CITIZEN SCIENCE:
THEORY AND PRACTICE

Engaging Citizen Scientists in Biodiversity Monitoring: Insights from the WildLIVE! Project

RESEARCH PAPER

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ABSTRACT

The growing public interest in biodiversity monitoring has led to a significant increase in initiatives that unite citizen scientists, researchers, and machine learning technologies. In this context, we introduce WildLIVE!, a dynamic biomonitoring and citizen science project. In WildLIVE!, participants analyze a vast array of images from a long-term camera trapping project in Bolivia to investigate the impacts of shifting environmental factors on wildlife. From 2020 to 2023, more than 850 participants registered for WildLIVE!, contributing nearly 9,000 hours of voluntary work. We explore the motivators and sentiments of participant engagement and discuss the key strategies that have contributed to the project's initial success. The findings from a questionnaire highlight that the primary motivational factors for our participants are understanding and knowledge, as well as engagement and commitment. However, expressions of positive and negative sentiments can be found regarding involvement. Participants appeared to be driven primarily by a desire for intellectual growth and emotional fulfillment. Factors crucial to the success of this digital citizen science project include media exposure, creating emotional connections through virtual and in-person communication with participants, and visibility on public citizen science portals. Moreover, the project's labeled dataset serves as a valuable resource for machine learning, aiding the development of a new platform that is compliant with the FAIR principles. WildLIVE! not only contributes to outcomes in science, society, and nature conservation, but also demonstrates the potential of creating a collaborative bridge between the general public, scientific research, biodiversity conservation, and advanced technological applications.

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INTRODUCTION

To recognize and react to the increasing local anthropogenic effects on nature at an early stage, constant monitoring of the environment is necessary (Rajkumar et al. 2010). Autonomous devices such as camera traps offer a wide range of options for accessible and non-invasive biomonitoring (Steenweg et al. 2017; Rudolfi and Poerting 2020); however, they generate large volumes of data, which can be difficult to manage (Norouzzadeh et al. 2018). With the increasing utilization of camera traps (Green et al. 2020) and audio recorders (Mutanu et al. 2022), the amount of stored data (images, videos, acoustic data) collected is rapidly expanding. Scientists and conservationists need to meet the challenge of processing such data streams, and if possible, in real time, which is essential for nature conservation issues such as anti-poaching (Tan et al. 2016; Heyns 2021) and detecting biodiversity trends at a local and global scale (Chandler et al. 2017; Steenweg et al. 2017). Although there are approaches for effective data processing using machine learning, they require large, annotated ("labeled") training data sets, which are very time-consuming to create (Norouzzadeh et al. 2018; Schneider, Taylor and Kremer 2018). Moreover, machine learning–derived image classifications by existing open source tools or public platforms are still largely imprecise and require human verification (Vélez et al. 2023). Thus, the contribution of citizen science (CS) at the interface of data collection and AI-based processing of camera trap and other ecological data has large potential (Fraisl et al. 2022) and is fostered by new, more accessible, and inexpensive technologies (Silvertown 2009; Adler, Green, and Şekercioğlu 2020). Here, we use the term "citizen science" to describe scientific work that has been conducted in whole or in part by amateur (or nonprofessional) scientists, often in collaboration with professional scientists or institutions (Green et al. 2020). CS projects can be broadly categorized based on the extent of public involvement, with classifications including contractual, contributory, collaborative, co-created, and collegial (Bonney et al. 2009; Shirk et al. 2012; Green et al. 2020).

In 2017, we initiated a biomonitoring study using camera traps to gain more information about the diverse but understudied mammalian fauna of the endemic Chiquitano Dry Forest (CDF). The CDF represents the largest block of tropical broad-leaf dry forest in South America (Miles et al. 2006; Power et al. 2016). Today, the Chiquitano region faces significant anthropogenic pressure as it has been transformed from forest into a mixed-use landscape. The CDF is experiencing a rapid reduction in size, largely attributable to deforestation, which is occurring at an average rate of 108,000 hectares per year, resulting in a 15% loss of its original extent from 2001 to 2006 (Killeen et al. 2006). Additionally, human-induced wildfires have further exacerbated the decline, with a notable instance in 2019 where 12% of the forests were destroyed (Romero-Muñoz et al. 2019). In our own studies, we have documented large-scale habitat destruction since 2020, focusing on the effects of rapid land use change and deforestation on mammal communities, that is, the actual biodiversity loss or population declines (Jansen et al. 2020; Meißner et al. 2024). To process the large volumes of image data that derived from the camera trapping since 2017, in 2020 we initiated the contributory CS project WildLIVE! ("WildLIVE! Entdecke die wilden Tiere Boliviens;" Jansen 2021). In WildLIVE!, citizen scientists analyze large amounts of camera trap images using the platform Labelbox (Labelbox 2021). Similar to other studies on CS projects, we identified that participant motivation and engagement are paramount to the success of our CS project (Lotfian, Ingensand, and Brovelli 2020). Here, we describe our more than three years of experience concerning citizen engagement, challenges, and outcomes. We explore the quality and quantity of the engagement of our participants, in particular the motivation to contribute to a CS project that, on the one hand, is dealing with positive aspects of biodiversity (e.g., fascinating insights into wilderness), and on the other hand, with actual biodiversity loss (deforestation and wildfires). Moreover, we present strategies that we believe proved to be key to the success of this project. Lastly, we provide an outlook on the planned future development of the project.

MATERIAL AND METHODS

STUDY AREA

WildLIVE! is focused on data obtained from an ongoing camera trap biomonitoring project in the Chiquitano region, Bolivia, which was initiated in March 2017 (Jansen et al. 2020). Since its initiation, the monitored area was gradually expanded, and today comprises 25 camera trap stations, covering approximately 23,025 ha (Supplemental File 1: Figure 1). Each station was equipped with two (paired) cameras. This setup aimed to enhance the detection and identifiability of jaguars and other species based on individual coat patterns on each body side, with the jaguar as the focal species. For more details, please refer to former descriptions of the study site (Schulze et al. 2009) or the field methodology (Jansen et al. 2020) and analysis (Meißner et al. 2024).

WildLIVE! DEVELOPMENT AND CONSTRUCTION

The WildLIVE! project is structured as follows (Supplemental File 2: Figure 2): Data is collected by camera traps and is subsequently pre-processed (e.g., long runs of empty images or images with humans present are removed) and then uploaded to the external web based platform Labelbox, a closed-source web-based labeling platform frequently used to create training data sets for machine learning applications (Labelbox 2021). Participants register for WildLIVE! through the landing page (see Jansen 2021), and are subsequently added to Labelbox. Labelbox granted us an extended free educational license for non-commercial research purposes. The platform allows for the development of a customizable interface for the manual classification of images, and subsequently, further inspection by other users. Upon registration, participants gain access to view the camera trap images online, accompanied by an integrated tutorial that was developed in collaboration with experienced participants (Jansen et al. 2021) to assist with species identification. Citizen scientists process images by assigning them to predefined categories or annotations, for example a species name, or as "empty" (referred to as "blanks" in other projects). If an image is found to contain one or more animal(s), a bounding box is drawn around each individual and is then assigned an identification (Figure 1). For the purpose of this paper, we use the term "label" for a classified image, in contrast to the various "annotations" that participants use to classify each image. For more details about "quality control" please refer to Supplemental File 3: Appendix 1.

To obtain an index of biodiversity, we used camera trap data collected between January 2017 and December 2021. For the consensus of image classifications that did not have a unanimous label classification, the image classifications made by "expert reviewers" were accepted, and for images not reviewed, classifications that reached a consensus of 70% or higher were accepted (Adam et al. 2021; Hsing et al. 2022). The resulting extensive data resource is being used for scientific analysis and as input to train an AI model for future classification aid.

CITIZEN SCIENTISTS' ENGAGEMENT AND MOTIVATORS

The research utilized a mixed-methods approach, collecting both quantitative and qualitative data to explore participants' attitudes towards and involvement in WildLIVE!. To identify citizen scientist participation and engagement, we analyzed user data obtained from our online landing page and Labelbox. Participation was measured as the number of registrations over time between 5 April 2020 and 5 April 2023. Engagement was measured based on user data collected by Labelbox ("Created At," "Seconds to Create," "Seconds to Review," "Created By;" for more details, refer to Supplemental File 3: Appendix 1).

Quantitative data were collected through a two-part questionnaire titled "Meine Teilnahme an WildLIVE!" (refer to Supplemental File 4: Appendix 2 for a more detailed description of its content and methodology) to understand the perceptions, motivations, and expectations of participants. The original version of the questionnaire was in German, but translated subsequently into English by two bilingual researchers in the subject matter who are fluent in both languages. This approach ensured that the nuances and contextual meanings of the questions were preserved (Bradley 1994).

