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# iNaturalist insights illuminate COVID-19 effects on large mammals in urban centers

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ABSTRACT

Restricted human activity during the COVID-19 pandemic raised global attention to the presence of wildlife in cities. Here, we analyzed iNaturalist observations of prominent wildlife species around North-American urban centers, before and during the COVID-19 pandemic outbreak. We suggest that the popular notion of 'wildlife reclaiming cities' may have been exaggerated. We found that while pumas ventured deeper into urban habitats during the COVID-19 pandemic, bears, bobcats, coyotes, and moose did not. Species differential behavioral responses may highlight their evolutionary history cohabiting human habitats. Nevertheless, our results highlight the importance of urban nature for people during the pandemic. Our insights could help manage urban wildlife, better plan greenspaces, and promote positive nature engagements.

## 1. Introduction

Interactions with nature promote key health benefits for people (Díaz et al., 2006) and are paramount for facilitating sound conservation actions (Schultz, 2011). During the COVID-19 outbreak such interactions were reduced (Cheval et al., 2020; Kleinschroth and Kowarik, 2020) due to stay-at-home orders and closure of national parks (Gostin and Wiley, 2020; https://www.latimes.com/california/story/2020-04-13/yosemite-national-park-closed-wildlife-waterfalls-muir). Nevertheless, lockdowns may have provided greater opportunities for people to reconnect with urban nature and wildlife closer to home (Chakraborty and Maity, 2020; Rose et al., 2020). Consequently, nature and particularly urban greenspaces, have become increasingly important to people during this period (Kleinschroth and Kowarik, 2020).

Furthermore, COVID-19 lockdowns and travel restrictions potentially changed animal behavior in different ways (Corlett et al., 2020; Manenti et al., 2020). For example, some animals switched to greater diurnality (Manenti et al., 2020), or ventured into urban areas which they have been previously precluded from (Searle and Turnbull, 2020; Zellmer et al., 2020). This 'urban reclamation' received much public attention – predominantly focused on large mammals (e.g., https://www.theguardian.com/world/gallery/2020/apr/22/animals-roaming-streets-coronavirus-lockdown-photos). Many pictures and videos showing wildlife roaming cities' empty streets spread across social media (Rutz et al., 2020) and were frequently featured in the popular media (e.g., https://www.thestar.com.my/tech/tech-news/2020/03/30/covid-19-wildlife-pics-go-viral-on-social-media-as-nature-takes-back-worlds-empty-city-streets). These alterations in animal behavior and people's interactions with them during the COVID-19 pandemic provide a unique opportunity to explore human-wildlife relationships, specifically in urban environments (Bates et al., 2020; Rutz et al., 2020).

The rise in global urbanization has led to an increase in research dedicated to wildlife inhabiting urban environments (Magle et al., 2012). Such research focuses both on the conservation potential and importance of urban species, and on the behavioral mechanisms enabling species to cope with urban environments (Lowry et al., 2013). Urban environments are unique and characterized by increased anthropogenic light and noise pollution, as well as high rates of direct human disturbances. Such environments further entail different microclimates (e.g., urban heat-island), resource availability, predation risk, and novel inter- and intraspecific interactions (Alberti, 2015; Bradley and Altizer, 2007). Animals' response to these and other characteristics of the urban environment involve morphological, behavioral, and physiological changes (Alberti, 2015). Consequently, some species are attracted to urban settings while others are precluded from them

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(Fischer et al., 2015). The COVID-19 pandemic provides a rare opportunity to better understand mechanisms underlying animals' attraction/repulsion from urban environments (Bates et al., 2020; Zellmer et al., 2020).

Here, we used a common citizen science platform – iNaturalist, to test the occurrence of five charismatic mammal species in and around urban centers in North America. We explored spatial trends in these observations during and prior to the COVID-19 pandemic and related these to potential spatial and social predictors that may drive these trends (Zellmer et al., 2020).

