

Detecting Plastic Across the Land-to-Sea Continuum: A Unified Space-Based Observing Strategy for Terrestrial and Aquatic Plastic Pollution

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Executive Summary

Plastic pollution is one of the most visible, fastest growing, and least systematically observed forms of environmental change on Earth today. Mismanaged plastic waste accumulates in informal dumps and agricultural land, is transported by rivers, and ultimately reaches coastlines and the open ocean, yet no operational space-based capability exists to detect, identify, quantify, and track it consistently from source-to-sink across this land-to-sea continuum. A sustained observing capability would direct cleanup and interception to where material has actually accumulated, and supply the outcome indicator against which upstream measures can be evaluated. We propose a coordinated, multi-sensor observing strategy rather than a single monolithic instrument, reflecting the fact that plastic-detection requirements differ meaningfully across the aquatic and terrestrial domains even as they share the same underlying spectral and structural identification principles, combining hyperspectral SWIR and multispectral imaging with complementary radar, fluorescence/lidar, thermal, and polarimetric sensing, supported by a distributed validation network. We recommend that future and planned Earth Observation instruments be explicitly optimized to meet plastic-detection requirements rather than treating this capability as an incidental byproduct of platforms designed for other purposes — in effect, pursuing a dedicated plastic-detection mission or instrument rather than assuming this capability follows automatically from a general-purpose space agency platform. Two decades of peer-reviewed research show that the physical and technological basis for this capability is increasingly mature, even though a sustained operational system does not yet exist.

1. Science Question and Societal Challenge

1.1 Scope of the problem

Global plastic production has grown roughly 230-fold since 1950 and now exceeds an estimated 400 million tonnes annually (OECD, 2022). A substantial share of this class of materials — produced mainly for single-use packaging and short-lived products — escapes formal collection and recycling systems. Because these materials are durable, buoyant in many forms, and fragments rather than fully degrades, they accumulate in multiple Earth-system reservoirs simultaneously (Rangel-Buitrago et al., 2026): informal and unmanaged dumpsites and agricultural lands (Biosphere), rivers and estuaries (Hydrosphere), coastlines — corals, mangroves, salt marshes, beaches — and the open ocean (Hydrosphere/Biosphere), and, as fragmentation proceeds, the atmosphere itself as airborne microplastic (Atmosphere). Aquatic plastic pollution is the most visible and heavily studied of these reservoirs, but a comparable terrestrial-source problem — poorly managed dumps, agricultural film and mulch, and urban litter — is now understood to be a dominant origin of the material that ultimately reaches rivers and coasts (Lamb et al., 2018; Walther and Bergmann, 2022; UNEP, 2021, 2023; Kruse et al., 2023; Rillig et al., 2024). Long-lasting floating plastics provide a persistent substrate for fouling species, enabling them to cross historical biogeographic boundaries and reach distant ecoregions (Carlton et al., 2017), with potential biological invasions and significant consequences for pelagic ecosystems (Haram et al., 2023). The increasing frequency and intensity of climate-related extreme events may further enhance the input and redistribution of plastic into the marine environment through maritime incidents and natural disasters.

The consequences of this accumulation extend across the food web and, increasingly, to human health. A synthesis of ingestion and entanglement records found impacts on 914 marine species — including ingestion in more than half of studied marine mammal species, over 40% of studied seabird species, and all studied sea turtle species — through blockage, starvation, and injury (Kühn and van Franeker, 2020; Santos et al., 2021; Perold et al., 2024). As larger debris fragments into microplastics and nanoplastics that enter food, water, and air, a growing body of animal and emerging human evidence has linked exposure to endocrine disruption and adverse reproductive outcomes, including altered hormone levels and the direct detection of plastic particles in human placental tissue (Barboza et al., 2018; Ragusa et al., 2021; Xu et al., 2024; Zurub et al., 2024; Chartres et al., 2024; Thompson et al., 2024; Landrigan et al., 2025). These findings elevate plastic pollution monitoring from a primarily environmental concern to one with direct public-health relevance, reinforcing the case for systematic observation of where this material accumulates and how it moves across the land-to-sea continuum.