The questionnaire was developed using a construct-centered approach (Messick 1995), ensuring that it accurately captured the constructs of interest. In the first section of the questionnaire, Part A, participants expressed their level of agreement with motivational statements crafted from ad-hoc email feedback received from citizen scientists. These statements were presented on a 6-point Likert scale ranging from 1 (do not relate) to 6 (strongly related; Zanbar and Ellison 2019). Motivational statements were carefully selected to be representative of the feedback received and to be aligned with the five constructs of knowledge and understanding, engagement and commitment, personal benefits and enjoyment, community and advocacy, and emotional response (Santori et al. 2021; Kim, Chan, and Gupta 2007; for examples of participants' feedback via emails, see Supplemental File 5: Appendix 3).

Part B of the questionnaire offered open-ended questions to capture narrative responses, allowing for a richer understanding of participants' experiences with WildLIVE! (see Supplemental File 3: Appendix 1 for more details). We carried out all analyses in R 3.6.1 (R Core Team, 2023) if not specified otherwise.

RESULTS

CITIZEN SCIENCE PARTICIPATION, ENGAGEMENT, AND THE COVID-19 PANDEMIC

The WildLIVE! initiative was launched on 4 April 2020 at the beginning of the COVID-19 pandemic as part of several other CS projects at the Senckenberg Institute for Biodiversity Research (Senckenberg 2023). Until 4 April 2023, 858 participants had registered. Active participants donated more than 8,938 hours of work, which equates to 1,117.3 working days or 4.98 years (assuming a 40-hour work week including German public holidays and vacation). In total, 108,198 images were processed with 10 to 11 classification iterations, resulting in 976,268

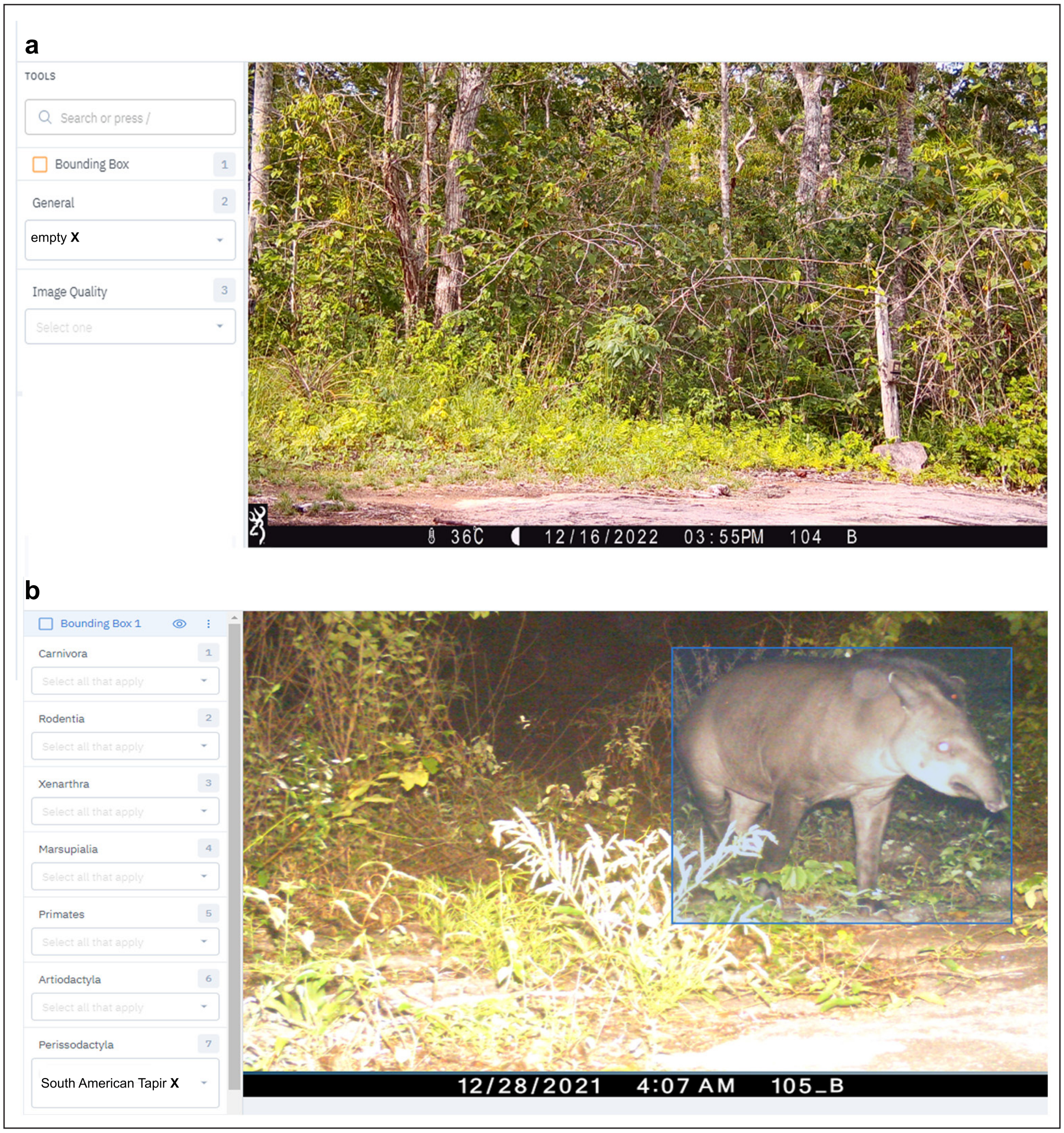

Figure 1 (a) Screenshot of the WildLIVE! platform interface on labelbox.com. The interface showcases the camera trap image alongside project-specific hierarchical classifications. The image displayed in panel *a* does not contain any captured animals, and consequently, should be classified as "empty," whereas image **(b)** shows an animal (South American Tapir) record enclosed by a bounding box (*blue*). Citizen scientists draw the bounding boxes, and animals are subsequently identified using the hierarchical classifications presented next to the image (*left*), and the identification tool (not shown). Once the species is identified, additional information such as interactions or feeding activity can be classified, if applicable.

image classifications (labels) with an estimated 1,500,000 annotations assigned by citizen scientists.

The participants' engagement had an intrinsic pattern affected by the national lockdowns during the COVID-19 pandemic (Supplemental File 6: Figure 3). Sudden spikes in registrations and engagement can be attributed to public outreach activities by us such as social media posts, print media articles, radio interviews, etc., as well as group registrations by university students during courses or school class registrations (Figure 2a). Bottlenecks in the upload of data in the initial phase caused a negative impact on citizen scientists' engagement (Supplemental File 6: Figure 3).

Out of the 858 registered participants, 504 (59%) actively contributed to the classifications. The image classification-to-participant ratio was 1,937:1. The extent of the active citizen scientists' contributions varied between 1 and 97,403 labels each (mean 1,943). Notably, a small number of participants were responsible for the majority of classifications: While 158 of the 504 active participants (31%) classified less than 100 images each, the most active 10% (50 individuals) contributed to 78% (n = 763,622) of all image classifications (labels). The top three participants alone accounted for an impressive number of labels, with individual throughputs of 97,403, 62,636, and 57,092 labels respectively (Figure 2b).

