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Face masks invading protected areas: Risks and recommendations

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HIGHLIGHTS

- Protected areas (PAs) are subject to personal protective equipment (PPE) pollution.
- Tourism is the main driver of PPE pollution in PAs.
- PPE releases secondary contaminants and poses entanglement hazards.
- Management recommendations for the current and future scenarios are provided.

ABSTRACT

Among the indirect environmental impacts generated by the global COVID-19 pandemic, contamination with personal protective equipment (PPE), like face masks, may be one of the most relevant ones. PPE has been found in multiple aquatic, marine, and terrestrial environments, including places of absolute relevancy to biodiversity conservation, such as protected areas (PAs). Here, a brief report of the presence of PPE in six PAs of Peru is presented. PPE pollution in PAs consisted mainly of single-use and reusable face masks, as well as plastics associated with PAs, such as KN95 respirator wrappings. The mean PPE density was estimated as $1.32 \times 10^{-3}$ PPE/m$^2$. FTIR spectroscopy confirmed that face masks and wrappers mainly consisted of polypropylene and polyethylene, two of the most commonly available synthetic polymers. The material was poorly degraded according to their FTIR spectra, possibly suggesting that they were discarded recently. The recent ban on single-use plastic in Peruvian PAs is regarded as a great step forward toward the efforts made to preserve these invaluable places. However, these measures seemed insufficient to prevent PPE and other types of litter from contaminating areas of ecological importance. Considering the current scenario, several recommendations were proposed to be implemented in PAs in order to prevent PPE from becoming a new plastic issue to tackle. These recommendations are expected to also serve for future events where the use of single-use plastics becomes inevitable, like global pandemics.

1. Introduction

The International Union for Conservation (IUCN) defines Protected Areas (PAs) as geographical spaces clearly delimited and recognized that...
are dedicated and managed to conserve nature (IUCN, 2008). They are highly valuable for the sustainability of the society and economy as they protect wilderness, cultural values, ecological processes, and environmental services; preserve species and genetic diversity; promote the sustainable use of resources, and play a key role in the adaptation and mitigation of climate change and are an object of scientific research (Glazer, 2013; Watson et al., 2014). As an example, a third of the world’s 100 largest cities depend on PAs for the supply of a significant proportion of drinking water (WorldBank, 2003). Currently, PAs are threatened by the impact of illegal economic activities and legal economic activities managed in an unsustainable way, such as tourism, hunting, logging, fishing, etc. (Glazer, 2013; Watson et al., 2014). In the case of tourism, their impacts are important to study as national parks are popular destinations for tourists all over the world (Glazer, 2013).

Since the outbreak of the novel coronavirus (COVID-19) was declared a global pandemic on March 11 of 2020 (Cucinotta and Vanelli, 2020), several measures were taken by governments worldwide to stop its spread. Some of these measures translated into a higher waste management burden, particularly in developing countries. For instance, waste segregation and recycling streams were disrupted in face of a potential transmission through infected waste materials (fomites) (Roy et al., 2021). The use of personal protective equipment (PPE), such as face masks, became mandatory in public spaces. However, PPE turned into a new type of highly consumed single-use plastic since most face masks, gloves, and face shields are composed of synthetic polymers (Aragaw, 2020; Fadare and Okoffo, 2020). Most single-use face mask layers consist of polypropylene (PP) (Aragaw, 2020), while reusable face mask consist of cotton-polyester blends with polyethylene terephthalate (PET) ear loops (De-la-Torre et al., 2022b). On the other hand, the most commercially available gloves generally consist of polysisoprene (latex), polyethylene (PE), nitrile butadiene rubber, or polyvinyl chloride (PVC) (Jędruchniwicz et al., 2021). It is now widely known that PPE are polluting natural and urban environments (Akharbazadeh et al., 2021; Ammendolia et al., 2021; Ben-Haddad et al., 2021; Rakib et al., 2021; Ribeiro et al., 2022), releasing secondary contaminants (Chen et al., 2021; De-la-Torre et al., 2022a; Pizarro-Ortega et al., 2022), and causing detrimental effects on biota (Hiemstra et al., 2021; Mghili et al., 2021).

