Journal of Environmental Protection, 2024, 15, 874-886
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Determinants of COVID-19 Face Mask Litter in Coastal Urban Parking Lots: Implications for Source Modelling of Potential Microplastic Pollution

Robert France*, Brandon Heung

Department of Plant, Food and Environmental Science, Dalhousie University, Nova Scotia, Canada
Email: *rfrance@dal.ca

How to cite this paper: France, R. and Heung, B. (2024) Determinants of COVID-19 Face Mask Litter in Coastal Urban Parking Lots: Implications for Source Modelling of Potential Microplastic Pollution. *Journal of Environmental Protection*, **15**, 874-886.
https://doi.org/10.4236/jep.2024.158050

Received: July 11, 2024
Accepted: August 17, 2024
Published: August 20, 2024

Abstract

Despite cities being recognized as being potential sources of microplastic pollution to the wider environment, most surveys of COVID-19 plastic-based litter have been undertaken through linear transects of marine beaches. For the far fewer number of studies conducted on inland and urban locations, the site-specific focus has primarily been surveys along the length of streets. The present study is the first to specifically assess the standing stock (*i.e.*, moment-in-time) of littered face masks for the entire surface area of urban parking lots. The density of face masks in 50 parking lots in a Canadian coastal town (0.00054 m^2 ± 0.00051 m^2) was found to be significantly greater than the background level of littering of town streets. Face mask density was significantly related to visitation "usage" of parking lots as gauged by the areal size of the lots and of their onsite buildings, as well as the number of vehicles present. Neither parking lot typology nor estimates of inferred export (various measures of wind exposure) and entrapment (various metrics of obstruction) of face masks had a significant influence on the extent of whole-lot littering. In consequence, modelling of the potential input of mask-derived microplastics to the marine environment from coastal communities can use the areal density of face masks found here in association with the total surface area of lots for individual municipalities as determined through GIS analysis.

Keywords

COVID Face Masks, Parking Lot Litter, Prediction Areal Abundance

1. Introduction

The COVID-19 pandemic has generated a global problem through the cavalier abandonment or deliberate discarding of personal protection equipment (PPE) by the public [1]-[5]. This has raised concerns that the billions of improperly disposed face masks pose a threat to wildlife through physical entanglement, or, when broken down, through ingestion of derived microplastics [6]-[9]. The waning of virus pathogeny and the consequent relaxation or abandonment of masking mandates has meant that face mask pollution is much lower now compared to the height of the pandemic between 2020 and 2022. As a result, the threat of physical entanglement to wildlife will have been significantly reduced. However, the degradation of face masks into microplastics through ultraviolet radiation, physical abrasion, chemical oxidation, and climatic (temperature, water) influences and biological agents are processes that take time [10]-[14]. As a result, although the pandemic may be considered to be largely "over" in terms of its immediate lethality to a substantial number of humans, an argument can certainly be made that from the perspective of long-term effects on marine food chains—some of which lead to humans—that the deleterious environmental consequences of the pandemic microplastic pollution are in their early days and can expected to persist for many decades [5]. Because of this, quantifying site-specific determinants of face mask littering from the height of the pandemic will provide useful empirical information for those involved with modelling the potential input of mask-derived microplastics to the marine environment. Unfortunately, despite the widespread recognition that urban stormwater runoff is an important pathway for transporting microplastic pollution across the land-sea continuum [15], the lack of data means that "it is not possible to quantify littering as a source of microplastics with available monitoring data" [13]. The present study was designed to address this paucity of data.

With rare exceptions, previous surveys of the magnitude of face mask litter have been based on single moment-in-time samplings to provide estimates of the standing stock or abundance of pollution. Many of these studies have focused on congregation locations, such as tourist beaches and festival sites—as summarized by Kutralam-Muniasamy *et al.* [16] and Kutralam-Muniasamy and Shruti [17]—in addition to mobility thoroughfares, such as streets in large urban centers [18]-[24], as well as country roads and streets in peri-urban and small municipalities [25]. Ammendolia *et al.* [19] surveyed contrasting site typologies within an urban framework, finding densities of PPE litter to be higher in several parking lots compared to a few streetscapes and a recreational trail. It seems reasonable to assume that this is related to differences between the locations where people were required to wear face masks to be able to linger, versus sites of transit through which they passed without needing to be masked to arrive at the former locations. The first purpose of this study was to conduct the first specifically targeted survey of the standing stock of COVID-19 face masks in urban parking lots to test the assumption that levels of litter in these locations will be higher than the background levels observed along city streets.

Beaches have long been recognized to be locations where plastic pollution is known to accumulate, leading to hundreds of published studies on the topic from around the world. Litter in such locations reflects that which is generated in situ by visitors, as well as that which is imported from afar through the focusing action of waves and other hydrodynamic processes, e.g. [26]-[28]. Coastal studies have frequently linked litter abundance to beach activity usage, occasionally to distance from urban centers or municipal dumpsites, and less frequently, for example, De-la-Torre *et al.* [29] with respect to PPE waste, to population density. Far fewer investigations have been made of the determinants of plastic litter abundance for inland and urban locations, e.g. [30] [31]. Occasionally this work has included various socioeconomic and demographic data, e.g. [32]-[34], of which certain elements may be deemed by some to be controversially sensitive (e.g., race, education, employment, income, property value). In consequence, restricting consideration of potential determinants to those of a physical or non-cultural nature will be the safest approach. With respect to beaches, for example, Bowman *et al.* [35] found that physical metrics characterizing geomorphology were dominating factors affecting the abundance of litter. The second purpose of the present study was to investigate whether a suite of heuristic attributes concerning the physical nature and environmental conditions of parking lots might influence the consequent standing stock of COVID-19 face mask litter.

