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Tracking the impacts of COVID-19 pandemic-related debris on wildlife using digital platforms

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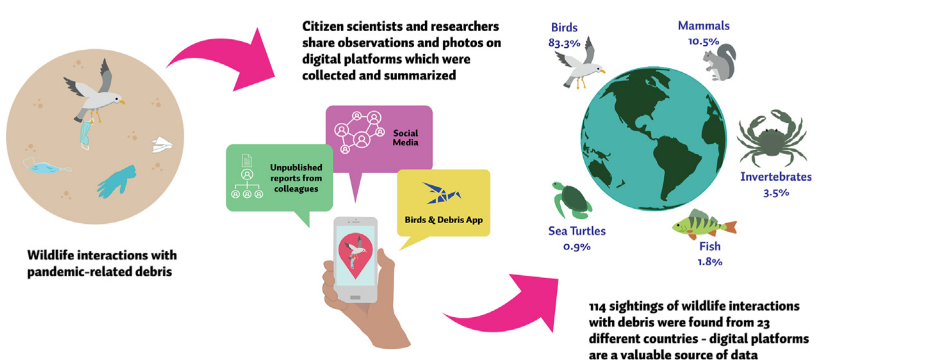
HIGHLIGHTS

- The COVID-19 pandemic has increased use of single-use personal protective equipment.
- 114 interactions between wildlife and pandemic-related debris were recorded.
- Most interactions occurred between birds and debris.
- Interactions mostly consisted of entanglements and nest incorporations.
- Social media platforms are a valuable way to collect citizen science observation.

GRAPHICAL ABSTRACT



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ABSTRACT

Since the start of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2; COVID-19) pandemic in December 2019, there have been global surges of single-use plastic use. Due to the importance of personal protective equipment (PPE) and sanitation items in protecting against virus transmission and from testing, facemasks, respirators, disposable gloves and disposable wet wipes have become global staples in households and institutions. Widespread use and insufficient infrastructure, combined with improper waste management have resulted in an emerging category of litter. With widespread presence in the environment, such items pose a direct threat to wildlife as animals can interact with them in a series of ways. We examined the scope of COVID-19 pandemic-related debris, including PPE and sanitation items, on wildlife from April 2020 to December 2021. We document the geographic occurrence of incidents, debris types, and consequences of incidents that were obtained from social media searches, unpublished reports from colleagues, and reports available from the citizen science database "Birds and Debris". There were 114 unique sightings of wildlife interactions with pandemic-related debris (38 from 2020 and 76 from 2021). Within the context of this dataset, most incidents involved birds (83.3 %), while fewer affected mammals (10.5 %), invertebrates (3.5 %), fish (1.8 %), and sea turtles (0.9 %). Sightings originated in 23 countries, and consisted mostly of entanglements (42.1 %) and nest incorporations (40.4 %). We verified sightings by contacting the original observers and were able to identify replicated sightings and increase the resolution of the data collected compared with previously published results. Due to the complexities associated with global use and accessibility of digital platforms, we likely

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underestimate the number of animals harmed by debris. Overall, the global scope of this study demonstrates that online and social media platforms are a valuable way to collect biologically relevant citizen science data and track rapidly emerging environmental challenges.

1. Introduction

The global pandemic caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2; Cucinotta and Vanelli, 2020), is now in its third year (World Health Organization, 2022, 2020a). As this virus spreads primarily through aerosols and airborne pathways (Anderson et al., 2020), governments have been recommending physical distancing and the use of personal protective equipment (PPE) in addition to vaccination, to limit transmission (MacIntyre and Wang, 2020). As a result, there has been a widespread increase in the use of PPE.

Medical-grade PPE used in healthcare settings includes surgical masks, eye protection, gloves (e.g., latex, nitrile and polyethylene), facial protection (e.g., masks and eye protection, face shields or masks with visor attachment) or respirators (e.g., KN95, N95 and N94) (Ilyas et al., 2020; Tian et al., 2020; World Health Organization, 2020b). These items are critical to limiting the exposure to and transmission of the virus (Institute of Medicine, 2011). However, due to global shortages in medical-grade PPE in the initial months of the pandemic, the general public was advised to use commercially available non-medical grade, disposable facemasks, and reusable face coverings (i.e. cloth masks) (Barcelo, 2020; Ilyas et al., 2020; Livingston, 2020; Woolley et al., 2020). Other sanitation items, not specifically recommended by public health authorities, were also widely-used by the public. Disposable wet wipes surged in production and sales because they provided a convenient way of disinfecting surfaces (Shruti et al., 2021; Stankiewicz, 2021). These items are commonly made of synthetic plastic derivatives, consisting of polyethylene and polypropylene (Aragaw, 2020; Fadare and Okoffo, 2020).