Tourism was one of the most affected economic activities in the world due to strict lockdown measures and social distancing (Abbas et al., 2021). However, as the strategies to control the pandemic, such as increasing vaccination rates and new treatments, advanced, this economic sector reactivated progressively (Navarro-Drazich and Lorenzo, 2021). In Peru, some of the most popular tourist destinations are located in PAs due to their unique landscapes and archeological heritage (Cambré-Fierro et al., 2022). Nature tourism in Peru was reactivated by implementing basic protocols to prevent the spread of the virus, such as wearing face masks and maintaining social distance. However, Peru suffers from poor solid waste management systems and infrastructure, which has been heavily impacted during the pandemic (Torres and De-la-Torre, 2021). This scenario has raised concerns regarding the reactivation of the touristic sector as a potential driver of the new type of plastic pollution, namely PPE pollution.

Although multiple studies evidenced the prevalence of PPE, particularly face masks, in various urban and marine environments, not much is known regarding PPE pollution in PAs where tourism takes place. This issue is of particular interest because many PAs are home to endemic and endangered species. In the present study, we provide and discuss field observations of PPE pollution in PAs from Peru. We aim to report an overview of the current state of PPE pollution and its risks, as well as provide recommendations to prevent this issue from exacerbating.

2. Methods

2.1. Studied area and sampling

In order to preliminarily evaluate the presence of PPE items, six PAs from Peru were visited between September and November of 2021. The PAs were selected for being well-distributed in the Peruvian territory and being representative of different natural environments (e.g., wetlands, coastal and marine, jungle forest, Andean mountains, and Lomas). The description and map of each PA are provided in Table 1 and Fig. 1, respectively. In each PA, a regular touristic route was followed, without taking any unusual or forbidden trails. PPE was visually identified and photographed along the touristic trails. The main touristic route of each PA was visited once by 2 or 3 observers and the covered area was estimated using Google Earth (Web version, https://earth.google.com/web/) (see Table 1). Surveys took one day to complete, except for HNP, where the survey was carried out in two days. Due to logistical constraints, we were unable to clearly determine the area sampled in the YCNP, thus, only qualitative (presence/absence) data was presented for this site. Following previous studies (Hatami et al., 2022; Kutralam-Muniasamy et al., 2022; Rakib et al., 2021; Ribeiro et al., 2022), PPE density was expressed in terms of PPE per m².

2.2. FTIR analysis

Three face masks and one KN95 wrapper from HNP were recovered and stored in Ziploc bags until further analysis. In the case of face masks, the inner and outer layers were analyzed by Fourier transformed infrared (FTIR) spectroscopy in order to confirm the polymeric composition of the face masks and identify indicators of chemical degradation. The analysis was carried out with a Perkin Elmer Frontier FTIR-at wavelengths between 500 and 4000 cm⁻¹, at a resolution of 8 cm⁻¹, and 30 scans per reading (De-la-Torre et al., 2020). The spectra were visually analyzed by identifying the main absorption bands to determine the most probable polymer type following (Jung et al., 2018).

3. Results and discussions

PPE were found in all sites, mostly consisting of surgical face masks (83.3 %) of different colors (blue, black, and white). Other types of PPE included reusable face masks (4.8 %) and masks with prints (apparently for kids) (7.1 %). Face shields, gloves, and other types of PPE were not found. Additionally, some KN95 respirator wrappings were observed (4.8 %). The latter is not regarded as a PPE itself, but as a plastic associated with the use of PPE. Photographs of different types of PPE and PPE-associated plastics are presented in Fig. 2. The mean PPE density by considering the touristic routes evaluated (except for YCNP) was estimated as 1.32 × 10⁻³ PPE/m². The highest and lowest densities were found at HNP (3.38 × 10⁻³ PPE/m²) and LNP (5.00 × 10⁻⁴ PPE/m²), respectively. These results show a relatively higher concentration compared to recent literature. For instance, nationwide surveys for PPE in Peruvian and Argentinian beaches reported mean concentrations of 6.60 × 10⁻⁷ and 7.21 × 10⁻⁴ PPE/m², respectively (De-la-Torre et al., 2022b). On the beaches of Brazil and Morocco, the mean concentrations reported were at least 2 orders of magnitude lower than in the present study (Ben-Haddad et al., 2021; Ribeiro et al., 2022). This is probably due to the concentration of a great number of national and international tourists daily. Although not quantified, other types of litter were observed at HNP, YCNP, and LIHRCA. These mostly consisted of empty food wrappers, such as candy/cookie wrappers and snack bags, as well as nappies and plastic bags.

