UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO

CENTRO DE CIÊNCIAS HUMANAS E NATURAIS

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS BIOLÓGICAS

O que os cidadãos cientistas informam sobre os crocodilianos?

Maryana Tavares de Souza

Vitória, ES

Novembro, 2023

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Dissertação submetida ao Programa de Pós-Graduação em Ciências Biológicas (Biologia Animal) da Universidade Federal do Espírito Santo, como requisito parcial para a obtenção do grau de Mestre em Biologia Animal

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DISSERTAÇÃO DE MESTRADO

O que os cidadãos cientistas informam sobre os crocodilianos?

Maryana Tavares de Souza

ORIENTADOR: Prof. Dr. Rodrigo Barbosa Ferreira

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No dia oito do mês de dezembro de dois mil e vinte e três, às 09h, em sessão pública, através de webconferência, conforme Portaria Normativa nº 08 da Pró-Reitoria de Pesquisa e Pós-Graduação/UFES de 01 de julho de 2021, procedeu-se a avaliação da dissertação da aluna **Maryana Tavares de Souza**. Às nove horas, o Prof. Dr. Rodrigo Barbosa Ferreira - UFES, Orientador e Presidente da Comissão Examinadora de Defesa de Dissertação, deu início aos trabalhos, convidando a compor a banca a Profª Drª Ednilza Santos - UFRPE, Examinadora Externa, e a Profª Drª Melina Simoncini - Conicet/Cicyttp, Examinadora Externa. A seguir, o presidente solicitou à mestranda que fizesse uma explanação de seu trabalho intitulado **"O que os cidadãos cientistas informam sobre os crocodilianos?".** Finda a apresentação, o presidente passou a palavra aos examinadores, que procederam à arguição da candidata. Ao final, a Comissão em sessão reservada deliberou pela **APROVAÇÃO** da referida dissertação nos termos do Regimento Interno do Programa de Pós-Graduação em Ciências Biológicas e alertou que a aprovada somente terá direito ao título de Mestre após entrega da versão final de sua dissertação, em meio digital, à Secretaria do Programa. Encerrada a sessão, eu, Prof. Dr. Rodrigo Barbosa Ferreira, presidente da Comissão Examinadora, lavrei a presente ata que vai assinada digitalmente, por mim e pelos demais componentes da Comissão.

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O que os cidadãos cientistas informam sobre os crocodilianos?

Maryana Tavares de Souza

Dissertação de mestrado em Biologia Animal

Resumo Geral

A ciência cidadã desempenha um papel fundamental na conservação, contribuindo para a coleta abrangente de dados, o monitoramento de populações, o engajamento da comunidade local, a identificação de ameaças e a obtenção de informações de longo prazo. Ela promove a conscientização pública e capacita as pessoas a participarem ativamente na proteção de espécies e de seus habitats. Nesse contexto, este projeto tem como objetivo avaliar o uso do *iNaturalist* como uma ferramenta útil para complementar os dados científicos, favorecendo a pesquisa e os esforços de conservação dos crocodilianos em todo o mundo.

A dissertação foi separada em dois artigos, o artigo 1 tem como título "Citizen science informing about spatial and temporal distribution of crocodilians worldwide", que traz um panorama geral sobre a distribuição espacial e temporal dos crocodilianos em escala global. Os dados finais contemplaram 65.014 observações de 22.753 observadores, representando 27 espécies de crocodilianos de nove gêneros e três famílias. Além de abordar o aumento de observações e do número de usuários da plataforma *iNaturalist* ao longo dos anos, também possui espécies contempladas nas observações que se encontraram em alguma categoria de espécies ameaçadas de extinção.

O artigo 2 tem como título "*Caiman latirostris*: O que sabemos através da ciência cidadã?" Reunimos informações de 853 observações sobre a espécie, que foi registrada por 433 cidadãos cientistas na plataforma *iNaturalist* em 5 países. Tropical e Subtropical Moist Broadleaf Forest (Mata Atlântica) e Tropical e Subtropical grasslands, savannas, and shrublands (Cerrado) foram os biomas que mais tiveram observações. Além disso, analisamos o número de observações ao longo do tempo, o perfil dos usuários do *iNaturalist* quanto ao gênero e observações de animais atropelados e vítimas de caça.

Os resultados apontam que a pesquisa que soma informações de cidadãos cientistas fornece valiosos dados sobre como e onde os crocodilos estão distribuídos ao redor do mundo. Portanto, a utilização da plataforma *iNaturalist* se revela uma ferramenta eficaz para aprimorar os dados científicos, o que por sua vez contribui para o progresso na pesquisa e nos empenhos de conservação de crocodilianos em nível mundial.

Palavras chaves — conservação; conscientização pública; distribuição espacial; crocodilianos; bancos de dados abertos

Herpetological Conservation and Biology

Citizen science informing about spatial and temporal distribution of crocodilians worldwide

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Abstract

The effective conservation of crocodilians needs to be addressed through partnerships such as crocodilian conservation projects, alliances between conservationists and citizen scientists. Citizen science is an effective tool in expanding scientific knowledge because it may engage more people and on a larger scale than scientists can collect data. In the present study, we compiled data of crocodilians recorded by citizen scientists from the *iNaturalist* platform on a global scale. We also evaluated the number of observations of crocodilians across families, genera, and species, their geographic distribution and the number of observations and users of *iNaturalist* over time. Our final dataset had 65,014 observations from 22,753 observers, representing 27 species of crocodilians from nine genera and three families. *Alligator mississippiensis* (41,083 observations; 63%) and *Crocodylus acutus* (6,400 observations; 10%) had the highest number of observations. Regarding conservation status, 11 (41%)

species are threatened to extinction on the IUCN Red List (IUCN, 2023), of which seven (26%) are Critically Endangered (CR) and four (15%) Vulnerable (VU). The final dataset included observations from 100 countries. USA (N = 41,954; 65%) had the highest number of observations and Brazil (N = 6 species; 22%) and Colombia (N = 6 species; 22%) had the highest number of species. The number of observations increased significantly in 2016 (2,479), and reached a mean of 8,843 observations per year until 2022. Due to the Covid-19 pandemia, there was a decrease in the number of observations (8,118) in 2020. It is therefore concluded that the study covering data from citizen scientists provides valuable data regarding the spatial and temporal distribution of crocodilians on a global scale. Therefore, the use of *iNaturalist* is a useful tool to complement scientific data, favoring research and conservation efforts for crocodilians around the world.

Key Words — crocodilian; citizen science; conservation status; crowdsourcing; open databases; public participation

Introduction

Citizen science is a practice that involves scientists and volunteers to generate data on biodiversity and answer scientific questions (Dickinson et al. 2012; Bonn et al. 2016). Studies demonstrate that this data collection can be as effective as collections conducted by specialists, with the added benefit of involving a large number of people committed to generating scientific information (Koffler et al. 2021; Fontaine 2022). Therefore, the lack of knowledge about species distribution (i.e., Wallacean deficit) can be reduced with the application of citizen science (Bini et al. 2006; Whittaker et al. 2011).

