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A review of microplastic impacts on seagrasses, epiphytes, and associated sediment communities

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Microplastic impacts on seagrasses, epiphytes, and associated sediment communities

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Highlights

- Microplastics accumulate within seagrass ecosystems, both on blades and in sediments.
- Potential microplastic impacts on seagrass ecosystem processes are examined.
- A special focus is given to plant, epiphyte, and sediment processes.
- Direction for future experimentation is provided.

Abstract

Microplastics have been discovered ubiquitously in marine environments. While their accumulation is noted in seagrass meadows, little attention has yet been given to microplastic impacts on valuable ecosystem functions. We initiate this discussion by synthesizing the potential impacts microplastics may have on plant, epiphyte, and sediment processes. We suggest that microplastics may harm epiphytes and seagrasses via impalement and light/gas blockage, and increase local concentrations of toxins, causing a disruption in metabolic processes. Further, microplastics may alter nutrient cycling by inhibiting dinitrogen fixation by diazotrophs, preventing microbial processes, and reducing root nutrient uptake. They may also harm benthic organisms via complications associated with ingestion and sediment characteristic alteration. All impacts will be exacerbated by seagrasses' high microplastic trapping efficiency. As microplastics become a permanent and increasing member of seagrass ecosystems it will be pertinent to direct future research towards understanding the extent of microplastic impacts on seagrass ecosystem processes.

Keywords

Seagrass; epiphytes; microplastics; photosynthesis; nutrient cycle; food web

The State of Microplastics in Seagrass Ecosystems

Microplastic debris, defined as plastic particles that measure <5mm in length and persist in a variety of shapes and colors, have been increasing in global oceanic abundance. Inputs include primary microplastics from commercially produced particles such as synthetic textile fibers and cosmetic microbeads, as well as secondary microplastics that result from the breakdown of larger plastics like water bottles and bags (Barnes et al., 2009; Rocha-Santos et al., 2015; Shim et al., 2018). Microplastics are recalcitrant and remain in systems indefinitely following their introduction (Bowley et al., 2021). They can be further subdivided into categories based on their chemical composition (polyethylene, polyester, nylon etc.) and appearance (fiber, bead, fragment) (Andrady 2011; Goss et al., 2018). Since their discovery, microplastics have been found pervading many regions of the marine environment, including remote locations like deep-sea sediments in the Arctic (Carpenter et al., 1972; Bergmann et al., 2017). Though marine microplastics can be found ubiquitously, a large proportion of them accumulate on shorelines in close proximity sources, making it pertinent to study the impacts of this pollution on populated nearshore ecosystems (Thiel et al., 2013). Adverse effects of microplastics, such as complications following ingestion by marine organisms and toxicity, have been reported in numerous studies, further solidifying the need to advance investigation of this novel pollutant (Nobre et al., 2015; Zhang et al., 2017; Rotjan et al., 2019; Dantas et al., 2020).

Coastal systems on every continent except Antarctica are colonized by a wide variety of seagrass species, which are susceptible to many anthropogenic impacts due to their proximity to developed areas (Short et al., 2007; Unsworth et al., 2018). Stressors such as disturbance from trawling and dredging, aquaculture, and eutrophication have created a worldwide crisis in seagrass communities (Duarte, 2002; Unsworth et al, 2018). The culmination of these threats has resulted in a tenfold reduction in global seagrass ecosystems in the last forty years (Orth et al, 2006). This decline is significant both economically and ecologically, as seagrasses provide unequivocal services to the surrounding environment and human population (Nordlund et al., 2018). Seagrass meadows are particularly valuable for their ability to sequester carbon at high rates proportional to their biomass. Though they occupy only 0.1% of the total ocean floor, seagrasses are responsible for 11%, or upwards of 83 million metric tons of organic carbon sequestration every year, with a global storage capacity upwards of 19.9 Pg organic carbon (Howard et al., 2017; Fourqurean et al., 2012). Other services include, but are not limited to, preventing coastal erosion via wave impact reduction and sediment stabilization, improving water quality, accreting sediments, and offering food and habitat to a variety of marine organisms, many of which are commercially important or endangered (Cornell et al, 2018; Fonesca et al., 1992; Nordlund et al., 2018; Nordlund et al., 2017).

