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Review

Aerial Remote Sensing of Aquatic Microplastic Pollution: The State of the Science and How to Move It Forward

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Abstract: Microplastics (MPs) are pervasive environmental contaminants in aquatic systems. Due to their small size, they can be ingested by aquatic biota, and numerous negative effects have been documented. Determining the risks to aquatic organisms is reliant on characterizing the environmental presence and concentrations of MPs, and developing efficient ways to do so over wide scales by means of aerial remote sensing would be beneficial. We conducted a systematic literature review to assess the state of the science of aerial remote sensing of aquatic MPs and propose further research steps to advance the field. Based on 28 key references, we outline three main approaches that currently remain largely experimental rather than operational: remote sensing of aquatic MPs based on (1) their spectral characteristics, (2) their reduction of water surface roughness, and (3) indirect proxies, notably other suspended water constituents. The first two approaches have the most potential for wide-scale monitoring, and the spectral detection of aquatic MPs is seemingly the most direct approach, with the fewest potential confounding factors. Whereas efforts to date have focused on inherently challenging detection in coarse-resolution satellite imagery, we suggest that better progress could be made by experimenting with image acquisition at much lower altitudes and finer spatial and spectral resolutions, which can be conveniently achieved using drones equipped with high-precision hyperspectral sensors. Beyond developing drone-based aquatic MP monitoring capabilities, such experiments could help with upscaling to satellite-based monitoring for global coverage.

Keywords: debris; earth observation; freshwater; image analysis; litter; methods; oceans; plastic; pollutants; waste

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1. Introduction

Microplastics (MPs) are ubiquitous environmental contaminants globally, including in marine and freshwater systems [1]. They are plastic particles less than 5 mm in size that can enter the environment as primary MPs or through the breakdown of larger plastic objects, and can be considered a complex contaminant class due to their high variability (e.g., plastic type, particle shape and size, weathering; [2]). MPs are small enough to be ingested by aquatic biota of all sizes, including microscopic plankton [3], and the implications of exposure are not fully known. However, current research efforts are multitudinous, and evidence is mounting that these pollutants can have negative impacts [4]. Effects on aquatic biota have been recorded at all levels of biological organization and include oxidative stress, genetic effects, inflammation, digestive disruption, and reduced growth [4,5], which may be influenced by MPs' chemical additives and/or contaminants or pathogens that can adhere to their surface [1].

One of the most important elements in understanding the risks microplastics pose to aquatic biota is to characterize current real-world exposures and consistently monitor them over time. For example, in Canada alone, an estimated 5000 kilotons of plastic waste is produced per year and is projected to increase [6]; therefore, we may expect MP concentrations to continue rising as these products break down over their long lifespans. Developing methods to efficiently monitor MPs on a wide scale would be highly beneficial and could help fill existing data gaps in monitoring [7,8]. Currently established methods for determining aquatic MP concentrations and characterizing plastics involve collecting water samples followed by specialized laboratory microscopy techniques [9], which are time-consuming, costly, and require sophisticated instruments and high levels of expertise [10], effectively precluding frequent or wide-scale monitoring. While in situ sampling and detailed analyses of this nature cannot be replaced with higher-level monitoring, the benefits of wide-scale techniques could be used to advance various goals, including mapping aquatic MP spatial distributions, examining broad temporal trends, informing modeling of MP fate and behavior in aquatic systems, and identifying sources and hotspots where detailed research can be focused.

Aerial (i.e., satellite-, crewed aircraft-, or drone-based) remote sensing techniques have the potential to fill this gap, but as of yet have been an underdeveloped resource in aquatic microplastic research. Remote sensing relies on the measurement of electromagnetic radiation, i.e., pure energy traveling in the form of waves, with varying wavelengths giving rise to a spectrum that includes, from shortest to longest wavelength: radioactive gamma rays, X-rays, ultraviolet rays, visible light, infrared waves, microwaves, and radio waves. The Sun is a significant source of electromagnetic radiation, and so-called ‘passive’ sensors measure solar radiation that travels down through the Earth’s atmosphere and reflects back up off features and objects on the ground or on or below water surfaces. Alternatively, ‘active’ sensors emit their own radiation toward surfaces and targets and measure the reflected radiation to gain information about the nature and characteristics of the targets. Many studies over the past two decades have employed aerial remote sensing to detect and survey larger floating and beached plastic litter [11], suggesting potential applicability to aquatic microplastics, although publications related to the latter seem to be comparatively sparse.

