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Ciência Cidadã no Monitoramento Ambiental: Lacunas na Produção Científica, Vieses Geográficos e Taxonômicos

Anápolis

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SUMÁRIO

RESUMO

A ciência cidadã, embora não seja uma novidade, tem ganhado popularidade desde meados da década de 90, impulsionada pelo avanço da tecnologia e da informação. O processo colaborativo entre pessoas comuns e cientistas profissionais tem se intensificado diante das crescentes demandas ambientais do planeta em diversas áreas de atuação. No primeiro artigo, discutimos os avanços temporais da produção científica, e percebemos vieses nessa demanda, como um maior número de produção científica para grupos como insetos e aves, além de uma tendência para o monitoramento de espécies terrestres. Países como EUA e Austrália possuem elevada produção científica em detrimento de países da região neotropical, como Brasil e México, que detêm maior biodiversidade. Mesmo com os vieses observados, a ciência cidadã tem sido dinâmica nas mudanças temáticas em relação às problemáticas ambientais mundiais, como encontramos a partir dos anos de 2015/16, inclusive com temas recentes como o da COVID-19. Partindo de uma análise mundial da produção científica, que demonstrou um descompasso na produção, procuramos avaliar fatores que influenciaram os últimos 30 anos para a observação de aves no Brasil. Dessa forma, no artigo 2, percebemos que em cidades de médio e grande porte há mais observações sendo realizadas na região sudeste do país, especialmente na cidade de São Paulo. Essas observações estão diretamente ligadas ao tamanho da população e da área da cidade, assim como ao número de observações feitas por cientistas, índice de desenvolvimento humano e número de unidades de conservação. Ou seja, atributos econômicos, geográficos e ações de conservação, como o número de unidades de conservação, são fatores que influenciam na demanda de observação de aves por pessoas comuns. No terceiro artigo, restringimos as observações realizadas para o bioma Cerrado para analisar fatores específicos das aves que favorecem a observação dessas através de ciência cidadã. Encontramos que atributos como observação de aves pela ciência profissional (espécimes em coleções científicas, por exemplo), da mesma forma que a coloração das aves, comportamento de bando, tamanho das aves, dispersão por diferentes ambientes, ameaça e endemismo são fatores que influenciam na observação por parte dos cientistas amadores. Entendemos que são atributos complexos e, por isso, devem ser levados em consideração em futuras pesquisa. Porém, foi perceptível que as aves mais observadas estão inseridas em ambientes urbanos de forma generalista, essa migração deve ser monitorada, e a ciência cidadã é um instrumento importante para isso, principalmente nos centros urbanos. A tecnologia e o engajamento da população são fatores primordiais para o monitoramento ambiental, principalmente o uso de novas tecnologias e o constante fomento das diversas instituições e atores sociais. Há uma relação forte entre cientistas e não cientistas na observação das espécies, especialmente em cidades que possuem preocupação com a conservação, reservando locais de ambiente natural. Essas conclusões destacam a importância da organização, engajamento, apoio político e consideração de diversos fatores na promoção e sustentação de iniciativas de ciência cidadã para monitoramento ambiental, bem como esforços de conservação de espécies destacando em especial a avifauna do Cerrado brasileiro.

PALAVRAS-CHAVES: Ciência cidadã, Biodiversidade, Monitoramento, Conservação, Espécies, Colaboração

ABSTRACT

Citizen science, although not a novelty, has gained popularity since the mid-90s, driven by advancements in technology and information. The collaborative process between ordinary citizens and professional scientists has intensified in response to the growing environmental demands worldwide across various fields of operation. In the first article, we discussed the temporal advancements of scientific production, yet noted biases in this demand, such as a higher production of scientific data for groups like insects and birds, and a predisposition towards monitoring terrestrial species. Countries like the USA and Australia exhibit high scientific production, contrasting with countries in the neotropical region such as Brazil and Mexico, which harbor greater biodiversity. Despite these biases, citizen science has proven dynamic in thematic shifts concerning global environmental issues, evident since around 2015/16, including recent topics like COVID-19. Conducting a global analysis of scientific production, which revealed discrepancies, we sought to evaluate factors influencing bird observation in Brazil over the past 30 years. In the second article, we observed that in medium and large cities, more observations are conducted in the southeastern region, particularly in São Paulo. These observations are directly linked to factors like population size, city area, scientist-led observations, human development index, and the number of conservation units. Hence, economic and geographical attributes, alongside conservation actions like the number of conservation units, influence the demand for bird observation by laypersons. In the third article, we restricted observations to the Cerrado biome to analyze specific factors influencing bird observation by citizen science. We found that attributes such as professional bird observation (e.g., specimens in scientific collections), bird coloration, flock behavior, bird size, dispersion across different environments, threat level, and endemism influence observation by amateur scientists. Recognizing these as complex attributes, future research should consider additional factors. However, it was noticeable that the most observed birds are typically found in urban environments in a generalist manner, necessitating close monitoring. Citizen science emerges as a crucial tool for such monitoring, particularly in urban centers. Technology and community engagement are pivotal for environmental monitoring, especially with the utilization of new technologies and continuous support from various institutions and social actors. There exists a strong relationship between scientists and non-scientists in species observation, particularly in cities with conservation concerns that preserve natural environments.

These findings underscore the importance of organization, engagement, political support, and consideration of various factors in promoting and sustaining citizen science initiatives for environmental monitoring, as well as species conservation efforts, with particular emphasis on the avifauna of the Brazilian Cerrado.

KEYWORDS: Citizen Science, Biodiversity, Monitoring, Conservation, Species, Collaboration, Crowdsourcing

INTRODUÇÃO

Nos anos 1990, emergiu o termo “ciência cidadã”, motivada pela curiosidade de indivíduos comuns, destituídos de especialização e alheios aos paradigmas científicos convencionais. Essa abordagem visa à prestação de serviços científicos ao público em geral, enquanto simultaneamente proporcionava benefícios recíprocos aos profissionais da área, com o voluntariado de pessoas "ordinárias" como seu pilar fundamental (Irwin, 1995; Bonney, 1996). A ideia de ciência cidadã não é nova. Willian Whewell´s desenvolveu um experimento chamado “Great Tide Experiment”, no ano de 1835, que é historicamente uma das primeiras experiências de prática colaborativa relatadas na comunidade científica. Nessa, nove países diferentes reuniram mais de um milhão de dados vindos de pessoas comuns a respeito do efeito das marés, mesmo antes do surgimento da internet ou o telefone (Cooper, 2016; Jones, 2017).

Neste sentido, a base da ciência cidadã está na colaboração entre especialistas e leigos, ou pessoas que não estão ligadas com a ciência tradicional e profissional, sem considerar a natureza específica de suas contribuições, que podem variar desde a coleta de dados até o suporte no desenvolvimento do processo, independentemente de sua competência, desempenho ou reconhecimento (Jordan et al., 2015). Atualmente, há uma busca pela participação pública nas pesquisas científicas, que não apenas evidencia habilidades científicas, mas também oferece oportunidades valiosas de aprendizado a pessoas que estão fora das instituições produtoras de conhecimento (Becker-Klein et al., 2016). Dessa forma, os indivíduos comuns são envolvidos na prática científica, integrando-se à comunidade acadêmica e exercendo uma influência positiva em suas próprias comunidades (Conrad & Hilchey, 2011).

Assim, diversos setores, como cidadãos preocupados com o meio ambiente, órgãos governamentais, ONGs, empresas privadas, universidades e outros, trabalham juntos para monitorar e gerenciar questões ambientais. Essa colaboração não apenas ajuda a enfrentar os desafios ambientais, mas também enriquece as abordagens de análise e interpretação de dados (Whitelaw et al., 2003; Cashman et al., 2008).

Em termos de atividades, a ciência cidadã engaja-se em diversas áreas (Burgess et al., 2017). Por exemplo, na astronomia, o projeto Galaxy Zoo mobiliza entusiastas do campo, fornecendo grandes conjuntos de dados em colaboração com amadores da astronomia (Raddick et al., 2013). Pessoas comuns podem contribuir para a ciência através de atividades lúdicas, como é o caso do FOLDIT, no qual usuários e gamers podem montar moléculas virtuais tridimensionais, muitas vezes solucionando problemas que especialistas não conseguiram identificar (Curtis, 2015). Outro exemplo é o EteRNA, que se concentra em pesquisas médicas, permitindo que usuários e gamers desenvolvam, por exemplo, vacinas estáveis por meio de jogos, com potencial para beneficiar a população global (Anderson-Lee et al., 2016). Para melhor organizar essas iniciativas e permitir que os usuários encontrem projetos alinhados com seus interesses, foi criada, em 2010, a plataforma SCISTARTER 2.0. Essa já conta com mais de 3000 projetos e serve como uma ferramenta de apoio para cientistas cidadãos em busca de projetos adequados (Hoffman et al., 2017; Conroy, 2019; SCISTARTER, 2020).

Esse campo de estudo tem desempenhado um papel crucial na ecologia e conservação ambiental (Oberhauser et al., 2008; Kobori et al., 2016). Além disso, tem sido explorada em estudos para reduzir incidentes ou desastres, revelando desafios significativos (Marchezini et al., 2017). O monitoramento ambiental é outra área vital em que a ciência cidadã se destaca (Roy et al., 2012), combinando pesquisa e educação ambiental com observações da biodiversidade (Conrad & Hilchey, 2011). Iniciativas como o estudo da variação temporal e espacial dos gases do efeito estufa para entender o aquecimento global (Weyhenmeyer et al., 2017), o aumento do monitoramento da perda de biodiversidade (Pocock et al., 2018), a modelagem da migração de espécies (Coxen et al., 2017) e a análise de padrões de paisagem que afetam os sistemas aquáticos (Cunha et al., 2019) demonstram como a colaboração pública está sendo empregada em questões ambientais urgentes.

Essa colaboração pode ser vista de várias maneiras distintas. Segundo Bonney e colaboradores (2009), podemos dividir essa colaboração em três campos:

i) Contributiva, seja de maneira passiva ou ativa; ii) Colaborativa, indo além da simples coleta de dados. Ambas (i e ii) envolvem a supervisão de especialistas. No segundo exemplo de colaboração, os participantes trazem sua expertise para resolver problemas, como nos casos mencionados do Foldit e EteRNA; iii) Co-criação, também conhecida como comunidades baseadas em pesquisa, onde uma comunidade tenta resolver seus problemas compartilhando soluções por eles desenvolvidas, frequentemente na área da antropologia. Portanto, a colaboração levanta dados que passam por um crivo científico, podendo ser validados sem maiores problemas de ordem epistemológica ou metodológica (Bonney et al., 2009).

O monitoramento ambiental desempenha um papel crucial devido à sua capacidade de fornecer orientação para tomadas de decisão assertivas, ou pelo menos as mais próximas possíveis, visando um manejo eficaz da biodiversidade em meio aos desafios da produção e conservação ambiental (Niemelä, 2000). Diante da ampla gama de desafios impostos pelas mudanças ambientais recentes, os cientistas se esforçam cada vez mais para encontrar respostas que estabeleçam limites adequados para o uso do meio ambiente, garantindo sua segurança, respeito e equilíbrio necessário para os processos ambientais do planeta (Rockström et al., 2009).

As mudanças nas características ambientais do mundo, decorrentes das atividades humanas, demandam um aumento na intensidade dos monitoramentos ambientais para compreender esse novo cenário. Nesse contexto, a ciência cidadã desempenha um papel fundamental no monitoramento de diversas áreas, como a identificação e acompanhamento de espécies invasoras, preenchendo lacunas no conhecimento sobre sua dinâmica e distribuição temporal e espacial (Giovos et al., 2019). Além disso, contribui para a coleta de dados sobre a ocorrência de espécies (Lodi & Tardin, 2018), aumentando também a vigilância sobre animais mortos em estradas e explorando o impacto da agricultura com o auxílio de tecnologia de smartphones (Dehnen-Schmutz et al., 2016).

No que diz respeito ao monitoramento dos recursos hídricos, a ciência cidadã mostra-se altamente eficiente em termos de custo, envolvendo as comunidades locais na coleta de dados com grande precisão. Isso é crucial, uma vez que os recursos hídricos desempenham um papel fundamental em uma variedade de processos de valoração ecossistêmica (Weeser et al., 2018).

Iniciativas de monitoramento da floração de algas ao redor do mundo também são relevantes, pois contribuem para a detecção de toxinas produzidas por essas algas, que representam um grave problema de saúde pública. Um exemplo é o projeto Cyano-Tracker, que utiliza tecnologias como satélites e sensores para permitir que pessoas comuns monitorem a floração de algas prejudiciais à saúde humana e animal, usando apenas um celular (Mishra et al., 2020).

Diante das pandemias enfrentadas pela população mundial, como o recente Sars-Cov-2, o monitoramento de patógenos provenientes da vida selvagem se torna de extrema urgência. Essa iniciativa pode ser realizada por cientistas cidadãos (Chame et al., 2019). Como resultado, a ciência cidadã tem gerado um vasto conjunto de dados que podem ser explorados pela comunidade científica e não científica, contribuindo para diversas áreas e ampliando o conhecimento (ver Kelling et al., 2015).

OBJETIVOS

O objetivo deste trabalho é compreender a ciência cidadã no monitoramento ambiental, abordando três perspectivas distintas em três artigos. Inicialmente, foi realizada uma análise ampla e global da produção científica relacionada à ciência cidadã. Essa revisão teve como objetivo compilar e analisar criticamente a literatura disponível sobre o tema, identificando tendências, lacunas de conhecimento e melhores práticas em relação à participação da comunidade no monitoramento ambiental. Através dessa revisão, buscamos fornecer uma visão atual do estado da arte da ciência cidadã no monitoramento ambiental e contribuir para o avanço dessa área de pesquisa. Em seguida, analisamos os dados coletados por cientistas cidadãos na observação de aves em nível nacional, nos últimos 30 anos, em cidades de médio e grande porte, contrastando esses dados com aspectos econômicos e geográficos. Por fim, realizamos uma análise a nível de espécies de aves, focando nas cidades do bioma Cerrado, investigando diversos fatores que influenciam a observação dessas espécies. Com essa investigação, almejamos fornecer insights valiosos sobre a biodiversidade das aves em cidades de médio e grande porte do cerrado brasileiro, bem como o papel da ciência cidadã em seu monitoramento e conservação.

Os três artigos juntos respondem à pergunta central desta tese, que busca compreender os fatores que influenciam a observação de espécies pela ciência cidadã. Partimos do pressuposto de uma tendência global de crescimento na produção científica, com vieses nessa produção, influenciados por questões econômicas e geográficas na coleta de dados por observadores amadores, e culminando na constatação de que certas espécies são mais observadas do que outras devido a atributos ambientais, comportamentais e ao conhecimento profissional sobre essas espécies.

Em resumo, esta pesquisa visa contribuir para o avanço do conhecimento sobre ciência cidadã e sua aplicação no monitoramento ambiental, especialmente no contexto das cidades brasileiras e do cerrado. Esperamos que, ao alcançar esses objetivos, possamos fornecer informações valiosas que possam embasar políticas e práticas de conservação da biodiversidade e promover uma maior participação da comunidade na ciência e na tomada de decisões ambientais.

REFERÊNCIAS

Anderson-Lee, J., Fisker, E., Kosaraju, V., Wu, M., Kong, J., Lee, J., ... & Das, R. (2016). Principles for predicting RNA secondary structure design difficulty. Journal of molecular biology, 428(5), 748-757.

Becker-Klein, R., Peterman, K., & Stylinski, C. (2016). Embedded assessment as an essential method for understanding public engagement in citizen science. Citizen Science: Theory and Practice, 1(1).

Bonney, R. (1996). Citizen science: A lab tradition. Living Bird, 15(4), 7-15.
Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? Public Understanding of Science, 25(1), 2-16.

Burgess, H. K., DeBey, L. B., Froehlich, H. E., Schmidt, N., Theobald, E. J., Ettinger, A. K., ... & Parrish, J. K. (2017). The science of citizen science: exploring barriers to use as a primary research tool. Biological Conservation, 208, 113-120.

Cashman, S. B., Adeky, S., Allen III, A. J., Corburn, J., Israel, B. A., Montaño, J., ... & Eng, E. (2008). The power and the promise: working with communities to analyze data, interpret findings, and get to outcomes. American journal of public health, 98(8), 1407-1417.

Chame, M., Barbosa, H. J., Gadelha, L. M., Augusto, D. A., Krempser, E., & Abdalla, L. (2019). SISS-Geo: Leveraging Citizen Science to Monitor Wildlife Health Risks in Brazil. Journal of Healthcare Informatics Research, 3(4), 414-440.

Clusa, L., Miralles, L., Fernández, S., García-Vázquez, E., & Dopico, E. (2018). Public knowledge of alien species: a case study on aquatic biodiversity in North Iberian.

Conrad, C. C., & Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: issues and opportunities. Environmental monitoring and assessment, 176(1-4), 273-291.

Conroy, G. (2019). How to run a successful citizen Science Project: keeping participants involved can go a long way. Natureindex, 09 de agosto de 2020. Disponível em: https://www.natureindex.com/news-blog/how-to-run-successful-citizen-science-project. Acesso em: 31 de julho de 2020.

Coxen, C. L., Frey, J. K., Carleton, S. A., & Collins, D. P. (2017). Species distribution models for a migratory bird based on citizen science and satellite tracking data. Global Ecology and Conservation, 11, 298-311.

Cunha, D. G. F., Magri, R. A. F., Tromboni, F., Ranieri, V. E. L., Fendrich, A. N.,

Campanhão, L. M. B., ... & Velázquez, J. A. (2019). Landscape patterns influence nutrient concentrations in aquatic systems: citizen science data from Brazil and Mexico. Freshwater Science, 38(2), 365-378.

Curtis, V. (2015). Motivation to participate in an online citizen science game: A study of Foldit. Science Communication, 37(6), 723-746.

Dehnen-Schmutz, K., Foster, G. L., Owen, L., & Persello, S. (2016). Exploring the role of smartphone technology for citizen science in agriculture. Agronomy for sustainable development, 36(2), 25.

Giovos, I., Kleitou, P., Poursanidis, D., Batjakas, I., Bernardi, G., Crocetta, F., ... &

Langeneck, J. (2019). Citizen-science for monitoring marine invasions and stimulating public engagement: a case project from the eastern Mediterranean. Biological Invasions, 21(12), 3707-3721.

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(4), 601-611.

Hoffman, C., Cooper, C. B., Kennedy, E. B., Farooque, M., & Cavalier, D. (2017).

Scistarter 2.0: A digital platform to foster and study sustained engagement in citizen science. In Analyzing the Role of Citizen Science in Modern Research (pp. 50-61). IGI Global.

Jones, A. G. (2017). Many Hands Make Light Work: Citizens Changing the Face of Modern Science.

Jordan, R., Crall, A., Gray, S., Phillips, T., & Mellor, D. (2015). Citizen science as a distinct field of inquiry. Bioscience, 65(2), 208-211.

Irwin, A. 1995. Citizen science: A Study of People, Expertise, and Sustainable Development. London and New York: Routledge.