The proliferation of single-use items resulted in an estimation of 129 billion facemasks and 65 billion gloves used monthly (Benson et al., 2021; Prata et al., 2020). Global mismanagement and exacerbated pressures on inadequate waste management streams were widespread (Spennemann, 2021), and COVID-19 pandemic-related debris has been found in freshwater systems (Aragaw et al., 2022; Cordova et al., 2021), urbanised areas (Ammendolia et al., 2021; Ryan et al., 2020) and marine systems (De-la-Torre et al., 2021a, 2022; Haddad et al., 2021). Aquatic environments are particularly susceptible to accumulating pandemic-related debris as an estimated 1.56 billion facemasks travelled into oceans in 2020 (OceansAsia, 2020) and 107,219 pieces of PPE were removed from beaches and waterways by community scientists (Ocean Conservancy, 2021). PPE and pandemic-related macrodebris entering the environment can host colonizing microorganisms and can facilitate the movement of invasive species across geographic regions (De-la-Torre and Aragaw, 2021). Furthermore, larger debris can result in the emission and generation of microfiber and microplastic contamination that can cause harm to wildlife and potentially implicate human health (see review by De-la-Torre et al., 2021a; Rathinamoorthy and Balasaraswathi, 2022). Though harm to wildlife is the most readily observable by the general public, it is challenging to document using traditional ecological sampling methods.

Plastic debris negatively impacts wildlife in multiple ways including, but not limited to ingestion, entanglement, and nest incorporation (Provencher et al., 2019). The outcome of such interactions results in either sublethal impacts of reduced fitness through decreased feeding and energy stores (Galloway et al., 2017) and altered blood chemistry (Lavers et al., 2019) or lethal impacts (e.g., Battisti et al., 2019; Provencher et al., 2019). Previous work has examined these interactions through the lens of specific categories of plastics (e.g., fishing ropes and gear; Bond et al., 2012) to encourage source-based modifications to waste production. Pandemic-related debris is an ideal, and important, category of plastics to examine in relationship with wildlife because of its distinctive items and widespread presence. Hiemstra et al. (2021) were the first to produce an overview of wildlife interactions with PPE including ingestion, entanglement, and nest incorporation. This study was initiated in the Netherlands during a Plastic Spotter canal clean-up event, during which community scientists found a dead perch (*Perca fluviatilis*) entrapped in a digit of a latex glove (Hiemstra et al., 2021; Rambonnet et al., 2019). After learning about this incident, researchers set up an online depository for citizen scientists and researchers to share their sightings on the webpage Covid Litter and they conducted online searches for similar reports. A total of 28 sightings from April 2020 to January 2021 were documented, including interactions of wildlife and domestic animals (e.g., dogs and cats) with PPE debris. This study was critical in establishing the connection between pandemic-related debris and wildlife and also led to broader social awareness about the adverse environmental impact of the COVID-19 pandemic (Arnold, 2021).

Monitoring the environmental impact of pandemic-related debris is especially important given the volume of plastics being produced, used and escaping waste management streams. However, maintaining the continuity of monitoring programs during the COVID-19 pandemic was difficult given the extent and variability of local, regional, national, and international movement restrictions. As a result, many field research programs were disrupted and cancelled, preventing researchers from gathering empirical data (Ammendolia and Walker, 2022; Mallory, 2020). The conditions of the pandemic highlighted the importance and utility of sharing and mobilising information through online platforms (Hiemstra et al., 2021). Using data collected by citizen scientists on the platform Litterati, Roberts et al. (2021), described the global abundance and geographic distribution of pandemic-related debris. Building capacity for data collection and sharing through social media platforms and citizen science platforms such as mobile applications (e.g., Marine Debris Tracker, Litterati, Clean Swell) and websites (e.g., Birds and Debris, Covid Litter) is critical to identifying the geographic distribution of hotspots and regions where pandemic-related debris will likely impact wildlife.

Here, we examine the scope and impact of pandemic-related debris including both PPE and pandemic-related sanitation items on wildlife from April 2020 to December 2021. We expand on previously published work by providing detailed documentation of the geographic occurrence of incidents, debris types, and consequences of incidents that were obtained from social media searches, unpublished reports, and reports available from the citizen science database Birds and Debris. Within the scope of this paper we also identify the strengths and weaknesses of collecting data through these online search methods.

2. Methods

We recorded sightings from public posts on the social media platforms Facebook, Twitter, and Instagram. Data were also accessed from submissions made to the citizen science platform Birds and Debris. When available, unpublished sightings were obtained from the observers or organisations that posted the initial content or colleagues from professional networks that recorded sightings. Searches were made and sightings were collected between 01 August 2021 to 31 January 2022.

We adapted methods used in Hiemstra et al. (2021) to search for sightings directly on social media platforms. Searches made in English on Facebook, Twitter, and Instagram using the following keywords either alone or in combination: “mask”, “face mask”, “facemask”, “wet wipes”, disposable wipes”, “covid-mask”, “disposable mask”, “personal protective equipment", "glove", "COVID mask", "Covid-19 discarded face masks", "respirator", "COVID discard", "COVID19 litter", "litter", "plastic pollution", "entangled", "entanglement", "mask tangle", "nest", "nest discarded" "nesting material" and "wildlife". The resulting posts, tweets and/or images were assessed to ensure that content was posted within the range of COVID-19 pandemic (i.e., from 11 March 2020 to January 2022). Previous studies have collected biologically important data and images using social media platforms (Hiemstra et al., 2021) and search engines like Google (Leighton et al., 2016; Ryan, 2018). Data were also collected from the community science platform Birds and Debris which relies on individuals to post their sightings in accordance with the platform criteria.

