is a programme managed by the Satellite Applications Catapults that supports innovative RS ideas through research, investigation and development of an early-stage prototype within an accelerated time scale. This process also allows access to networks of partners and looks to open investment opportunities.
- **Environmental Living Lab:** Managed by the Satellite Applications Catapults, The Environmental Living Lab aims to enable collaborations between the space sector and the environmental sectors, demonstrating the economic benefits of satellite-enabled technologies across real-world environments and challenges.

3. Encourage Cohesion of the Innovation Ecosystem

Lastly, this roadmap recognises the importance of building a cohesive and collaborative ecosystem for knowledge sharing, establishing a network of stakeholders, and supporting policy. By promoting knowledge exchange, regulatory frameworks, and global collaboration, the roadmap aims to inform national and international policy development, diminish the fragmentation of the ecosystem, and establish a more interdisciplinary and collaborative environment.

- **Knowledge Exchange:** Host events and thought leadership initiatives to reduce ecosystem fragmentation and advance trust in the technology. This includes webinars, conferences, and policy forums.
- **Global Collaboration:** Facilitate international collaborations through innovation-based challenges and policy fora.
- **Policy Support:** Advocate for monitoring and reporting requirements for industries contributing to plastic pollution as a catalyst to develop a market like the Carbon Market through changes in policy and innovation action.

Alignment with products across the Innovate UK Family

- **Global Expert Missions (GEM):** GEMs aim is to drive the UK's vision as a global hub for innovation. The GEM programme is funded by Innovate UK, and it is designed to build international collaborations with governments, societies, enterprises, institutions, and people to tackle global challenges that requires an international perspective. Their goals are: Building International Collaboration, Showcasing UK Capabilities and Providing market insights.
- **Innovation Networks:** Innovate UK Business Connect's Innovation Network programme aims to unite some of the best minds and greatest thinkers from across the UK in areas of innovation, development, and new technologies. Some examples of a spin out from innovation networks include the I3P, which is now an independent self-funded community governed by representatives from its member organisations.
- **Global Innovation Networks:** Like the Innovation Network but focused on challenges in Kenya, Nigeria, and South Africa. Innovate UK Global Alliance Africa is a six-year project funded by UK International Development through Innovate UK and the Foreign, Commonwealth and Development Office.
- **Thought Leadership**: The Innovate UK family through the Reach and Engagement team and other departments engage regularly in thought leadership activities. Any activity recommended in this report should include funding for hosting events, webinars, conferences, and policy forums starting with publishing a revised version of this report.

Recommendations

In the pursuit of accelerating innovation within the field of remote sensing for plastic litter monitoring it is advisable to develop a cohesive strategy that encompasses the entire spectrum of technology readiness.

To this end, it is desirable to consolidate the actions delineated previously into an overarching funding initiative. This initiative would seek to secure the necessary resources to inaugurate a comprehensive innovation funding call. Such a call is envisioned to span the full range of projects, providing end-to-end support across the TRL spectrum from early-stage concepts to commercialisation.

This approach could well work within the Contracts for Innovation initiative to include public-private sector entities and stimulate collaborative innovation amongst remote sensing companies that have the capability to monitor litter but currently don't utilise this ability because there is no scalable market to address. This could also create the condition for pre-procurement across public-sector entities and stimulate the development of a market. Similarly, to the Geospatial Commission and the UKSA, DEFRA could be the recipient of such calls, therefore supporting the development of policy through market/innovation-led initiatives.

The funding could be broken into two calls (or two phases):

- **Kick Starter (KS)** which will provide small grants (i.e., £50-£150k) over 12 months for low TRL (3-5) projects for feasibility or proof-of-concept studies with an emphasis on innovation and disruption.
- **Major Projects (MP)** that will offer larger scale grants (i.e., £500K-£1m) for up to 24 months for higher TRL projects (6-9) for demonstrator with an emphasis on catalysing investment and commercialisation.

Disclaimer

The findings & recommendations represented in this document were produced following an online survey & series of workshops involving independent stakeholders (Industry, NGOs, Academic/Research, Gov & Other) and the recommendations are a representation of their discussions and views.

Roadmap for Actions

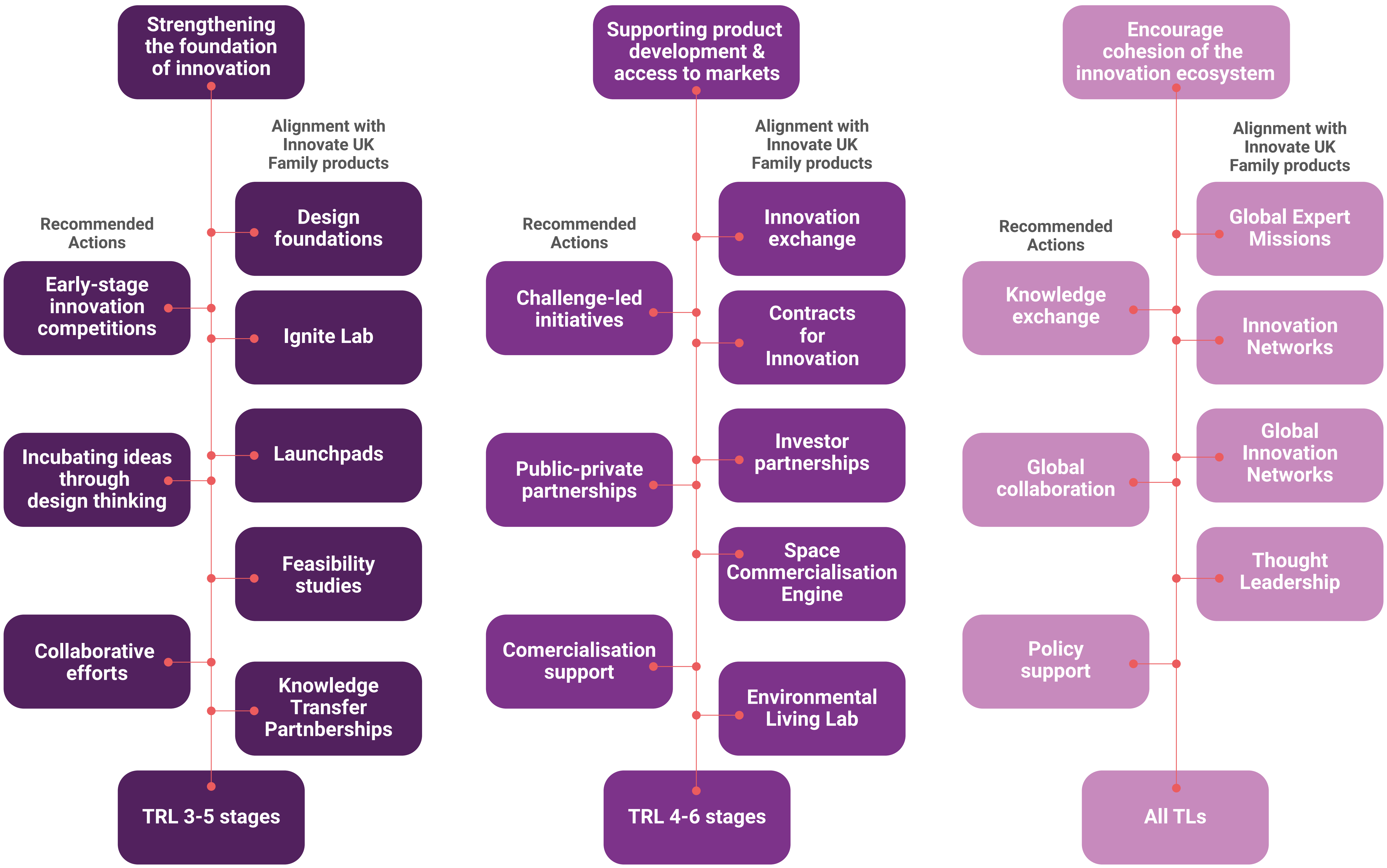


Figure 7

Infographic flow chart of recommendations to achieve objectives towards successful utilisation of remote sensing for the plastic litter issue via low TRL, high TRL and ecosystem-wide interventions.

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Website Links

Landsat
https://landsat.gsfc.nasa.gov/satellites/landsat-8/

SkySat
https://earth.esa.int/eogateway/missions/skysat

Rapid Ete
https://earth.esa.int/eogateway/missions/rapideye

Sentinel-2A and 2B
https://sentinel.esa.int/web/sentinel/missions/sentinel-2

SkyflowX
https://skyflox.eu/project-air-sos-airborne-satellite-observation-strategies-for-marine-litter-monitoring/

Plastic-i
https://www.plastic-i.com/

Argans
https://marineplastic.argans.co.uk/

Pixalytics
https://www.pixalytics.com/

Vito Remote Sensing
https://remotesensing.vito.be/

LifeLema
https://www.lifelema.eu/en/

The Marless Project
https://programming14-20.italy-croatia.eu/web/marless

Preventing Plastic Pollution
www.preventingplasticpollution.com/

EU Marine Strategy Framework Directive
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0056

EU Plastic Strategy
https://environment.ec.europa.eu/topics/plastics_en

OSPAR
https://www.ospar.org/

GESAMP
http://www.gesamp.org/

Digital Twins of the Ocean
https://digitaltwinocean.mercator-ocean.eu/

Open-geospatial consortium
https://www.ogc.org/

UNEP
https://www.unep.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution/global-partnership-plastic

Appendix A

COMPANY NAME	COMPANY LOCATION	ORGANISATION CATEGORY
4EI	International	Industry
Abhyuday Bharat Mega Defense Cluster	International	Industry
Air & Space Evidence	United Kingdom	Industry/Business
AIR Centre	International	Research Technology Organisation/Government/ NGO
Animal Philanthropy Partnership	International	Other
Apem ltd.	International	Industry
ARGANS Ltd	South West	Industry/RTO
Arribada Initiative	UK Wide (based in more than one region)	Industry/RTO/GOV/NGO
Avient Cooperation	International	Industry
Beibu Gulf University	International	Academia
Biome Bioplastics	South East	Industry
BlueGreen Labs	International	Other
Bond Morgan	UK Wide (based in more than one region)	Other
Bournemouth University	UK Wide (based in more than one region)	Academia
British Antarctic Survey	International	Government/NGO
Business Finland	International	Government/NGO
Cambridge Consultants	International	Industry
CAPAS	International	Industry
Cardiff University, UK	Wales	Academia
CEAB-CSIC	Spain and anywhere	Research
Centre for Environment, Fisheries and Aquaculture Science (Cefas)	East Anglia	Government/NGO
CGG Satellite Mapping	International	Industry
Ciimar	International	Academia
City Interaction Lab	International	Government/NGO
CNR-IFAC	Italy	Research
CNRS	France	Research
COFFEE NET AMIR , HOME	International	Other
CONISMA	International	Academia

