Global birdwatching data reveal uneven consequences of the COVID-19 pandemic

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Abstract

Birdwatching is a global phenomenon involving many thousands of people. Citizen science generates data providing insights into global patterns of bird distribution across space and time, yet how the pandemic may cast a longer shadow remains unassessed. Here, we explore whether pandemic restrictions influenced observations globally from 2020-May 2021, considering also GDPc and tourism income. We analysed 10,338 bird species (93% of all bird species) and found that whilst high-income regions recover to pre-pandemic assessment rates quickly, middle and low-income regions remain at low levels. Furthermore, protected areas see huge losses in recorded richness. Whilst observer count increased overall, the number of bird species recorded dramatically decreased, especially in 2020. These trends are most marked in developing countries and regions, especially where tourism is important. Due to increased bushmeat consumption during the pandemic, some species may become more threatened, but with no data we cannot yet discern such trends.

Keywords: biodiversity, conservation, eBird, citizen science, SARS-CoV-2

Introduction

Recording bird sightings has been popular for centuries, but citizen (community) science has revolutionized the hobby (Sullivan et al. 2009; Sullivan et al. 2014). Platforms such as eBird have transformed the way we understand bird distributions and behaviour, enabling us to track migration, or shifts in ranges in a way previously unimagined (Supp et al. 2015; Walker & Taylor 2017). Furthermore, with the fanaticism that surrounds some elements of "birding," new records and migrants are quickly noticed and shared, providing unique insights into how species respond to climate and weather (La Sorte et al. 2019). Enabling the appreciation of nature has a myriad of benefits, both in terms of making people more environmentally conscious and bettering our data resources (Callaghan & Gawlik 2015; Sullivan et al. 2017).

While birdwatching and associated activities continue to peak yearly (Steven 2015), the COVID-19 pandemic has transformed the way we live and observe nature. How it impacted on bird observations, and the legacies for species' long-term observations remains largely unknown. The end of international travel for much of the world, as well as periodic lockdowns and easing, might severely impact birdwatching, varying based on region development state and reliance on tourist income, with potential downstream consequences to species protections (Conradie & Van Zyl, 2016; Lindsey et al. 2020). Thus, whilst the "anthropause" has been popularised as a "positive break" for biodiversity, including sighting of species in urban environments which are typically associated with more natural areas (Schrimpf et al. 2021), or by common species like sparrows calling more quietly due to less background noise in some cities (Derryberry et al. 2020). However, the situation is actually more complicated and understanding the negative implications or potential data loss, particularly in more diverse regions, is difficult in the long-term. A recent paper explored trends for North America in March-May 2020 for 82 selected species (Shrimpf et al. 2021), but exploring these trends for a larger set of species in a more diverse range of regions and across waves of the pandemic will be necessary to understand its broader consequences. Heterogeneous responses are demonstrated by the inconsistency between studies, for example in that a study in Spain no increase in probability of occurrence of birds in urban areas (Gordo et al. 2021), although another found more observations there, as well as decreased records in non-urban areas there and in Italy but not the UK (Basile et al. 2021). So far, all studies have focused on developed countries, using different methods, making a global view imperative. National income status impacts how birding and citizen science occurs in different regions, so assessing these patterns in a broader range of situations and environments is essential to better understanding the impacts of the pandemic. Here, we unpick how the various restrictions and behaviours associated with the Covid-19 pandemic impacted on bird observations worldwide, providing a unique window for viewing human behavioural changes in the face of a global pandemic.

First, we explore overall trends in changing observations and how observed richness correlates with access to different spaces and international travel to regions with different economic statuses and reliance on tourism. We then examine how what was observed by whom changed in terms of endangered and common species in rural, urban and agricultural areas in concert with changing restrictions. As well as the rate of recovery to pre-pandemic observations in different regions. Lastly, we discuss the implications of these changing observations for different regions, particularly those reliant on tourist revenue, which is key for conserving diversity in some of the most biodiverse areas on Earth.

Methods

Modeling expected patterns and divergence from expected during pandemic

We used an exponential smoothing state space model (ETS; Hyndman et al. (2002)) and the number of species from 2015 to 2019 to build a model that predicts the number of species from 2015 to 2021. ETS parameter: "AAA". A three-character string identifying method using the framework terminology of Hyndman et al. (2002) and Hyndman et al. (2008). The first letter denotes the error type ("A", "M" or "Z") ("N"=none, "A"=additive, "M"=multiplicative and "Z"=automatically selected); the second letter denotes the trend type ("N","A","M" or "Z"); and the third letter denotes the season type ("N","A","M" or "Z"). We then calculated the difference between the predicted and empirical number of species with the formula (number of species-predicted species)/number of species. We then used the Mean and Standard Deviation of absolute difference from 2015 to 2019 as a metric to evaluate the model's accuracy. Here, we focus on 62 regions that had sufficiently high-quality data for analysis (mean and SD are higher than 10%, Supplemental text).

We then determined when areas were under pandemic restrictions, using the finest-scale data available such that some countries might be split into multiple regions. Lockdown type was based on daily restrictions (international tourist arrivals: UNWTO 2021, Lockdown stringency, Mobility in different sectors, international travel restrictions: OurWorld in Data 2021, Tourist GDP: Knoema 2019; GDP: Hughes et al., 2021), but our analyses are monthly so we calculated lockdown days per month (some restrictions=1 and hard lockdown=2; so numbers close to 60 indicate harder lockdowns, multiplying days by lockdown classification). Then we used the differences above to evaluate the change in number of species post-2019. If the difference was higher than 10%, it means that the observed number of species is 10% higher than predicted. Steps were repeated for the number of observations, events and observers, then plotted to observe differences. The code is available at: https://github.com/qiaohj/covidbirds/blob/master/lockdown/lockdown_stat.r

We then coded each successive period of lockdown, eased restrictions and no restrictions and, using summary statistics in ArcMap 10.3, calculated the mean, maximum and minimum difference between each of these periods and the prediction by the model for each region. This enabled us to detect changes in observer responses to restrictions throughout the pandemic and successive lockdowns.

Changing birds by IUCN status and landuse type

For each record in eBird (based on all data globally), we recorded the fields: scientific name, longitude, latitude, and observation date. Via the information above, we categorised urban/rural landuse types for each species before and during the pandemic.

For urban-rural classification, we used Europa (2019) and made a 500m buffer as an indicator of urban areas, and all the other areas are labelled as rural areas. We extracted the urban types for all the occurrences of a given species between 2015 to 2019, and calculated the proportion of urban areas in the occurrences. If the proportion is larger than 66.7%, the species was labelled as an urban-type species before the pandemic. Conversely, if the proportion is lower than 33.3%, the label is rural-type, and between 33.3% and 66.7% are mixed-type. We reclassified the species during the pandemic to compare before and during.

For landuse type, we used the Annual Plant Functional Types (PFT) classification in MODIS Land Cover Type Product (MCD12Q1, Sulla-Menashe., in review, see Table S1 for legend) as the standard to classify the landuse of the species before and after the pandemic. We merged the 12 landuse types in PFT into three types, Cereal Croplands (7) and Broadleaf Croplands (8) were regarded as 'CROP'. Urban and Built-up Lands (9) were regarded as 'URBAN' and all the other types were regarded as 'PRISTINE'. If more than 33.3% occurrences of a given species before/after pandemic were predominantly in the categories listed above, the species was given a corresponding label. The landuse type of a species is given in three characters 'XXX'. The 1st number is 1 if the proportion of pristine is larger than 33.3%, and the 2nd number represents crop and the 3rd one is urban, calculated similarly. We also analysed the occurrences before and after the pandemic of each species in eBird. https://github.com/qiaohj/covidbirds/tree/master/species_modis

We mapped out whether species had been lost, gained or stayed stable relative to former years, both for all species and for endangered species https://github.com/qiaohj/covidbirds/blob/master/species_turnover/species_richness.r). These were then imported into ArcMap 10.3, and the change in richness overall and for endangered in protected areas during the pandemic relative to before the pandemic analysed. To do this, we first dissolved protected areas (using the protected planet map: https://www.protectedplanet.net/en, downloaded 21st March 2021) so that all overlapping designations were removed and then used this to clip regions so we had National protected area coverage. We then used the tabulate statistics tool to extract the average statistics for each protected area, and analysed this for each month of 2020. Statistics gauged the differences in richness in the pandemic relative to those prior, we also tabulated for how many protected areas observations were recorded in 2019 relative to the same month in 2020 to assess how the representativeness of recording had changed.

Changes in observer status (domestic vs international)

To classify if an observer was largely domestic or international, we calculated the count of regions that an observer uploaded from within a year. (https://github.com/qiaohj/covidbirds/tree/master/observer_stat). Based on the results above, we categorised the observers into two types, "international" who submitted the data from at least two regions within a year, and "domestic" who submitted the data from one region in a year. We grouped all the Schengen countries and the United Kingdom as a region because people can travel throughout without visas, and they are adjacent to extensive transportation networks.

After labelling the observers, we calculated the proportion of different observer types from 2015 to 2021 in each region, and labelled the region type in a given year into two categories; "international-based region" are regions where more than 50% of observers were international observers in a year; for "domestic-based regions" at least 50% of observers are domestic in a year. If the type of a region changed between 2015 and 2019, it was labelled as "mixed before pandemic," or "mixed after pandemic (the type changed in 2020 and 2021)".

Species loss and gain

Whilst numbers of observers, events, and observations remained relatively similar, the number of species in 2020 declined dramatically from previous years (Figure S1). For the species lost and gained, we extracted the species list for each region before and after the pandemic. To develop a comparable species list, in this analysis, we used 2019 as the year before the pandemic, and 2020-2021 as the pandemic. Species gain means the species was recorded for the first time in any given region during the pandemic, species loss indicates species were recorded prior to the pandemic (in 2019) but not recorded during the pandemic within a region. There will inevitably be some stochasticity, but equal weighting does show if patterns in a region have changed if a region loses more species than it gains (or vice-versa) due to changing observation patterns. In plots, each species status was reported for every region it was recorded in**.** We also calculated the total events of each species in a given region between 2019 to 2020 to represent species visibility.

Results

Global patterns of birding

Changes in observation pattern during the pandemic

From 2015-2021, the number of bird species observed showed demonstrable changes during the pandemic, whereas the number of records, number of observers and numbers of birdwatching events was largely unchanged (Figure S1). Prior to the pandemic, almost all regions showed annual increases in the popularity of birdwatching, and the number of species recorded. We analysed trends for 62 regions which had enough data to model. All 62 regions had a minimum number of species below the prediction during 2020, with 25 of these having a loss of over a 100% loss relative to the model and several regions having over 500 less than the prediction (Peru and Ecuador), and nine regions had a mean of over 100 loss, with all but three of these (India, Malaysia and Tanzania) falling in Latin America. Even for the maximum value in the prediction, 19 regions are still below the expected values (Table S2).