Kobori, H., Dickinson, J. L., Washitani, I., Sakurai, R., Amano, T., Komatsu, N., ... & Miller-Rushing, A. J. (2016). Citizen science: a new approach to advance ecology, education, and conservation. Ecological research, 31(1), 1-19.

Marchezini, V., Trajber, R., Olivato, D., Munoz, V. A., de Oliveira Pereira, F., & Luz, A. E. O. (2017). Participatory early warning systems: youth, citizen science, and intergenerational dialogues on disaster risk reduction in Brazil. International Journal of Disaster Risk Science, 8(4), 390-401.

Niemelä, J. (2000, January). Biodiversity monitoring for decision-making. In Annales Zoologici Fennici (pp. 307-317). Finnish Zoological and Botanical Publishing Board.

Oberhauser, K., & Prysby, M. D. (2008). Citizen science: creating a research army for conservation. American Entomologist, 54(2), 103-104.

Pocock, M. J., Chandler, M., Bonney, R., Thornhill, I., Albin, A., August, T., ... & Jackson, C. (2018). A vision for global biodiversity monitoring with citizen science. In Advances in ecological research (Vol. 59, pp. 169-223). Academic Press.

Raddick, M. J., Bracey, G., Gay, P. L., Lintott, C. J., Cardamone, C., Murray, P., ... & Vandenberg, J. (2013). Galaxy Zoo: Motivations of citizen scientists. arXiv preprint arXiv:1303.6886.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., ... & Nykvist, B. (2009). A safe operating space for humanity. nature, 461(7263), 472-475.

Roy, H. E., Pocock, M. J., Preston, C. D., Roy, D. B., Savage, J., Tweddle, J. C., & Robinson, L. D. (2012). Understanding citizen science and environmental monitoring: final report on behalf of UK Environmental Observation Framework.

SCISTARTER (2020). Disponível em: scistarter.org Acesso: 27 de julho de 2020.

Weeser, B., Kroese, J. S., Jacobs, S. R., Njue, N., Kemboi, Z., Ran, A., ... & Breuer, L. (2018). Citizen science pioneers in Kenya–A crowdsourced approach for hydrological monitoring. Science of The Total Environment, 631, 1590-1599.

Weyhenmeyer, G. A., Mackay, M., Stockwell, J. D., Thiery, W., Grossart, H. P., Augusto-Silva, P. B., ... & Kirillin, G. (2017). Citizen science shows systematic changes in the temperature difference between air and inland waters with global warming. Scientific reports, 7, 43890.

Whitelaw, G., Vaughan, H., Craig, B., & Atkinson, D. (2003). Establishing the Canadian community monitoring network. Environmental monitoring and assessment, 88(1-3), 409-418.

Zheng, H., Yang, H., Long, D., & Hua, J. (2017). Monitoring surface water quality using social media in the context of citizen science. Hydrology and Earth System Sciences, 21(2), 949.

ARTIGO 01 – CITIZEN SCIENCE AND THE ENVIRONMENTAL MONITORING: A GLOBAL SYSTEMATIC MAPPING OF SCIENTIFIC LITERATURE

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Abstract

The potential application of citizen science has been extensively explored in scientific literature. Therefore, comprehending the state of the art in scientific literature on this subject, as well as biases and future trends, is crucial for planning future studies. Therefore, this paper aimed to synthesize the global scientific literature on citizen science-based environmental monitoring, therefore, identifying the gaps, biases, and trends in the scientific literature. We utilized the Web of Science and Scopus databases for our research, conducting an in-depth analysis of 1,059 papers focused on citizen science-based environmental monitoring. Over the years, there has been a significant increase in the number of papers. However, our analysis revealed certain biases, such as a disproportionately lower number of articles focusing on aquatic environments compared to terrestrial environments. Notably, 86% of the sample consisted of data collected either through online platforms/sites or through contributory data collection in loco. We observe that "general public" category focused most of the studies on different biological groups and on distinct environmental phenomena. The keyword analysis shows us that there is a trend for using a preferential variety of keywords after 2015, demonstrated the increase of the thematic about citizen science over the years. Citizen science has been expanding scientific knowledge and making the relationship between science and society more inseparable. However, future studies should aim to reduce these taxonomic and geographic asymmetries, further enhancing the potential of citizen science.

Keywords: community science, public participation, monitoring, structured mapping, scientometrics, terrestrial environment

Introduction

What do you do with your free time? To play soccer, tennis, swim, or picnic in the park. All these things can be the first thing that comes to our minds. But many people voluntarily use their free time to contribute to science as citizen scientists. Citizen Science (CS) refers to the common people that are committed to asking questions, collecting data, or interpreting results as non-professional scientists (Miller-Rushing et al, 2012, but see Haklay et al. 2021 for more definitions). In this case, common people refer to those outside universities/colleges or some science institution, for example. The term citizen science did not exist until the 20th century. It was coined simultaneously by Alan Irwin in 1995 in the United Kingdom and Rick Bonney in the United States in 1996 (Robinson et al; 2018). Currently, there was an “explosion” of “amateur” environmental monitoring after the internet and smartphones arise resulting in the get accurate data because of the big volume of information that volunteers can gather in research around the planet in different areas (Bonney, 2021).

Citizen scientists are doing science as amateur observers, monitors, or data collectors (e.g., Devictor et al., 2010; Phillips et al., 2021; Harley and Kinsela, 2022). Nowadays there are many projects on the internet that ordinary people can contribute it (Dickson and Bonney, 2012, p. 1; Cavalier et al., 2020, p. 45-133). For example, the Cornell Lab of Ornithology, the North American Breeding Bird Survey, and the Audubon Christian Bird as successful projects in the US (Bonney et al; 2014, Kasperowski and Hillman; 2018) as well as the British Trust for Ornithology in the UK (Silvertown, 2009). This kind of consideration has a great constructive model to sustain environmental monitoring mainly for the possibility and frequency of observations by common people (Lehtiniemi et al; 2020).

Environmental projects involving citizen science vary greatly across regions, scopes, and time durations, consequently leading to variations in data quality and the produced articles. Currently, citizen science data can be classified into structured actions - projects in which citizen scientists are trained and monitored by scientists; semi-structured actions - citizen scientists have minimal contact with manuals and guides developed by researchers; and unstructured actions - where no specific guidelines are provided, and citizen scientists' observations are opportunistic and incidental (e.g., Johnston et al. 2023). Moreover, the type of data can generate different biases, such as unstructured actions potentially over-representing species with larger body sizes (Callaghan et al. 2021)

Therefore, the variety of citizen science projects and the distinct purposes among different countries worldwide (Conrad and Hilchev, 2011) along with the expansion of environmental monitoring, result in a significant number of articles being produced on this subject. In light of this, techniques for literature review and synthesis are crucial to recognize trends in scientific literature (Fink, 2019) and guide future work towards reducing asymmetries (Booth et al., 2021).

Considering the significant increase in the number of articles on citizen science in environmental monitoring, and the need to produce a synthesis on this topic, the objective of this paper was to conduct a systematic review in the form of a systematic mapping of the global scientific literature on citizen science-based environmental monitoring. For that, we have the following questions: i) Is there a temporal trend for the papers? ii) what is the type of study of the papers? iii) Which biological group or environmental phenomenon were monitored by citizen scientists? iv) Are citizen science studies biased towards any specific type of environment (terrestrial, aquatic, or aerial)? v) What types of volunteers are found in the analyzed papers? vi) What is the data source of the analyzed publications? i.e. How do scientists obtain the information generated by citizen scientists? vii) Do the different types of volunteers tend to monitor a particular biological group or environmental phenomenon more frequently? viii) Is there a temporal dynamism regarding the topics (based on keywords) in citizen science articles over the years, and what are these changes?

Materials and Methods

Literature Search

In this paper, we work on specific criteria to search documents on the Web of Science (WoS) and Scopus databases in April 2021. Considering any time of databases (1945 to 2020), the first paper on search appeared in 1971 (Scopus) the next between 1997 and 1999 all papers this period being out of the environmental monitoring by citizen science. This way, the analysis was based on papers published between 2000 to 2020. We used the following terms and Boolean structure to TITLE only: “citizen* science*”. We chose to search by title because we believe that searching in other parts of the article (e.g., abstract and keywords) would increase the number of articles unrelated to the theme. By searching only by title, there is greater specificity in the search, reducing sampling errors.

In our survey, we identified 1,872 papers on Scopus and 1,601 on WoS. After merging both datasets and removing duplicates (papers that appeared simultaneously on both Scopus and WoS), we were left with a total of 1,640 papers. However, in order to maintain the focus on environmental monitoring, we had to exclude papers unrelated to the subject, such as those in astronomy, social science, or psychology. As a result, our final dataset consisted of 1,059 papers (Fig. 1).

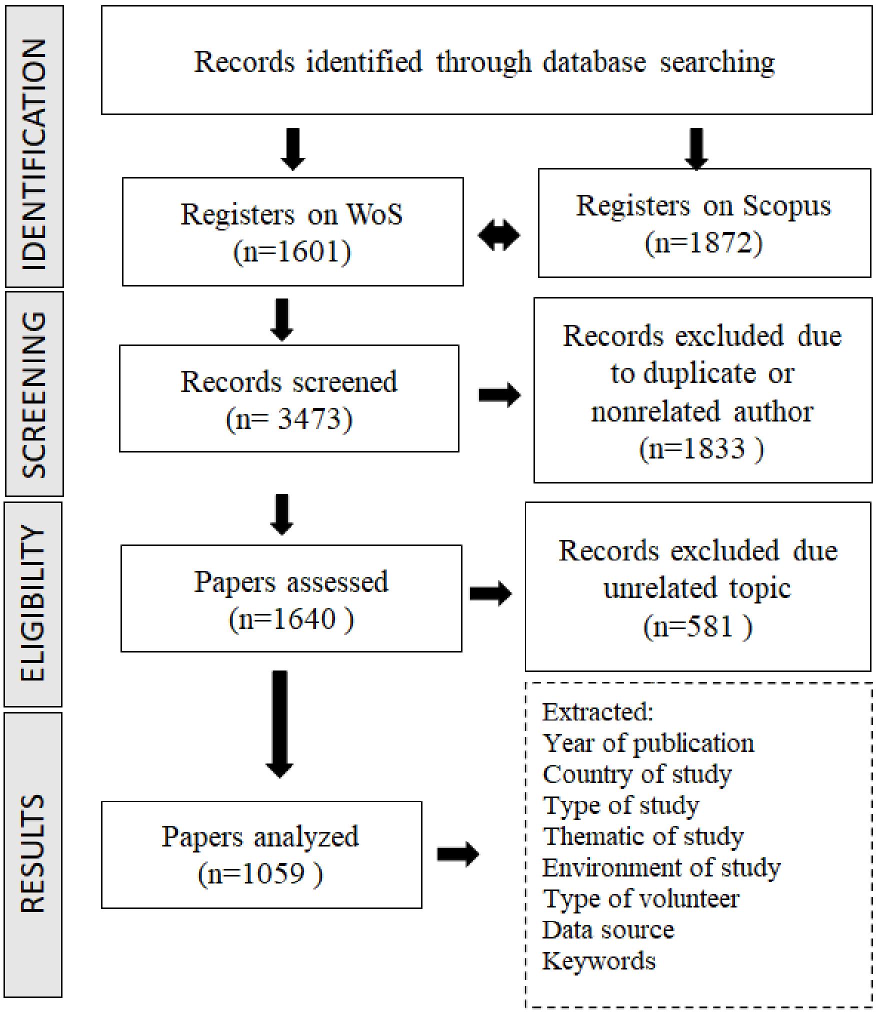


Fig.1. Methodological procedure since a search on WoS and Scopus databases went through for removing duplicates and unrelated topics until the final worksheet was set to statistical analysis.

Classification of the papers

Each paper was classified considering: i) Year of publication, ii) Country of study, iii) Type of study (see detail above); iv) Variable monitored by citizen scientist: Biological group (taxon), or Environmental phenomenon; v) Environment of study; vi) Types of volunteers; vii) Data Source; and viii) keywords. All these pieces of information were listed by reading the abstract or the full paper.

Some papers did not have explicit information about the country or region of study, therefore we classified them as a “no_detect” and others only regions, for example, the Mediterranean Sea, East Africa, or Eurasia. The only one that we considered a country was the UK, the other, as they are more extensive, we considered regions, as well as, we still had global papers. They don’t get into the analysis.

The type of study encompassed three main categories: environmental monitoring (involving citizen scientists directly monitoring organisms or environmental variable), review/theoretical (comprising review papers or papers focusing on theoretical aspects of environmental monitoring by citizen scientists), and monitoring experiments. Thematic of study was considered into two categories: biological group and environmental phenomenon. Otherwise, both could be monitored biological group (i.e., birds, plants, mammals), environmental phenomenon (i.e., climate change, fire, roadkill), or both at the same time. The data could be obtained in three different environments of study: i) terrestrial, ii) aquatic, and iii) aerial (i.e., papers mostly from pollutants disasters, for example, radioactive monitoring, pouring toxic pollutants, gas, etc.). We classified citizen scientists’ profiles (volunteers) into three types: 1) general public (ordinary people), 2) Students (primary, secondary, or high school - exclusives), and 3) College students.

We define the “Data Source” as the means through which CS data is incorporated into the paper. We identified three clustering of data source: a) social network/media (e.g., in-person or online platforms), b) Mobile applications (e.g., capturing photos and getting the geographic coordinates) or Citizen Science platforms (e.g., INaturalist, EBird, among others), and c) contributory data collect (i.e., getting notes independently).

Data Analysis

A portion of the results were analyzed descriptively, examining the temporal trend and article counts within different categories. Furthermore, multivariate statistics were employed to synthesize the findings. These analyses are described below.

Correspondence Analysis (CA) was employed as an analytical tool to assess the relationship between different categories of the present paper. We performed two CA: Relationship between the profile of citizen science: i) with types of biological groups; or ii) type of environmental phenomenon. The significance of the relationship was analyzed using Pearson's chi-square test, with a significance level set at $p < 0.05$. The analysis of temporal keywords was conducted using Principal Component Analysis (PCA) based on the correlation matrix of the 3,024 keywords' frequency. This was followed by Varimax rotation of axes to assess the similarity of keywords used in the papers across different years (Carneiro et al., 2008; Nabout et al., 2012). The measure was log-transformed to enhance the analysis. In our temporal scale, the most frequently used keyword in the papers was "citizen science" since it was included in the search criteria. We excluded this keyword from the statistical analysis. Synonymous words were combined, and a cut-off point was applied, considering words that appeared in more than three papers, resulting in a total of 169 keywords (Nabout et al., 2022).

We used Program R for the PCA and CA to make all the figures (R Core Team, 2022). The PCA was performed using the *prcomp* function in the stats package, the CA was performed using the FActoMineR package (Lê et al., 2008), and the figures were created using the package ggplot2 (Wickhan, 2016). All data used to perform the figures and statistical analysis are available in Supplementary Material.

Results

We found a total of 1,059 papers that studied CS in environmental monitoring, and over the last two decades, the number of publications about CS in environmental monitoring has increased along the years, even considering different thematic or environment of study (Figure 2). Moreover, the most part of the citizen science literature was focused on biological groups (fig. 2A) and terrestrial studies (Fig. 02 B).

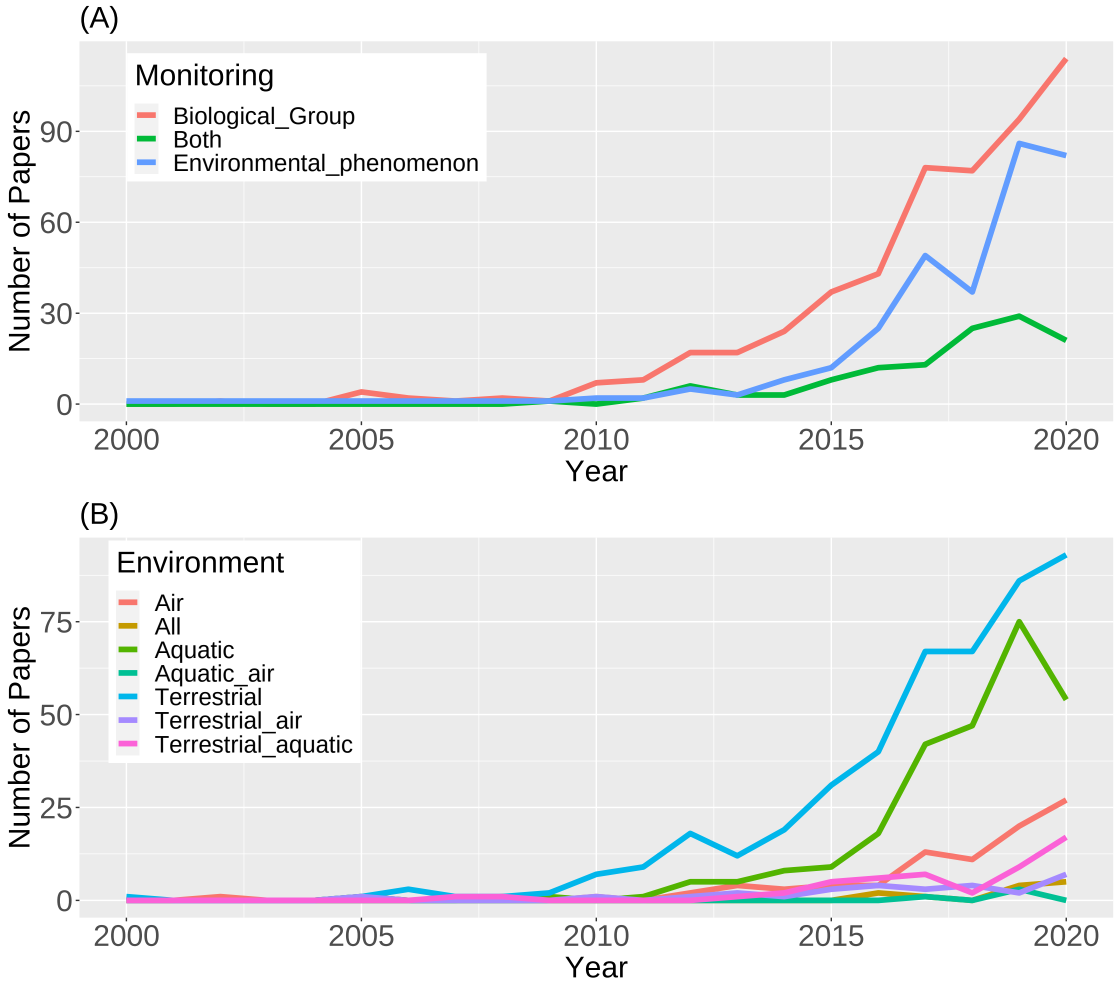


Fig. 2. Temporal trend of the number of papers: these publications have a different scope (A) and environment (B). We measure the temporal trend through the interaction of different scopes and environments.