COMPANY NAME	COMPANY LOCATION	ORGANISATION CATEGORY
Connected Conservation Foundation	International	Government/NGO
Coventry University	West Midlands	Academia
Cultivocean	While I'm based in Berlin, the startup I'm associated with has its roots in the UK.	Other - early-stage startup
Cyprus University of Technology	Greece-Cyprus	Research
Dept. For Environment, Food & Rural Affairs	UK Wide (based in more than one region)	Government/NGO
Environment Agency Abu Dhabi	International	Government/NGO
Environment and Health Association for Development and Peace	Tunisia	NGO
EOC TECHNOLOGY	International	Research Technology Organisation
Fauna & Flora	International	Government/NGO
Fila Surface Care Products ltd	International	Industry
GalaxEye Space	International	Industry
GlobalTrust	International	Industry
GMV	International	Industry
Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences	Potentially worldwide	Research
Heriot-Watt University	UK	Research
Huhtamaki	International	Industry
HVM Catapult	UK Wide (based in more than one region)	Research Technology Organisation
Hydro Informatics Unit, Assam Water Centre,Govt. Of India	International	Government/NGO
Icoteq Ltd	South West	Industry
Innoflair	International	Industry
Innovate UK Business Connect	UK Wide (based in more than one region)	Industry

COMPANY NAME	COMPANY LOCATION	ORGANISATION CATEGORY
Institute of Vietnamese Studies and Development Science - Vietnam National University, Hanoi	International	Academia
Institute of zoology	UK Wide (based in more than one region)	Academia
Interdisciplinary Centre of Marine and Environmental Research	International	Research Technology Organisation
ISA	International	Academia
IUK	UK Wide (based in more than one region)	Government/NGO
Ixion Innovation (not for profit), part of Shaw Trust	UK Wide (based in more than one region)	Industry
Kenyatta University	International	Academia
KPLC	UK Wide (based in more than one region)	Government/NGO
LAMCE/Aquamet	International	Research Technology Organisation
Lancaster University	North West	Academia
Latam Business	UK Wide (based in more than one region)	Other
Limosaero Limited	East Anglia	Industry
Lionlandscapes	International	Government/NGO
LitterLotto (litter aware ltd)	International	Industry
Loop Recyclers Tech	International	Industry
Malawi-Liverpool Wellcome Programme	International	Academia
Marble	South West	Industry
Mechanizm Design Ltd.	East Anglia	Industry
Ministry of Housing and Land Use Planning	International	Government/NGO
Mizkan EU	International	Industry

COMPANY NAME	COMPANY LOCATION	ORGANISATION CATEGORY
Moderate Ltd	North West	Industry
Mott Macdonald	UK Wide (based in more than one region)	Industry
Independant	International	Industry
Independant	International	Industry
Independant	International	Other
Newcastle University	UK, England	Research
Ngai pe	UK Wide (based in more than one region)	Academia
Northumbria University	North East	Academia
Nottingham Trent University	East Midlands	Academia
NWU	International	Academia
ONE. CONGO	International	Other
ONE. Sustainability Fund	UK Wide (based in more than one region)	Industry
Open Earth Foundation	International	Government/NGO
Oxfordshire County Council	South East	Government/NGO
Packamama	London	Industry
Pixalytics Ltd	South West	Industry
Plastecowood	UK	Industry/Business
Plastic-i	South East	Industry
Ploughshare	South East	Government/NGO
Plymouth Marine Laboratory	South West	Academia
PML Applications	South West	Research Technology Organisation
Private capacity	Ireland	Government
Pure Energy (REGen) Ltd.	Scotland	Other
QinetiQ	South East	Industry
Remote Sensing Technology Center of Japan	International	Research Technology Organisation
Retina Space	West Midlands	Research Technology Organisation
Riverfresh	UK Wide (based in more than one region)	Industry

COMPANY NAME	COMPANY LOCATION	ORGANISATION CATEGORY
Satellite Applications Catapult	UK Wide (based in more than one region)	Government/NGO/RTO
Satlantis	International	Industry
SensFish Ltd	Scotland	Research Technology Organisation
South West Business Council	South West	Government/NGO
Suez Recycling & Recovery UK	UK Wide (based in more than one region)	Industry
Superorganism	International	Other
Sustainable Seas Trust	International	Government/NGO
The Responsible Plastic Management Program	International	Other
Trinity College Dublin	International	Academia
Tyrec (Pty) Ltd	International	Industry
UCC	Ghana	Research
UHI North Highland	UK and global	Research
UK Hydrographic Office	Almost global, primary nautical charting responsibility for 71 countries	Government
Ulster University	Northern Ireland	Academia
Universidade nova de Lisboa	International	Academia
Universitat Politecnica de Catalunya	International	Academia
Universitatea POLITEHNICA Bucuresti	International	Academia
University of Bremen	International	Academia
University of Bristol	South West	Academia
University of Central Lancashire	North West	Academia
University of East Anglia	United Kingdom	Research
University of Edinburgh	Scotland	Academia
University of Exeter	South West	Academia
University of Hull	Yorkshire & Borders	Academia
University of Kent	South East	Academia
University of Nottingham	International	Academia

COMPANY NAME	COMPANY LOCATION	ORGANISATION CATEGORY
University of Plymouth	UK Wide (based in more than one region)	Academia
University of Portsmouth	South East	Academia
University of South Florida	United States	Research
University of Southampton	South West	Academia
University of Stirling	Scotland	Academia
University of the Aegean	International	Academia
UWE	South West	Academia
Valpak Ltd	UK Wide (based in more than one region)	Industry
Van Lang University	International	Academia
Vietnam National University, Hanoi	International	Academia
WRAP	International	Government/NGO
ENİ KURULACAK UZAY ÜNİVERSİTESİY	International	Academia
York St John University	Yorkshire & Borders	Academia
Zane Sustainable Ventures	London	Other
Zero Waste Maldives	International	Government/NGO
Zoological Society of London	International	Government/NGO

