Disentangling the overlooked urban colonization of the Asian water monitor (*Varanus salvator*) along its distribution range.

Comentario [NN1]: Consider changing the title to a more open-ended one that does not reveal the work's results but remains engaging. suggest reviewing the objectives to craft the title. For example:

*Exploring the knowledge about the Asian water monitor (Varanus salvato

* A scientific survey of the Asian wat monitor (Varanus salvator) along its distribution range

* Urban colonizer: Asian water monito (Varanus salvator)

Álvaro Luna [1*], Armand Rausell-Moreno [2]

1. Department of Biosciences, Universidad Europea de Madrid, 28670 Madrid, Spain.
2. Department of Biogeography and Global Change, National Museum of Natural Sciences (MNCN-CSIC), José Gutierrez Abascal 2, 28006 Madrid, Spain.

*Corresponding author: Álvaro Luna

Universidad Europea de Madrid, C/Tajo s/n, 28670 Villaviciosa de Odón, Madrid

: alvaro.luna@universidadeuropea.es

Álvaro Luna: ORCID 0000-0002-8566-6367

Armand Rausell-Moreno: ORCID 0000-0002-5651-1462

Abstract

Background: This study aims to investigate the urban colonization of the Asian water monitor (Varanus salvator) across its entire range, addressing the paucity of research on this species in urban ecosystems. The research spans the geographic range of the Asian water monitor, focusing on urbanized areas where the species accumulates more observations (Bangkok, Colombo, Jakarta, Kuala Lumpur and Singapore).

Methods: We conducted a systematic review to comprehensively assess the current knowledge of the species' presence in cities. Additionally, citizen science data from repositories like GBIF were utilized to analyze the distribution patterns of V. salvator in urban environments. To elucidate urban distribution and correct collection biases, observations were weighted by sampling effort, using as a proxy all squamate occurrences available from 2010-2023, including *V. salvator*.

Results: Despite the widespread presence of the Asian water monitor in numerous cities within its distribution range, the available studies on the topic are limited. Existing research primarily consists of descriptive reports on diet and behavior. Our findings indicate that V. salvator predominantly colonizes green patches in urban areas, such as parks and small gardens. Larger cities exhibit higher records, potentially due to both permanent populations and increased citizen science reporting.

Conclusions: The Asian water monitor, as the largest lizard with established populations in cities, remains inadequately studied on a broader scale. However, the urban design of each city seems relevant understand the distribution patterns within each context. Our study underscores the need for further research to explore the ecological and human dimensions associated with the species' presence in urban environments.

Keywords: Citizen science, City, Lizard, Reptile ecology, Southeast Asia, Species Distribution, Urban Ecology, Varanus salvator

Introduction

Urbanization is one of the most important drivers of habitat transformation, accelerated in recent decades due to the growth of the human population, especially in Africa and Asia (Seto et al. 2012; Johnson and Munshi-South 2017). The sprawl of cities usually results in the simplification and homogenization of animal communities through local extinction processes (Sol et al. 2014). However, wildlife responses to urbanization can be more varied than expected, and even endemic and threatened species are able to colonize and successfully exploit the most populated cities (Vignoli et al. 2009; Luna et al. 2018; Woolley et al. 2019). Although urban ecological science is now a widely recognized field within ecology, some major gaps still remain unresolved (Shochat et al. 2006). Thus, to date, most of the research is focused on single cities located in Europe, North America and Australia, with a significant preponderance of studies about plants, birds and mammals (Magle et al. 2012; Rega-Brodsky et al. 2022). Regarding urban reptiles, a review conducted by Brum et al. (2023) confirmed that some biases still persist and the current knowledge is unbalanced, with developing tropical and megadiverse countries often overlooked in comparison to studies about reptiles inhabiting cities of temperate areas. This study also shows how, within reptiles, research focused on the order Squamata is underrepresented, as is also the case with those of Lacertilia among this order.

Comentario [NN2]: Your research species reflects significant adaptations t may not be being considered for study... behavioral, physiological...

In general, the sprawl of cities is considered a threat to reptiles worldwide (Cox et al. 2022), due to the loss of habitat for feeding, breeding and shelter, the urban pollution, the increasing number of paved roads and the impact of domestic animals such as dogs and cats

(White and Burgin 2004; Croteau et al. 2008; Perry et al. 2008; Cordier et al. 2021). However, reptiles show different responses to urbanization, related both to the life-history of each species, their dispersal strategies, the habitat and key resources availability and the connectivity between suitable patches (Garden et al. 2007; Hamer and Mcdonnell 2010), and sometimes can prosper in these human-dominated environments (Ackley et al. 2015; Davis and Doherty 2015; Entiauspe-Neto et al. 2016). As an example, Turak et al. (2020) explored the presence of reptiles related to freshwater ecosystems within 50 km of cities at global level, using records from online databases like GBIF, and revealed how several species (specially turtles and crocodilians) are sighted in or near many cities with more than 100,000 inhabitants.

Comentario [NN3]: I would emphas these references more in the discussion your results.

As an increasing majority of humans will reside in cities in coming years (70% of the human population is expected to live in cities by 2050; United Nations 2018), scientists, conservationists, and politicians highlight that a better understanding of the patterns that explain the biodiversity of cities and recognizing the value of their conservation is a key challenge for the next decades (Dearborn and Kark 2010; Shwartz et al. 2014; Threlfall et al. 2015). In this sense, citizen science offers new opportunities for researchers, being a cost-effective method for collecting valuable ecological data through public participation (Cooper et al. 2007). As many people live in urban areas, projects involving citizen science can have special success in cities, helping to monitor populations and detect new species (McCaffrey 2005; Anton et al. 2018; Roger and Motion 2022). For example, the increasing popularity and data validation of online platforms like eBird and iNaturalist (Sullivan et al. 2014; Beninde et al. 2023) provide millions of digital observations submitted by global users, most of them in cities (Kelling et al. 2015). Here we explore the presence of the Asian water monitor

(*Varanus salvator)* in cities along its natural distribution, including the Indian subcontinent and Southeast Asia. For our purpose, we first review the scientific literature available for this species, gathering information about how many studies are conducted in cities in proportion to other habitats and the topic studied in the articles analyzed. Moreover, we use citizen science data obtained from the Global Biodiversity Information Facility (GBIF) focusing on the urban areas where most of the records of Asian water monitors are concentrated, their location in a city border-center gradient, and the urban spaces they preferentially exploit.