2. Methods

Fifty parking lots were surveyed for the presence of discarded or abandoned face masks in the coastal town of Truro, Nova Scotia, Canada. Because the town often floods [36] [37] litter can be easily transported to the marine environment. Microplastic pollution has been found along Nova Scotia coasts [38], including in intertidal sediments in the Bay of Fundy [39]. Truro has a population of 13,000 people residing within a land area of 38 km^2. The village of Bible Hill (pop. 5,000) is situated on the other side of the Salmon River from Truro. Together these communities serve as the regional hub for government, education and health services, recreation facilities, and shopping for their residents as well as an additional 34,000 residents from the surrounding Colchester County, a rural municipality of 3,600 km^2, the fourth largest in the province.

Consistent with the widely established methodology in the literature of conducting surveys of plastic pollution at single moments-in-time to assess the standing stock of litter abundance, sampling in this study took place from daybreak to the afternoon on the first Sunday in November 2021. This was when shops, offices, and other buildings—except the hospital and 24-hour automobile service stations—were closed and the parking lots were largely empty of vehicles, thereby permitting unhampered searching for face masks. Most studies of COVID-19 face mask litter have utilized line-transect surveys of small areal segments deemed to be representative of larger landscapes. In contrast, for the present study, the entire surface area of each of the 50 parking lots was completely scoured of all observable face masks (disposable surgical, damaged, and reusable cloth types). Additionally, two-meter-wide swaths on opposite sides of

7 streets were surveyed, with counts made of PPE waste on sidewalks and abutting curbside edges of the thoroughfares, as in France [25]. The total surface area surveyed was 491,312 m^2 (parking lots = 464,676 m^2, streets = 26,636 m^2), making this one of the largest monitoring endeavors of pandemic PPE waste to be undertaken.

The surveyed parking lots represent a considerable proportion of the total number of lots in the entire town. All lots were located within the small 2 × 4 km developed core of the town (**Figure 1**), an area of uniform socioeconomic and demographic conditions. The lots fall into 8 broad categories of approximately equal-weighted sampling effort: (1) grocery stores and shopping malls (n = 6); (2) health and education centers (n = 5); (3) recreation or club facilities (n = 6); (4) general shops (n = 6); (5) automobile service stations (n = 6); (6) offices, hotels, and public lots (n = 7); and (7) restaurants with (n = 7), or (8) without (n = 7), drive-through takeaway services. This selection of lots represents the broad range of typologies present in the town, with only those other lots associated with infrequently visited establishments selling large or expensive items, such as furniture or automobiles, being excluded.