For 2021, some regions did recover to pre-pandemic levels, yet only two regions did not show a minimum below pre-pandemic levels (Belgium and Hong Kong), and 12 remained at a loss of over 100 species (and eight of these have a mean loss of over 100). In total, only 17 regions had a mean of, or above pandemic levels, but 33 had maximums that exceeded them for at least some time. In terms of the number of events across 2019-2020, the majority of events globally recorded species both years (stable Figure S1), this was followed by events where species were only sighted in 2019 but not 2020, and the fewest events not previously recorded in a region. Mapping these impacts out, we see similar patterns in terms of areas showing the greatest decreases in occurrences (Figure 1).

Recovery and rate of recovery

Most regions implemented different levels of restrictions at different times, and understanding these trends and their implications for observations is important (Figure 2; Figure S2, S3). Regions that showed the greatest mean losses during the initial lockdown typically also showed the greatest losses during subsequent periods, many of which were in developing regions. Peru showed the greatest mean losses during the first lockdown (because regulations were ongoing), but in Ecuador and Columbia whilst mean losses were similar to Peru during the first lockdown they remained high as restrictions were eased, and increased again in Colombia during the second lockdown. China has an interesting profile, though difficult to adequately capture as no nationwide restrictions existed following the first lockdown, yet mean losses remained through all subsequent periods. However, it should be noted that China has its own system for bird recording (bird-tracker) and that like other countries with languages which do not use Roman script, these countries may be particularly reliant on international observers for sharing records via eBird. Similarly, many tropical regions showed major losses, yet many developed regions showed relatively little mean difference between observed and expected species richness, though maximum differences were often greater. Furthermore, a subset of largely European countries showed mean losses during periods when restrictions were being eased following lockdown (possibly due to a return to workplaces). Interestingly, regions which had lower mean and maximum decreases also had fewer periods of lockdown or eased regulations which showed a substantive difference from the model of what would be expected in terms of seasonal change during previous years.

How these vary based on economic state, main correlates

Whilst lockdowns were implemented widely, especially during initial phases of the pandemic, how they impacted on behaviours varied. Changes in activity levels relative to the same period in previous years in a range of places (grocery and pharmacy, parks, residential, retail and recreation, transit stations, workplaces) were directly compared to differences between the model and observations, and levels of international tourist arrivals. For 2020-21, we found a significant relationship between the degree of loss and a number of the activity factors ($p < .001$), including lockdown regulations, decreases in activity in grocery and pharmacy, parks, workplaces and increases in activity in residential areas. When examined by reliance on tourism as a percentage of GDP and region income status (based on IMF definitions), different patterns emerge (Table S3a). Overall, the relationship between activity in any of these sectors and the loss of recorded bird species is weaker and less significant in low-income regions, stronger in middle-income regions and highest in high-income regions, with negative relationships with activity in all sectors except residential, where positive relationships existed (Figure S4a-b). When analysed by status for the 2020-21 period, high-income regions showed the strongest relationship with lockdown status, international visitor controls, and activity in retail and recreation, transit areas and workplaces; middle-income regions showed significant relationships with activity in residential areas, retail and recreation and workplaces (Figure S5); and low-income regions showed no significant relationships. In terms of reliance on tourism for high proportions of GDP, those with a very low reliance on tourism showed significant relationships between the difference between observed and expected with lockdown status, grocery and pharmacy, retail and recreation and workplace activity. Those with low tourist reliance showed relations with visitors in parks, and grocery and pharmacy, whereas those with a medium reliance showed relationships between activity in transit stations, retail and recreation and residential and those with high reliance only on activity in parks where species may be directly observed.

When 2020 was evaluated independently (and more international travel data was available- Table S3b), activity in transit stations was the strongest factor overall. For high-income regions, activity in grocery and pharmacy, residential, retail and recreation and parks were significantly related, whereas for middle-income regions only the relationship with retail and recreation were significant and no predictors were significant for low-income regions. For tourist reliance, those with very little reliance on tourism showed relationships between international travel control, park visitors, residential, retail and recreation and workplace activity. Those with a low reliance with international travel levels and residential levels, and those with a higher reliance on tourism showed little significant relationship, though notably most of these still remain at below pre-pandemic levels in terms of species recording. Therefore, whereas developed regions could quickly "normalise" activities, diverse developing regions remain at low levels of observation.

IUCN status and changing patterns of where species are located and recorded

Changing patterns of observation as well as relative disturbance impact on what species might be observed in different parts of the landscape. We divided the landscape from two different perspectives, one simply dividing urban and rural areas, and the other dividing the region into "pristine", agricultural, and "built-up" and looked at the relative change in the percentage of records for each species recorded in each constituent part between threatened and non-threatened species. We included a total of 10,338 bird species (93% of bird species) (and 348 subspecies) in analysis, though notably 9,505 of these were Least Concern (or Near threatened), 29 data deficient, 666 vulnerable, 371 endangered and 115 critically endangered (Table S4).

We used a total of 869.78 million records from 2016-2019, and 154.49 million records from 2020 (representing about a 29% reduction in average records collected). For the 984 species recorded in previous years, there are no records in 2020. In total, there was an 82% reduction in the number of species records, with 76.4% in natural areas, 73.1% in croplands and 71.1% in built-up areas. Many species were only recorded in natural areas

(Table S5, Figure S6). Only eight species of 10,686 showed no overall loss of records in 2020 compared to the average for former years; all other species were recorded less in 2020. However, some species did show increases in specific types of landcover, though most of the species with the greatest increases were actually subspecies, though certain species (i.e. *Euptilotis neoxenus*) whilst showing decreases in the number of records overall showed increases in the number of records in rural areas. Likewise, the data-deficient species *Oceanites pincoyae* only had 33% of the average annual amount of data but a 300% increase in pristine areas, these species have low sample sizes (Table S2) but the number of records for these rare species showed the greatest losses. In total, 22 species showed increases in pristine areas (and 13 in rural areas). Yet 9,407 species showed fewer records in natural areas. Some cases are particularly interesting, for example *Pterocles decorates* shows an 88% reduction in the number of records in total but a 1,100% increase in records in builtup areas, and 135 species in total show increases in the number of records in builtup areas, though all of these show a decrease in the total number of records (though at least 6, 072 species show a decrease of records in urban areas). Similarly, 195 species showed increases in the number of records in croplands, three of which had over 1000% increases, yet 4,616 species show decreases in records of at least 10%. When explored based on threat the majority of species of all threat classifications lost points, however threatened species showed few gains in any areas but under 1-2% of all species showed gains in built-up areas (with 23-36% showing losses), and under 4% of species showed gains in croplands (Table 1).

Data from key areas and species

Whilst changes in park activity correlate with the difference between observed and expected values in some income classes, this does not differentiate urban parks from more extensive protected areas which are key to biodiversity. However, results also show that low and middle-income regions remain continuously low for records. When we examine protected areas on a national basis and compare species observed to those observed in previous years over the same period, we see broad-scale losses in the number of species observed in most regions. In total, 203 regions had at least some data in protected areas, and 170 of these had at least six months with data, yet all regions but two with 12 months of data showed on average decreases in species observed in protected areas (Madagascar and Syria), and both these two showed an average increase of under 3 species, whereas 92.4% of species show an average loss of at least 10 species in protected areas, and 53 of these show a mean loss of over 50 species (Table S6). Notably, both these countries (Madagascar and Syria) are also outliers when we examine the loss and gain of species (Figure 5). Furthermore, of the 118 of 203 regions which had all 12 months of data, 81 were negative for all 12 months, and 33 were negative for at least 6 months. Similarly, 43 of the 114 regions with 12 months of data also had a mean monthly diversity value below that of previous years for all months.

In terms of endangered species, some areas saw major losses in records of endangered species in protected areas. For example, Tanzania saw a mean maximum loss of endangered species in protected areas of eight species (though many lose more) and an average loss of 3.2. South Africa saw similar losses of a mean maximum of 6.7 and a mean of 1.9. Kenya and Brazil showed similar losses of 6.5/2.3 and 6/1.6. Zimbabwe and Zambia also showed significant losses of endangered species in protected areas with a loss of 11 species in February 2020 and mean maximums in both cases of 5.42 and 5.25 species. These losses may actually be more significant as data for all protected areas do not exist, and many protected areas have no data for endangered species for much of 2020, for example, South Africa had endangered species data for 113 protected areas in January 2020 to only 7 in April (Table S6). Thus, many areas showed a huge loss of data, and many regions in Latin America and across

Africa had data on species from 200-500 protected areas in January 2020 to only 10-30 protected areas within a few months.

Changing observer status

Whilst the number of observers increased from 110,000 observers in 2016, this increased to almost 180,000 by 2019, and up-to 225000 in January 2020. The count of one region observers is the only one that increased after 2019 (Figure 3), but observers in more than one region within the year all decreased dramatically, especially for observers who previously visited high numbers of regions. Consequently, because of the pandemic, international observers decreased and domestic observers increased. However, whilst species numbers did change dramatically through lockdown, number of observers and observer events largely did not (Figure S1). However, many developing regions may have seen losses in observed species due to the loss of international observers, thus we analysed the changing status of bird watchers in each region. Through the pandemic, international observers decreased and domestic observers increased overall (Figure 4), and whilst between 2016-2019 the numbers of domestic and international observers in different regions was approximately similar in 2020 the number of domestic observers increased whilst the number of international observers decreased, and both decreased in 2021. These trends were persistent in most regions, though very high GDP regions (Bermuda, UAE, Bahamas, Kuwait) maintained more international observers than most other regions, and most lower-income regions saw a transition from largely international observers to largely domestic observers, and middle-high income regions maintained a large proportion of domestic observers.

Discussion

Recent years have seen a growing popularity of birdwatching and the sharing of data through portals like eBird and iNaturalist in almost all regions. The popularity of these platforms has grown exponentially in recent years, almost doubling the number of users between 2016 and 2020. However, patterns of activity through the pandemic differed massively as a consequence of changes in international and domestic travel. Whilst some of these patterns are likely to be temporary, they provide insights into the role and value of international travel as a means of generating data, and may have long-term consequences given the importance of ecotourism in some regions. These differences in observer activities must be carefully accounted for in any future analyses of such data. Notably, whilst many regions showed a similar number or slight increase in observers, most showed a loss in species and a decline in the records of more threatened species during the pandemic. It is clear now that, contrary to popular messaging of a net-benefit “anthropause,” there are real negative consequences of the pandemic for biodiversity research, even when using data generated by the public.