Comentario [NN4]: To give a bit mo recognition to the effort of achieving th goals, I consider that adding an objectiv that highlights the benefits of sharing th results would be beneficial.
For example: focusing studies on unexplored areas, conservation management, raising awareness about sampling issues, or other relevant topics and proposing public awareness campai in urban areas upon observing that thes lizards are more densely distributed in these zones.

Comentario [NN5]: This would go under methodology.

Material and methods

Study species and area

Comentario [NN6]: Could you provi more information about the species' ecology... annual activity, sexual dimorphism?... behavior

The Asian water monitor (*Varanus salvator*, Laurenti 1768) is a reptile of the order Squamata that belongs to the family Varanidae (Auliya 2006, IUCN 2021). This species is among the biggest lizards in the world, reaching almost 3 meters from head to tail. It is also one of the most widely distributed varanids, ranging from Sri Lanka to the west, to the Celebes Islands (Indonesia) to the east and South China to the north, occurring in general in all of Southeast Asia (Gaulke and Horn 2004, Bennett et al. 2010, Quah et al. 2021). This species has been intensively harvested for the skin industry (Shine et al. 1996; Traeholt 1998; Khadiejah et al. 2019), the traditional medicine (Mardiastuti et al. 2021) and also for its consumption as food (Arida et al. 2021). They are able to thrive in both terrestrial and aquatic environments (Zhao et al. 1999; Gaulke and Horn 2004, Weijola 2010, Weijola et al. 2010, Bennett et al. 2010), including highly human-altered landscapes such as farmlands and cities (Cota et al. 2009). They have a very flexible diet, that includes invertebrates, eggs, fish and even carrion (Leong ad Lim 2003, Somaweera and Somaweera 2009, Bennett et al. 2010, Grismer 2011).

Review

To review the scientific literature available about the Asian water monitor we followed the guidelines proposed by Haddaway et al. (2015). First, we studied peer-reviewed articles published in journals available on Scopus and Web of Science databases. The search was applied to the title, including any dates. We also included an additional non-systematic search using Google Scholar (Gehanno et al. 2013; Piasecki et al. 2018). We used the "snowball" procedure, including those articles related to our topic found in the selected and analyzed references (Lozano et al. 2019). First, we considered the inclusion of the so-called grey literature, considering the additional contribution of technical reports and other sources beyond scientific articles for our aims (Haddaway and Bayliss 2015). We only considered articles written in English, and we discarded those articles without an online version and also those where the link provided and parallel searches did not lead to the referred article. The review was conducted using a search with the term "*Varanus salvator"* AND "urban environment", but previously we used other potential combinations that did not yield adequate results for the objective of the work (i.e.: papers non related to Varanus lizards, papers in urban ecosystems but focused on human well-being and other aspects related to urban life of humans, etc). Regarding the topic in the studies we reviewed, in our final list we discarded those studies based on reviews and theoretical/conceptual papers without their own data and analyses. Lastly, to avoid the heterogeneity of inclusion criteria inherent to different observers, only one of the authors carried out the search and the subsequent exploration of the articles.

We revised the content of the retained articles by a two-step process. First, we screened titles and abstracts of the first 200 articles obtained in our search, ordered by relevance and without limiting to any date. We do not consider as urban those articles conducted in human modified landscapes such as agricultural areas but not considered properly urban. Similarly, articles focused on the use of *Varanus salvator* in laboratory conditions for medical research were discarded. Secondly, we read the main text of the articles to gather basic information to separate the studies conducted in urban environments, and to obtain information regarding the year of publication, the topic addressed and the country in which the study was conducted. Regarding the topics, we considered that an article is focused on 'behavior' when, for example, it describes aspects of its reproductive, hunting or agonistic behavior, 'diet' when the study describes items the Asian water monitors consume, 'physiology' when it deals with thermal physiology, hormones or some other aspect related to physiology, 'distribution' when it explores how they are distributed in different regions or ecosystems within their native area, 'habitat selection' when the article focuses on how the species occurs or is absent in a given habitat or microhabitat, 'parasitology' when it offers information on ecto- and/or endoparasites found in the species, and 'conservation' when it analyzes concerns and threats related to the Asian water monitor. A given article can be included in more than one category, if it focuses on more than one aspect according to our classification.

GBIF data collection and analyses

We acquired occurrence data of Asian water monitors from the Global Biodiversity Information Facility (GBIF) (www.gbif.org), one of the largest sources of open data, that includes information from different citizen science online platforms, hence being of great

Comentario [NN7]: Referring to wh is considered urban, I would define it as city, which is a space/landscape modifie by humans.

Comentario [NN8]: It would have b important to consider this aspect, as the collection points are likely located there

Comentario [NN9]: This type of information is also crucial for the resear aiming to verify their presence in urban areas and their interaction with humans These studies would provide significant insights in this context, contributing to future proposals and strengthening topi such as conservation.

Comentario [NN10]: It is important justify why only those specific themes w focused on.

Comentario [NN11]: Are there any other topics to consider?