Where possible, data and sighting descriptions were obtained directly from the posted content. If the content referred to a tertiary platform that reported the incident in more detail, those platforms were accessed and further information was collected (i.e., articles and editorial photography). The authenticity of the sightings was verified by tracing posts back with the original source (i.e., each observer). For every sighting obtained through social media, we initiated contact the original owner to ensure that details about the sighting were as accurate as possible. When different sightings by different observers seemed to report the same incident (e.g., similarities of species, locations and dates) the observers were contacted to verify replication.

The following details from each social media post were collected: species name, life stage, pandemic-related debris type, types of interaction with pandemic-related debris, GPS coordinates, date of sighting, date of public posting and available images of the sightings. Debris items included facemasks (e.g., disposable masks, long-strapped medical mask and reusable cloth masks), respirators (e.g., PFF-2, FFP-2 and KN-95) and gloves (e.g., latex, nitrile, polyethylene and vinyl). The types of interactions between wildlife and pandemic-related debris were adapted from Hiemstra et al. (2021). We describe interactions as: ingestion, entanglement, nest incorporation, carrying, pulling apart, playing, anchoring, entrapment and poking/biting. Entanglement refers to incidents in which animals were trapped within debris (i.e. inside the digit of a glove) while entanglement describes animals that were tangled in debris (i.e. strings of facemasks). We also include records of regurgitated pellets produced from animals after debris ingestion that contained pandemic-related debris.

3. Results

3.1. Quantitative summary

We found 114 unique sightings of wildlife interactions with pandemic-related debris (38 from 2020 and 76 from 2021). All sightings are detailed in Table A1 and contain corresponding ID codes which are referenced in the text. Within the context of this dataset, most were sightings of birds (n = 95; 83.3 %), followed by mammals (n = 12; 10.5 %), fish (n = 2; 1.8 %), invertebrates (n = 4; 3.5 %) and sea turtles (n = 1; 0.9 %) (Figs. 1, 2, 3A). The most commonly reported species were: mute swan (*Cygnus olor;* n = 9), herring gull (*Larus argentatus;* n = 6), Australian white ibis (*Threskiornis molucca;* n = 7), red kite (*Milvus milvus;* n = 5) and Eurasian coot (*Fulica atra;* n = 7). There were other species of gulls reported which included: unknown gull sp., yellow-legged gull (*L. michahellis*), great black-backed gull (*L. marinus*), silver gull (*Chroicocephalus novaehollandiae*) and ring-billed gull (*L. delawarensis*; n = 8). Of the bird sightings, there were eight where the species could not be identified from the nest type in which the pandemic-related debris had been incorporated. The eastern gray squirrel (*Sciurus carolinensis*) had the highest number of mammal sightings with 3 made in southeastern Canada. There were sightings of two different mammals: European hedgehog (*Erinaceus europaeus*) and red fox (*Vulpes vulpes*).

Of the total sightings, from all taxa, nine individuals (7.9 %) were found dead in direct contact with PPE items. There were 13 (11.4 %) sightings in which animals removed the debris themselves, and humans intervened and removed debris from animals in 17 cases (14.9 %). However, the majority of the fates of animals were unknown as observers could not capture them to remove debris (75 incidents; 65.8 %) (Fig. 3B). Observations were made from a wide breadth of environments and ranged from a total of 23 countries (Fig. 1). The majority of observations were made from the United States (n = 29), England (n = 16), Canada (n = 13) and Australia (n = 11). Countries that were found to have 2 to 10 observations, included: the Netherlands (n = 10), Germany (n = 5), Scotland (n = 4), Ireland (n = 3), France (n = 3), Portugal (n = 2), India (n = 2), Poland (n = 2), Finland (n = 2) and Italy (n = 2). Only one observation was obtained for each of the following countries: Philippines, Singapore, Brazil, Greece, Barbados, Malaysia, Morocco, Turkey, Finland, Italy, Gibraltar and Slovakia (Fig. 3C).

The most frequently observed form of pandemic-related debris was facemasks (n = 106; 93 %), most of which were disposable, (n = 93; 87.7 %) followed by reusable masks (n = 7, 6.6 %) and respirators (n = 3; 2.8 %) (Fig. 3D). In two additional cases, other facemask types were observed, which were not intended for COVID-19 protection, but may have been used for that purpose. This included a dust mask incorporated into the nest of a Carolina wren (*Thryothorus ludovicianus*) in the United States and an industrial facemask model entangling a common murre (*Uria aalge*) in England (Fig. 4; see Discussion for more about these cases). The only other form of pandemic-related debris recorded was disposable gloves (n = 7; 6.1 %; Fig. 3E); there were no reports of disposable wet wipes. In one incidence, a combination of facemasks and gloves were observed to be incorporated into a single nest (n = 1; 0.9 %). The nature of interactions between wildlife and pandemic-related debris were mostly entanglements (n = 48; 42.1 %) followed by nest incorporation (n = 46; 40.4 %). Other types of interactions included: carrying (n = 9; 8 %), and regurgitated pellet (n = 3; 2.6 %), with one or several cases of ingestion, pulling apart, biting, entrapment, chewing, anchoring and hiding.