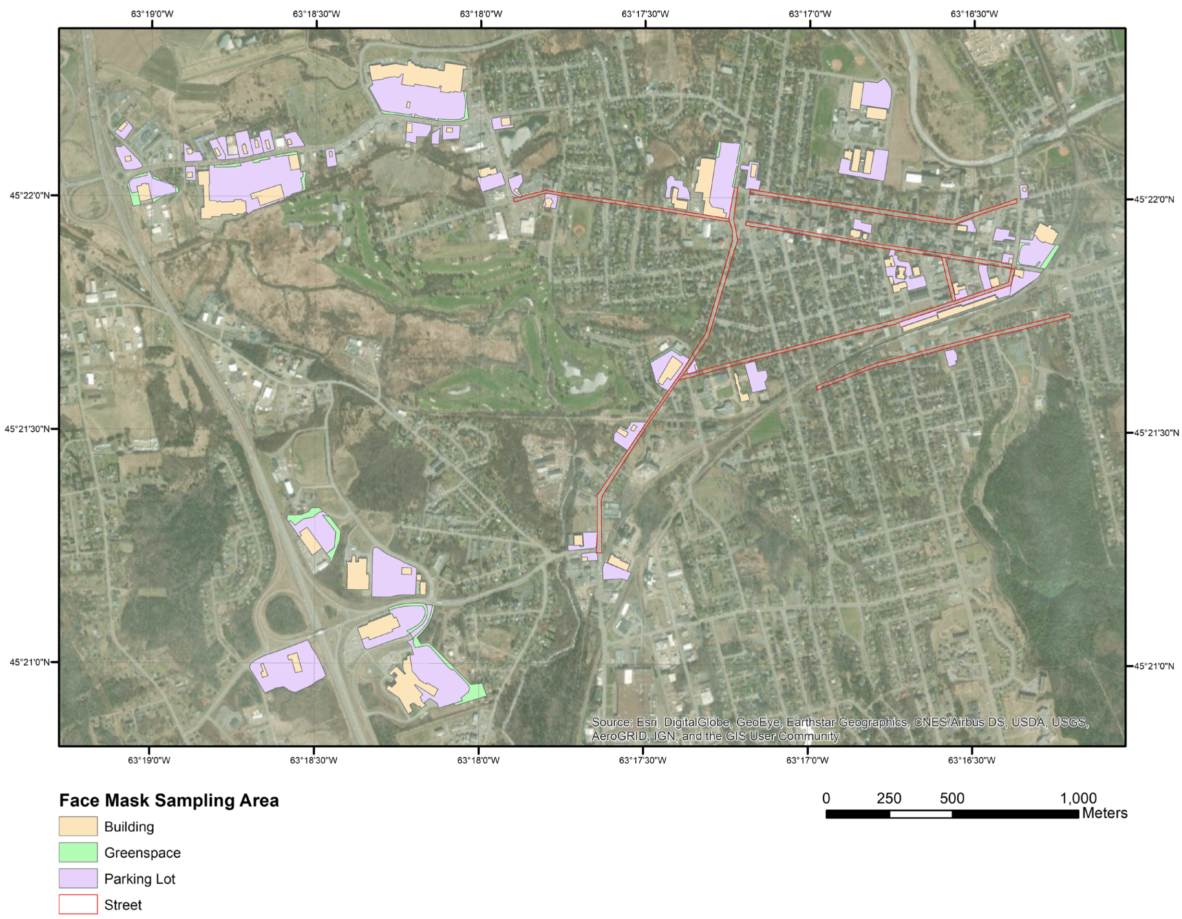

Figure 1. Location of the 50 surface areas of parking lots (blue-grey shaded) and the 14 linear streetscapes (red line highlighted) surveyed for face mask litter in Truro, Nova Scotia, Canada in November 2021.

Following a preliminary reconnoitering of a dozen of the parking lots, 11 physical and easily measurable—through either on-site visual assessment or subsequent geographic information system (GIS) analysis—attributes were selected as being site characteristic variables that might influence the standing-stock (*i.e.*, single point-in-time abundance) of face masks. These fall into three broad categories: (1) estimated "usage" of lots by visitors; (2) "wind exposure" and the consequent export of litter from lots; and (3) obstructions and the consequent "entrapment" of litter in lots.

The metrics corresponding to estimated site usage include (a) the surface area of parking lots; (b) the surface area of all onsite buildings; and (c) the cumulative number of vehicles in lots assessed at four different times during a single week (mid-morning, mid-afternoon, and evening after work hours on three different weekdays, and mid-day on Saturday). The surface area of each parking lot was measured by digitizing aerial imagery using the imagery from the ArcMap 10.8.1 software. The surface area of onsite buildings was acquired using the Town of Truro Building Footprint spatial dataset, acquired from the town's GIS data repository (https://interactive-truro-townoftruro.hub.arcgis.com/). This dataset included a digitization of buildings, whereby areas were subsequently calculated, based on the number of floors for individual buildings. To estimate the approximate floor space of each building, the area and the number of floors were simply multiplied. Additionally, each building was visited to confirm the number of floors. In cases where a building footprint was not available, a manual delineation was carried out using aerial imagery and GIS.

The metrics corresponding to site wind exposure include (a) the lot elevation above sea level; (b) the maximum fetch or uninterrupted distance over which wind can blow across lots; and (c) an index of overall exposure that accounts for surrounding buildings, trees, and other obstructions. To estimate the lot elevation, LiDAR (light detection and ranging) data were acquired from GeoNOVA, the provincial spatial data repository (https://geonova.novascotia.ca/). Using the 1 m spatial resolution digital elevation model, generated for 2019, zonal statistics were calculated for each lot polygon and the average elevation for that parking lot was retained. To estimate the maximum fetch, the longest distance of each polygon was measured using GIS. Lastly, to represent the overall exposure of each lot, a LiDAR-based, digital surface model (including buildings, trees, fences, and other obstructions), produced at a 1 m spatial resolution for 2019, was used as an input for a wind exposition (*i.e.*, exposure) model. This model simulates the wind flow from multiple directions and generates a dimensionless index whereby values < 1 represent sheltered areas, while values > 1 represent wind-exposed areas. This analysis was carried out using the freely available System for Automated Geoscientific Analyses (SAGA) GIS software [40] [41]. Similar to the calculation of the lot elevation, zonal statistics were generated for the wind exposition index values.

The metrics corresponding to site entrapment include (a) the number of internal lot obstructions (light poles and signs, collection areas for shopping carts, infrastructure such as instruments, fire hydrants, and garbage bins, landscaping features); and the extent of lot perimeter lengths subsumed by abutting (b) structures (fences, walls), (c) vegetation (planted, natural), and (d) landscaping (ditches, banks, gravel).

Ranges of the metrics for the 50 parking lots are shown in **Table 1**. Due to the non-normalcy of the frequency-abundance distribution (Shapiro-Wilk test) and the non-homogeneity of variances across means (Taylor's power law) determined for the present litter data [42], nonparametric rather than parametric statistics are used herein. The previous paper focused exclusively on the sampling methodology of both our own and other published studies with no mention made of any empirical searches for predictive measures of the extent of littering, the purpose of the present paper. In short, the first paper dealt with the statistical methods used in the present paper (as well as in other studies), with no overlap existing in terms of intent or presentation of data between the two publications.