Recently, microplastics have been discovered as yet another potential threat to seagrass ecosystems. Seagrasses have been identified as substantial sinks for microplastics, both in the sediment within meadows and adhered to seagrass blades (Goss et al., 2018; Jones et al., 2020). Once present in the ecosystem they can become incorporated into food webs via blade consumption and bioaccumulate in higher trophic levels (Goss et al., 2018). While impacts on higher trophic organisms are important, little attention has yet been given to the effects of microplastics on the ecosystem's foundation species: seagrasses themselves and their associated epiphytic and benthic communities. In an effort to motivate and direct future research in this area, as well as bring attention to the growing microplastic crisis in seagrass ecosystems, this article synthesizes studies of known microplastic impacts on relevant algal, macrophytic, and benthic communities and hypothesizes how they may impact seagrass ecosystem processes, noting key gaps and opportunities in the literature.

Seagrass Ecosystem Characteristics

To understand the potential impact of microplastics on seagrasses, baseline ecosystem characteristics must be established. Seagrasses are marine angiosperms that can form dense meadows. They have extensive root and rhizome systems that stabilize sediments, while their high above ground biomass and architectural complexity reduces water currents, causing particulate matter to become trapped amongst blades and settle to the ground (Miyajima et al., 2015; Smit et al., 2021). Because of this, seagrass beds accumulate large quantities of particulate organic matter (POM), both onto their blades and to the sediments below (Ward et al. 1984). The hydrodynamics of seagrass meadows also allow for the settlement of epiphytes; small sessile organisms such as cyanobacteria, diatoms, crustose coralline algae, and macroalgae that adhere to seagrass blades (Bologna et al. 1999). Epiphyte abundance can be influenced by nutrient availability, water motion, light, and temperature, factors which similarly impact seagrass abundance (Borum et al., 1985; Borowitzka et al., 2007). In some instances, these organisms can account for more than half of a seagrass ecosystem's total aboveground primary production and aboveground biomass (Morgan and Kitting, 1984; Pollard and Korure, 1993). They also provide nutrients and spatial complexity, increasing faunal density in the ecosystem (Bologna et al., 1999). However, they have adverse effects on seagrasses themselves, namely through the reduction of light available for photosynthesis, reduction in the rate of CO_2 , O_2 and nutrient diffusion across the blade surface, and increase in drag (Nelson, 2017; Brodersen et al., 2015; Brodersen et al., 2020).

Seagrass ecosystems sequester large quantities of carbon via photosynthesis, contributing the most per unit area among all vegetated coastal habitats (IUCN, 2017). Carbon stored within seagrass meadows is found in above and belowground plant biomass (Macreadie et al., 2014). However, most of the stored carbon is found within sediments, stored via bacteria, algae, detritus, and carbonates (Gacia et al., 2002). Because seagrass sediments are generally anoxic, less than 10% of organic material entering the sediment decomposes, allowing for long term storage (Gacia et al., 2002). The anaerobic rhizosphere of seagrass sediments also boasts substantial contributions to the plant's nitrogen requirement, as bacterial nitrification and denitrification processes interplay to regulate nutrient availability and seagrass primary production (Capone & Taylor, 1980). Seagrass sediments are an important component of the ecosystem from the perspective of long-term carbon storage and nutrient cycling.