The inner and outer layers of three surgical face masks and one KN95 wrapper recovered from HNP were analyzed by FTIR spectroscopy. Following Jung et al. (2018), the FTIR spectra of all face mask layers and wrapper showed typical PP and PE absorption bands, as displayed in Fig. 3. Since PP and PE are polyolefins, these materials may be subject to photooxidation in contact with sunlight, possibly resulting in the embrittlement of the material (Fayolle et al., 2000). This behavior has been observed in PP face masks and LDPE gloves exposed to the sun under controlled conditions as indicated by the occurrence of sharp peaks between 1700 and 1600 cm⁻¹ and broader bands between 3700 and 3000 cm⁻¹ (De-la-Torre et al., 2022a). However, no apparent indicators of photooxidation were observed in the FTIR spectra, possibly suggesting that the materials have been in the
environment for a short amount of time. Several studies have evaluated the composition of surgical face masks, generally agreeing on PP-based materials, while reusable cloth masks as mostly polyester blends (e.g., Aragaw et al., 2022; De-la-Torre et al., 2022b). PPE-associated materials, like wrappers, may have been overlooked in the recent literature despite being a type of single-use plastic strictly associated with the COVID-19 pandemic.

Plastic and microplastic (plastics smaller than 5 mm in size, MPs) contamination research in PAs worldwide has gained attention in the last 5 years (Kutralam-Muniasamy et al., 2021). Marine PAs are of particular interest, considering that coastal and marine areas are regarded as plastic hotspots (Rech et al., 2021; Reinold et al., 2021) and contamination sources of single-use plastic strictly associated with the COVID-19 pandemic. A recently published investigation may be associated with the transboundary transportation of plastics (De-la-Torre et al., 2022). PPE-associated materials, like wrap-