3.2. Cases of replicated sightings

There were four cases of duplicate sightings. The first was an adult black bittern (*Ixobrychus flavicollis*) from Central Region, Singapore. Two observers posted an image of a black bittern entangled with a disposable facemask around its beak, the posts were describing the same location and posts were made one day after the other (March 15 and 16, 2021) on different platforms (ID Code: 16, 17). In another case, two photographers captured two different images of a herring gull with a disposable facemask on August 11, 2020 on the shoreline of a marina in Dover, Kent, England (ID Code: 50, 51). Through personal correspondence it was shared that both individuals were capturing images of the same bird. An Atlantic puffin (*Fratercula arctica*) was found dead with a mask wrapped around its neck and two different images were published in two media sources on 6 and 8 June 2021 (ID Code: 05, 06). Upon contacting one of the photographers it was confirmed that this was the same bird just placed on a different surface. Lastly, the Australian Royal Society for the Prevention of Cruelty to Animals obtained two reports of an Australian white ibis tangled with a facemask around its foot in the same general area about 3 weeks apart and the descriptions of the incidents matched (ID Code: 08, 09).

4. Discussion

This study expands on knowledge of the scope and impact of pandemic-related debris on wildlife. We identified 114 sightings of wildlife interactions with PPE debris among dozens of species around the world between 2020 and 2021. The interactions ranged from seemingly benign, such as individuals carrying debris, to fatal through entanglements and ingestion of items. The broad dataset was facilitated by our search methods which used digital platforms, including social media and citizen science. We refined and validated our methods by establishing contact with the original observers of these sightings. Although this study sheds important light on the data available from digital platforms, we emphasize caution must be practiced when comparing the results among different phyla and geographic regions due to the absence of standardized global surveys. While our results are still telling of trends that occurred through the global

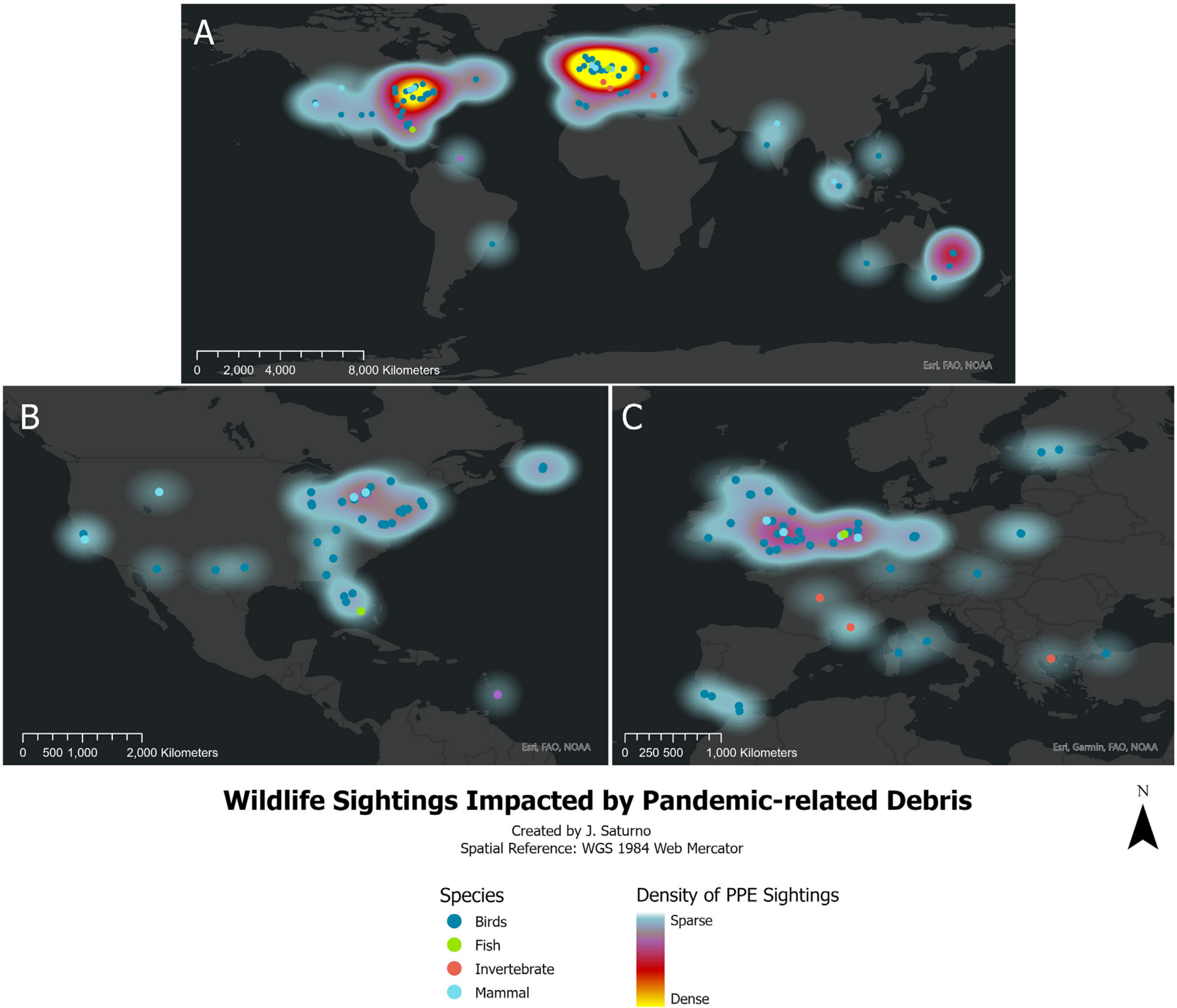

Fig. 1. (A) Global map depicting sightings of wildlife and pandemic-related debris. Two inset maps highlight continents of high interaction sightings, including: (B) North America and, (C) Europe.

pandemic, observation biases of debris interactions observed and accessibility to digital platforms may have resulted in some of the trends we report (as described below).