According to the type of study, about 80% (n=850) of the papers were directly conducting environmental monitoring followed by 16% (n=170) Review/Theoretical, and 4% (49) of papers related to monitoring experiments (Fig. 3A). We found 14 biological groups (taxon) in the sample of papers being bird/nest the most studied (n=167) followed by insects (n=148), plants (n=110), and mammals (n=101) (Fig. 3B). The environmental phenomenon was integrated into 12 topics being specific environments (e.g., stream, river, forest), pollutants/litter, the relation scientists/volunteers, and water, (respectively, n= 189, 92, 80, 55 papers) the topics most frequents on the sample (Fig. 3C). Furthermore, according to environment of study the CS papers were developed in the terrestrial environment (n=458), followed by aquatic (n=267), and aerial (n=91), all these unique environments (Fig. 3D). About 96 papers worked in two or three environments at the same time. It was possible to analyze 751 papers on an organism, 608 papers on a specific subject, and 912 papers with considerable certainty to classify the environment.

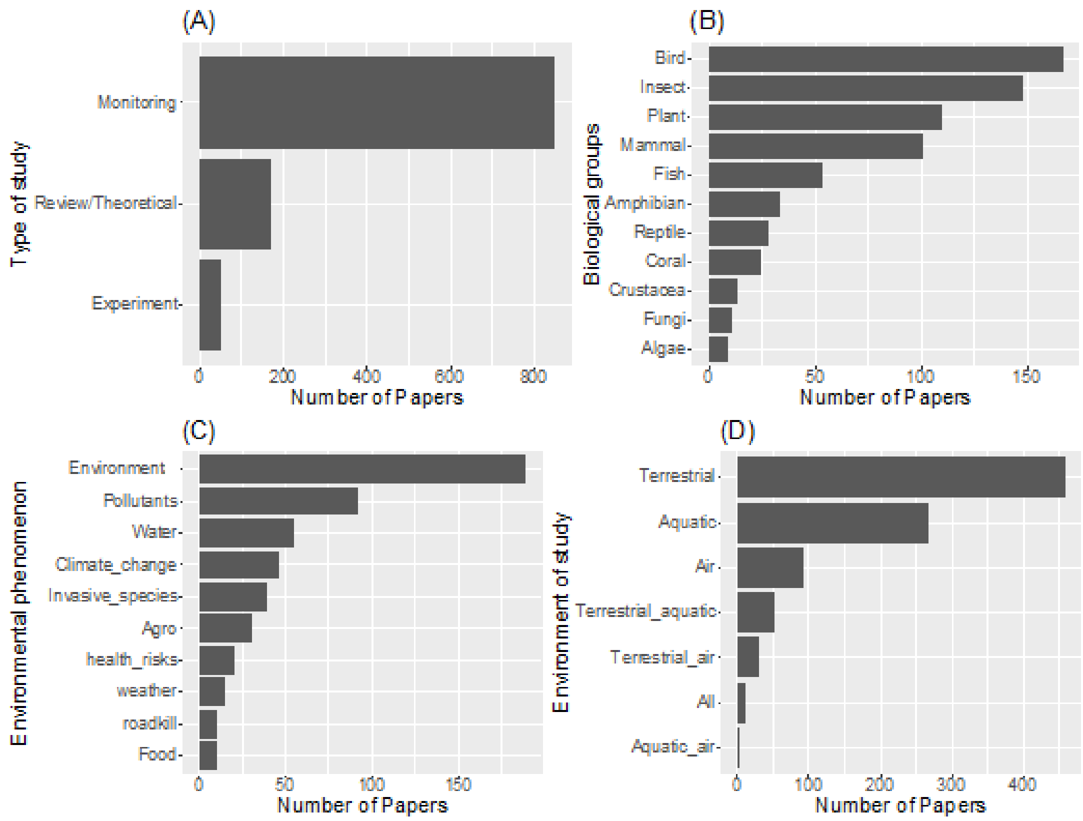


Fig. 3. Number of papers considering: (A) Type of study; (B) Biological group; (C) Environmental phenomenon explored on CS paper; (D) Environment of the study.

From this perspective, numerous countries have demonstrated their commitment to publishing studies pertaining to CS in environmental monitoring. A total of 99 countries contributed to the publications in our analysis. Among them, the United States, United Kingdom, and Australia emerged as the top three countries with the highest participation in papers worldwide during our selected period (Fig.

4).

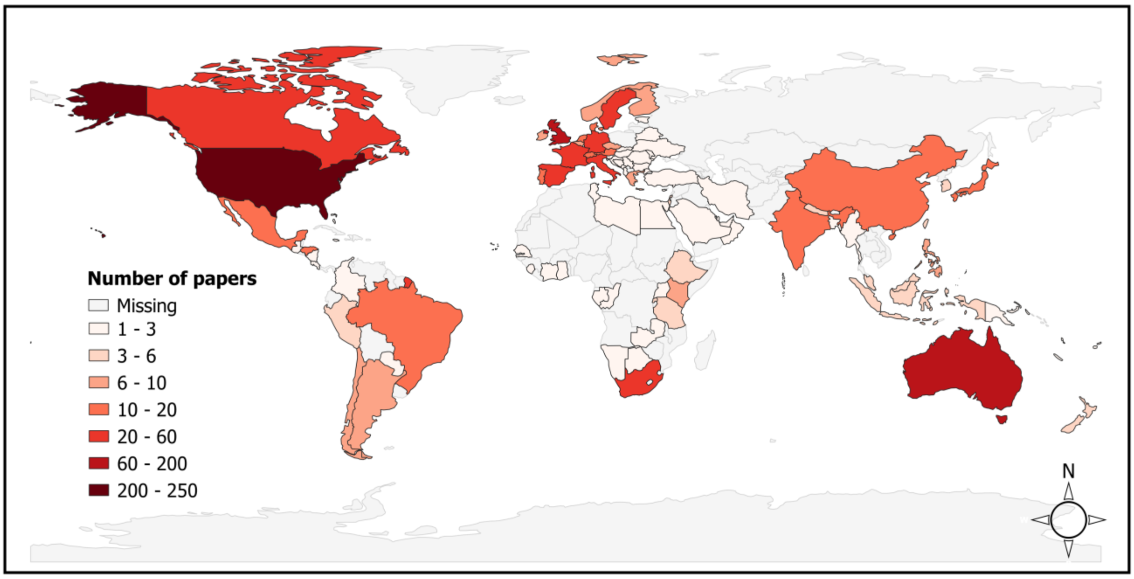


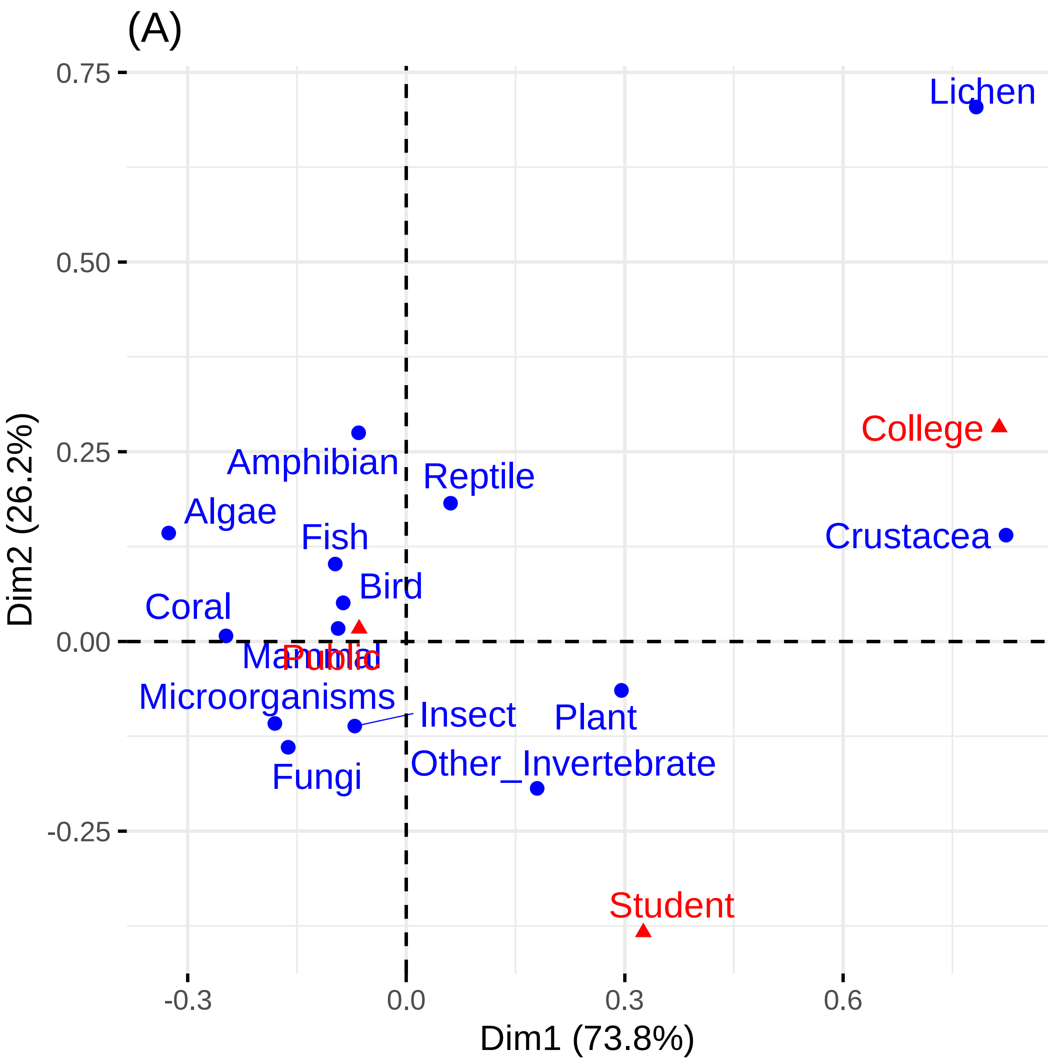
Fig. 4. Global Distribution of Scientific Research Papers on Citizen Science Applications in Environmental Monitoring by Country

It was perceptive that the ordinary people (i.e., common people) as citizen scientists were the most participative tendency in CS projects. It was 81% (861 papers) that the public, in general, participated in some level of the paper while students/teachers and college students accounted for 7% (75 papers) and 3% (31 specific papers) respectively. In this case, general public get this data through social media (38 papers), App/CS platform (393 papers), and contributory data collected (i.e., CDC - collected by ordinary people exclusive to the paper – 524 papers). Most of the data was getting into the papers through general public as a profile of citizen scientist and App/CS platforms, or contributory data collection (CDC) as a data source totalizing 86% of the sample of papers (Tab. 1).

Tab. 1. Frequency of data distribution as a form to get this data into the paper (data source) to a total number of papers (% of 1,059 papers). CDC is contributory data collected - i.e., collected by ordinary people exclusive to the paper.

	SOCIAL NETWORK/MEDIA	APP/CS PLATFORMS	CDC
GENERAL PUBLIC	3.5	37.1	49.4
STUDENTS/TEACHERS	0.1	3.3	4.2
COLLEGE STUDENTS	0.1	1.5	1.7

The data were explored for identifying patterns from the perspective of citizen scientists to two categories: biological group, and environmental phenomenon. We found the significant relationship between citizen science's profile with biological groups (chi=43.93, degree freedom=26; p=0.015), or environmental phenomenon (chi=45.39, degree freedom=20; p<0.001), in other words, the category general public, focused most of the studies on different biological groups and also on distinct environmental phenomenon (Fig. 5).



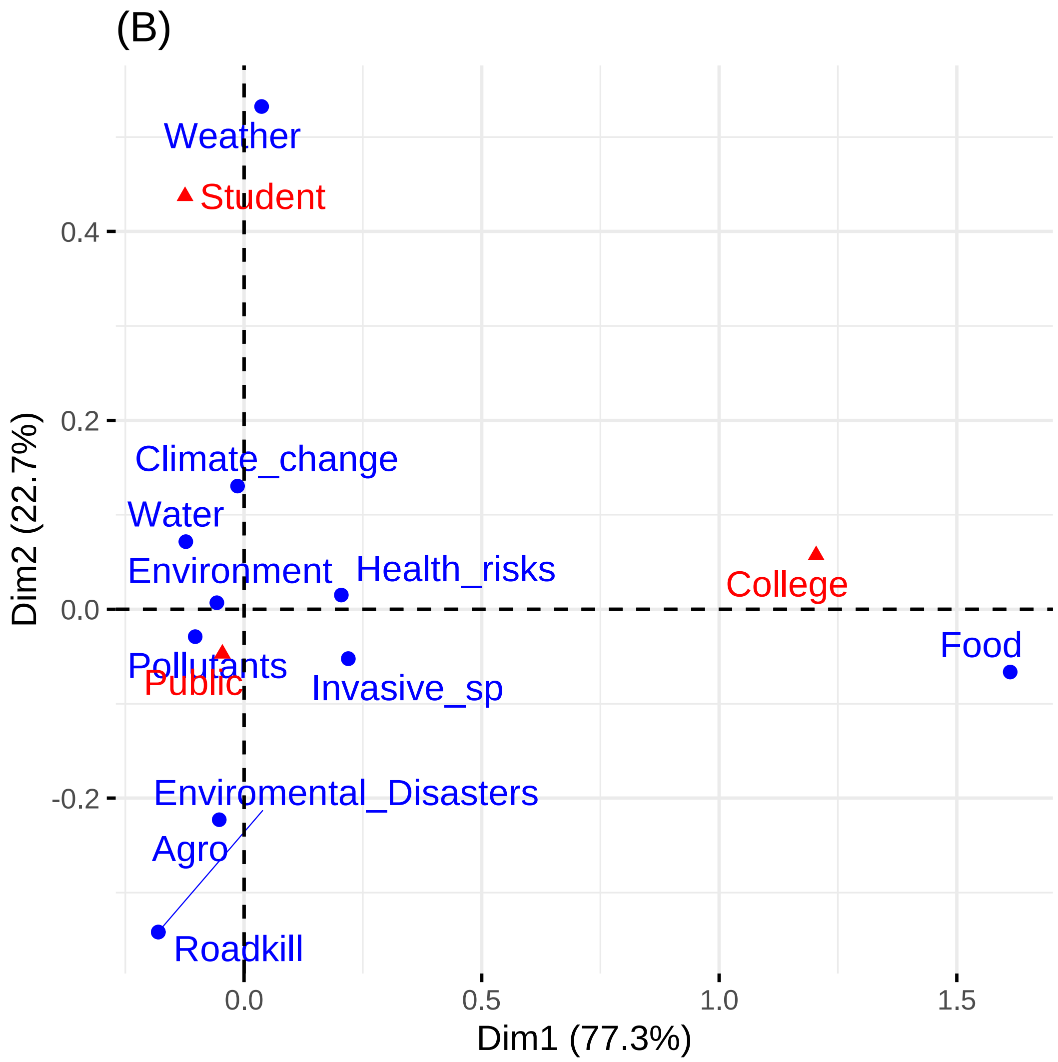


Fig. 5. Correspondence Analysis between citizen scientists' profiles to the biological groups (A), environmental phenomenon (B). The citizen scientists are in red while the factors analyzed are in blue.

Additionally, the authors' keywords were synthesized through Principal Component Analysis (PCA). The variability of the data was 68% explained by two principal components. Accordingly in the test, the words used until 2014 were more similar but, since 2015, there has been an increase in the variety of keywords used, with the most frequent of commons terms being "public participation", "urbanization", "science education", "species distribution model, "biodiversity" and "conservation". It´s important to highlight the year 2020 as an outliner over influence on axes 2 of the graph with the most frequent of commons terms being "sustainable development goal", "Australia", "COVID 19", "full annual cycle", "transdisciplinary research", and "co. creation". (Fig. 6).

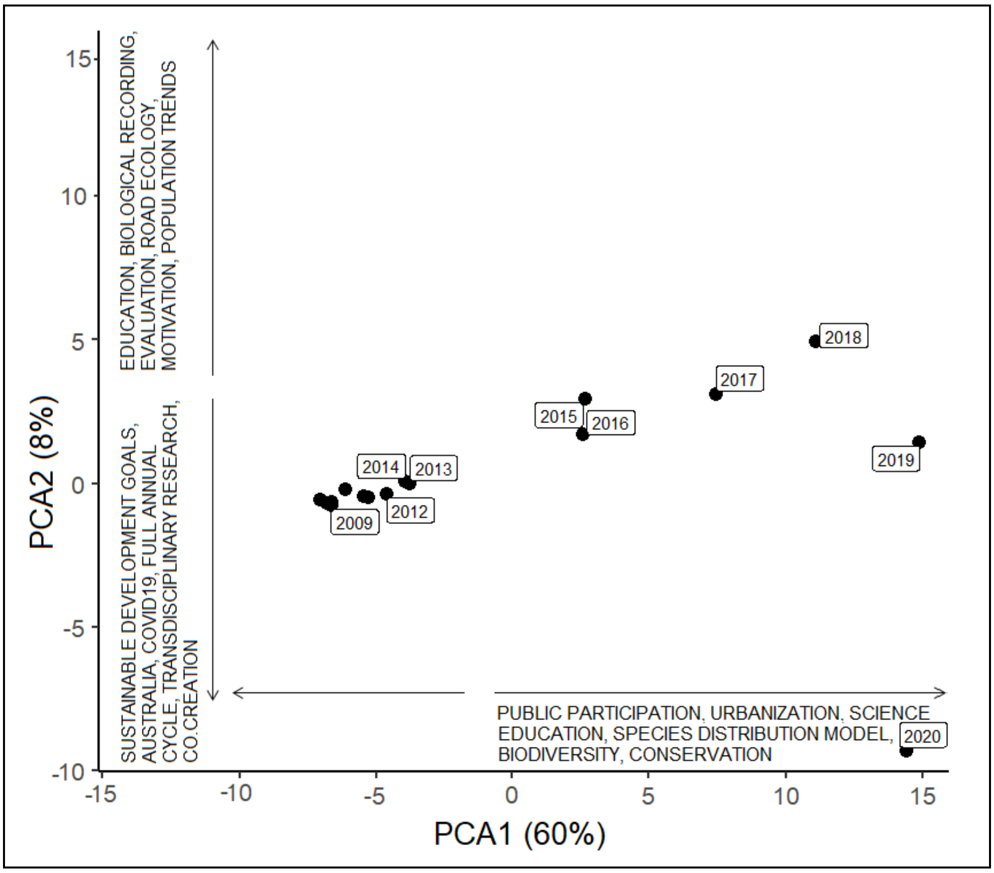


Fig. 6. PCA scores using the keywords' frequencies from papers on citizen science environmental monitoring. Only the most important keywords for the formation of axes 1 and 2 are presented. The list of all keywords and their relationships to the PCA axes can be found in Supplementary Material.

Discussion

We revised the global scientific literature about contributions of citizen science in environmental monitoring. The synthesis showed the temporal increase of number of papers, and some biases, for example, the birds and insects were the biological groups most evaluated; the great part of the environmental of study was terrestrial regions. In addition, citizen scientists were mostly represented by the general public, with a volunteer profile, which has contributed through data collection or insertion of information in the App/CS platforms. Despite these indicators providing a snapshot of citizen science studies, PCA has shown that there is a temporal dynamism, with new themes being incorporated over the years, and that the diversity of topics/subjects related to citizen science has increased over time.