### Table 1

| Name                        | Area (km²) | Number of visitors in 2018 | Sampled area (m²) | Importance and touristic attraction |
|-----------------------------|------------|----------------------------|-------------------|-------------------------------------|
| Huascarán National Park (HPN) | 3400       | 378,440                    | 3252.8            | HNP encompasses the majority of the Cordillera Blanca, the highest tropical mountain range in the world consisting of glaciers, and the highest mountain in Peru, named Huascarán (6768 m above sea level). HNP is home to a wide range of Andean plant and animal communities. It has been recognized as a Natural World Heritage site and a Biosphere Reserve by UNESCO due to its cultural and biodiversity importance. The national park also plays a main role in water conservancy as it feeds three important river basins: Santa, Marañon, and Pativilca. The main touristic activities are nature sightseeing, mostly consisting of peak lakes, and mountain trekking. |
| Yanachaga-Chemillén National Park (YNCP) | 1220       | ND                         | –                 | The YCNP is located in the province of Oxapampa, the central jungle of Perú, in the Yanachaga Cordillera. It is home to a high variety of ecosystems with high biological diversity due to its geography and variety of climates. Furthermore, the YNCP has been considered one of the irreplaceable natural areas in the world for the conservation of vertebrate species (Le Saout et al., 2013). It is also considered a Pleistocene shelter as it embraces relic forest conserved due to the geographical isolation. The province of Oxapampa does not have a constant touristic flow but the visits are growing, and the touristic infrastructure is improving. The main touristic activities are nature sightseeing, bird and orchid watching, and trekking. |
| Lachay National Reserve (LN) | 50.7       | 70,008                     | 12,000            | The LNR lies in the coastal desertic line of Perú, an area of extreme aridity. The reserve is part of the coastal Lomas system that are “green islands” in the desert formed by the dynamics of the Current of Humboldt, the trade winds, and the orography of the coast. The Lomas work as temporal refugees for coastal fauna and is considered a unique ecosystem due to the high number of endemic species. Particularly, the LNR is one of the few natural reserves in Peru that preserve a representative sample of the Lomas ecosystem. Moreover, it is recognized as a source of valuable genetic information for arid condition resistance and a bank of germplasm. It also plays a key role in water management as it helps to irrigate water to the soil, preventing soil erosion as well. Due to the proximity of LNR to the city of Lima the reserve is recognized as an important point for environmental education. In 2018, around 70,000 tourists visited the LNR. The main touristic activities are trekking and bird watching. |
| Pantanos de Villa Wildlife Refuge (PVWR) | 2.63       | 43,322                     | 4659              | The PVWR is located in the city of Lima, the capital city of Peru, being a natural oasis in the southern part of the highly urbanized metropolis. It is one of the four wetlands in Peru that are on the Ramsar list of wetlands of international importance. It plays a role as a breeding area for endemic birds and temporal habitat or stopover site for migratory birds. The refuge preserves a representative sample of the swamps from the subtropical desertic coast, as well as migratory and endemic bird species. It also preserves natural water bodies and provides conditions to promote research on biological diversity. The reserve also plays an important role in environmental education for the citizens of Lima. Among the most common touristic activities that visitors can do in PVWR are birdwatching, trekking, and boat rides. |
| Paracas National Reserve (PNC) | 3350       | 427,013                    | 5851              | The PNR is a national reserve that protects coastal desert and oceanic ecosystems located in the Pisco Province, Ica Region. The national reserve protects one of the most productive and diverse areas of the Peruvian coast, which concentrates key nuclei of terrestrial and aquatic fauna. This is indispensable for the maintenance of biological cycles that are crucial for the conservation of species and the economic activities of the area. The reserve is included in the Ramsar list of wetlands of international importance and is recognized as a regional reserve for migratory birds by the Western Hemisphere Shorebird Reserve Network. Furthermore, the PNR is also one of the 17 particularly sensitive sea areas in the world acknowledged by The International Maritime Organization the PNR. Between the period 2009 and 2017, the PNR was the second most visited natural protected area in Perú. In 2019, the reserve had almost half a million visitors. Visiting the Ballesta islands and the recreational use of beaches are the most common touristic activities of the reserve. Tourists also visit museums, and archeological sites in the area and buy tours for nature sightseeing. |
| Lake Huacachina Regional Conservation Area (LHRCA) | 24.1       | ND                         | 24,259            | LHRCA is a conservation area situated in the Province and Department of Ica. The conservation area preserves ecosystems of the coastal desert and due to its proximity, it complements the PNR working as a conservation corridor. The Huacachina Lake is one of the few coastal lakes in the Ica valley, being a natural oasis in the middle of the desert. For its beauty, the LHRCA is one of the main touristic destinations of the Ica Department. Restaurants, hotels, and bars settle in the surroundings of Huacachina Lake. Extreme sports, boat trips, and recreational use of the lakeshore are common touristic activities in the area. |

ND: No data.

* Source: National Services for Natural Protected Areas: [https://cdn.www.gob.pe/uploads/document/file/1185135/12_ANP_mas_visitas.pdf](https://cdn.www.gob.pe/uploads/document/file/1185135/12_ANP_mas_visitas.pdf)
significant source of MPs, thus, becoming bioavailable to a wider range of organisms (Anastopoulos and Pashalidis, 2021; Benson et al., 2022; Ma et al., 2021).

Several studies reported the occurrence of PPE in Peru in previous years. De-la-Torre et al. (2021b) initially quantified the abundance of PPE on 11 beaches of Lima. The mean abundance was estimated to be $6.42 \times 10^{-5}$ PPE/m² and mostly consisted of face masks (87.7 %), although other types were also observed, such as face shields (6.5 %) and gloves (4.3 %). Later research carried out along the coast of Peru (36 beaches) included a sampling site within Punta San Juan, part of the Guano Islands, Islets, and Capes National Reserve System, and the bank (680 m) of an urban canal that feeds the PVWR (De-la-Torre et al., 2022b). Punta San Juan, which had restricted access at the time, was completely clean from PPE. However, a total of 135 items were reported along the urban canal. Although the PPE were not located in the protected area of the PVWR, it is suggested that the detachment and leaching of secondary contaminants could reach the lagoons and marshes of the PVWR. Multiple studies have concluded that face masks physically and chemically degrade in the environment, leading to the generation of thousands to millions of MPs that enter aquatic media (Chen et al., 2021; Sullivan et al., 2021), as well as leaching chemical additives (UV stabilizers, phthalate esters, among others) (Fernández-Arribas et al., 2021; Fukuoka et al., 2022; Jin et al., 2021) and heavy metals (Arduo et al., 2021; Sullivan et al., 2021).