The global market of PPE increased from the 2019 pre-pandemic value of $800 million (USD) to over $166 billion (USD) in the first year of the pandemic (Allison et al., 2021; Wu et al., 2020) and represents an unprecedented increase in the production and use of single-use plastics. Though small scale production estimates specific to countries and multinational corporations have been released, global data describing the total production and impact of these single-use plastics are limited. For instance, in 2020 3 M (US), a multinational conglomerate corporation, projected an increase in PPE production from 1.1 billion to 2 billion to meet pandemic demands (Gereffi, 2020). Presumably, this ramp-up scaled to all major producers of PPE products. This global increase in demand and production led to a noticeable global increase in the amount of COVID-19-related debris from the beginning of the pandemic in March to October 2020 (Roberts et al., 2021). Pandemic-related debris in the form of facemasks increased in abundance by >80-fold from March to October 2020 across 11 countries where citizen science data were available (Roberts et al., 2021).

The abundance of pandemic-related debris and reporting of them is unlikely to be uniform across countries. Shortly after the WHO announcement of the pandemic, reports of pandemic-related litter items began to emerge in numerous countries including Canada, the United States, and Germany (Roberts et al., 2021). Data from citizen science mobile application Litterati showed that from March to October 2020 the United Kingdom had the highest proportions of discarded facemasks, gloves and disposable wet wipes (Roberts et al., 2021) in the countries for which data were available. While the lowest proportion of pandemic-related debris were observed in Australia, it was inferred that national lockdowns resulted in reduced outdoor traffic that impacted debris presence (Roberts et al., 2021). Similarly, the relationship between strict lockdowns and street debris reduction was observed in South Africa, where street litter loads were reduced by threefold during periods of lockdown (Ryan et al., 2020).

However, we must exercise extreme caution when comparing such debris quantities among countries or other geographic regions because of the lack of standardisation and omission of measuring areas in data collection. Systematic surveys conducted by different research groups around the world have indicated that pandemic-related debris and debris densities vary greatly across different stages of the pandemic and geographies (Ammendolia et al., 2021; De-la-Torre et al., 2021b; Ryan et al., 2020). Similarly, even within the international clean-ups facilitated by the Ocean Conservancy in 2020, there was not full consensus on whether facemasks or

Fig. 2. Images of interactions between wildlife and pandemic-related debris taken by the original observer of the sighting. (A) Mute swan cygnet entangled in a disposable facemask in Italy (Paolo Nicolai); (B) Black bittern entangled in a disposable facemask in Singapore (Adrian Silas Tay); (C) Herring gull entangled in a disposable facemask (Lancy Cheng); (D) Mallard duck entangled in a disposable facemask (Mary Caporal); (E) Hamerkop incorporating a disposable facemask into its nest (Tom Barclay III); (F) Herring gull tangled in reusable facemask (Katerina Gillis); (G) Common coot with disposable facemasks and respirators incorporated into its nest (Declan Friel); (H) Silver gull entangled in a disposable facemask (Sheree Marris); (I) Toukley osprey carrying a disposable facemask to its nest (Robert Olive); (J) Red kite with a respirator incorporated into its nest (Martin Kolbe); (K) Euroasian oystercatcher carrying disposable facemask (Dirk Blondeel); (L) Razorbill entangled dead in a disposable facemask (Trish Loli Brewster), and; (M) Red kite with a reusable facemask incorporated into its nest (Martin Kolbe).

gloves were the most abundant PPE litter items (Ocean Conservancy, 2021). Despite this discrepancy, citizen science initiatives that provide a lot of data can highlight trends to inform policy-makers on environmental changes (Ammendolia and Walker, 2022; Nelms et al., 2017). The present study has added to the growing body of literature that demonstrates the adverse effect that the COVID-19 pandemic has had on the growing plastic