Recent studies have shown that there are geographical and taxonomic biases in data derived from citizen science (e.g., Fernandez and Nakamura, 2015; Tiago et al., 2017; Callaghan et al., 2021). However, even data obtained by scientists themselves also exhibit biases (e.g., Almeida et al., 2021). Therefore, detecting and understanding the causes of biases are fundamental for future research. In this study, we found biases based on scientific literature, and one of the detected biases is a preference for studies with birds. This can be explained by the fact that birds are more attractive to the public, and therefore, flagship species tend to be more recognized and studied (Żmihorski et al., 2013; Gomes et al., 2019). The pioneers' studies of birdwatching indicated the importance of birds as a connection between human beings and nature (Moss, 2013). In recent years images of birds are covered by US magazines rather than other species to illustrate and promote conservation goals converging as the dominant topic in our sample of publications (Clucas et all., 2008; Follet and Strezov, 2015). The first article with birds on this sample is from 2005 from Michigan Bird Records Committee (see Lepczyk, 2005). Coincidentally, eBird is a project managed by Cornell Lab of Ornithology that has been growing since 2002 integrating volunteer amateur observers with more than 100 million bird sightings contributed each year by eBirders around the world (www.ebird.org). There is a set of conditions that indicate that the contribution of projects like eBird, INaturalist, since 2008 (www.inaturalist.org), contributed to higher numbers of publications about environment monitoring by citizen scientists after this period as the dissemination of the term citizen scientist, especially with birds.

In relation to the most environment studies, showed that terrestrial environments have more publications, followed by aquatic environment. Indeed, the bias towards research in terrestrial environments has been greater even among other research (e.g., in global climate change – Nabout et al. 2012). The accessibility and ease of equipment and monitoring specifically designed for terrestrial environments are likely contributing factors to the prevalence of studies in this environment.

The United States, The United Kingdom, and Australia stand out in publications on environmental monitoring by citizen scientists. Technology and engagement have a fundamental place in this process. Public engagement depends on the expansion of technology to make networks for those called non-traditional audiences provoking a sense of belonging to the process (Aristeidou et al., 2017). Mobile applications and wireless sensors are examples of developing CS (Newman et al., 2012; Catlin-Groves, 2012). From this perspective, these countries have invested in different forms of technology, more than developing countries (Alvarado et al.; 2020), since CS platforms with apps for common people to understand biodiversity, ecology, or environmental sciences submit and analyze online data (Kobori et al., 2016). The other face of this bias is the reduced number of articles in countries within the Neotropical region.

Countries in the neotropical region are important to the biodiversity of the planet, however, gaps in studies were observed in these regions. In addition, this region has been slowing in nonbirds records (Amano et. al. 2016). Even though the efforts in the neotropical area have increased much because of citizen science practitioners' attempts (Brazil=15 papers, Mexico=19 papers) but they already point out that inaccessibility is a factor that does not allow or bring difficulty to scientific evidence for the conservation of the tropical place (Amano et al., 2016). Therefore, for increase the participation of CS in neotropical region is necessary the Government’s and private’s participation. Government policy as well as private support is like a seal providing financial support and commitment as an important piece for the future of the project. For example, the Great Koala Count project was developed in 2012 in Australia. It´s an example of engagement as well as from an organization gathering radio, social media activity, internet with online videos, and resources for school projects, and of course, they used an app for smartphones and a webpage to get for themselves the data (Hollow et al; 2015).

We quantified the categorical data of citizen scientists' profiles, considering factors that could influence their collected data. Through our analysis, we discovered a bias: the general public exhibited a greater focus on studying biological groups and environmental phenomena. Possibly, part of this bias is due to the higher number of articles being concentrated on the general public. In fact, there are fewer studies focusing, for example, on university or high school students. Therefore, it is recommended that projects using structured, semi-structured, and unstructured actions should aim to reduce asymmetries, for example, developing projects focused on less evaluated biological groups, and/or diversify citizen science groups.

Despite the biases detected in studies on citizen science, we have also observed a temporal shift in the addressed topics and an increase in the diversity of these themes. Furthermore, some of the explored themes in CS articles are of great global importance and have been present in the keywords, such as sustainable development, public participation, and conservation. Therefore, citizen science plays a decisive role in addressing these problems (e.g., Albagli and Iwama 2022), and integrating society and academia are fundamental strategies for future research. Additionally, keywords such as "species distribution model" demonstrate the use of data collected by citizen scientists (e.g., geographic coordinates) for ecological research aiming to estimate species distribution (e.g., Tiago et al. 2017). This temporal shift in research reflects changes in societal demands. For instance, CS articles related to COVID-19 research were found in 2020. The pandemic was a sad mark for the world and Citizen scientists worldwide attempted to understand this catastrophe and have been influencing the kind of monitoring at this point.

Conclusion

This study conducted a global systematic review of articles that utilized citizen science for environmental monitoring, and the results found have the potential to guide future studies. In general artifices like technology, flagship species like birds, and institutional support to biodiversity conservation give us the engagement necessary to keep with good environmental projects to citizen science. Thereby, we think that the organization of citizen science and new internet solutions to set data, besides engagement and training of citizen scientists are essential factors in citizen science culture’s future that might be shared with neotropical countries for setting this gap of publications on CS environmental monitoring. Inclusive, share the citizen science experience through school projects with young people in developing countries.

References

Abdi, H., & Béra, M. (2014). Correspondence Analysis.

Albagli, S., & Iwama, A. Y. (2022). Citizen science and the right to research: building local knowledge of climate change impacts. Humanities and Social Sciences Communications, 9(1), 1-13.

Alvarado, C. M. M., Rendon, A. Z., & Pérez, A. D. S. V. (2020). Integrating public participation in knowledge generation processes: Evidence from citizen science initiatives in Mexico. Environmental Science & Policy, 114, 230-241.

Amano, T., Lamming, J. D., & Sutherland, W. J. (2016). Spatial gaps in global biodiversity information and the role of citizen science. Bioscience, 66(5), 393-400.

Aristeidou, M., Scanlon, E., & Sharples, M. (2017). Profiles of engagement in online communities of citizen science participation. Computers in Human Behavior, 74, 246-256.
ACSA: Australian Citizen Science Association. Available from: <https://citizenscience.org.au/> [December 2022].

Beck, J., Ballesteros-Mejia, L., Nagel, P., & Kitching, I. J. (2013). Online solutions and the 'W allacean shortfall': what does GBIF contribute to our knowledge of species' ranges? Diversity and Distributions, 19(8), 1043-1050.

Bonney, R., Phillips, T. B., Enck, J., Shirk, J., & Trautmann, N. (2014). Citizen science and youth education. National Research Council Committee on Out-of-School Time STEM. Washington, DC: National Research Council.

Bonney, R. (2021). Expanding the impact of citizen science. BioScience, 71(5), 448-451.

Booth, A., Sutton, A., Clowes, M., & Martyn-St James, M. (2021). Systematic approaches to a successful literature review.

Brown, E. D., & Williams, B. K. (2019). The potential for citizen science to produce reliable and useful information in ecology. Conservation Biology, 33(3), 561-569.

Bybee, R. W. (2011). Scientific and engineering practices in K-12 classrooms: Understanding a framework for K-12 science education. Science and Children, 49(4), 10.

Carneiro, F. M., J. C. Nabout & L. M. Bini, 2008. Trends in the scientific literature on phytoplankton. Limnology 9(2): 153–158

Callaghan, C. T., Poore, A. G., Hofmann, M., Roberts, C. J., & Pereira, H. M. (2021). Large-bodied birds are over-represented in unstructured citizen science data. Scientific reports, 11(1), 19073.
Catlin-Groves, C. L. (2012). The citizen science landscape: from volunteers to citizen sensors and beyond. International Journal of Zoology, 2012.

Cavalier, D., Hoffman, C. and Cooper, C.; (2020). Citizen Science: How you can contribute to scientific research and make a difference. Portland, Oregon: Timber Press, Inc.; p. 45-133.

Chandler, M., See, L., Copas, K., Bonde, A. M., López, B. C., Danielsen, F., ... & Turak, E. (2017). Contribution of citizen science towards international biodiversity monitoring. Biological Conservation, 213, 280-294.

Clucas, B., McHugh, K., & Caro, T. (2008). Flagship species on covers of US conservation and nature magazines. Biodiversity and Conservation, 17(6), 1517-1528.

Colwell, R. K., & Coddington, J. A. (1994). Estimating terrestrial biodiversity through extrapolation. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 345(1311), 101-118.

Conrad, C. C., & Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: issues and opportunities. Environmental monitoring and assessment, 176(1), 273-291.

Cooper, C. (2016). Marking a Tide. In Citizen Science: How ordinary people are changing the face of discovery. Abrams. The Overlook Press, New York, p 3-11.
CSA: Citizen Science Association (2022). Available from: < https://citizenscience.org/> [December 2022].

Dahlin, K. M., P. L. Zarnetske, Q. D. Read, L. A. Twardochleb, A. G. Kamoske, K. S. Cheruvelil & P. A. Soranno, 2021. Linking Terrestrial and Aquatic Biodiversity to Ecosystem Function Across Scales, Trophic Levels, and Realms. Frontiers in Environmental Science 9. https://doi.org/10.3389/fenvs.2021.692401.

De Almeida, T. C., Tessarolo, G., Nabout, J. C., & Teresa, F. B. (2021). Non‐stationary drivers on fish sampling efforts in Brazilian freshwaters. Diversity and Distributions, 27(7), 1224-1234.

Devictor, V., Whittaker, R. J., & Beltrame, C. (2010). Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. Diversity and Distributions, 16(3), 354–362. doi:10.1111/j.1472-4642.2009.00615.x

Dickinson, J., & Bonney, R. (2012). Why citizen science? In Citizen Science. Public participation in environmental research, Cornell University Press, p 1-14.
eBird, 2022. Available from: https://ebird.org/about [December 2022].
ECSA: European Citizen Science Associatin. Available from: https://www.ecsa.ngo/ [December 2022].

Fernández, D., & Nakamura, M. (2015). Estimation of spatial sampling effort based on presence-only data and accessibility. Ecological Modelling, 299, 147-155.
Fink, A. (2019). Conducting research literature reviews: From the internet to paper. Sage publications.

Follett, R., & Strezov, V. (2015). An analysis of citizen science based research: usage and publication patterns. PloS one, 10(11), e0143687.
GBIF: The Global Biodiversity Information Facility (2022) What is GBIF? Available from: <https://www.gbif.org/what-is-gbif> [January 2020].

Gibson, H., & Venkateswar, S. 2015. Anthropological engagement with the Anthropocene: a critical review. Environment and Society: Advances in Research, 6, 5–27. DOI:10.3167/ares.2015.060102.

Gomes, M. A. D. A., Goncalves, T. V., Teresa, F. B., da Cunha, H. F., Lima, F. P., & Nabout, J. C. (2019). High school students' knowledge of endangered fauna in the Brazilian Cerrado: a cross-species and spatial analysis. PloS one, 14(4), e0215959.

Groulx, M., Brisbois, M. C., Lemieux, C. J., Winegardner, A., & Fishback, L. (2017). A role for nature-based citizen science in promoting individual and collective climate change action? A systematic review of learning outcomes. Science Communication, 39(1), 45-76.

Haklay, M.; Dörler, D.; Heigl, F.; Manzoni, M.; Hecker, S. and Vohland, K. 2021. What is citizen science? The challenges of definition. In: Vohland, K., et al.,The Science of the Citizen Science. pp. 13-33.

Harley, M. D., Kinsela, M. A. 2022. CoastSnap: A global citizen science program to monitor changing coastlines. Continental Shelf Research, 245, 104796

Higa, M., Yamaura, Y., Koizumi, I., Yabuhara, Y., Senzaki, M., & Ono, S. (2015). Mapping large-scale bird distributions using occupancy models and citizen data with spatially biased sampling effort. Diversity and Distributions, 21(1), 46-54.

Harris, K., Sithole, A., & Kibirige, J. (2017). A Needs Assessment for the Adoption of Next Generation Science Standards (NGSS) in K-12 Education in the United States. Journal of Education and Training Studies, 5(9), 54-62.

Hollow, B., Roetman, P. E., Walter, M., & Daniels, C. B. (2015). Citizen science for policy development: The case of koala management in South Australia. Environmental Science & Policy, 47, 126-136.

Honorato-Zimmer, D., Kruse, K., Knickmeier, K., Weinmann, A., Hinojosa, I. A., & Thiel, M. (2019). Inter-hemispherical shoreline surveys of anthropogenic marine debris–A binational citizen science project with schoolchildren. Marine pollution bulletin, 138, 464-473.

INaturalist. 2022. Available from: < https://inaturalist.org/> [December 2022].

Johnston, A., Matechou, E., & Dennis, E. B. (2023). Outstanding challenges and future directions for biodiversity monitoring using citizen science data. Methods in Ecology and Evolution, 14(1), 103-116.

Kobori, H., Dickinson, J. L., Washitani, I., Sakurai, R., Amano, T., Komatsu, N., ... & Miller-Rushing, A. J. (2016). Citizen science: a new approach to advance ecology, education, and conservation. Ecological research, 31(1), 1-19.

Kang W, Nam S, Han Y, Lee S. Improved heading estimation for smartphone-based indoor positioning systems. 2012 Nov 29 Presented at: IEEE 23rd International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC);2012; Sydney, NSW, Australia. [doi: 10.1109/pimrc.2012.6362768]

Lehtiniemi, M., Outinen, O., & Puntila-Dodd, R. (2020). Citizen science provides added value in the monitoring of coastal non-indigenous species. Journal of Environmental Management, 267, 110608.

Lê, S., Josse, J., & Husson, F. (2008). FactoMineR: an R package for multivariate analysis. Journal of statistical software, 25, 1-18.

Lepczyk, C. A. (2005). Integrating published data and citizen science to describe bird diversity across a landscape. Journal of Applied Ecology, 42(4), 672-677.

Lima, N. E. D., Carvalho, A. A., Lima-Ribeiro, M. S., & Manfrin, M. H. (2018). Caracterização e história biogeográfica dos ecossistemas secos neotropicais. Rodriguésia, 69, 2209-2222.

Mackechnie, C., Maskell, L., Norton, L., & Roy, D. (2011). The role of 'Big Society'in monitoring the state of the natural environment. Journal of Environmental Monitoring, 13(10), 2687-2691.

Miller-Rushing, A., Primack, R., & Bonney, R. (2012). The history of public participation in ecological research. Frontiers in Ecology and the Environment, 10(6), 285-290.

Morrone, J. J. (2014). Biogeographical regionalisation of the Neotropical region. Zootaxa, 3782(1), 1-110.

Moss, S. (2013). A bird in the bush: A social history of birdwatching. Aurum.

Nabout, J. C., P. Carvalho, M. U. Prado, P. P. Borges, K. B. Machado, K. B. Haddad & T. N. Soares, 2012. Trends and biases in global climate change literature. Natureza & Conservaçao 10(1): 45–51.

Nabout, J. C., Machado, K. B., David, A. C. M., Mendonça, L. B. G., Silva, S. P. D., & Carvalho, P. (2022). Scientific literature on freshwater ecosystem services: trends, biases, and future directions. Hydrobiologia, 1-15.

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., & Crowston, K. (2012). The future of citizen science: emerging technologies and shifting paradigms. Frontiers in Ecology and the Environment, 10(6), 298-304.

Penner, L. A. (2002). Dispositional and organizational influences on sustained volunteerism: An interactionist perspective. Journal of social issues, 58(3), 447-467. DOI: https://doi.org/10.1111/1540-4560.00270

Phillips, T. B., Bailey, R. L., Martin, V., Faulkner-Grant, H., & Bonter, D. N. (2020). The role of citizen science in management of invasive avian species: What people think, know, and do. Journal of Environmental Management, 111709. doi:10.1016/j.jenvman.2020.111709

Pocock, M. J., Chandler, M., Bonney, R., Thornhill, I., Albin, A., August, T., ... &

Danielsen, F. (2018). A vision for global biodiversity monitoring with citizen science. In Advances in ecological research (Vol. 59, pp. 169-223). Academic Press.

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Robertson, T., Döring, M., Guralnick, R., Bloom, D., Wieczorek, J., Braak, K., ... & Desmet, P. (2014). The GBIF integrated publishing toolkit: facilitating the efficient publishing of biodiversity data on the internet. PloS one, 9(8), e102623.

Robinson, L. D., Cawthray, J. L., West, S. E., Bonn, A., & Ansine, J. (2018). Ten principles of citizen science. In Citizen Science: Innovation in open science, society, and policy (pp. 27-40). UCL Press.

Silvertown, J. (2009). A new dawn for citizen science. Trends in ecology & evolution, 24(9), 467-471.

Storksdieck, M., Shirk, J. L., Cappadonna, J. L., Domroese, M., Göbel, C., Haklay, M., ... & Vohland, K. (2016). Associations for citizen science: regional knowledge, global collaboration. Citizen Science: Theory and Practice, 1(2).

Tiago, P., Ceia-Hasse, A., Marques, T. A., Capinha, C., & Pereira, H. M. (2017). Spatial distribution of citizen science casuistic observations for different taxonomic groups. Scientific reports, 7(1), 1-9.

Tiago, P. (2017). The social context of citizen science projects. In Analyzing the role of citizen science in modern research (pp. 168-191). IGI Global.

Troudet, J., Grandcolas, P., Blin, A., Vignes-Lebbe, R., & Legendre, F. (2017). Taxonomic bias in biodiversity data and societal preferences. Scientific reports, 7(1), 1-14.

Tulloch, A. I., Possingham, H. P., Joseph, L. N., Szabo, J., & Martin, T. G. (2013). Realizing the full potential of citizen science monitoring programs. Biological Conservation, 165, 128-138.

UN (2016) Indigenous and Local Knowledge(s) and Science(s) for Sustainable Development. Scientific Advisory Board of the UN Secretary-General 12. https://unesdoc.unesco.org/ark:/48223/pf0000246104.

Wickham, H. (2016). Data analysis. In ggplot2 (pp. 189-201). Springer, Cham.

West, S. E., & Pateman, R. M. (2016). Recruiting and retaining participants in citizen science: what can be learned from the volunteering literature?. Citizen Science: Theory and Practice.

Yamamoto, J.K. 2020. Estatística, análise e interpolação de dados geoespaciais. São Paulo, Gráfica Paulo’s. 308p.

Żmihorski, M., Dziarska-Pałac, J., Sparks, T. H., & Tryjanowski, P. (2013). Ecological correlates of the popularity of birds and butterflies in Internet information resources. Oikos, 122(2), 183-190.