1.2 A land-to-sea Earth-system question

The central science question is not simply how much plastic is present in the ocean, but rather: where does plastic accumulate across the land-to-sea continuum, at what rate does it move between reservoirs, and how can these fluxes be observed with enough consistency to inform mitigation, interception, and policy? This is inherently an Earth-system question because no single sphere captures it. Rivers are the dominant conduit linking terrestrial mismanaged waste to ocean input, and this concentration is not diffuse (Weiss et al., 2021; Gonzalez-Fernandez et al., 2021; van Emmerik et al., 2022; Gnann et al., 2026). Just over 1,000 rivers account for roughly 80% of riverine plastic emissions to the ocean (Meijer et al., 2021), meaning a targeted rather than uniform-coverage observing strategy is scientifically justified and operationally feasible. Floating aggregations (“windrows”) are similarly strategic, observable targets for tracking that transport (Cózar et al., 2021). The physical oceanography governing where floating debris subsequently accumulates — in convergence zones, coastal retention areas, and ocean gyres — is reasonably well modeled, but requires observed source terms and boundary conditions that do not currently exist at global scale (van Sebille et al., 2020; Chaturvedi et al., 2020). On land, informal dumps and agricultural plastic films are simultaneously a Biosphere land-cover signature and a direct predictor of Hydrosphere input; mapping one without the other leaves half of the transport pathway unconstrained.

1.3 Community recognition of the observational gap

This gap is not newly identified. A community white paper for the prior decadal cycle called for dedicated marine-debris-sensing mission concepts (Maximenko et al., 2016), and a subsequent effort proposed an “Integrated Marine Debris Observing System” spanning satellite, aircraft, and in-situ elements (Maximenko et al., 2019); the first systematic assessment of space-based observation requirements followed the same year (Martínez-Vicente et al., 2019; Martínez-Vicente et al., 2020), and literature reviews (Vighi et al., 2022; GIZ, 2023; Guan et al., 2026) and stakeholder recommendations (UNEP, 2021; NASEM, 2022; UN Secretariat, 2025) continue to indicate the relevance of remote sensing as the missing source of complementary information about aquatic plastics. Despite a decade of community input, no dedicated operational capability exists, and current detections rely on repurposing ocean-color and land-imaging missions not designed for the task, with real, well-documented limitations (Hu, 2021, 2022, 2025). Addressing this gap would advance decadal-survey priorities under the Hydrosphere theme (coastal and ocean water quality, land–ocean material exchange) and the Biosphere themes (ecosystem health, land-cover and land-use characterization).

1.4 Domestic and global policy context

The importance of this capability is reinforced by recent national and state findings. The United States generates more plastic waste by weight and per capita than any other nation as of 2016 (Law et al., 2020). A National Academies consensus study explicitly recommended a nationally coordinated, expanded monitoring system to track plastic pollution, identify its sources, and measure progress against reduction targets (NASEM, 2022). That report’s central conclusion — that the absence of regular, standardized data collection is itself a barrier to understanding U.S. contributions — is precisely the gap a space-based observing capability is positioned to close.

State-level action reinforces the same conclusion. In February 2022, California’s Ocean Protection Council (CA OPC) adopted the nation’s first Statewide Microplastics Strategy, a multi-year roadmap for the state to assume a national and global leadership role in microplastics management (CA OPC, 2022), whose science-track pillars — monitoring trends, prioritizing sources and pathways, assessing risk thresholds, and evaluating solutions — map directly onto the deliverables described in Section 2. States are moving faster on policy than on the means to verify it: extended producer responsibility statutes in seven states, including California’s statutory 25 percent packaging reduction requirement by 2032 (SB 54, 2022), set measurable targets with no environmental verification mechanism, underscoring the state- and regional-level demand a national space-based observing capability could serve.

Internationally (ESA, 2020; UNEP, 2021), UNEP member states have been negotiating a legally binding global plastics treaty since 2022 (pursuant to UN Environment Assembly resolution 5/14); as of this writing, five negotiating sessions have not yet produced a final agreement, and the committee reconvened under new leadership in early 2026. Provisions on monitoring and verification in successive draft texts remain largely non-binding and rest on national self-reporting, with no independent means of confirming reported figures against observed conditions. This gap is drawing attention: the SDG 14.1.1 plastic debris density indicator remains Tier III for lack of an established methodology, though its own framework already designates Earth observation as a core data source (UNEP, 2021), and the Third UN Ocean Conference in Nice (June 2025) further underscored remote sensing’s role in closing it. U.S. Earth observation assets are well positioned to contribute to this developing MRV architecture if planning begins now.