Comentario [NN12]: Since there ha been a significant effort in searching for bibliographic references, it would be optimal to organize the number of work by defined categories, authors/year, in a table. This would provide a more structured way to present your data and would be very helpful for the reader.

interest to ecologists working on the spatial distribution of species (Telenius 2011; Beck et al. 2014; Ivanova and Shashkov 2021). GBIF data can be used for different purposes, e.g., the construction of ecological niche models or to assess the conservation status of a species. As a first step, we downloaded 4584 occurrences (Gbif.org, 27 November 2022). We then filtered by year (>2010) and verified veracity of data one by one by spatial confirmation using QGIS (v. 3.16) (i.e. avoiding those records that for any reason appeared on the sea instead of on terrestrial ecosystems), but also by checking the linked image (we only considered data with pictures) from iNaturalist (GBIF uses observations from iNaturalist as well) associated with each occurrence, discarding, when necessary, any doubtful data, for example when the individual in the image is in captivity or when the record was not correctly identified and could refer to other Varanus species. We only kept data within urbanized areas from all the distribution range of the species.

As a second step, for subsequent analysis we selected the top 5 cities (Singapore, Bangkok, Colombo, Jakarta, Kuala Lumpur) with more occurrences, obtaining a final sample size of 2299 data. For those cities, we delimited urban areas as raster cells with a value higher than 20 for Human Footprint (HFP) index (Venter et al. 2018), as a clear boundary could be detected between less anthropized environments surrounding the city and the urban limits at this threshold. We chose this layer because of its common usage and its great potential to indicate human influence, quantifying the impacts of human disturbance on a global scale. Since observations can have spatial biases with proven consequences on species distribution modelling and spatial analysis (Hortal et al. 2008), we sought to reduce them by calculating the ratio of observation, therefore, avoiding working with occurrence abundance. In order to gather enough information about sampling efforts, this ratio used all squamate occurrences available from 2010-2023 (Gbif.org, 11 December 2023), including *V. salvator*, as a proxy, and the observations were divided by the number of different observers (Squamate observations/Nº Observers) per pixel (≈ 1km^2). By doing this, we obtained an estimation of how the sampling effort is distributed along our cities in order to support if the accumulation of water monitor observations could correspond to real abundance. Afterwards, we calculated the distance of those pixels with at least one *V. salvator* observation to the urban border defined by the HFP, which allowed us to explore possible patterns of distribution inside cities.

Comentario [Viviana_J13]: Refere e?

Additionally, we analyzed where these observations occur within the urban matrix, and we also checked whether we could determine patterns that reveal greater sampling efforts, and therefore, higher *V. salvator* presence, in urban green areas (parks and big gardens) in comparison to other urban environments such as neighborhoods, small gardens, natural and artificial streams, etcetera. For this, we determined as "Park" those areas with a Vegetation Continuous Field (vcf) value higher than 7, as in the previous case, it seemed to be a natural break to distinguish urban from green areas. This last raster layer is global representation of surface vegetation cover (DiMiceli et al. 2015) and was generated using Google Earth Engine derived from a 250m resolution from MODIS. In both cases, hfp and vcf, there was a pixel size of 0.00833° (~1 km^2 at the equator).

Results

Review

Our search was conducted on 8th April 2021. We retained 148 scientific articles after the steps applied to discard or include them. Most of the articles (96) were found in Scopus, Web of Science or in both sources. Moreover, we added 49 scientific articles found in Google Scholar and 3 articles detected by snowball. Although we initially considered grey literature, we did not find technical reports, conferences and similar publications, so we only included scientific articles. Most of the articles (117) were published after the 2000s, and only 31 articles before. There are 13 countries represented in those studies (Bangladesh, China, India, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Sri Lanka, Thailand, Timor-Leste, Vietnam), that in most cases are focused on the anatomy, behavior, conservation status, diet and distribution of the Asian water monitors. However, in 46 cases the country was not described, or the study was conducted in laboratory conditions, not with the species in its habitat. Considering the total of studies reviewed, only 17 articles focus in urban habitats. We found that the studies of urban Asian water monitors started around the 2000s, and between 0-2 papers focused on urban populations of this species are published yearly to date. Moreover, we detect that all the studies analyzed in urban habitats are conducted in 3 countries: 12 in Thailand, 3 in Sri Lanka and 2 in Indonesia (Figure 1A). The predominant topics of those studies were the behavior of these reptiles in cities, their diet, and to a lesser extent the distribution of the species, while studies focused on

Comentario [NN14]: I propose presenting a table highlighting the countries most represented, the type/number of jobs found (physiology, behavior...), and the citations. This woul be a quick reference search that could benefit the reader!

Comentario [NN15]: This sentence very similar to the highlighted sentence above. Unify it.

physiological aspects, parasitology, habitat selection and the conservation of the species are only represented with 1 species (Figure 1B).

Comentario [NN16]: What species would it be?

Urban occurrence using GBIF data

Initially we downloaded 4584 observations about the occurrence of Asian water monitors along its distribution range, of which 2299 were present in urban environments (Figure 2A). We show how the species occur in Asian urbanized areas from Sri Lanka in the west to East Indonesia, with most records concentrated in cities of Thailand, Sri Lanka, Singapore, peninsular Malaysia, Java and Sumatra (Figure 2A). Using this source, we did not find data from Vietnam, Laos, Cambodia, Timor Leste, Philippines and China. It should be noted that we only have access to presence-only data, from which we can extract information about where the animals are, but not where they are not. Therefore, there could be cities from other countries where the species is present but not reported to these platforms. Looking more closely to our data, we detect the five cities with the most records: Colombo (n=36), Kuala Lumpur (n=99), Jakarta (n=42), Bangkok (n=481), Singapore (n=1641) (Figure 2B)

Comentario [NN17]: They could discuss why scientific jobs are not found these countries.

Comentario [NN18]: Are there any updates on the species' distribution area

Comentario [NN19]: According to t distribution area described for the species... based on the data obtained in this study, could it expand its distributio area?

or Colombo, and Jakarta, we observe that sampling effort (i.e., more observations per observer) tends to accumulate near the city center (Figure 3). Singapore, Kuala Lumpur and a to lesser extent Bangkok, show a balanced distribution of sampling effort with a slight increase towards the centered areas mainly for the first two. Bangkok, however, shows a maximum observation ratio at a distance of 6,25 km from the border.