ARTIGO 02 - BIRDWATCHING INTO BRAZILIAN CITIES: REVEALING THE INFLUENCE OF LOCAL RESEARCH, GEOGRAPHIC AREA, ENVIRONMENTAL AND SOCIO-ECONOMIC FACTORS ON CITIZEN SCIENCE

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Abstract

Citizen science has greatly improved the study of biodiversity by providing large amounts of data. One of the most popular forms of citizen science is birdwatching, which involves ordinary individuals contributing to scientific observations. Nowadays, there are various platforms available to gather this information and provide scientists and policymakers with valuable data to aid in environmental conservation efforts. Given Brazil's vast biodiversity and the popularity of birdwatching in the country, citizen science can play a significant role in addressing various challenges. For instance, it can help shed light on species distribution patterns. To explore this further, we analyzed citizen science observations from GBIF between 1992 and 2022, focusing on Brazilian cities with more than 100,000 inhabitants, and examined how socio-economic and environmental factors influenced the data. Our analysis revealed a spatial bias in the distribution of citizen science observations, with a concentration of observations in the southeastern region of the country. To address this, we employed statistical techniques to remove spatial dependence and found that citizen science observations in Brazil are indeed influenced by these factors after three decades of data collection. Citizen science has proven instrumental in biodiversity research. Addressing biases and gaps in data, we can focus on taking necessary conservation actions, especially in tropical areas where biodiversity is particularly rich and faces significant threats.

Keywords: biodiversity monitoring, species distribution, environmental conservation, data analysis, spatial bias

Introduction

Citizen science has emerged as an important tool for studying biodiversity and monitoring the environment. It enables scientists to gather data on a large scale that would otherwise be challenging to obtain (McKinley et al., 2017). Birdwatching, a popular form of citizen science, plays a significant role in many programs that promote public awareness of the natural world. It can encourage ordinary citizens to collect data on bird populations and behaviors while observing and appreciating the diverse species in a particular area (Randler, 2023).

After the 2000s, eBird, iNaturalist, and GBIF (Global Biodiversity Information Facility), among others, emerged as significant platforms for citizen science, attracting scientists and individuals of all backgrounds to contribute at different levels (Bonney, 2021). They facilitate activities such as pushing forward computational techniques, monitoring bird populations and deepening the knowledge of avian migration ecology, tracking seasonal changes, providing insights for conservation policy and implementation, promoting education through student involvement, and addressing regional challenges (Meyer et al., 2015).

In Brazil, citizen science birdwatching has grown in popularity over the past few decades, and this trend has been driven by a variety of factors as a brazilian richness biodiversity, the need for conservation efforts, and the role of citizen science birdwatching in promoting conservation and scientific research (Piacentini et al., 2015). However, it is important to carefully consider the spatial and temporal biases inherent in such data (Tiago et al., 2017). This understanding is vital for informing decision-makers and formulating effective policies, particularly in relation to population distribution of biodiversity (Meyer et al., 2015).

Several studies have found that the geographical distribution of samples can introduce biased predictors, resulting in higher numbers of observations and leading to spatial biases in both professional and non-professional observations of. Therefore, correcting these biases becomes essential to ensure reliable and representative data, enabling conclusions that genuinely reflect biodiversity patterns and dynamics biodiversity (Di Cecco et al., 2021).

Birds, known for their high sensitivity to environmental changes, often act as indicators of ecosystem health (Zhang et al., 2023). In this way, we understand that to ensure accurate assessments of avian biodiversity, it is essential to carefully analyze the data and emphasize data collection in areas with limited information, indicating what could lead to this bias (Meyer et al., 2015). Additionally, it's worth noting that socio-economic factors, including infrastructure and accessibility, as mentioned by Myers (2015), can significantly influence the accessibility of terrestrial biodiversity within a region (Oliveira et al., 2016).

Therefore, the aim of the present paper was to evaluate the spatial distribution of the number of citizen science observations among Brazilian cities. We hypothesize that cities with a higher number of registered citizen science initiatives exhibit a greater presence of professional scientific observations, a higher Municipal Human Development Index (MHDI), larger population and geographical size, as well as an increased extent of protected areas.

Methods

Data sampling

The sample for this study were all cities in Brazil with a population of more than 100,000 inhabitants, totalizing 323 brazilian cities between 1992 and 2022. We selected this threshold, because represents cities with medium to large size and presented variation in predictors variables. For each city in our study, we gathered vital information such as population size, geographical area in square kilometers, Gross Domestic Product (GDP) data, Municipal Human Development Index (HDI), and the school enrollment rate for children aged 6 to 14. These crucial data points were sourced from the Instituto Brasileiro de Geografia e Estatística (IBGE), providing a comprehensive understanding of each city's demographics, economic performance, human development, and education accessibility. We obtained professional scientists and citizen science observations of birds on the site of Global Biodiversity Information Facility (see gbif.org/ accessed January/February 2023). We downloaded files for each city, filtering observations by column institutionCode. Ebird, Inaturalist, among others e.g., Naturgucker (see https://www.gbif.org/dataset/6ac3f774-d9fb-4796-b3e9-92bf6c81c084#description) were classified as citizen science observations while data from a university e.g., UNICAMP, USP, among others, were classify as a scientist observation.

The forest rate (the rate of natural forest formations per capita by city) and data on conservation units (the proportion of territory occupied by Conservation Units with full protection and sustainable use) are sourced from the IDSC (Índice de Desenvolvimento Sustentável das Cidades – Brasil) website. The IDSC is a platform initiated by the Sustainable Cities Institute (ICS) as part of the Sustainable Cities Program (PCS) in collaboration with Brazilian cities to help them achieve the Sustainable Development Goals (SDGs). For more details: https://idsc.cidadessustentaveis.org.br/introduction/".

The geographic coordinates for each city were obtained by searching for the centroid of the respective city on Google Maps.

Data analysis

We performed the multiple linear regression (OLS) where the number of birdwatching was the response variable. The predictors variables were the number of professional scientist observation; forest rate (rate of natural forest formations per inhabitant); conservation units (proportion of the territory occupied by Conservation Units of full protection and sustainable use); population size (2022); gross domestic product (GDP); the municipal human development index (MHDI); schooling rate (6-14 years old) and city area were the predictors variables. All data was log transformed (logx+1) and standardized (mean equal zero and standard deviation equal one). We also evaluated the collinearity of predictor variables using the Variance Inflation Factor (VIF), and all variables were posteriorly used in the regression models because they had VIF values less than three.

In a cross-spatial analysis, the absence of spatial independence can increase the Type I error (the statistical test erroneously rejects a null hypothesis that is true), and it needs to be controlled (Legendre, 2002). Thus, we evaluated the assumptions of spatial independence by investigating the spatial structure of residuals from the best regression model. In the first analysis we detected the spatial structure of the residual of the regression; therefore, we re-ran the linear regression to control for the spatial dependence. For this, first we obtained the spatial filters based on the principal coordinates of neighborhood matrix (PCNM) using the central coordinates of each municipality (Dray et al., 2006) and selected the spatial filters using the forward selection procedure (Blanchet et al., 2008). The procedures considered two conditions: i) it was selected significant spatial filters ($p < 0.05$); ii) it was selected spatial filters that removed the spatial structure in the regression residuals. We selected eight spatial filters (indicated by the numbers 05,11, 16, 23, 98, 106, 109 and 111), and these spatial filters were inserted in OLS models. To confirm that spatial dependence was removed, we evaluated the spatial correlograms of the residuals of the regressions. The significance of each predictor obtained in regression models were tested for significant deviations from null model using the number of 999 Monte Carlo simulation (Manly 2006).

Results

During our study period, the number of citizen science observations per city ranged from zero in Itumbiara, the only city in our sample without any citizen science observations, to 177,593 in Foz do Iguaçu, located in the southern region of Brazil. Beside the spatial distribution of birdwatching along Brazil, most part of the observation was concentrated in southeastern of the Brazil.

We observed that the factors such as scientist observations, proportion of conservation units, population and geographical size (city area), and MHDI (Municipal Human Development Index), were significant in determining the number of observations made by citizen scientists, with an adjusted R-squared of 0.53 and $p < 0.001$ (table 1; figure 1). Note that we applied spatial filters solely to eliminate spatial autocorrelation from the regression residuals. The regression without the filters yielded an R^2 of 0.46 and $p < 0.001$. Therefore, the introduction of the filters did not inflate the R^2 value; instead, it effectively corrected and removed the autocorrelation in the regression residuals (figure in the supplementary material). The slope in linear regression measures the relationship between variables, where a higher slope indicates a greater change in the dependent variable for a given change in the independent variable (table 1).

Table 1. Results of linear regression analysis with Monte Carlo-based p values. PCNM indicates the spatial filter employed in the regression.

Output	Slope	p-valor
Scientist observations	**0.230**	**<0.001**
Forest rate	-0.006	0.539
Conservation unit	**0.201**	**<0.001**
Population size	**0.162**	**0.022**
City area	**0.230**	**0.017**
Gross Domestic Product (GDP)	0.108	0.134
Municipal Human Development Index (MHDI)	**0.325**	**<0.001**
Schooling rate	-0.049	0.516
PCNM23	1.303	0.217
PCNM16	-1.849	0.091
PCNM11	1.727	0.097
PCNM98	-1.325	0.194
PCNM109	1.896	0.064
PCNM106	-1.484	0.153
PCNM111	-1.622	0.097
PCNM5	3.212	0.004

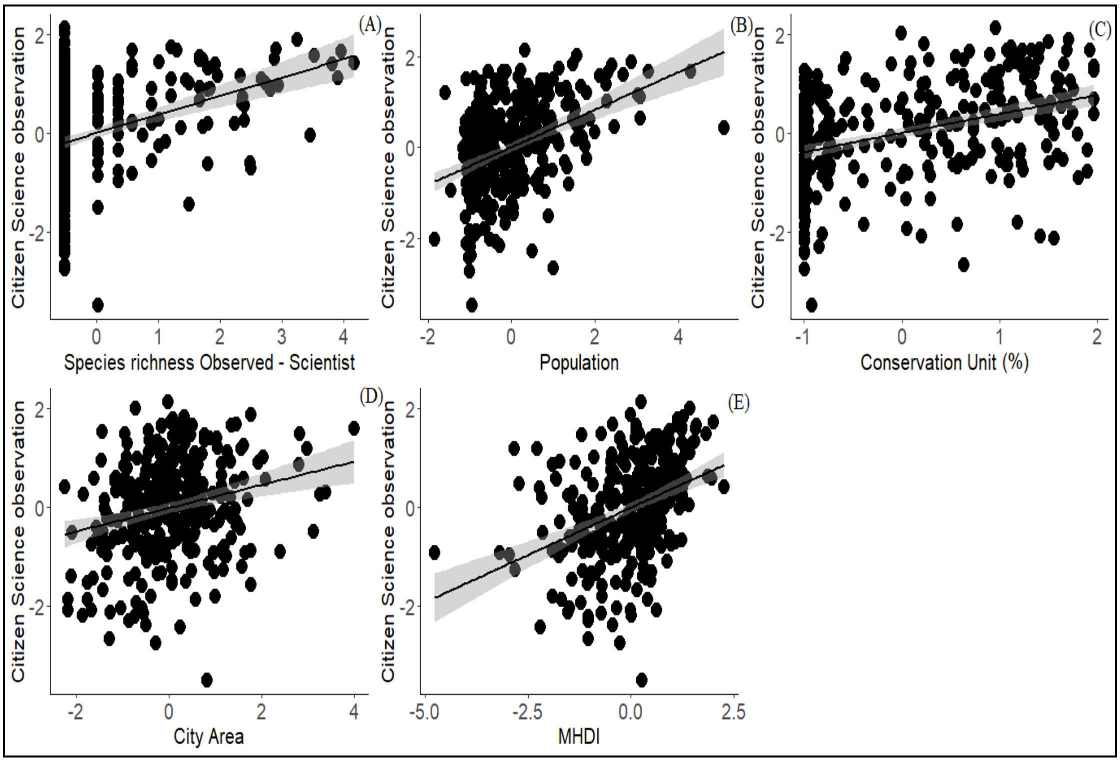

Fig. 01 - Correlation between significant predictor variables (Scientist Observations (A), Population (B), Conservation Unit (C), City Area (D), and Municipal Human Development Index (E)) on the X-axis and the response variable of Citizen Scientist Observations on the Y-axis.

Discussion

When analyzing citizen science birdwatching observations over the past 30 years in Brazilian cities with a population of over 100,000, we found that most of the cities were in the southeastern region, with overlapping observations. We found that the number of citizen science birdwatching observations was positively related to presence of conservation units, number of professional scientist observations, population size, city area and the municipal human development index.

Conservation units can have an impact on birdwatching, as they are designated areas for the protection and preservation of wildlife and natural habitats. As a result, they may offer important habitats for various bird species, which could attract birdwatchers who are interested in observing birds in their natural environment. Moreover, the establishment of conservation units to protect biodiversity and ecosystems may create opportunities for scientific research, monitoring, and conservation initiatives, which could attract professional scientists to work in these areas (Pressey et al., 2006). Citizen science birdwatchers can complement professional scientists in their investigative monitoring efforts (Zhou et al., 2020).

In the same direction, HDI (Human Development Index) is a composite measure of different socio-economic factors such as income, education, and health, which can influence the availability of resources and opportunities for citizens, including those interested in birdwatching. Higher HDI values may indicate higher levels of human development and quality of life, in our case, it is more specific because we worked with MHDI (Municipal Human Development Index) that measures per city, which could be related to a greater interest in and ability to participate in citizen science activities such as birdwatching (Haklay and Basiouka, 2018). Therefore, we observed in our sample that cities with higher human development indexes had a greater number of citizen science bird observations. In other words, we can infer that populations with better access to social well-being may have more opportunities or interest for birdwatching.

Our analysis unveiled a notable positive correlation between a city's population size and its geographical area, and the quantity of observations recorded by citizen scientists. As cities expand and their populations grow, they often encroach upon natural habitats, resulting in alterations to bird populations. This may also lead to an increase in citizen science birdwatching as people become more interested in monitoring bird populations or other kinds of species in urban areas. Additionally, larger cities may have more resources and funding available to support citizen science programs, which could also contribute to the higher number of observations. It is important to consider these factors when developing strategies to promote citizen science observations and conservation efforts in urban areas (Bonney et al., 2009).

While the forest cover was not statistically significant for this sample, it is important to note that the relationship between forest cover and birdwatching observations may be more complex than a simple linear relationship. Other factors such as the type and quality of forest habitat, as well as the presence of other habitats like wetlands or grasslands, may also play a crucial role in predicting bird diversity and abundance (Patten et al., 2008). Therefore, it is crucial to consider the location and characteristics of urban forests when designing and implementing urban forestry programs, as different types of forests provide varying benefits and face different challenges, as emphasized by Wilson et al. (2022).

Additionally, it is worth noting that different motivations can drive birdwatchers. Randler (2023) includes self-oriented, social-oriented, and nature-oriented dimensions, however, according to the author, the least important predictor of birdwatching behavior was the nature-oriented dimension, which includes appreciation of nature and environmental concerns, suggesting that these factors alone may not be strong enough to motivate people to engage in birdwatching. Through this, we can improve economic and environmental elements and provide together factors for influencing citizen science birdwatching in Brazilian cities over the last 30 years.

Young students are not the primary contributors to citizen science observations as noted in our data sample. Although there are many projects that cater to young people (Bonney et al., 2009). When it comes to birdwatching, we did not find a significant correlation between the presence of young students (ages 6-14) in each city and the level of birdwatching activity in that area. Bonney et al. (2009) review the benefits and challenges of engaging young people in citizen science projects and provide examples of successful projects that have targeted youth. The authors argue that involving young people in citizen science can help to improve their science literacy, increase their interest in science, and provide valuable contributions to scientific research.

GDP is not statistically significant in relation to the number of citizen science birdwatching observations in our analysis. This could be due to a variety of reasons, such as a lack of correlation between GDP and the level of public interest in birdwatching, or a lack of access to resources or technology that would enable citizen science participation. Barbier (2010) discusses how economic growth, as measured by GDP, can impact natural resources and the environment. This could help explain why GDP may not be a significant predictor of citizen science birdwatching observations. For example, economic growth may lead to urbanization and habitat loss, which could reduce bird diversity and the number of observations. Additionally, economic growth may not necessarily lead to increased interest in birdwatching or improved access to resources or technology that would enable citizen science participation.

Conclusion

In conclusion, our study aimed to investigate the factors influencing citizen science birdwatching in Brazil over the past 30 years. We found several key insights from our analysis of citizen science birdwatching observations in Brazilian cities. One significant finding is that professional scientists' observations strongly correlate with amateur birdwatching observations, especially in cities with a significant proportion of conservation units. These cities typically have concentrated populations and high levels of MHDI (Human Development Index). These factors highlight the importance of promoting citizen science experiences in diverse locations, including smaller communities. Achieving this requires encouragement and support from political leaders, particularly in the realms of education and popular participation. Our data show that economic factors have influenced the citizen science experience. Citizen science emerges as an economical and effective approach to achieve these goals. By incentivizing citizen engagement, we can foster greater conservation efforts and contribute to the preservation of bird species and their habitats. In summary, our study highlights the multifaceted nature of factors influencing citizen science birdwatching in Brazilian cities. It underscores the importance of considering both environmental and socio-economic elements to promote and sustain citizen science efforts over time.

References

Barbier, E. B. (2010). Introduction to natural resource economics. Palgrave Macmillan.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: a developing tool for expanding science knowledge and scientific literacy. BioScience, 59(11), 977-984.

Bonney, R. (2021). Expanding the impact of citizen science. BioScience, 71(5), 448-451.

Blanchet, F. G., Legendre, P., & Borcard, D. (2008). Forward selection of explanatory variables. Ecology, 89(9), 2623-2632.

Dray, S., Legendre, P., & Peres-Neto, P. R. (2006). Spatial modelling: a comprehensive framework for principal coordinate analysis of neighbour matrices (PCNM). Ecological modelling, 196(3-4), 483-493.

Di Cecco, G. J., Barve, V., Belitz, M. W., Stucky, B. J., Guralnick, R. P., & Hurlbert, A. H. (2021). Observing the observers: how participants contribute data to iNaturalist and implications for biodiversity science. BioScience, 71(11), 1179-1188.

Haklay, M. E., Antoniou, V., Basiouka, S., Soden, R., Deparday, V., Ryan, M., & Mooney, P. (2018). Identifying success factors in crowdsourced geographic information use in government.

Legendre, P., Dale, M. R., Fortin, M. J., Gurevitch, J., Hohn, M., & Myers, D. (2002). The consequences of spatial structure for the design and analysis of ecological field surveys. Ecography, 25(5), 601-615.

Manly, B. F. (2006). Randomization, bootstrap and Monte Carlo methods in biology (Vol. 70). CRC press.

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., ... & Shapiro, L. H. (2017). The rise of citizen science in ecology and conservation. Ecological Applications, 27(1), 1-14.

Meyer, C., Kreft, H., Guralnick, R., & Jetz, W. (2015). Global priorities for an effective information basis of biodiversity distributions. Nature communications, 6(1), 1-8.

Oliveira, U., Paglia, A. P., Brescovit, A. D., de Carvalho, C. J., Silva, D. P., Rezende, D. T., ... & Santos, A. J. (2016). The strong influence of collection bias on biodiversity knowledge shortfalls of Brazilian terrestrial biodiversity. Diversity and Distributions, 22(12), 1232-1244.

Patten, M. A., & Smith, W. P. (2008). Habitat structure, patch size, and habitat composition: relationships with avian community structure and dynamics. Ecography, 31(5), 649-660.