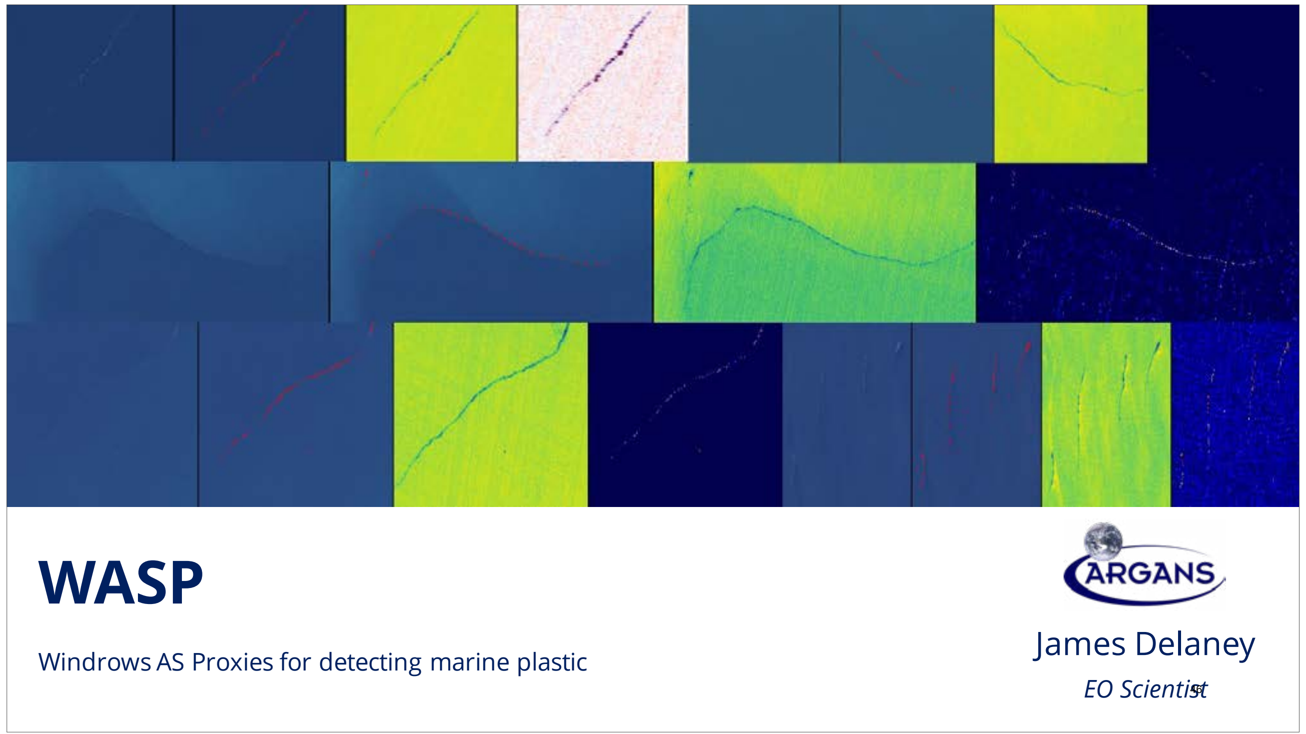
Appendix B

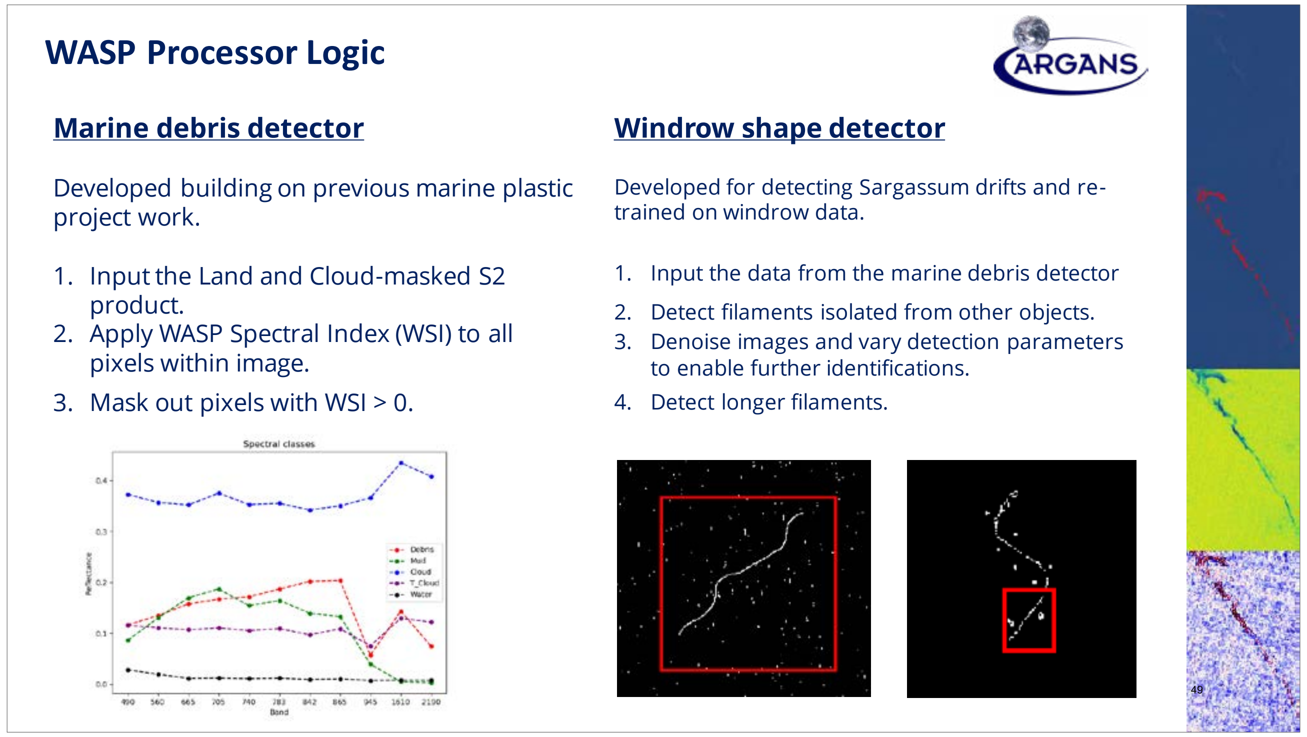
Survey Questions

1. Name:
2. Organisation:
3. Email:
4. Role:
5. What field of work are you in (e.g. researcher, industry, government)?
   a) Research
   b) Industry/Business
   c) Government
   d) NGO
   e) Other: [Open text box]
6. In which country is your work based or which country does it primarily affect?
   a) [Open text box]
7. What is your work's main focus:
   a) Using existing or developing new remote sensing technologies to research plastic litter.
   b) Using the results of plastic litter studies to create or investigate guidance, ideas, actions or policy for businesses, governments, or other groups.
   c) Using remote sensing to build a product or service related to plastic litter
   d) Funding organisations/individuals who research or mitigate plastic litter problems
   e) Other:
8. Which remote sensing techniques or data analysis methods do you use or are you developing, if any?
   a) [Open text box]
   b) Does not apply to me
9. For which groups do you create or investigate guidance, ideas, actions, or policy, if any?
   a) Government
   b) Industry/business
   c) NGO
   d) Academia/research institution
   e) Other:
   f) Does not apply to me
10. Are the results of your work public? If yes, please, provide publicly available links to your project(s):
    a) Yes
    b) No
    c) [Open text box for people to input links]
11. What do you think are the current top three challenges to working in your area of remote sensing and plastic litter?
    a) [Open text box]
12. What do you think would be the top three priority actions, interventions, or innovations that would help improve your area of work and help understand or mitigate plastic litter problems?
    a) [Open text box]
13. In your opinion, where is additional funding most needed?
    a) Feasibility Studies
    b) Adapting or developing new technologies, including raising Technology Readiness Levels
    c) Building new products
    d) Raising awareness or demonstrating currently employed technology or guidance/policy solutions
    e) Creating new policy/guidance/actions
    f) Please explain why: [Open Text box]
14. Are there any other peers/colleagues/organisations you suggest we contact to further our investigation?
    [Open text box]

Appendix C

Highlighted case study 1 - WASP

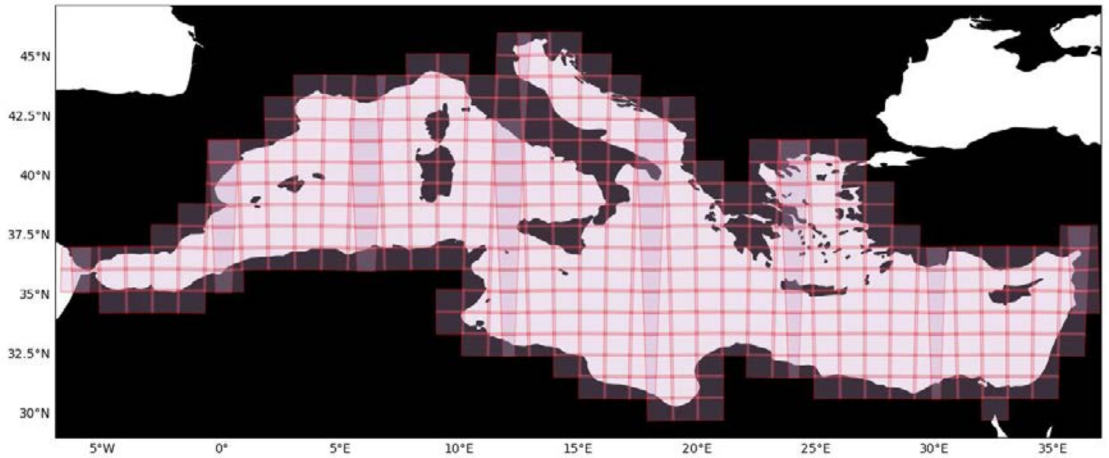




WASP Processing Campaign

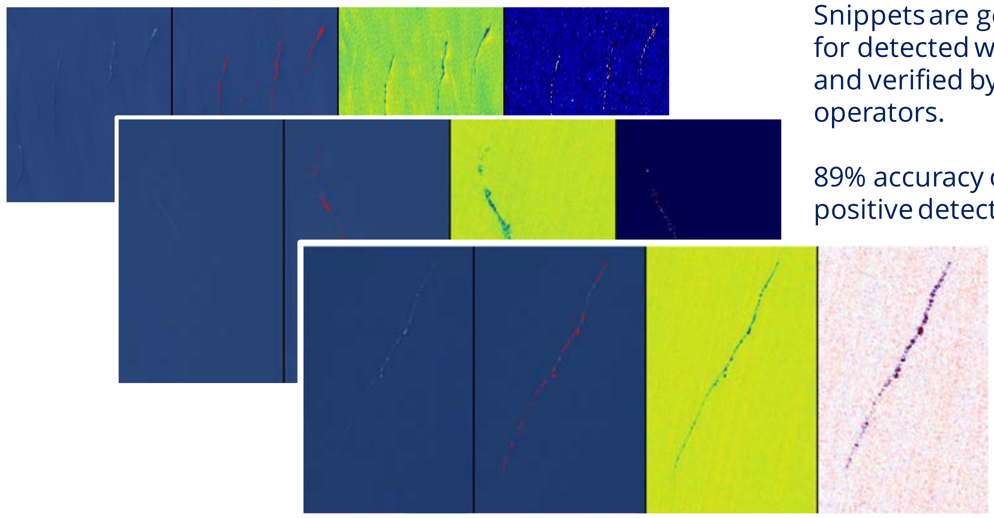
Data processed: Full Sentinel-2 time series over the Mediterranean Sea

- 410 area tiles
- 287 475 individual Sentinel-2 products over 6 years



Sentinel-2 product areas available over Mediterranean Sea

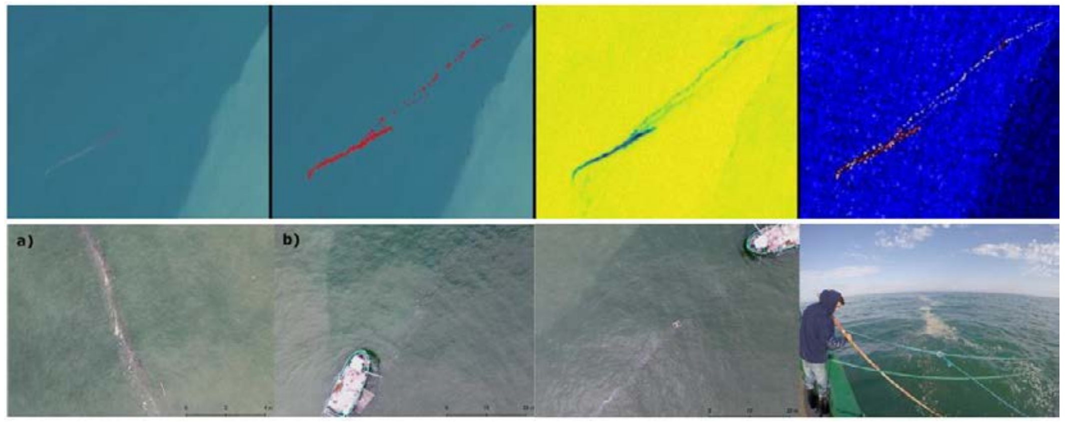
WASP Windrow Detections



Snippets are generated for detected windrows and verified by operators.

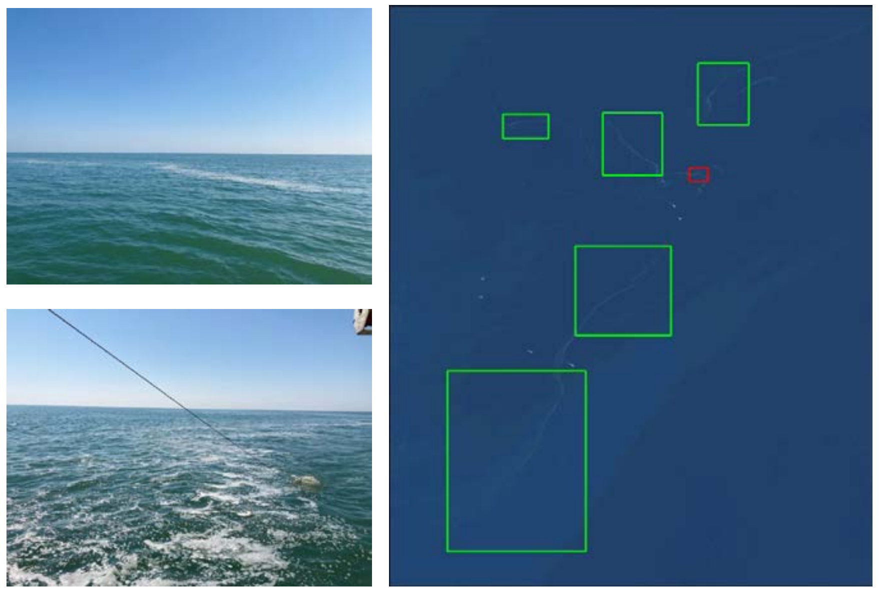
89% accuracy of positive detections.