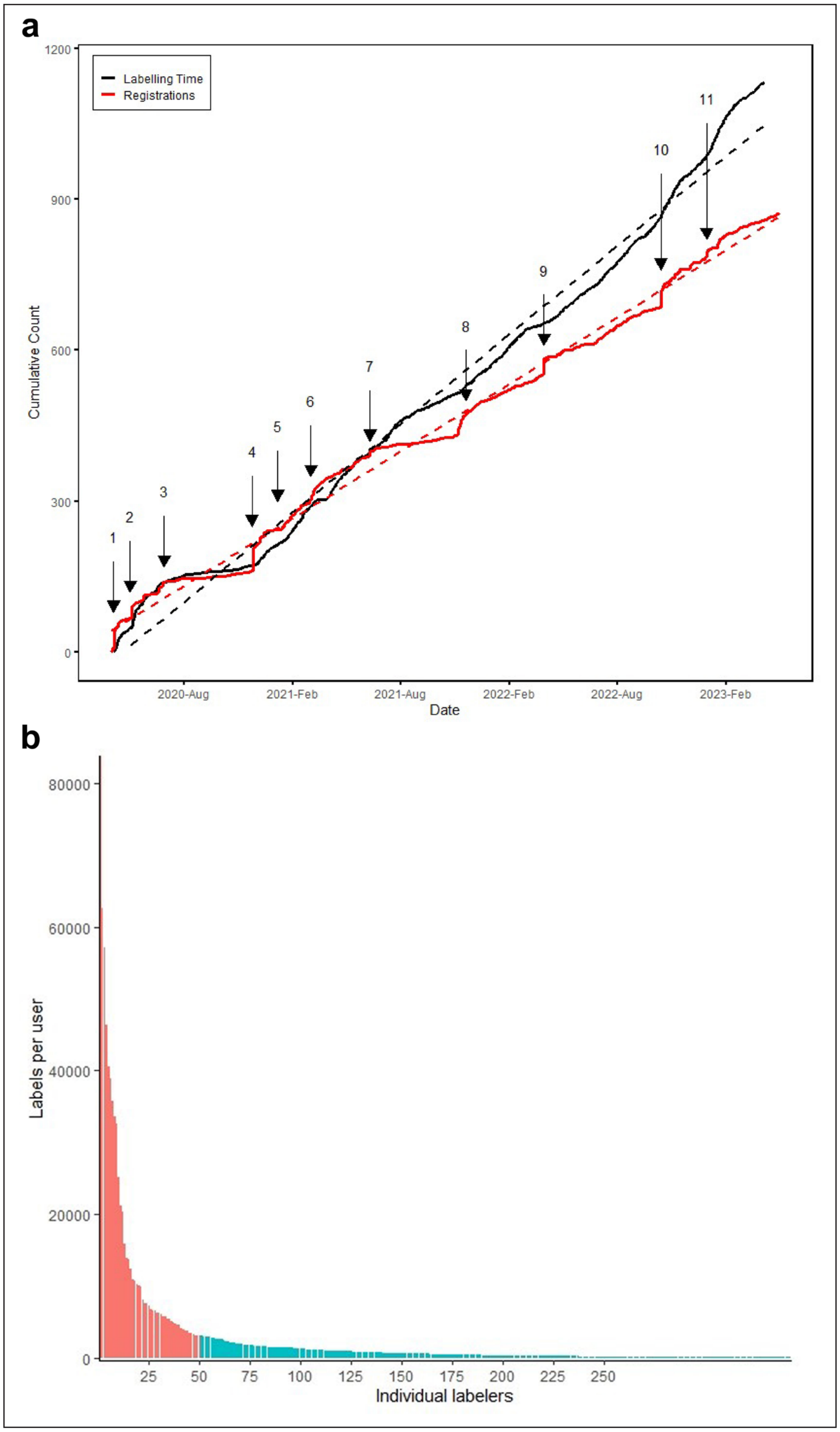

Figure 2 (a) Citizen scientist engagement: The number of registrations steadily increased since the project started in April 2020 (*red line*). Steep increases in registrations can be attributed to group registrations through educational events in schools and universities, as well as public outreach efforts. Key factors contributing to this growth include. (1–3) initial social media posts and newsletters through mailing list for members of the Senckenberg society from Senckenberg PR department; (4) interview in print media ["P.M-Magazin"], November 2020; (5) joining national citizen science platform [bürgerschaffenwissen.de], January 2021; (6) radio interview ["HR Funkkolleg "], joining local citizen science platform [ehrensache.jetzt], and short mentioning in print media [Wohllebens Welt], March 2021; (7) university teaching course, June 2021; (8) podcast ["Sag' mal Du als Biologin" featured by audible], November 2021; (9) school event [Helmholtz-school, Frankfurt], April 2022; (10) radio interview [WDR 5 Quarks], October 2022; and (11) interview in local TV [HR maintower]. Time investment of citizen scientists (*black line*), measured in cumulative 8-hour days, reflecting the total time participants dedicated to the project. Solid lines: raw data; dashed lines: regression lines. **(b)** Label contribution by active participants (only participants with more than 100 labels are shown, n = 334). The red bars indicate the upper 10% of active participants (n = 50) who contributed with 763,622 labels to 78% of all classifications (n = 976,268).

ANALYSIS OF TAXONOMIC CLASSIFICATIONS

The taxonomic classifications for 42,088 images containing mammals were assigned by at least 10 or 11 different citizen scientists. Of these images, 29,437 (69.9%) were identified unanimously to species level. For 10,314 images (24.5%) with non-unanimous labels, the identification of expert reviewers was accepted. There were 1,437 images (3.4%) that were not reviewed by expert reviewers for which an identification was accepted if a consensus of 70% or higher was reached. 900 images (2.1%) that did not yield a consensus were discarded from this study.

Overall we recorded 24 mammalian species representing the native trophic structure including apex-predators (puma, jaguar), meso-carnivores (ocelots, jaguarundi, margays), large herbivores (tapir, collared and white lipped peccary), and small mammals (agouti, tamandua, nine-banded armadillo; Jansen et al. 2020). Because of the vulnerability of large carnivores to population decline and local extinction caused by habitat loss, we conducted a separate study (Meißner et al. 2024) focussing on the jaguar (*Panthera onca*). The study involved characterizing the life histories of 15 individuals and inferred four reproduction events between March 2017 to December 2019. The results of this separate study, which also determined a massive (33%) reduction of dense forest cover, provides strong evidence of the anthropogenic pressure on the CDF, and the imminent threat of habitat destruction in the Chiquitano region.

CITIZEN SCIENTISTS' MOTIVATIONS, INCENTIVES, AND BENEFITS

Out of 858 registered users, 504 were active participants, with 121 (24%) responding to the questionnaire. Participants predominantly expressed positive sentiments about their involvement in the WildLIVE! project, as reflected in the weighted average responses across construct themes. The constructs with the most positive responses were "Engagement and Commitment" (86.3% weighted average of positive responses for this construct), "Knowledge and Understanding" (83%), and "Emotional Responses" (78.4%). Responses in "Personal Benefits and Enjoyment" and "Community and Advocacy" were also positive, though to a lesser extent (68.7% and 55.6% respectively). The motivational statements with the three highest weighted averages of positive responses were (1) "gives me insights into wilderness" (92%), (2) "is a lot of fun" (91%), and (3) "is meaningful to me because I can support current research", and "expands my knowledge on biological taxa/species" (89% for both, Figure 3; for presentation of responses presented on 6-point Likert scale, please refer to Supplemental File 7: Figure 4).The majority (85%) of participants expressed interest in continuing with the project, especially if new elements were introduced.

Conversely, there is also evidence that the project affects the participants in a negative way, with 83% feeling saddened by the observed biodiversity loss. Interestingly, 79% of participants had their first experience with CS through the WildLIVE! project. Yet, the project did not significantly improve awareness about other CS projects (25%) or contribute to reducing the feeling of wanderlust (35%; Figure 3).

In part B of the questionnaire, participants used a total of 3,127 words in the open-ended questions to describe their involvement, of which 467 were unique. Sentiment analysis revealed 69 positive, 31 negative, and 367 neutral words. The most frequently used words by participants to describe their experience were positive or neutral, including "knowledge" (75%), "interesting" (72%), "meaningful" (71%), "exciting" (63%) and "fascinating" (56%) (Table 1). Negative sentiments were reflected by the choice of words such as "monotonous" (26%), "exhausting" (23%), and "sad" (10%), as well as in personal communications conveying a decrease in motivation as a result of frustration about biodiversity loss (Figure 4; Supplemental File 8: Appendix D). These findings underscore the varied impact of WildLIVE!, from educational benefits to emotional challenges associated with conservation efforts (Table 1; Figure 3; see also Supplemental File 8: Appendix D).

DISCUSSION

LAUNCHING WildLIVE!

Virtual science projects have gained significant attention and utilization in biodiversity research, presenting an innovative and cost-effective approach to gathering and analyzing data. Participants are offered the opportunity to contribute to in-situ surveys, encompassing a variety of ecosystems and species, from freshwater habitats and avian populations to plant life (Rose et al. 2020; Dwivedi 2021; Ramvilas et al. 2021). They also facilitate ex-situ surveys in a digital space, where volunteers can assist, for example, in the classification of camera trap images and videos, such as "chimp&see," "Snapshot Serengeti," and "Wildlife Insights" (Swanson et al. 2015; Arandjelovic et al. 2016; Ahumada et al. 2020).

For most people, the COVID-19 pandemic demanded a shift from in-person nature observation to digital nature observation and may have changed how humans relate to the natural environment by driving us to observe nature from a more distant position (Poerting and Rudolfi 2021). A number of digital interactive projects such as BirdTrack

POSITIVE	OCC.	PART.	NEUTRAL	OCC.	PART.	NEGATIVE	OCC.	PART.
exciting	133	63	species	159	80	monotonous	37	26
meaningful	129	71	knowledge	138	75	sad	13	10
interesting	102	72	nature	113	61	frustrated	11	9
useful	65	52	fascinating	71	56	boring	7	6
enthusiastic	64	52	research	66	52	lonely	5	4
important	59	48	discover	65	52	upset	4	3
curious	59	47	conservation	64	50	angry	4	3
love	53	43	science	62	48	tiring	4	3
fun	50	38	protection	58	45	tedious	2	2
satisfying	47	38	ecology	52	42	confused	2	2

Table 1 The top ten positive, neutral, and negative sentiment words according to number of occurrences (Occ.) and the percentage of participants that used that word (Part.) to describe their involvement in the WildLIVE! project.