Piacentini, V. Q., Aleixo, A., Agne, C. E., Maurício, G. N., Pacheco, J. F., Bravo, G. A., ... & Silveira, L. F. (2015). Annotated checklist of the birds of Brazil by the Brazilian Ornithological Records Committee. Revista Brasileira de Ornitologia, 23(2), 91-298.

Pressey, R. L., Bottrill, M. C., & Possingham, H. P. (2006). Bridging the gap between conservation research and conservation management: evaluating the effectiveness of a large-scale network of marine reserves. Australian Journal of Zoology, 54(1), 21-29.

Randler, C. (2023). Motivations for birdwatching: Support for a three-dimensional model. Human dimensions of wildlife, 28(1), 84-92.

Tiago, P., Ceia-Hasse, A., Marques, T. A., Capinha, C., & Pereira, H. M. (2017). Spatial distribution of citizen science casuistic observations for different taxonomic groups. Scientific reports, 7(1), 1-9.

Wilson, S.J., E. Juno, J.R. Pool, S. Ray, M. Phillips, S. Francisco, and S. McCallum (2022). "Better Forests, Better Cities." Report. Washington, DC: World Resources Institute. Available online at doi.org/10.46830/wrirpt.19.00013.

Zhang, Y., Ye, E., Liu, F., Lai, N., You, X., Dong, J., & Dong, J. (2023). The Relationship between Landscape Construction and Bird Diversity: A Bibliometric Analysis. International Journal of Environmental Research and Public Health, 20(5), 4551.

Zhou, Y., Chen, A., Ouyang, J. Q., Liu, Y., Zheng, A., Yang, Z., ... & Lu, C. (2020). Comparing community birdwatching and professional bird monitoring with implications for avian diversity research: a case study of Suzhou, China. Avian Research, 11(1), 1-11.

ARTIGO 03 - INFLUENCE OF SCIENCE RECORDS, FLOCK BEHAVIOR, BODY SIZE, COLOR, HABITATS, ENDEMIC SPECIES, AND THREATENED BIRDS ON BIRDWATCHING IN BRAZIL OVER THE LAST THREE DECADES

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Abstract

Birdwatching is not only an important cultural activity that promotes social and cultural benefits for the population of large cities but also makes a valuable contribution to the conservation of species. This paper explores the integral role of citizen science in monitoring bird biodiversity in Brazil, with a specific focus on cities within the ecologically diverse Cerrado biome. The study focuses on the cities if Brazilian Savanna, with the aim of characterizing birds observed by citizen scientists in terms of size, color, flock behavior, habitats, threats, and endemism. Additionally, we consider which of the collected records are also documented in research institutions by professional scientists within the dataset of the GBIF platform. The research spans from 1992 to 2022, incorporating citizen science observations from 34 cities in central Brazil with a dataset comprising 815 bird species and 229,957 records of bird observations. The analysis reveals the significant influence of flock behavior and habitats besides color, size, endemism, and threat. This result is significantly influenced by records made by professional scientists. The article underscores the importance of understanding the ecological dynamics of bird species, particularly in the face of habitat fragmentation and urbanization. In conclusion, the research emphasizes the pivotal role of citizen science in monitoring bird biodiversity, offering valuable insights into observer preferences and contributing to conservation efforts. Future studies are suggested to explore deeper into bird attributes, habitat preferences, and the ecological significance of behaviors and colors, highlighting the continued need for collaboration between scientists and citizen scientists for effective biodiversity conservation in the Brazilian Cerrado.

Keywords: citizen science, brazilian savanna, cerrado, birdwatching, biodiversity, environmental diversity

Introduction

The 'land of birds' (Pacheco et al., 2021) refers to none other than Brazil, a country known for its vast size and remarkable bird biodiversity. Brazil faces shared challenges in species monitoring due to its rich ecological diversity. The active engagement of volunteers in monitoring bird biodiversity has catalyzed the rise of citizen science, an indispensable and cost-effective tool implemented globally and, specifically, within the country (Miller-Rushing et al., 2012; Dickinson et al., 2012; Tiago et al., 2017; Pocock et al., 2017; Callaghan et al., 2021; de Camargo Barbosa et al., 2021; Bonney, 2021). Engaging in citizen science for species monitoring provides a valuable amount of data, shedding light on various aspects of the observed community (McKinley et al., 2017). In the case of birds, factors such as habitat, size, coloration, and group behavior are crucial for consolidating the profile of these avian species. Similarly, understanding the status of threatened and endemic species is vital for molding this scenario (Teixeira et al., 2014). Shaping meaningful conservation efforts and preservation policies, the comprehensive citizen science approach also influences changes in citizen behaviors. This influence is evident because ordinary individuals in citizen science actively participate in shaping the environmental landscape, they are a part of (MacPhail et al., 2020).

In central Brazil, particularly, it encompasses one of the largest and most vital biomes globally, referred to as the Cerrado or Brazilian Savanna. Recognized as a global biodiversity hotspot (Hofmann et al.; 2021), the Cerrado faces substantial threats primarily from the rapid expansion of extensive agriculture, leading to deforestation and biodiversity loss (Barbosa et al.; 2023). The largest savanna in South America (Silva & Santos, 2005; dos Santos et al., 2023) boasts a rich diversity of bird species, totaling approximately 837, with 29 of these being endemic. Among these, 67% are associated with forested environments, as reported by the Chico Mendes Institute for Biodiversity Conservation (ICMBio, 2023). While there has been a surge in citizen science (Bonney, 2021) and global bird monitoring efforts (Sullivan et al., 2009; Neate-Clegg et al., 2020), knowledge gaps persist, particularly in the Brazilian savanna. Addressing these gaps is crucial to enhancing the result of conservation processes (Teixeira et al., 2014; de Marçal & Lopes, 2019). Efforts are being made, such as identifying remaining areas in the Cerrado that can serve as refuges for bird species considering climate change and land use (Borges & Loyola, 2020), or the importance of birds in seed dispersal and consequently the composition of the Cerrado (Medeiros & Marini, 2007), signify positive steps. However, understanding the profile of the monitored bird species in the Brazilian savanna, pivotal for the biome's conservation and preservation, is essential for the efforts to change citizens' attitudes toward these essential biological processes to be impactful (MacPhail et al., 2020). Utilizing citizen science for this purpose emerges as a cost-effective and direct tool, given that it involves individuals' intentional participation in the process (Miller-Rushing et al., 2012; Callaghan et al., 2021).

We acknowledge the presence of geographical and taxonomic biases in species observation within citizen science (Fernandez and Nakamura, 2015; Tiago et al., 2017; Callaghan et al., 2021). For example, charismatic species like birds tend to be more prominently observed in citizen science (Żmihorski et al., 2013; Gomes et al., 2019), or even overrepresented in observations near accessibility roads (Sicacha-Parada et al., 2021). However, delving into the same group, such as birds, and examining the specific profile monitored for a given region using citizen science as a sampling method holds the potential to reveal the ecological weight of the sampled data. This understanding can guide efforts towards developing targeted projects for the observed biodiversity and fostering environmentally conscious thinking among the population directly impacted in the region.

Birdwatching is intricately tied to the biodiversity of urban habitats, notably within expansive and historically significant parks (Zhang and Huang, 2020). Similarly, citizen science finds its place in urban settings for diverse reasons, including convenient access to observation points, such as roads (Sicacha-Parada et al., 2021), contributing to geographical biases in citizen science (Tiago et al., 2017). Moreover, birdwatching not only serves as a crucial cultural activity, fostering social benefits for urban populations, but also makes a substantial contribution to species conservation (Chan et al., 2012; Lopez et al., 2020). Cultural services related to birdwatching contribute significantly to ecosystem services (Chan et al., 2012). Birdwatching actively engages individuals in conservation efforts, fostering a heightened interest in biodiversity (Lopez et al., 2020).

In this context, the contribution of local birdwatchers is crucial to monitoring bird biodiversity. Within city limits, local birdwatchers uncover refuges for avian species, emphasizing the vital contribution of urban spaces to bird conservation. (Hrycyna, 2023). Analyzing the potential biodiversity linked to habitat diversity provides valuable insights for conservation efforts (Kurnia et al., 2021).

Therefore, this study's goal is to investigate and describe the characteristics of birds observed by citizen scientists in cities of the Brazilian savanna. The focus will extend to features that could influence these observations, including scientific records, bird size, color, flock behavior, potential habitats, threats, and endemism. Our hypothesis is that all these variables contribute to birdwatching.

Material and Methods

Data sampling

In the pursuit of a nuanced comprehension of avian biodiversity, a systematic investigation was undertaken, encompassing a nationwide selection of cities, each hosting a population exceeding 100,000 inhabitants (Artigo 2). To enhance analytical precision, the cerrado biome was selected to standardize observations, avoiding that different species pool could influence the analyses, focusing exclusively on cities situated in central Brazil (n=34, supplementary material). Studies show that different functional patterns are linked to various environmental patterns (Teresa et al., 2021). Therefore, by highlighting the specific biome, we expect species patterns to be influenced more directly by this biome, as we know that many bird species transit across different biomes. This methodological refinement aimed to discern and concentrate on avian species documented solely during dedicated birdwatching endeavors within these designated brazilian municipalities (Figure 01). The temporal scope of our inquiry extends from 1992 to 2022, resulting in the 815 avian species. This comprehensive dataset encompasses a cumulative total of 229,957 individual bird sightings, thus providing detailed insights into the complexities of avian life within the specified regions.

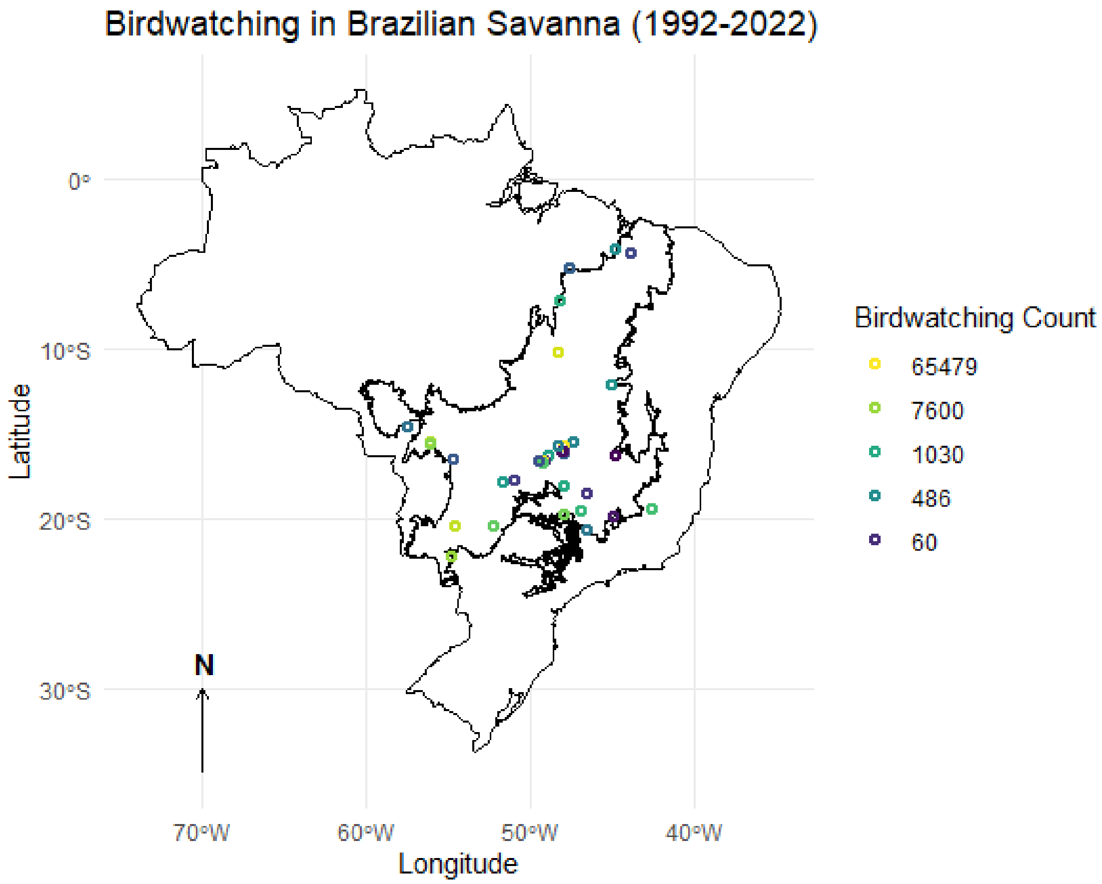

Figure 01 – Map locating the sampled cities (>100,000 inhabitants) with birdwatching records by citizen science in the cerrado biome between the years 1992 and 2022. The colored circles represent the number of observations in a decreasing gradient from yellow to purple. For more details, see attached supplementary material.

We collected bird records from citizen scientists through Global Biodiversity Information Facility - GBIF (gbif.org/ accessed January/February 2023). City-specific data were filtered based on the 'institution code,' incorporating platforms such as iNaturalist and eBird. Specifically, unstructured data, which includes opportunistic species additions, and semi-structured projects were included when protocols were applied, requiring checklist approval from regional experts (Callaghan, et al. 2021). After downloading, we filtered bird species in a cross-city analysis. We employed the Wiki Aves taxonomy, derived from the Linnaean classification system. The sample encompassed factors such as body size, flock behavior, bird color, threat, endemism, habitat considerations, and bird records made by professional scientists. Body size and flock behavior was defined according to the descriptions provided on Wiki Aves and Sick et al., (1997). In the context, the body size is measured from the tip of the beak to the end of the tail (Sick et al.; 1997). Coloration was assessed through observations of specific anatomical parts such as the upper breast, lower breast, crown, forehead, nape, and throat (adapted from Callaghan, et al. 2021). The observations were conducted using photos available on Wiki Aves platform (Figura 02). A species was classified as colorful (1) if any of these parts exhibited vivid colors, capturing the observer's attention; otherwise, it received a score of zero. Also, we classify as flocking behavior (1) or not (0) using information from the Wiki Aves platform.

Non-colored Colored

Figura 02 – From left to right, an example of a non-colored species *Buteo nitidus* and a colored species *Pitangus sulphuratus*

To address threat, endemism, and habitat, we sourced information from the IUCN Red List (https://www.iucnredlist.org/). Using a binary factor, we assigned 1 to signify both threatened and endemic species, while zero indicated no threatened or no endemic species. Regarding habitat, we aggregated the total count of diverse habitats where the species could be found. The IUCN-recommended habitats for the sample of bird species included forest, savanna, shrubland, grassland, wetlands, rocky areas, caves, desert, marine, artificial/terrestrial, and artificial/aquatic. In this article, we employed the metric 'sum habitat' to indicate the potential occurrence area of the bird species, based on data obtained from the IUCN website.

We consider records made by professional scientists to include those recognized by GBIF as originating from universities, research institutions, and similar entities.

Data analysis

We conducted Generalized Linear Mixed Models (GLMM) to investigate the relationship between the number of species records by citizen scientists (response variable) and morphological traits (body size and bird color), behavioral traits (flock), and environmental traits (threat, endemic, and sum habitat) of birds besides records made by professional scientists (explanatory variables), as outlined in the data sampling procedure. GLMM was crucial in addressing non-independence among observations by incorporating groups. 'Family' was chosen as the taxonomic clustering category used as a random effect, recognizing the presence of numerous similar species in the sample, which makes them non-independent (Cassey et al., 2004; Tiago et al., 2017a). We assessed the collinearity among predictor variables using the Variance Inflation Factor (VIF). Subsequently, all variables were included in the regression models as they exhibited VIF values below five (Maroco, 2007). The explanatory variables were log-transformed and standardized using Z-scores. We employed the method outlined by Nakagawa & Schielzeth (2013) to calculate pseudo-R squared values, alongside Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) and conducted residual analysis using Dharma Residual Analysis to determine the optimal model. We applied various R packages for our analyses: the 'vegan' package (Oksanen et al., 2022) for log-transformation and Z-score standardization, the 'car' package (Fox et al., 2019) for Variance Inflation Factor (VIF) calculations, the 'irr' package (Gamer and Lemon, 2019) for inter-observer reliability assessments, the 'lme4' package (Bates et al., 2015) for implementing Generalized Linear Mixed Models (GLMM), model selection was carried out using the 'MuMIn' package (Barton, 2023), and the 'DHARMa' package (Hartig, 2022) for residual analyses of the GLMM. The pseudo-R square was obtained using “r2glmm” package (Jaeger, 2017). All figures were created using the 'sjPlot' package (Lüdecke, 2023) in R version 3.1.2 (R Development Core Team, 2023), and bird silhouette images were obtained from 'PhyloPic' (2023).

Results

We compiled a comprehensive dataset from 1992 to 2022, consisting of 229,957 citizen science records from 34 cities in Central Brazil (refer to the supplementary material for a list of cities). These records, obtained through the GBIF platform, represent 1,06% of the total nationwide records during this time frame. Our analysis encompassed 815 bird species across 78 families. Citizen scientists predominantly observed *Pitangus sulphuratus*, with 6,061 records. Following were *Brotogeris chiriri (n=5,357), Furnarius leucopus (n=4973), Patagioenas cayennensis (n=4,619) and Columbina talpacoti (n=4,605),* which collectively accounted for more than 10% of the total records. Families with a notable number of observed species included Tyranidae (83 species; 27,208 records) and Thraupidae (80 species; 17,216 records) surpassing Picidae, which had only 28 species in the sample and 12,975 records (Figure 2). Thraupidae and Tyranidae together make up about 19% of the sample. Among the sampled species, 98 are considered rare, each having been observed only once. As examples, *Camptostoma obsoletum* from the Tyranidae family and *Accipiter poliogaster* from the Accipitridae family, both recorded only one record each during the specified time frame. Even though these species, and others, had only one record in the sample, the families themselves have a large abundance of records (Figure 03).

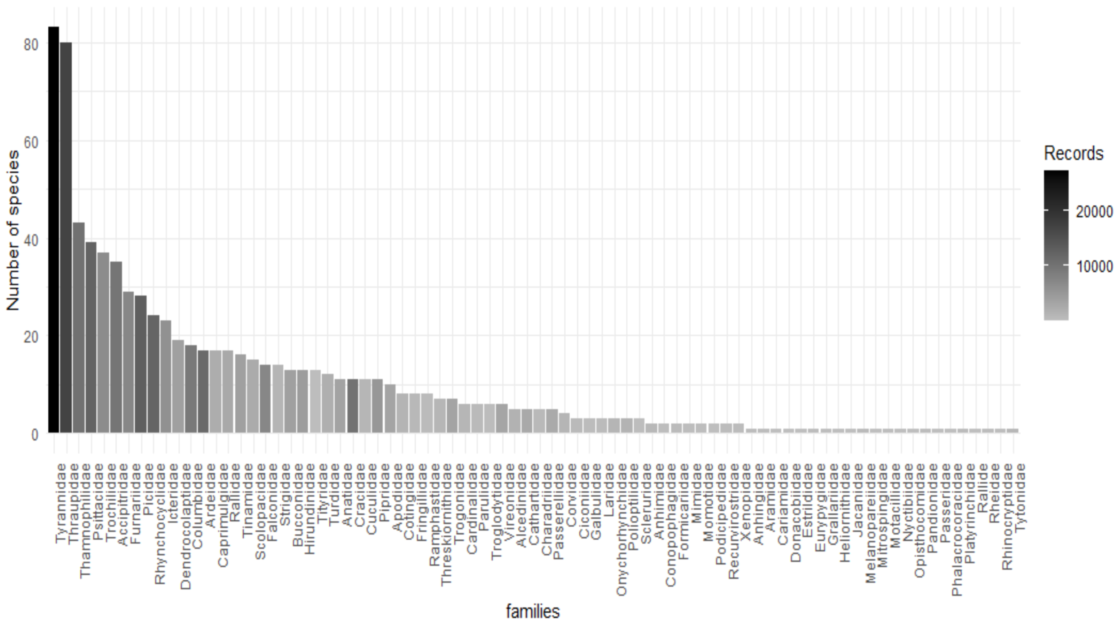

Figure 03 – The figure illustrates birdwatching in the Brazilian Savanna at Central Brazil. The axis displays the number of species per family with the color gradient indicating the record of bird observations along the time frame from 1992 to 2022.