WASP Verification

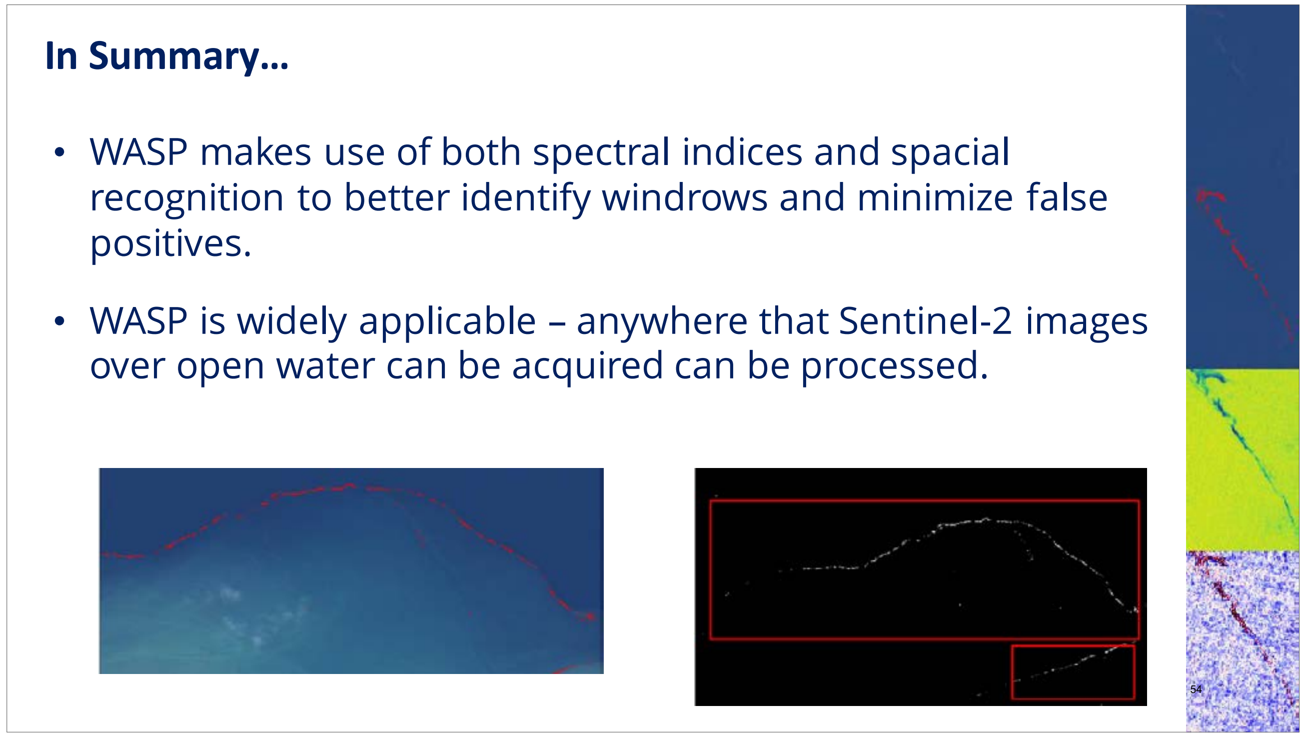


Debris collected from Windrows by Ruiz et al 2019, also identified in WASP data.

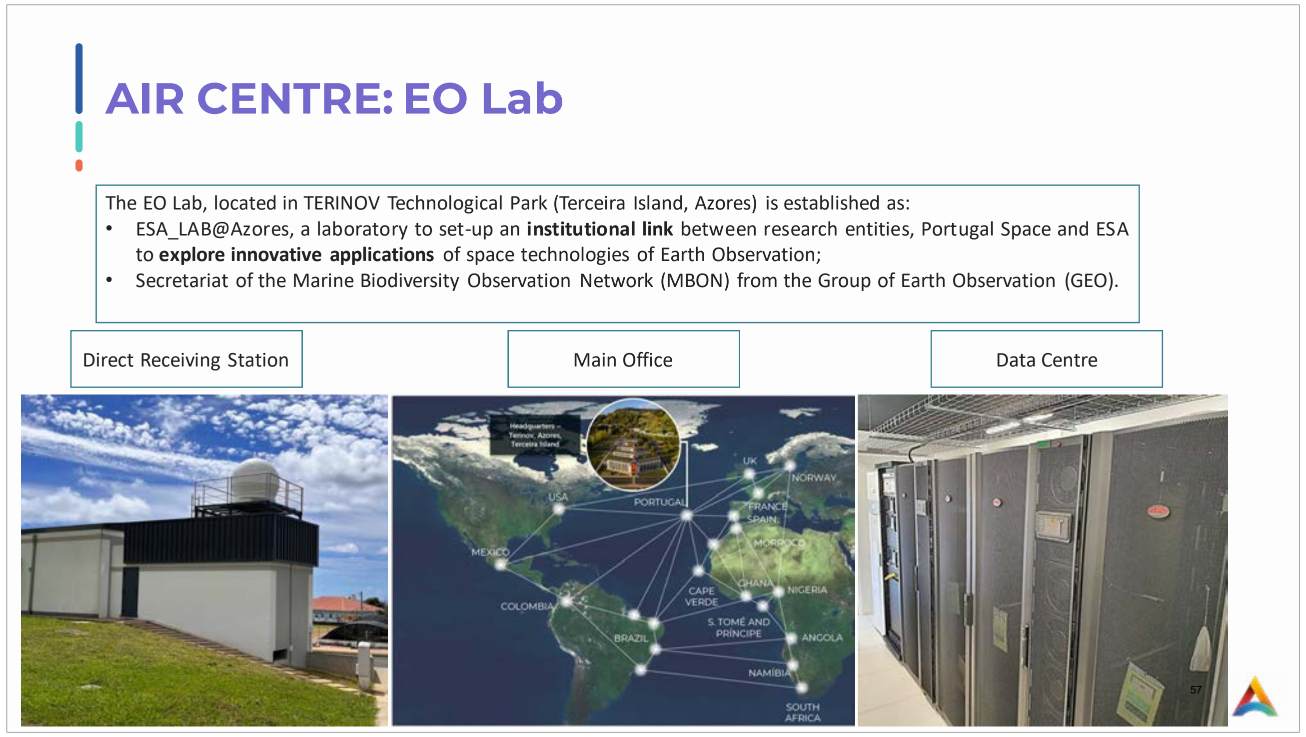
WASP Verification



Windrow identified in the North Adriatic Sea by WASP in S2 data and by an ISMAR-CNR research vessel.



Highlighted case study 2 - POS2IDON



AIR CENTRE: Thematic Missions and Projects


Clean and productive bays and estuaries


Resilience to coastal natural hazards


Sustainable food production


Improved management of marine and coastal resources


Improved environmental and maritime monitoring

Horizon 2020 European Union Funding for Research & Innovation

Iceland Liechtenstein Norway grants

EEA Grants Portugal

LABPLAS

Azores EcoBlue

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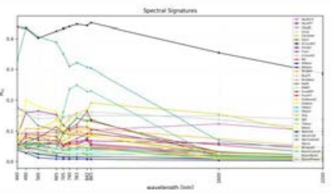
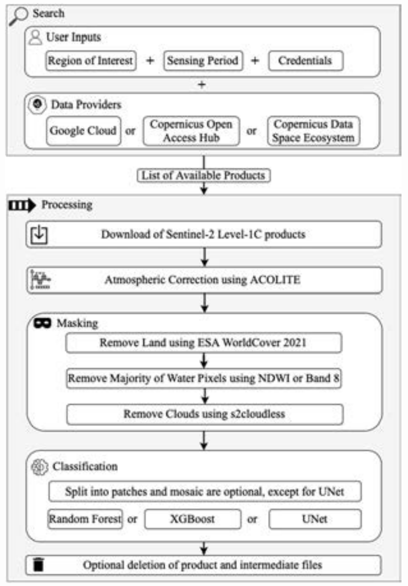
POS2IDON: Description

- Sentinel-2 mission has been proven to detect artificial floating plastic patches in the ocean.
- This new automated pipeline based on Kikaki et al (2022) spectral library brings together several machine learning models trained with more spectral signatures, different satellite data providers, atmospheric correction and masking in a single simple to use tool.





Open-Source Code on GitHub

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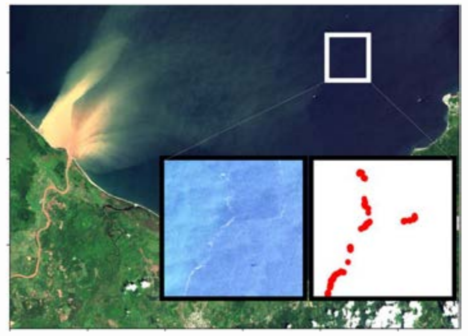
POS2IDON: Models and Results

Random Forest and XGBoost ML models show satisfactory metrics. Tests are being performed with UNet.

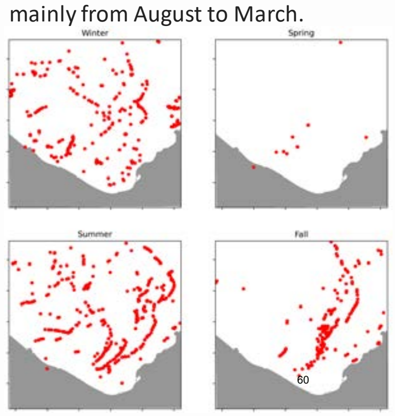
MD – Marine Debris (anthropogenic plastics included).