Citizen science has been employed in various scientific fields, such as research on inventories, geographic distribution, and population monitoring (Frigerio et al. 2017). Citizen scientists have contributed to the assessment of biological and ecological aspects of various invertebrate and vertebrate species, including birds (Sullivan et al. 2009; Alexandrino et al. 2022), corals (Marshall et al. 2012), sharks (Vianna et al. 2014), bees (Domroese and Johnson 2017; Koffler et al. 2021), anurans (Rowley et al. 2019; Forti et al. 2023), and reptiles (Maharani et al. 2022). With numerous species threatened with extinction, citizen science has immense potential to engage local communities and tourists in collecting data on the distribution and abundance of crocodilians (crocodiles, alligators, and gharials).

Currently, there are 27 species of crocodiles recognized worldwide (Uetz et al. 2022), and 11 of them are classified as threatened to extinction (IUCN 2023). Caiman inhabit only South and Central America, while alligators are found only in the United States and China. Crocodiles, on the other hand, have a broader distribution, being found in the Americas, Africa, Asia, and Oceania. Gharials, meanwhile, live in isolation in India, confined to small and threatened populations (Maddok 2010). The ecological value of these animals has been assessed as indicators of ecosystem health, ecosystem engineers, top predators in food chains, keystone species contributing to energy flow and nutrient cycles in aquatic and terrestrial ecosystems (Somaweera et al. 2020).

iNaturalist (https://www.inaturalist.org) is a collaborative and participatory citizen science platform that documents biodiversity observations worldwide, allowing its users (approximately 6.7 million citizen scientists) to submit photographic and audio records with geographic locations of biological sightings, suggesting taxonomic identifications of species. There are several projects on the platform related to crocodilian studies, such as the Herpetological Association of Zimbabwe, Crocodiles of the World, Crocodilianos do Brasil, UC Jacaré Serra dos Pintos, Jacarés da Região Metropolitana de Manaus, and Projeto Caiman - Jacarés da Mata Atlântica. Therefore, these citizen science projects have the potential to combine data collection with education and environmental awareness, providing benefits to society and biodiversity (Frigerio et al. 2017).

This work encompasses all existing crocodilian species in the world, using citizen science data available on the *iNaturalist* platform, regarding geographic and temporal distribution, conservation status, the number of observations, and platform users. Its aim is to contribute to reducing the Wallacean deficit of crocodilians.

Materials and Methods

We downloaded observations and metadata for all 27 crocodilian species available on the *iNaturalist* platform (https://www.inaturalist.org) until December 2022. We organized a database with the metadata of each observation including all relevant variables recorded by citizen scientists: location, date, geographic coordinates, species identification, and other user information. We excluded species recorded in captivity (e.g., labs and zoos) to avoid erroneous distribution data. The taxonomic classification follows The Reptile Database (Uetz et al. 2022).

The dataset comprised 65,014 crocodilian observations, divided into three quality levels. In *iNaturalist*, a record is “Research_grade” when the *iNaturalist* community (at least three collaborators and/or experts) agrees on the species identification. A record is labeled as “Needs_ID” when the identification of the species is not consensual by the *iNaturalist* community (mainly professionals in the field of biological sciences), but a set of specific technical criteria is satisfied (i.e., date, geographic coordinates, photos or sounds). Otherwise, it is considered “Casual”.

We analyzed the final dataset extracting information about the absolute and relative numbers of families, genera, and species of crocodilians included in this platform. To understand possible biases and gaps in the representation of crocodilians in the final dataset, we also evaluated the number of observations over time (from the first observation in 1949 to 2022), the number of users, the geographical distribution of the observations, and the conservation status of each recorded species (based on IUCN 2023). In addition, we analyzed the spatial distribution of the observations to understand spatial distribution of the species. For this, we used a heatmap plugin in QGis version 3.22.4 (QGis Development Team 2014) to create a heatmap that uses Kernel density estimation (i.e., a density map) from crocodilian location. For the color scale, a base 10 logarithmic function was used so that the color attenuation could be smoother.

Results

Our final dataset had 65,014 observations from 22,753 observers, representing 27 species of crocodilians from nine genera and three families (Table 1), of which 62,595 observations (96%) were “Research level” (i.e., research level for publishable data), 358 observations (1%) “Needs ID” (species identification is required) and 2,061 observations (3%) “Casual” (e.g., absence of geographic or temporal data). Alligatoridae (N = 48,141 records; 74%; 8 spp.;

30%) and Crocodylidae (N = 16,662 observations; 26%; 17 spp.; 63%) had the highest number of observations and species. Within genera, *Alligator* (N = 41,087 observations; 63%; 2 spp.; 7%) had the highest number of observations, and *Crocodylus* (N = 16,500 observations; 25%; 13 spp.; 48%) had the highest number of species. Regarding the species, *Alligator mississippiensis* (N = 41,083 observations; 63%) and *Crocodylus acutus* (N = 6,400 observations; 10%) had the highest number of observations. Four species had less than 10 observations 15% (Table 1; Fig. 1).

Regarding conservation status, 11 (41%) species are threatened to extinction on the IUCN Red List (IUCN 2023), of which seven (26%) are Critically Endangered (CR) and four (15%) Vulnerable (VU). Twelve species (44%) are Least Concern (LC). *Gavialis gangeticus* (N = 192 observations; <1%) had the highest number of records within the CR species, while *C. acutus* (N = 6,400 observations; 25%) had the highest number of observations within the VU species. Four (15%) species have not been assessed by IUCN.

The final dataset included observations from 100 countries (Fig. 2). USA (N = 41,954 observations; 65%) had the highest number of observations (Fig. 4), followed by Mexico (N = 4,487 observations; 7%), and Costa Rica (N = 3,089 observations; 5%). Brazil (N = 6 species; 22%) and Colombia (N = 6 species; 22%) had the highest number of species, followed by Bolivia, Ecuador, and Guyana (N = 5 species; 18% each). *Crocodylus niloticus* was the most dispersed species occurring in 21 countries.

The first observation of crocodilians was in 1949. From 1949 to 2009 (the beginning of *iNaturalist*) the mean number of observations was 75 per year. From 2009 to 2016, the mean number of observations was 4,488 per year. The number of observations increased significantly in 2016 (N = 2,479), and reached a mean of 8,843 observations per year until 2022 (Fig. 3). In 2020, there was a decrease in the number of observations (N = 8,118) but it increased again in 2021 (N = 12,059) and 2022 (N = 13,717). The number of users also increased in 2017 (N = 1,629) with a mean number of users of 2,115 per year (from 2009 to 2022). The number of observed species in 2014 increased from 2 (7%) to 15 (55%) species and in 2022 all 27 species were recorded.

Table 1. Crocodilian species observed by citizen scientists on the iNaturalist platform. Details: N = Number of observations, Status = Conservation status according to IUCN, 2023: CR (Critically Endangered), VU (Vulnerable), LC (Least Concern) and NE (Not Evaluated). Total dataset: 65,014 observations of 27 crocodilian species, recorded by 22,753 observers, from 1949 to 2022.