We discovered that all variables utilized in the GLMM analysis were significant for the model, with particular emphasis on scientific records, flock behavior and sum habitats, as indicated in Table 1 and Figure 04. The best model had pseudo-R square of 0,07 with AIC and BIC respectively 347454.5 and 347494.8. Over 11 different habitats are suggested to the species in the sample by IUCN site. In the data analysis, forest habitats (636 species), artificial/terrestrial environments (322 species), and savannas (318 species) were prominently featured, as illustrated in Figure 05. It is noteworthy that, in this context, 'savanna' specifically refers to the distinct characteristics of the Cerrado biome, including spaced arrangements between trees, for example, providing a comprehensive understanding of the unique landscape of the Cerrado (supplementary material for a comprehensive overview of all habitats). However, we must consider that these habitats are a possibility observed in the data presented by the IUCN. This does not necessarily mean that they were sighted in specific environments, but rather that there is a possibility of them being observed in these habitats according to the literature.

Table 1 – The table summarizes the key predictor variables used in the GLMM to explain the variation in the number of bird observations in the Brazilian Savanna cities of Central Brazil, as sampled by citizen scientists. These variables include whether the species has a record on GBIF from a research institution (scientist), the number of habitats where the species could be observed (sum habitats), species size (body size), bird behavior in groups (flock), threat according to the International Union for Conservation of Nature (threat), bird color assessed through an inter-observer reliability method (bird color), and whether the species is endemic to the Brazilian Savanna (endemic).

Explanatory Variables	Relative Importance	Estimate	P
Science observation	1	0.316	<0.01
Flock	0.582	0.518	<0.01
Body size	0.223	0.277	<0.01
Sum habitat	0.176	0.112	<0.01
Bird color	0.010	0.063	<0.01
Endemic	0.008	0.167	<0.01
IUCN status	0.003	0.065	<0.01

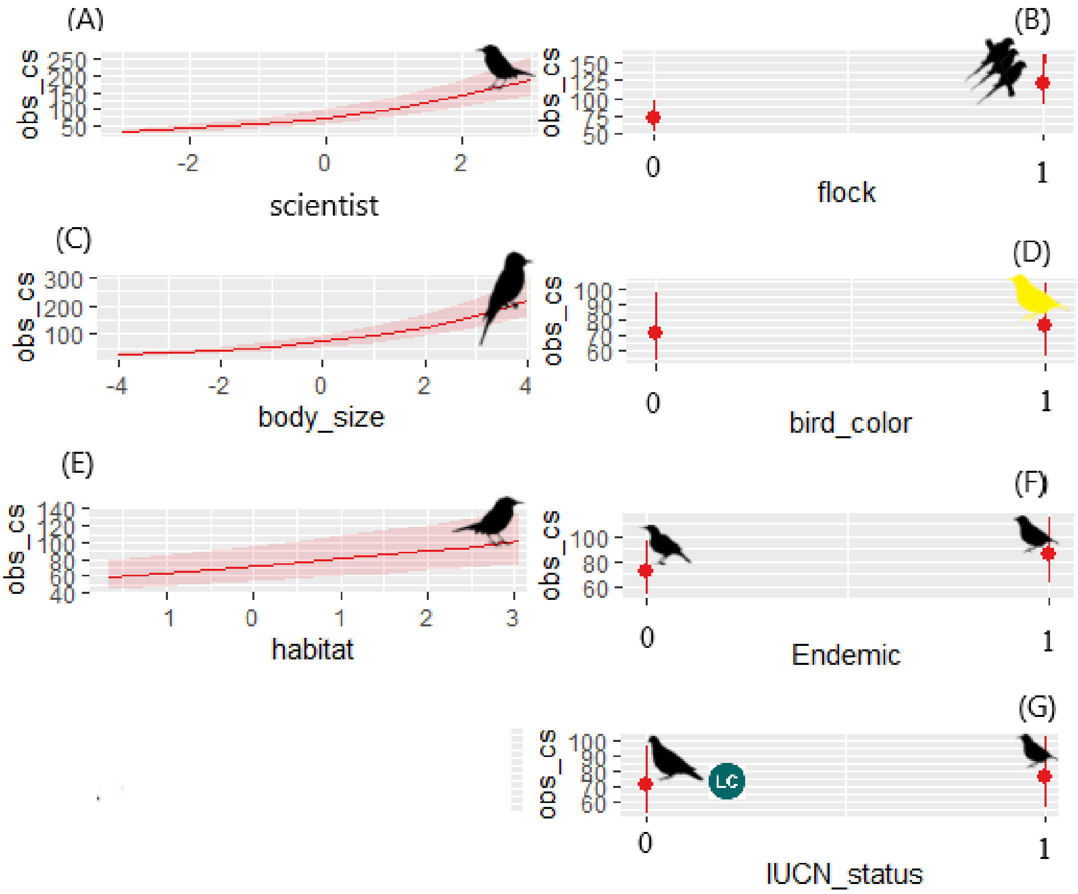

Figura 04 – The relationship among (A) records made by professional scientists, (B) flock behavior, (C) body size, (D) bird_color, (E) sum of habitats where the species could be observed, (F) whether the species are endemic to the Brazilian Savanna, and (G) the IUCN threat status of the species. All values are log-transformed and standardized using Z scores. For categorical variables, we use a binary scale, represented as 1 or 0, to clearly illustrate the relationships. For the binary values 1 represents colored bird, flock behavior, endemic and threatened birds. This figure was based in Callaghan, et al. (2021).

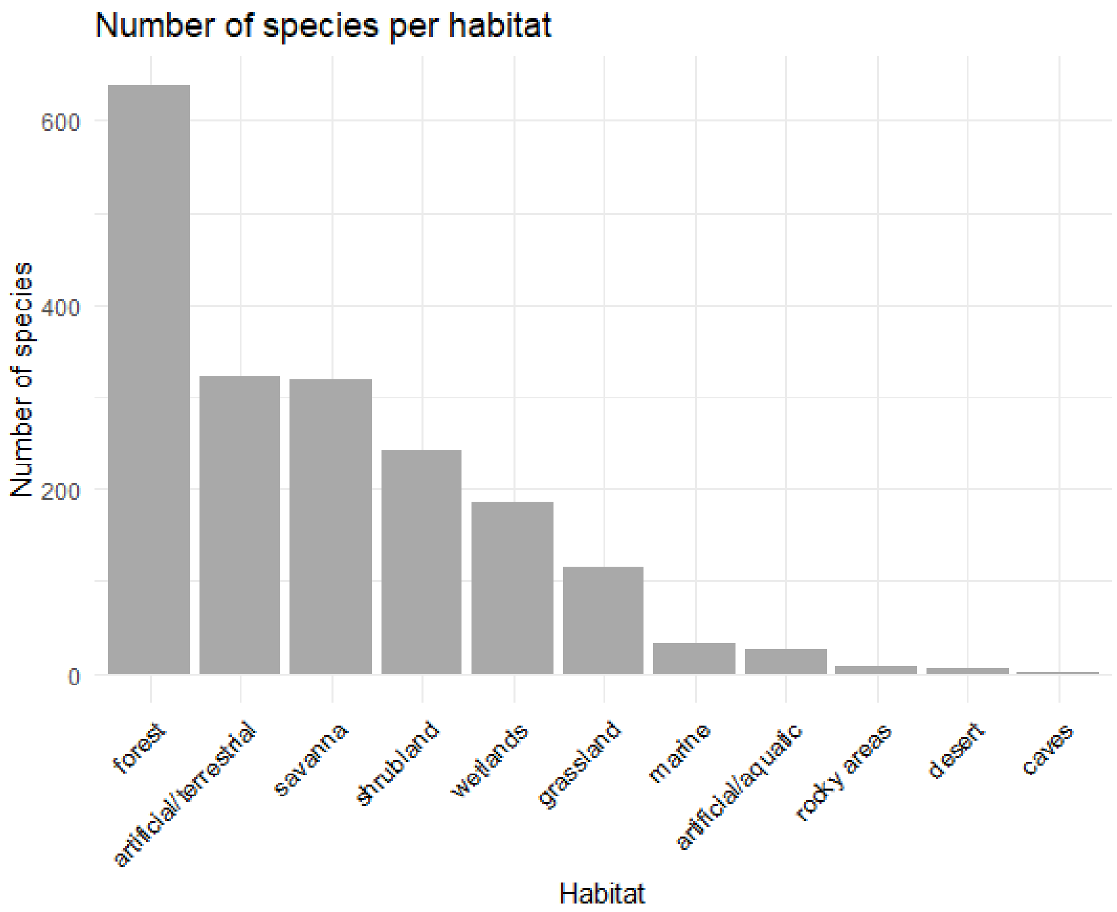

Figure 05 - A barplot illustrating the number of species (y-axis) across different habitats (x-axis) observed in the Brazilian savanna through citizen science from 1992 to 2022.

Discussion

This study investigated biodiversity in the Brazilian Cerrado using bird observation data collected over three decades. By incorporating records from citizen scientists, the study offers a more comprehensive view of bird distribution and ecology in the region. The significance of participatory research in expanding scientific knowledge and promoting community engagement in biodiversity conservation is emphasized. We analyzed records compiled by professional scientists, flock behavior of birds, habitat diversity, color, size, threat, and endemism of the birds to understand their impact on the quantity of bird records made by citizen scientists. The findings indicate that all these variables held statistical significance, particularly records compiled by professional scientists, flock behavior of birds, body size, and the sum of possible habitats for the species, demonstrating their relatively higher importance in data variance compared to others.

It is acknowledged that with appropriate training, ordinary individuals can gather robust and reliable data (Van der Velde et al., 2017). Our results revealed that the variation in records made by citizen scientists is statistically associated with the species that had records in research institutions, i.e., made by professional scientists. Engagement helps bridge the gap between scientific knowledge and ordinary people (Newman et al., 2012). In this context, despite species identification being a complex process influenced by multiple factors, scientific knowledge has reached the general populace through technological assistance such as Ebird, Inaturalist, Wiki Aves, among others, thus benefiting both academics and the general population (Sullivan et al., 2009; Callaghan et al., 2009; Tubelis, 2023). Therefore, technology access could significantly influence the sample composition studied in cities within the Brazilian Cerrado, warranting further investigation in future research.

The data were collected from cities with populations exceeding 100,000, indicating areas with more robust economic infrastructure. Tiago et al. (2017b) discuss various biases inherent in citizen science observations, one of which is spatial bias, where amateur observers tend to favor specific locations. In our dataset, we included species identified across diverse environments, reflecting the rich habitat diversity of the Cerrado (Hargreaves, 2008), which correlates with higher species richness (MacArthur, 1965). However, a notable portion of the records pertained to species favoring forested habitats. Additionally, records were found for species in urbanized settings. Silva (1995) highlights that approximately 80% of Cerrado species prefer forested habitats, consistent with ICMBio data and our study findings. Given the spatial bias in observation and the tendency for observers to favor easily accessible areas, as highlighted by Sicacha-Parada et al. (2021), it becomes imperative to understand how forest species are being observed in such proximity to urban areas. Citizen science not only aids in species identification but also enriches our comprehension of their ecological dynamics.

However, it is essential to consider the effects of urbanization, as indicated by studies highlighting negative impacts on avifauna's functional diversity (Matuoka et al., 2020). Considering that urbanized environments have been observed with one of the highest species richness over the citizen science sampling period, there arises a need for a deeper discussion on the effects of urbanization and proposals for solutions, especially concerning green areas within cities (Liu et al., 2023). Thus, citizen science has provided an opportunity to observe a significant richness of species in anthropized environments. Despite the observer's convenient access to monitor biodiversity, as highlighted in studies such as Sicacha-Parada et al. (2021), it is crucial to analyze later the migration of forest species to urban environments and evaluate the functional losses for these species. One potential consequence of this migration process, attributed to the expansion of urban areas, is the loss of natural habitat and the need for adaptation to new urbanized environments. It is important to note that all the environments indicated by the IUCN, used as data for our paper, suggest that the species could have higher scatter rates in the Cerrado. In other words, they frequent diverse habitats, which can be observed by citizen scientists, even in urban areas.

Recognizing that the frequently observed birds are often larger and tend to traverse diverse environments, it can be inferred that these birds are primarily generalists, displaying a notable capacity for swift adaptation. For instance, they may incorporate novel techniques for foraging, capitalizing on newly available food sources (Ducatez et al., 2015). Upon closer examination of the most observed species, it becomes evident that many of them exhibit characteristics typical of generalist birds. A notable example is the *Pitangus sulphuratus*, belonging to the Tyranidae family. This species, commonly observed in both natural and urban environments (Sick et al., 1997; Argel-de-Oliveira et al., 1998; Munin et al., 2012; da Paz Pereira & Melo, 2023), is renowned for its adaptability. Predominantly feasting on insects but also including fruits in its diet, this bird showcases dietary versatility, contributing to its success across a diverse range of habitats.

This example highlights how generalist birds, such as the Great Kiskadee, could thrive in urbanized environments, contributing to the bird community observed by citizen scientists. As mentioned by Franzén et al. (2020), thermophilic species capable of adapting to high-temperature environments often exhibit generalist behavior. This, in turn, suggests that urbanized environments tend to attract and sustain communities of generalist birds, which are highly adaptable to diverse conditions.

Nevertheless, it is imperative to consider the crucial balance between generalist and specialist species to ensure functional diversity and ecosystem equilibrium, especially in the Brazilian savannas observed by citizen scientists (Dehling et al., 2021). Given the significant habitat fragmentation in the Cerrado and its impact on bird biodiversity (Marini, 2001), and the theoretical concept that specialist bird species are presumed to have superior dispersal capabilities compared to generalists (Martin & Fahrig, 2018), it becomes crucial to further explore the adaptations undertaken by species in this new setting. This involves evaluating the niche characteristics and their evolutionary changes (Diniz-Filho, 2023a), both within fragmented areas and urbanized environments. The Great Kiskadee is just one example among many species that play crucial roles in this context, and understanding how these communities interact in urbanized environments is vital for effective biodiversity conservation and management (Callaghan et al., 2021b).

The discussion surrounding the flock behavior of bird species has persisted, with a primary focus on the potential advantages of increased foraging efficiency and reduced predation pressure (Beauchamp, 2022). In the Brazilian savanna, particularly fascinating questions arise, specifically regarding mixed-flock behavior and the additional anti-predator vigilance linked to the roles of nucleus species (Alves and Cavalcanti, 2023). Thus, with the increase in the sighting of these species in urban areas, a new opportunity arises to investigate how flock behavior would unfold given the new dynamics in anthropized environments and the introduction of possible new predators or their absence in non-natural habitats, knowing that it is a characteristic that influences birdwatching in the Cerrado.

The study of bird colors stands out as one of the most extensively researched systems in biology, providing valuable insights into the roles of natural and sexual selection (Roulin & Ducrest, 2013). The vibrant and diverse colors observed in birds serve various functions, and understanding the evolutionary mechanisms behind these colors can significantly enhance our knowledge of ecological and behavioral processes (Delhey et al., 2023).

This highlights a unique dynamic in the central Brazilian avifauna, possibly related to the modifications the biome has undergone since the 1960s, marked by the expansion of agricultural frontiers in the country (Barbosa et al., 2023). Additionally, climate change, with alterations in the patterns of geographical plant distribution, as exemplified by Simon et al., (2013) the case of *Caryocar braziliensis*, has impacted its production (Nabout et al., 2011). Notably, parrots emerge as dispersal agents for this species (Purificação et al., 2014), with the Psittacidae family being the fourth most observed family by citizen scientists in our sample, totaling 12,389 records of individual observations adding 39 different families. Species of the Psittacidae family are known for their flock behavior, mainly in search of food, in most cases (Brucks and Von Bayern, 2020), being a characteristic that in our sample had a high importance for the variation of the data.

Deforestation often follows spatial patterns linked to economic, environmental, and local-scale issues (Trigueiro et al., 2020). Therefore, understanding this biodiversity becomes particularly coherent when utilizing data from citizen science. It is emphasized that, when considering spatial biases in biodiversity observation by citizen science (Tiago et al., 2017b; Sicacha-Parada et al., 2021), observations near cities, where access to the observed community is more facilitated, tend to show a trend towards non-endemic and non-threatened species. This outlines a profile of generalist species that are easily adaptable (Franzén et al., 2020), reinforcing the importance of discussing the species observed in anthropized areas.

Our analysis, driven by three decades of citizen science data, revealed the significant influence of scientific records, habitat diversity, body size, coloration, and flock behavior on bird records, highlighting the importance of these factors in the practice of birdwatching by citizen scientists. Additionally, the frequent inclusion of non-threatened and non-endemic species as common targets for observation offers valuable insights into the factors guiding observers' choices and influencing observation dynamics over time.

Considering that socioeconomic and structural characteristics of cities strongly influence species richness (Kinnunem et al., 2024), this opens a field for future studies to be developed for the Brazilian Cerrado to investigate actions that consider bird characteristics such as flock behavior, different habitats, size, color, or endemic and threatened aspects for bird species conservation in cities at central Brazil. For future investigations, we suggest exploring how specific bird attributes contribute to observer choices and the long-term dynamics of observations. Additionally, delving into a deeper understanding of habitat preferences could impact conservation efforts and indicate ecological needs for these bird species. Future projects might also examine the impacts of urbanization on bird species, focusing particularly on the role of green spaces within cities. Finally, we emphasize the need for future initiatives to acknowledge and leverage the contributions of citizen scientists, especially in large-scale studies requiring substantial data. These research suggestions aim to deepen our understanding of avifaunal biodiversity, enriching knowledge, and promoting effective conservation of birds in the Brazilian Cerrado. The collaborative effort between scientists and citizens not only enriches ornithological knowledge but also highlights the pivotal role of public engagement in preserving the unique avian life in this dynamic ecosystem.