Our objectives were to assess and summarize the state of the science of aerial remote sensing of aquatic microplastics by means of a literature survey, and to identify potential next steps that are likely to help advance the science. We aim to present this brief critical review in a way that is accessible to non-experts in remote sensing, providing basic background information on relevant remote sensing concepts for the benefit of anyone involved in MP research who may be interested in this topic.

2. Methods

We performed a systematic search for published scholarly papers—including research articles, literature reviews, and conference proceedings—relevant to aerial remote sensing of aquatic microplastics in the Scopus database (Elsevier, Amsterdam, Netherlands). The following string of microplastic-, remote sensing-, satellite-, aerial survey-, and drone-related terms were searched across the combined title, abstract and keywords of indexed documents with the aim of maximizing the discovery of relevant results while limiting the volume of irrelevant results to filter through: “microplastic*” AND (“remote* sens*” OR “satellite*” OR “aerial” OR “aircraft” OR “drone*” OR “unmanned” OR “unoccupied” OR “uncrewed” OR “remotely piloted” OR “UAV*” OR “UAS*” OR “RPA*”).

The initial search returned 179 results (as of 26 July 2024). These were reviewed in Scopus, and papers that appeared definitely or potentially relevant to aerial remote sensing of aquatic MPs based on the title, abstract, and keywords were exported to EndNote (Clarivate, Philadelphia, USA), resulting in an initial batch of 35 tentatively relevant papers. We then reviewed the full texts of the exported papers to identify and retrieve further relevant papers cited within, and discarded several papers deemed insufficiently relevant upon closer examination.

We grouped the final selection of relevant papers among broad themes that emerged over the course of the review process, within which we synthesized and summarized key information collectively gleaned from the papers. Finally, we formulated a concluding discussion of the current state of aerial remote sensing of aquatic MPs and recommendations for future research based on a critical assessment of the literature.

3. Literature Survey

A total of 28 key papers were retained and cited in the following subsections, spanning the years 2016–2024 and including 19 research articles, six literature reviews, and three conference papers. The journals and conference proceedings in which the largest number of key papers were published are *Marine Pollution Bulletin* (5), *Remote Sensing of Environment* (3), *International Geoscience and Remote Sensing Symposium* (2), and *Scientific Reports* (2). Three general approaches to remote sensing of aquatic microplastics were identified: remote sensing based on (1) spectral characteristics, (2) physical water surface effects, and (3) indirect proxies. Simplified representations of the first two approaches are illustrated in Figure 1, and the specifics of all three approaches, along with literature reviews for each, are covered in Sections 3.1–3.3 below.

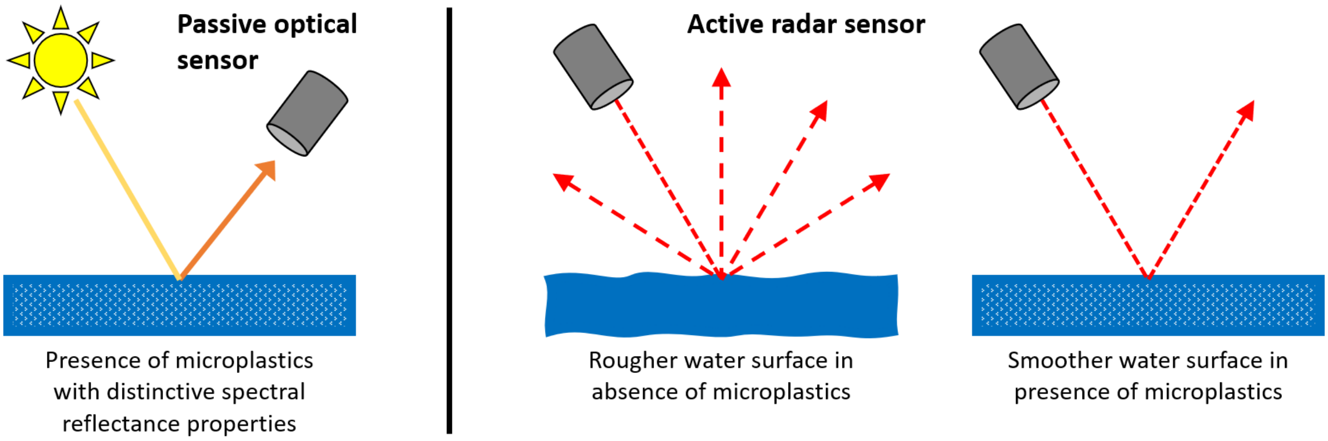


Figure 1. Simplified visual summaries of the two primary approaches to aerial remote sensing of aquatic microplastics: (**left**) based on their spectral reflectance of solar radiation measured with passive optical sensors and (**right**) based on their reduction of water surface roughness measured with active radar sensors.