Patterns, trends, and implications

Our analyses show that in regions with higher incomes, levels of activity in residential areas, shopping areas and parks did have strong relationships with the difference in the number of species expected and observed during the pandemic. Thus, unsurprisingly when residential activity was high (during lockdown phases) and access to natural areas was lower, we see decreases in the number of species recorded in developed regions, whereas as activity levels resume more “normal” levels the difference in observed and expected decrease, with fastest recoveries within higher income regions with a lower dependence on international tourism. For middle-income regions, these patterns are slower, and there is a stronger relationship with the amount of activity at transit stations, showing that regional movement contributes to species recording. Additionally, whilst initial lockdowns showed major decreases in recorded richness in almost all regions, these impacts dissipated in high-income regions through successive stages of the pandemic and is less demonstrable in consecutive lockdowns, whilst low-income regions do not show this recovery, and show much less relationship between human activity and observations due at least in part to a common reliance on international observers for record generation. Notably, even in regions that saw increases in the number of observers, these observers did not increase the number of species recorded, as they may have disproportionately focused on areas which were easy to access and thus unlikely to host less common or novel species.

Furthermore, endangered species remain unlikely to be recorded in urban areas, and thus decreased access to more remote and "pristine" habitat is associated with a loss of these species. Common species (least concerned or near threatened) showed significant increases in the proportion of records observed within urban areas, as suggested by Schrimpf et al. (2021), but this is not true for most species with higher threat levels (via IUCN) and species classed as data deficient often show the greatest levels of loss, so clearly the subset that they used could not represent the full breadth of avian diversity. These patterns are also indicative of a wider problem, this lack of data generation from natural habitats also indicates that protected areas are visited less during the pandemic, and again the data shows this, with many low and middle-income regions showing no data from around 80% of their protected areas within months of the pandemic starting.

There are clearly strong patterns relating to GDPc, with many countries and regions showing the largest losses and fewest gains being developing regions or islands (Figure 5), with countries across Africa showing particularly interesting patterns (Figure 1, Figure 5). This loss of data not only hampers long-term understanding of species activities, but with no tourist income parks may struggle to protect rarer species, especially when security might be lax due to a loss of tourist revenue needed to support rangers such that poachers have free reign (World Ranger Challenge., 2021; Boyle 2020; Lindsay et al., 2020). This has led to increased consumption of bushmeat across much of the African continent as well as parts of Asia, exposing a wide suite of species to hunting for subsistence (InfoNile, 2021; Ghosal & Casey., 2021; Borzee et al., 2020). These impacts should not be under-estimated; surveys show that tourist revenues in regions like Kenya dropped by 96%, and that in a survey of 19 African countries, three quarters of regions surveyed said the pandemic hindered their ability to monitor wildlife trade, whilst two thirds of rangers said hunting had increased (Baldwin., 2021). Single reserves such as Hwange in Zimbabwe have seen increases in the numbers of snares and traps of up to 8000%, and the loss of an estimated $250 billion in tourist revenue across Africa in 2020 alone may have long-term implications for conservation across the region (Baldwin, 2021; Wildlife Ranger Challenge., 2021). Tourism has long been promoted as a mechanism for regions to transition away from unsustainable hunting for subsistence, so the loss of access to those incomes has major consequences for species in these regions (Secretariat of the Convention on Biological Diversity, 2011).

Our results show hundreds of species recorded in previous years were not recorded during the pandemic, particularly from protected areas. With increased hunting due to a loss of revenue and a need for incomes, and the loss of data from these key areas, we do not yet know the impact of this hunting on the status of these species. Furthermore, whilst the "anthropause" has been heralded as positive for biodiversity (Derryberry et al. 2020), the positive impacts have been largely temporary incursions of common, often generalist species into urban areas (Rutz., 2020; Zulanga et al., 2021 Sumasgutner et al., 2021). Worryingly, the ability of areas to recover post-covid may be hampered by the slow return of tourism needed to fund local economies, the loss of rangers and other staff, and the suspension of environmental regulations to stimulate economic recovery post-covid (Bobylev 2020). The loss of staff during the pandemic means enforcing environmental regulations even after the pandemic may be challenging, meaning more unsustainable development and hunting, and less data to detect or understand the impacts, especially in regions which saw particularly high economic losses during the pandemic (Kazaz & Walton, 2020; OHCHR 2020; Goodday, 2021).

Synthesis

Whilst the impact of the pandemic on wildlife globally has often been painted as positive, from a reduction of use of natural areas and of pollution, former analysis has been both short-term and has failed to account for parts of the world where rural incomes depend on tourism (Schrimpf et al. 2021). The loss of this tourism not only means a dramatic reduction in the number of protected areas with data, but also a loss of data from many high-diversity regions. In concert, this means we cannot truly know the impact of subsistence hunting or poaching in these key regions, due to a lack of monitoring data provided through international observers within eBird, and a slow recovery in many of these regions. Birdwatching is still dominated by observers from high-income regions, thus whilst activity in these regions linked explicitly to pandemic-related regulations and were able to recover rapidly, this was not the case in the most diverse parts of the planet. Gains in species records have also largely been limited to a subset of species able to utilise highly-modified spaces, whereas endangered and data-deficient species have shown major reductions in their levels of recording. We need measures to support tourist-dependent economies, and to facilitate the return of tourists in a way that is safe for local residents (as these regions are frequently also struggling to provide the medical support needed to enable these regions to not be seen as “high-risk” by higher-income economies). Ultimately, the long-shadow of covid, and covid regulations may continue to hinder not only our ability to monitor biodiversity in key regions, but also to provide a means of support for economies where tourism is crucial for both providing biodiversity data and financially supporting conservation.

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Competing interests statement: We declare no competing interests.

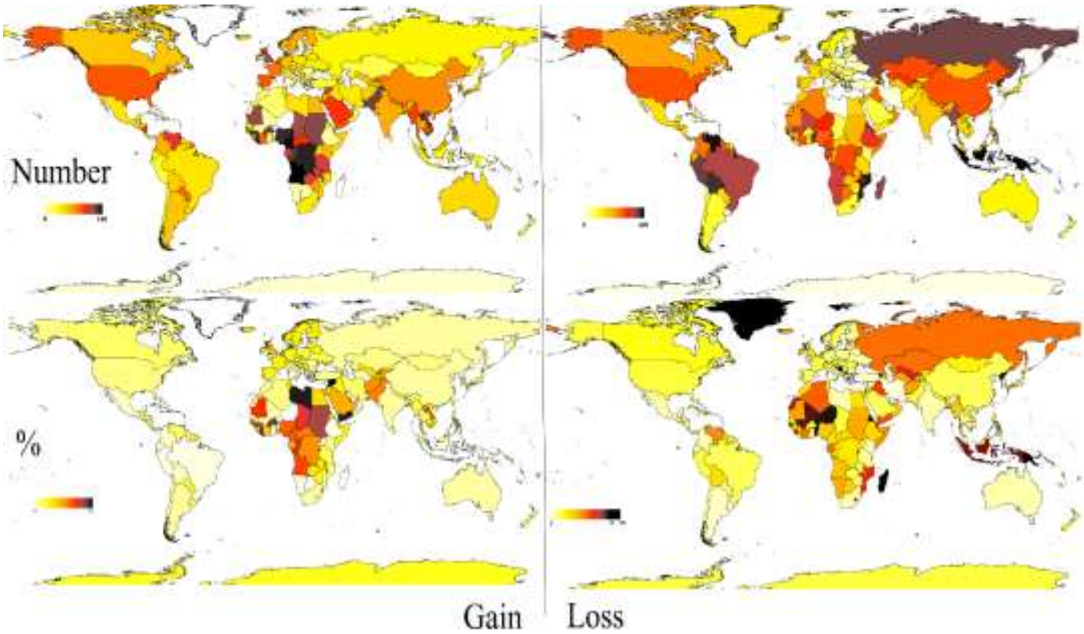


Figure 1. Loss and gain of species as a number and percentage of all species recorded in each region, for overall numbers see Figure S2.

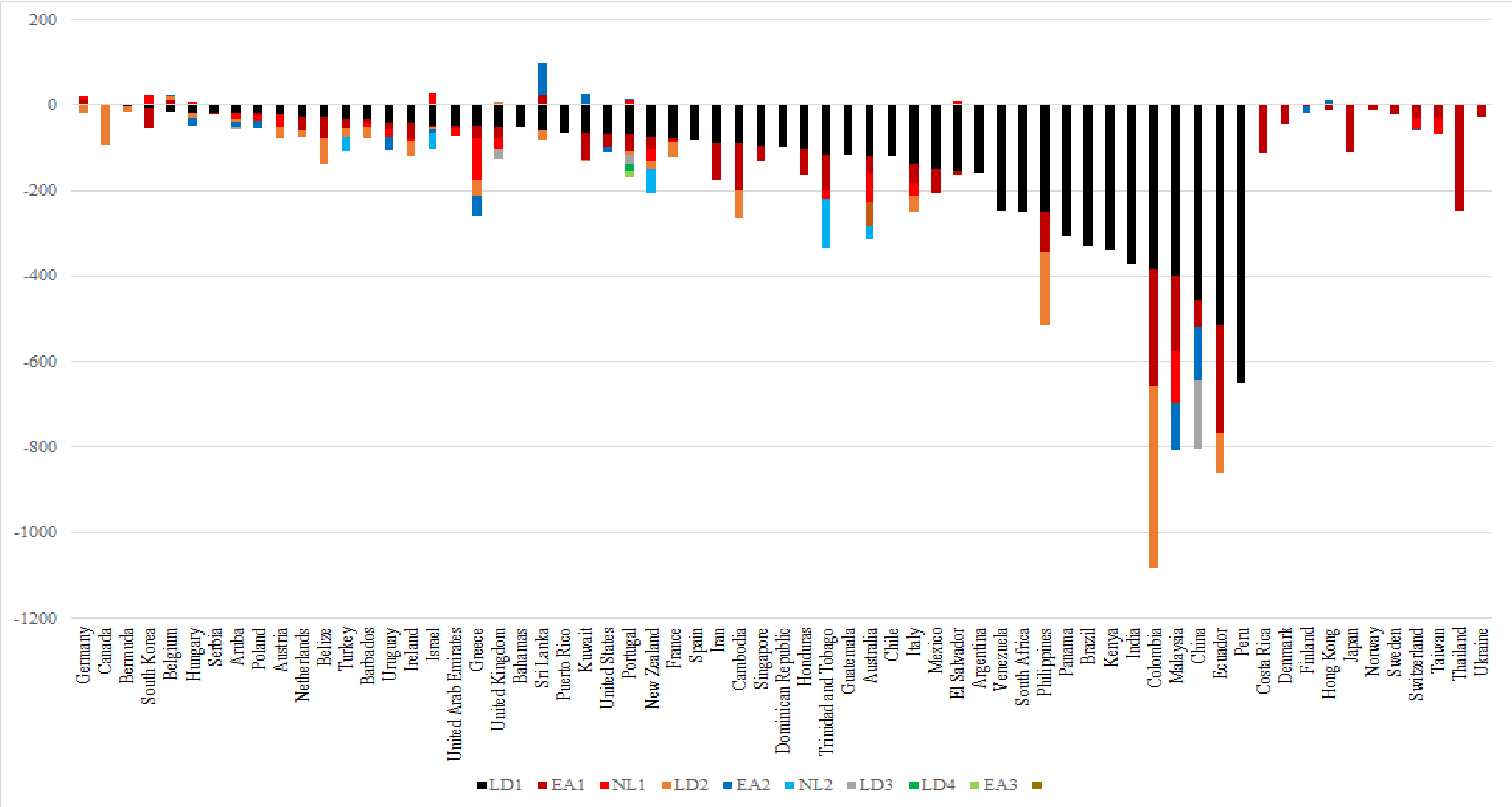


Figure 2. Minimum species difference from projection during each phase of lockdown (LD: Lockdown, EA: Eased restrictions, NL: No Lockdown, numbers are sequential in each region).