Table 1. Ranges of potential determinants of face mask litter in 50 parking lots in Truro, Nova Scotia, Canada in November 2021 (see text for explanation of metrics).

Usage	
Lot surface area (m^2)	1,386 - 54,383
Building surface area (m^2)	204 - 54,702
Total vehicles (#)	8 - 1,100
Wind exposure	
Elevation (m)	8 - 45
Onsite fetch (m)	58 - 470
Offsite exposure index ($\times 10^{-3}$)	902 - 966
Entrapment	
Onsite obstructions (#)	0 - 33
Perimeter structures (m)	0 - 280
Perimeter vegetation (m)	0 - 149
Perimeter landscaping (m)	0 - 155
Perimeter total (%)	0 - 64

3. Results

A total of 311 abandoned face masks were collected from the 50 parking lots. The number of face masks per parking lot ranged between 0 and 97. All three measures of 'usage' were found to influence the standing stock (abundance) of face masks found in parking lots. Kruskall-Wallis H tests, followed by Dunn's multiple comparison tests, revealed significant ($p < 0.003$) differences between pair groups with respect to both parking lot area and the cumulative total count of automobiles (**Figure 2**), as well as for the building area. Because the areal extent of parking lots is correlated with both the size of onsite buildings ($r^2 = 0.56$, $p < 0.0001$) as well as with the occupation of the site in terms of the number of automobiles present ($r^2 = 0.79$, $p < 0.0001$), lot surface area can serve as a convenient surrogate for overall visitation usage. Sites with larger buildings have larger accompanying parking lots, which are correspondingly filled with more automobiles, which, not surprisingly, consequent higher levels of face mask littering. For the dozen lots in which 5 or more abandoned face masks were collected, there was a correlation (Spearman's $r_s = 0.79$, $p = 0.002$) between the area size of the lot and the abundance of littered masks. However, the strength of this relationship decreased with the inclusion of all 50 parking lots ($r_s = 0.61$, $p = 0.001$), indicating that other factors besides lot size must be affecting the resulting litter abundance.

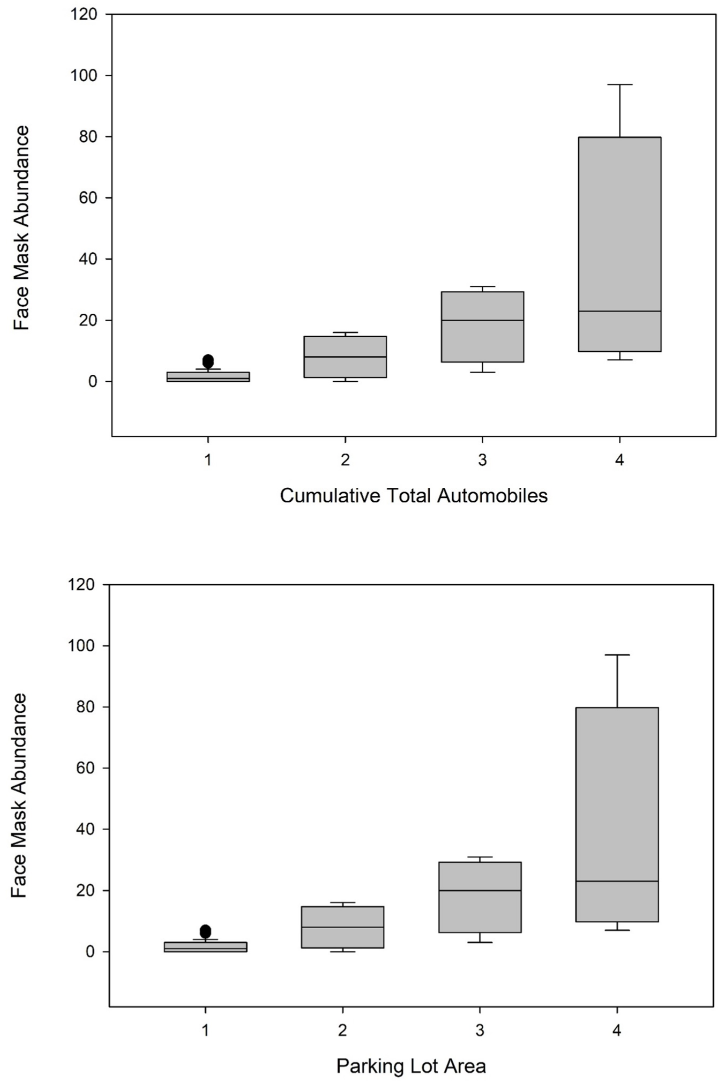

Figure 2. Significant relationships (Kruskall-Wallis and Dunn's tests) of the standing stock of littered face masks to four categories of (upper panel) the weekly presence of automobiles (left-to-right x-axis divisions "1" = < 50, "2" = 51 - 225, "3" = 225 - 500, and "4" = > 500 vehicle counts) and (lower panel) four categories of the surface area (left-to-right x-axis divisions "1" = < 10, "2" = 11 - 20, "3" = 21 - 30, and "4" = > 30 thousand m^2) of the surveyed parking lots.