2. Utility of the Proposed Measurement / Observing Capability

We propose a coordinated, multi-sensor observing strategy rather than a single monolithic instrument, since plastic-detection requirements differ meaningfully between the aquatic and terrestrial domains even though both rely on the same underlying spectral and structural discrimination principles.

Passive VIS and SWIR reflectance together form the most mature channel, though the two play distinct roles: visible imagery mainly supports anomaly detection — flagging a color or brightness anomaly consistent with debris — while the diagnostic, polymer-specific absorption features enabling material identification, detailed in Section 2.1 (Garaba and Dierssen, 2018, 2020), sit in the SWIR. Even together, a resilient observing capability should not depend on passive reflectance alone. Multi-angle polarimetry exploits the fact that plastic surfaces are commonly birefringent or semi-transparent and generate distinctive polarized reflectance signatures, particularly under sun-glint geometries (Parrish et al., 2023; de Fockert et al., 2024; Herrera et al., 2025; Consola and Camps, 2026); laboratory and radiative-transfer studies of the polarized light-scattering properties of microplastics (Koestner et al., 2023, 2024; Foster et al., 2025) are directly relevant to NASA’s PACE mission, whose HARP2 and SPEXone polarimeters were not designed for plastic detection but currently offer a first operational opportunity to test the technique from orbit. Polarimetry need not be stand-alone: integrated with standard VIS/SWIR channels at the same wavelengths, it also improves atmospheric correction and suppresses natural ocean-surface clutter, reducing false positives — a capability future mission concepts could incorporate deliberately rather than incidentally. Active fluorescence and LiDAR techniques offer a complementary route to submerged and low-light detection: laboratory and at-sea trials of hyperspectral and laser-diode fluorescence LiDAR have demonstrated discrimination of several plastic polymers from natural dissolved organic matter and water Raman signals, including in submerged and night-time conditions where passive reflectance cannot operate (Palombi and Raimondi, 2022; Cadondon et al., 2024; Mahmoud and El-Sharkawy, 2024; Foster et al., 2025). An ESA-funded feasibility study investigated backscatter, fluorescence, and Raman LiDAR for detecting and characterizing raw, marine-harvested, and biofouled plastics in the laboratory and at sea (Raimondi et al., 2023, 2024), and a NASA-funded concept study characterized the fluorescence signatures of beached, netted, and biofouled plastic samples in the laboratory and these data informed the construction of an airborne instrument and the future design of a spaceborne system (Cowell et al., 2025). Thermal infrared sensing offers a third complement, exploiting thermal emissivity and surface temperature rather than reflected sunlight, and has been demonstrated from suborbital platforms for day and night floating-litter detection (Goddijn-Murphy and Williamson, 2019; Goddijn-Murphy et al., 2022). SAR and related microwave techniques add an all-weather channel: Sentinel-1 C-band imagery has detected large floating aggregations

via wave-damping and backscatter anomalies at river dams (Simpson et al., 2022), and the CYGNSS constellation has been explored for spaceborne ocean-microplastic sensing (Evans and Ruf, 2021), though not all aggregations produce a SAR anomaly and SAR alone cannot distinguish plastics from other floating material, requiring confirmation from an optical or thermal channel. No single sensing technology is adequate across all litter types and conditions (GIZ, 2023; Goddijn-Murphy et al., 2024; de Fockert et al., 2024; Kato et al., 2026; Guan et al., 2026), so the strategy proposed here is explicitly multi-modal, using SWIR reflectance to “fingerprint” plastics and VIS-NIR to flag anomalies, with polarimetric, fluorescence/LiDAR, thermal, and radar as targeted complements. Sections 2.1–2.2 describe how these channels come together in the aquatic and terrestrial domains; Section 2.3 turns to how the two connect, since neither alone captures the land-to-sea transport at the heart of the problem.