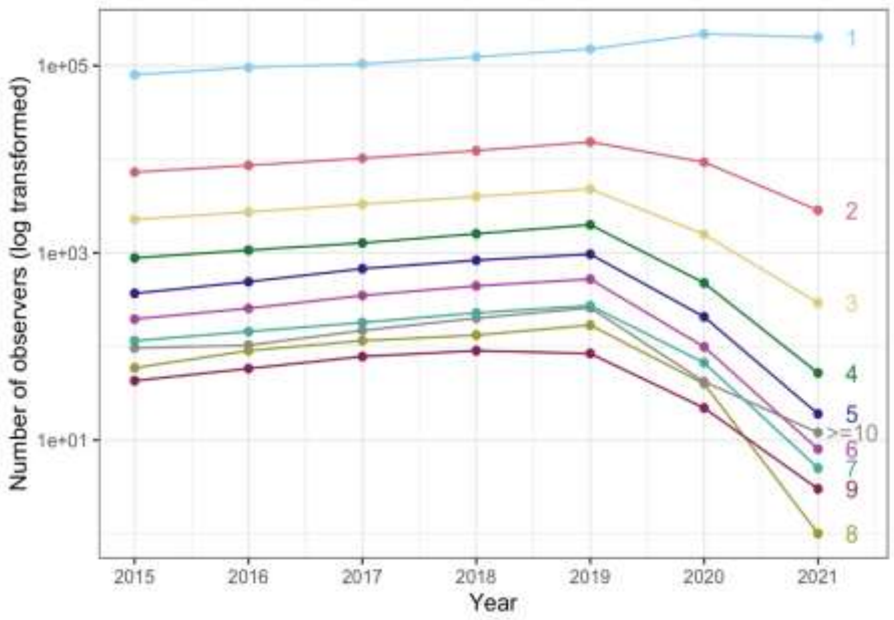


Figure 3. Number of observers visiting X number of regions to upload data per year.

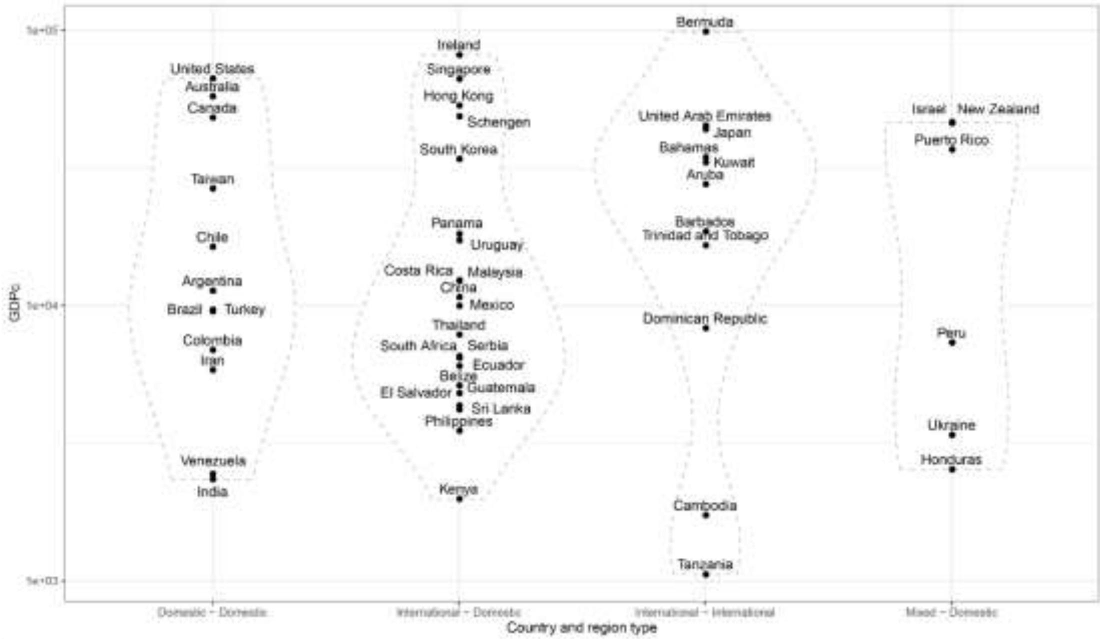


Figure 4. Observer status and origin before and during the pandemic (2020).

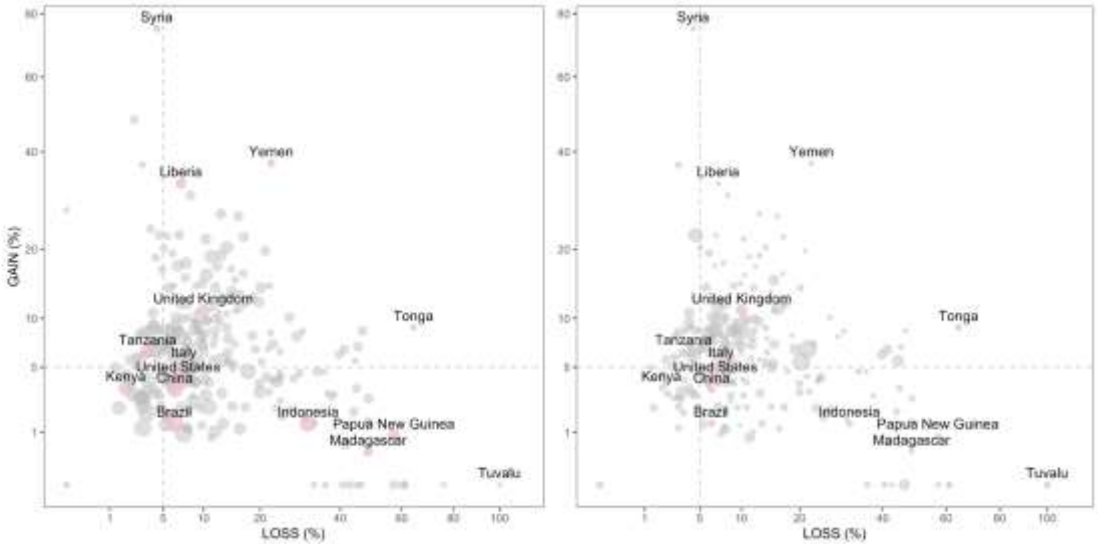


Figure 5. The loss or gain of species by region with richness (left) and GDPc (right)

Table 1. Number of species losing or gaining records in different landcover categories (nat: natural, crop: croplands).

	loss_all	nat_loss	nat_gain	buildup_loss	buildup_gain	crop_loss	crop_gain
common	8521	8468	14	5756	124	4438	178
CR	82	81	1	19	1	16	1
DD	9	8	1	1			
En	295	291	1	93	1	55	9
Vu	548	538	4	198	8	104	5

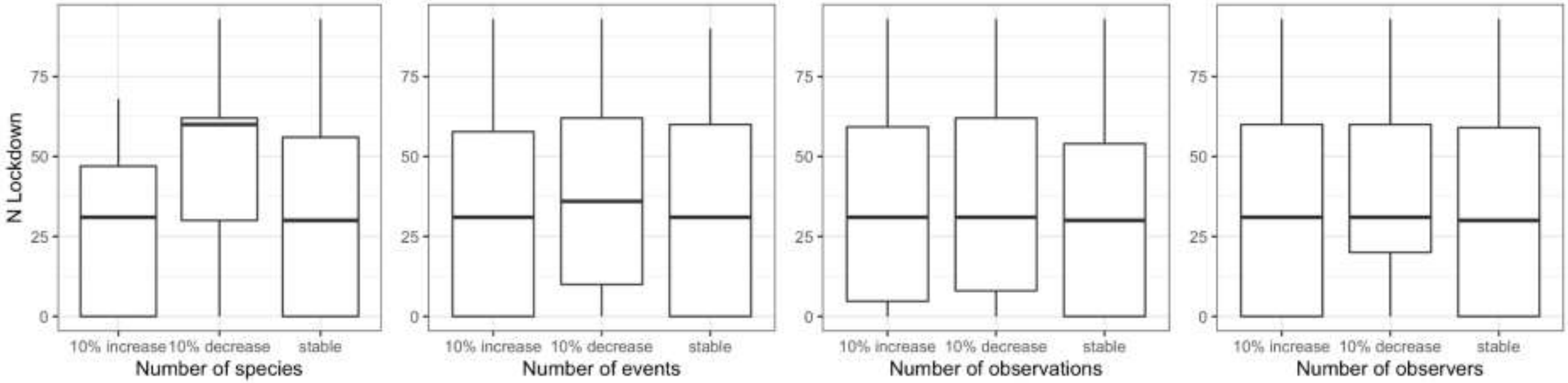


Figure S1. Changes in observers, events, number of observations and number of species during the pandemic.