Family/species	N (%)	Countries	Status
Alligatoridae			
Alligator mississippiensis (Daudin 1801)	41,083 (63%)	USA	LC
Alligator sinensis (Fauvel 1879)	4 (<1%)	China	CR
Caiman crocodilus (Linnaeus 1758)	3,645 (6%)	Bolivia, Brazil, Colombia, Costa Rica, Ecuador, El Salvador, French Guiana, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Peru, Suriname, Trinidad and Tobago, United States of America, Venezuela	LC

Caiman latirostris (Daudin 1801)	908 (1%)	Argentina, Bolivia, Brazil, Paraguay, Uruguay	LC
Caiman yacare (Daudin 1801)	1,591 (2%)	Argentina, Bolivia, Brazil, Paraguay	LC
Melanosuchus niger (Spix 1825)	466 (<1%)	Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru	LC
Paleosuchus palpebrosus (Cuvier 1807)	137 (<1%)	Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru	LC
Paleosuchus trigonatus (Schneider 1801)	307 (<1%)	Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru	LC
Crocodylidae			

Crocodylus acutus (Cuvier 1807)	6,400 (10%)	Belize, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Peru, USA Venezuela	VU
Crocodylus halli (Murray et al. 2019)	15 (<1%)	Indonesia, Papua New Guinea	NE
Crocodylus intermedius (Graves 1819)	24 (<1%)	Colombia, Venezuela	CR
Crocodylus johnstoni (Krefft 1873)	386 (<1%)	Australia	LC
Crocodylus mindorensis (Schmidt 1935)	4 (<1%)	Philippines	CR

Crocodylus moreletii (Duméril and Bibron 1851)	2,541 (4%)	Belize, Guatemala, Mexico	LC
Crocodylus niloticus (Laurenti 1768)	3,475 (5%)	Angola, Botswana, Burundi, Democratic Republic of Congo, Egypt, Eswatini, Ethiopia, Gabon, Kenya, Madagascar, Malawi, Mozambique, Namibia, Republic of Congo, Rwanda, South Africa, Sudan, Tanzania, Uganda, Zambia, Zimbabwe	LC
Crocodylus novaeguineae (Schmidt 1928)	1 (<1%)	Indonésia	LC
Crocodylus palustris (Lesson 1831)	895 (1%)	India, Iran, Nepal, Pakistan, Sri Lanka	VU
Crocodylus porosus (Schneider 1801)	2,321 (4%)	Australia, Bangladesh, Brunei, East Timor, India, Indonesia, Malaysia, Myanmar, Palau, Papua New Guinea, Phillippines, Singapore, Sri Lanka, Thailand	LC

Crocodylus rhombifer (Cuvier 1807)	23 (<1%)	Cuba	CR
Crocodylus siamensis (Schneider 1801)	105 (<1%)	Camboja, Laos, Thailand, Vietnam	CR
Crocodylus suchus (Saint-Hilaire 1807)	310 (<1%)	Benin, Burkina Faso, Cameroon, Costa do Marfim Chad, Gambia, Ghana, Guinea, Guinea- Bissau, Mali, Mauritania, Niger, Nigeria, Republic of Congo, Senegal, Sierra Leone, Uganda	NE
Mecistops cataphractus (Cuvier 1825)	4 (<1%)	Cote d'Ivoire, Ghana, Sierra Leone	CR
Mecistops leptorhynchus (Bennett 1835)	59 (<1%)	Central African Republic, Democratic Republic of the Congo, Gabon, Republic of the Congo	NE
Osteolaemus osborni (Schmidt 1919)	11 (<1%)	Cameroon, Gabon, Republic of Congo	NE

Osteolaemus tetraspis (Cope 1861)	48 (<1%)	Benin, Cameroon, Cote d'Ivoire, Gabon, Gambia, Ghana, Nigeria, Sierra Leone	VU
Tomistoma schlegelii (Müller 1838)	59 (<1%)	Indonesia, Malaysia	VU
Gavialidae			
Gavialis gangeticus (Gmelin 1789)	192 (<1%)	Índia, Nepal	CR

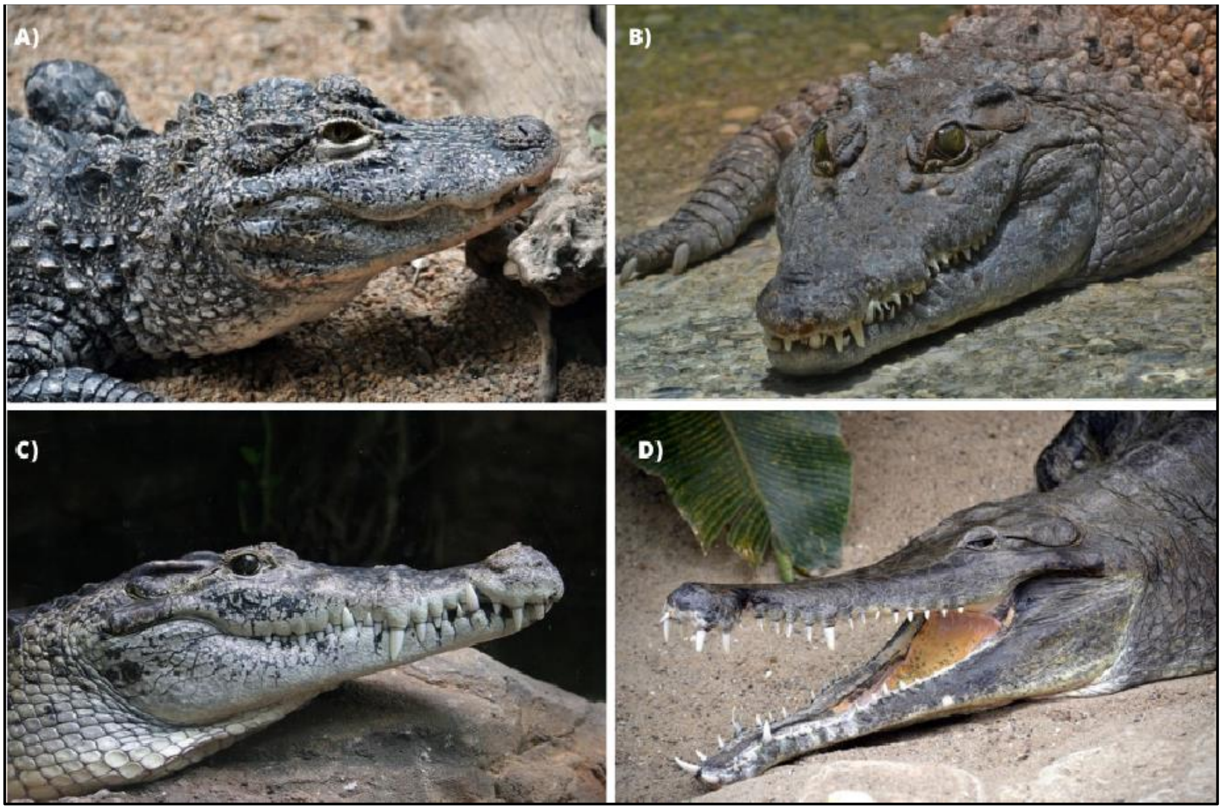

FIGURE 1. Species with less than 10 records on the *iNaturalist* platform: A) *Alligator sinensis*, B) *Crocodylus mindorensis*, C) *Crocodylus novaeguineae*, and D) *Mecistops*

cataphractus. Photos by: Wilfried Berns (A), Jonathan Zimmermann (B), Roger Smith (C), Tim Strater (D).

