Monitoring Plastic Density in the Ocean: A Comparison of Approaches

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Abstract

Plastic pollution has been a global problem that threatens marine life, with an estimated 50 to 75 trillion pieces of plastic and microplastics currently in Earth's oceans. One major ocean plastic accumulation zone, the Great Pacific Garbage Patch (GPGP), forms in the subtropical waters between California in Hawaii and is estimated to contain over 1.8 trillion plastic pieces weighing 79 k tonnes. The long-term accumulation of plastic in aquatic environments generates considerable environmental harms, including through ingestion by marine animals such as zooplankton, cetaceans, seabirds, and marine reptiles. Plastic pollution is a global crisis that no nation or continent is immune to, requiring remedial action from the scientific community. Among new developments in microplastic pollution research is the emergence of artificial intelligence (AI)-based imaging technologies. The potential of artificial intelligence to quantify plastic debris is an on-going process where scientists pivot from manual detection to AI-based algorithms to detect marine litter abundance. This method of remote sensing, published by researchers from The Ocean Cleanup, a non-profit organization that aims to remove 90% of floating ocean plastic pollution by 2040 in areas such as the GPGP, could serve as a new tool to monitor plastic accumulation consistently and systematically in offshore regions.

Keywords

Artificial Intelligence; Plastic Pollution; Marine Environment; Public Policy; Greenwashing; Sustainability; Imaging; Microplastics; Macroplastics; Deep Learning; Marine Pollution

Background

Research on the accumulation of plastic waste in aquatic environments has increased in recent decades. Marine plastic debris was first identified to potentially pose a wide-scale impact in the 1980s, when researchers documented small floating particles in plankton nets, synthetic fibers in water samples, and shipboard visual observations of large floating debris [1]. Since then, measures have been taken to address concerns internationally: in March 2022, United Nations (UN) member states agreed on a mandate to negotiate a legally binding global instrument to end plastic pollution [2]. Although this treaty was expected to be in place by the end of 2024, negotiations were adjourned and will resume at INC-5.2 in August 2025 [3]. As plastic pollution becomes an increasingly prevalent issue–with an estimated 9.2 billion tonnes of plastic produced between 1950 and 2017 and 8-11 million tonnes escaping to the oceans each year–new measures have been taken at both the local and international scale to address this growing problem [4].

In classifying plastic pollution, size is one of the most common reporting descriptors due to its universal application. Plastic contamination is typically divided into three size classifications: macroplastics (>20 mm diameter), mesoplastics (5-20 mm diameter), and microplastics (<5 mm diameter), with some reports occasionally utilizing nanoplastics (<1000 nm diameter) [5]. Macroplastics are both visible and can typically be categorized according to their original usage–making it the target of many ocean cleanup projects–whereas microplastics are still visible, but much smaller in comparison, and account for the majority of plastic items in marine systems [6].

Although there are thousands of different types of plastic polymers, marine plastic pollution is dominated by six substances: polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polyurethane (PUR), polyterephthalate (PET), and polystyrene (PS) [7]. Research by Kor and Mehdina in 2020 evaluating plastic abundance on the surface of the Persian Gulf found that of the plastics collected, 48% were PE and 28% were PP [8]. The classification of plastics into categories such as size and substance allows researchers to better understand the scale and source of ocean plastic contamination when developing cleanup solutions.

Ingestion and entanglement in plastic debris can directly result in the injury or death of marine biotic organisms as well as permanently impair their reproductive systems and mobility [9]. According to a literature review of aquatic life conducted by Gall and Thompson, they noted that >13,000 individuals from 208 species ingested marine debris, and they reported entanglement for >30,000 individuals from 243 species–92% of which were caused by plastic [10]. The degradation properties of plastics in aquatic environments may also negatively impact the surrounding ecosystems. In an analysis posited by Gewert et al., researchers found that PVC's high sensitivity to UV radiation causes this type of polymer to dechlorinate when exposed to sunlight and subsequently form hydrochloric acid (HCl) in the presence of water [11]. The release of HCl into aquatic environments can decrease the pH level of oceans, and combined with the acidification caused by atmospheric CO2, has the potential to amplify the rate of global warming [12]. Models of the effects of microplastics pollution suggest that if left unaddressed, gyres–which have recorded high concentrations of microplastics–and other biologically productive oceanic regions may be negatively impacted, including the North Pacific and North Atlantic oceans [13]. Because the load-bearing capacity of the environment is finite, efforts to prevent the rapidly accumulating ecological and toxicological impacts associated with marine plastic pollution are critical and must be addressed.