	RF			XGBoost		
Class	IoU	Rec	F1	IoU	Rec	F1
MD	0.68	0.83	0.81	0.73	0.84	0.84
DenseS	0.92	0.95	0.96	0.93	0.96	0.96
SpS	0.82	0.90	0.90	0.85	0.90	0.92
NatM	0.73	0.80	0.85	0.75	0.81	0.86
Ship	0.69	0.75	0.82	0.76	0.81	0.86
Clouds	0.93	0.96	0.96	0.97	0.98	0.98
MWater	0.94	0.97	0.97	0.97	0.99	0.98
SLWater	1.00	1.00	1.00	1.00	1.00	1.00
Foam	0.59	0.74	0.74	0.66	0.78	0.80
TWater	0.99	1.00	1.00	0.99	1.00	1.00
SWater	0.93	0.96	0.96	0.96	0.97	0.98
Cyanob	1.00	1.00	1.00	1.00	1.00	1.00
Noctil	0.99	0.99	0.99	0.99	1.00	1.00
Phaeoc	0.86	0.94	0.92	0.91	0.96	0.95
Average	0.86	0.91	0.92	0.89	0.93	0.94

Image classification of a verified event in Honduras Gulf in 2020. Red dots indicate the likely presence of Marine Debris detected along the river front.

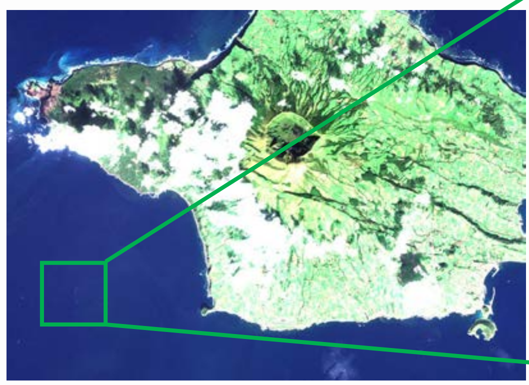


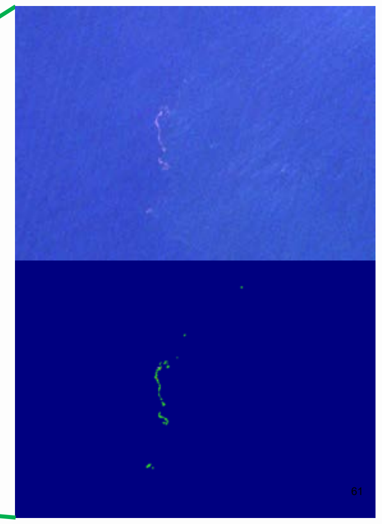
Pipeline application for the Honduras Gulf, over 1 year, after cloud and land buffering. Debris originated from rivers accumulate along river fronts, mainly from August to March.



POS2IDON: More than Plastic Detection

The pipeline is being tested on several islands in the Azores within the scope of the ECOBLUE project to detect possible agglomerations of materials with potential for the development of fibers that can be transformed and used as a raw material in fabrics.





POS2IDON: Validation

Events in Literature and News

GEOSAT-2 very-high resolution

Field Campaign February 2023 (LABPLAS project)

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WHAT'S NEXT?

- **Spectral Library:** Continuous increasing of the existing MARIDA dataset with new signatures of verified events, such as oil spills…
- **Field Campaigns:** Process satellite data of the latest LABPLAS ALKOR field campaign (June);
- **Ensemble Models:** Combines multiple models in the prediction process, using an UNCERTAIN class when there is a mismatch between models;
- **Other satellites:** Support the classification results of the POS2IDON pipeline with sensors, such as OLCI on Sentinel-3 with 21 spectral bands and 300 meters spatial resolution, to explore proxies of marine debris.

Field Campaign June 2023 (LABPLAS project)

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REFERENCES AND FURTHER READING

- Kikaki et al, 2022. MARIDA: A benchmark for Marine Debris detection from Sentinel-2 remote sensing data
- Hu, 2021. Remote detection of marine debris using satellite observations in the visible and near infrared spectral range: challenges and potentials
- Topouzelis et al, 2021. Floating marine litter detection algorithms and techniques using optical remote sensing data: a review
- Biermann et al, 2020. Finding plastic patches in coastal waters using optical satellite data
- Martínez-Vicente et al, 2019. Measuring Marine Plastic Debris from Space: Initial Assessment of Observation Requirements
- Topouzelis et al, 2019. Detection of floating plastics from satellite and unmanned aerial systems (Plastic Litter Project 2018)

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Appendix D

Workshop 1 Mentimeter questions

Workshop demographics

1. In which sector do you primarily work?
   a) MULTIPLE CHOICE - BAR GRAPH
      i) Research/Academia
      ii) Industry/Business
      iii) Government
      iv) NGO
      v) Other
2. What is your work's main focus?
   a) MULTIPLE CHOICE - BAR GRAPH
      i) Using existing or developing new remote sensing technologies to research or monitor plastic litter.
      ii) Using the results of plastic litter studies to create or investigate guidance, ideas, actions, or policy for businesses, governments, or other groups.
      iii) Developing a product or service related to plastic litter monitoring
      iv) Funding organisations/individuals who research or mitigate plastic litter problems
      v) Other

Barriers

3. Innovation/Research: How would you rank the following as barriers to the quality of your results and your understanding of plastic litter?
   a) RANKING - BAR GRAPH WITH RANKINGS
      i) Quality or ability of sensors or other technology
      ii) Standardised methodologies for data collection and comparison
      iii) Ease of managing, processing, or analysing collected data
      iv) Ability to share data and ideas with others
4. Innovation/Product development: How would you rank the following as barriers to creating a product that effectively mitigates plastic waste?
   a) RANKING - BAR GRAPH WITH RANKINGS
      i) Availability of funds to develop new products
      ii) User adoption of the products
      iii) Access to research findings or support to understand the plastic problems needing a solution
      iv) Ability to understand the product effectiveness
5. Policymaking: How would you rank the following as barriers to creating policy for the reduction of plastic litter?
   a) RANKING - BAR GRAPH WITH RANKINGS
      i) Ability to understand a specific plastic litter problem and craft a policy to combat it
      ii) Ability to understand or monitor who is complying with the policy
      iii) Ability to understand or monitor the policy's effectiveness
      iv) Accessing the latest plastic litter research to update policies so they align with new understanding

Innovation and change

6. Innovation/Research: what action or change would most improve your work or increase its impact on plastic litter mitigation?
   a) WORD CLOUD
7. Innovation/Product development: what action or change would most improve your work or increase its impact on plastic litter mitigation?
   a) WORD CLOUD
8. Policymaking: what action or change would most improve your work or increase its impact on plastic litter mitigation?
   a) WORD CLOUD

Interaction between innovation and policy

9. Innovation/research: What is the greatest barrier to sharing your results with policy or guidance makers?
   a) WORD CLOUD
10. Innovation/product development: What is the greatest barrier to sharing your results with policy or guidance makers?
    a) WORD CLOUD
11. Policymaking: What is the greatest barrier to using remote sensing data to inform plastic litter policy?
    a) WORD CLOUD

12. To whom do you feel remote sensing data should be presented to have the greatest impact on policy or guidance-making?
    a) RANKING - RANKING GRAPH
        i) Locally to councils and regional policymakers
        ii) Nationally to Government departments
        iii) Internationally (i.e the UN Convention on Plastic Pollution)
        iv) Industries who working in plastic waste management or who want to reduce their plastic waste

Interventions

13. In your opinion, where should most funding be allocated to help mitigate plastic litter?
    a) RANKING - RANKING
        i) Feasibility research to understand current opportunities and limitations
        ii) Monitoring/data collection on plastic litter or developing new analytical techniques
        iii) Adapting or developing new technologies, including raising Technology Readiness Levels
        iv) Building or improving products or services that allow more people or organisations to monitor plastic litter
        v) Raising awareness about currently employed technology or guidance/policy solutions that could be adopted elsewhere
        vi) Opening access to data and results from plastic litter research
        vii) Creating new policies or guidance for industry or government

14. In your opinion, what events could facilitate the best collaboration between different stakeholders within remote sensing for plastic litter?
    a) RANKING - RANKING GRAPH
        i) Webinars with experts from different sectors sharing
        ii) Training/education opportunities to learn more about different technology/techniques
        iii) A collaborative consortium of interested parties with regularly scheduled meetings
        iv) Workshops with policymakers and those in research and innovation to discuss in depth how the areas can help each other

Increased data sharing through centralised databases or data-sharing agreements

Appendix E

WORKSHOP OBJECTIVES

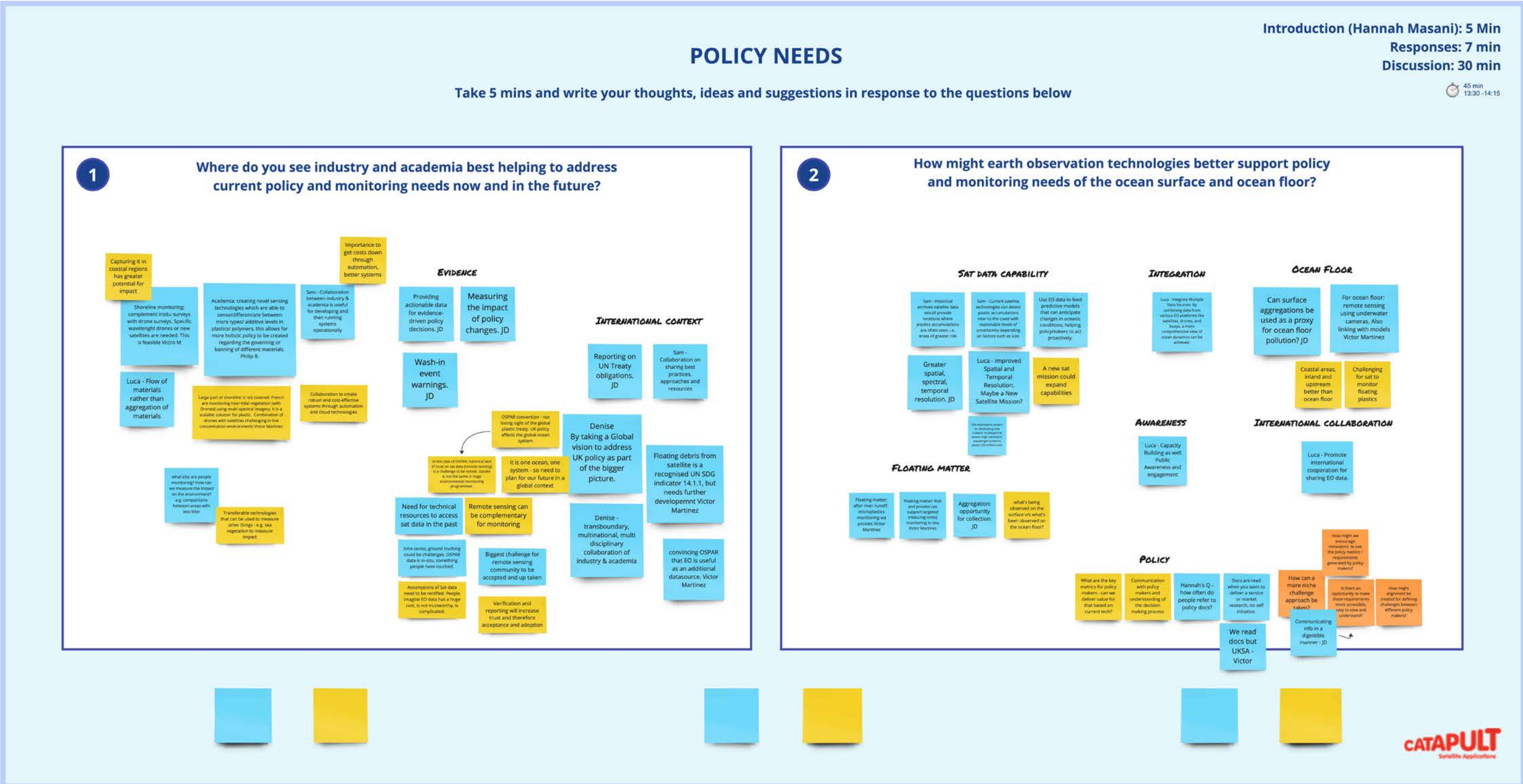
- To understand how Remote Sensing can better support policy to reduce plastic pollution
- To understand what interventions are needed to stimulate the innovation value chain
- To explore collaboration and knowledge exchange opportunities between all stakeholders