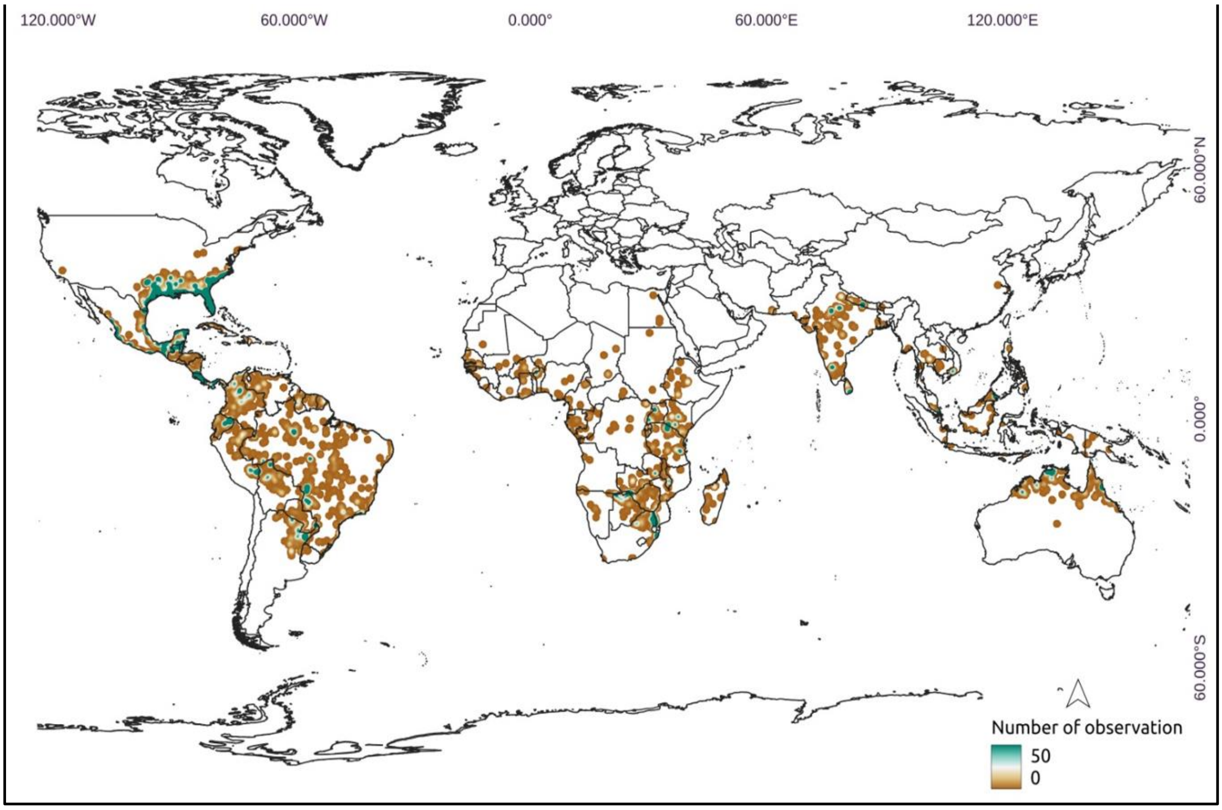

Figure 2. Citizen scientists observations of crocodilians around the world.

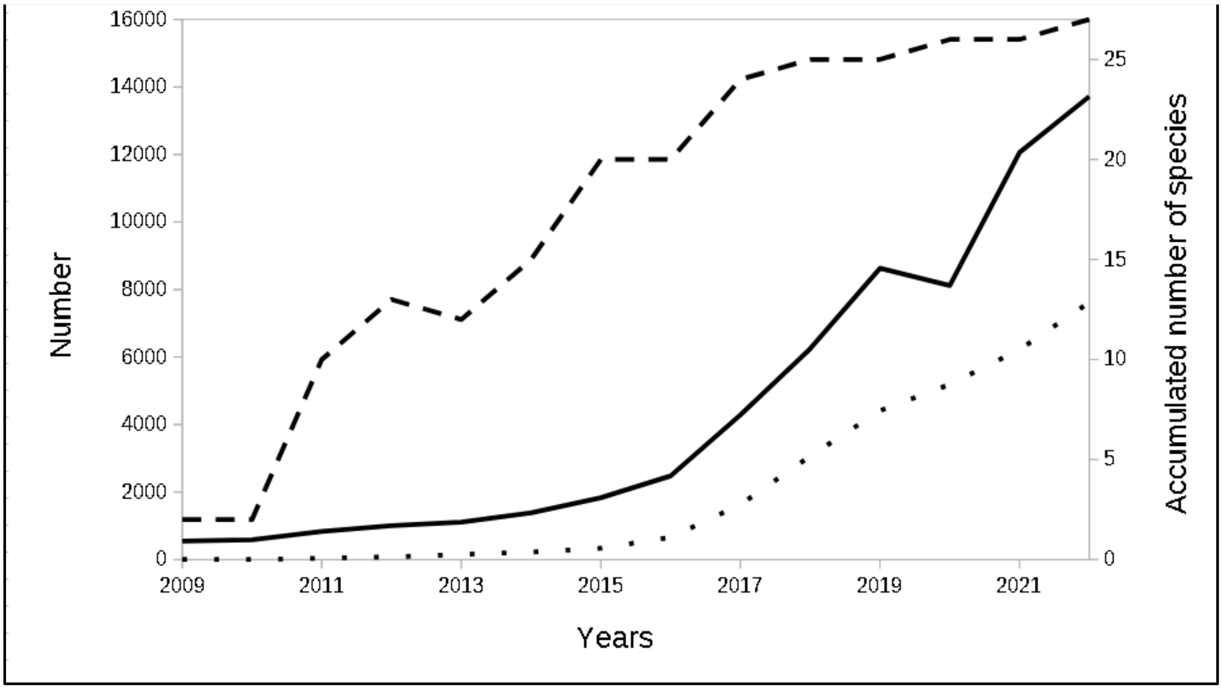

Figure 3. Number of observations (continuous line), number of species over years (dashed line), and number of citizen scientists (spaced dotted line).

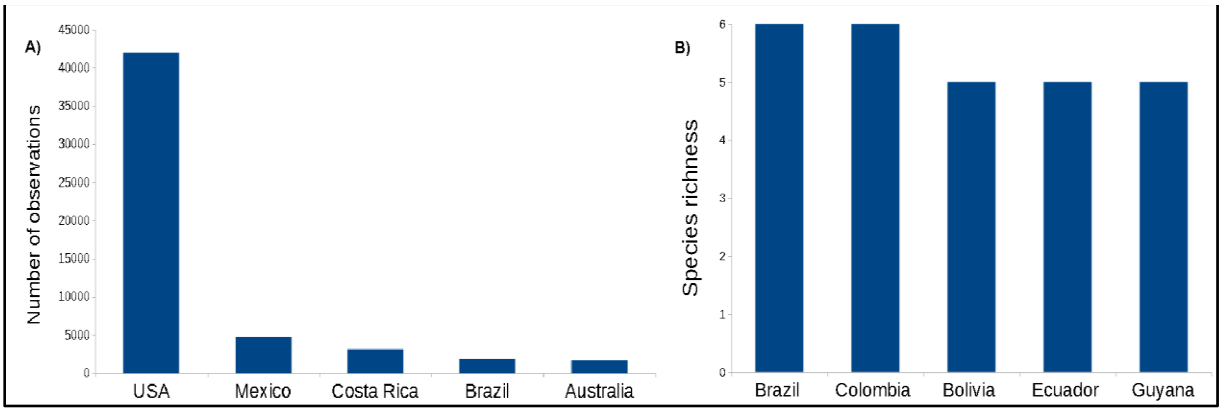

Figure 4. A) Countries with the highest number of observations of crocodilians, and B) Countries with the greatest species richness.