2.1 Aquatic detection (ocean, coastal, riverine)

Plastics exhibit diagnostic absorption features in the SWIR arising from polymer C–H bond overtones, distinguishing them spectrally from water, foam, sea ice, and biogenic material such as Sargassum and algal mats (Garaba and Dierssen, 2018, 2020; Knaeps et al., 2021; Moshtaghi et al., 2021; Ohall et al., 2025). These features underlie essentially all optical plastic-detection algorithms developed over the past decade, including Sentinel-2-based plastic and windrow indices (Biermann et al., 2020; Themistocleous et al., 2020; Arias et al., 2021; C  zar et al., 2024), indices applied to hyperspectral PRISMA data (Kremezi et al., 2021, 2022; Taggio et al., 2022; Corbari et al., 2023), and the MARIDA benchmark dataset used to train and compare machine-learning classifiers (Kikaki et al., 2022). A dedicated hyperspectral capability with adequate SWIR sampling and signal-to-noise would substantially improve on today’s opportunistic use of ocean-color and land-imaging missions, whose coarse spectral sampling is a documented source of false positives and ambiguous detections given the ubiquity of non-plastic floating materials such as algae mats and scums (Hu, 2021, 2022, 2025; Qi et al., 2026). Complementary radar and thermal sensing extend detection to cloudy and low-light conditions and provide independent confirmation of large floating aggregations through wave-damping and thermal-contrast signatures, though their use remains exploratory (Goddijn-Murphy & Williamson, 2019; Evans & Ruf, 2021; Simpson et al., 2022; Qi et al., 2022; Sun et al., 2023; Hadjal et al., 2025). For rivers, image-based transport-quantification methods already demonstrate that discharge-normalized macro-debris flux can be estimated from repeat imagery at bridges and choke points (Kataoka & Nihei, 2020), directed studies have begun testing which direct and indirect river signals are detectable from orbit (Schreyers et al., 2022), and fine-resolution multispectral imagery has been demonstrated for general detection, quantification, and tracking of riverine floating litter (Mohsen et al., 2023; Garaba and Park, 2024; Acuna-Ruz et al., 2026; Perez-Garcia et al., 2026).

2.2 Terrestrial detection (informal dumps, agricultural plastic, urban litter)

Very-high-resolution multispectral imagery has been used to derive normalized-difference plastic indices that discriminate plastic sheeting and film from other urban and agricultural surfaces (Guo and Li, 2020), and comparable indices map plastic-covered greenhouses using Sentinel-2 (Aguilar et al., 2022; Zhang et al., 2022). A global-scale demonstration combined commercial very-high-resolution imagery with deep-learning classifiers to map terrestrial plastic-waste sites across dozens of countries, providing early evidence this approach can scale from local case studies to a global product (Kruse et al., 2023). Most directly relevant to this proposal, NASA’s EMIT imaging spectrometer — an ISS-hosted VSWIR instrument built for an unrelated purpose — has now been used to detect HDPE and PVC absorption signatures at global scale using a column-wise adaptive matched filter and an open-access spectral library, providing the first orbital, hyperspectral, land-focused demonstration of essentially the capability this white paper recommends (Estrela et al., 2025). This builds on a longer airborne heritage: nearly a decade earlier, AVIRIS imagery was used to map synthetic-hydrocarbon signatures at a Southern California landfill using the same diagnostic SWIR features EMIT now exploits from orbit (Garaba and Dierssen, 2018), establishing that hyperspectral imaging — airborne or spaceborne — resolves terrestrial plastic independent of the aquatic case. AVIRIS combined with ASI PRISMA imagery has likewise improved detection of plastic greenhouses (Despini et al., 2025), and a more recent experiment using open-access PRISMA, EnMAP, and EMIT imagery mapped LDPE greenhouse structures across diverse geographic locations using the same SWIR characteristics (Garaba, 2026). Complementary work has mapped informal dumps and cleanup priorities in under-observed coastal

megacities (Dasgupta et al., 2022; Nahid Ferdous et al., 2024), and land-based UAS litter surveys provide a validation pathway analogous to the beach- and coastal-litter protocols already standardized for the aquatic domain (Andriolo et al., 2020, 2021; Gonçalves et al., 2020; Swanepoel et al., 2023).