Efforts to Combat Plastic Pollution

One of the main methods used to combat plastic pollution in aquatic environments is through policy initiatives. To encourage sustainable practices among consumers, some governments have introduced financial incentives for returning used plastic commodities and imposing bans on single-use plastic products [14]. The European Union's (EU) Packaging and Packaging Waste Regulation (PPWR) proposal mandates that Member States implement deposit-refund systems–where consumers are surcharged on the price of potentially polluting products and reimbursed when the items are returned [15]. Many countries in the EU have already implemented these systems, with the first one being institutionalized in Iceland in 1989 and 16 nations following suit, and studies indicate that the return rates could achieve approximately 95% [16]. Various policies have been adopted by governments to ban plastic products, some of the most notable being India and California's ban on plastic shopping bags; Canada's ban on the use of microbeads in cosmetic products; and Rwanda's ban on all non-biodegradable plastic [17]. Controlling the distribution of plastic in everyday life before the pollution reaches marine environments is one way to help mitigate harm through a governmental approach.

Aside from initiatives targeted at consumers, corporations have played an increasingly larger role in limiting plastic waste production. While policies directed at the everyday consumer are effective, multinational organizations have pushed the idea of corporate social responsibility (CSR) in managing plastic usage [18]. One specific case study on how major corporations have addressed environmental concerns is the Coca-Cola Company. Coca-Cola has been consistently ranked as the foremost plastics polluter and is responsible for around 11% of the total branded plastic pollution observed in audit events [19]. In response to rising concerns about plastic pollution, Coca-Cola launched the World Without Waste (WWW) initiative in 2018, which focuses on the inadequate waste management of plastic after it is produced [20]. The company announced plans to work with recycling programs, national governments, investment funds, and more to achieve three overarching goals: to collect and recycle a Coca-Cola bottle or can for each one sold by 2030, to make 100% of packaging recyclable by 2025 globally by 2025, and to use at least 50% recycled material in packaging by 2030 [20][21].

Although the aims by Coca-Cola to establish large-scale recycling systems in the Global South have been laudable, this initiative failed to address the root cause of plastic pollution–the overproduction of plastics. Furthermore, since the WWW campaign was launched, Coca-Cola has repeatedly backed away from numerous targets–changing its goal to collect only 70-75% of bottles of cans instead of the promised 100%, and completely eliminating their original goal of making 25% of packaging reusable by 2030 without explanation [22]. Critics have accused Coca-Cola of greenwashing after the company backtracked from their initial recycling goals [23]. Greenwashing is a term used by environmentalists to describe companies that convey a false impression of responsibility in sustainable practices, and is not just prevalent in the beverage industry. In an analysis conducted on 14 companies in the Fortune Global 300 participating in voluntary environmental programs–including Coca-Cola, Walmart, Procter & Gamble, and Unilever–researchers noted that the corporations' consistent rhetoric targeting the recycling industry reflects efforts to shift responsibility to consumers and deny any liability [24]. As more companies begin to make environmental pledges targeting plastic pollution, it is critical to hold them accountable.

Although corporations and consumers share in the responsibility to reduce plastic pollution, policing their practices does not always produce consistent results; as such, entrepreneurs have established sustainable nonprofit organizations to address the negative effects of plastic accumulation in aquatic environments. The Ocean Cleanup, an environmental engineering company dedicated to extracting plastic pollution in rivers and oceans, was established in 2013 and continues to drive cleanup initiatives. One of The Ocean Cleanup's largest projects, located in the Great Pacific Garbage Patch (GPGP), utilizes a connected system of two ocean vessels, a floating barrier, and a retention zone to passively catch plastic debris located in ever-shifting hotspots of high plastic concentration by moving against the current [25]. This project is part of the organization's larger effort to remove 90% of floating ocean plastic by 2040, and they have since made considerable progress–removing 11.5 million kilos of trash in 2024 [26]. In an analysis evaluating the environmental impact of cleaning the GPGP, researchers studying The Ocean Cleanup found that even when taking into account the carbon emissions from the ocean vessels and bycatch of marine life, removing legacy macroplastic pollution will have an overall benefit on aquatic ecosystems near the GPGP [27]. Other examples of cleanup technology targeting plastic waste include Mr. Trash Wheel, a Maryland landmark and semiautonomous trash interceptor located in the Baltimore Harbor, and Seabin, a non-profit that deploys automated floating rubbish bins in hotspots to continuously filter marine debris from the water's surface [28][29].

The Future of Ocean Cleanup

Given that organizations such as The Ocean Cleanup can only target a minimal percentage of the ocean, utilizing artificial intelligence (AI) to optimize the placement of cleanup vessels alongside global plastic dispersal models and science mapping tools is one recent notable development in the worldwide cleanup initiative. The concept of monitoring plastic pollution using aerial imaging technology has been explored before, with Deidun et al. conducting an experiment analyzing the effectiveness of deploying drones to capture images of litter on prominent coastlines [30]. In the study, drones flew over a targeted flight path over three coastal stretches in the Maltese Islands [30]. The drones automatically captured images every three seconds and repeated the process during a three-month period [30]. The image sets were then processed into one georeferenced orthophoto map, and placemarks were then manually added to all recorded litter items [30]. The total number of litter items varied from location to location, with one site recording 30 and another 578 [30]. The researchers concluded that implementing a similar method at a larger scale could aid coastal managers in identifying prominent coastal litter accumulation areas, especially in places not easily accessible by land or boat [30].