Due to seagrasses' ability to reduce currents, house epiphytic communities, and trap and accumulate particulate matter, they are poised as an ideal location for microplastic settlement. Huang et al., (2021) found that seagrass ecosystems were enriched with microplastics 1.3 to 17.6 times compared to unvegetated sites, while Huang et al. (2020) found an enrichment factor of up to 2.9. This significant accumulation, coupled with the ecosystems' diverse and important inhabitants, positions seagrasses as a necessary system to consider microplastic impacts (Nordlund et al., 2017). Further, seagrasses worldwide are highly valued for their unequivocal ecosystem services, which are already under threat from numerous other stressors, making it crucial to determine the relative threat of microplastics when assessing ecosystem health and longevity, particularly because there is little to no widespread technology currently available to remove microplastics from coastal systems (Duarte et al., 2002; Nordlund et al. 2018; Malankowska et al., 2021). It is therefore vital to elucidate the potential impacts of microplastics on this ecosystem and identify gaps in the literature to guide future experimentation regarding this phenomenon.

Microplastic Effects on Seagrass and Epiphyte Communities

Once microplastics enter seagrass ecosystems, they can become incorporated into epiphytic communities attached to seagrass blades. Microplastics in the water column get trapped amongst seagrass plants due to reduced currents in a similar fashion as POM (De los Santos et al., 2021). Then the rough surface of epiphytes provides a substrate onto which microplastics can adhere and become trapped. Epiphytes overgrow the trapped microplastics, keeping them attached to the blade surface (Fig. 1). This is supported by Goss et al. (2018) and Datu et al. (2019), who both found that many microplastics on seagrass blades were embedded within epiphyte assemblages. There is also emerging evidence that microplastic abundances are significantly related to epiphyte density, suggesting that more epiphytes on a blade directly correlate to more microplastics (Gerstenbacher et al., in prep). Some genuses of seagrass, namely *Posidonia*, are not only capable of trapping microplastics within their own ecosystem, but within their exported ball shaped wrack, known as aegagropilae, which accumulate on beaches adjacent to seagrass meadows, indicating that seagrasses may also play a role in exporting microplastics out of marine environments, as well as trapping them within their own ecosystem (Sanchez-Vidal et al., 2021).

While there are several documentations of microplastics embedded in epiphytic assemblages on seagrass blades, there are no peer reviewed publications exploring the impacts of this accumulation directly on epiphytes and seagrass blade surfaces (Table 1). Existing research regarding the impacts of microplastics and related issues on marine algae including diatoms and cyanobacteria, which are often part of epiphytic assemblages, as well as marine macrophytes, may provide insight on potential impacts, directing future experimentation in the area.

One of the greatest threats associated with microplastics is their ability to absorb or heteroaggregate with toxins including Persistent Organic Pollutants (POPs) and nanoparticles (NPs). This occurs because many pollutants have a greater affinity for microplastics' hydrophobic surface than seawater (Tueten et al., 2009; Wang et al., 2016). This affinity can vary among different types of plastic, as physical and chemical attributes impact sorption capabilities (Wang et al., 2016). More than 78% of these pollutants are considered toxic to marine life, and their interactions with microplastics may increase their toxicity towards marine algae (Rochman, 2013; Thiagarajan et al., 2019). The majority of contaminated microplastics sink in nearshore marine systems where seagrass meadows reside (Bakir et al., 2014). Due to the physical attributes of seagrasses, contaminated plastics are more likely to sink within seagrass ecosystems than nearby bare sediments, likely coming in contact with epiphytic algae during the process (de los Santos et al., 2021). Once trapped amongst an epiphytic community, POPs and other toxins attached to microplastics can become bioavailable to algae, including those found in epiphytic assemblages, via desorption (Heinrich & Braunbeck, 2019). This is evident in the marine algae *Chlorella sp*., which is capable of absorbing toxins transported by microplastics, including nanoparticles and triphenyltin chloride (Thiagarajan et al., 2019; Thiaigarajan et al., 2021; Yi et al., 2020). This process is variable and depends on the type of plastic, its chemical composition, and the type of algal species, however it is evident that microplastic associated toxins are capable of being absorbed by marine algae (Heinrich & Braunbeck, 2019). Once present in marine algae, these pollutants cause a variety of negative impacts. Generally, organic pollutants can inhibit both light and dark reactions in photosynthesis, subsequently reducing growth and vitality (Tomar et al., 2019). This impact is seen in higher order plants as well as algae (Tomar et al., 2019). In marine algae, nanoparticles and other toxins result in oxidative stress, a reduction in Chlorophyll A, cell lysis, and lipid membrane damage (Thiagarajan et al., 2019; Thiagarajan et al., 2021; Yi et al., 2020). Cell membrane damage is particularly concerning, as it may facilitate the internalization of further toxins (Thiagarajan et al., 2021). While some level of pollutant contamination already exists in seagrass ecosystems, microplastic's role as a vector brings these toxins directly to epiphytic communities, potentially making them more locally available within blade microenvironments, exacerbating negative effects (Huang et al., 2020., McLachlan et al., 2001).