Removing the dominating influence of usage by expressing litter data as the density of face masks per m^2 allows comparisons to be made across sites (and between studies) with lots of variable sizes. Kruskall-Wallis and Dunn's tests showed that the litter density was not significantly ($p > 0.05$) influenced by the typology of parking lots (**Figure 3**), indicating that lots need not be differentiated in subsequent analyses. Kruskall-Wallis and Dunn's tests did not find any of the three wind exposure measures, nor any of the four entrapment metrics to have a significant effect ($p > 0.05$) on the litter density in parking lots. Finally, the overall mean density of face masks in all parking lots was 0.00054 ± 0.00051 (SD) m^{-2}, an amount that was significantly greater (Mann-Whitney U test, $p < 0.05$) compared to densities on town streets (0.00014 ± 0.00011 m^{-2}).

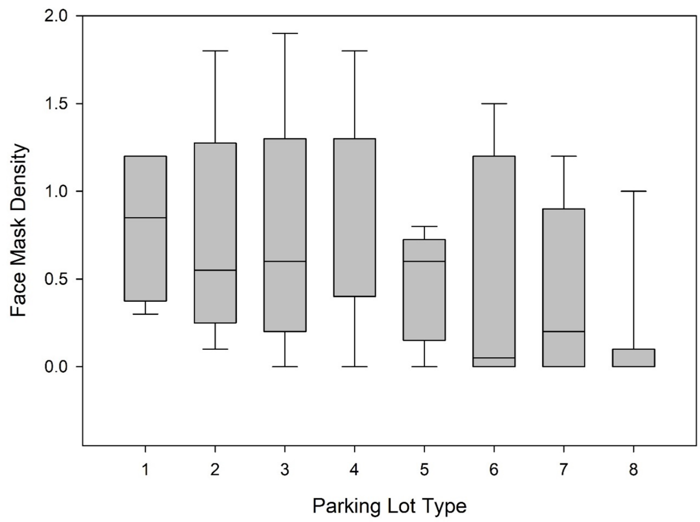

Figure 3. Nonsignificant relationship (Kruskall-Wallis and Dunn's tests) of the standing stock of littered face masks to eight types of the surveyed parking lots (ordered left-to-right in the same numerical sequence as identified and explained in the Methods: "1" = grocery stores and shopping malls; "2" = health and education centers; "3" = recreation or club facilities; "4" = general shops; "5" = automobile service stations; "6" = offices, hotels and public lots; "7" restaurants; and "8" restaurants with drive-through takeaways).

4. Discussion

There are very few similar studies in which to compare the present results. This is because most surveys of the standing stock of PPE litter have been undertaken in locations where, or at times when, people occasionally congregate in large numbers, such as at recreational beaches or during religious festivals. In contrast, the present investigation, rather than focusing on such atypical or exceptional circumstances, addresses the issue of pandemic littering with respect to the mundanity of daily urban life, including shopping, dining out, refueling automobiles, going to work, attending school, or visiting the hospital or fitness center. The average densities of face mask litter found in the present survey of parking lots and streets of a Nova Scotian town are similar to levels observed in other Canadian locations, such as the metropolitan city of Toronto [19] and small towns in Quebec [25]. Abandoned or discarded face masks were more prevalent in Truro parking lots where people lingered and were legally obligated to 'mask-up' to enter onsite buildings than along streets, which could be transited free of the need to wear masks. Although several studies have surveyed face mask littering by walking along city streets [21] [23] [24] [43] [44], in one case doing so ancillary to another purpose [22], the present results suggest that if the overarching goal is to reckon the total deposition of PPE waste for municipalities, from which to then estimate loading rates of microplastic pollution to the surrounding environment, it is necessary to specifically target the hot-spots of parking lots.

Most studies of the standing stock of PPE litter present results without undertaking empirical investigations of potential determinants of the magnitude of the observed pollution. An exception is Costa *et al.* [45], who found that litter abundance on a set of beaches could be predicted by the level of urbanization. Several other studies, in contrast, have found that certain predictor variables, despite their heuristic appeal, may not have a significant influence on the consequent density of face mask litter [24] [25] [29]. For the present survey, beyond the dominating significance of the surrogate usage variable of parking lot area, other variables related to the inferred entrapment or to the export of face masks did not play a major role in the resulting litter densities as assessed on the scale of the entire lots.

5. Conclusions

The absence of overt influences modifying the standing stock assessment of PPE litter in these parking lots, apart from the dominating influence of surface area, turns out to be a beneficial finding. This is because it means that the average density value recorded herein can be assumed to be robustly representative of a generic parking lot. This will be useful to those involved with modelling the potential input of mask-derived microplastics from coastal communities to the marine environment. In this regard, measurements of the total surface area of parking lots for any municipality can be easily obtained through GIS analysis and then multiplied by the average areal density of face masks in relation to any length of time. In like fashion, there is a long-established tradition of relating the areal extent of parking lots to deleterious effects on the biological integrity of surrounding waters [46].