## 2. Methods

iNaturalist is a growing global citizen science platform used to record observations of many taxa (www.inaturalist.org; Nugent, 2018). iNaturalist data have been used to explore human-nature relationship in different regions and settings (Altrudi, 2020; Unger et al., 2020). We downloaded iNaturalist observation reports for five charismatic mammalian species (American black bear - *Ursus americanus*; bobcat - *Lynx rufus*; coyote - *Canis latrans*; moose - *Alces alces*; and puma - *Puma concolor*) in the United States and Canada from 2010 to 2020. We restricted our exploration to 40 urban counties (or corresponding census division in Canada), found in 18 regions that had at least 10 observations (during both 2010–2019, and 2020) of at least one of the above species (see Table S1).

We considered all observations during the months of March to July 2010–2019 as pre COVID-19 and those from 2020 (March to July) as the COVID-19 period. The number of observations reported to iNaturalist has been increasing gradually throughout these ten years (Fig. S1). However, the increase in 2020 was not higher than expected following the trends of previous years (i.e., falls within the 95% prediction interval of an exponential regression of observations against years; Fig. S1). As each state (USA) and province (Canada) issued different restrictions at different times, we chose to focus on this entire period of the pandemic outbreak (March to July). During this period, people may have decreased their mobility even without official governmental lockdowns (Badr et al., 2020). We identified areas where animals were predominantly sighted during these two periods by constructing 95% kernel density estimates based on the observations (sp package; Bivand et al., 2008). We calculated these estimates separately per species and region (a single county or several neighboring counties), pre COVID-19 and during the COVID-19 period (see Fig. S2). We overlapped the 95% kernels of the two periods to highlight areas newly explored during 2020.

We then explored the effects of landscape characteristics and social drivers on the spatial trends we found. These included distance from the nearest primary road (EarthDATA: https://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1/data-download); night-light intensity levels as a proxy of urbanization (Li et al., 2020), (separated per year so that observations from 2010 received night light values from the 2010 night-light image and so on; observations from 2019 and 2020 were matched with values from the 2018 night-light image; https://figshare.com/articles/Harmonization_of_DMSP_and_VIIRS_nighttime_light_data_from_1992-2018_at_the_global_scale/9828827/2); and NDVI values (Normalized Difference Vegetation Index; separated per year and month so that observations between March 1 and May 15 of every year received the NDVI values of April that year, and observations between May 16 and July 31 received the NDVI values of June that year; EarthDATA: https://search.earthdata.nasa.gov/search?q=C203669719-LPDAAC_ECS). Beyond these we explored the potential effects of county (or census division) median household income on observations (Canada ArcGIS online: https://www.arcgis.com/home/item.html?id=6951da2ea34848758d21552792837a09; USA Department of Agriculture Economic Research Service: https://data.ers.usda.gov/reports.aspx?ID=17828). For analyses of observations during 2020 (see below) we further examined the effects of mobility trends for places of work and residence per county (Google mobility report: https://support.google.com/covid19-mobility/answer/9824897?hl=en&ref_topic=9822927). These values represent the percent of change in mobility per day during the COVID-19 outbreak compared to a baseline established prior to the COVID-19 outbreak (January 3–February 6, 2020).

To explore whether observations reported prior to or during the COVID-19 pandemic differed in their spatial and social variables, we ran random forest classification models (randomForest package; Liaw and Wiener, 2002). We used the pre/during COVID-19 observation identity as a response and matched them spatially to gain parameter values for: county median household income, distance from roads (log 10 transformed of distance in meters +1), night light level (Digital Number values (0–63) representing low to high luminance), and NDVI value. Each model was fitted with 10,000 iterations and two variables randomly sampled per node (Hastie et al., 2001). To obtain mean absolute prediction error rates, we employed a tenfold cross-validation procedure. We explored the change in classification rate along the variable gradient of classes using partial dependence plots. We ran a model for all species combined as well as separate models for each species. We conducted similar analyses to classify observations during COVID-19 that fell inside or outside the pre COVID-19 kernels (hereafter old and new areas respectively; Fig. S2). These analyses further included mobility trends for places of work and residence. All analyses were constructed in the R programing language (R-Core-Team, 2020).

iNaturalist observations entail inherent biases, which may have been exacerbated during the pandemic. Specifically, observations during this period may have been skewed towards more urban settings (Zellmer et al., 2020). Such trends in the observation data may mask true changes to animals' behavior. To deal with this challenge we took the following approaches. First, we focused on large more charismatic species that are more likely to be reported when sighted also prior to the pandemic. Second, we explored observations in North America, which are more voluminous (https://www.inaturalist.org/posts/25692-inaturalist-world-tour). Lastly, we specifically explored trends of observations reported during the COVID-19 pandemic that were either spatially aligned with prior observations or found in new areas.