2.3 Connecting land and water: quantifying flux

The greatest scientific value of a coordinated capability lies not in either domain alone but in pairing them. A terrestrial source map combined with river and coastal detection would, for the first time, allow direct observational estimation of land-to-river-to-ocean mass flux rather than the model-based apportionment used today, providing essential validation and boundary-condition data for the Lagrangian ocean-transport models the community already relies on (van Sebille et al., 2020). Purpose-built modeling tools illustrate the kind of observational input this capability would provide; the examples named here are part of a broader and growing modeling ecosystem. In the ocean, PlasticParcels — an open-source Lagrangian particle-tracking package built on the Parcels framework for simulating plastic dispersal and testing settling, degradation, and beaching parameterizations (Denes & van Sebille, 2024) — sits alongside other transport models such as Onink et al. (2021) and the near-real-time plastic tracer model of Maximenko and Hafner (2024). On land, the Plastic Pathfinder is an early terrestrial counterpart, simulating wind- and runoff-driven macroplastic mobilization and transport across river basins and identifying where terrestrial pollution enters freshwater systems (Mellink et al., 2022). These models currently run on assumed or sparsely observed source terms rather than direct measurements. A coordinated observing capability would let their parameters be calibrated against actual detections, meaningfully tightening the land-to-ocean mass-flux estimates on which cleanup prioritization and policy depend. Realizing this potential will also require a coordinated data-management framework linking satellite detections with in-situ observations — standardized metadata, harmonized measurements, persistent archives, and interoperable products essential for comparing observations across platforms and time. This capability also has immediate applications value: rapid response assessment following storms, floods, and tsunamis has already been demonstrated with existing sensors (Matthews et al., 2017; Hu et al., 2023; Qi et al., 2024; Jiao et al., 2026), and a dedicated, higher-revisit capability would make this response systematic rather than opportunistic, supporting cleanup and river-interception infrastructure investment (Dasgupta et al., 2022; Acuna-Ruz et al., 2026). The same observations would also serve a distinct verification function: extended producer responsibility targets and international treaty provisions currently rest on self-reported figures with no independent means of confirmation (Section 1.4), and systematic land-to-sea observation would provide exactly that check.

3. Key Measurement Requirements

Requirements fall into two categories that should be specified separately. Table 1 summarizes the demonstrated capability, principal limitation, and plastic-specific requirement for each instrument technology introduced in Section 2. Table 2 summarizes the cross-cutting, mission-level requirements — coverage, latency, resolution, and validation — that apply regardless of instrument. Two points merit emphasis. First, adequate signal-to-noise in diagnostic SWIR windows (e.g., ~1045, 1215, 1660, 1732, 2310 nm) is what separates genuine polymer identification from color- or brightness-based proxy detection (Garaba and Dierssen, 2020; de Vries et al., 2023; Ohall et al., 2025). Second, nominal temporal revisit in Table 2 is a best-case, clear-sky number. Cloud cover routinely reduces usable observations well below the nominal repeat, particularly over tropical and monsoon-affected regions where several of the highest-emitting rivers are located (Meijer et al., 2021), so an operational capability needs a faster nominal revisit or an all-weather complement (e.g., SAR, thermal).

4. Likelihood of Achieving within the Decadal Time Frame

4.1 Heritage and near-future instruments

Table 1 summarizes the demonstrated capability, principal limitation, and plastic-specific requirement for each relevant instrument technology. Aquatic detection has real heritage, but each existing or planned platform carries a specific, documented gap. NASA’s PACE Ocean Color Instrument, launched in 2024, offers a ~2-day global revisit but only ~1 km spatial sampling — far coarser than most plastic aggregations — and its polarimeters (HARP2, SPEXone) were not designed for plastic detection, though already being

explored for it (Koestner et al., 2023, 2024; Foster et al., 2025). The ISS-hosted EMIT imaging spectrometer has moved beyond a technology precursor to an operational demonstration, detecting LDPE, HDPE and PVC signatures on land at global scale (Estrela et al., 2025; Garaba, 2026); however, its ISS-based data collection is opportunistic and irregular rather than systematic, limiting its use for tracking episodic events.

NASA’s Surface Biology and Geology effort, recently restructured as the cost-capped, Explorer-class EAGLE-VSWIR mission, is the most directly relevant program of record. Its existence should not be read as evidence that the observational gap in Section 1.3 is already closed. EAGLE-VSWIR inherits baseline design parameters (~30 m spatial sampling, ~16-day equatorial revisit) optimized for mineralogy and vegetation objectives rather than plastic detection, and its accelerated, cost-capped timeline increases the risk that plastic-specific requirements are traded away by default. Protecting plastic-diagnostic band placement, adequate SNRs, and finer spatial/temporal sampling for planned and successor missions is the single highest-leverage action available to the decadal survey.

A further distinction matters here. Multispectral sensors can detect a spectral anomaly consistent with plastics, supporting quantity/extent mapping at high revisit and low cost, but their handful of broad bands cannot resolve the narrow polymer-specific SWIR features needed to determine composition; only hyperspectral sensors provide that finer identification capability with low risk of spectral ambiguities (Table 1). Commercial hyperspectral capability now exists in principle — Planet’s Tanager constellation shares design and processing heritage with EMIT and has been on orbit since September 2024 — but it has not yet been demonstrated for plastic detection specifically, and its imagery is not currently offered as open-access data.