Discussion

This inventory of crocodilians observed by citizen scientists reported all 27 described species (Uetz et al. 2022). Several factors may have favored the recording of all crocodilian species, such as human fascination with top predators, ease of visibility due to their resting near water bodies, their immobility when at rest, and their large size (Ross 1998; Grigg and Kirshner 2015). In contrast, studies of smaller taxa with limited geographic distribution were not as efficient in recording species (Brow and Williams 2019; Di Cecco et al. 2021; Fontaine et al. 2022). Citizen science has also been successful in crocodilian studies focusing on nest ecology (Campos 2019), monitoring (Tallamy 2011; Kilpatrick 2016), and the health of these animals (Manolis 2002; Densmore 2018). Therefore, citizen science is becoming an increasingly efficient sampling method for crocodilians, particularly for inventory and spatial and temporal ecology (Maharani et al. 2022).

The species *Alligator mississippiensis* had the highest number of observations (63%), being seven times more frequently observed than the second most recorded species, *C. acutus* (9%). *Alligator mississippiensis* is found in various parts of the southeastern USA, where it is the most studied species among crocodilians (Joanen and Mcnease1987; Mazzotti and Brandt 1994). The maximum total length for adult males rarely exceeds 4.5 m, and for females, it is 3 m (Woodward et al. 1995; Brunell et al. 2015), making it easy to observe near water bodies (Woodward et al. 1992). Most observations of *A. mississippiensis* were in Everglades National Park, USA, a popular destination for citizen scientists, especially tourists and professional photographers. Since its opening to visitors in 1948, the number of visitors has increased, reaching 1,100,000 in 2012, which aligns with the more than 40,000 observations of this species. This high number of observations can also be explained by the widespread popularity of citizen science in the USA, which is widely practiced and encouraged by people of all ages (Shirk et al. 2012).

All 11 species classified as globally threatened by the IUCN were observed by citizen scientists. *Gavialis gangeticus* (N = 194 observations; <1%) had the highest number of observations among critically endangered (CR) species. It is worth noting that in recent decades, this species has been recovering from the brink of extinction due to studies and investments in egg incubation and initial rearing of hatchlings in captivity (Magnussun 1986; Maddock 2010). Alarmingly, four species (*Alligator sinensis*, *Crocodylus mindorensis*, *Crocodylus novaeguineae*, and *Mecistops cataphractus*) obtained fewer than 10 observations. *Alligator sinensis* (N = 5 observations; <1%) had the fewest observations among CR species, possibly due to a combination of factors, including limited geographic distribution, habitat loss and degradation, water pollution, illegal trade, and hunting (Mckinley et al. 2017; IUCN 2018). *Crocodylus mindorensis* (N = 4 observations; <1%), endemic to the Philippines, is heavily impacted by habitat fragmentation, hunting, illegal captures, and accidental capture by fishermen (Ortega 1998; Hilton-Taylor 2000). *Crocodylus novaeguineae* (N = 1 observation; <1%) is the only one of these four species that is not threatened with extinction, but it had only one observation on the *iNaturalist* platform. This species is endemic to the island of New Guinea, primarily nocturnal, rarely thermoregulating on the edges of water bodies, and has a low population density (Johnson 1973; Britton 2012). Finally, *Mecistops cataphractus* (N = 4 observations; <1%), found in parts of West Africa, is threatened by habitat loss due to the agricultural and urban expansion, timber and mining extraction, as well as conflict with local communities due to predation on domestic animals (Aoki 1976; Salisbury 2006; Shirley 2014).

Four species of crocodilians have not been evaluated by the IUCN. This lack of evaluation may be due to insufficient data or research on these species, making it difficult to assess their conservation status accurately. Comprehensive assessments for each species require time, expertise, and resources (Allouche 2006; IUCN 2023). The IUCN relies on experts and organizations to provide data and conduct assessments, and resource constraints can affect the assessment process. Studies show that more than half of the species that have not been evaluated or have remained data deficient may be listed in threatened categories (Borgelt et al. 2022). On the *iNaturalist* platform, *Crocodylus suchus* has 291 observations, *Mecistops* *leptorhynchus* 59 observations, *Crocodylus halli* 15 observations, and *Osteolaemus osborni* 11 observations, demonstrating the potential of citizen science to contribute data for assessing the conservation status of species in such categories.

There are observations of crocodilians made by citizen scientists in 100 countries on the *iNaturalist* platform. The USA, with 41,954 (64%) observations, and Mexico, with 4,487 (7%), had the highest number of observations. The USA has a strong tradition of involving the public in citizen science projects. A history of civic participation, a large population, geographic diversity, and the use of technology and social media make the country a significant driver of public engagement in scientific research projects (Shirk et al. 2012; Haklay et al. 2016). This fact also explains the higher number of *A. mississippiensis* records. In terms of species richness, some tropical countries, especially those with aquatic ecosystems, stand out. In this regard, Brazil and Colombia are notable for holding the highest recent crocodilian richness, each with six species (Medem 1983; Churio 2006; Churio 2015; Costa and Bérnils 2018). By allowing more people to actively participate in data collection, citizen science can play a significant role in understanding species distribution and thus reducing the Wallacean deficit (Cooper et al. 2007; Silvertown 2009; Bonney et al. 2014; Mckinley et al. 2017).

The number of species observations and the number of citizen scientists contributing to *iNaturalist* substantially increased in 2016. Since the platform was created in 2008, the number of users and observations has grown significantly in a short period. This result may be due to the widespread availability and use of smartphones and mobile devices, making it easier for people to record these animals. The popularization of ecotourism, allowing contact with natural environments, may have also contributed to the increase in the number of records (Sienknecht et al. 2018; Schaffer and Tham 2019; Ortega-Álvarez and Calderón-Parra 2021). Interestingly, the number of observations declined in 2020 (N = 8,118), possibly due to the onset of the COVID-19 pandemic and the subsequent confinement of people to their homes (Vardi et al. 2021). Contrarily, with the advent of COVID-19 treatment methods in 2021, the number of crocodilian observations (N = 12,059) increased again. Overall, the COVID-19 pandemic had a negative impact on citizen science data for various taxa (Manenti 2020; Zellmer 2020).

In conclusion, this study provided valuable information regarding the spatial and temporal distribution of crocodilians on a global scale by using data from citizen scientists. It is important to mention some limitations of citizen science data on the *iNaturalist* platform, such as the quality of some photos, geographic sampling bias, and the need for scientific validity (Brenton 2021). We encourage the creation of a CrocDay for citizen scientists to record crocodiles in the wild and upload the record on iNaturalist. Therefore, the use of *iNaturalist* has become a useful tool for complementing scientific data, supporting research and conservation efforts for crocodilians worldwide.

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Caiman latirostris: what do we know from citizen science?