Exposure to face mask-derived MPs and chemicals is likely to induce detrimental effects on aquatic and terrestrial life. For instance, the model organisms Folsomia candida (springtails) and Eisenia andreï (earthworm) displayed the inhibition of reproduction and spermatogenesis, respectively, after being exposed to high concentrations of face mask fibers (Kwak and An, 2021). In the copepod Tigriopus japonicus, exposure to face mask fibers extended its developmental time and inhibited fecundity at the highest concentration (100 MPs/mL) (Sun et al., 2021). The ecological impact of these contaminants is not well understood. Several knowledge gaps remain to fully understand the threat PPE represents. For instance, ecotoxicological effects have been observed generally at the highest concentrations. Although face masks are known to release extremely high amounts of MPs (Kutralam-Muniasamy et al., 2022), it is unknown if niches of ecological importance will be subject to MP concentrations of concern. Particularly because MPs are not inert in the environment and prone to be transported across matrices. On the other hand, it is hard to estimate what percentage of MPs found in the environment are derived from face masks (and other types of PPE). Thus, despite being widespread, the actual contribution of PPE to the already established MP environmental issue is difficult to estimate.

PPE, as a whole, poses other types of hazards to biota. It is well-known that the components of face masks, particularly their earloops or elastics, are easily entangled with the limbs of animals interacting with them, or gloves serve as traps for clueless organisms (Hiemstra et al., 2021; Mghili et al., 2021). On the other hand, recent investigations revealed that face masks may serve as a suitable substrate for microbial communities and fouling organisms, such as calcareous tubeworms and seaweed (Crisafi et al., 2022; De-la-Torre and Aragaw, 2021; Ma et al., 2022). The latter is particularly concerning, considering the arrival of non-native species through plastic litter colonization and raising the risks of biological invasions (De-la-Torre et al., 2021a; Póvoa et al., 2022; Póvoa et al., 2021; Rech et al., 2018a, 2018b). Since most PAs are exceptionally irreplaceable habitats...
for endemic and endangered species, the exacerbation of PPE pollution could impact biodiversity conservation efforts. For instance, the PVWR is a RAMSAR site recognized as a vital place for the reproduction, rookery, and passage of multiple local and migratory bird species (Pulido et al., 2020). Specifically, the face masks found in the PVWR were located on the sandy beach in the southern limit, a place for nesting (Fig. 2d). Similarly, in LHRCA a black-crowned night heron (Nycticorax nycticorax) and several common gallinules (Gallinula galeata) were observed standing or swimming near face masks. Because in LHRCA pedal boats are a popular attraction to navigate the lagoon, multiple face masks were found floating (Fig. 2g), presumably discarded by visitors. On the other hand, various face masks were found intentionally tied to the branches of Polylepis sericea (locally known as “queñual”) at HNP (Fig. 2b). Polylepis forests are located in the high Andes, and HNP homes some of the most abundant in Peru. It is unsure whether this type of unscrupulous behavior, including tying wastes to these species, will have notorious consequences on the wellbeing of P. sericea. It is plausible that the smaller branches are injured or broken apart while trying to attach the face masks, but the actual damage is unknown. Additionally, these types of waste may cause a significant aesthetic impact on the scenery of PAs, which is one of the main drivers of tourism and economic growth.