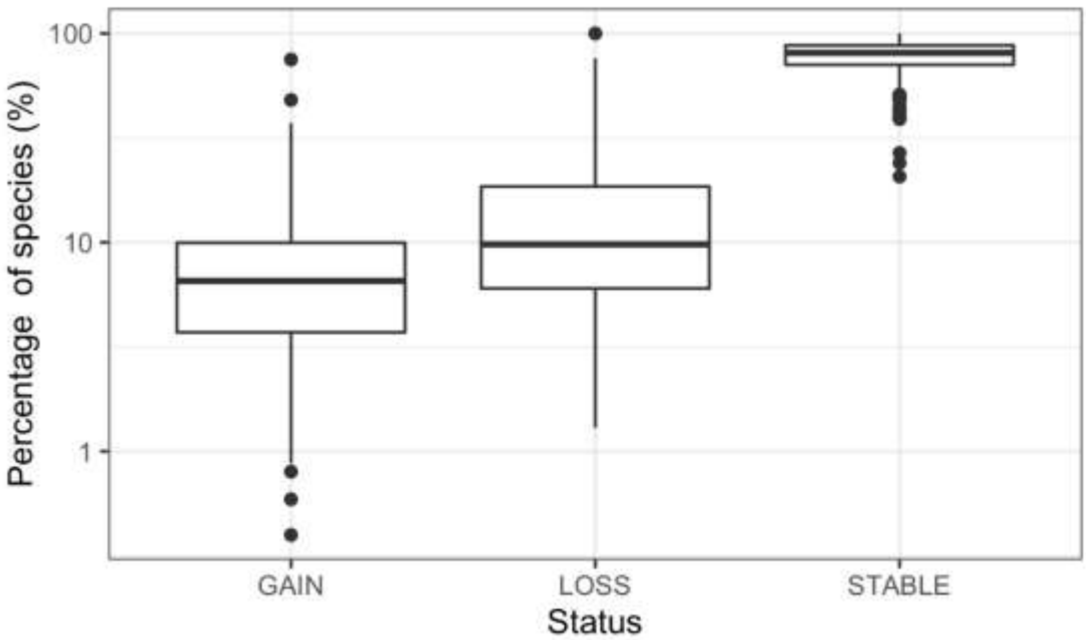


Figure S2. Changes in the number of species lost, gained or re-observed in any given region. The stable species (appeared in both 2019 and 2020) have the highest number of species. The loss species exceeds those gained

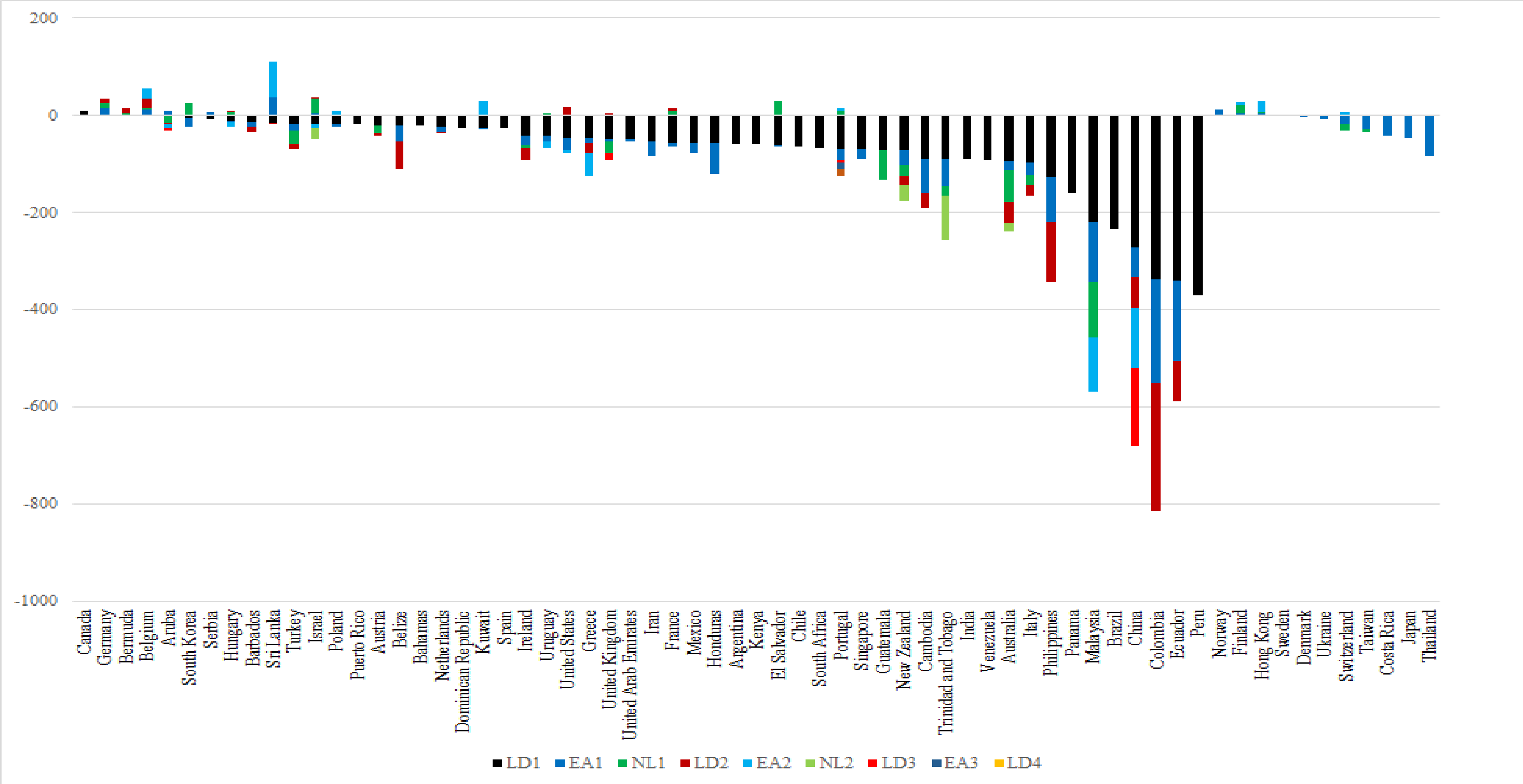


Figure S3. Mean differences between modelled expected and observed richness during each regulation period. LD=lockdown, EA=eased restrictions, NL=no lockdown.

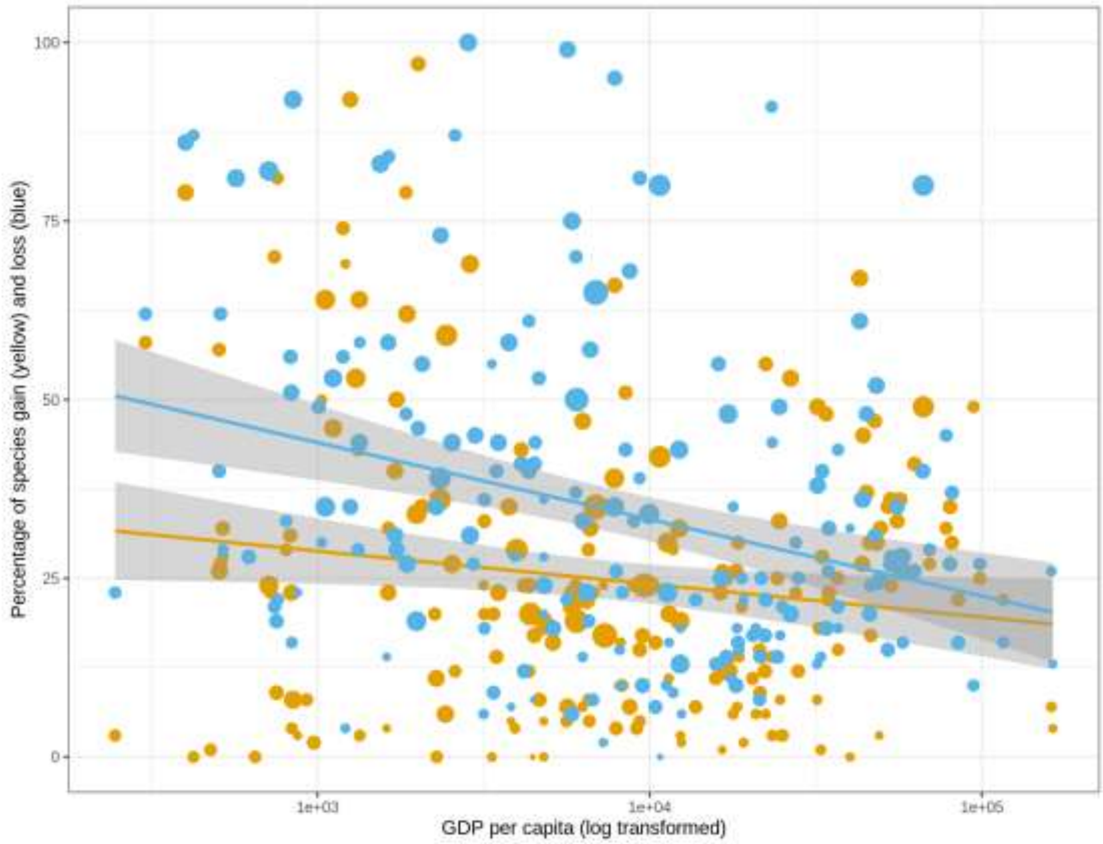
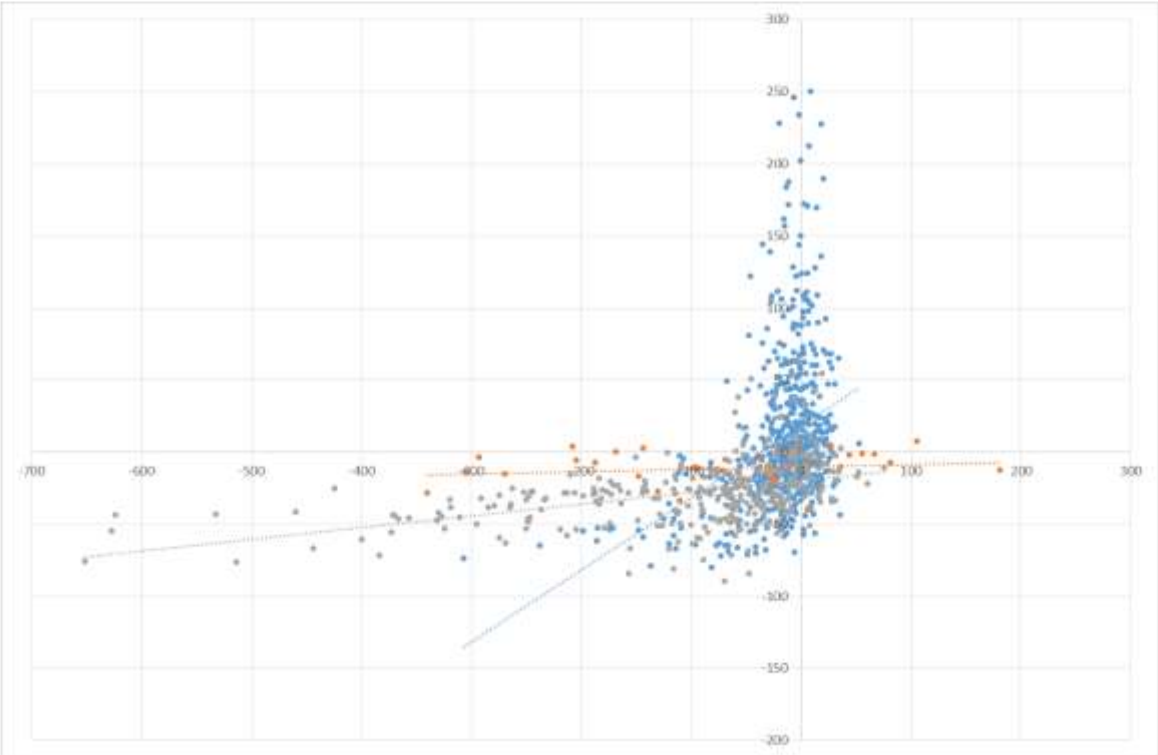
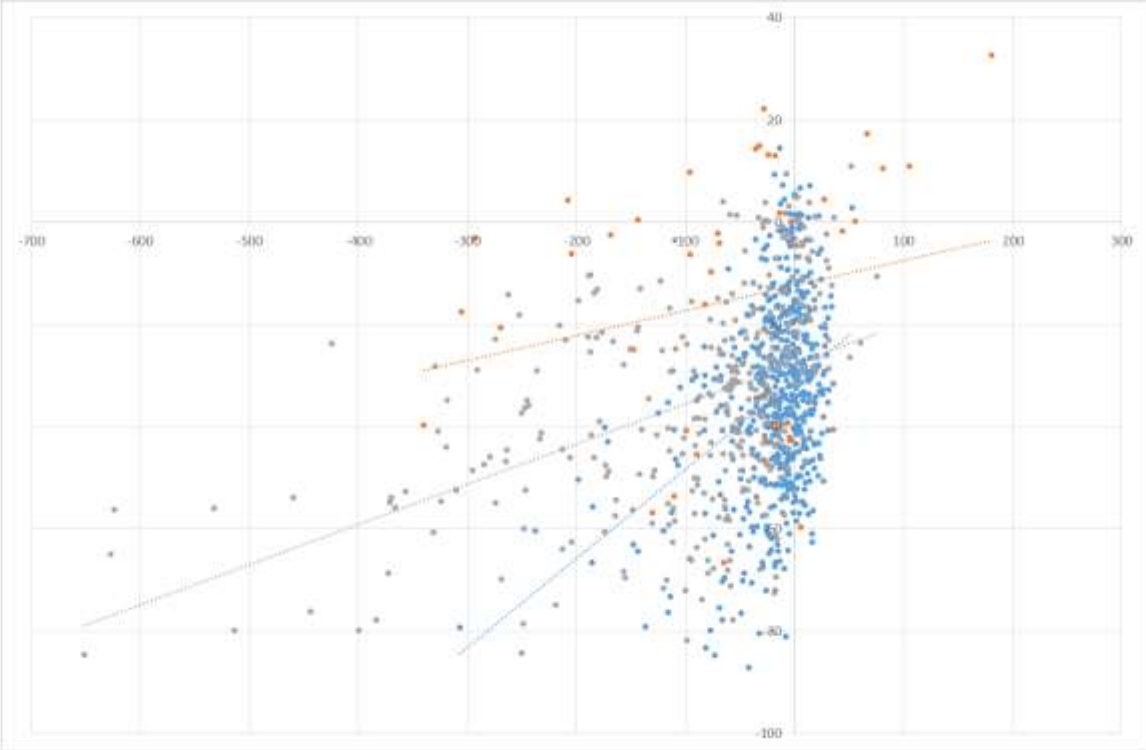