These observation spots ($1km^2$ pixels with at least one *V. salvator* observation) are not equally distributed either (Figure 3). Mainly for Colombo and Jakarta we see gaps on the distribution of black dots along the distance to border axis, which indicates uneven observation patterns or incomplete sampling within the city. Bangkok, Kuala Lumpur and Singapore show a more constant representation of observations along the border to city-center gradient

We also studied the distribution of records within the urban matrix and how this sampling effort is distributed among habitat types. Colombo, Jakarta and Bangkok experience at least some degree of net positive increase in the intensity of sampling when increasing VCF (Figure 4). Particularly, Jakarta experiences a high point at around a value of 7,25, near the stablished threshold for being considered as park (VCF > 7). Kuala Lumpur reaches its peak around a value of 12,25 for VCF. After that, the effort decreases. Singapore, however, again shows a homogenous pattern of sampling effort when it comes to different types of habitats.

Within a city, not all parks or green areas hold a continuum of values for VCF. As parks are discrete patches imbricated in the urban matrix, we could expect that only certain values of VCF would be available for *V. salvator* observation. Moreover, we could even find this pattern if we have incomplete sampling of sightings for all the actual possible values of VCF within a certain city. However, in our data we find few gaps between dots, which reflects a good distribution of samplings for the VCF variable. Colombo, Jakarta and Kuala Lumpur present some of these gaps, while in Singapore and Bangkok, the dots seem to be better distributed.

Comentario [NN20]: This should go discussion.

As a general picture, we can observe that spotting areas occur mainly in green urbanized environments: in Colombo (87.5%), Jakarta (77.4%), Kuala Lumpur (53.1%) and Singapore (76%) a great percentage of the spotting areas occur in to these defined park areas. Only in Bangkong, (26.9%) we observe a greater number of observations out of parks.

Finally, by observing the VCF range, we can infer information about the park infrastructure within each city. Bangkok has the lowest minimum VCF value of all the cities (= 0.0). Singapore is the second one (= 3.4) followed by Kuala Lumpur (= 3.6), Jakarta (= 4.5) and Colombo (= 6). On the other hand, the maximum VCF values are achieved by Singapore (= 61.5), Kuala Lumpur (= 49.6), Bangkok (= 21.6), Colombo (= 18) and Jakarta (= 14.7). For those maximum and minimum values, we have seen at least one observation, which does not imply that these boundaries could not be further expanded if new observations were done outside this range. However, it provides us with information about the possibilities within each city so far.

Discussion

Review

Our results confirm the apparent lack of scientific literature on the colonization and ecology of Asian water monitors in urban environments, with only 17 of the 149 articles reviewed conducted in urban environments, and few cities of 3 countries (Indonesia, Sri Lanka and Thailand) represented in those studies. Most of the articles reviewed that explore urban Asian water monitors consist of short notes and reports of field observations mostly about behavior, diet and the distribution of the species in this habitat. Further, those records confirm the generalist feeding habits of the species, which in cities consumes diverse birds, mammals, fish, amphibians and reptiles (Bundhitwongrut et al. 2008; Karunarathna et al. 2008; Stanner 2010; Cota and Sommerlad 2013; Mahaprom and Kulabtong 2018), but also exploit carrion and are attracted to human waste (Kulabtong and Mahaprom 2015; Lawton et al. 2018). Regarding behavior, the studies reviewed describe the mating of the species, the intraspecific relations in different seasons, the use of underwater burrows, its daily activity patterns, with both diurnal and nocturnal habits, and how the Asian water monitors preferentially use aquatic habitats, especially the hatchlings and juveniles (Rathnayake et al. 2003; Cota 2011a; Cota 2011b; Karunarathna et al. 2017). In this sense, the urban environment facilitates observations of basic ecological and behavioral aspects that could be more difficult to observe in other contexts, either due to the structural complexity of other habitats or due to the more elusive behavior of non-urban individuals. However, we regret the lack of more in-depth articles, with a larger sample size, comparisons in a greater geographical range and studies that present their hypotheses within the theoretical framework of urban ecology.

Comentario [NN21]: Based on the search and reading of information, coul you speculate why, despite the feasibilit of observing this species in urban areas, there are few studies conducted?

Urban colonization

By using the data obtained through GBIF we gathered relevant information about the extended occurrence of the Asian water monitor in cities along its native distribution range. The presence of the species in such distant cities, crossed by aquatic systems of different watersheds, suggests that independent and parallel colonization is the most plausible option. Although not included in our study because there is no data in GBIF, we have personal observations of *Varanus salvator* in some cities, as Siem Reap, Cambodia. This absence of occurrences in certain areas might reflect different factors, such as cultural, levels of tourism, population density, lack of devices like smartphones to take pictures or even the legislation of the country itself that prevents their citizens from sharing data with the rest of the world. It should be highlighted that citizen science is frequently subjected to representation biases that can affect spatial analysis or species modelling (Kadmon et al. 2004, Franklin 2010, Boria et al. 2014), in such a way that observations accumulate near accessible paths, roads or in urban areas. In that sense, we realized that most of our observations are concentrated towards the city center in populated cities with high levels of tourism, and also cities with big parks used by both local people and tourists.

Comentario [NN22]: It is worth not that it is novel and surprising that there few studies on this species, which is so easily observable.

The distribution of Asian water monitors within the urban matrix varied among cities. This is a common pattern in studies focused on urban wildlife, with population and species relationships with urbanization varying due to underlying reasons such as the urban landscape, the presence of corridors, the dimensions and spatial arrangement of habitat patches (Ortega-Álvarez and -MacGregor-Fors 2009; Fontana et al. 2011), but also due to the life history and behavior of each species (Ditchkoff et al. 2006; Jokimäki et al. 2011).