In September of 2020, the “Directive to implement the ban on the entry of single-use plastics in Protected Natural Areas” (Directive N° 004-2020-SERNANP-DGANP) was approved in Peru. The directive forbids acquiring inside and/or entering PAs with plastic bags, plastic straws, and expanded polystyrene food containers, with some exceptions (e.g., health reasons). The directive describes strategies to communicate this to the public and promote environmental education programs. Also, the single-use plastic control includes a 5-step process, starting with 1) informing the visitors about the single-use plastic ban, 2) requesting the visitors to hand out their single-use plastics, 3) disposing the single-use plastics in appropriate bins, 4) cooperating with municipal authorities for the collection, transportation, and final disposition of the wastes. In the case visitors refuse to hand in their single-use plastics, they are not allowed to enter the PA. Although the results expected by the directive are still to be evaluated, this is a great step forward for conservation efforts. However, it is clear that PPE bypassed the demands expressed by the directive. Of course, while the COVID-19 pandemic continues to constitute a public health emergency, it is not possible to refrain visitors from wearing PPE. Under this scenario, PA authorities must seek ways to prevent PPE from being incorrectly discarded in the environment and reincorporate recyclable plastics into innovative production lines. For instance, some studies have evaluated the potential of PPE conversion from waste to energy via pyrolysis (Aragaw and Mekonnen, 2021; Mekonnen and Aragaw, 2021), incorporating face mask material into asphalt pavement mix (Wang et al., 2022), or even advanced carbon-based materials for advanced energy materials (Yu et al., 2022).

Fig. 2. Photographs of face masks and KN95 respirator wrapping in HNP (a-c), PVWR (d), LNR (e, f), LHRCA (g), YCNP (h), PNR (i).
To achieve this, some recommendations have been provided in Section 4.

4. Conclusions and recommendations

The measures imposed to contain the spread of the COVID-19, particularly PPE usage, brought an unprecedented form of plastic pollution. This type of pollution has been evidenced in multiple aquatic, marine, terrestrial, and urban environments around the world, and PAs are no exception. Based on the observations presented here, it is concluded that tourism is the main driver of PPE pollution in PAs of Peru. However, this could mark a precedent and opportunity for the improvement of solid waste management in PAs, and be prepared for future events, like pandemics, that will result in unusual fluxes of production, use, and incorrect disposal of single-use plastics. Here are some recommendations to be implemented:

1) Education: Educational programs promoted by the PA administrations should include relevant information regarding the type of PPE waste (plastic-based materials) and highlight the consequences they pose to the biota (entanglement/ingestion hazards, release of microplastics). Businesses associated with touristic activities within or in the vicinity of PAs, such as hotels and restaurants, should participate in educational programs and comply with single-use plastic-free policies.

2) Information: Information panels, like signposts, related to COVID-19 measures (indicating social distancing, wearing a face mask, etc.) must indicate the correct way to discard commonly used PPE and point to the main containers or bins meant for this purpose. Also, PA authorities must inform visitors about the importance of correctly discarding their PPE and the penalties for contaminating the natural environment.

3) Infrastructure: Plastic disposal and storage infrastructure, like bins or storage spaces (e.g., shelves), must be located near the entrance of each protected area or natural attraction. This is expected to generate a better notion of where to discard/place their PPE, which is sometimes regarded as a contaminated or special type of waste, and single-use plastics.

4) Supervision: Additional to sufficient infrastructure, supervisors should be located at the entrance of each PA/natural attraction to check if the visitors are carrying plastic-based goods and require them to be tagged and stored in a designated area until they exit the PA. This measure will prevent plastic materials from entering PAs.

5) Recycling: Local governments must seek to establish new and expand the existing recycling systems, aiming to avoid plastic waste to reach landfills or natural environments. Several innovative recycling alternatives have been investigated, such as waste-to-energy conversion. However, a detailed viability analysis is required considering the possible inaccessible nature of advancing infrastructure and investment in developing countries.

CRediT authorship contribution statement

Diana Carolina Dioses-Salinas: Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. Carlos Ivan Pizarro-Ortega: Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. Sina Dobaradaran: Data curation, Formal analysis, Writing – original draft, Writing – review & editing. Mohamed Ben-Haddad: Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. Gabriel Enrique De-la-Torre: Project administration, Conceptualization, Funding acquisition, Software, Writing – original draft, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
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To the Editors: As the public becomes more aware of the impact of personal protective equipment (PPE) pollution driven by the COVID-19 pandemic in coastal environments, there is an urgent need for organizations with a central role in PPE pollution to do their part. One example is the National Park Service, which could play a crucial role in eliminating PPE pollution by implementing environmentally friendly practices such as reducing the use of single-use plastics and promoting the use of reusable PPE. Furthermore, the National Park Service could collaborate with other organizations and governmental bodies to develop a comprehensive plan for addressing PPE pollution in coastal environments.
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