Several of the review papers we found focused on remote sensing of aquatic MPs to varying degrees. Although they do not provide additional information on the main approaches detailed below, they offer alternative summaries and perspectives that may be of interest to readers and cite additional references that are more loosely related to remote sensing of aquatic MPs, which may also be of interest. In particular, some contain information on remote sensing of larger-size plastic pollution in aquatic environments, which is germane to understanding remote sensing of MPs. Here, we list only the literature reviews that are both significantly focused on remote sensing of aquatic MPs and relatively recent (i.e., published in the last ~3 years): Salgado-Hernanz et al., 2021 [12], Mukonza and Chiang 2022 [13], Park et al., 2022 [14], Veettil et al., 2022 [11], and Ma et al., 2023 [15].

3.1. Remote Sensing of Aquatic MPs Based on Their Spectral Characteristics

Different materials and substances absorb and reflect different wavelengths of incident solar radiation (including visible light) in different proportions (proportion reflected = 'reflectance'; proportion absorbed = 'absorbance'), resulting in unique 'spectral signatures' that can be detected by passive 'optical' sensors that measure reflected radiation. For example, plastics have a distinct spectral signature compared to other materials, and accordingly, the presence of microplastics at or near the water surface should produce a theoretically detectable unique signature. However, it can be expected that the signal is faint due to a combination of the very small size of the particles, their limited concentration relative to the water surface area, and the rapid attenuation (i.e., weakening) of the reflectance signal of submerged features with increasing depth as a result of water's absorption of radiation.

As a potential precursor to aerial optical remote sensing of aquatic MPs, several studies have analyzed the spectral reflectance of marine-harvested MPs in laboratory or outdoor controlled conditions with stationary sensors placed directly above samples, in some cases in a wet state or water suspension to approximate the natural conditions encountered by remote sensing [16–20]. These studies have notably employed 'hyperspectral' sensors capable of precisely measuring spectral signatures by recording numerous (up to hundreds of) narrow and typically contiguous spectral bands (i.e., discrete intervals of the electromagnetic spectrum) that may collectively span the near-ultraviolet (UV) to shortwave infrared (SWIR) regions (~350–2500 nm wavelengths), passing through the visible (~400–700 nm) and near-infrared (NIR; ~700–1000 nm) regions [21]. In contrast, conventional optical cameras record three wide and overlapping bands centered in the visible red, green, and blue (i.e., 'RGB') regions, respectively; while 'multispectral' sensors typically record a larger number of narrower bands that may extend into the NIR and SWIR regions, although the bands are significantly wider and less numerous than those of hyperspectral sensors.

The key findings of these studies are as follows. First, the reflectance of a weathered, marine-harvested mixture of MPs of various plastic types is relatively flat (i.e., indistinctive) in the visible region (meaning RGB sensors will have a limited capacity to detect them) while presenting more pronounced (i.e., distinctive) absorption and reflection peaks in the NIR and particularly the SWIR region (best detected by multispectral or hyperspectral sensors). Second, wet MPs present significantly attenuated reflectance compared to dry MPs, with attenuation increasing with wavelength from ~10% in the near-UV region to ~90% in the SWIR region [17,20]. The spectral characteristics of this environmentally representative MP mixture are illustrated in Figure 2, including a comparison between dry and wet samples. Such a spectral signature poses a challenge for detecting aquatic MPs via aerial remote sensing because water′s absorbance exponentially increases with wavelength across the visible–SWIR range, making particles below ~15 cm in depth likely impossible to detect [22]. It should also be noted that different plastic types (e.g., polyethylene, polypropylene, polystyrene, etc.), when examined individually, present moderately varying spectral signatures [20].