In this study we employed overall squamate observation as a proxy to understand what areas within the cities had greater sampling efforts. This approach provided an estimation of the observation patterns in these five cities and allowed us to evaluate by extrapolating to the V. salvator observations if those could be attributed to real occurrence abundance. Many observations made by different observers can belong to the same individuals that usually frequent the same locations. Therefore, it is relevant to design a way to weight our occurrences by better understood sampling patterns, such as those for bigger groups like scaled reptiles, and acknowledge that uneven distributions of sampling effort do exist in this kind of approaches. We chose squamates as they account for many records within our study areas and as a group have proximate ecological and behavioral habits to our study species. We acknowledge that observation patters could differ between the different types of squamates and water monitors. However, water monitor observations are not abundant enough to calculate an observation ratio of its own and relatedness of the squamates make it a suitable group to know the distribution of sampling effort along the cities.

In our case, in Singapore we saw slight increase in sampling effort when approaching the city center, but most of the occurrences are recorded at parks and gardens. In Colombo the urban matrix is imbricated with green avenues, parks and gardens. Therefore, the Asian water monitor appears in many parts of the city homogenously, explaining its ability to reach particularly central parts of the city. A similar situation is observed in Jakarta, with higher distribution of observation ratio relying on the city center, and many of these observations occurring in gardens and water courses throughout the city. Bangkok demonstrates a similar pattern, with a smooth increase in the observation ratio as one approaches the city center and a tip around 6,25 km away from the border, and most of the records concentrated in small urban parks. In this case, the monitor lizards seem to be using the water canal system and even the sewage system to move within the city, disperse and connect parks and the outside of the city. Lastly, in Kuala Lumpur, where the city core is densely occupied by human-made buildings, the observation ratio tends to be similar even along the border-center gradient with a little increase in these core areas. Also, in this case, the ratio of observation in green areas is similar to that in the urban matrix. It should be noted that at a higher pixel resolution, we could better characterize this species' use of urban space. Nonetheless, the results illustrate sufficiently well how this species is colonizing urban environments and how the design of the city, in terms of urban planning (i.e. presence of parks, gardens, distance to water ecosystems, etc.), can affect the spatial distribution of their urban populations.

In conclusion, the present study shows how despite being the second largest living lizard in the world and the biggest lizard with permanent populations in cities, the colonization of the Asian water monitor in many big cities of Asia has remained out of focus for ecologists. We show how in urban environments the Asian water monitor occurs in the urban matrix and big parks within the city, including those far from the city border, but in some cases also parks close to the sea, probably using water ecosystems to connect between urban areas and also with environments less influenced by the city. Further research is needed to disentangle the ecological aspects related to the urban life of the Asian water monitor along its distribution range. Specifically, the dispersal patterns and movements across the urban matrix could help

Comentario [NN23]: It is worth not that it is novel and surprising that there few studies on this species, which is so easily observable.

to explain both the colonization and the urban space usage of the species. Moreover, a deeper explanation and comparison of their demographical parameters, the ecosystem services they provide as predators and scavengers (Karunarathna et al. 2017; Luna et al. 2021), as well as the health status of urban individuals in comparison with their counterparts inhabiting less humanized areas could be relevant for the management of the urban populations, even more to consider the exploitation that the species suffer in less urbanized areas. Lastly, the relationship with tourists and citizens should be better assessed through social perception surveys, a key aspect to study in urban areas (Botzat et al. 2016; Ribeiro et al. 2021). This is especially relevant in the case of the Asian water monitor, as they represent one of the most extreme cases of human-wildlife coexistence in urbanized areas (Ceríaco 2012; Pradhan and Yonle 2022).

Acknowledgments

We acknowledge all the users of platforms as iNaturalist, whose contribution is offering a valuable source of global scientific information with growing scientific value. We also thank Jorge Juan Rueda for his contributions in the first steps of the project. Finally, we acknowledge Guillermo Fandos, Julio Rabadán and Pedro Romero Vidal for their useful opinions that helped us to improve the final version of this work, and also Nicholas West who contributed to improve the readability of the study.

Statements & Declarations

Funding. No funding.

Competing interests. The authors have declared that no competing interests exist.

References

1. Ackley, J. W., Wu, J., Angilletta Jr, M. J., Myint, S. W., & Sullivan, B. (2015). Rich lizards: how affluence and land cover influence the diversity and abundance of desert reptiles persisting in an urban landscape. Biological Conservation, 182, 87-92.
2. Anton, V., Hartley, S., Geldenhuis, A., & Wittmer, H. U. (2018). Monitoring the mammalian fauna of urban areas using remote cameras and citizen science. Journal of Urban Ecology, 4(1), juy002.
3. Arida, E. A., Boscha, E., Fauzi, M. A., Ardiantoro, A., & Maireda, N. L. (2021). Beliefs in the dietary benefits of water monitor, Varanus salvator meat in Western Java, Indonesia. Journal of Tropical Ethnobiology, 4(1), 21-32.
4. Auliya, M. 2006. Taxonomy, Life History and Conservation of Giant Reptiles in West Kalimantan (Indonesian Borneo). ntv-Verlag, Münster.
5. Beck, J., Böller, M., Erhardt, A., & Schwanghart, W. (2014). Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. Ecological Informatics, 19, 10-15.
6. Beninde, J., Delaney, T. W., Gonzalez, G., & Shaffer, H. B. (2023). Harnessing iNaturalist to quantify hotspots of urban biodiversity: the Los Angeles case study. Frontiers in Ecology and Evolution, 11, 983371.

7. Bennett, D., Gaulke, M., Pianka, E.R., Somaweera, R. and Sweet, S.S. 2010. Varanus salvator. The IUCN Red List of Threatened Species 2010: e.T178214A7499172.

8. Boria, R. A., Olson, L. E., Goodman, S. M., & Anderson, R. P. (2014). Spatial filtering to reduce sampling bias can improve the performance of ecological niche models. Ecological modelling, 275, 73-77.

9. Botzat, A., Fischer, L. K., & Kowarik, I. (2016). Unexploited opportunities in understanding liveable and biodiverse cities. A review on urban biodiversity perception and valuation. Global environmental change, 39, 220-233.