Beyond the vectoring of pollutants to epiphytic communities, microplastics themselves raise a threat to these assemblages. Contact between marine algae and plastic polymers, including the common Polyvinyl Chloride (PVC) and Polypropylene (PP), induce a shading effect, limiting energy and substance transfer, ultimately resulting in reduced nutrient and light uptake (Thiagarajan et al., 2021; Wang et al., 2020; Zheng et al., 2021). Microplastic algal interactions may also result in injured cell structure due to impalement, as well as other morphological changes including cell wall thickening and deformed thylakoids (Mao et al., 2018; Zhang et al., 2017). This ultimately results in a reduction of Chlorophyll content and growth (Thiagarajan et al., 2021; Wang et al., 2020; Zheng et al., 2021). Because epiphytes act as a significant trap for microplastics, and microplastics are often found adhered to and/or covering epiphytes, shading and impalement may be more likely to occur than in free floating marine algae (Gerstenbacher et al., 2022).

Microplastics further threaten marine algae through the development of biofilms; a thin film of bacteria and algae that sticks to microplastic surfaces, whose formation is caused by a combination of environmental and plastic attributes, including surface roughness, charge, electrostatic interactions, light, and temperature (Rummel et al., 2017, Oberbeckmann et al., 2015). Biofilm formation predisposes microplastic-algae hetero-aggregations; microplastics devoid of biogenic particles do not aggregate, whereas those covered in biofilms can form aggregates, interact with other existing aggregates, and lend to the creation of new aggregates (Michels et al., 2018). These aggregates often cause marine algae to precipitate or be rendered inactive, reducing photosynthesis and growth (Long et al., 2017; Zhang et al., 2017). Biofilms also increase attributes of microplastics, such as charge and roughness, which allows them to vector heavy metals like Ag, Ni, Pb, and Zn (Wang et al., 2016). Marine algae can absorb these metals and have shown decreased growth and chlorophyll content under heavy metal stress (Saleh, 2015; Sheng et al., 2004). Similarly, to other pollutants, microplastics may make heavy metals more locally abundant to epiphytes when they become trapped amongst them.

Seagrass epiphytes have thus far been majorly overlooked when considering microplastic ecosystem impacts, though the majority of microplastics on seagrass blades are adhered to epiphytes (Goss et al., 2018; Gerstenbacher et al., 2022; Table 1). Because epiphytes perform vital ecosystem functions by enhancing spatial complexity, above ground biomass, and primary production, identifying potential effects associated with their microplastic contamination is vital when assessing overall ecosystem health (Bologna et al. 1999; Borowitzka et al., 2007).