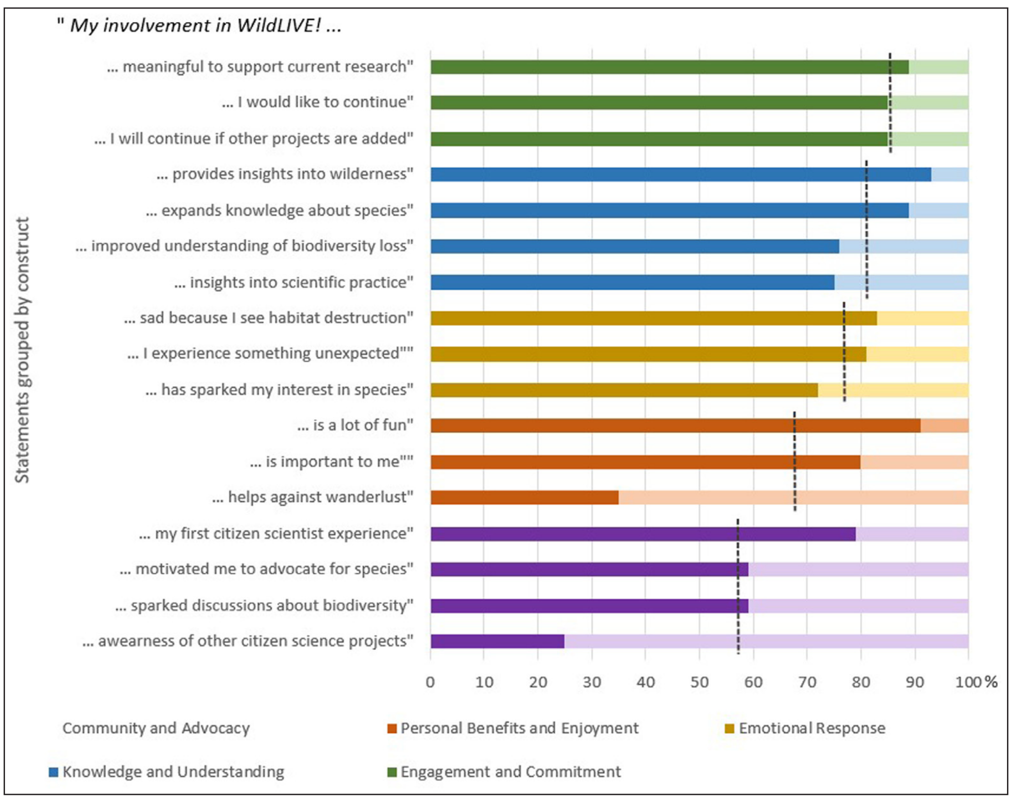

Figure 3 The aggregated results of participant responses from questionnaires are presented, which assess their agreement level with selected quotations derived from email feedback provided by citizen scientists. The data are reported as weighted average response rates. Darker shades represent responses with a positive sentiment and light shades represent negative sentiments. Statements are grouped according to five distinct constructs. The dashed lines indicate the weighted average response per construct. See text for details.

(Shoesmith et al. 2021) and COVID-19 Sounds (Han et al. 2022) were launched as a result of the pandemic, and existing platforms such as eBird and iNaturalist (Kishimoto et al 2021; Sánchez-Clavijo et al. 2021) saw a marked increase in participation. In response to the COVID-19 pandemic, WildLIVE! was developed to offer opportunities for remote participation in biodiversity research, catering to the increased number of individuals seeking engagement from home during lockdown periods. In the context of this study, a "lockdown period" is defined based on the official restrictions imposed in Germany, where the study was conducted. These lockdown periods typically included government-mandated

"My motivation took a major hit when you [the project leaders] informed us [the participants] about the fires that had destroyed a lot of primary forest since 2019. Soon after, I came across the first images depicting these fires. Every image prior to 2019 felt like a dagger to my heart, and even the newer ones, devoid of any forest, evoked the same pain."

Figure 4 Feedback from a participant showing a decrease in motivation and increasing frustration in relation to biodiversity loss.

stay-at-home orders, closure of non-essential businesses, and restrictions on public gatherings.

It is important to note that while our analysis primarily draws upon the lockdown in Germany, we acknowledge the potential global reach of the WildLIVE! platform. Therefore, we do not assume that all participants are German or residing in Germany; however, the peaks in participant engagement from our data closely align with the lockdown periods in Germany, suggesting an impact of these restrictions on participation levels. Future studies could extend this analysis to examine the relationship between participant engagement and lockdown periods in other countries, providing a more comprehensive understanding of how global events and local policies influence digital CS participation.

While Labelbox provides a robust and reliable platform, it is important to highlight that it is a closed-source software. Therefore, risks are introduced such as vendor lock-in and limited interoperability, which might be significant considerations for some projects. Other platforms such as Zooniverse (www.zooniverse.org), eMammal (emammal.si.edu), and Agouti (agouti.eu) are open-source and potentially provide researchers with greater flexibility and control over their own projects. By opting for open-source solutions in the future, researchers can mitigate the risks associated with proprietary software platforms, fostering a more adaptable and resilient project environment.

At the moment, WildLIVE! is making use of the Labelbox platform to host the project until we have finished developing our own custom platform. This will be a combination of archive, analysis, and CS on one portal where data sets will be open source to enable open source research and CS according to the FAIR (Findability, Accessibility, Interoperability, and Reusability) principles (Wilkinson et al. 2016) and as described further in the section "Conclusion and Outlook." One major benefit of the planned platform will be the open source availability of labeled camera trap datasets to train machine learning algorithms for automated classification.

CITIZEN SCIENCE ENGAGEMENT AND MOTIVATION

We found that the top 10% of participants (i.e., the 50 most active) contributed to 79% of image classifications (Figure 2b). This aligns with the outcomes of similar CS projects. For example, Sauermann and Franzoni (2015) analyzed participant engagement data across several projects and found that the majority of participants engaged only once, with minimal effort, whereas a small percentage of the participants contributed the greatest effort. The same trend was observed in the project MammalWeb (Hsing et al. 2022). However, in comparison with similar projects, WildLIVE! has a relatively high image-classification-to-participant ratio (~1,900:1) relative to MammalWeb (~550:1), and Snapshot Serengeti (~43:1), with 1.2 million images for 28,000 participants (Hsing et al. 2018; Swanson et al. 2016). On the one hand, this shows a huge potential for growth of WildLIVE! in terms of participant numbers in comparison with similar projects. On the other hand, it demonstrates a strong commitment resulting in heavy engagement of single participants. Approximately a year after the launch of WildLIVE!, the cumulative number of labels generated exceeded the number of participant registrations (Figure 2a), evidencing this strong engagement and activity by our participants.

Several studies have indicated the positive impacts of CS projects, including direct personal benefits and other broader outcomes such as behavioral alterations (see Green et al. 2020 for a review). Through involvement in CS projects, participants can increase their knowledge about the topics researched (Masters et al. 2016; Forrester et al. 2017), and provide a sense of purpose and community (Curtis 2015; Domroese and Johnson 2017). While we did not conduct an extensive or systematic survey on the underlying motivations of our participants, we received valuable personal feedback through our questionnaire, as well as through ad hoc email correspondence (see some examples in Supplemental File 5: Appendix 3). The results of our questionnaire indicate that the primary motivations of our participants, reflected by the statements "insights into wilderness, "expands my knowledge," and "meaningful" align predominately with the categories of "Engagement and Commitment," followed by "Knowledge and Understanding" and "Emotional Responses." The words most commonly used by participants to describe their involvement in WildLIVE! include "knowledge," "species," "exciting," and "interesting." This reinforces the idea that understanding and knowledge, purposeful engagement, and enjoyment are key drivers motivating our participants, and suggests that our participants appear to be driven primarily by a desire for intellectual growth and emotional fulfillment.

Conversely, some participants are affected in a negative way, feeling saddened by the observed biodiversity loss. Involvement in the project has also been described as "monotonous" and "exhausting." While their engagement in WildLIVE! represented the first interaction with CS for most participants, it did not improve their awareness about other CS projects or reduced the feeling of wanderlust. Our participants are becoming increasingly concerned about habitat destruction occurring in or nearby our study area, and occasionally reported a resulting decrease in motivation. Unfortunately, this is in line with other studies reporting on a growing body of evidence relating to emotional distress responses arising from perceptions on environmental change in society (Cianconi et al. 2022).