Two further institutional factors bear on feasibility. First, relying on a constellation of commercial or international assets to achieve adequate revisit requires cross-sensor harmonization and verifiable calibration (Table 2); without it, differences between platforms can be mistaken for genuine detection signal. Second, government-provided calibration and validation carry a trust value — a fidelity assurance — that commercial data alone does not yet establish for many regulatory users. NASA and partner agencies are positioned to provide this function even where data are commercially sourced.

4.2 Algorithm and data maturity

The volume and diversity of existing peer-reviewed work is substantial. The IOCCG’s Task Force on Remote Sensing of Marine Litter and Debris (RSMLD) bibliography exceeds 280 entries spanning spectral-library development, index-based detection, and machine-learning benchmarks, most published within the past six years — including open spectral-reflectance datasets (Knaeps et al., 2021; de Vries et al., 2023; Ohall et al., 2025), benchmarked classifiers (Mifdal et al., 2021; Kikaki et al., 2022), and reproduced detection indices (Biermann et al., 2020; Themistocleous et al., 2020; Arias et al., 2021). This places core algorithms at approximately TRL 4–6; the primary remaining gap is operational validation at TRL 7–9, requiring dedicated calibration and validation rather than further algorithm development alone.

4.3 International and commercial partnerships

The decadal survey does not need to build this capability alone. Japan’s Ministry of the Environment has issued formal guidelines for remote-sensing-based marine litter monitoring (Isobe et al., 2024); ESA’s Sentinel-1/2 record and the planned Copernicus Hyperspectral Imaging Mission (CHIME) provide complementary capability; and Italian (PRISMA) and German (EnMAP) missions have already supported operational demonstrations (Taggio et al., 2022; Corbari et al., 2023; Garaba, 2026). IOCCG functions as an existing coordination body (Garaba et al., 2021) a U.S.-led effort could build on rather than duplicate.

4.4 Workforce, infrastructure, and institutional considerations

The research community is productive but unevenly distributed. Most of the 280+ RSMLD publications originate from Europe, Japan, and North America, while the highest-emitting source regions — much of South/Southeast Asia and West Africa — remain under-represented in both the validation-data record and trained workforce (Dasgupta et al., 2022; Kruse et al., 2023; UN Secretariat, 2025). A decadal-scale investment should fund capacity-building in these regions, both to close this gap and ensure local usability, not only global-scale science. Equally important is institutional ownership. A sustained operational product requires an identified agency home — NASA, NOAA, or an international partner — and its absence is a

central reason a decade of community calls (Maximenko et al., 2016, 2019, 2022) has not yet produced an operational system. This should extend to long-term data stewardship: sustained archival, quality control, harmonization, and public dissemination of both satellite-derived products and validation observations, using existing federal infrastructure to keep these records discoverable and reusable.

4.5 Overall assessment

We assess likelihood by capability type, since the same pattern emerges across domains. Sensing technology and physical basis: HIGH, given the heritage in Table 1 and Section 4.1. Algorithm and analysis maturity: MODERATE — algorithms are demonstrated across multiple sensors and geographies (Section 4.2), but operational validation (TRL 7–9) is lacking, and terrestrial mapping remains demonstrated rather than operationalized (Kruse et al., 2023). Polymer-type discrimination at global scale: MODERATE-LOW, constrained by spatial resolution, SNR, and natural-material spectral confusion (Hu, 2021, 2022, 2025). Together, these point the same way: the technology is ready, but algorithm maturity and composition-level discrimination will not advance without a mission optimized for plastic detection.

5. Contextual Considerations

Beyond the policy context outlined in Section 1.4, two further points merit mention. First, the geography of the problem raises an environmental-justice dimension: the terrestrial and riverine sources most in need of observation are disproportionately in lower- and middle-income coastal nations with the least ground-validation infrastructure and fewest resources for independent monitoring (Dasgupta et al., 2022; Kruse et al., 2023), a burden that falls especially on island nations accumulating disproportionate transboundary debris across vast exclusive economic zones with limited capacity for in situ validation (Lavers and Bond, 2017; Burt et al., 2020). A decadal investment that does not also fund regional capacity-building risks reproducing an asymmetry in which the highest-emitting regions remain least studied. Second, plastic pollution is a compelling example of the “Earth as a unified, dynamic system” framing the survey has adopted: it cannot be understood, let alone mitigated, through a single-sphere lens, and demonstrates the cross-cutting relevance the committee may wish to highlight in its final report.