While microplastics are capable of significantly reducing algal growth and photosynthesis, net impacts on seagrasses themselves may be more complex. If epiphyte growth and photosynthesis is decreased due to microplastics, this may benefit the seagrass plant, as epiphytes are direct competitors with seagrasses for light, nutrients, and space (Bulthuis and Woelkerling, 1983; Brodersen et al., 2015; Brodersen et al., 2020). A reduction in epiphytes may lead to increased passive diffusion of CO_2 , O_2, and nutrients into the blades, and higher inorganic carbon availability in the leaf microenvironment (Brodersen et al., 2015; Brodersen et al., 2020). However, these benefits can only be achieved if microplastics do not also have negative impacts on seagrasses themselves. While the breadth of literature on this topic is limited, evidence suggests this is unlikely. Microplastics adhered to seagrass blades may act physically like epiphytes themselves by obstructing seagrass cells, creating a shading effect and subsequently decreasing light attenuation and nutrient transfer (Silberstein et al., 1986; Brodersen et al., 2020). From a toxicity perspective, microplastics may make pollutants more locally abundant on and surrounding seagrass blades via desorption (Heinrich & Braunbeck, 2019). While documentation of toxin bioavailability via microplastic desorption does not yet exist for seagrasses, evidence in marine and aquatic algae suggest the pathway's viability (Ge et al., 2021; Yi et al., 2020). Under circumstances where pollutants become bioavailable to plant surfaces, seagrasses will likely have adverse reactions (Adamakis et al., 2021; Ralph & Burchett, 1998; Macinnis-Ng & Ralph, 2002, Zheng et al., 2019). Heavy metals such as Zn and Cu have negative effects on several species of seagrasses' photosynthetic rates, reducing chlorophyll *a* fluorescence in instances of only 1 mg litre^{-1} of exposure, and causing metabolic and morphologic effects in many instances (Ralph & Burchett, 1998; Macinnis-Ng & Ralph, 2002, Gaeckle et al., 2012; Zheng et al., 2019). The seagrass *Cymodocea nodosa* was negatively impacted by exposure to environmentally relevant quantities of bisphenol A (BPA), where cells lost chlorophyll auto-flourescence and accumulated H_2O_2. Further, polycyclic aromatic hydrocarbons (PAHs) have been found accumulating and inhibiting growth in thylakoid membranes of chloroplasts in the seagrass *Posidonia oceanica*, as well as other aquatic plants (Apostolopoulou et al., 2014; Adamakis et al., 2021).

Microplastic adherence to seagrass blades may place not only epiphytic communities, but seagrasses themselves at risk. Microplastics likely have the capacity to physically obstruct plant cells and increase pollutant concentrations in the blade microenvironment, ultimately leading to reduced photosynthesis and growth. Seagrasses are valued highly for services related to growth and photosynthesis, including carbon sequestration and wave attenuation (Nordlund et al., 2018). Because these services are already at risk from many other local and global stressors, new and increasing threats such as microplastics, whose impact severity is largely unknown, will be valuable to study when considering the overall health and stability of seagrasses now and in the future (Duarte, 2002; Unsworth et al, 2018).

Impacts of Microplastics on Seagrass Sediment Communities

Just as microplastics get trapped amongst seagrass blades, they can become accreted into the ecosystem's sediments. In fact, seagrass bed sediments are a significant sink for microplastics compared to bare sediments, due mainly to near-bed turbulent kinetic energy (TKE), the same process which leads to sediment trapping (Huang et al., 2020; Smit et al., 2021) Seagrass blades with adhered microplastics may also shed to the sediments below, contributing to the stock (Huang et al., 2021). Furthermore, aggregations of microplastics and their associated biofilms result in an increase in density, causing rapid sinking into sediments (Leiser et al., 2021; Rummel et al., 2017). Huang et al. (2020) found that microplastics within seagrass meadow sediments were enriched by a factor of up to 2.9 compared to bare sediments. While there is a considerable amount of research detailing adverse impacts of microplastics on benthic organisms, these impacts are not often considered in the context of seagrass ecosystems' significant microplastic enrichment, where effects may be heightened and there is a higher density and diversity of flora and fauna (Huang et al., 2020; Browne et al., 2008; Sussarellu et al., 2016; Duffy, 2006). Increased microplastic density may heighten local sediment pollutant concentrations, as microplastics vector heavy metals, residual monomers, and other pollutants into marine sediments (Li et al., 2020; Cauwenberghe et al., 2015). This could cause higher loads of microplastics and associated toxins in the bodies of benthic organisms like mussels ((*Mytilus edulis)*, oysters (*Crassostrea gigas)*, and crustaceans (*Carcinus maenas & Nephrops norvegicus)*. These species, and many others, have all had negative reactions to relevant quantities of microplastics, including digestive inflammation, reduced fertility, reduced feeding, and trophic transfer (Cauwenberghe et al., 2015; Browne et al., 2008; Sussarellu et al. 2016). Benthic organisms in two seagrass ecosystems in Indonesia show a microplastic contamination level of 28.29% and 25%, indicating that high levels of contamination within the meadows correspond to high contamination in benthic organisms (Tahir et al., 2019). Sufficient quantities of microplastics are also capable of altering mean grain size, permeability, and decreasing thermal diffusivity, impacting some organisms and their eggs, which prefer certain sediment sizes, oxygen concentrations, moisture contents, and temperatures (Wang 2016). Harming benthic organisms would negatively impact many aspects of the ecosystem, as they perform key ecosystem functions like water filtration, bioturbation, predation/grazing, and organic matter decomposition (Duffy et al., 2006).