10. Brum, P. H. R., Gonçalves, S. R. A., Strüssmann, C., & Teixido, A. L. (2023). A global assessment of research on urban ecology of reptiles: patterns, gaps and future directions. Animal Conservation, 26(1), 1-13.

11. Bundhitwongrut, T., Saguensab, S., ThiraNhupt, K., & Pauwels, O. S. G. (2008). A case of predation of the water monitor Varanus salvator on the western snail-eating turtle Malayemys macrocephala (Reptilia: Varanidae & Bataguridae) in Bangkok. Biawak, 2(3), 106-108.

12. Ceríaco, L. M. (2012). Human attitudes towards herpetofauna: The influence of folklore and negative values on the conservation of amphibians and reptiles in Portugal. Journal of Ethnobiology and Ethnomedicine, 8(1), 1-13.

13. Cordier, J. M., Aguilar, R., Lescano, J. N., Leynaud, G. C., Bonino, A., Miloch, D., ... & Nori, J. (2021). A global assessment of amphibian and reptile responses to land-use changes. Biological conservation, 253, 108863.

14. Cooper, C. B., Dickinson, J., Phillips, T., & Bonney, R. (2007). Citizen science as a tool for conservation in residential ecosystems. Ecology and society, 12(2).

15. Cota, M, Chan-Ard, T. and Makchai, S. 2009. Geographical Distribution and Regional Variation of *Varanus salvator macromaculatus* in Thailand. Biawak 3(4): 134-143.

16. Cota, M (2011a). Mating and intraspecific behavior of Varanus salvator macromaculatus in an urban population. Biawak, 5(1/2), 17-23.

17. Cota, M. (2011b). Burrows with submerged and waterfilled entrances and nocturnal retirement of Varanus salvator macromaculatus in Thailand. *Biawak*, *5*(3), 44-47.

18. Cota, M., & Sommerlad, R (2013). Notes and observations on the fish prey of Varanus salvator macromaculatus (Reptilia: Squamata: Varanidae) in Thailand with a review of the fish prey of the Varanus salvator complex known to date. Biawak, 7(2), 63-70.

19. Cox, N., Young, B. E., Bowles, P., Fernandez, M., Marin, J., Rapacciuolo, G., ... & Xie, Y. (2022). A global reptile assessment highlights shared conservation needs of tetrapods. Nature, 605(7909), 285-290.

20. Croteau, M. C., Hogan, N., Gibson, J. C., Lean, D., & Trudeau, V. L. (2008). Toxicological threats to amphibians and reptiles in urban environments. Urban Herpetology, 197-209.

21. Davis, R. A., & Doherty, T. S. (2015). Rapid recovery of an urban remnant reptile community following summer wildfire. PLoS One, 10(5), e0127925.

22. Dearborn, D. C., & Kark, S. (2010). Motivations for conserving urban biodiversity. Conservation biology, 24(2), 432-440.

23. DiMiceli, C., Carroll, M., Sohlberg, R., Kim, D., Kelly, M., Townshend, J. (2015). MOD44B MODIS/Terra Vegetation Continuous Fields Yearly L3 Global 250m SIN Grid V006 [Data set]. NASA EOSDIS Land Processes DAAC. Accessed 2023-06-08 from https://doi.org/10.5067/MODIS/MOD44B.006.

~~23.~~

24. Ditchkoff, S. S., Saalfeld, S. T., & Gibson, C. J. (2006). Animal behavior in urban ecosystems: modifications due to human-induced stress. Urban ecosystems, 9, 5-12.

25. Entiauspe-Neto, O., Perleberg, T., & de Freitas, M. A. (2016). Herpetofauna from an urban Pampa fragment in southern Brazil: composition, structure and conservation. Check List, 12(5), 1-15.

26. Fontana, S., Sattler, T., Bontadina, F., & Moretti, M. (2011). How to manage the urban green to improve bird diversity and community structure. Landscape and Urban Planning, 101(3), 278-285.

Con formato: Color de fuente: Colo personalizado(RGB(34;34;34))

Con formato: Sangría: Izquierda: 1,38 cm, Sin viñetas ni numeración

27. Franklin, J. (2010). Mapping species distributions: spatial inference and prediction. Cambridge University Press.

28. Garden, J. G., Mcalpine, C. A., Possingham, H. P., & Jones, D. N. (2007). Habitat structure is more important than vegetation composition for local-level management of native terrestrial reptile and small mammal species living in urban remnants: A case study from Brisbane, Australia. Austral ecology, 32(6), 669-685.

~~29.~~ Gehanno, J. F., Rollin, L., & Darmoni, S. (2013). Is the coverage of Google Scholar enough to be used alone for systematic reviews. BMC medical informatics and decision making, 13(1), 1-5.

29. Gaulke, M. and Horn, H.-G. 2004. Varanus salvator (Nominate Form). In: Pianka, E.R. and King, D.R. (eds), Varanoid lizards of the world, pp. 244-257. Indiana University Press, Bloomington, USA.

30. GBIF.org (27 November 2022) GBIF Occurrence Download https://doi.org/10.15468/dl.sg6x5g

~~30.~~

31. GBIF.org (11 December 2023) GBIF Occurrence Download https://doi.org/10.15468/dl.78mgfn

Con formato: Izquierda, Sangría: Izquierda: 1,27 cm, Espacio Despué 0 pto, Interlineado: sencillo, Sin viñetas ni numeración

Con formato: Sin subrayado

Con formato: Espacio Después: 8 pto, Numerado + Nivel: 1 + Estilo de numeración: 1, 2, 3, … + Iniciar en: + Alineación: Izquierda + Alineación 0,75 cm + Sangría: 1,38 cm

Con formato: Numerado + Nivel: 1 Estilo de numeración: 1, 2, 3, … + Iniciar en: 1 + Alineación: Izquierda Alineación: 0,75 cm + Sangría: 1,38 cm

Con formato: Sin subrayado, Color fuente: Color personalizado(RGB(34;34;34))

Con formato: Color de fuente: Colo personalizado(RGB(34;34;34))

Con formato: Izquierda, Sangría: Izquierda: 1,27 cm, Espacio Despué 0 pto, Interlineado: sencillo, Sin viñetas ni numeración

Con formato: Sangría: Izquierda: 1,38 cm, Sin viñetas ni numeración

32. Grismer, L.L. 2011. Lizards of Peninsular Malaysia, Singapore and their adjacent archipelagos. Edition Chimaira, Frankfurt.