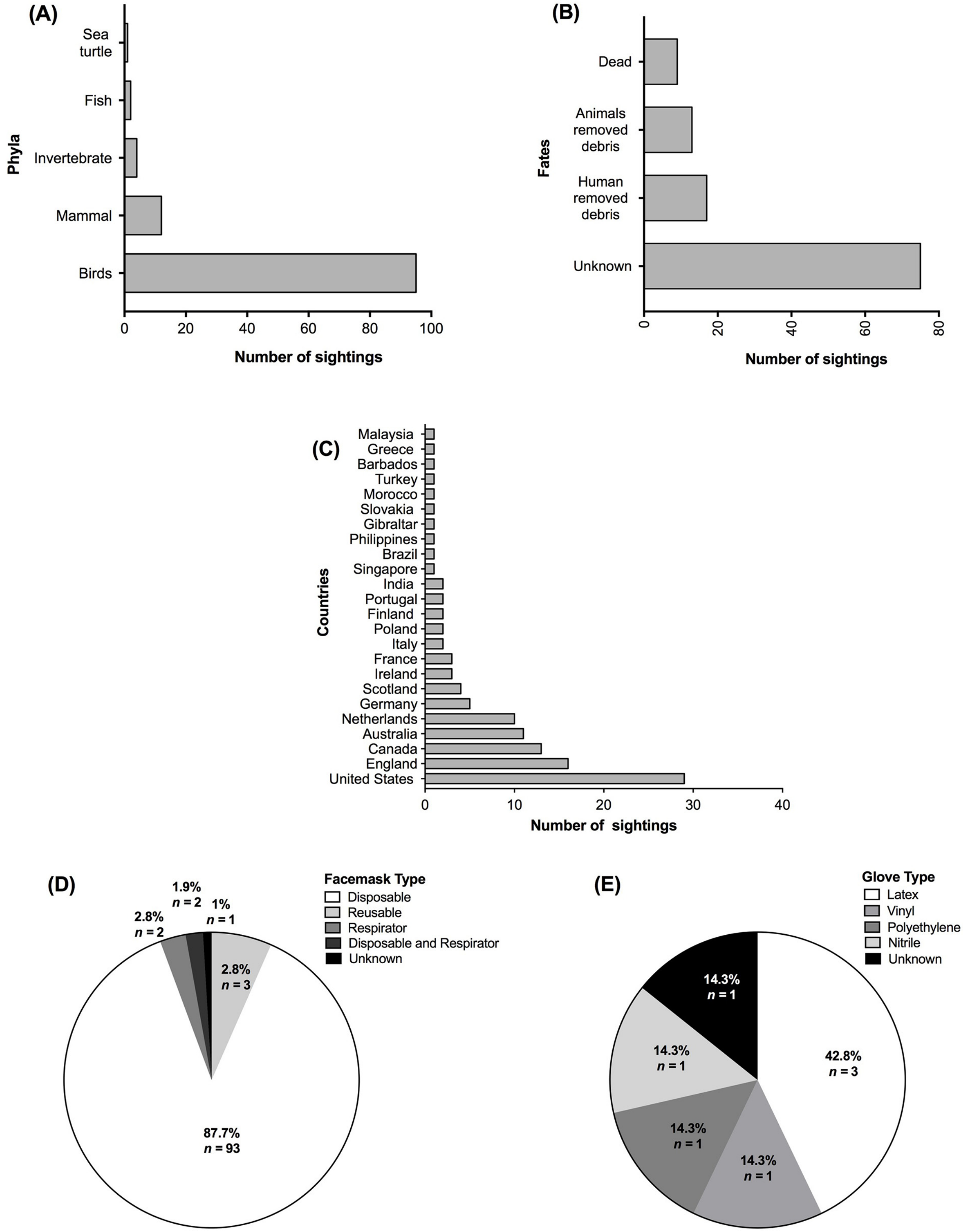

Fig. 3. The number of sightings recorded for: (A) various phyla, (B) fates of animals, and; (C) countries of the sightings. Also shown are the proportions of the various types of (D) facemasks, and (E) gloves that were found.

pollution problem. Therefore, it is important that we use the duration of the pandemic and the post-pandemic period to identify opportunities to improve the sustainability of PPE products and prevent leakages in waste management systems (Aragaw and Mekonnen, 2021; Mekonnen and Aragaw, 2021).

4.1. Citizen science and capturing environmental change

Building the capacity for citizen scientists to contribute their observations and collect data is critical to capturing real-time environmental changes during global situations like pandemics. The unique travel

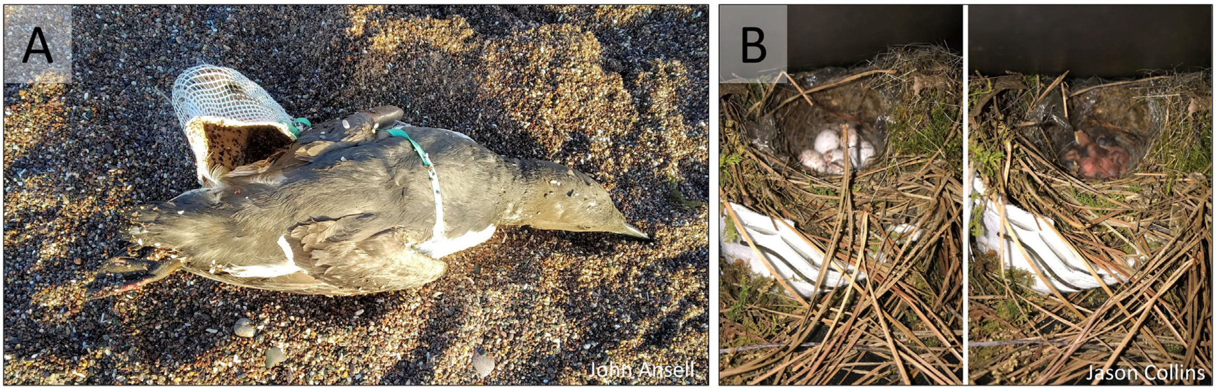

Fig. 4. Sightings of wildlife interactions with debris that were not confirmed to be pandemic-related debris: (A) Common murre entangled in an industrial facemask in Devon, England and, (B) Carolina wren nest with a dust mask used from a pre-COVID maintenance project in North Carolina, United States.