Microplastics within sediments may also impact microbial and plant communities, particularly by altering nutrient cycling. Seeley et al., 2020 shows that microplastics prevent nitrification and denitrification in sediment dwelling microbes, while van Weert et al. 2019 reveals microplastics experimentally decrease nutrient uptake and shoot to root ratios of sediment rooted macrophytes (Yao et al., 2019). High microplastic densities within seagrass sediments, which will likely increase local toxin concentrations, could also inhibit dinitrogen fixation in the diazotrophic flora on the roots and rhizomes of seagrasses, as seen in the seagrass species *Zostera marina* (Brackup & Capone, 1985). These impacts may alter nitrogen dynamics within the ecosystem, causing a limitation. As many seagrass ecosystems are already limited by nitrogen, any further alteration to this cycle will be vital to understand (Johnson et al., 2006; Powell et al., 1989). Regarding carbon sequestration, Huang et al., 2021 shows that the accumulation of particulate organic carbon (POC) and microplastics within seagrass sediments is linked, as higher POC is correlated to higher microplastic abundance. There is currently no published work done exploring the impacts of this association, nor regarding microplastic's influence on carbon cycling within seagrass sediments. Future research should focus on identifying the capacity of microplastics to influence these processes (Shen et al., 2020).

Microplastic Impact Implications and Gaps

Microplastics retained within seagrass sediments and blades may have the ability to complexly alter ecosystem functions with their chemical and physical attributes. Epiphyte and seagrass photosynthesis and growth, nutrient cycling, and benthic organism health and function could be impacted (Fig. 1). Effects may be exacerbated further by seagrasses' high microplastic trapping efficiency, and dense and diverse flora and fauna (Huang et al., 2019). Currently, microplastic concentrations on Turtle Grass (*Thalassia testudinum*) blades with high epiphytic loads average 4.0 ± 2.1 microfibers and 0.714 ± 0.42 microbeads per blade (Goss et al., 2018). Because microplastic concentrations in the low ppm cause negative impacts to marine algae, there is reason to believe that microplastic concentrations on seagrass blades may already cause adverse effects (Prata et al., 2019). Similarly, Huang et al., 2019 found microplastic concentrations ranging from 80 to 884.5 particles/kg of dry seagrass sediment in China, enriched by factors of 2.1 and 2.9 relative to bare sediments. Experimentally, 500 particles/kg or less cause negative impacts to the survival and growth of benthic organisms (Ziajahromi et al., 2018). It is possible that current microplastic concentrations within seagrass sediments are negatively impacting many aspects of the ecosystem which are vital to its function, including microbial and plant nutrient dynamics, and benthic organism functions.