ATTRACT NEW AND RETAIN EXISTING PARTICIPANTS

In our experience, the two major challenges in the WildLIVE! project are (1) to attract new participants and (2) to retain existing and experienced users. To draw new participants, social media platforms are crucial for the distribution of information about the project (Liberatore et al. 2018). To promote our project, our institution's public relations department used social media platforms such as Facebook (facebook.com/SenckenbergWorld), Twitter (twitter.com/Senckenberg), and Instagram (instagram.com/SenckenbergWorld), as well as newsletters through the mailing list for members of the Senckenberg society. WildLIVE! also has its own webpage (Jansen 2021), which is linked to several public portals for CS (Bürger Schaffen Wissen; engagement jetzt!; GoVolunteer). Important but somewhat ad hoc is the outreach gained through mainstream media coverage, for example, print media or radio interviews. These spontaneous mainstream media exposure events are usually followed by a sudden increase in participant registrations (Figure 2a).

To enhance the retention and engagement of participants already registered in the WildLIVE! project, we implemented a variety of strategies, which have demonstrated promising results. Below, we describe these strategies along with practical examples of how they were applied:

(1) **Positive introduction:** Providing a welcoming tutorial and introductory email helps create a positive first impression, setting the tone for participant involvement.

(2) **Personal care:** Responding personally to emails, inquiries, and telephone calls from participants demonstrates our commitment to their positive experience, fostering a supportive community.

(3) **Dynamic and enriching experience:** Facilitating digital access allows for time-flexible engagement, while providing content related to biodiversity and conservation keeps the experience relevant and educational. For example, we put effort into creating a dynamic home page, including news about the study area and an online museum of selected photographs.

(4) **Ownership and purpose:** Encouraging co-design of project aspects, such as writing specific aspects of the tutorial (many participants intrinsically offered to write species identification keys), and participation in small sub-projects provides participants with a sense of ownership and purpose. Participants can become "expert reviewers" by classifying > 3 000 images within a project, providing acknowledgment of their efforts and additional motivation.

(5) **Clear impact goals:** Communicating research questions, preliminary results, and conservation issues in an accessible and authentic manner ensures that participants understand the impact and importance of their contributions.

(6) **Transparency:** Maintaining transparency in project development and providing frequent updates through newsletters (~ twice a year) and email correspondence have been instrumental in building trust and maintaining participant interest.

(7) **Appreciation and feedback:** Showing appreciation for participant involvement through special acknowledgments, small gifts (e.g., a plaster cast of a jaguar track), and providing feedback on their contributions helps validate their efforts and encourages continued participation.

(8) **Community and exchange:** Hosting online events and regular online meetings between project management and participants promotes a sense of community, facilitates knowledge exchange, and provides opportunities for co-design. Additionally, WildLIVE! has been successfully integrated into school enrichment events covering a range of curriculum subjects such as geography, biology, and ecology.

(9) **Visability, range, and outreach:** WildLIVE! is hosted and promoted by Senckenberg – Leibniz Institution for Biodiversity and Earth System Research. The project also appears on two CS platforms, with the national platform BürgerSchaffenWissen attracting a large and growing user base. The project's outreach, detailed in Figure 2, has positively impacted the attraction of new participants. In addition, a public and coached workspace in the "Aha?! Science Lab" hands-on exhibition at the Senckenberg Natural History Museum in Frankfurt, Germany, along with school events, continuously recruits new participants (Supplemental File 9: Figure 5).

(10) Sustainability through institutional support and commitment: Embedded in Senckenberg's broader CS initiative ("Gemeinsam forschen"), WildLIVE! along with various other CS projects benefit from coordinated support and a dedicated press office. The project is also showcased in the public museum (Supplemental File 9: Figure 5A), highlighting institutional commitment and support.

The effectiveness of these strategies is reflected in the observed peaks in participant engagement, the positive feedback received, as well the relatively high engagement (e.g., the high image-per-labeler ratio) and time investment of the participants, indicating a successful implementation of engagement-enhancing practices in the WildLIVE! project. A wealth of studies suggest that employing methods similar to those previously described can cultivate emotional connections with participants, thereby substantially boosting engagement in CS initiatives (Baruch et al. 2016; Hsing et al. 2022; Hart et al. 2022).

CITIZEN SCIENTISTS EXPLORE "DIGITAL ECOLOGY"

The WildLIVE! project fosters collaboration between professional and citizen scientists in a digital space, driven by a shared interest in biodiversity and conservation. Citizen scientists enjoy the exposure to a diversity of exotic animals, and in particular the jaguar, a focal species of the project, which is not only of ecological importance but also boasts aesthetic charisma for people (Lorimer 2007), making the species particularly suitable for CS projects.

The CDF is a topographical space in which we conduct research on jaguars and other wildlife. However, WildLIVE! provides an additional layer as a topological space where characteristics of medialized human-animal encounters allow for further analysis of engagement (Pütz and Schlottmann 2020). In this context, the jaguar is not only significant as an important variable in the ecosystem, but also as an "object" that brings different working groups across differing professional backgrounds together in digital space for heterogeneous cooperation.

While our initial results have a primary focus on jaguar biology and population dynamics (Jansen et al. 2020; Meißner et al. 2024), the jaguar may also be regarded as a flagship species that functions as a boundary object, "where each social world has partial jurisdiction over the resources represented by that object" (Star and Griesemer 1989, p. 412). This perspective opens the discussion towards more socio-ecological research, and takes into account the social dimensions of CS. It underlines the importance of integrating societal actors, such as landowners and farmers. Since our analysis shows the need to take measures to prevent the further deforestation of CDF, this issue remains open on a sociopolitical level.

The WildLIVE! project, while not directly connected to tangible biodiversity conservation efforts, plays an important role in promoting biodiversity conservation by raising awareness. For example, citizen scientists might reflect on their environmental impact and consumption habits. Additionally, it provides valuable insights for decision-makers like landowners and farmers by providing evidence of the extent and impacts of land use changes on wildlife. Participant involvement in WildLIVE! plays a critical role in connecting individuals from urban environments with wildlife in a real "hands-on" way. Thus, participant engagement in this project promotes a connectedness with nature and builds a sense of responsibility towards our natural heritage. And on the flip side, citizen scientists are playing a critical role in enabling research by aiding the processing of a large data set. We need the continued participation and engagement of citizen scientists for the sustainability of long-term biomonitoring that can be used to track the effects of land use change in the CDF and possibly other areas.

CONCLUSIONS AND OUTLOOK

We herein demonstrate that the CS project WildLIVE! makes significant contributions in three key areas: science, society, and nature conservation. More specifically, WildLIVE! provides a digital infrastructure that aids scientists in analyzing large datasets through CS engagement. This collaborative effort not only facilitates scientific research but also generates annotated training data sets valuable for machine learning. Moreover, WildLIVE! enables science communication, encourages citizen engagement, and facilitates learning about different species and their taxonomic classifications. Importantly, WildLIVE! contributes to an emerging form of wildlife experience in "digital ecologies" that plays a vital role in connecting people to biodiversity (Poerting and Rudolfi 2021). It raises awareness about biodiversity, environmental challenges, and the critical issue of biodiversity loss.

There is a growing need from science and conservation for the development of tools to deal with the "data deluge" generated by modern sensor devices, which rapidly produce vast amounts of data (Anderson 2008; Groom et al. 2022). Consequently, we see substantial demand for a platform that offers the integrated capabilities for data archiving, analysis, and CS engagement. Currently, in its prototype phase, we are developing the Wildlive Portal (Figure 5), accessible at http://wildlive.senckenberg.de. The