## 3. Results

Our random forest model to predict whether observations were reported before or during the COVID-19 outbreak had a cross validated error rate of 17.5% (±1.2%). Similar models for each species separately also had high predictive ability (cross validated error rates: bear 19.2±4.1%; bobcat 23.3±2.2%; coyote 16.7±1%; moose 18.5±3.5%; puma 21.3±10%). All four predictors had fairly similar importance to model performance across models (16.3–31.1% mean decrease accuracy; Fig. S3a). Nevertheless, household income and NDVI were often the more important predictors. Observations during 2020 had higher probabilities of having increased night light levels. Moreover, these observations were either very close to roads or farthest away from them. NDVI values had more complex relationships for different species, but when analyzed together we see higher NDVI values during the COVID-19 pandemic (Fig. S3). For bears and moose, there were more reports during the pandemic in counties with low household income (Figs. S3e, S4).

We found a mean overlap of 45.5% between the 95% kernels of pre and during COVID-19 observations (bear: mean 42.2%, range: 21.35–63.39%; bobcat: 46.0%, 4.57–80.62%; coyote: 45.6%, 17.56–99.94%; moose: 40.5%, 13.27–85.73%; puma: 64.3%, 42.83–83.74). Therefore, during 2020, species were observed in many new locations where they have not been previously sighted. Comparing COVID-19 observations in new vs. old areas yielded some interesting results.

Our random forest model to predict whether observations reported during 2020 were in old or new areas had a cross validated error rate of 22.5% (± 2.6%). Most models analyzing each species separately reached