Existing literature on this topic has focused primarily on documenting microplastics within seagrass ecosystems and exploring the mechanisms of their accumulation (Table 1). While this body of work is by no means complete, as it becomes evident that microplastics are pervasive within seagrass meadows with little hope for removal, literature must pivot towards exploring the impacts of this accumulation. Microplastic quantification within seagrass ecosystems is becoming increasingly available for several seagrass species (Table 1). With this, it is possible to set up in vitro experimentation using environmentally relevant microplastic concentrations, to explore their impact on epiphytic and plant photosynthesis and growth, nitrogen and carbon cycling, and benthic organism health. This review informs and motivates such work, so we may understand the effects of microplastics on vital ecosystem members and processes. Only then can we properly assess the health and longevity of seagrasses in the plasticine.

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Author Contributions

C.M.G: Conceptualization, Writing: original draft preparation, Funding acquisition, Visualization. **A.C.F**: Conceptualization, Writing: reviewing and editing, Supervision. **A.B.N**: Writing: reviewing and editing, Funding acquisition, Supervision. **R.R**: Writing: reviewing and editing, Funding acquisition, Supervision.

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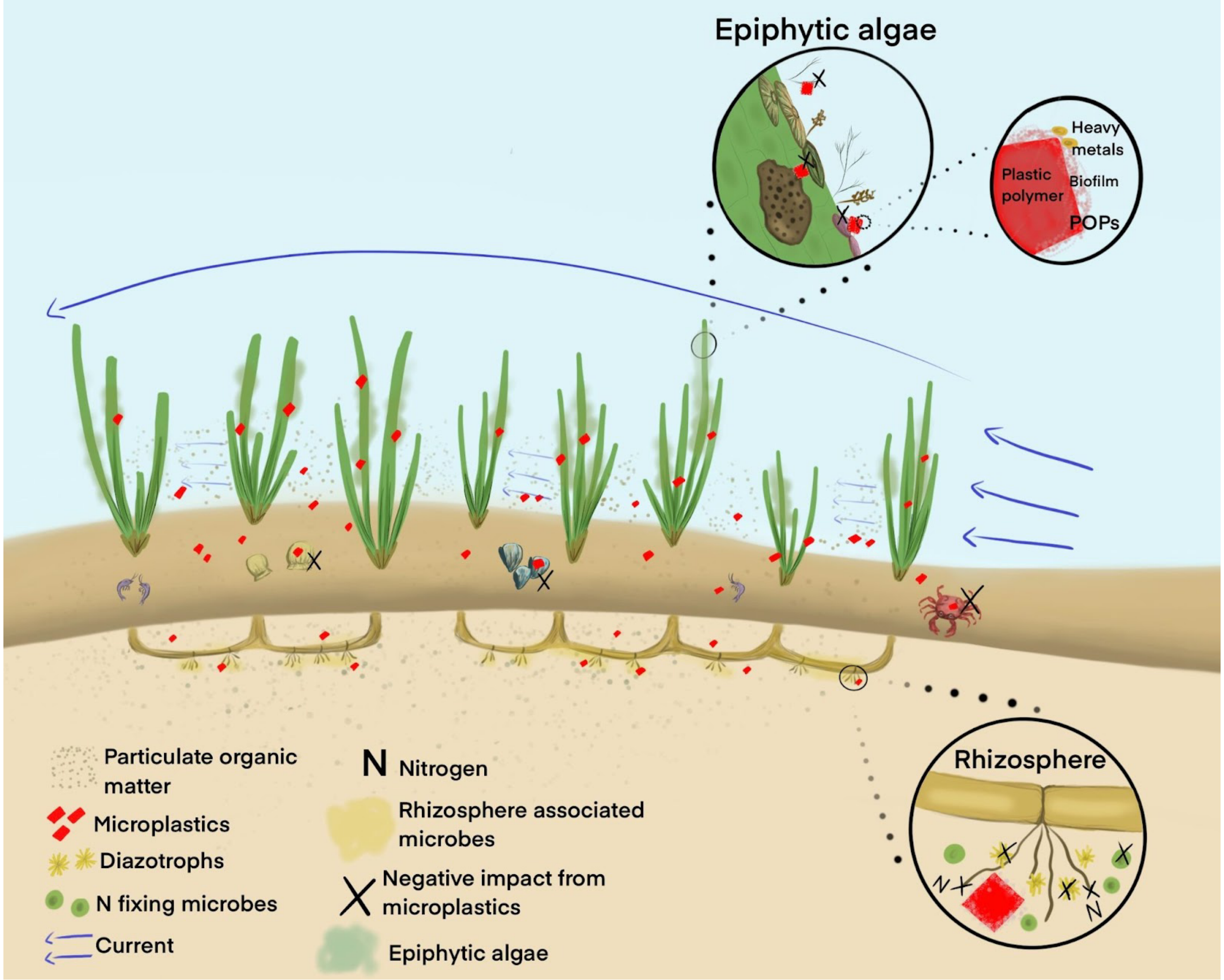