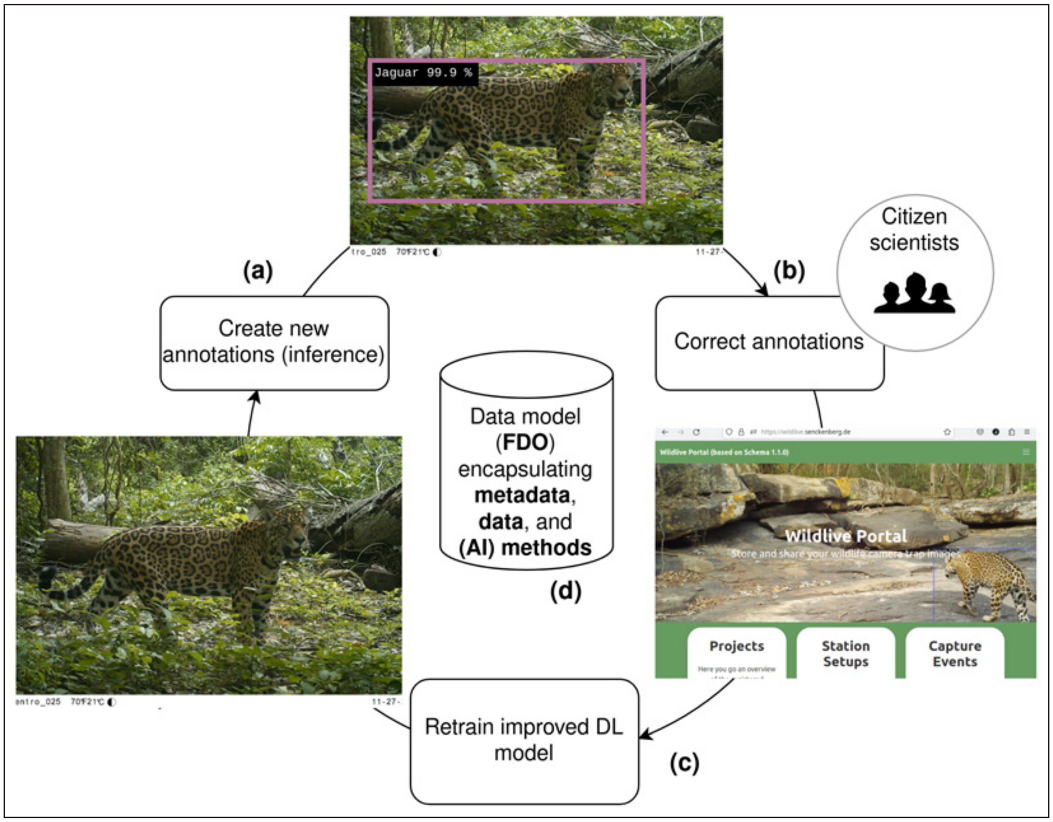

Figure 5 Overview of the Wildlive platform currently in development: The platform follows an integrated approach combining data models and a network of microservices enabling data processing and downstream analysis by both humans and machines. **(a)** Within an iterative processing pipeline, a machine learning service can be used to provide automatic high throughput annotations as a baseline, **(b)** which can then be subject to review and refinement by citizen scientists. **(c)** Subsequently, annotated data is compiled into new training data sets to improve the machine learning-based annotation. **(d)** The involved data model based on FAIR Digital Objects provides the operational semantics of how to process the data and capture rich contextual (provenance) information from both humans' and machines' operations on the data.

Wildlive Portal enables sharing, discovering, and analyzing camera trap images, as well as supports crowdsourcing and machine-based curation and processing of biomonitoring data, in conformity with FAIR principles (Wilkinson et al. 2016). These principles provide guidelines to foster findability, accessibility, interoperability, and reuse of digital resources, thereby enabling efficient navigation and processing of resources by software agents or, in short, "machines" (Jacobsen et al. 2020, Wittenburg and Strawn 2021). To improve the FAIRability of data in the Wildlive Portal, primary data (digital images, audio, and video streams from the camera traps) are accompanied by comprehensive contextual metadata including details of the station setup, the context of data capturing, and the history of taxonomic assertions such as revisions. These data packages adhere to a platform-independent standard for the exchange of datasets designated as FAIR Digital Objects (Soiland-Reyes et al 2023).

In summary, by integrating machine observations with crowd-sourced and machine learning–based analysis within a single technical framework (Grieb et al. 2021), the portal will contribute to the development of a comprehensive and substantiated database. This portal will support the broader goal of biodiversity conservation by enabling more effective data management and post-processing, providing the foundation for informing evidence-based conservation strategies.

DATA ACCESSIBILITY STATEMENT

Selected data have been made available on the "Wildlive Portal" (https://wildlive.senckenberg.de) under Creative Commons Attribution 4.0 license (https://creativecommons.org/licenses/by/4.0). The portal provides an interactive, browsable interface to access the image data with contextual metadata. The dataset is registered with Datacite (DataCite Metadata Working Group 2021) and can be accessed at http://doi.org/10.12761/34zr-fh25, which directly links to the specific image collection in concern. Individual camera trap data can be accessed under https://wildlive.senckenberg.de/showArea/captureevent. In the future, we plan to add more datasets, which will be made available under Creative Commons licenses.

SUPPLEMENTARY FILES

The Supplementary files for this article can be found as follows:

- **Supplemental File 1: Figure 1.** Location of the study area. DOI: https://doi.org/10.5334/cstp.665.s1
- **Supplemental File 2: Figure 2.** Circulation concept of the data pipeline in the WildLIVE! project. DOI: https://doi.org/10.5334/cstp.665.s2
- **Supplemental File 3: Appendix 1.** Methodology. DOI: https://doi.org/10.5334/cstp.665.s3
- **Supplemental File 4: Appendix 2.** WildLIVE! Questionnaire: Methodology and content. DOI: https://doi.org/10.5334/cstp.665.s4
- **Supplemental File 5: Appendix 3.** Selected quotations derived from ad hoc participant feedback via email correspondence. DOI: https://doi.org/10.5334/cstp.665.s5
- **Supplemental File 6: Figure 3.** Weekly participant engagement on WildLIVE!. DOI: https://doi.org/10.5334/cstp.665.s6
- **Supplemental File 7: Figure 4.** Results of participants feedback on selected motivational statements. DOI: https://doi.org/10.5334/cstp.665.s7
- **Supplemental File 8: Appendix 4.** Results from the WildLIVE! Questionnaire. DOI: https://doi.org/10.5334/cstp.665.s8
- **Supplemental File 9: Figure 5.** (a) Museum and (b) school WildLIVE! engagement. DOI: https://doi.org/10.5334/cstp.665.s9

ETHICS AND CONSENT

The questionnaire for this study was cleared by our institution, as participant involvement was entirely voluntary and anonymous. Detailed information on the purpose of the questionnaire (including the planned publication of the results) was provided to all participants. Participants had the option to skip any questions they preferred not to answer, and their participation could be terminated at any time.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Study management and supervision: MJ; study design: MJ, M Beukes; data collection in the field: YCC, JLAB, GAL, RM, M Blumer, MJ; data analysis: MJ, M Beukes, MW; portal programming/machine learning: CW, JG, AW; writing: MJ, M Beukes, M Blumer, MR, JP, CW, RM; figures: MJ, M Beukes, M Blumer; external funding: MJ.

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REFERENCES

Adam, M., Tomášek, P., Lehejček J., Trojan, J., and **Juunek, T.** (2021). The role of citizen science and deep learning in camera trapping. *Sustainability*, 13(18), p. 10287. DOI: https://doi.org/10.3390/su131810287

Adler, F.R., Green, A.M. and **Şekercioğlu, Ç.H.** (2020). Citizen science in ecology: a place for humans in nature. *Annals of the New York Academy of Sciences*, 1469(1), pp.52–64. DOI: https://doi.org/10.1111/nyas.14340

Ahumada, J.A., Fegraus, E., Birch, T., Flores, N., Kays, R., O'Brien, T.G., Palmer, J., Schuttler, S., Zha, J.Y., Jetz, W. and **Kinnaird, M.** (2020). Wildlife insights: A platform to maximize the potential of camera trap and other passive sensor wildlife data for the planet. *Environmental Conservation*, 47(1), pp.1–6. DOI: https://doi.org/10.1017/S0376892919000298

Anderson, C. (2008). Wired. The end of theory: the data deluge makes the scientific method obsolete. Retrieved from http://www.wired.com/2008/06/pb-theory [last accessed 11 June 2023]

Arandjelovic, M., Stephens, C.R., McCarthy, M.S., Dieguez, P., Kalan, A.K., Maldonado, N., Boesch, C. and **Kuehl, H.S.** (2016). Chimp&See: An online citizen science platform for large-scale, remote video camera trap annotation of chimpanzee behaviour, demography and individual identification. *PeerJ Preprints*. DOI: https://doi.org/10.7287/peerj.preprints.1792v1

Baruch, A., May, A. and **Yu, D.** (2016). The motivations, enablers and barriers for voluntary participation in an online crowdsourcing platform. *Computers in Human Behavior*, 64, pp.923–931. DOI: https://doi.org/10.1016/j.chb.2016.07.039

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V. and **Shirk, J.** (2009). Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience*, 59(11), pp. 977–984. DOI: https://doi.org/10.1525/bio.2009.59.11.9

Bradley, C. (1994). Translation of questionnaires for use in different languages and cultures. In B. C. Chur, eds. *Handbook of Psychology and Diabetes: a guide to psychological measurement in diabetes research and practice*. Switzerland: Harwood Academic Publishers. pp. 43–55.