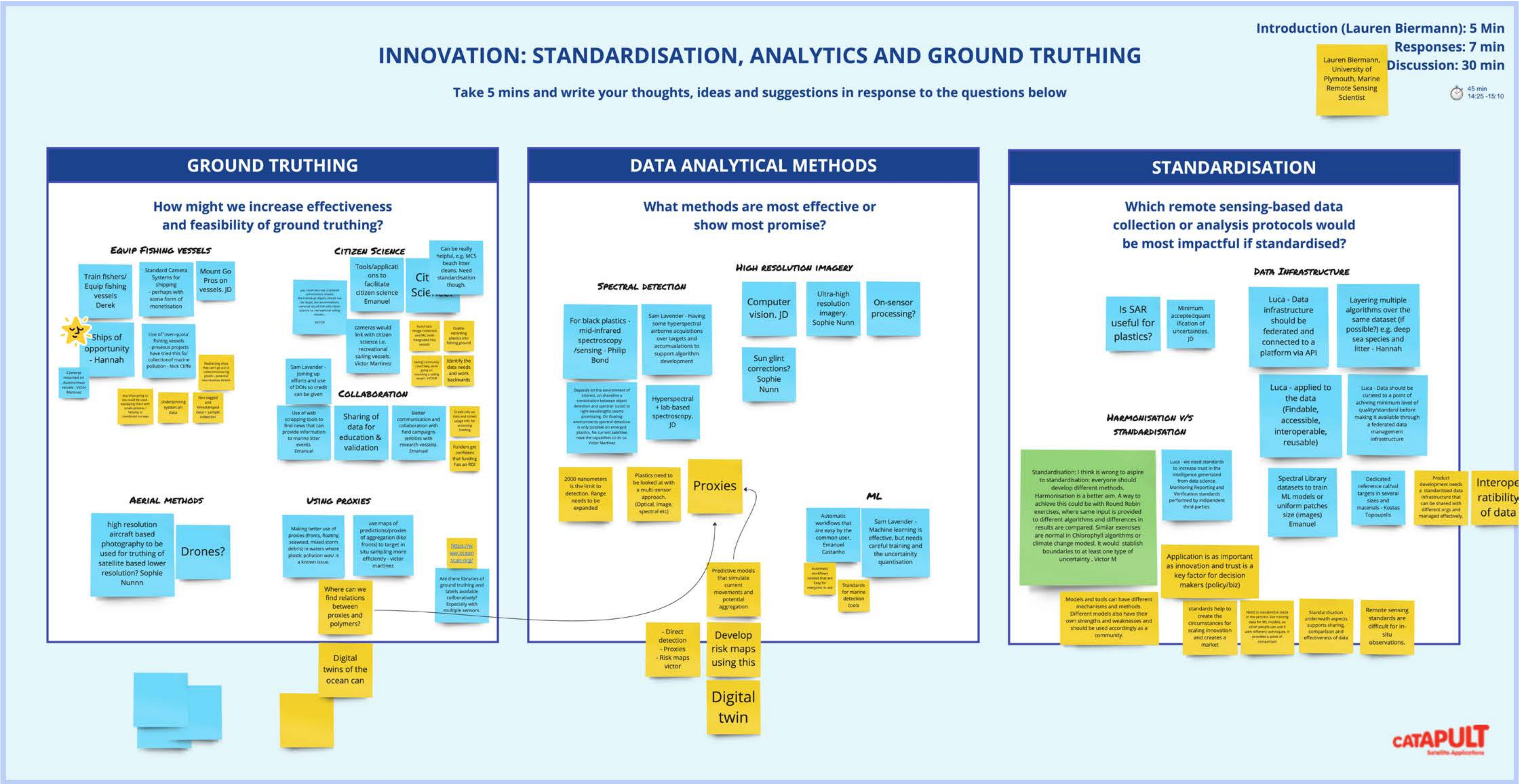
CATAPULT

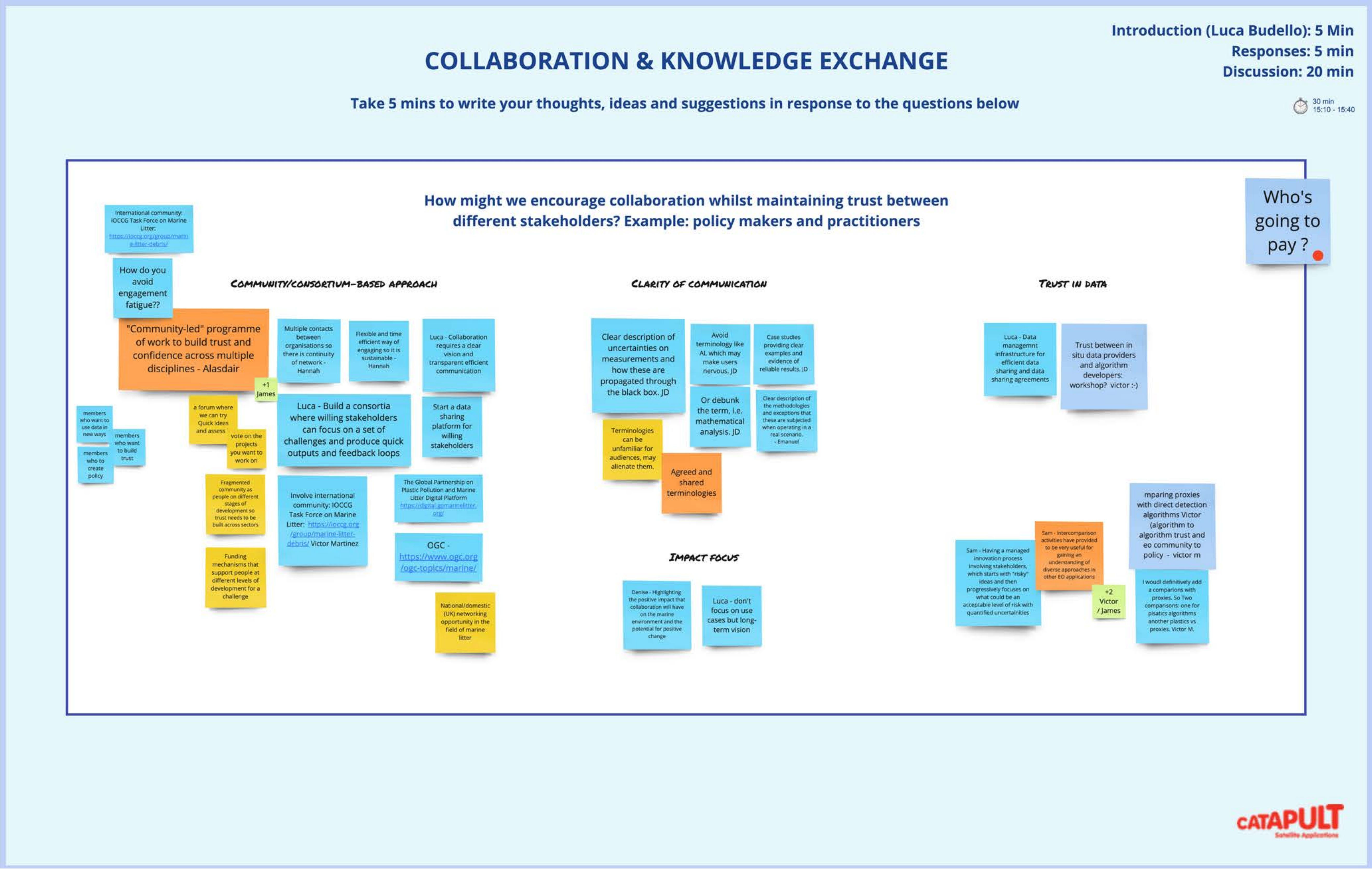
AGENDA FOR THE SESSION

13:00	Welcome to the workshop
13:05	Overview of the session
13:07	Summary of emerging themes and challenges
13:20	Introduction to Miro: Icebreaker
13:30	Introduction to Theme 1 + Activity (45 min)
14:15	Break (10 min)
14:25	Introduction to Theme 2 + Activity (45 min)
15:10	Introduction to Theme 3 + Activity (30 min)
15:40	Prioritisation of ideas and suggestions (10 min)
15:50	Response and next steps
16:00	Close