Figure S4a. The percentage of lost and gained by GDPc. The proportion of gained species decreased slightly along with GDPc, while the percentage of lost species greatly decreased, which means that lower-income regions have higher species loss. Point size indicates the number of species in a given region in 2015 to 2021

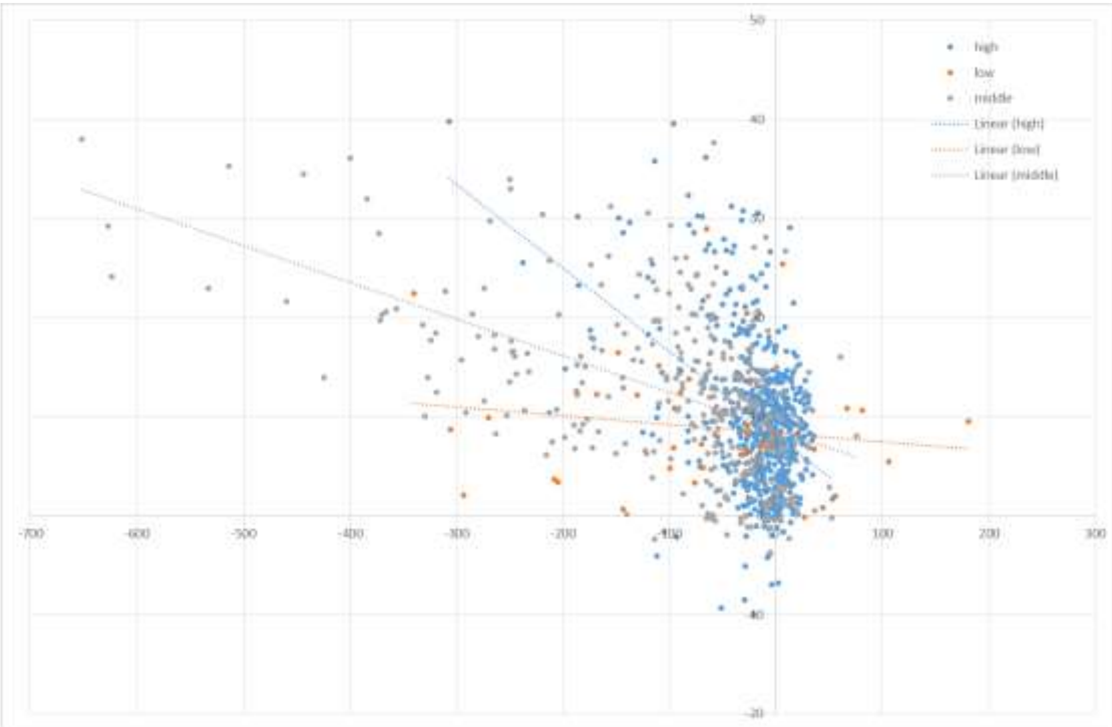
(Figure S5a) Workplace: Low income (y = 0.0211x - 14.279, R^2 = 0.0435); Middle income (y = 0.1372x - 21.824, R^2 = 0.1189); High income (y = 0.0499x - 20.826, R^2 = 0.1485)



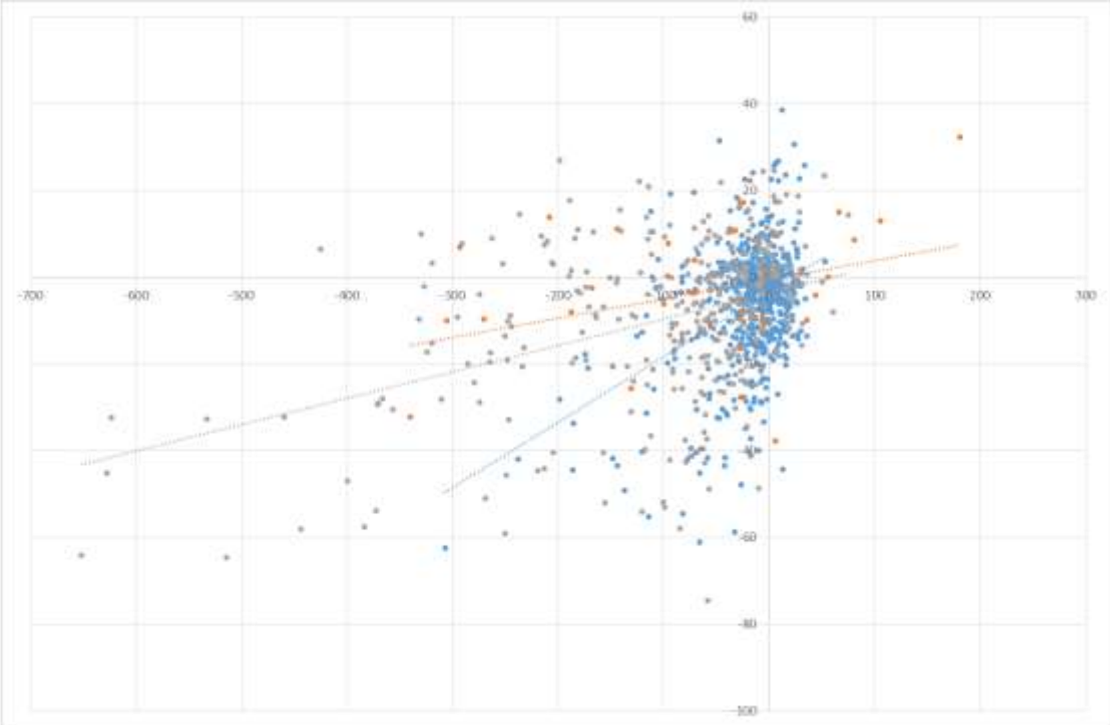
(Figure S5b) Parks: Low income (y = 0.0162x - 10.26, R^2 = 0.0234); Middle income (y = 0.5005x + 18.506, R^2 = 0.1187); High income (y = 0.0812x - 19.981, R^2 = 0.1734)



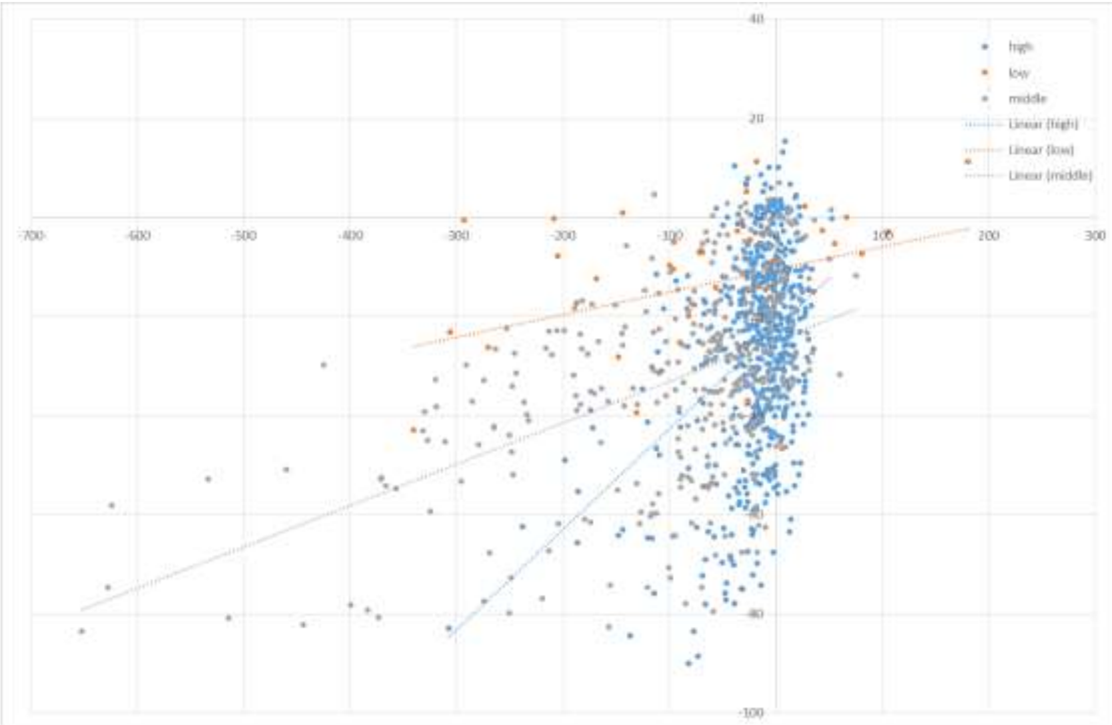
(Figure S5c) Transit: Low income (y = 0.0486x - 12.366, R^2 = 0.043); Middle income (y = 0.1744x - 30.76, R^2 = 0.1208); High income (y = 0.0787x - 27.587, R^2 = 0.2053)