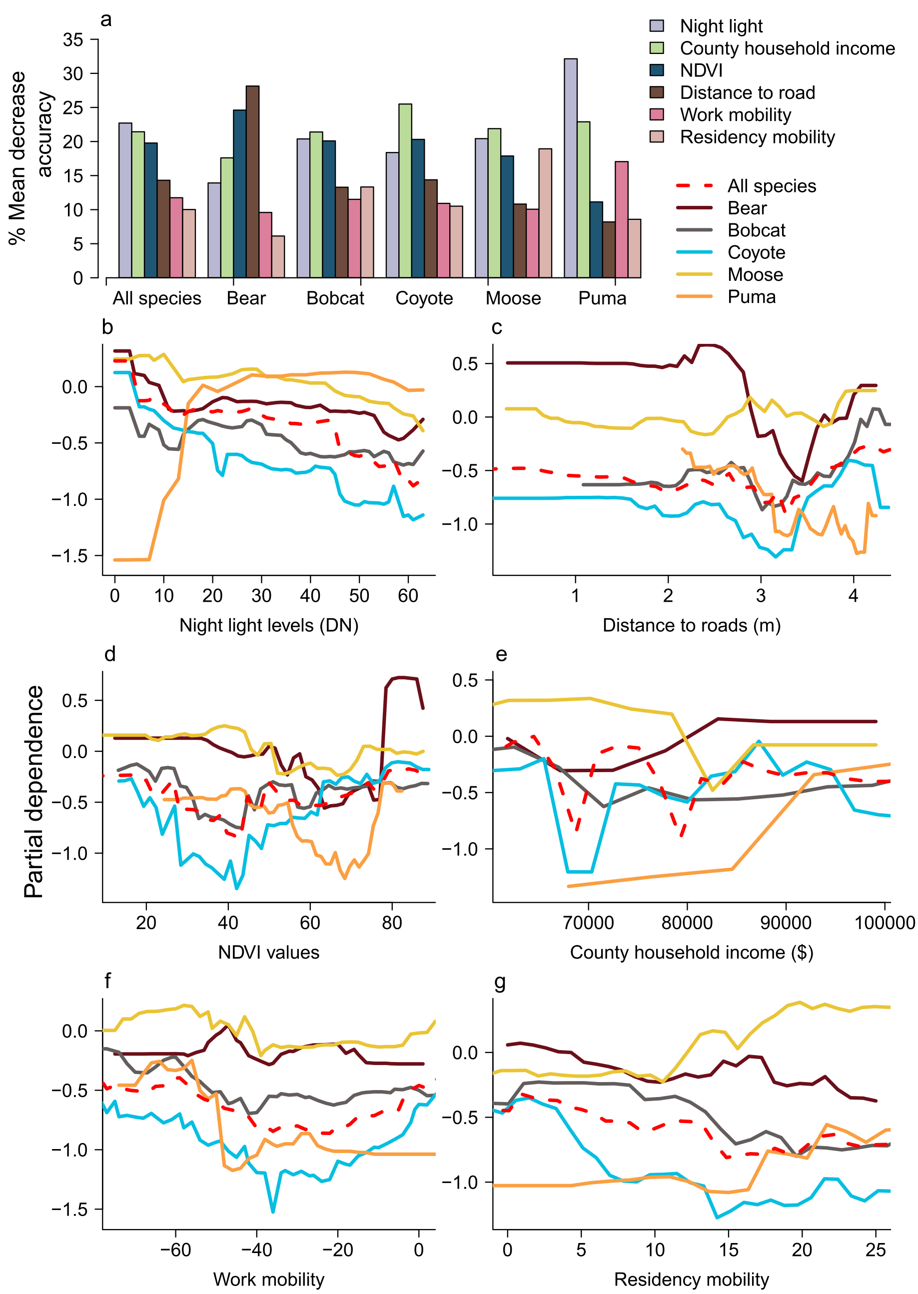


**Fig. 1.** Random forest model results comparing iNaturalist observations during the COVID-19 pandemic in previously sighted areas and new ones. (a) The relative importance (% mean decrease accuracy) for all predictors (night light, county median household income, NDVI values, distance to road, mobility to workplaces, and mobility in residential areas). (b–f) Partial dependence plots for the abovementioned predictors showing the probability to find observations in new areas across the value-range of each predictor (mean(logit(probability$_{\text{new areas}}$)/2)).

good prediction (cross validated error rates: bear 27.3±8.7%; bobcat 22.6±5.2%; coyote 14.2±2.9%; moose 52±6.4%; puma 18.3±11.5%; as the model for moose performed poorly, we do not discuss it further). However, these models differed across species in predictor importance and partial dependence trends (Fig. 1). For most models, household income, NDVI, and night light were the most important predictors. However, for bears, distance to roads and NDVI were most important, and for pumas, night light was most important for prediction, together with household income and mobility to work trends (Fig. 1).

The model for all species combined showed decreased night light for observation in new areas during 2020 (Fig. 1b), with coyotes showing the strongest decrease. However, pumas showed the opposite trend with increased night light in new areas (Fig. S5). Neither NDVI nor distance to road showed clear trends between new and previously explored areas. Nevertheless, in the combined model we see a general trend of greater distance to roads in newly explored areas; a pattern most prominent in bobcats. NDVI values showed non-monotonic trends when explored per species (Fig. 1d). Household income did not show clear trends for all species combined, suggesting it may not have affected animal's behavior. However, pumas were more likely to be reported in new areas in counties with higher household incomes (Fig. 1e). More observations in new areas were reported either during periods with least mobility to work, or those similar to baseline. However, bears and pumas did not show such a pattern (Fig. 1f). For all species but puma, observations in old areas were reported during periods of increased mobility in residential areas (Fig. 1g).

## 4. Discussion

In this work we investigated changes in observations of charismatic wildlife prior to and during the COVID-19 pandemic. Animals were observed in more urban habitats during the pandemic. Nevertheless, when comparing sightings during the pandemic in areas where species were previously sighted in with sightings in new areas, we found that for most species, the new areas were less urbanized (i.e., areas with lower night light levels). Pumas were unique in that their new areas were found in more urban locations. Our results show that species responded differently to the reduced human activity caused by COVID-19, but that overall, the popular notion of 'wildlife reclaiming cities' may have been exaggerated.