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Abstract

Citizen science may be effective in the conservation of *Caiman latirostris* by involving the community in data collection on its populations and distribution. This can increase public awareness and provide long-term data. Ensuring proper training, clear protocols, and collaboration between scientists and citizens through environmental education would be highly effective in data quality and the success of the initiative. In this study, we compiled data on *Caiman latirostris* recorded by citizen scientists on the *iNaturalist* platform on a global scale. We also assessed its geographic distribution, the number of observations, and the number and profile of *iNaturalist* users over time. Our final dataset obtained 853 observations, 433 observers, and included 5 countries. Brazil (N = 493; 56%) and Argentina (N = 342; 41%) had the highest number of observations. The number of observations increased significantly in 2019 (N = 80) and reached a mean of 129 observations per year until 2022. The Covid-19 pandemic (2020-2021) did not alter the number of observations, which has been steadily increasing since 2018. The number of users also significantly increased in 2019 (N = 56), with an average of 64 observations per year, where 76% of user

profiles are male and only 18% are female. The biomes where the most observations were found were Tropical and Subtropical Moist Broadleaf Forest, and Tropical and Subtropical grasslands, savannas, and shrublands. We detected six observations of dead animals. Our analyses indicate that research incorporating information from citizen scientists provides valuable insights into how and where *Caiman latirostris* is distributed. Therefore, the use of iNaturalist represents a valuable tool to enrich scientific data, which, in turn, benefits research and conservation efforts for *Caiman latirostris*.
Keywords - conservation; crocodilian; open databases; public participation; spatial distribution

Introduction

Caiman latirostris (Daudin, 1801) occurs across Brazil, Argentina, Paraguay, Uruguay, and Bolivia at altitudes ranging from 0 to 800 m (Coutinho et al., 2013; Roberto et al., 2020; Verdade and Piña, 2006). The species has significant cultural and economic values because it is used in mythology and folklore (Barboza et al., 2021). This species is most common in the Tropical and Subtropical Moist Broadleaf Forests biome, although it is also found in the Deserts and Xeric Shrublands, Tropical and subtropical grasslands, savannas, and shrublands, and Temperate Grasslands, Savannas, and Shrublands (Olson et al., 2001). Despite being listed as Least Concern (LC) by the IUCN (Barreto-Lima et al., 2023; Filogônio et al., 2010; Martins, 2005), some states in Brazil classify it as endangered (see Bergallo et al., 2000; Bérnils et al., 2009; Verdade et al., 2010), mainly due to the threats of hunting (Bergallo et al., 2000) and urban expansion into natural areas, leading to habitat loss (Freitas-Filho et al., 2009; Freitas-Filho, 2013).

The lack of information on the current geographic distribution and population size of *C. latirostris* makes studies on population ecology necessary (Verdade, 1998). Citizen science is a useful and ideal tool for engaging volunteers in scientific research and is increasingly seen as a cost-effective method for biodiversity monitoring in ecological and environmental studies (Fontaine et al., 2021; Koffler et al., 2021). In this sense, the number and diversity of citizen science projects in ecological and environmental sciences are increasing (Pocock et al., 2017). Such projects are rapidly accumulating hundreds of millions of biodiversity observations worldwide, expanding the spatial and temporal scope of our understanding of ecology, conservation, and natural resource management (Chandler et al., 2017). Citizen science data can improve our understanding of biodiversity, including species distribution and richness estimation, and population trend quantification (Callaghan et al., 2020; Delaney et al., 2008; Schultz et al., 2017).

iNaturalist (https://www.inaturalist.org) is a multi-taxon citizen science platform where citizen scientists contribute opportunistic photographic records or recordings (audio) using smartphones or the web. In this context, it is possible to observe the type of habitat in which the individual is found, its developmental stage, or how it was photographed (Callaghan et al., 2021). It is an interactive platform that globally documents biodiversity observations. This tool allows its vast member community to share photographic records, including location details, text reports, and even audio recordings related to live organism observations, as well as providing guidance for taxonomic species identification.

The *iNaturalist* platform can be an important tool for mapping the occurrence of *C. latirostris* populations. In this sense, this study aims to provide a general survey using citizen science data available on the *iNaturalist* platform, covering the geographic distribution, number of records, and users on the platform, in order to contribute necessary information that can be used in *C. latirostris* conservation actions.

Materials and Methods

A virtual profile called "Projeto Caiman" was created on iNaturalist (https://www.inaturalist.org/projects/projeto-caiman-jacares-da-mata-atlantica) to compile *C. latirostris* observations. A record is considered "Research Grade" when the iNaturalist community (comprising at least three contributors and/or experts) agrees on the species identification. Records can also be classified into two other categories: "Needs ID" (indicating that species identification is required) and "Casual" (used when the record lacks geographic or temporal data). Thus, a record is labeled "Needs ID" when species identification is not consensual among the iNaturalist community (mainly professionals in the field of biological sciences), but specific technical criteria are met (i.e., date, geographic coordinates, photos, or sounds). Otherwise, it is considered "Casual". The data generated on *iNaturalist* is publicly accessible and available for download.

We compiled observations of *C. latirostris* from "Projeto Caiman" until the end of 2022. Records classified as "Needs ID" and "Casual" were excluded from our analysis. Each photograph was individually analyzed by one of us (MT) for greater accuracy in the identification of *C. latirostris*. We created a database with metadata for each observation, including all relevant variables recorded by citizen scientists (location, date, geographic coordinates, and user information such as gender and profiles related to conservation projects).

We analyzed the final dataset by extracting information on the total number of records. We also evaluated the number of active users by year, the profile of these users, as well as countries and states. In addition, we analyzed the spatial distribution of observations to understand the distribution of *C. latirostris*. For this purpose, we used a heatmap plugin in QGis version 3.22.4 (QGis Development Team, 2014) to create a heatmap that uses Kernel density estimation (i.e., a density map) of the species' location and the shapefile of biome divisions from Olson et al. (2001). A base 10 logarithmic function was used for the color scale to create smoother color gradients.

Results

We compiled 853 observations of *C. latirostris* classified as Research Level from the Caiman Project on the *iNaturalist* platform (Fig. 1). The species has 433 observers on the platform, of which 328 (76%) are male, 78 (18%) are female, and 27 (6%) profiles were not identified. There were also 194 identifiers, 157 (81%) of whom were male, 22 (11%) female, and 15 (8%) were unidentified.

The first observation of *C. latirostris* was made in 2000. From 2000 to 2019, the average number of observations was 20 per year. The number of observations increased significantly in 2019 (N = 80) and reached an average of 129 observations per year until 2022 (Fig. 1). The number of *C. latirostris* observations showed a similar trend to the number of *iNaturalist* users, which also increased from 2019 (N = 56), with an average of 64 users per year.

Observations of *C. latirostris* covered five countries in South America, with 493 (56%) in Brazil, 342 (41%) in Argentina, 8 (1%) in Bolivia, 8 (1%) in Uruguay, and 2 (<1%) in Paraguay (Fig. 2). In Brazil, the states with the highest number of observations were Rio de Janeiro (N = 129 observations; 26%), São Paulo (N = 89; 18%), and Paraná (N = 61; 12%). In Argentina, the states with the highest number of observations were Corrientes (N = 87; 25%), Misiones (N = 84; 24%), and Santa Fe (N = 60; 18%) (Fig. 3). The biomes with the highest number of observations were Tropical and Subtropical Moist Broadleaf Forest, Tropical and Subtropical grasslands, savannas, and shrublands.

Finally, six observations of *C. latirostris* were of dead animals (four in Argentina, one in Uruguay, and one in Bolivia). Three observations were of road-killed individuals, and one record was of an individual apparently burned, all from Argentina.