Building on these studies, others [23,24] have aimed to theoretically assess the potential of spaceborne remote sensing of aquatic MPs (among other plastic pollution and debris) based on their known spectral characteristics in relation to the capabilities and specifications of current optical Earth observation satellites. Since MP particles are only a minute fraction of the size of a pixel in a typical satellite image (>1 m to >100 m; also called the 'spatial resolution'), it is expected at minimum that a technique called 'sub-pixel spectral unmixing' will be necessary to identify the signature of MPs among other features (e.g., open water) sharing the same pixel space. Hu [23] in 2021 provided valuable detailed calculations taking into account factors such as measured marine MP concentrations and the sensitivity of satellite sensors, concluding that the particles are unlikely to be detectable. However, they only considered the visible–NIR range, whereas the most distinctive spectral features of MPs are in the SWIR region. Schmidt et al. [24] in 2023—additionally considering the SWIR region—similarly suggested that satellite detection of aquatic MPs, given the coarse spatial resolution of the imagery, may not be possible unless they are present in very high concentrations. Nevertheless, their work facilitates the identification of satellites that could potentially achieve detection based on the positions and widths of their bands in relation to the most pronounced spectral features of environmental aquatic MPs (Figure 2). Among multispectral satellites, MODIS (launched in 2002; free imagery) and WorldView-3 (2014; imagery for purchase) stand out: both have NIR bands aligned with MPs' most pronounced NIR feature at the 931 nm wavelength, although WorldView-3′s band may be too wide to resolve it; both have relatively narrow bands at or very near MPs' most pronounced SWIR feature at 1215 nm; and WorldView-3 additionally has a band aligned with MPs' second most pronounced SWIR feature at 1732 nm. Two more recently launched hyperspectral satellites—PRISMA (2019) and EnMAP (2022), both providing imagery at no cost—have contiguous narrow bands spanning the entire visible–SWIR range, also making them potentially capable of detecting MPs.