Chandler, M., See, L., Copas, K., Bonde, A.M., López, B.C., Danielsen, F., Legind, J.K., Masinde, S., Miller-Rushing, A.J., Newman, G. and **Rosemartin, A.** (2017). Contribution of citizen science towards international biodiversity monitoring. *Biological conservation*, 213, pp.280–294. DOI: https://doi.org/10.1016/j.biocon.2016.09.004

Cianconi, P., Hirsch, D., Chiappini, S., Martinotti, G. and **Janiri, L.** (2022). Climate change, biodiversity loss and mental health: a global perspective. *BJPsych International*, 19(4), pp.83–86. DOI: https://doi.org/10.1192/bji.2022.20

Curtis, V. (2015). Motivation to participate in an online citizen science game: A study of foldit. *Science Communication*, 37, pp. 723–746. DOI: https://doi.org/10.1177/1075547015609322

DataCite Metadata Working Group (2021). DataCite Metadata Schema Documentation for the Publication and Citation of Research Data and Other Research Outputs. Version 4.4. DataCite e.V. DOI: https://doi.org/10.14454/3w3z-sa82

Domroese, M.C. and **Johnson, E.A.** (2017). Why watch bees? Motivations of citizen science volunteers in the Great Pollinator Project. *Biological Conservation*, 208, pp. 40–47. DOI: https://doi.org/10.1016/j.biocon.2016.08.020

Dwivedi, A.K. (2021). Role of digital technology in freshwater biodiversity monitoring through citizen science during COVID-19 pandemic. *River Research and Applications*, 37(7), pp.1025–1031. DOI: https://doi.org/10.1002/rra.3820

Forrester, T.D., Baker, M., Costello, R., Kays, R., Parsons, A.W. and **McShea, W.J.** (2017). Creating advocates for mammal conservation through citizen science. *Biological Conservation*, 208, pp. 98–105. DOI: https://doi.org/10.1016/j.biocon.2016.06.025

Fraisl, D., Hager, G., Bedessem, B., Gold, M., Hsing, P.Y., Danielsen, F., Hitchcock, C.B., Hulbert, J.M., Piera, J., Spiers, H. and **Thiel, M.** (2022). Citizen science in environmental and ecological sciences. *Nature Reviews Methods Primers*, 2(1), p.64. DOI: https://doi.org/10.1038/s43586-022-00144-4

Green, S.E., Rees, J.P., Stephens, P.A., Hill, R.A. and **Giordano, A.J.** (2020). Innovations in camera trapping technology and approaches: The integration of citizen science and artificial intelligence. *Animals*, 10(1), p.132. DOI: https://doi.org/10.3390/ani10010132.

Grieb, J., Weiland, C., Hardisty, A., Addink, W., Islam, S., Younis, S. and **Schmidt M.** (2021). Machine Learning as a Service for DiSSCo's Digital Specimen Architecture. *Biodiversity Information Science and Standards*, 5, e75634. DOI: https://doi.org/10.3897/biss.5.75634

Groom, Q., Dillen, M., Addink, W., Ariño, A., Bölling, C., Bonnet, P., … & Gaikwad, J. (2022). Envisaging a global infrastructure to exploit the potential of digitised collections. *Authorea Preprints*. DOI: https://doi.org/10.22541/au.166678848.82362633/v2

Han, J., Xia, T., Spathis, D., Bondareva, E., Brown, C., Chauhan, J., Dang, T., Grammenos, A., Hasthanasombat, A., Floto, A. and **Cicuta, P.** (2022). Sounds of COVID-19: exploring realistic performance of audio-based digital testing. *NPJ digital medicine*, 5(1), p.16. DOI: https://doi.org/10.1038/s41746-021-00553-x

Hart, A. G., Adcock, D., Barr, M., Church, S., Clegg, T., Copland, S., De Meyer K., Dunkley R., Pateman R.M., Underhill R., Wyles K. and **Pocock, M. J.** (2022). Understanding engagement, marketing, and motivation to benefit recruitment and retention in citizen science. *Citizen* Science: Theory *and Practice*, 7(1). DOI: https://doi.org/10.5334/cstp.436

Heyns, A.M. (2021). Optimisation of surveillance camera site locations and viewing angles using a novel multi-attribute, multi-objective genetic algorithm: A day/night anti-poaching application. *Computers, Environment and Urban Systems*, 88, p.101638. DOI: https://doi.org/10.1016/j.compenvurbsys.2021.101638

Hsing, P.Y., Bradley, S., Kent, V. T., Hill, R.A., Smith, G.C., Whittingham, M.J., Cokill, J., Crawley, D., MammalWeb Volunteers, and **Stephens, P.A.** (2018). Economical crowdsourcing for camera trap image classification. *Remote Sensing in Ecology and Conservation*, 4(4), pp. 361–374. DOI: https://doi.org/10.1002/rse2.84

Hsing, P.Y., Hill, R.A., Smith, G.C., Bradley, S., Green, S.E.,Kent, V.T.,Mason, S.S., Rees, J., Whittingham, M.J., Cokill, J.,MammalWeb citizen scientists, and **Stephens, P.A.** (2022). Large-scale mammal monitoring: The potential of a citizen science camera-trapping project in the United Kingdom. *Ecological Solutions and Evidence*, 3, e12180. DOI: https://doi.org/10.1002/2688-8319.12180

Jacobsen, A., de Miranda Azevedo, R., Juty, N., Batista, D., Coles, S., Cornet, R., Courtot, M., Crosas, M., Dumontier, M., Evelo, C., Goble, C., Guizzardi, G., Kryger Hansen, K., Hasnain, A., Hettne, K., Heringa, J., Hooft, R., Imming, M., Jeffery, K., Kaliyaperumal, R., Kersloot, M., Kirkpatrick, C., Kuhn, T., Labastida, I., Magagna, B., McQuilton, P., Meyers, N., Montesanti, A., van Reisen, M., Rocca-Serra, P., Pergl, R., Sansone, S., Bonino da Silva Santos, L., Schneider, J., Strawn, G., Thompson, M., Waagmeester, A., Weigel, T., Wilkinson, M., Willighagen, E., Wittenburg, P., Roos, M., Mons, M., Schultes, E. (2020). FAIR Principles: Interpretations and Implementation Considerations. *Data Intelligence* 2 (1–2): pp. 10–29. DOI: https://doi.org/10.1162/dint_r_00024

Jansen, M. (2021). WildLIVE! – Entdecke die wilden Tiere Boliviens, 22 December 2021. Available at https://wildlive.sgn.one/de/ [last accessed 11 June 2023].

Jansen, M, Engler, M, Blumer, LM, Rumiz, DI, Aramayo, JL, Krone, O. (2020). A camera trapping survey of mammals in the mixed landscape of Bolivia's Chiquitano region with a special focus on the jaguar. *CheckList*, 16(2), pp. 323–335. DOI: https://doi.org/10.15560/16.2.323

Jansen, M., Dick, W., Thieme, M. and **Russ, S.** (2021). Senckenberg WildLIVE!. Dynamic tutorial with participation of various citizen scientists. Available at https://wildlive.sgn.one/de/ueber-das-projekt/projektseite-1/ [last accessed 11 June 2023].

Killeen, T.J., Chavez, E., Pena-Claros, M., Toledo, M., Arroyo, L., Caballero, J., Correa, L., Guillén, R., Quevedo, R., Saldias, M. and **Soria, L.** (2006). The Chiquitano dry forest, the transition between humid and dry forest in eastern lowland Bolivia. In: Pennington, R.T., Lewis G.P., and Ratter J.A. *Neotropical Savannas and Seasonally Dry Forests: Plant Diversity, Biogeography and Conservation.* Boca Raton, USA. CRC Press, pp. 213–223. DOI: https://doi.org/10.1201/9781420004496.ch9

Kim, H.W., Chan, H.C. and **Gupta, S.** (2007). Value-based adoption of mobile internet: an empirical investigation. *Decision support systems,* 43(1), pp.111–126. DOI: https://doi.org/10.1016/j.dss.2005.05.009

Kishimoto, K. and **Kobori, H.** (2021). COVID-19 pandemic drives changes in participation in citizen science project "City Nature Challenge" in Tokyo. *Biological Conservation*, 255, pp.109001. DOI: https://doi.org/10.1016/j.biocon.2021.109001

Labelbox. (2021). Labelbox. Available at https://www.labelbox.com [last accessed 12 July 2023].

Liberatore, A., Bowkett, E., MacLeod, C.J., Spurr, E. and **Longnecker, N.** (2018). Social media as a platform for a citizen science community of practice. *Citizen Science: Theory and Practice*, *3*(1), p. 3. DOI: https://doi.org/10.5334/cstp.108

Lorimer, J. (2007). Nonhuman charisma. Environment and Planning D: *Society and Space*, 25(5), pp.911–932. DOI: https://doi.org/10.1068/d71j

Lotfian, M., Ingensand, J. and **Brovelli, M.A.** (2020). A framework for classifying participant motivation that considers the typology of citizen science projects. *ISPRS International Journal of Geo-Information*, 9(12), p.704. DOI: https://doi.org/10.3390/ijgi9120704

Masters, K., Oh, E.Y., Cox, J., Simmons, B., Lintott, C., Graham, G., Greenhill, A., and **Holmes, K.** (2016). Science Learning via Participation in Online Citizen Science. *Journal of Scientific Communication*, 15, pp. 1–33. DOI: https://doi.org/10.22323/2.15030207

Meißner, R., Blumer, M., Weiß, M., Beukes, M., Ledezma, G.A., Callisaya, Y.C., Bejarano, J.L.A. and **Jansen, M.** 2024. Habitat destruction threatens jaguars in a mixed land-use region of eastern Bolivia. *Oryx*, 58(1), pp.110–120. DOI: https://doi.org/10.1017/S0030605322001570

Messick, S. (1995). Validity of psychological assessment: Validation of inferences from persons' responses and performances as scientific inquiry into score meaning. *American Psychologist*, 50(9), pp. 741–749. DOI: https://doi.org/10.1037/0003-066X.50.9.741

Mutanu, L., Gohil, J., Gupta, K., Wagio, P. and **Kotonya, G.** (2022). A review of automated bioacoustics and general acoustics classification research. *Sensors*, 22(21), p.8361. DOI: https://doi.org/10.3390/s22218361

Norouzzadeh, M.S., Nguyen, A., Kosmala, M., Swanson, A., Palmer, M.S., Packer, C. and **Clune, J.** (2018). Automatically identifying, counting, and describing wild animals in camera-trap images with deep learning. *Proceedings of the National Academy of Sciences*, 115(25), pp.E5716-E5725. DOI: https://doi.org/10.1073/pnas.1719367115

Poerting, J. and **Rudolfi, M.** (2021). Camera trap observations and the delocalisation of wildlife. In: *Digital Ecologies 2021: Political Ecologies of Camera Trapping,* University of Cambridge, England on 29–30 March.