Conclusion

In conclusion, we realize that the set of factors influencing observations made by citizen scientists is complex. Several attributes of species, as well as behavioral phenomena, need further investigation. These factors should be considered when setting monitoring objectives with the collaboration of citizen scientists. However, we understand that incorporating these parameters into the monitoring process is commonplace and adds value to species conservation, particularly those adapting near or within urban centers. Further studies are necessary to gather more data on these species' attributes and on green areas within cities, as well as their effect on species conservation. In this regard, citizen science monitoring has made a significant contribution and should be encouraged, promoting environmental engagement, especially among future generations.

References

Argel-de-Oliveira, M. M., Curi, N. A., & Passerini, T. (1998). Alimentação de um filhote de bem-te-vi, Pitangus sulphuratus (Linnaeus) (Passeriformes, Tyrannidae), em ambiente urbano. Revista Brasileira de Zoologia, 15, 1103-1109.

Ashton, K. G. (2002). Patterns of within-species body size variation of birds: strong evidence for Bergmann's rule. Global Ecology and Biogeography, 11(6), 505-523.

Barbosa, V. A., Nabout, J. C., & da Cunha, H. F. (2023). Spatial and temporal deforestation in the Brazilian Savanna: The discrepancy between observed and licensed deforestation in the state of Goiás. Land Use Policy, 131, 106730.

Barnard, P., Lee, A. T. K., Fraser, M., Lennard, C., Smit, B., & Oschadleus, H. D. (2020). Body mass and condition of a fynbos bird community: investigating impacts of time, weather and raptor abundance from long-term citizenscience datasets. Ostrich: Journal of African Ornithology, 91(2), 142-157.

Bartoń K (2023). _MuMIn: Multi-Model Inference_. R package version 1.47.5, <https://CRAN.R-project.org/package=MuMIn>.

Bates, D., Maechler, M., Bolker, B., Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48. doi:10.18637/jss.v067.i01.

Bonney, R. (2021). Expanding the impact of citizen science. BioScience, 71(5), 448-451.

Borges, F. J. A., & Loyola, R. (2020). Climate and land-use change refugia for Brazilian Cerrado birds. Perspectives in ecology and conservation, 18(2), 109-115.

Bloch, D. A., & Kraemer, H. C. (1989). 2 x 2 Kappa Coefficients: Measures of Agreement or Association. *Biometrics*, *45*(1), 269–287. https://doi.org/10.2307/2532052

Brucks, D., & von Bayern, A. M. (2020). Parrots voluntarily help each other to obtain food rewards. Current Biology, 30(2), 292-297.

Callaghan, C. T., Poore, A. G., Hofmann, M., Roberts, C. J., & Pereira, H. M. (2021a). Large-bodied birds are over-represented in unstructured citizen science data. Scientific reports, 11(1), 19073.

Callaghan, C. T., Sayol, F., Benedetti, Y., Morelli, F., & Sol, D. (2021b). Validation of a globally-applicable method to measure urban tolerance of birds using citizen science data. Ecological Indicators, 120, 106905.

Callaghan, C. T., Mesaglio, T., Ascher, J. S., Brooks, T. M., Cabras, A. A., Chandler, M., ... & Young, A. N. (2022). The benefits of contributing to the citizen science platform iNaturalist as an identifier. PLoS biology, 20(11), e3001843.

Cassey, P., Blackburn, T. M., Sol, D., Duncan, R. P., & Lockwood, J. L. (2004). Global patterns of introduction effort and establishment success in birds. Proceedings of the Royal Society of London. Series B: Biological Sciences, 271(suppl_6), S405-S408.

Chan, K. M., Satterfield, T., & Goldstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. Ecological economics, 74, 8-18.

da Paz Pereira, Z., & Melo, C. (2023). Nestling's pellets of the Great Kiskadee (Pitangus sulphuratus) in Brazilian urban environment. Ornitologia Neotropical, 23(2), 13.

de Camargo Barbosa, K. V., Develey, P. F., Ribeiro, M. C., & Jahn, A. E. (2021). The contribution of citizen science to research on migratory and urban birds in Brazil. Ornithology Research, 29, 1-11.

Delhey, K., Valcu, M., Muck, C., Dale, J., & Kempenaers, B. (2023). Evolutionary predictors of the specific colors of birds. Proceedings of the National Academy of Sciences, 120(34), e2217692120

de Marçal, B. F., & Lopes, L. E. (2019). Breeding biology of the Helmeted Manakin Antilophia galeata in an ecotone between the Atlantic Forest and the Cerrado. Revista Brasileira de Ornitologia, 27, 1-9.

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., ... & Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. Frontiers in Ecology and the Environment, 10(6), 291-297.

Diniz-Filho, J. A. F. (2023a). The Macroecological Understanding of Ecological Niches. In The Macroecological Perspective: Theories, Models and Methods (pp. 167-201). Cham: Springer International Publishing.

Diniz-Filho, J. A. F. (2023b). Patterns in Body Size. In The Macroecological Perspective: Theories, Models and Methods (pp. 293-338). Cham: Springer International Publishing.

dos Santos, T. F., Santos, S. S., Brandão, B. A., de Araujo Gomes, I. S., da Silva Siqueira, A. J., dos Santos, M. D. F., ... & Gomes, M. D. J. P. (2023). Aves do Cerrado: uma revisão bibliométrica de estudos de avifauna no segundo maior bioma da América do Sul. CONTRIBUCIONES A LAS CIENCIAS SOCIALES, 16(10), 24728-24744.

Ducatez, S., Clavel, J., & Lefebvre, L. (2015). Ecological generalism and behavioural innovation in birds: technical intelligence or the simple incorporation of new foods? Journal of Animal Ecology, 84(1), 79-89.

Fernández, D., & Nakamura, M. (2015). Estimation of spatial sampling effort based on presence-only data and accessibility. Ecological Modelling, 299, 147-155.

Fox J, Weisberg S (2019). _An R Companion to Applied Regression_, Third edition. Sage, Thousand Oaks CA. <https://socialsciences.mcmaster.ca/jfox/Books/Companion/>.

Franzén, M., Betzholtz, P. E., Pettersson, L. B., & Forsman, A. (2020). Urban moth communities suggest that life in the city favours thermophilic multi-dimensional generalists. Proceedings of the Royal Society B, 287(1928), 20193014.

Gamer, M. and Lemon, J. (2019). _irr: Various Coefficients of Interrater Reliability and Agreement_. R package version 0.84.1, <https://CRAN.R-project.org/package=irr>.
Gomes, M. A. D. A., Goncalves, T. V., Teresa, F. B., da Cunha, H. F., Lima, F. P., & Nabout, J. C. (2019). High school students' knowledge of endangered fauna in the Brazilian Cerrado: a cross-species and spatial analysis. PloS one, 14(4), e0215959.

Hargreaves, P. (2008). Phytosociology in Brazil. J Plant Sci Biotechnol, 2, 12-20.

Hartig, F. (2022). _DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models_. R package version 0.4.6, <https://CRAN.R-project.org/package=DHARMa>.

Hofmann, G. S., Cardoso, M. F., Alves, R. J., Weber, E. J., Barbosa, A. A., de Toledo, P. M., ... & de Oliveira, L. F. (2021). The Brazilian Cerrado is becoming hotter and drier. Global Change Biology, 27(17), 4060-4073.

Hrycyna, A. (2023). Exploring the world through Black's Nook: an experiment in collaborative patch birding in Cambridge, Massachusetts. Bird Observer, 41(3), 3.

Instituto Chico Mendes para a Biodiversidade - ICMBio. (2023). Conservation of Biodiversity. Retrieved from https://www.icmbio.gov.br/cbc/conservacao-da-biodiversidade/biodiversidade.html

Jaeger B (2017). _r2glmm: Computes R Squared for Mixed (Multilevel) Models_. R package version 0.1.2, <https://CRAN.R project.org/package=r2glmm>.

Johnston, A., Newson, S. E., Risely, K., Musgrove, A. J., Massimino, D., Baillie, S. R., & Pearce-Higgins, J. W. (2014). Species traits explain variation in detectability of UK birds. Bird Study, 61(3), 340-350.

Kinnunen, R. P., Fraser, K. C., Schmidt, C., & Garroway, C. J. (2024). Structural and socioeconomic features of cities predict migratory bird species richness. Journal of Avian Biology, e03189.

Kurnia, I., Arief, H., Mardiastuti, A., & Hermawan, R. (2021). The potential of bird diversity in the urban landscape for birdwatching in Java, Indonesia. Biodiversitas Journal of Biological Diversity, 22(4).

Liu, Z., Zhou, Y., Yang, H., & Liu, Z. (2023). Urban green infrastructure affects bird biodiversity in the coastal megalopolis region of Shenzhen city. Applied Geography, 151, 102860.

Lopez, B., Minor, E., & Crooks, A. (2020). Insights into human-wildlife interactions in cities from bird sightings recorded online. Landscape and Urban Planning, 196, 103742.

Lüdecke D (2023). _sjPlot: Data Visualization for Statistics in Social Science_. R package version 2.8.15, <https://CRAN.R-project.org/package=sjPlot>.

MacArthur, R. H. (1965). Patterns of species diversity. Biological reviews, 40(4), 510-533.

MacPhail, V. J., & Colla, S. R. (2020). Power of the people: A review of citizen science programs for conservation. Biological Conservation, 249, 108739.

MARINI, M. Â. (2001). Effects of forest fragmentation on birds of the cerrado region, Brazil. Bird Conservation International, 11(1), 13-25.

Maroco, J. (2007). Análise estatística com utilização do SPSS.

Martin, A. E., & Fahrig, L. (2018). Habitat specialist birds disperse farther and are more migratory than habitat generalist birds. Ecology, 99(9), 2058-2066.

Matuoka, M. A., Benchimol, M., de Almeida-Rocha, J. M., & Morante-Filho, J. C. (2020). Effects of anthropogenic disturbances on bird functional diversity: A global meta-analysis. Ecological Indicators, 116, 106471.

McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, H., Cook-Patton, S. C., ... & Shapiro, L. H. (2017). The rise of citizen science in ecology and conservation. Ecological Applications, 27(1), 1-14.

Medeiros, R. D. C. S., & Marini, M. Â. (2007). Reproductive biology of Elaenia chiriquensis (Lawrence) (Aves, Tyrannidae) in the Cerrado of the Central Brazil. *Revista Brasileira de Zoologia*, *24*(1), 12–20.

Miller-Rushing, A., Primack, R., & Bonney, R. (2012). The history of public participation in ecological research. Frontiers in Ecology and the Environment, 10(6), 285-290.

Munin, R. L., Fischer, E., & Longo, J. M. (2012). Foraging of Great Kiskadees (Pitangus sulphuratus) and food items offered to nestlings in the Pantanal. Brazilian Journal of Biology, 72, 459-462.

Nabout, J. C., Oliveira, G., Magalhães, M. R., Terribile, L. C., & Almeida, F. A. S. D. (2011). Global climate change and the production of "Pequi" fruits (Caryocar brasiliense) in the Brazilian Cerrado.

Neate-Clegg, M. H., Horns, J. J., Adler, F. R., Aytekin, M. Ç. K., & Şekercioğlu, Ç. H. (2020). Monitoring the world's bird populations with community science data. Biological Conservation, 248, 108653.

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., & Crowston, K. (2012). The future of citizen science: emerging technologies and shifting paradigms. Frontiers in Ecology and the Environment, 10(6), 298-304.

Olson, V. A., Davies, R. G., Orme, C. D. L., Thomas, G. H., Meiri, S., Blackburn, T. M., ... & Bennett, P. M. (2009). Global biogeography and ecology of body size in birds. Ecology Letters, 12(3), 249-259.

Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens M, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, Chirico M, De Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill M, Lahti L, McGlinn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C, Weedon J (2022). _vegan: Community Ecology Package_. R package version 2.6-4, <https://CRAN.R-project.org/package=vegan>.

Pacheco, J. F., Silveira, L. F., Aleixo, A., Agne, C. E., Bencke, G. A., Bravo, G. A., ... & de Q. Piacentini, V. (2021). Annotated checklist of the birds of Brazil by the Brazilian Ornithological Records Committee—second edition. Ornithology Research, 29(2), 94-105.

Pocock, M. J., Tweddle, J. C., Savage, J., Robinson, L. D., & Roy, H. E. (2017). The diversity and evolution of ecological and environmental citizen science. PloS one, 12(4), e0172579.

PhyloPic. (2023). PhyloPic: Free Silhouette Images for Tree of Life. Retrieved from https://www.phylopic.org/

Pichorim, M., da Silva, M., de França, B. R. A., de Oliveira-Júnior, T. M., & Rodrigues, M. C. (2014). A Cerrado bird community in the northernmost portion of northeastern Brazil-recommendations for conservation. Revista Brasileira de Ornitologia, 22, 347-362.

Purificação, K. N., Pascotto, M. C., Pedroni, F., Pereira, J. M. N., & Lima, N. A. (2014). Interactions between frugivorous birds and plants in savanna and forest formations of the Cerrado. Biota Neotropica, 14, e20140068.

R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Roulin, A., & Ducrest, A. L. (2013, June). Genetics of colouration in birds. In Seminars in cell & developmental biology (Vol. 24, No. 6-7, pp. 594-608). Academic Press.

Sicacha-Parada, J., Steinsland, I., Cretois, B., & Borgelt, J. (2021). Accounting for spatial varying sampling effort due to accessibility in Citizen Science data: A case study of moose in Norway. Spatial Statistics, 42, 100446.

Sick, H., Haffer, J., Alvarenga, H. F., Pacheco, J. F., & Barruel, P. (1997). Ornitologia Brasileira Editora Nova Fronteira. Rio de Janeiro.

Silva, J. D. (1995). Birds of the Cerrado region, South America. Steenstrupia, 21(1), 69-92.

Silva, J., & Santos, M. (2005). A importância relativa dos processos biogeográficos na formação da avifauna do Cerrado e de outros biomas brasileiros p. 219-233. Cerrado: ecologia, biodiversidade e conservação. MMA, Brasília.

Simon, L. M., Oliveira, G. D., Barreto, B. D. S., Nabout, J. C., Rangel, T. F. L. V. B., & Diniz-Filho, J. A. F. (2013). Effects of global climate changes on geographical distribution patterns of economically important plant species in cerrado. Revista Árvore, 37, 267-274.

Sullivan, B. L., Wood, C. L., Iliff, M. J., Bonney, R. E., Fink, D., & Kelling, S. (2009). eBird: A citizen-based bird observation network in the biological sciences. Biological conservation, 142(10), 2282-2292.

Teixeira, T. S., Weber, M. M., Dias, D., Lorini, M. L., Esberard, C. E. L., Novaes, R. L., ... & Vale, M. M. (2014). Combining environmental suitability and habitat connectivity to map rare or Data Deficient species in the Tropics. Journal for Nature Conservation, 22(4), 384-390.

Tiago, P., Pereira, H. M., & Capinha, C. (2017a). Using citizen science data to estimate climatic niches and species distributions. Basic and Applied Ecology, 20, 75-85.
International Union for Conservation of Nature. (2023). IUCN Red List of Threatened Species. https://www.iucnredlist.org/

Tiago, P., Ceia-Hasse, A., Marques, T. A., Capinha, C., & Pereira, H. M. (2017b). Spatial distribution of citizen science casuistic observations for different taxonomic groups. Scientific reports, 7(1), 12832.

Teresa, F. B., de Sousa Rodrigues Filho, C. A., & Leitão, R. P. (2021). Diversidade funcional de comunidades de peixes de riacho. Oecologia Australis.

Trigueiro, W. R., Nabout, J. C., & Tessarolo, G. (2020). Uncovering the spatial variability of recent deforestation drivers in the Brazilian Cerrado. Journal of Environmental Management, 275, 111243.

Tubelis, D. P. (2023). Spatiotemporal Distribution of Photographic Records of Brazilian Birds Available in the WikiAves Citizen Science Database. Birds, 4(1), 28-45.

Van der Velde, T., Milton, D. A., Lawson, T., Wilcox, C., Lansdell, M., Davis, G., Perkins, G., & Hardesty, B. D. (2017). Comparison of marine debris data collected by researchers and citizen scientists: Is citizen science data worth the effort? Biological Conservation, 208, 127-138. https://doi.org/10.1016/j.biocon.2016.05.025

WikiAves. (2023). Birds of Brazil. WikiAves. https://www.wikiaves.com.br/

Zhang, Z., & Huang, G. (2020). How do urban parks provide bird habitats and birdwatching service? Evidence from Beijing, China. Remote Sensing, 12(19), 3166.

Żmihorski, M., Dziarska-Pałac, J., Sparks, T. H., & Tryjanowski, P. (2013). Ecological correlates of the popularity of birds and butterflies in Internet information resources. Oikos, 122(2), 183-190.

CONSIDERAÇÕES FINAIS

Dos três estudos, podem ser extraídas várias considerações importantes:

Organização e Engajamento na Ciência Cidadã: O primeiro estudo enfatiza a importância da organização e engajamento em projetos de ciência cidadã, especialmente no contexto do monitoramento ambiental. Utilizar tecnologia, focar em espécies emblemáticas como pássaros e fomentar o apoio institucional à conservação da biodiversidade são identificados como fatores essenciais para iniciativas bem-sucedidas de ciência cidadã. Além disso, há um chamado para compartilhar experiências e conhecimentos em ciência cidadã, principalmente por meio de projetos escolares, para preencher a lacuna nas publicações sobre monitoramento ambiental por meio da ciência cidadã, especialmente em países neotropicais.

Fatores Influenciando a Observação de Aves na Ciência Cidadã no Brasil: O segundo estudo destaca vários fatores que influenciam a observação de aves na ciência cidadã em cidades brasileiras ao longo dos últimos 30 anos. Ele enfatiza a correlação entre as observações de cientistas profissionais e as observações de observadores amadores de aves, especialmente em cidades com unidades de conservação significativas e níveis mais altos de desenvolvimento humano. Fatores econômicos também são encontrados para influenciar a experiência de ciência cidadã. O estudo enfatiza a necessidade de apoio político, principalmente em educação e participação popular, para promover experiências de ciência cidadã em locais diversos, incluindo comunidades menores. Incentivar o engajamento dos cidadãos é visto como uma abordagem econômica para promover esforços de conservação e preservar espécies de aves e seus habitats.

Complexidade dos Fatores nas Observações da Ciência Cidadã: O terceiro estudo reconhece a complexidade dos fatores que influenciam as observações feitas por cientistas cidadãos. Ele enfatiza a importância de considerar tanto os atributos ambientais das espécies quanto os fenômenos comportamentais ao estabelecer objetivos de monitoramento com a colaboração de cientistas cidadãos. O estudo reconhece o valor de incorporar esses parâmetros ao processo de monitoramento para aprimorar os esforços de conservação de espécies, especialmente em áreas urbanas. Ele pede mais estudos para reunir mais dados sobre os atributos das espécies e o impacto das áreas verdes dentro das cidades na conservação das espécies. No geral, o estudo enfatiza a significativa contribuição do monitoramento da ciência cidadã e defende seu incentivo para promover o engajamento ambiental, especialmente entre as futuras gerações.

Em resumo, essas conclusões destacam a importância da organização, engajamento, apoio político e consideração de diversos fatores na promoção e sustentação de iniciativas de ciência cidadã para monitoramento ambiental e esforços de conservação de espécies em especial a avifauna do Cerrado brasileiro.