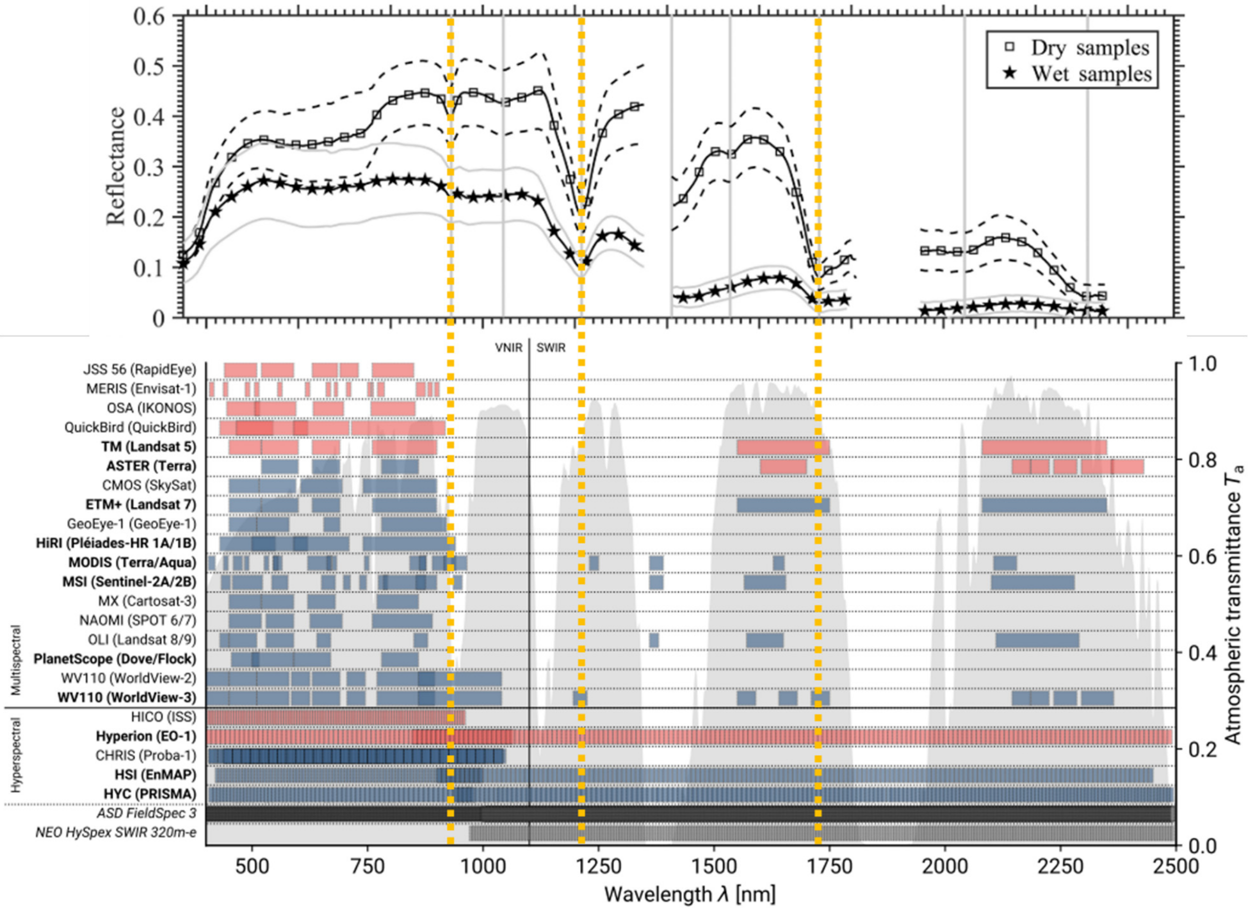


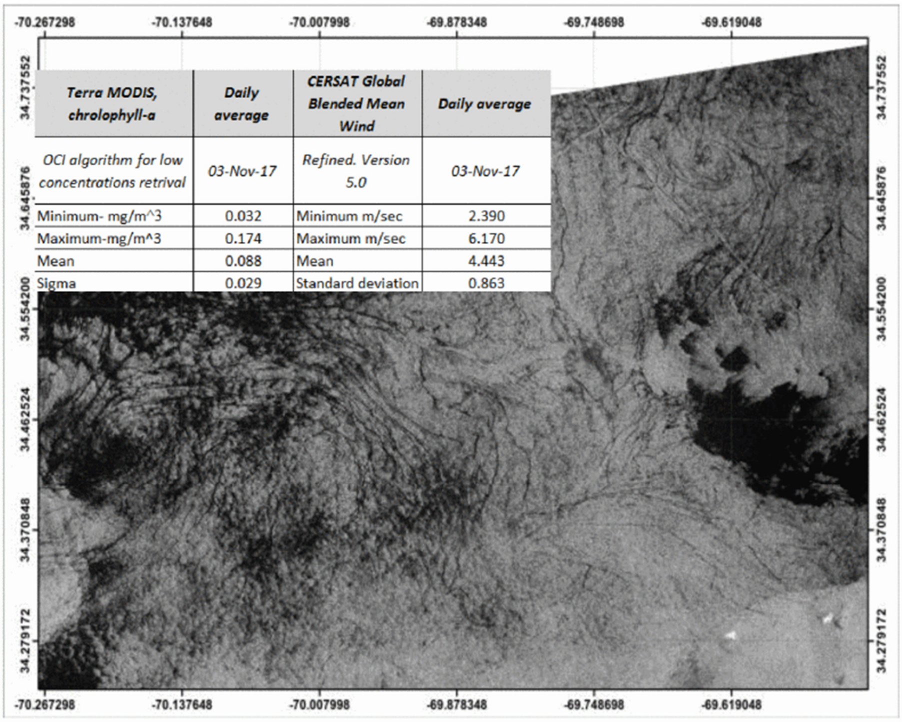
Figure 2. Comparison of the reflected spectral signature of a marine-harvested mixture of microplastics (top illustration, from Garaba and Dierssen [20]) to the spectral band distributions of currently operational (blue) and decommissioned (red) optical Earth observation satellites (bottom illustration, from Schmidt et al. [24]); the orange dotted lines overlaying both illustrations indicate the most distinctive spectral features of microplastics that could potentially be detected by passive satellite-borne sensors, taking into account the atmospheric transmittance of solar radiation.

Despite the skepticism expressed by the authors of these earlier studies, Hong et al. [25] recently (2024) reported successful detection of MPs in the Bohai Sea, China, in MODIS imagery. Rather than directly detecting the spectral signature, they tested for correlations between reflectance levels in MODIS bands and lab-measured MP concentrations in water samples collected from a series of locations throughout the sea. Several correlations were found, most significantly in the two bands corresponding to the most pronounced spectral features of MPs in the SWIR and NIR regions. The correlations were used to create a predictive model of MP concentrations based on MODIS imagery that was then applied to the full extent of the sea, as well as across imagery captured on different dates. However, the authors caution that uncertainties remain in the model and require further investigation. Most recently, Ali et al. [26] employed a similar correlative approach to detect and predict MP concentrations in coastal waters adjacent to Dubai, UAE. Interestingly, they did so solely using NIR bands from the Sentinel-2 multispectral satellite constellation (2015; free imagery), which may have been made possible by significantly higher MP concentrations along the coast of a major urban center than would be expected farther offshore. In contrast, in 2023, Mohsen et al. [27] reported that neither Sentinel-2 nor PlanetScope multispectral satellite imagery was effective for detecting MPs in the Tisza River across Central and Eastern Europe.