CATAPULT


POLICY NEEDS
Take 5 mins and write your thoughts, ideas and suggestions in response to the questions below
Introduction (Hannah Masani): 5 Min
Responses: 7 min
Discussion: 30 min
45 min
13:30 -14:15
1
Where do you see industry and academia best helping to address current policy and monitoring needs now and in the future?
Capturing it in coastal regions has greater potential for impact
Importance to get costs down through automation, better systems
Shoreline monitoring: complement insitu surveys with drone surveys. Specific wavelenght drones or new satellites are needed. This is feasible Victro M
Academia: creating novel sensing technologies which are able to sense/differentiate between more types/ additive levels in plastics/ polymers, this allows for more holistic policy to be created regarding the governing or banning of different materials. Philip B.
Sam - Collaboration between industry & academia is useful for developing and then running systems operationally
Luca - Flow of materials rather than aggregation of materials
Collaboration to create robust and cost-effective systems through automation and cloud technologies
what else are people monitoring? How can we measure the impact on the environment? e.g. comparisons between areas with less litter
Transferable technologies that can be used to measure other things - e.g. sea vegetation to measure impact
EVIDENCE
Providing actionable data for evidence-driven policy decisions. JD
Measuring the impact of policy changes. JD
Wash-in event warnings. JD
OSPAR convention - not losing sight of the global plastic treaty. UK policy affects the global ocean system
It is one ocean, one system - so need to plan for our future in a global context
Need for technical resources to access sat data in the past
Remote sensing can be complementary for monitoring
time series, ground truthing could be challenges. OSPAR data is in-situ, something people have touched
Biggest challenge for remote sensing community to be accepted and up taken
Assumptions of Sat data need to be rectified. People imagine EO data has a huge cost, is not trustworthy, is complicated.
Verification and reporting will increase trust and therefore acceptance and adoption
INTERNATIONAL CONTEXT
Reporting on UN Treaty obligations. JD
Sam - Collaboration on sharing best practices, approaches and resources
Denise By taking a Global vision to address UK policy as part of the bigger picture.
Floating debris from satellite is a recognised UN SDG indicator 14.1.1, but needs further developemnt Victor Martinez
Denise - transboundary, multinational, multi disciplinary collaboration of industry & academia
convincing OSPAR that EO is useful as an additional datasource. Victor Martinez
2
How might earth observation technologies better support policy and monitoring needs of the ocean surface and ocean floor?
SAT DATA CAPABILITY
Sam - Historical archives satellite data would provide locations where plastics accumulations are often seen, i.e. areas of greater risk
Sam - Current satellite technologies can detect plastic accumulations near to the coast with reasonable levels of uncertainty depending on factors such as size.
Use EO data to feed predictive models that can anticipate changes in oceanic conditions, helping policymakers to act proactively.
Greater spatial, spectral, temporal resolution. JD
Luca - Improved Spatial and Temporal Resolution. Maybe a New Satellite Mission?
A new sat mission could expand capabilities
INTEGRATION
Luca - Integrate Multiple Data Sources: By combining data from various EO platforms like satellites, drones, and buoys, a more comprehensive view of ocean dynamics can be achieved.
OCEAN FLOOR
Can surface aggregations be used as a proxy for ocean floor pollution? JD
For ocean floor: remote sensing using underwater cameras. Also linking with models Victor Martinez
Coastal areas, inland and upstream better than ocean floor
Challenging for sat to monitor floating plastics
AWARENESS
Luca - Capacity Building as well Public Awareness and engagement
INTERNATIONAL COLLABORATION
Luca - Promote international cooperation for sharing EO data.
FLOATING MATTER
Floating matter: after river runoff: microplastics monitoring via proxies Victor Martinez
Floating matter: Risk and proxies can support targeted (reducing costs) monitoring in situ Victor Martinez
Aggregation: opportunity for collection. JD
what's being observed on the surface v/s what's been observed on the ocean floor?
POLICY
What are the key metrics for policy makers - can we deliver value for that based on current tech?
Communication with policy makers and understanding of the decision making process
Hannah's Q - how often do people refer to policy docs?
Docs are read when you want to deliver a service or market research, no self initiative.
We read docs but UKSA - Victor
How can a more niche challenge approach be taken?
How might we encourage innovators to use the policy metrics / requirements generated by policy makers?
Is there an opportunity to make these requirements more accessible, easy to view and understand?
How might alignment be created for defining challenges between different policy makers?
Communicating info in a digestible manner - JD
CATAPULT
Satellite Applications


INNOVATION: STANDARDISATION, ANALYTICS AND GROUND TRUTHING
Take 5 mins and write your thoughts, ideas and suggestions in response to the questions below
Introduction (Lauren Biermann): 5 Min
Responses: 7 min
Discussion: 30 min
Lauren Biermann, University of Plymouth, Marine Remote Sensing Scientist
45 min 14:25 -15:10
GROUND TRUTHING
How might we increase effectiveness and feasibility of ground truthing?
Equip Fishing vessels
Train fishers/ Equip fishing vessels Derek
Mount Go Pros on vessels. JD
Ships of opportunity - Hannah
Citizen Science
Sharing of data for education & validation
Collaboration
Aerial methods
high resolution aircraft based photography to be used for truthing of satellite based lower resolution? Sophie Nunnn
Drones?
Using proxies
Where can we find relations between proxies and polymers?
Digital twins of the ocean can
DATA ANALYTICAL METHODS
What methods are most effective or show most promise?
Spectral detection
High resolution imagery
Computer vision. JD
Ultra-high resolution imagery. Sophie Nunn
On-sensor processing?
Sun glint corrections? Sophie Nunn
For black plastics - mid-infrared spectroscopy /sensing - Philip Bond
Hyperspectral + lab-based spectroscopy. JD
Proxies
ML
Develop risk maps using this
Digital twin
STANDARDISATION
Which remote sensing-based data collection or analysis protocols would be most impactful if standardised?
Data Infrastructure
Is SAR useful for plastics?
Luca - Data infrastructure should be federated and connected to a platform via API
Layering multiple algorithms over the same dataset (if possible?) e.g. deep sea species and litter - Hannah
Luca - applied to the data (Findable, accessible, interoperable, reusable)
Harmonisation v/s Standardisation
Application is as important as innovation and trust is a key factor for decision makers (policy/biz)
Interoperatibility of data
CATAPULT Satellite Applications


Introduction (Luca Budello): 5 Min
Responses: 5 min
Discussion: 20 min
COLLABORATION & KNOWLEDGE EXCHANGE
Take 5 mins to write your thoughts, ideas and suggestions in response to the questions below
30 min
15:10 - 15:40
How might we encourage collaboration whilst maintaining trust between different stakeholders? Example: policy makers and practitioners
Who's going to pay ?
International community: IOCCG Task Force on Marine Litter: https://ioccg.org/group/marine-litter-debris/
How do you avoid engagement fatigue??
COMMUNITY/CONSORTIUM-BASED APPROACH
"Community-led" programme of work to build trust and confidence across multiple disciplines - Alasdair
+1 James
Multiple contacts between organisations so there is continuity of network - Hannah
Flexible and time efficient way of engaging so it is sustainable - Hannah
Luca - Collaboration requires a clear vision and transparent efficient communication
members who want to use data in new ways
members who want to build trust
members who to create policy
a forum where we can try Quick ideas and assess
vote on the projects you want to work on
Luca - Build a consortia where willing stakeholders can focus on a set of challenges and produce quick outputs and feedback loops
Start a data sharing platform for willing stakeholders
Fragmented community as people on different stages of development so trust needs to be built across sectors
Involve international community: IOCCG Task Force on Marine Litter: https://ioccg.org/group/marine-litter-debris/ Victor Martinez
The Global Partnership on Plastic Pollution and Marine Litter Digital Platform https://digital.gpmarinelitter.org/
OGC - https://www.ogc.org/ogc-topics/marine/
Funding mechanisms that support people at different levels of development for a challenge
National/domestic (UK) networking opportunity in the field of marine litter
CLARITY OF COMMUNICATION
Clear description of uncertainties on measurements and how these are propagated through the black box. JD
Avoid terminology like AI, which may make users nervous. JD
Case studies providing clear examples and evidence of reliable results. JD
Or debunk the term, i.e. mathematical analysis. JD
Clear description of the methodologies and exceptions that these are subjected when operating in a real scenario. - Emanuel
Terminologies can be unfamiliar for audiences, may alienate them.
Agreed and shared terminologies
IMPACT FOCUS
Denise - Highlighting the positive impact that collaboration will have on the marine environment and the potential for positive change
Luca - don't focus on use cases but long-term vision
TRUST IN DATA
Luca - Data managemnt infrastructure for efficient data sharing and data sharing agreements
Trust between in situ data providers and algorithm developers: workshop? victor :-)
Sam - Having a managed innovation process involving stakeholders, which starts with "risky" ideas and then progressively focuses on what could be an acceptable level of risk with quantified uncertainities
Sam - intercomparison activities have provided to be very useful for gaining an understanding of diverse approaches in other EO applications
+2 Victor / James
mparing proxies with direct detection algorithms Victor (algorithm to algorithm trust and eo community to policy - victor m
I woudl definitively add a comparions with proxies. So Two comparisons: one for pisatics algorithms another plastics vs proxies. Victor M.
CATAPULT Satellite Applications


PRIORITISATION ACTIVITY
Spend a few minutes going through different intervention ideas and vote on 2 ideas using dot voting
Voting: 10 min
Response and closure: 10 min
20 min
15:40 - 16:00
"Community-led"
trust and confidence
across multiple disciplines
Interopability of data
Increasing ground-truthing through citizen science and 'ships of opportunity'
Don't focus
use cases
but long-
term visi
Intercomparison exercise (inc. proxy)
Building trust & confidence in data
Increase the acceptance of EO by building trust.
Better understanding of Proxies
Better communication of policy
Marine Digital Twin
Standardisation of particular aspects e.g. training data, validation data, ground-truth.
Introduction of greater spatial, spectral, temporal resolutions (i.e new satellite missions)
Development of a marine plastics satellite sensor
Proxy between surface and sub-surface?
CATAPULT


Closing Remarks and Next steps
Alasdair Davies
THANK YOU
Innovate UK
ARRIBADA initiative
CATAPULT
Satellite Applications

Appendix F

Detailed Findings

Here we present more detailed recommendations for the three sections of our roadmap:

Low TRL (TRL 3-5) - Strengthening the foundation of innovation

High TRL (TRL 6-9) - Supporting product development and access to markets

Ecosystem-Wide Interventions - Encourage cohesion of the innovation ecosystem

We also provide a table with direct quotes from scoping activity participants that support the recommendations in this section (see table).

Low TRL (3-5) Interventions

Objective
Elevate the TRL of new concepts and technologies.