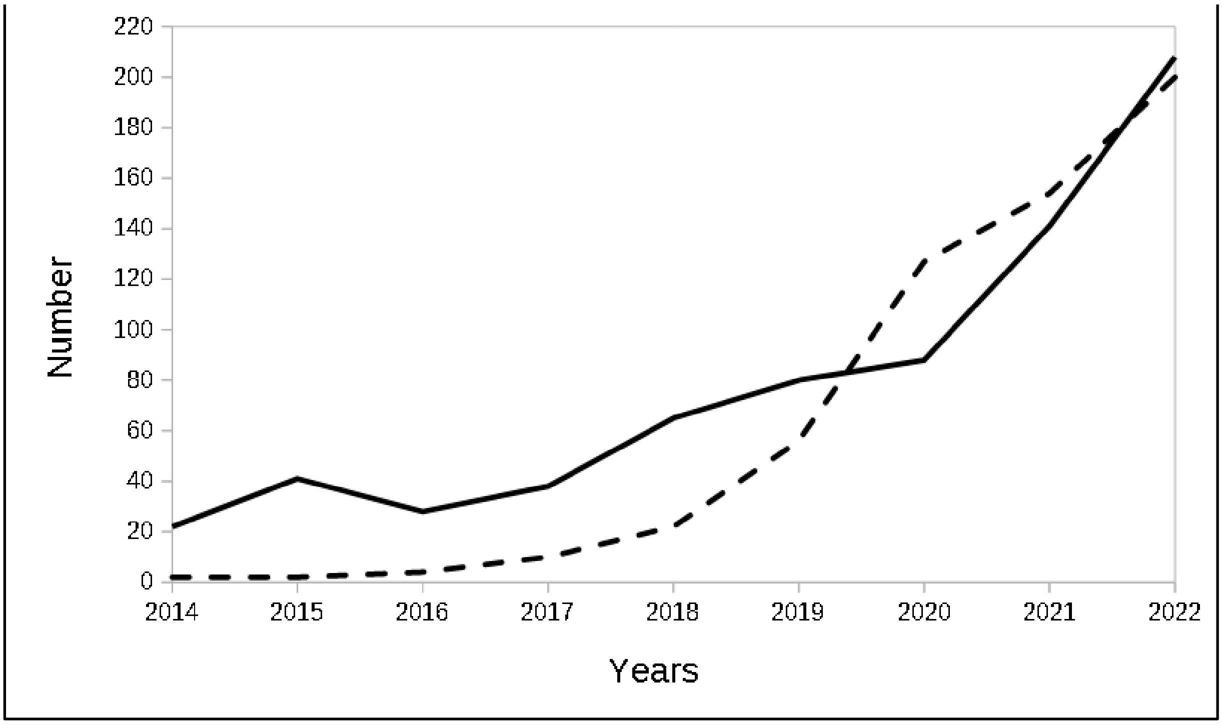

Figure 1. Number of *Caiman latirostris* observations by citizen scientists (continuous line), number of users on the *iNaturalist* platform over the years (dashed line).

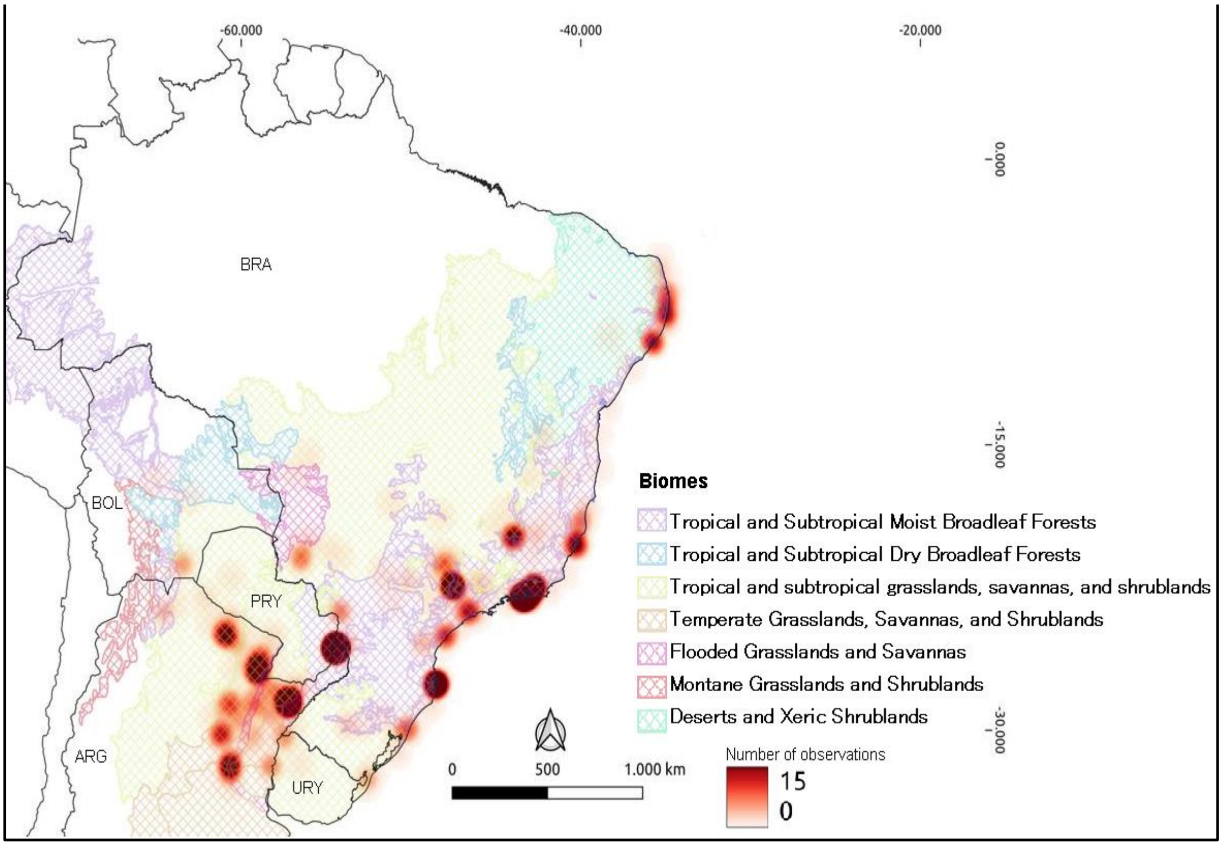

Figure 2. Kernel Density analysis of observations of *C. latirostris* in South America. Argentina (ARG), Bolivia (BOL), Brazil (BRA), Paraguay (PRY), and Uruguay (URY).

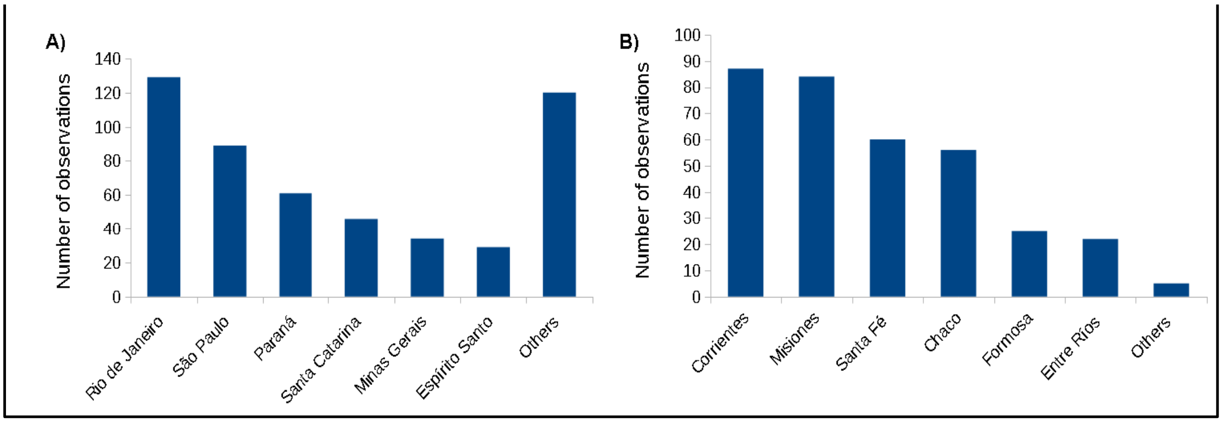

Figure 3. Number of observations by states with the highest records from A) Brazil and B) Argentina.