Figure 1. Conceptual model of microplastics and their sorbed pollutants' impact on seagrass communities. Model demonstrates microplastics sinking within seagrass ecosystems, accumulating both amongst epiphytic algae adhered to seagrass blades and within sediments. Biological members of the ecosystem whose function may be compromised by high microplastic concentrations are delineated by a black X; these include: rhizospheres and associated microbes, Benthic organisms like crustaceans and mollusks, epiphytes, and seagrass plants. Considering seagrasses' considerable microplastic trapping ability, many ecosystem members and processes may be compromised.

Table 1: Comprehensive list of papers regarding microplastic accumulation and/or impacts in seagrass ecosystems.

Topic	**Location**	**Comments**
Seagrass Plants and Associated Epiphytes	Turneffe Atoll, **Belize** (Goss et al., 2018); Barrang Caddi Island, **Indonesia** (Datu et al., 2019); Pramuka Island, **Indonesia** (Pricilla et al., 2019); Deergrass Sound, Orkney, **Scotland** (Jones et al., 2020); **Singapore** (Seng et al., 2020); Mallorca Island, Western **Mediterranean Sea** (Sanchez-Videl et al., 2021); Ria Formosa, **Portugal** (Cozzolino et al., 2020)	No peer reviewed work regarding microplastics on seagrasses exists for North America and Australia. Most articles to date quantify microplastics on blades, but do not assess impacts to plant and epiphyte biology.
Sediments	Makassar Strait, **Indonesia** (Tahir et al., 2019); Southern **China** Sea (Huang et al., 2021); Xincun Bay and Li'an Bay, **China** (Huang et al., 2020); Deergrass Sound, Orkney, **Scotland** (Jones et al., 2020); **Baltic Sea** (Kreitsberg et al., 2021); Southern **England & Wales** (Unsworth et al., 202); Rameswaram Island, **India** (Jeyasanta et al., 2020); Ria Formosa, **Portugal** (Cozzolino et al., 2020); New Hampshire, **USA** (Cheng et al., 2021)	Most articles focus on accumulation and quantification, but do not assess impacts on biogeochemistry and sediment characteristics.
Benthic organisms	Ria Formosa, **Portugal** (Cozzolino et al., 2020); Pramuka Island, **Indonesia** (Pricilla et al., 2019); Deergrass Sound, Orkney, **Scotland** (Jones et al., 2020); Florida Keys, **USA** (Plee et al., 2020); Barranglompo Island, Makassar, **Indonesia** (Sawalman et al., 2021)	There is an extensive body of literature that assesses microplastic accumulation in marine organisms and explores impacts to biology. (Miller et al., 2020). However, few studies are durectly associated with seagrass ecosystems.
Mesocosm studies assessing retention and/or impacts	Gullmars Fjord, **Sweden** (De los Santos et al., 2021); **Red Sea** (De Smit et al., 2021)	Mesocosm experiments assessing microplastic accumulation and impacts remains the most understudied topic.