33. Haddaway, N. R., & Bayliss, H. R. (2015). Shades of grey: two forms of grey literature important for reviews in conservation. Biological Conservation, 191, 827-829.

34. Haddaway, N. R., Woodcock, P., Macura, B., & Collins, A. (2015). Making literature reviews more reliable through application of lessons from systematic reviews. Conservation Biology, 29(6), 1596-1605.

35. Hamer, A. J., & Mcdonnell, M. J. (2010). The response of herpetofauna to urbanization: inferring patterns of persistence from wildlife databases. Austral Ecology, 35(5), 568-580.

36. Ivanova, N. V., & Shashkov, M. P. (2021). The possibilities of GBIF data use in ecological research. Russian Journal of Ecology, 52, 1-8.

37. Johnson, M. T., & Munshi-South, J. (2017). Evolution of life in urban environments. Science, 358(6363), eaam8327.

38. Jokimäki, J., Kaisanlahti-Jokimäki, M. L., Suhonen, J., Clergeau, P., Pautasso, M., & Fernández-Juricic, E. (2011). Merging wildlife community ecology with animal behavioral ecology for a better urban landscape planning. Landscape and Urban Planning, 100(4), 383-385.

39. Kadmon, R., Farber, O., & Danin, A. (2004). Effect of roadside bias on the accuracy of predictive maps produced by bioclimatic models. Ecological Applications, 14(2), 401-413.

40. Karunarathna, D. M. S. S., Amarasinghe, A. T., & De Vos, A. S. H. A. (2008). preliminary notes on the Monitor lizards (Family: Varanidae) within the national Zoological Gardens (nZG) dehiwala, Colombo district, sri lanka. Biawak, 2(3), 109-118.

41. Karunarathna, S., Surasinghe, T., Madawala, M., Somaweera, R., & Amarasinghe, A. T. (2017). Ecological and behavioural traits of the Sri Lankan water monitor (Varanus salvator) in an urban landscape of Western Province, Sri Lanka. Marine and Freshwater Research, 68(12), 2242-2252.

42. Kelling, S., Fink, D., La Sorte, F. A., Johnston, A., Bruns, N. E., & Hochachka, W. M. (2015). Taking a 'Big Data'approach to data quality in a citizen science project. Ambio, 44, 601-611.

43. Khadiejah, S., Razak, N., Ward-Fear, G., Shine, R., & Natusch, D. J. (2019). Asian water monitors (Varanus salvator) remain common in Peninsular Malaysia, despite intense harvesting. Wildlife Research, 46(3), 265-275.

44. Kulabtong, S., & Mahaprom, R. (2015). Observation on food items of Asian water monitor, Varanus salvator (Laurenti, 1768)(Squamata Varanidae), in urban eco-system, Central Thailand. Biodiversity Journal, 6(3), 695-698.

45. Lawton, D., Parlindungan, D., Pratama, A., Aswin, P., Jundara, P., Darmawan, R., ... & Matthews, C. E. (2008). Living among Water monitors: an exploratory study of an urban Water monitor (Varanus salvator) population in Bengkulu, Indonesia. Biawak, 12(1), 42-47.

46. Leong, T.M. and Lim, K.K.P. 2003. Herpetofaunal records from Fraser's Hill, Peninsular Malaysia with larval descriptions of Limnonectes nitidus and Thelmoderma asperum (Amphibia: Ranidae and Rhacophoridae). The Raffles Bulletin of Zoology: 123-136.

47. Lozano, J., Olszańska, A., Morales-Reyes, Z., Castro, A. A., Malo, A. F., Moleón, M., ... & Martín-López, B. (2019). Human-carnivore relations: a systematic review. Biological Conservation, 237, 480-492.

48. Luna, A., Romero-Vidal, P., Hiraldo, F., & Tella, J. L. (2018). Cities may save some threatened species but not their ecological functions. PeerJ, 6, e4908.

49. Luna, Á., Romero-Vidal, P., & Arrondo, E. (2021). Predation and scavenging in the city: A review of spatio-temporal trends in research. Diversity, 13(2), 46.

50. Magle, S. B., Hunt, V. M., Vernon, M., & Crooks, K. R. (2012). Urban wildlife research: past, present, and future. Biological conservation, 155, 23-32.

51. Mahaprom, R., & Kulabtong, S. (2018). Observation of feeding habit of the Asian water monitor, Varanus salvator (Laurenti, 1768)(Squamata Varanidae)

on a Asian toad, Duttaphrynus melanostictus (Schneider, 1799)(Anura Bufonidae) in Thailand. Biodiv. Jour, 9(3), 213-216.

52. McCaffrey, R. E. (2005). Using citizen science in urban bird studies. Urban habitats, 3(1), 70-86.

53. Mardiastuti, A., Masy'ud, B., Ginoga, l. N., Sastranegara, H., & Sutopo, S. (2021). Wildlife species used as traditional medicine by local people in Indonesia. Biodiversitas Journal of Biological Diversity, 22(1).

54. Nijman, V. (2015). Water monitor lizards for sale as novelty food in Java, Indonesia. Biawak, 9(1), 28-32.

55. Ortega-Álvarez, R., & MacGregor-Fors, I. (2009). Living in the big city: Effects of urban land-use on bird community structure, diversity, and composition. Landscape and urban planning, 90(3-4), 189-195.