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Benson, N.U., Bassey, D.E. and Palanisami, T. (2021) COVID Pollution: Impact of COVID-19 Pandemic on Global Plastic Waste Footprint. *Heliyon*, **7**, e06343. https://doi.org/10.1016/j.heliyon.2021.e06343

[2] Mahmoudnia, A., Mehrdadi, N., Golbabaei Kootenaei, F., Rahmati Deiranloei, M. and Al-e-Ahmad, E. (2022) Increased Personal Protective Equipment Consumption during the COVID-19 Pandemic: An Emerging Concern on the Urban Waste Management and Strategies to Reduce the Environmental Impact. *Journal of Hazardous Materials Advances*, **7**, Article 100109. https://doi.org/10.1016/j.hazadv.2022.100109

[3] Roberts, K.P., Phang, S.C., Williams, J.B., Hutchinson, D.J., Kolstoe, S.E., de Bie, J., *et al.* (2021) Increased Personal Protective Equipment Litter as a Result of COVID-19 Measures. *Nature Sustainability*, **5**, 272-279. https://doi.org/10.1038/s41893-021-00824-1

[4] Patrício Silva, A.L., Tubić, A., Vujić, M., Soares, A.M.V.M., Duarte, A.C., Barcelò, D., *et al.* (2022) Implications of COVID-19 Pandemic on Environmental Compartments: Is Plastic Pollution a Major Issue? *Journal of Hazardous Materials Advances*, **5**, Article 100041. https://doi.org/10.1016/j.hazadv.2021.100041

[5] Yang, Q., Yang, S. and Jiao, Y. (2023) Assessing Disposable Masks Consumption and Littering in the Post COVID-19 Pandemic in China. *Environmental Pollution*, **334**, Article 122190. https://doi.org/10.1016/j.envpol.2023.122190

[6] Patrício Silva, A.L., Prata, J.C., Mouneyrac, C., Barcelò, D., Duarte, A.C. and Rocha-Santos, T. (2021) Risks of COVID-19 Face Masks to Wildlife: Present and Future Research Needs. *Science of the Total Environment*, **792**, Article 148505. https://doi.org/10.1016/j.scitotenv.2021.148505

[7] Ammendolia, J., Saturno, J., Bond, A.L., O'Hanlon, N.J., Masden, E.A., James, N.A., *et al.* (2022) Tracking the Impacts of COVID-19 Pandemic-Related Debris on Wildlife Using Digital Platforms. *Science of the Total Environment*, **848**, Article 157614. https://doi.org/10.1016/j.scitotenv.2022.157614

[8] Mvovo, I. and Magagula, H.B. (2022) Prevalence of COVID-19 Personal Protective Equipment in Aquatic Systems and Impact on Associated Fauna. *Environment Systems and Decisions*, **42**, 328-337. https://doi.org/10.1007/s10669-022-09851-5

[9] Fonseca, T., Edo, C., Vilke, J.M., Astudillo-Pascual, M., Gonçalves, J.M. and Bebianno, M.J. (2023) Impact of Face Masks Weathering on the Mussels *Mytilus galloprovincialis*. *Water Emerging Contaminants & Nanoplastics*, **3**, Article 3. https://doi.org/10.20517/wecn.2023.57

[10] Saliu, F., Veronelli, M., Raguso, C., Barana, D., Galli, P. and Lasagni, M. (2021) The Release Process of Microfibers: From Surgical Face Masks into the Marine Environment. *Environmental Advances*, **4**, Article 100042. https://doi.org/10.1016/j.envadv.2021.100042

[11] Sullivan, G.L., Delgado-Gallardo, J., Watson, T.M. and Sarp, S. (2021) An Investigation into the Leaching of Micro and Nano Particles and Chemical Pollutants from Disposable Face Masks—Linked to the COVID-19 Pandemic. *Water Research*, **196**, Article 117033. https://doi.org/10.1016/j.watres.2021.117033

[12] De-la-Torre, G.E., Dioses-Salinas, D.C., Dobaradaran, S., Spitz, J., Nabipour, I., Keshtkar, M., *et al.* (2022) Release of Phthalate Esters (PAEs) and Microplastics (MPs) from Face Masks and Gloves during the COVID-19 Pandemic. *Environmental Research*, **215**, Article 114337. https://doi.org/10.1016/j.envres.2022.114337

[13] Oborn, L., Oserlund, H., Svedin, J., Nordqvist, K. and Viklander, M. (2022) Litter in Urban Areas May Contribute to Microplastics Pollution: Laboratory Study of the Photodegradation of Four Commonly Discarded Plastics. *Journal of Environmental Engineering*, **148**, 1-4. https://doi.org/10.1061/(ASCE)EE.1943-7870.0002056

[14] Hasan, J., Shahriar, S.I.M. and Shahjahan, M. (2023) Release of Microfibers from

Surgical Face Masks: An Undesirable Contributor to Aquatic Pollution. *Water Emerging Contaminants & Nanoplastics*, **2**, Article 18. https://doi.org/10.20517/wecn.2023.31