Strategies
Stimulate Technology-Led Innovation

1. **Technology Roadmapping:** Encourage the development of technology roadmaps that outline the path from concept to commercialisation for promising remote sensing innovations. Roadmaps help align efforts and resources. Innovate UK Business Connect's Ignite lab and SAC's design team could tackle this by deploying design thinking to find multiple innovation pathways.
2. **Early-Stage Research Grants:** Offer research grants for early-stage projects focused on developing novel remote sensing technologies and data science techniques for plastic litter detection. This could include exploring new sensors, data processing algorithms, or data fusion methods.
3. **Collaboration Promotion:** Foster collaborations among diverse stakeholders to harness a range of expertise and resources. Consider grants for collaborative research and development (R&D).
4. **Innovation Competitions:** Organise/fund innovation competitions or challenges that incentivise the development of novel remote sensing technologies and data science techniques for plastic litter detection and monitoring.
5. **Technology Incubators:** Support technology incubators or innovation hubs dedicated to advancing remote sensing solutions for plastic pollution. These hubs can provide resources, mentorship, and collaborative opportunities to innovators and startups.
6. **Industry Partnerships:** Facilitate partnerships between research institutions and industry stakeholders. These partnerships can help translate research findings into practical applications and accelerate technology transfer. Using the KTP network to develop academia-industry projects in engineering and data science could be a solution to address many challenges through an established IUK funded innovation programme.
7. **Blue Sky Ideas:** Allocate funding to support technological advancements such as launching new satellite missions or enhancing spectral capabilities for plastic detection (e.g. black plastic). For example, work with the UK Space Agency for a joint proposal in the upcoming Comprehensive Spending Review (CSR).

High TRL (6-9) Interventions

Objective
Bridge the gap between advanced technologies and scalable products/solutions.

Strategies
Stimulate Market-Led Innovation

1. **Challenge-Led Approaches:** Embrace challenge-led initiatives tailored to address specific market needs and to ensure the relevance and applicability of remote sensing solutions. For example, Innovate UK Business Connect's Innovation Exchange open innovation platform bridges the gap between industry players with a market challenge with technology SMEs with potential solutions.
2. **Public-Private Partnerships:** Foster partnerships between public and private sectors to jointly invest in research and development efforts, share resources, and accelerate technological advancements. For example, UK's Contracts for Innovation, incentivise innovators to develop solutions aligned with public sector procurement.
3. **Commercialisation Engines:** Promote initiatives to fund innovation for commercialisation. Consider initiatives like commercialisation engines or incubation for startups looking at developing new business models and opening new markets. For example, SAC's Commercialisation Engine that supports new businesses, aimed at accelerating innovative and commercially viable Earth Observation (EO) ideas into the market.
4. **Product Development and Testing:** Invest in rigorous product development and testing processes to ensure the reliability and accuracy of remote sensing solutions. Conduct field trials and validation studies in diverse environmental settings to demonstrate the effectiveness of the technology, increase trust and raise the TRL.
5. **Pilot Deployments:** Support pilot deployments of emerging remote sensing technologies in targeted plastic pollution hotspots. These deployments can help refine technology performance and readiness.
6. **Technology Transfer:** Facilitate technology transfer from research institutions and government agencies to commercial entities. This can expedite the translation of research findings into practical solutions. KTP can be a vehicle to support innovation across academia and industry.
7. **Ships of Opportunity:** Deploy an innovation competition to advance the use of high-resolution mounted cameras on vessels, a concept known as "Ships of Opportunity." These cameras collect in-situ data to support ground truthing of remote sensing outputs, enhancing the accuracy of plastic litter detection and monitoring.
8. **Blue Sky Ideas:** Support initiatives that are building robust data-sharing infrastructure, such as "Digital Twins of the Ocean," to facilitate seamless data exchange and collaboration among stakeholders. This infrastructure can enhance data accessibility and utilisation. This may require working in collaboration with other departments of His Majesty the Government (HMG) to build joint CSR calls.

Ecosystem-Wide Interventions

Objective
Enhance the entire technological ecosystem to be more interdisciplinary and collaborative.

Strategies
Stimulate ecosystem-wide interactions:

1. **Thought Leadership:** Establish thought leadership initiatives to provide guidance and inspiration to the remote sensing technology industry. Share insights on the role of remote sensing in addressing plastic litter challenges through publications, webinars, expert discussions and policy forums.
2. **Knowledge Sharing Events:** Organise events, conferences, webinars and workshops dedicated to facilitating knowledge sharing and network building between a diverse audience. These events should aim to foster cross-disciplinary collaborations and showcase innovative projects to reduce fragmentation of the ecosystem and enhance trust across participants.

3. **Stakeholder Engagement:** Foster engagement between remote sensing technology developers, policymakers, and environmental organisations. Create platforms for industry, academia, policymakers, and NGOs to collaborate effectively. Consider Contracts for Innovation and KTPs (Knowledge Transfer Partnerships) as available products to bolster stakeholder engagement.
4. **Enhance Interdisciplinary Collaboration:** Promote interdisciplinary collaboration, such as oceanographic modelling, to develop predictive models. These models can contribute to international policy initiatives, such as the UN Plastics Treaty, by providing data-driven insights and recommendations. Innovation competitions may be set up to respond to combined policy and market challenges.
5. **International Collaboration:** Encourage international collaboration and data sharing to address plastic pollution on a global scale, as plastic debris is a transboundary issue. For example, Innovate UK Business Connect can support by developing Global Scoping Workshops (GSW) and Global Expert Missions (GEM) to engage industries across geographical boundaries.
6. **Develop a Taskforce:** Collaborate with relevant end users to establish a regulatory framework for the use of remote sensing technologies in plastic litter detection and monitoring. Define standards, data-sharing protocols, and compliance requirements to ensure the responsible and effective use of these technologies. This will enhance trust in the process, increase compliance and open new market opportunities. Initiatives such as OGC can provide a blueprint for an effective industry led and international taskforce to tackle technical, market and policy challenges.
7. **Monitoring and Reporting Requirements:** Implement monitoring and reporting requirements for businesses and industries that may contribute to plastic pollution. Remote sensing data can play a role in verifying compliance with plastic waste reduction targets and regulations. While beyond Innovate UK's direct interventions, Innovate UK can still have a significant impact by providing valuable insights to inform policy decisions and other relevant stakeholders.
8. **Capacity Building:** Encourage policies that invest in capacity building and training programmes for researchers, technologists, and policymakers to enhance their understanding and utilisation of remote sensing technologies for plastic litter assessment.

INTERVENTION TYPE	RECOMMENDATION	DIRECT QUOTE FROM SCOPING ACTIVITIES
Low TRL	Technology Roadmapping	"A value chain needs to be built so there is funding for all aspects of the chain and the overall solution is commercially viable" *(Survey participant)*
	Early-Stage Research Grants	"Creation of deliberate knowledge-sharing programs in the form of training to allow the development of the technical capacity of early career researchers like me who have slightly limited technical expertise" *(Survey participant)*
	Collaboration Promotion	"This plastic community seems fragmented, and we need to build trust so we can create a unifying view that is not case based" *(Workshop participant)*
	Innovation Competitions	"Open calls, helps translate lengthy policy documents into an easier challenge approach" *(Workshop participant)*
	Technology Incubators	"Collaboration with technology partners to innovate a device to monitor and recycle plastic litter" *(Survey participant)*
	Industry Partnerships	"Develop new sensors or make available commercial remote sensing data available to researchers" *(Survey participant)*
	Blue Sky Ideas	"Development of a satellite mission focused on plastic litter pollution with appropriate sensor resolutions (more feasibility studies like Marlise)" *(Survey participant)*
High TRL	Challenge-Led Approaches	"Develop EO payloads with specs that are aligned with the real user needs" *(Survey participant)*
	Public-Private Partnerships	"There is an existing model for business-led collaboration, the Contracts for Innovation model, where there is a particular need to stimulate innovation specifically" *(Workshop participant)*
	Commercialisation Engines	"We want to see a marketplace evolving around plastic like that exists around carbon" *(Workshop participant)*
	Product Development and Testing	"More access to very high-resolution SAR imaging over real-world locations of either test targets of plastic, or either, real world cases of plastic pollution. The availability of ICEYE high-res imagery is good for this, but freely-available imagery like the Copernicus programme would be helpful" *(Survey participant)*
	Pilot Deployments	"Getting regulatory agency support in pitching for funding and participating in pilot/funded projects (even at no cost) e.g. looking at data collected" *(Survey participant)*
	Technology Transfer	"Having projects that jointly involve industry and research partners is useful, because the main interest in academia is for peer-reviewed publications rather than collecting data over long period of time. In industry, publications are important but getting a system up and running and making it robust" *(Workshop participant)*
	Ships of Opportunity	"I've heard of people using cameras on vessels to look at what is at the sea. Any ships could be equipped with cameras. This could give more data"*(Workshop participant)*
	Blue Sky Ideas	"Digital twins of the ocean are already trying to create data standards so scientists' data outputs could be compatible with these larger models" *(Workshop participant)*

INTERVENTION TYPE	RECOMMENDATION	DIRECT QUOTE FROM SCOPING ACTIVITES
Ecosystem-Wide	Thought Leadership	“The market/policy needs to be aware of possibilities and then actively promote them” *(Survey participant)*
	Knowledge Sharing Events	“Profession isolation. Very few people are working on developing or utilizing remote sensing for mapping plastics, of the few, there are very limited (if any) opportunities in the form of conferences or workshops to allow sharing of knowledge and experiences” *(Survey participant)*
	Stakeholder Engagement	“We need to involve in-situ people like policy makers to communicate what types of data are needed vs what scientists are producing” *(Workshop participant)*
	Interdisciplinary Collaboration	Apply ocean circulation, currents and surface windspeed/wave data (along with probabilistic model) as a predictor for where litter is likely to be carried. A better understanding of coastal topography and bathymetry and interaction with waves/currents/tides as a predictor to which beaches or seabed features are particularly susceptible to accumulations of litter *(Survey participant)*
	International Collaboration	“Encourage collaborations and exchange visits. In addition, creating unique funding opportunities to allow researchers to procure data or equipment might also help. Related to the same, creating mechanisms for renting out equipment, especially between the global north and south, it can help a lot” *(Survey participant)*
	Develop a Taskforce	“We must not think in isolated spaces, but if we are thinking of a whole line from research to policy, we need some kind of large-scale structure that can be shared between stakeholders and effectively managed” *(Workshop participant)*
	Monitoring and Reporting Requirements	“If you can make your intervention at the coast before it goes out to sea, you can mitigate it before it disperses into the ocean and becomes bio-fouled and sinks. Greater potential for impact with coastal monitoring” *(Workshop participant)*
	Capacity Building	“Global policy and integrating remote sensing technologies as potential solutions” *(Survey participant)*

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