restrictions of the COVID-19 pandemic resulted in a limited number of systematic studies that reported the presence of pandemic-related debris (also see Akhbarizadeh et al., 2021; Ammendolia et al., 2021; Cordova et al., 2021; De-la-Torre et al., 2021b; Haddad et al., 2021; Okuku et al., 2021; Rakib et al., 2021; Ryan et al., 2020; Thiel et al., 2021); while sightings of wildlife interactions with debris reported in peer-reviewed publications were even fewer (Hiemstra et al., 2021; Mghili et al., 2022; Neto et al., 2021). Our study demonstrates that citizen scientists do not only share their sightings on citizen science platforms like Birds and Debris but also on social media platforms, along with other users of social media who are not active members of a citizen science community. In fact, the majority of sightings were made on social media platforms posted images with captions that made an effort to raise awareness about the harm and risks of pandemic-related debris, either directly from the observer or a secondary organization that was resharing content (e.g., Palo Alto Animal Control, Western Australian Seabird Rescue, Royal Society for the Prevention of Cruelty to Animals). Overall, data mining images from social media platforms for ecological studies are quite limited. Hiemstra et al. (2021) initially established the link between these platforms and biologically relevant observations resulting from the impact of COVID-19-related debris during the first year of the pandemic. In an earlier study by Proulx et al. (2014), Google Trend was used to search for keywords related to invasive species and pollen release in order to paint a temporal picture of environmental trends. The authors concluded this was an effective method for collecting data with a high temporal resolution (Proulx et al., 2014). The above examples suggest that the passive participation of citizens is important to consider in mining data from digital platforms, because individuals can post scientifically valuable observations to general platforms even without contributing to an established citizen science database.

Using citizen science-derived data sets for comparison among geographic regions, even at a smaller scale (e.g. neighbourhoods) is problematic and should be done with extreme caution because the demographics of citizen scientists are those associated with privilege. Participants are disproportionately white, of higher socioeconomic status, less concerned about environmental social justice (Blake et al., 2020) and more formally educated (Domhnaill et al., 2020; Walter et al., 2018). The reasons for disproportionate participation have much to do with the availability of ‘free time’ to engage in voluntary activities (e.g. Farnham et al., 2017). And though there are methods by which we can ‘account’ for this disparity (i.e. Wine et al., 2015) by including the socioeconomic variable within the statistical models, the economic advantage of using volunteer data collectors (Cohn, 2008) is likely at a great cost to data scalability. Developing more inclusive practices (also see Walter et al., 2018) for the benefit of both the potential citizen scientist and the data set will advance the use of citizen science data in environmental and biological research.

The importance of developing our citizen science platforms to streamline data collection including uploads made to other digital platforms can not be understated. Although an extensive number of interactions between fauna and plastic debris have been reported across decades of peer-reviewed literature (see review: Provencher et al., 2019); higher numbers of observations by citizen scientists have only recently emerged with the development of mobile technologies. As the methods developed by the present study are relatively new, we are limited in being able to comment on the trends of the number of fauna-plastic interactions over a temporal scale spanning across the pre-pandemic and pandemic period. Therefore, there is importance in developing these methods so that trends can be reliably identified. Furthermore, future citizen science platform development should recognize the value of involving the more inclusive and less intensive participation of citizens (i.e. images uploaded to Facebook, Instagram or Twitter to share awareness messages to local networks). Although usable images might require more effort to obtain information, because some might not contain geographic information (Leighton et al., 2016; described in further detail below). Overall, obtaining robust datasets produced by citizen scientists can lead to the identification of debris leakage in waste pathways and result in preventative action which will be cost effective in reducing cleanup effort (Ammendolia and Walker, 2022; Borrelle et al., 2020).

4.2. Study strengths

Uniquely, we followed up with the person responsible for the original post for each of the sightings posted on social media. In a few cases (n = 5), we identified cases of ‘broken telephone’, or the changing of the details over time. This method, although time intensive proved important in obtaining high resolution data and geographic information about the actual sighting. For example, an Italian media report of a mallard (*Anas platyrhynchos*) with a mask around its neck (ArezzoNotizie, 2020) was reported to have occurred in Casentino, Italy (Hiemstra et al., 2021) but after contacting the photographer and observer of this sighting, it was confirmed that the incident took place in Wisconsin, United States and the mallard was eventually able to free itself from the facemask (ID Code: 55). Another case reported that an American robin (*Turdus migratorius*) tangled up in a disposable facemask was located in British Columbia (Hiemstra et al., 2021), however the incident occurred across the country in Windsor, Ontario, Canada (ID Code: 01). It was also important to contact the original observers because some social media posts were not relevant to the pandemic although they were reposted in this context. For instance, reposts of an image taken in 2018 of a trapped and deceased fish inside of a plastic disposable glove were circulated in the context of pandemic-related waste (Daily Mail Reporter, 2018). Furthermore, our internet searches yielded cases of wildlife interacting with PPE debris that could not be proven to be pandemic-related. In North Carolina, United States, a Carolina.