(Figure S5d) Residential: Low income (y = -0.0087x + 8.3458, R^2 = -0.0226); Middle income (y = -0.0843x + 8.0913, R^2 = -0.1711); High income (y = -0.0371x + 8.7417, R^2 = -0.2732)



(Figure S5e) Grocery: Low income (y = 0.044x - 0.5898, R^2 = 0.0941); Middle income (y = 0.0609x - 3.5044, R^2 = 0.1554); High income (y = 0.1509x - 3.2445, R^2 = 0.1633)



(Figure S5f) Retail and recreational: (y = 0.0456x - 10.418, R^2 = 0.1128); Middle income (y = 0.203x - 22.368, R^2 = 0.1341); High income (y = 0.0833x - 24.819, R^2 = 0.2388)

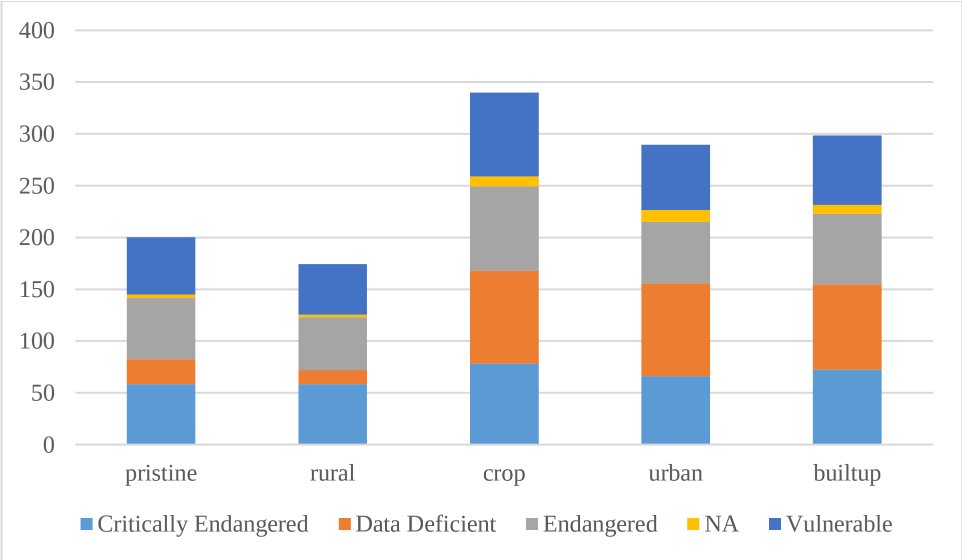


Figure S6a. The loss of species records based on threat status in different landuse types.

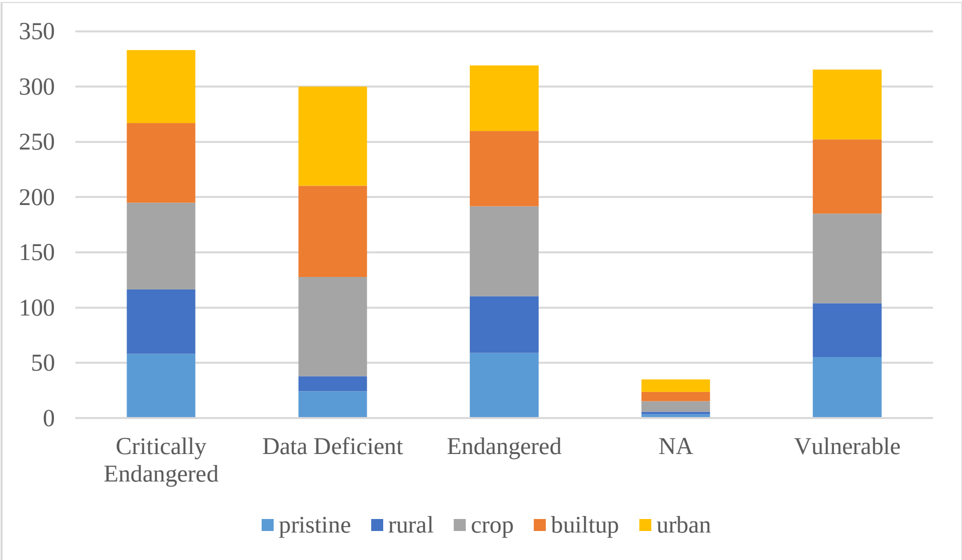


Figure S6b. The loss of species records based on threat status in different landuse types.

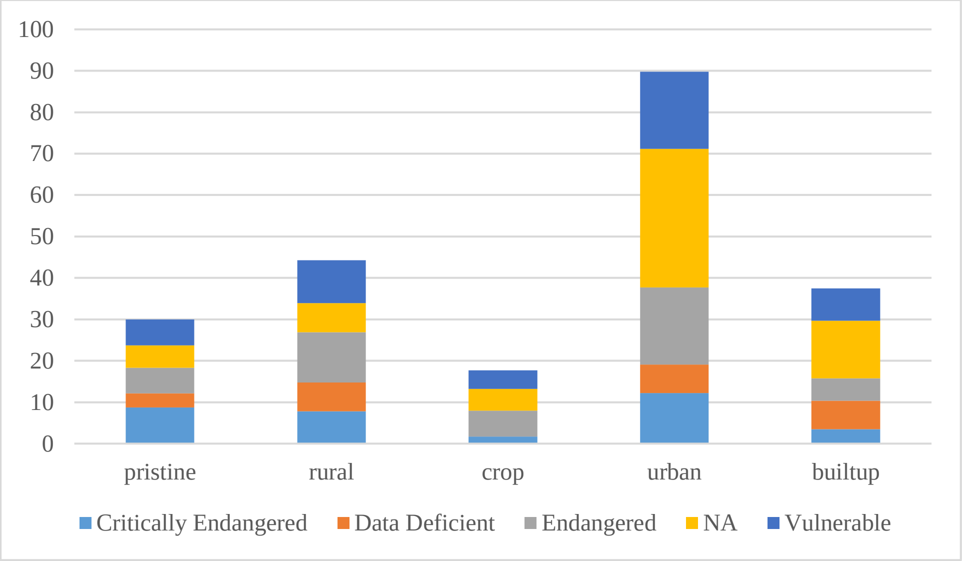


Figure S6c. Species showing at least a 5% gain of records based on threat status in different landuse types.

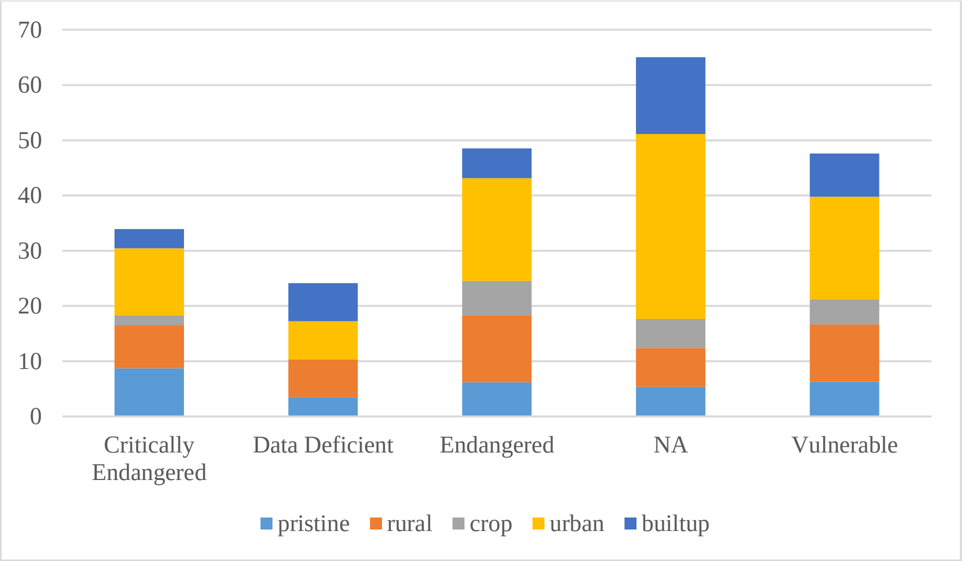


Figure S6d. Species showing at least a 5% gain of records based on threat status in different landuse types.

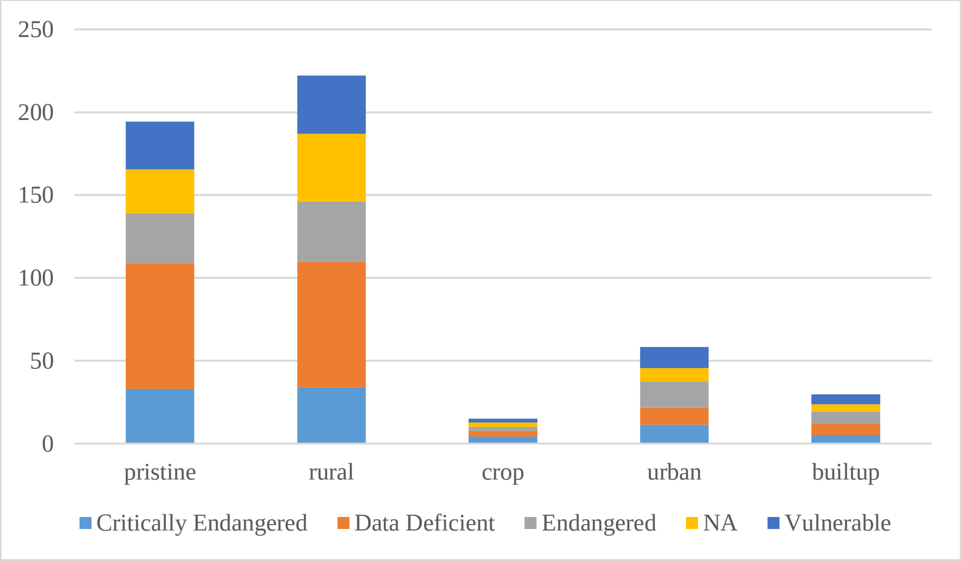


Figure S6e. Species showing at least a 5% loss of records based on threat status in different landuse types.