Discussion

The dataset compiled from iNaturalist included 853 observations of *C. latirostris*. When analyzed individually, this number of observations exceeds those available in scientific databases, such as the Global Biodiversity Information Facility (GBIF) with 579 observations, the Environmental Information System of the Biota/Fapesp Program (SinBiota) with 7 observations, the Biodiversity Portal (PortalBio) with 829 observations, VertNet with 230 observations, and Specieslink with 105 observations. Therefore, this comparison demonstrates that *iNaturalist* citizen science data are of fundamental importance for spatial and temporal studies as they expand the knowledge available in scientific databases.

The first observation of *C. latirostris* was made in 2000, after which observations began to increase significantly in 2019. The number of users followed a similar pattern, with a significant increase in memberships also in 2019. Citizen science projects are increasing worldwide, as are the number of observations and new users (Di Cecco et al., 2021; Rumenos and Spazziani, 2020). This public interest may be due to awareness campaigns, environmental education, and individual interest (Di Cecco et al., 2021). Technological improvements, such as smartphones with high-quality cameras and greater internet access, also facilitate biodiversity observations and data sharing (Aristeidou, 2021). It's worth noting that the COVID-19 pandemic (mainly between 2020 and 2021) did not affect the annual number of *C. latirostris* observations made by citizen scientists on the *iNaturalist* platform, as these data continued to grow steadily.

A total of 433 citizen scientists contributed observations of *C. latirostris* on the *iNaturalist* platform. There was a marked difference in the gender of the profiles of citizen scientists, with 75% being male and only 18% female. In some cultures, women may face social barriers to participating in outdoor activities such as biodiversity observation, limited access to technology and the internet, as well as family and social responsibilities that may limit the time women have available for collaborative activities on *iNaturalist*, influencing their overall participation in citizen science platforms (Hill et al., 2010; Lopes, 1998).

Observations of *C. latirostris* were predominantly reported in the biomes of Tropical and Subtropical Moist Broadleaf Forest, Tropical and Subtropical grasslands, savannas, and shrublands, and Temperate Grasslands, Savannas, and Shrublands. These biomes offer the type of habitat that *C. latirostris* utilizes, such as swamps and rivers (Coutinho et al., 2013; Piña et al., 2010). A higher concentration of observers, as well as research and conservation projects in these regions, may have contributed to the high number of observations (Brenton, 2021; Di Cecco et al., 2021).

All five countries with occurrences of *C. latirostris* were represented in the observations by citizen scientists. Brazil had the highest number of observations (56%), followed by Argentina (41%). Brazil and Argentina are known for their diverse ecosystems, such as wetlands, rivers, and swamps, where *C. latirostris* is commonly found (Coutinho et al., 2013). The species may be relatively more abundant in these countries, making it more likely for people to observe and document them (Coutinho et al., 2013).

Regarding Brazilian states, Rio de Janeiro had the highest number of *C. latirostris* observations on *iNaturalist* (26%). The proximity of the species to urban areas in cities in the states of RJ and SP (18%) could be a determining factor for the high number of observations (IBGE, 2018). In Paraná, with 61 (14%) of the observations, the environmental conditions of the state appear to be suitable for *C. latirostris* populations, both due to the presence of well-preserved ecosystems (Mikish and Bérnils, 2004) and the possibility of having a larger population, facilitating sightings and observations. Additionally, monitoring projects for *C. latirostris* and research activities, especially in the southeastern region, may have a significant influence on expert and citizen scientist observations in the iNaturalist platform.

In the case of Argentina, the northern provinces with the highest number of observations are within the distribution area of *C. latirostris*, with many populations of the species (Piña et al., 2010). The intense tourist activity in the Corrientes and Misiones regions, especially due to the presence of Iguaçu National Park (shared by Brazil, Argentina, and Paraguay), facilitates the observations and records of caimans. Additionally, in Santa Fe, there are research centers and many specialized biologists who can also influence citizen scientist observations on *iNaturalist*.

The countries with the lowest number of observations were Bolivia, Uruguay, and Paraguay. Bolivia has populations with low density of individuals (Aparicio and Ríos, 2008; Verdade and Piña 2006). The geographic distribution of *C. latirostris* remains uncertain in Uruguay (Borteiro, 2006), and there is a lack of recent research available for Paraguay (Verdade et al., 2010). Citizen science and research in these countries are still developing (Verdade et al., 2010), and citizen science seems to have not gained the level of popularity reached in some other countries. Without a solid foundation of awareness and environmental education, the population may not be motivated to engage in such activities or may not fully understand the importance of their contributions to science (Heberling and Isaac, 2018; Wehn et al., 2021).

We found six *iNaturalist* observations reporting dead *C. latirostris*. In addition to living in natural environments, *C. latirostris* can also inhabit urban areas, near industries, power plants, dams, roads, sewer canals, or rural areas, being considered a synanthropic species (Coutinho et al., 2013; Filogônio et al., 2010; Freitas-Filho, 2013; Mascarenhas-Júnior et al., 2020; Ornelas et al., 2021). Therefore, observations of roadkill have been a significant threat to these animals, especially in protected areas crossed by roads or highways (Collinson et al., 2019). Roadkill data may be underestimated because carcasses can be rapidly removed by scavenging species (Teixeira et al., 2013), and road-killed individuals may die far from the road and go unnoticed. The species may also exhibit some characteristic behavior that minimizes the risk of death from vehicle collisions on roads (Dias et al., 2022). Therefore, understanding these records enables more efficient mitigating actions in specific areas highlighted by citizen science, its collaborators, and associated tools (i.e., collaborative platforms).

Citizen science has expanded substantially in the early 2020s, but it still appears to be a targeted effort by researchers and groups of individuals interested in specific taxonomic groups (Taklis, 2020). Citizen scientists are located in various regions around the globe, allowing for data collection in a broad geographic area and over extended periods, thereby contributing to long-term data records and furthering biodiversity monitoring. Therefore, involving a large number of citizen scientists can significantly increase the volume of data and contribute more to citizen science research projects. It is known that citizen science programs are often more productive in collecting data than traditional research methods (Araújo et al., 2021; Sousa and Alturas, 2020), and also over a larger scale. Overcoming limitations such as photo quality, sampling bias, technological, geographic, and resource constraints in each locality, as well as ensuring the scientific validation of identified species (Brenton, 2021; Di Cecco, 2021), citizen science can play an essential role in the conservation of *C. latirostris* by involving and educating the local community in data collection. Therefore, the *iNaturalist* platform becomes a valuable tool for filling gaps in scientific data, favoring research and conservation efforts for *Caiman latirostris*.

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