[15] Hajiouni, S., Mohammadi, A., Ramavandi, B., Arfaeinia, H., De-la-Torre, G.E., Tekle-Röttering, A., *et al.* (2022) Occurrence of Microplastics and Phthalate Esters in Urban Runoff: A Focus on the Persian Gulf Coastline. *Science of the Total Environment*, **806**, Article 150559. https://doi.org/10.1016/j.scitotenv.2021.150559

[16] Kutralam-Muniasamy, G. and Shruti, V.C. (2022) The Case of "Public Congregation vs. COVID-19 PPE Pollution": Evidence, Lessons, and Recommendations from the Annual Pilgrimage to the Catholic Holy Site in Mexico City, Mexico. *Science of the Total Environment*, **821**, Article 153424. https://doi.org/10.1016/j.scitotenv.2022.153424

[17] Kutralam-Muniasamy, G., Pérez-Guevara, F. and Shruti, V.C. (2022) A Critical Synthesis of Current Peer-Reviewed Literature on the Environmental and Human Health Impacts of COVID-19 PPE Litter: New Findings and Next Steps. *Journal of Hazardous Materials*, **422**, Article 126945. https://doi.org/10.1016/j.jhazmat.2021.126945

[18] Ryan, P.G., Maclean, K. and Weideman, E.A. (2020) The Impact of the COVID-19 Lockdown on Urban Street Litter in South Africa. *Environmental Processes*, **7**, 1303-1312. https://doi.org/10.1007/s40710-020-00472-1

[19] Ammendolia, J., Saturno, J., Brooks, A.L., Jacobs, S. and Jambeck, J.R. (2021) An Emerging Source of Plastic Pollution: Environmental Presence of Plastic Personal Protective Equipment (PPE) Debris Related to COVID-19 in a Metropolitan City. *Environmental Pollution*, **269**, Article 116160. https://doi.org/10.1016/j.envpol.2020.116160

[20] Okuku, E., Kiteresi, L., Owato, G., Otieno, K., Mwalugha, C., Mbuche, M., *et al.* (2021) The Impacts of COVID-19 Pandemic on Marine Litter Pollution Along the Kenyan Coast: A Synthesis after 100 Days Following the First Reported Case in Kenya. *Marine Pollution Bulletin*, **162**, Article 111840. https://doi.org/10.1016/j.marpolbul.2020.111840

[21] Tesfaldet, Y.T., Ndeh, N.T., Budnard, J. and Treeson, P. (2022) Assessing Face Mask Littering in Urban Environments and Policy Implications: The Case of Bangkok. *Science of the Total Environment*, **806**, Article 150952. https://doi.org/10.1016/j.scitotenv.2021.150952

[22] Cueva, A. (2023) Temporal Considerations for an Effective Sampling of Personal Protective Equipment Litter Derived from the COVID-19 Pandemic. *Science of the Total Environment*, **858**, Article 160047. https://doi.org/10.1016/j.scitotenv.2022.160047

[23] Aslan, H., Yılmaz, O., Benfield, M.C. and Becan, S.A. (2023) Temporal Trends in Personal Protective Equipment (PPE) Debris during the COVID-19 Pandemic in Çanakkale (Türkiye). *Science of the Total Environment*, **898**, Article 165377. https://doi.org/10.1016/j.scitotenv.2023.165377

[24] Araña, K.N.D., Dimaongon, N.G., Mauyag, N.D., Hadji Morad, N.M., Manupac, S.R.R. and Bacosa, H.P. (2023) Personal Protective Equipment (PPE) Litter in Terrestrial Urban Areas of Iligan City, Philippines. *Environmental Monitoring and Assessment*, **195**, Article No. 1486. https://doi.org/10.1007/s10661-023-12044-5

[25] France, R.L. (2022) First Landscape-Scale Survey of the Background Level of COVID-19 Face Mask Litter: Exploring the Potential for Citizen Science Data Collection during a 'Pollution Pilgrimage' of Walking a 250-km Roadside Transect. *Science of the Total Environment*, **816**, Article 151569. https://doi.org/10.1016/j.scitotenv.2021.151569

[26] Ryan, P.G., Moore, C.J., van Franeker, J.A. and Moloney, C.L. (2009) Monitoring the Abundance of Plastic Debris in the Marine Environment. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **364**, 1999-2012. https://doi.org/10.1098/rstb.2008.0207

[27] Eriksson, C., Burton, H., Fitch, S., Schulz, M. and van den Hoff, J. (2013) Daily Accumulation Rates of Marine Debris on Sub-Antarctic Island Beaches. *Marine Pollution Bulletin*, **66**, 199-208. https://doi.org/10.1016/j.marpolbul.2012.08.026

[28] Haddad, M.B., De-la-Torre, G.E., Abelouah, M.R., Hajji, S. and Alla, A.A. (2021) Personal Protective Equipment (PPE) Pollution Associated with the COVID-19 Pandemic Along the Coastline of Agadir, Morocco. *Science of the Total Environment*, **798**, Article 149282. https://doi.org/10.1016/j.scitotenv.2021.149282