A feature of these imaging applications that makes them challenging to adapt to offshore areas is that they depend on stationary environments or highly concentrated debris accumulation, which cannot be guaranteed in rapidly changing aquatic environments. Basic algorithms struggle to adjust to moving plastic hotspots and fluctuating waves in vast oceans. By lessening the imaging technologies' reliance on static models and manual identification, and implementing a learning-based approach using artificial intelligence, researchers may be able to provide a more consistent identification of plastic pollution on both land and marine-based environments.

With the recent rise of artificial intelligence, research on the plausibility of AI-based imaging technologies to assist in both microplastic and macroplastic cleanup has increased. In a literature analysis conducted in May 2022, researchers found that 97% of all published literature in the field of AI-based microplastic imaging technologies were published after 2019, with publications in 2021 accounting for 44% and publications in 2022 up to May accounting for 20% [31]. As of July 2024, over 1600 studies on microplastics detection and 100 studies on AI in microplastics detection have been published [32]. In a comparison done on 34 research papers analyzing the performance of experimental AI models in detecting macroplastics, researchers concluded that the use of deep learning to automatically detect macroplastic litter was promising [33]. To improve upon previous models, they made three suggestions: implement enhanced generalization capabilities across varying geographical, environmental, and device setup conditions; focus on the quantification of macroplastic fluxes and hotspots; and integrate machine learning operations (MLOps) to advance basic deep learning models [33].

One example of the integration of artificial intelligence-based macroplastic imaging into cleanup initiatives is The Ocean Cleanup research team's 2022 development of an AI object detection software. The program was trained on over 600 GB of images and could create geometric projections of ocean macroplastic concentrations [34]. In July 2025, The Ocean Cleanup announced that it would be partnering with Amazon Web Services (AWS), a subsidiary of Amazon that provides cloud computing services, to accelerate the organization's goals and address environmental challenges [35]. The collaboration announced that it would focus on two major initiatives: developing a new AI-based system to more effectively identify, track, and predict ocean plastic accumulation; and implementing a cloud-based infrastructure to improve marine life detection systems during cleanup [35].

Discussion

With a threat as large and widespread as plastic pollution in aquatic environments, it is crucial to innovate beyond current solutions. While governmental initiative through enforcing policies has shown positive results in the past, these bans are often limited to specific areas, and laws fluctuate depending on a location's priorities. No clear consensus exists for a plastic product ban or financial incentives, and attempts by the UN to create a global resolution have been delayed. Social pressure has pushed companies that are large manufacturers of plastic into taking action, but these corporations often utilize greenwashing to shift responsibility and avoid accountability. Cleanup initiatives have the potential to reduce ramifications, but innovations are needed to expand the scope of these projects. Implementing artificial intelligence-based imaging technology onto cleanup vessels via drones or cameras is a promising solution to the shortcomings associated with tracking millions of square kilometers for potential plastic hotspots.

Utilizing artificial intelligence provides a reasonable and efficient pathway into expanding the scale of plastic pollution cleanup initiatives. Test cases of potential AI models have shown accurate results, and expanding this project to collect data worldwide is feasible. The installation of video cameras onto vessels is cost-effective, easy to implement, and can be universally applied to all ships traveling in the ocean. By collaborating with other parties to build opportunities for vessels to attach these cameras, cleanup initiatives will be able to reliably map out plastic hotspots and macroplastic fluxes to target. Organizations such as The Ocean Cleanup have already started to implement these strategies by partnering with AWS to build better algorithms, enlisting sailors to install imaging technology onto their vessels, and drawing attention to research in this field. Thus, the addition of AI to aid in ocean cleanup efforts can potentially prevent plastic accumulation from threatening marine life.

While the use of AI-based imaging technology is beneficial, there are also downsides associated with it. Currently, the computational power required to build generative AI models pose sustainability and environmental issues, with concerns rising over the amount of energy required, water consumed, and resources needed to use this technology [36]. Using artificial intelligence to aid in creating a more sustainable marine environment may seem counterintuitive–if AI already poses environmental risks, why should researchers utilize it in efforts to promote sustainability? Additionally, while cleanup initiatives help by clearing out the rapidly accumulating plastic debris in aquatic environments, this focus fails to address the root of the issue: excess plastic production. Clearing plastic pollution before finding a solution to prevent plastic from accumulating in the first place can seem ineffective, as the trash that is removed will be replaced over time. Before investing in AI-powered cleanup, it is important to first address concerns related to the long-term efficiency and impact of the project.

Conclusion

In spite of the concerns associated with incorporating artificial intelligence into efforts to combat plastic pollution, the benefits of AI implementation make this technology worthy of future research and consideration. While AI does pose environmental risks, by developing further upon advancements in this field, more sustainable models can be built in the future. Organizations such as The Ocean Cleanup using AI for environmental good may inspire engineers to apply the technology in the ever-growing fight to protect the planet. Artificial intelligence provides a unique and personalized approach that effectively tracks plastic accumulation for cleanup projects. Through the collaboration of old and new methods to address plastic pollution as well as further development in this category, researchers have the potential to pave the way for building a more sustainable Earth.

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