3.2. Remote Sensing of Aquatic MPs Based on Physical Water Surface Effects

Inferences can be made about substances and materials at or near the water surface via their effects on surface roughness/smoothness, viscosity, tension, etc.; for example, an oil slick covering the water surface. These effects can be detected by measuring and analyzing the geometric reflective properties of the surface; for example, whether incident radiation scatters from the surface in many directions (indicative of a rough texture), reflects more unidirectionally (smoother texture), or experiences changes in wave polarization (the orientation of the waves in the plane perpendicular to their direction of travel) post-reflection. In remote sensing, such properties are most commonly measured using active sensors such as synthetic aperture radar (SAR) and bistatic radar, which emit pulses of radiation in the microwave region and measure the 'backscatter' that reflects back to the sensor.

Davaasuren et al. [28] were the first, in 2018, to hypothesize that smoother-than-expected ocean surface conditions—assessed via satellite-borne SAR imaging—under certain wind speeds may result from the presence of microplastics (Figure 3). Further research by several of the same authors [29] provided evidence that surface roughness suppression is caused by surfactants—substances that alter water surface tension, and a known by-product of microbial colonization and digestion of MPs—and that the surfactants in their study areas were not associated with other known sources, such as algal blooms. Ghosh and Kumari [30] reported using the same approach to detect MPs in the Yamuna River, India, while Mohsen et al. [27] reported that it was ineffective in the Tisza River. Separately, Evans and Ruf [31] presented a similar approach to detect and quantify concentrations of ocean MPs using satellite-borne bistatic radar. Notably, they showed that MP concentrations predicted by their approach were generally consistent with previous models based on large-scale ocean circulation patterns, but had a better ability to reveal short-term variations. They further noted that detection of the water surface effects required moderate wave-inducing sea surface winds in the range of 3–11 m/s. Sun et al. [32] followed up with controlled laboratory experiments that elucidated the mechanisms and conditions through which surface roughness suppression is induced, demonstrating conclusively that surfactants and not MPs themselves are responsible for the satellite-observed phenomenon.



Terra MODIS, chrolophyll-a	***Daily average***	***CERSAT Global Blended Mean Wind***	***Daily average***
OCI algorithm for low concentrations retrival	*03-Nov-17*	*Refined. Version 5.0*	*03-Nov-17*
Minimum- mg/m^3	0.032	Minimum m/sec	2.390
Maximum-mg/m^3	0.174	Maximum m/sec	6.170
Mean	0.088	Mean	4.443
Sigma	0.029	Standard deviation	0.863

Figure 3. When the water surface is calm, microwave radiation pulses emitted by satellite-borne synthetic aperture radar (SAR) experience mirror-like (i.e., 'specular') reflection from the surface.

Since SAR pulses are emitted at an angle, they reflect away from the sensor, and the water surface therefore appears dark in the resulting image. Under moderate wind conditions, the formation of capillary waves results in a more uneven (or 'rough') water surface that reflects SAR pulses in multiple directions (i.e., 'diffuse' reflection), including back toward the sensor, causing the water surface to appear brighter. The presence of surfactants at the surface generated by microbial digestion of microplastics partially suppresses capillary waves, causing the water surface to be smoother than usual under moderate wind conditions, and therefore appear darker than expected in SAR imagery. In this Sentinel-1 SAR image of the North Atlantic Ocean from Davaasuren et al. [28]—acquired under moderate wind conditions in an area of low chlorophyll-a concentrations (precluding algal bloom-generated surfactants)—it is hypothesized that the patterns of varying water surface brightness result from concentrations of microplastic-related surfactants in the darker areas, where they have caused relative smoothening of the surface.

Another physical water surface property, the refractive index of the surface microlayer, was shown by Ottaviani et al. [33] to affect the degree of polarization of reflected SWIR radiation, as measured by an airborne passive polarimeter. They demonstrated the detection of this effect caused by an ocean oil slick and suggested that other water surface entities, including MPs, may produce a similar effect; however, to date, this avenue has not yet been pursued further in the case of MPs.