Pütz, R. and **Schlottmann, A.** (2020). Contested conservation–neglected corporeality: the case of the Namib wild horses. *Geographica Helvetica,* 75(2), pp. 93–106. DOI: https://doi.org/10.5194/gh-75-93-2020

R Core Team. (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org/ [last accessed 19 January 2021]

Rajkumar, R., Lee, I., Sha, L. and **Stankovic, J.** (2010). Cyber-physical systems: the next computing revolution. In: *Proceedings of the 47th Design Automation Conference*, Anheim, CA, US on 13–18 June, 2010, pp. 731–736. DOI: https://doi.org/10.1145/1837274.1837461

Ramvilas, G., Dhyani, S., Kumar, B., Sinha, N., Raghavan, R., Selvaraj, G., Divakar, N., Anoop, V.K., Shalu, K., Sinha, A. and **Kulkarni, A.** (2021). Insights on COVID-19 impacts, challenges and opportunities for India's biodiversity research: From complexity to building adaptations. *Biological Conservation*, 255, p.109003. DOI: https://doi.org/10.1016/j.biocon.2021.109003

Romero-Muñoz, A., Jansen, M., Nuñez, A. M., Almonacid, R. V. and **Kümmerle, T.** (2019). Fires scorching Bolivia´s Chiquitano forest. *Science*, 366(6469), 1089. DOI: https://doi.org/10.1126/science.aaz7264

Rose, S., Suri, J., Brooks, M. and **Ryan, P.G.** (2020). COVID-19 and citizen science: lessons learned from southern Africa. *Ostrich*, 91(2), pp.188–191. DOI: https://doi.org/10.2989/00306525.2020.1783589

Rudolfi, M. and **Poerting, J.** (2020). Infrastructures of Ecological Evidence. *Society and Space*, 30 November [online access at https://www.societyandspace.org/articles/infrastructures-of-ecological-evidence last accessed 13 July 2023].

Sánchez-Clavijo, L.M., Martínez-Callejas, S.J., Acevedo-Charry, O., Diaz-Pulido, A., Gómez-Valencia, B., Ocampo-Peñuela, N., Ocampo, D., Olaya-Rodríguez, M.H., Rey-Velasco, J.C., Soto-Vargas, C. and **Ochoa-Quintero, J.M.** (2021). Differential reporting of biodiversity in two citizen science platforms during COVID-19 lockdown in Colombia. *Biological Conservation,* 256, p.109077. DOI: https://doi.org/10.1016/j.biocon.2021.109077

Santori, C., Keith, R.J., Whittington, C.M., Thompson, M.B., Van Dyke, J.U. and **Spencer, R.J.** (2021). Changes in participant behaviour and attitudes are associated with knowledge and skills gained by using a turtle conservation citizen science app. *People and Nature*, 3(1), pp.66–76. DOI: https://doi.org/10.1002/pan3.10184

Sauermann, H., and **Franzoni, C.** (2015). Crowd science user contribution patterns and their implications. *Proceedings of the National Academy of Sciences*, 112(3), pp. 679–684. DOI: https://doi.org/10.1073/pnas.1408907112

Schneider, S., Taylor, G.W. and **Kremer, S.** (2018). Deep learning object detection methods for ecological camera trap data. In: *2018 15th Conference on computer and robot vision (CRV),* Toronto, ON, Canada on 8- 10 May 2018, pp. 321–328. DOI: https://doi.org/10.1109/CRV.2018.00052

Schulze, A., Jansen, M. and **Köhler, G.,** 2009. Diversity and ecology of anuran communities in San Sebastián (Chiquitano region, Bolivia). *Salamandra*, 45(2), pp.75–90.

Senckenberg. (2023). Senckenberg: Gemeinsam forschen. Available at https://gemeinsamforschen.senckenberg.de/ [last accessed 31 October 2023]

Shirk, J.L., Ballard, H.L., Wilderman, C.C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B.V., Krasny, M.E. and **Bonney, R.** (2012). Public participation in scientific research: a framework for deliberate design.

Ecology and Society, 17(2), 29. DOI: https://doi.org/10.5751/ES-04705-170229

Shoesmith, E., Shahab, L., Kale, D., Mills, D.S., Reeve, C., Toner, P., Santos de Assis, L. and **Ratschen, E.** (2021). The influence of human–animal interactions on mental and physical health during the first COVID-19 lockdown phase in the UK: A qualitative exploration. *International Journal of Environmental Research and Public Health*, 18(3), p.976. DOI: https://doi.org/10.3390/ijerph18030976

Silvertown, J. (2009). A new dawn for citizen science. *Trends in ecology & evolution*, 24(9), pp.467–471. DOI: https://doi.org/10.1016/j.tree.2009.03.017

Soiland-Reyes, S., Goble, C., & Groth, P. (2023). Evaluating FAIR Digital Object and Linked Data as distributed object systems. *arXiv*. DOI: https://doi.org/10.48550/arXiv.2306.07436

Star, S.L. and **Griesemer, J.R.** (1989). Institutional Ecology, "Translations" and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. *Social Studies of Science*, 19(3), pp. 387–420. DOI: https://doi.org/10.1177/030631289019003001

Steenweg, R., Hebblewhite, M., Kays, R., Ahumada, J., Fisher, J.T., Burton, C., Townsend, S.E., Carbone, C., Rowcliffe, J.M., Whittington, J., Brodie J. Royle, J. A., Switalski, A., Clevenger, A. P., Heim, N., & Rich, L. N. (2017). Scaling-up camera traps: Monitoring the planet's biodiversity with networks of remote sensors. *Frontiers in Ecology and the Environment*, 15(1), pp.26–34. DOI: https://doi.org/10.1002/fee.1448

Swanson, A., Kosmala, M., Lintott, C. and **Packer, C.** (2016). A generalized approach for producing, quantifying, and validating citizen science data from wildlife images. *Conservation Biology*, 30(3), pp. 520–531. DOI: https://doi.org/10.1111/cobi.12695

Swanson, A., Kosmala, M., Lintott, C., Simpson, R., Smith, A. and **Packer, C.** (2015). Snapshot Serengeti, high-frequency annotated camera trap images of 40 mammalian species in an African savanna. *Scientific data*, 2(1), pp.1–14. DOI: https://doi.org/10.1038/sdata.2015.26

Tan, T.F., Teoh, S.S., Fow J.E. and **Yen, K.S.** (2016). Embedded human detection system based on thermal and infrared sensors for anti-poaching application. In: *2016 IEEE Conference on Systems, Process and Control (ICSPC)*, Bandar Hilir, Malaysia on 16–18 December 2016, pp. 37–42. DOI: https://doi.org/10.1109/SPC.2016.7920700

Vélez, J., McShea, W., Shamon, H., Castiblanco-Camacho, P.J., Tabak, M.A., Chalmers, C., Fergus, P. and **Fieberg, J.** (2023). An evaluation of platforms for processing camera-trap data using artificial intelligence. *Methods in Ecology and Evolution*, 14(2), pp.459–477. DOI: https://doi.org/10.1111/2041-210X.14044

Wilkinson, M.D., Dumontier, M., Aalbersberg, I.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.W., da Silva Santos, L.B., Bourne, P.E. and **Bouwman, J.** (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific data*, *3*(1), pp.1–9. DOI: https://doi.org/10.1038/sdata.2016.18

Wittenburg, P. and **Strawn, G.** (2021). Revolutions Take Time. *Information*, 12(11), pp. 472. DOI: https://doi.org/10.3390/info12110472

Zanbar, L. and **Ellison, N.** (2019). Personal and community factors as predictors of different types of community engagement. *Journal of community psychology*, 47(7), pp.1645–1665. DOI: https://doi.org/10.1002/jcop.22219

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