6. Summary Recommendations

We recommend that the ESAS 2028 decadal survey (see also Garaba et al., 2025, reaching similar conclusions independently at IOCS 2025):

- Designate plastic pollution detection and quantification as an explicit cross-cutting science and applications target spanning the Hydrosphere and Biosphere themes, rather than a niche ocean-only application.
- Optimize SWIR band placement and signal-to-noise for plastic diagnostics in the next hyperspectral, ocean-color, or coastal-imaging mission(s) — in effect, pursue a dedicated plastic-detection mission or instrument rather than assume this follows automatically from a general-purpose platform such as EAGLE-VSWIR.
- Engage commercial hyperspectral providers to validate existing sensors (e.g., Tanager-class constellations) for plastic detection.
- Fund a coordinated, internationally partnered calibration and validation network that prioritizes currently under-observed, high-leakage regions rather than concentrating further effort where infrastructure already exists.

Table 1. Instrument technologies: program of record, demonstrated capability / key limitation, technology readiness level (TRL, 1–9 scale, authors’ assessment specific to the plastic-detection application), and plastic-specific requirement.

Technology	TRL	Program of record	Demonstrated capability / key limitation	Plastic-specific requirement
Multispectral	7	Sentinel-2, Landsat 8/9; commercial VHR (e.g., WorldView-3, PlanetScope)	High revisit (sub-daily to weekly), low cost, proven for quantity/extent mapping of suspicious features on land and water (Kruse et al., 2023; Guo and Li, 2020; Biermann et al., 2020; Garaba and Park, 2024; Acuna-Ruz et al., 2026). Limitation: a handful of broad bands cannot resolve polymer-specific absorption features or determine composition; persistent spectral confusion with Sargassum, Ulva, foam, driftwood, pollen, and algae scums (Hu, 2021, 2022, 2025).	Maintain for broad-area screening; pair with hyperspectral confirmation wherever composition matters
Hyperspectral	6-7	EMIT (ISS); PACE OCI; EAGLE-VSWIR; PRISMA (ASI); EnMAP (DLR); commercial Tanager (Planet)	Only technology resolving polymer-specific SWIR absorption features; demonstrated at global scale from ISS for land plastic (Estrela et al., 2025; Garaba 2026) and from PRISMA/EnMAP for aquatic plastic (Corbari et al., 2023; Taggio et al., 2022). Limitations vary by platform: EMIT’s ISS orbit gives irregular, opportunistic revisit; PACE OCI is only ~1 km (Martínez-Vicente et al., 2019); EAGLE-VSWIR baseline (~30 m, ~16-day revisit) is not optimized for plastic bands; Tanager exists commercially but is undemonstrated for plastic and is not freely available.	Protect plastic-diagnostic SWIR band placement and SNRs in the next sustained, high-revisit hyperspectral mission
Thermal infrared	5-6	Landsat TIRS; ASTER (Terra); UAV-based FLIR systems	Day/night detection independent of reflected sunlight; UAV-demonstrated (Goddijn-Murphy & Williamson, 2019; Goddijn-Murphy et al., 2022). Limitation: spaceborne spatial resolution far too coarse (Landsat TIRS ~100 m, ASTER ~90 m); hyperspectral TIR not yet applied to plastic from air or space. Practical application still needs to be demonstrated.	Conduct more feasibility studies; improve spaceborne TIR spatial resolution; couple with VSWIR as a night/cloud complement; exploratory in nature
SAR / microwave	7	Sentinel-1 (C-band); TerraSAR-X/TanDEM-X (X-band); CYGNSS (GNSS-R); Capella and Ice-Eye (X-band)	All-weather, day/night detection of large floating aggregations (Simpson et al., 2022; Evans & Ruf, 2021). Limitation: cannot itself distinguish plastic from other floating material; anomaly-only, requires independent confirmation; plastic detectability is very low.	Conduct more feasibility studies; combine with optical/thermal confirmation; not a stand-alone detection channel; exploratory in nature
Polarimetry	4	PACE (HARP2, SPEXone) — not designed for plastic detection	Adds glint-geometry contrast and independent diagnostic data at standard VSWIR wavelengths; laboratory and radiative-transfer studies of polarized light scattering by microplastics (Koestner et al., 2023, 2024; Foster et al., 2025). Improved atmospheric correction of VSWIR channels, suppressed scene clutter. Limitation: real-ocean plastic concentrations are largely below current passive polarimetric detection thresholds; early-stage research.	Conduct more feasibility studies; integrate polarimetric sensitivity alongside standard VSWIR radiometric channels in future mission concepts rather than as a standalone payload.
Fluorescence / Lidar	4	Laboratory and at-sea prototypes (e.g., NASA-funded FLORO concept study continued to FLORA; ESA-funded BLUE feasibility study)	Submerged and night-time detection with early polymer discrimination in lab settings (Palombi & Raimondi, 2022; Cadondon et al., 2024; Mahmoud & El-Sharkawy, 2024; Cowell et al., 2025). Limitation: demonstrated only in laboratory/proximal settings; deployment from a satellite platform remains a major open question.	Conduct more feasibility studies; assess satellite feasibility as a targeted, non-primary channel; explore the concept of tip-and-queue with larger swath instruments