COVID-19 lockdowns restricted many people to the vicinity of their homes and provided them with more spare time. During this period, people had greater opportunities to appreciate and reconnect with urban nature (Bates et al., 2020). Beyond this, reduction in human activities during lockdown have been reported to alter animals' behavior, also in cities (Manenti et al., 2020). We indeed found that there were many more iNaturalist observations in more urban settings during the COVID-19 outbreak (Fig. S3). This increase may either be a consequence of true greater urban encroachment of animals during this period, or a result of increased reporting of observations specifically in urban settings during lockdowns (Zellmer et al., 2020). Our comparison of observations during the pandemic (see below) supports the latter hypothesis. Irrespective of the source of this change, rekindling people's awareness and recognition of nature can and should be harnessed to promote conservation (Corlett et al., 2020).

To remove the abovementioned observation bias from our analysis, we focused solely on observations during 2020, differentiating between newly observed locations and ones species have previously been sighted in (during 2010–2019). Contrary to popular-media claims, we found that for most species, 'urban reclamation' predominantly occurred in less urbanized areas. However, pumas may have used the relief in human activity to venture deeper into cities and explore more urbanized areas than before. Observations in new areas were also reported during periods when people's mobility to work places was either lowest or most similar to the pre COVID-19 period (Fig. 1). This suggests that people restricting their mobility to the vicinity of their homes, may have used this opportunity to explore new natural areas nearby. This trend was not found for bears for which sightings in old or new areas were not affected by people's mobility to work (Fig. 1f). Ultimately, while people reported animals in more urban settings during the COVID-19 pandemic, these seem to be areas where animals have been known to roam in previous years, except for pumas.

The occurrence of opportunistic wild species within urban areas is not a new phenomenon (Lowry et al., 2013). Urban areas provide predictable food resources, more stable climate, and lower predation risk (Oro et al., 2013). The degree to which a species will be found within urban environments depends on its evolutionary history, and the expression of certain traits such as dietary flexibility, high cognitive abilities, and aggressiveness (Sih et al., 2011). Therefore, while some species are already highly adapted to co-habiting human environments, others are less so. We explored five mammalian species of different families (Canidae, Cervidae, Felidae, and Ursidae), with different body size and life history traits. Among the species we explored, pumas are known to avoid humans, although individuals do visit urban areas regularly (Gehrt et al., 2010). Coyotes, in comparison, are more established in urban environments (Gehrt and McGraw, 2007). Thus, the Anthropause may have provided a great opportunity for species like pumas that are not yet fully urban exploiters, to reclaim more urban areas. Conversely, for more urbanized species such as coyotes and bobcats, further exploration of more urbanized areas did not occur.

The new areas explored by pumas during the pandemic were on average: more lit, farther away from roads, and reported during reduced mobility to work and increased residential mobility (Fig. 1b,c,f,g). These patterns were often opposed to those found for coyotes, bobcats, and bears, which are more urbanized species. This result emphasizes the importance of species' previous experience with humans in explaining their response to the Anthropause. Our results further support the need for better connectivity for pumas (Benson et al., 2019) and may shine a light on potential areas pumas may already utilize to move in the urbanized landscape and how they are affected by human mobility. The increased media attention during the COVID-19 outbreak can be a great opportunity to promote the importance of urban wildlife, recognize areas of greater potential for human-wildlife conflict, and better manage urban wildlife populations. Greater appreciation and positive connections to wildlife can encourage acceptance of urban wildlife and promote co-existence of humans and wildlife in cities (Drake et al., 2020).

Urban habitats represent a mosaic of landscapes. Proximity to roads, levels of human activity, and degree of naturalness, all affect how animals perceive urban settings. During the COVID-19 pandemic most species were sighted in more green habitats in cities when compared to pre-COVID-19 sightings (Fig. S3d). Moreover, during the pandemic animals' newly explored areas tended to be greener than areas previously utilized (Fig. 1d). These results emphasize the importance of urban greenspaces for both wildlife and humans (Kleinschroth and Kowarik, 2020; Slater et al., 2020). Our results also show more observation during the pandemic in counties with lower household incomes which may highlight the importance of greenspaces for people in such regions (Fig. S3e). This further supports the need to incorporate greenspaces in urban planning, in an accessible and equitable manner (Lai et al., 2020; Slater et al., 2020). Overall, insights regarding human-nature relationships during the Anthropause can be used to promote greater appreciation for nature and consequently, its protection.

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## Declaration of competing interest

There is no conflict of interest to declare.

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