[29] De-la-Torre, G.E., Dioses-Salinas, D.C., Pizarro-Ortega, C.I., Fernández Severini, M.D., Forero López, A.D., Mansilla, R., *et al.* (2022) Binational Survey of Personal Protective Equipment (PPE) Pollution Driven by the COVID-19 Pandemic in Coastal Environments: Abundance, Distribution, and Analytical Characterization. *Journal of Hazardous Materials*, **426**, Article 128070. https://doi.org/10.1016/j.jhazmat.2021.128070

[30] Schultz, P.W., Bator, R.J., Large, L.B., Bruni, C.M. and Tabanico, J.J. (2011) Littering in Context. *Environment and Behavior*, **45**, 35-59. https://doi.org/10.1177/0013916511412179

[31] Carpenter, E. and Wolverton, S. (2017) Plastic Litter in Streams: The Behavioral Archaeology of a Pervasive Environmental Problem. *Applied Geography*, **84**, 93-101. https://doi.org/10.1016/j.apgeog.2017.04.010

[32] Thornton, C.M., Conway, T.L., Cain, K.L., Gavand, K.A., Saelens, B.E., Frank, L.D., *et al.* (2016) Disparities in Pedestrian Streetscape Environments by Income and Race/Ethnicity. *SSM-Population Health*, **2**, 206-216. https://doi.org/10.1016/j.ssmph.2016.03.004

[33] Gibson, I. (2016) Predictors of Litter Pollution in Suburban Parks. Honors Thesis, University of Connecticut.

[34] Lockwood, B., Wyant, B.R. and Grunwald, H.E. (2020) Locating Litter: An Exploratory Multilevel Analysis of the Spatial Patterns of Litter in Philadelphia. *Environment and Behavior*, **53**, 601-635. https://doi.org/10.1177/0013916520906834

[35] Bowman, D., Manor-Samsonov, N. and Golik, A. (1998) Dynamics of Litter Pollution on Israeli Mediterranean Beaches: A Budgetary Litter Flux Approach. *Journal of Coastal Research*, **14**, 418-432.

[36] Patton, A.S.M. (2005) A Study of the Hydrological Characteristics of the North and Salmon Rivers in Relation to Central Colchester County Flooding. Master's Thesis. Dalhousie University.

[37] France, R.L., Patton, A.S.M. and Aitchison, P.W. (2019) Modeling Reforestation's Role in Climate-Proofing Watersheds from Flooding and Soil Erosion. *American Journal of Climate Change*, **8**, 387-403. https://doi.org/10.4236/ajcc.2019.83021

[38] Kelly, N.E., Trela, O., Gavel, H. and Vander Kuylen, A. (2024) Plastic and Anthropogenic Microfiber Pollution on Exposed Sandy Beaches in Nova Scotia, Canada. *Water Emerging Contaminants & Nanoplastics*, **3**, Article 6. https://doi.org/10.20517/wecn.2023.66

[39] Forsythe, C. (2016) The Quantification of Microplastics in Intertidal Sediments in the Bay of Fundy, Canada. 2016. https://www.viurrspace.ca

[40] Böhner, J. and Antonić, O. (2009) Land-Surface Parameters Specific to Topo-Climatology. *Developments in Soil Science*, **33**, 195-226. https://doi.org/10.1016/s0166-2481(08)00008-1

[41] Gerlitz, L., Conrad, O. and Böhner, J. (2015) Large-Scale Atmospheric Forcing and Topographic Modification of Precipitation Rates over High Asia—A Neural-Network-Based Approach. *Earth System Dynamics*, **6**, 61-81. https://doi.org/10.5194/esd-6-61-2015

[42] France, R.L. and Heung, B. (2023) Density Variability of COVID-19 Face Mask Litter: A Cautionary Tale for Pandemic PPE Waste Monitoring. *Journal of Hazardous Materials Advances*, **9**, Article 100220. https://doi.org/10.1016/j.hazadv.2022.100220

[43] Abedin, M.J., Khandaker, M.U., Uddin, M.R., Karim, M.R., Uddin Ahamad, M.S., Islam, M.A., *et al*. (2022) Amassing the COVID-19 Driven PPE Wastes in the Dwelling Environment of Chittagong Metropolis and Associated Implications. *Chemosphere*, **297**, Article 134022. https://doi.org/10.1016/j.chemosphere.2022.134022

[44] Amuah, E.E.Y., Agyemang, E.P., Dankwa, P., Fei-Baffoe, B., Kazapoe, R.W. and Douti, N.B. (2022) Are Used Face Masks Handled as Infectious Waste? Novel Pollution Driven by the COVID-19 Pandemic. *Resources*, *Conservation & Recycling Advances*, **13**, Article 200062. https://doi.org/10.1016/j.rcradv.2021.200062

[45] Costa, L.L., Rangel, D.F. and Zalmon, I.R. (2023) The Presence of COVID-19 Face Masks in the Largest Hypersaline Lagoon of South America Is Predicted by Urbanization Level. *Marine Pollution Bulletin*, **189**, Article 114746. https://doi.org/10.1016/j.marpolbul.2023.114746

[46] France, R.L. (2022) Handbook of Water Sensitive Planning and Design. CRC Press.