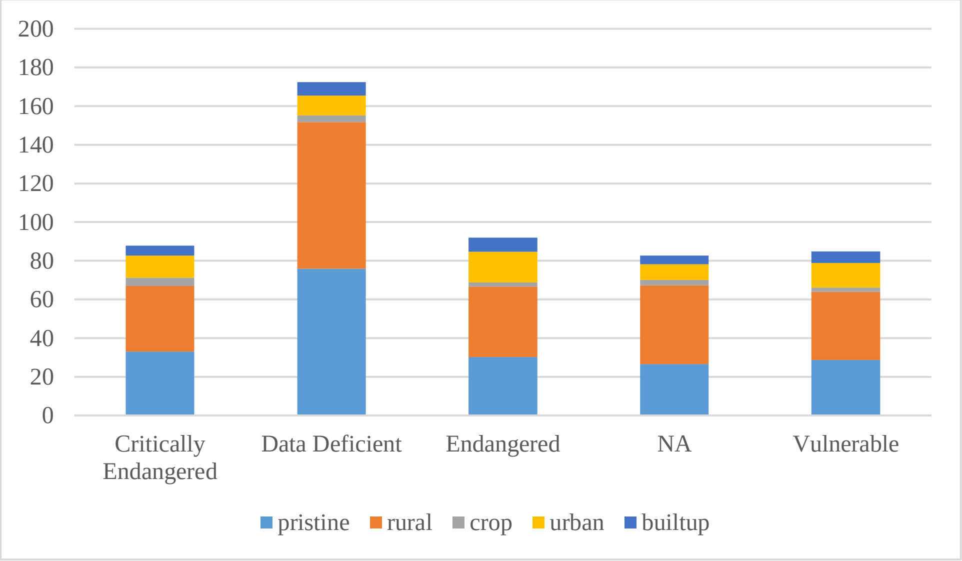


Figure S6f. Species showing at least a 5% loss of records based on threat status in different landuse types.

Name Color Hex Code	Value	Description
Water Bodies	0	At least 60% of area is covered by permanent water bodies.
Evergreen Needleleaf Trees	1	Dominated by evergreen conifer trees (>2m). Tree cover >10%.
Evergreen Broadleaf Trees	2	Dominated by evergreen broadleaf and palmate trees (>2m). Tree cover >10%.
Deciduous Needleleaf Trees	3	Dominated by deciduous needleleaf (larch) trees (>2m). Tree cover >10%.
Deciduous Broadleaf Trees	4	Dominated by deciduous broadleaf trees (>2m). Tree cover >10%.
Shrub	5	Shrub (1-2m) cover >10%.
Grass	6	Dominated by herbaceous annuals (<2m) that are not cultivated.
Cereal Croplands	7	Dominated by herbaceous annuals (<2m). At least 60% cultivated cereal crops.
Broadleaf Croplands	8	Dominated by herbaceous annuals (<2m). At least 60% cultivated broadleaf crops.
Urban and Built-up Lands	9	At least 30% impervious surface area including building materials, asphalt, and vehicles
Permanent Snow and Ice	10	At least 60% of area is covered by snow and ice for at least 10 months of the year.
Barren	11	At least 60% of area is non-vegetated barren (sand, rock, soil) with less than 10% vegetation.
Unclassified	255	Has not received a map label because of missing inputs

Table S1. Plant functional Types (PFTs) legend and class definitions from https://lpdaac.usgs.gov/documents/101/MCD12_User_Guide_V6.pdf

Table S2 (separate spreadsheet). Data for all countries and regions

Table S3a. Relations between recorded species and activity in different areas in regions with different income and tourism status for 2020 and 2021.

All	Overall	vlow_tour	low_tour	mid_tour	high_tour	high_incom	mid_incom	low_incom
p	< .001	< .001	< .001	< .001	0.323	< .001	< .001	0.204
R	0.476	0.564	0.451	0.79	0.361	0.488	0.551	0.48
R^2	0.227	0.318	0.203	0.624	0.131	0.238	0.304	0.23
Adjusted R^2	0.22	0.308	0.184	0.546	0.02	0.228	0.287	0.073
(Intercept)	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001
(Intercept)	0.373	0.411	0.166	0.252	0.054	0.424	0.989	0.468
grocery_and_pharmacy_MEAN_Vistor	0.004	< .001	0.01	0.312	0.068	0.17	0.318	0.961
lockdown	0.011	0.04	0.597	0.525	0.078	0.002	0.934	0.839
MAX_international_travel_controls	0.484	0.806	0.976	0.716	0.102	0.001	0.822	0.312
parks_MEAN_Vistor	0.006	0.417	0.021	0.239	0.026	0.117	0.59	0.705
residential_MEAN_Vistor	< .001	< .001	0.125	0.047	0.611	0.368	< .001	0.468
retail_and_recreation_MEAN_Vistor	0.928	0.351	0.048	0.014	0.488	< .001	0.031	0.151
transit_stations_MEAN_Vistor	0.639	0.237	0.523	0.001	0.69	0.003	0.332	0.311
workplaces_MEAN_Vistor	0.044	0.015	0.265	0.191	0.123	0.037	0.003	0.751

Table S3b. Relationship between recorded species and activity in different functional areas in regions with different income and tourism status for 2020.

2020	Overall	vlow_tour	low_tour	mid_tour	high_tour	high_incom	mid_incom	low_incom
p	< .001	< .001	< .001	< .001	0.44	< .001	< .001	0.11
R	0.998	0.742	0.625	0.819	0.468	0.643	0.624	0.785
R^2	0.995	0.551	0.39	0.671	0.219	0.413	0.389	0.616
Adjusted R^2	0.995	0.535	0.359	0.542	0.006	0.395	0.358	0.328
(Intercept)	< .001	< .001	< .001	< .001	< .001	< .001	< .001	0.011
(Intercept)	0.136	0.98	0.841	0.714	0.65	0.78	0.755	0.556

grocery_and_pharmacy_MEAN_Vistor	0.065	0.479	0.587	0.048	0.23	0.06	0.916	0.244
lockdown	0.168	0.901	0.891	0.283	0.182	0.228	0.261	0.436
MAX_international_travel_controls	0.37	< .001	0.149	0.877	0.994	< .001	0.363	0.894
parks_MEAN_Vistor	0.63	< .001	0.834	0.192	0.465	< .001	0.963	0.335
residential_MEAN_Vistor	0.075	< .001	0.002	0.957	0.454	0.005	< .001	0.38
retail_and_recreation_MEAN_Vistor	0.99	0.133	0.24	0.778	0.821	0.296	0.518	0.676
transit_stations_MEAN_Vistor	< .001	0.118	0.38	0.221	0.608	0.129	0.114	0.817
unwto	0.086	0.657	0.022	0.942	0.228	0.827	0.904	0.706
workplaces_MEAN_Vistor	0.453	0.027	0.753	0.374	0.346	0.582	0.99	0.667

Table S4. Number of records for threatened species in 2019 vs 2020 and the percentage of records in 2020 relative to 2019.

	prepan	**postpan**	**%prepan**
Total	869781983	154488670	17.76
D Deficient	14100	757	5.37
C Endangered	175126	18976	10.84
Endangered	925751	113894	12.30
Vulnerable	6437227	931612	14.47
NA	862229823	153423437	17.79

Table S5 (separate spreadsheet). Species data on records in different landuse types before and during the pandemic.

Table S6 (separate spreadsheet). Protected area losses or gains in species changes between 2020 and former years.

Supplemental text

Countries and regions included in model assessment

Argentina, Aruba, Australia, Austria, Bahamas, Barbados, Belgium, Belize, Bermuda, Brazil, Cambodia, Canada, Chile, China, Colombia, Costa Rica, Denmark, Dominican Republic, Ecuador, El Salvador, Finland, France, Germany, Greece, Guatemala, Honduras, Hong Kong, Hungary, Iceland, India, Iran, Ireland, Israel, Italy, Japan, Kenya, Kuwait, Malaysia, Mexico, Netherlands, New Zealand, Norway, Panama, Peru, Philippines, Poland, Portugal, Puerto Rico, Serbia, Singapore, South Africa, South Korea, Spain, Sri Lanka, Sweden, Switzerland, Taiwan, Tanzania, Thailand, Trinidad and Tobago, Turkey, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela

Threatened species and relative changes in distributions

In terms of the average change in the percentage of records, very few areas showed significant increases in species richness, with the highest gain a 3.6% increase in the proportion of records in urban areas for LC/NT species and a 1.35% increase in the proportion of records in built-up areas, converse to a relative to a -10.95% change in rural areas, and a -9.2% change in rural areas, with a slight increase in crops (0.3%). Other threat levels show major losses on average when we look at the percentage of records in different parts of the landscape, with for example -66.65% losses of data deficient species in pristine environments (in part driven by the loss of 100% of records for multiple species, 689 species in total, 17/29 data deficient (DD) species), and rural areas saw a -68.7% loss of DD species. Furthermore, the relative reduction of the proportion of points in pristine areas was highest in data deficient species (-66.65%, followed by Critically endangered (-27.06%), Endangered (-19.17), Vulnerable (-18.56%) then LC/NT at -9.2. Conversely, built-up areas had little or no reductions for most threatened groups (in part because there are relatively few threatened species in these areas) and increases (1.35%) for LC/NT species. Croplands show similar but less pronounced trends to built-up areas.

When we look at the number of species in different groups showing these trends, 56.3% of species in pristine areas (64.9% in rural areas) have shown decreases in the percentage of records in pristine areas, and only 5.47% showed an increase of over 5% of records in pristine areas (7.43% in rural areas), whilst 27% of species showed an over 5% loss of points (40.3% in rural areas). Conversely, 63.3% of species showed increases in built-up areas (69.19% in urban), 13.11% of species showed an increase of over 5% and 4.64% show losses of over 5%. Agricultural areas show a 68.49% increase in sampling, with 5.2% of species showing increases of over 5% and 2.8% showing decreases of over 5%. Thus overall whilst agricultural areas showed the number of species showing losses, in terms of large losses agricultural areas only lost marginally more than pristine areas, with data-deficient species showing the greatest losses, but all threatened species also show losses

In terms of threatened species overall in terms of the absolute number showing losses, threatened species continue to show the greatest losses, with crops and natural areas showing the greatest losses. However, when it comes to significant losses (5% or more loss) both pristine and natural areas showed the greatest number of species showing these losses, whilst urban areas show the greatest gains of over 5%, particularly for common species.