56. Perry, G., Buchanan, B. W., Fisher, R. N., Salmon, M., & Wise, S. E. (2008). Effects of artificial night lighting on amphibians and reptiles in urban environments. Urban herpetology, 3, 239-256.

57. Piasecki, J., Waligora, M., & Dranseika, V. (2018). Google search as an additional source in systematic reviews. Science and engineering ethics, 24, 809-810.

58. Pradhan, A., & Yonle, R. (2022). Socio-ecological assessment of squamate reptiles in a human-modified ecosystem of Darjeeling, Eastern Himalaya. Human Dimensions of Wildlife, 27(2), 134-150.

59. Rathnayake, N. D., Herath, N. D., Hewamathes, K. K., & Jayalath, S. (2003). The thermal behaviour, diurnal activity pattern and body temperature of Varanus salvator in Central Sri Lanka. HAMADRYAD-MADRAS-, 27, 179-184.

60. Rega-Brodsky, C. C., Aronson, M. F., Piana, M. R., Carpenter, E. S., Hahs, A. K., Herrera-Montes, A., ... & Nilon, C. H. (2022). Urban biodiversity: State of the science and future directions. Urban Ecosystems, 25(4), 1083-1096.

61. Ribeiro, J., Carneiro, I., Nuno, A., Porto, M., Edelaar, P., Luna, Á., & Reino, L. (2021). Investigating people's perceptions of alien parakeets in urban environments. European Journal of Wildlife Research, 67, 1-9.

62. Roger, E., & Motion, A. (2022). Citizen science in cities: an overview of projects focused on urban Australia. Urban Ecosystems, 25(3), 741-752.

63. Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences*, *109*(40), 16083-16088.

64. Shine, R., Harlow, P. S., & Keogh, J. S. (1996). Commercial harvesting of giant lizards: the biology of water monitors Varanus salvator in southern Sumatra. Biological Conservation, 77(2-3), 125-134.

65. Shochat, E., Warren, P. S., & Faeth, S. H. (2006). Future directions in urban ecology. Trends in Ecology & Evolution, 21(12), 661-662.

66. Shwartz, A., Turbé, A., Julliard, R., Simon, L., & Prévot, A. C. (2014). Outstanding challenges for urban conservation research and action. Global environmental change, 28, 39-49.

67. Sol, D., González-Lagos, C., Moreira, D., Maspons, J., & Lapiedra, O. (2014). Urbanisation tolerance and the loss of avian diversity. *Ecology letters*, *17*(8), 942-950.

68. Somaweera, R. and Somaweera, N. 2009. Lizards of Sri Lanka: A Colour Guide with Field Keys. Edition Chimaira, Frankfurt am Main, Germany.

69. Stanner, M. (2010). Mammal-like feeding behavior of Varanus salvator and its conservational implications. Biawak, 4(4), 128-131.

70. Sullivan, B. L., Aycrigg, J. L., Barry, J. H., Bonney, R. E., Bruns, N., Cooper, C. B., ... & Kelling, S. (2014). The eBird enterprise: An integrated approach to

development and application of citizen science. Biological conservation, 169, 31-40.

71. Quah, E., Lwin, K., Cota, M., Grismer, L., Neang, T., Wogan, G., McGuire, J., Wang, L., Rao,D.-Q.,Auliya, M. & Koch, A. 2021. Varanus salvator. The IUCN Red List of Threatened Species 2021:e.T178214A113138439. https://dx.doi.org/10.2305/IUCN.UK.20212.RLTS.T178214A113138439.en

72. Telenius, A. (2011). Biodiversity information goes public: GBIF at your service. Nordic Journal of Botany, 29(3), 378-381.

73. Threlfall, C. G., Walker, K., Williams, N. S., Hahs, A. K., Mata, L., Stork, N., & Livesley, S. J. (2015). The conservation value of urban green space habitats for Australian native bee communities. Biological Conservation, 187, 240-248.

74. Traeholt, C. (1998). Exploitation and trade of the water monitor lizard (Varanus salvator) in Malaysia. Mertensiella, 9, 131-135.

75. Turak, E., Bush, A., Dela-Cruz, J., & Powell, M. (2020). Freshwater reptile persistence and conservation in cities: Insights from species occurrence records. Water, 12(3), 651.

76. United, Nations. "World Urbanization Prospects: The 2018 Revision." Online Edition (2018).

77. Venter, O., E. W. Sanderson, A. Magrach, J. R. Allan, J. Beher, K. R. Jones, H. P. Possingham, W. F. Laurance, P. Wood, B. M. Fekete, M. A. Levy, and J. E.

Watson. 2018. Last of the Wild Project, Version 3 (LWP-3): 2009 Human Footprint, 2018 Release. Palisades, New York: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H46T0JQ4.

78. Vignoli, L., Mocaer, I., Luiselli, L., & Bologna, M. A. (2009). Can a large metropolis sustain complex herpetofauna communities? An analysis of the suitability of green space fragments in Rome. Animal Conservation, 12(5), 456-466.
79. Weijola, V. S.-Å. 2010. Geographic distribution and habitat use of monitor lizards of the North Moluccas. Biawak 4(1): 7-23.
80. Weijola, V. S.-Å. and Sweet, S.S. 2010. A new melanistic species of monitor lizard (Reptilia: Squamata: Varanidae) from Sanana Island, Indonesia. Zootaxa 2434: 17-32.
81. White, A. W., & Burgin, S. (2004). Current status and future prospects of reptiles and frogs in Sydney's urban-impacted bushland reserves.
82. Woolley, C. K., Hartley, S., Hitchmough, R. A., Innes, J. G., Van Heezik, Y., Wilson, D. J., & Nelson, N. J. (2019). Reviewing the past, present and potential lizard faunas of New Zealand cities. Landscape and Urban Planning, 192, 103647.
83. Zhao, E-M., Zhao, K-T. and Zhou, K-Y. 1999. Fauna Sinica, Reptilia Vol 2, Squamata, Lacertilia. Science Press, Beijing. 481), Singapore (n=1641) (Figure 2B).