3.3. Remote Sensing of Indirect Proxies for Aquatic MPs

While the remote sensing approach detailed in the preceding section relies on a proxy (surfactants) that directly results from the presence of microplastics, other studies have revealed or investigated other indirect proxies for MPs. In most cases [27,34–36], these were various suspended water constituents (e.g., chlorophyll-a, particulate matter, sediment, dissolved organic matter) that are detectable via satellite-borne optical sensors and may be associated with MPs, specifically in river and estuary systems; although Piehl et al. [35] found that in situ-sampled MP concentrations were correlated with such water constituents in only one of three study sites, underscoring that such proxies must be used with caution. Brach et al. [37] found ~10 times higher in situ-sampled MP concentrations in anticyclonic ocean eddies than cyclonic eddies, the fine-scale spatial structure of which can be mapped using satellite altimetry, providing another potential means of remotely sensing areas of the ocean with likely high MP concentrations. Finally, Liu et al. [38] found significant correlations between remotely sensed algal blooms and in situ-sampled MP concentrations in Chaohu Lake, China.

4. Discussion and Recommendations

Based on the literature, there has been interest in the potential to detect and quantify aquatic microplastics via aerial remote sensing for about a decade, but progress has been gradual, and no single approach has yet reached maturity or operational status. The main approaches that have emerged are the detection of MPs' spectral characteristics using passive optical sensors, the detection of water surface roughness suppression by MP-engendered surfactants using active radar sensors, and the detection of various indirect proxies for MPs.

The latter approach has been shown to be viable in certain cases, although in all instances to date, the utility or reliability of proxies is limited to specific locations, systems, or phenomena. Notably, in most cases, there is no direct causal relationship between MPs and proxies. Thus, these indirect proxy-based approaches can be ruled out as ideal wide-scale, broadly applicable aquatic MP remote sensing solutions, although they may remain useful in specific situations, provided adequate independent validation measures are taken.

The detection of aquatic MPs via satellite-borne radar remote sensing of water surface roughness reduction was reported as far back as 2018 [28], but relatively few studies have since followed up and built upon this approach, and three of the six published studies are brief conference papers [28–30]. However, the most recent contributions to this avenue of investigation [31,32] have taken a more promisingly rigorous and methodical turn, helping to clarify and elucidate some of the unknowns associated with this approach, namely whether the relationship between surfactant and MP concentrations is consistent or predictable, and the precise physics underlying the surface roughness suppression. Nevertheless, further unknowns would benefit from similarly methodical studies involving experiments under controlled conditions or rigorous comparisons between remote sensing and in situ observations. These unknowns may include questions surrounding (1) the mechanisms and conditions affecting microbial digestion of MPs and in turn the production of surfactants, which could impact the relationship between their respective concentrations; (2) other sources of ocean surfactants (including microbial digestion of larger plastic debris) or surface smoothening substances that might be mistaken for MP-engendered surfactants; and (3) precisely how wind conditions and small-scale ocean circulation patterns (e.g., Langmuir cells [28]) affect the manifestation, detectability, and interpretation of the water surface phenomenon.

Direct detection of aquatic MPs would be ideal, and doing so via their spectral signature seemingly involves fewer potentially confounding factors compared to the other two approaches, but is particularly challenging due to several limitations. From the outset, the very small size of the particles, combined with their relatively low proportional coverage of the near-water surface area (estimated to be 0.005% at most based on reported ocean concentrations [23]), are bound to result in a weak signal in the context of spectral unmixing in much larger image pixels. Second, most environmental MPs are weathered, which can cause various changes in the particles, including fading or loss of their distinct visible colors [39]. As such, weathered MPs may not be discernible in the visible light region in addition to being minimally distinctive in the NIR region, the range within which the most readily accessible and highest spatial resolution airborne and spaceborne optical sensors operate. Third, although a number of multispectral and hyperspectral sensors possess SWIR bands where MPs are most distinctive, the severe attenuation of the SWIR signal when the particles are wet and submerged under even a thin layer of water considerably reduces their detectability in this region. In the case of satellite remote sensing, there is also the question of what happens to such a weak signal as it travels all the way up through the atmosphere.