wren used a dust mask to construct its nest (ID Code: 100). Although this occurred during the pandemic in April 2020, it was shared that this type of facemask was used by the maintenance staff during pre-pandemic times (Collins pers. correspondence). Furthermore, an industrial facemask model was found entangled around a dead common murre in Devon, England in February 2021 (ID Code: 101). This mask could not be single-use given the high-quality nature of the fabric and elastics, leaving it unconfirmed if the mask was used in response to the COVID-19 pandemic (Ansell pers. correspondence). Despite these cases of inaccurate geolocation or context, that there were very few cases overall, suggests that the use of social media-derived data of this kind can be of great value, especially in regions of the world where access to engaging in citizen science projects is limited. Though posting to social media is a lot more barrier-reduced, still, a telephone with camera and internet access is required. Therefore, this must be considered when attempting to scale up the trends to other regions. The above examples demonstrate the nuance of collecting data through social media platforms and the necessity to consult with the observers or agencies that witness these sightings so that high resolution data can be obtained, especially in the early phase of data collection when sample sizes are smaller.

4.3. Study limitations

Our searches, conducted in English, resulted in a bias of overrepresentation of English speaking countries, while underrepresenting others. The countries with a high number of sightings included the United States, England, Canada, and Australia. Similarly, in Hiemstra et al. (2021), search terms were conducted in both English and Dutch and recorded sightings mostly came from the United Kingdom and Netherlands. Similarly, the use of different social media platforms, and their relative popularity and usage, varies between countries, and with time. For instance, whilst Facebook is the dominant social media platform worldwide, within countries such as China (StatCounter, 2022a), Russia (StatCounter, 2022b), and North Korea (StatCounter, 2022c) this is not the case. In addition, the relative usage of different social media platforms varies temporally with social, political, corporate pressures, and so using a range of platforms is likely beneficial to maximise the amount of data collected and minimise the impact of country-specific trends. It is important to note that our study very likely underestimates the actual number of animals that were harmed by pandemic-related debris.

Interestingly, our study yielded no sightings of wildlife interactions with disposable wet wipes; however, unlike disposable facemasks, which in many cases are a recognizable light blue colour, disposable wet wipes lack the characteristic and unique look of pandemic-related debris. It is possible to easily mistake wipes for tissue paper or biodegradable materials which do not usually alert potential observers to this form of plastic-based litter. As a result, these items might have been underrepresented in the sightings reported on digital platforms. Notably, there have been non-PPE items that may have been related to the pandemic found within nests of different species. For instance, in the nest of a Eurasian coot packaging from tissues was found in April 2020 (Hiemstra et al., 2021), while in a sparrow's nest in Poland, a plastic tissue package was identified (ID Code: 81). These types of debris are challenging to include in the category of pandemic-related debris since they are associated with personal hygiene products that were in common use before the pandemic.

Furthermore, it is difficult to assess the impact and harm that ingested plastic debris can have on wildlife given the difficulty of obtaining salvageable bodies and being able to identify ingested debris with cause of death. There were many online reports that record cases of domestic animals (e.g. cats and dogs) ingesting pandemic-related debris. Since the beginning of the pandemic in early 2020, a number of cases of ingestion of facemasks and gloves have been reported and widely publicized (Bennett, 2020; Dalton, 2021; King, 2021). The number of non-lethal cases in this study exceeded the lethal cases, presumably because it was more difficult to identify pandemic-related debris as the cause of death. However, there were cases in which animals interacted with debris but were able to free themselves of entanglement or simply dropped the items. For instance in Lake Bracciano, Italy in June 2020 a group of mute swan chicks were interacting with a disposable facemask and one chick was seemingly entangled until it freed itself (ID Code: 63). An Eurasian oystercatcher (*Haematopus ostralegus*) was carrying a disposable mask and the observer noted that the bird eventually dropped the mask without getting tangled (ID Code: 35). These cases exemplify the importance of contacting the observers to determine if animals were in fact able to remove themselves from potentially harmful scenarios.

5. Conclusions

This study provides a contemporary understanding of the harm and impact the pandemic-related litter has had on wildlife around the world. We present an extensive collection of sightings that outlines the impact the pandemic has had on a variety of wild animals and we describe a nuanced data collection method that harmonises data collection from citizen science platforms with data mining from digital platforms. We also want to emphasize the need for scientists to fact check information that is posted online back to the original source to ensure data validity. Despite the termination of mask mandates across different regions of the world, the billions of disposable pandemic-related debris items mismanaged during COVID-19 will remain in our terrestrial and aquatic environments for decades to come. Therefore, it is necessary to learn from this event, and assess the full impact that plastic waste from the pandemic has had on our global fauna and environments. It is crucial that we identify opportunities to improve our waste management infrastructure, so that we can prevent similar leakages during the inevitable future pandemics.

CRediT authorship contribution statement

Justine Ammendolia: Conceptualization, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jacquelyn Saturno:** Conceptualization, Investigation, Visualization, Writing – review & editing. **Alexander L. Bond:** Investigation, Methodology, Writing – review & editing. **Nina J. O'Hanlon:** Investigation, Writing – review & editing. **Elizabeth A. Masden:** Investigation, Writing – review & editing. **Neil A. James:** Investigation, Writing – review & editing. **Shoshanah Jacobs:** Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing.

Data availability

Data will be made available on request.

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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Appendix A. Supplementary data

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