Table 2. Cross-cutting mission-level requirements, independent of instrument technology.

Parameter	Requirement	Rationale (selected citations)
Spectral coverage & sampling	VSWIR 400–2500 nm; ≤10 nm sampling in diagnostic SWIR windows (~1215, 1732, 2310 nm)	Polymer-specific C–H overtone absorption is the primary basis for material ID and discrimination from natural clutter (Garaba and Dierssen, 2018, 2020; Knaeps et al., 2021; Moshtaghi et al., 2021)
Spatial resolution	≤10 m broad-area screening; ≤3–5 m at river mouths, coastlines, and dump sites; sub-meter via tasked VHR/UAS confirmation	Floating aggregations and stranded litter are frequently sub-pixel at 10–30 m (Biermann et al., 2020; Guffogg et al., 2021; Hu, 2022; Kikaki et al., 2022)
Temporal revisit	~2-5 day nominal global revisit; sub-daily to daily tasking at hotspots / episodic events. Treated as a clear-sky best case only — cloud cover routinely reduces usable observations well below the nominal repeat, especially over tropical/monsoon river-mouth regions	Debris presence is highly episodic; dedicated requirements work specifies sub-daily to ~24-hour revisit for river-discharge and spill scenarios specifically (Martínez-Vicente et al., 2019); cloud-degraded revisit undersamples true flux (Cózar et al., 2021; Kataoka & Nihei, 2020)
Coverage / priority sites	Global coastlines; highest-emitting river mouths; documented terrestrial informal-dump and agricultural-plastic hotspots	Just over 1,000 rivers account for ~80% of riverine plastic emissions, and terrestrial mismanaged-waste leakage concentrates in a comparatively small number of coastal nations (Meijer et al., 2021; Kruse et al., 2023; Dasgupta et al., 2022)
Latency	<24 hours for operational/alerting products; days–weeks acceptable for climate-quality products	Supports both rapid response (disaster debris, interception operations) and long-term Earth-system trend detection
Continuity	>10-year uninterrupted, cross-calibrated record	Natural variability (wind, currents, seasonal river discharge) is large relative to the pollution-trend signal (Herman & Węśławski, 2022)
Radiometric performance	SNRs sufficient for sub-pixel spectral unmixing of low areal-fraction targets and for spectral discrimination of polymers using the low-signal SWIR bands	Most real-world scenes have low fractional plastic cover; abundance retrieval requires unmixing, not just detection (Cerra et al., 2024; Hu, 2022; Kremezi et al., 2021, 2022; Qi and Hu, 2021)
Cross-sensor harmonization	Common calibration/validation standards where multiple platforms (government, international, commercial) are combined to meet revisit targets	Differences in spectral response, calibration, and geolocation between platforms can otherwise be mistaken for genuine detection signal; government-provided calibration/validation carries a trust value commercial data alone does not yet establish for many regulatory users
Validation infrastructure	Distributed in-situ / UAS / citizen-science network with harmonized sampling, metadata, and reporting protocols, supported by a centralized, openly accessible archive of validation observations.	Needed to calibrate/validate products and resolve persistent spectral confusion with Sargassum, foam, and other natural floating materials (Hu, 2021, 2022, 2025; Isobe et al., 2024). A sustained archive would also enable reproducible algorithm evaluation, cross-mission comparisons, and reprocessing as detection algorithms and satellite sensors evolve.

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