Despite two theoretical studies expressing skepticism about the feasibility of detecting aquatic MPs using satellite-borne optical sensors [23,24], it is encouraging that two more recent studies published in 2024 [25,26] reported having succeeded in doing so by way of correlation analyses between remotely sensed reflectance levels and in situ-sampled MP concentrations. Significant correlations were found in spectral bands near known absorption peaks of MPs in the NIR and SWIR regions, which seems to lend credence to the results.

Conspicuously absent from the published literature is any reported attempt to remotely sense aquatic MPs from closer proximity to the Earth's surface in much finer spatial resolution imagery, as could be acquired by low-altitude aircraft. Such attempts would be worthwhile given the steep challenges of detecting aquatic MPs with satellite-borne optical sensors and the need to better verify and validate findings such as those reported by the recent correlative studies. Hu's [23] estimate of 0.005% pixel coverage by aquatic MPs in satellite imagery assumed an average particle size of 2.5 mm and a uniform distribution of particles across the water surface area at their highest reported ocean concentration. If these assumptions are maintained while decreasing pixel size (i.e., increasing spatial resolution by decreasing image acquisition height), the % pixel coverage will only begin to increase when the spatial resolution becomes fine enough that a single 2.5-mm particle exceeds 0.005% of the pixel area—corresponding to a ~35-cm pixel size—beyond which the coverage will progressively increase with further decreasing pixel size. A 5-cm pixel size would result in 0.25% coverage, exceeding Hu's [23] estimate of at least 0.2% coverage required for aquatic MP detection by high-fidelity visible–NIR sensors. A 1-cm pixel size would result in 6.25% coverage, far exceeding the detection threshold. With the additional use of a SWIR-capable sensor, the plausibility of MP detection begins to seem quite likely.

Such spatial resolutions can most conveniently and economically be achieved by means of small drone-based remote sensing, as systems carrying high-performance visible–SWIR hyperspectral sensors are newly operational [40,41]. Thus, a sensible next step in investigating the feasibility and developing the capability of aerial optical remote sensing of aquatic MPs would be to conduct experiments at a much finer scale than reported to date, using drone-borne hyperspectral imaging. Such experiments could conceivably be performed outdoors under semi-controlled conditions (e.g., artificial reservoirs in which MPs are introduced), followed by trials in natural systems. The use of drones would enable convenient assessment of the detectability and spectral signal characteristics of MPs at varying heights above ground (subject to local airspace regulations) and, by extension, provide a currently lacking empirical baseline to model the upscaling of aquatic MP optical remote sensing from higher altitudes, helping to pave the way for the use of crewed aircraft and satellites that can survey much larger areas. Such experiments may also prompt development of the operational capacity to perform drone-based remote sensing of aquatic MPs in the environment over modest-size areas, for example, in freshwater systems, short distances offshore, or small areas at sea if launched from boats.

It should be emphasized that this approach is limited to detecting MPs at or near the water surface (down to ~15 cm in depth), which represent only a portion of environmental MPs in the water column [42]. The depth at which plastics occur depends on their density relative to that of water (or seawater), which varies by plastic type. Most are lighter than water, including environmentally pervasive polyethylene, polypropylene, and some polystyrene, all of which tend to float, whereas polyester polyamide and acrylics tend to be submerged. However, for all plastic particles, their mass can increase with time spent in aquatic environments as they weather and accrue materials, causing them to sink in the water column and eventually collect in the sediment [43]. Remote sensing of surface and near-surface MPs could contribute to a fuller understanding of whether surface plastics can be an indicator of recent environmental inputs and/or a source of MPs at greater depths. Further aspects that could be explored include the relationship between MP concentrations near the surface where they are optically detectable and concentrations at greater depths, and how vertical water circulation patterns may affect this relationship. Additional unknowns related to aerial optical remote sensing of aquatic MPs that may warrant investigation include how water surface perturbations such as ripples, waves, or white caps, as well as turbidity in freshwater, estuarine, or coastal systems, affect MP detectability; and whether it is possible to distinguish among different plastic types based on moderate variations in their spectral signatures.

In conclusion, despite the relatively sparse published literature and gradual progress to date, there have been promising developments toward aerial remote sensing of aquatic microplastics, and there are clear opportunities to continue moving the science forward, in particular with regard to detecting their spectral characteristics and their effects on water surface roughness. Although the feat is distinctly and inherently challenging, ongoing research efforts, in conjunction with continuously improving remote sensing technology (e.g., sensor resolution/precision and data analysis approaches), seem poised to advance the practice from its current experimental stage to operational status.

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