Web Ecol., 23, 135–144, 2023
https://doi.org/10.5194/we-23-135-2023

Revisiting the debate: documenting biodiversity in the age of digital and artificially generated images

Diego Sousa Campos[1,2], **Rafael Ferreira de Oliveira**[2,3], **Lucas de Oliveira Vieira**[1,2], **Pedro Henrique Negreiros de Bragança**[3,4], **Jorge Luiz Silva Nunes**[1,3,5], **Erick Cristofore Guimarães**[6], and **Felipe Polivanov Ottoni**[1,2,3]

[1]Programa de Pós-Graduação em Biodiversidade e Biotecnologia da Amazônia Legal – Rede BIONORTE, Doutorado, Universidade Federal do Maranhão, São Luís, MA, 65085-580, Brazil
[2]Laboratório de Sistemática e Ecologia de Organismos Aquáticos, Centro de Ciências de Chapadinha, Universidade Federal do Maranhão, Chapadinha, MA, 65500-000, Brazil
[3]Programa de Pós-Graduação em Biodiversidade e Conservação – PPGBC, Mestrado, Universidade Federal do Maranhão, São Luís, MA, 65085-580, Brazil
[4]Freshwater taxonomy group, South African Institute for Aquatic Biodiversity, Makhanda, Eastern Cape, 6140, South Africa
[5]Laboratório de Organismos Aquáticos, Departamento de Oceanografia e Limnologia, Universidade Federal do Maranhão, São Luís, MA, 65085-580, Brazil
[6]Programa de Pós-graduação em Sociedade, Natureza e Desenvolvimento, Instituto de Ciências da Educação, Universidade Federal do Oeste do Pará, Santarém, PA, 68040-070, Brazil

Correspondence: Felipe Polivanov Ottoni (fpottoni@gmail.com)

Received: 9 June 2023 – Revised: 10 September 2023 – Accepted: 24 October 2023 – Published: 7 December 2023

Abstract. This study examines the risks associated with relying solely on images for documenting new species records, rediscoveries, taxonomic descriptions, and distribution expansions. We highlight concerns regarding image authenticity, especially in cases where images may be altered, adulterated, or AI (artificial intelligence)-generated, potentially leading to inaccuracies in biodiversity documentation. To illustrate the evolving challenges, we conducted an experiment with 621 participants who assessed nine AI-generated images. Surprisingly, six were deemed authentic, while three raised doubts, highlighting the difficulty in discerning AI-generated content. Our main message emphasizes the critical role of trust in biodiversity documentation, particularly for taxonomy and conservation, and how eroded trust can hinder conservation efforts. Improved communication and collaboration between taxonomists and conservationists are needed, emphasizing scientific integrity. We urge a reevaluation of journal policies concerning data validation, especially in articles relying on images as primary evidence, to preserve the credibility of scientific research amidst technological advancements.

1 Background

In 2014, Minteer et al. (2014) published a paper titled "Avoiding (Re)extinction", in which they settled the following argument: "Collecting specimens is no longer required to describe a species or to document its rediscovery" (Minteer et al., 2014: p. 260). The authors argued that the traditional methods of documenting biodiversity, which involve collecting and depositing voucher specimens in natural history collections to confirm the species' existence and record their occurrence, should be replaced by alternative methodologies that avoid specimen euthanasia, such as high-resolution photographs, audio recordings, and nonlethal sampling methods. They also stated that "a series of good photographs", which could even be used to describe species, would be the most effective alternative method, particularly if complemented by other kinds of evidence (e.g., mating call records, molecular data). Minteer et al. (2014) recommended that these alternative methods should be used particularly in cases of

Published by Copernicus Publications on behalf of the European Ecological Federation (EEF).

species rediscoveries and documenting the occurrence of rare species and newly discovered species (new species descriptions), whose population(s) are often vulnerable due to their occurrence in small and isolated populations and/or areas. Therefore, they argued that in these cases, the collection of specimens may increase the risk of extinction, and consequently it should be avoided.

These ideas proposed by Minteer et al. (2014) have been widely disseminated in the scientific community but without unanimity. Later in the same year, Krell and Wheeler (2014) criticized the ideas defended by Minteer et al. (2014), arguing that "Describing a new species without depositing a holotype when a specimen can be preserved borders on taxonomic malpractice" (Krell and Wheeler, 2014: p. 815). They also argued that the necessity of the existence of voucher specimens varies depending on the taxon, but usually collecting and depositing specimens in museums and collections are the practices to be followed, as well as registering as many data and/or metadata as possible (e.g., photographs, DNA material). In addition, they also responded to Minteer and his followers regarding the argument that the collection of specimens by biologists may increase the risk of species extinction. According to Krell and Wheeler (2014), if the act of removing a single specimen from the wild may increase the extinction risk of a given species, this species has a population size below the naturally viable and may be considered a "walking dead" species and probably will go extinct anyway. They also argued that the aim of biologists would be not only to document the existence of a species but also to reveal and understand their morphology (and even morphology variation) and anatomy, which may be important for future taxonomic, phylogenetic, genetic variation, and other scientific fields. To meet these objectives, the collection and deposition of specimens in scientific collections are crucial. Additionally, Krell and Wheeler (2014) point out that good photographs or even DNA samples will never replace the plethora of information that can be obtained from specimens deposited in scientific collections. Rocha et al. (2014) concur that specimen collection is potentially detrimental to certain species, yet they also acknowledge that evidence such as photographs, recordings, and nonlethal tissue samples for DNA analysis are insufficient for determining biological diversity on a broader scale. In advance, Rocha et al. (2014) shed light on studies that have produced direct effects on species conservation, as well as discoveries of extinction mechanisms (e.g., chytridiomycosis vs. frogs) or trends in response to climate change (e.g., body size reduction), possible by analyzing individuals collected over time. Rocha et al. (2014) point out that the arguments proposed by Minteer et al. (2014) do not face the main problems, i.e., the mix of habitat loss, bioinvasions, and unsustainable exploitation, and that, therefore, responsible collection of specimens and associated data is "more necessary today than it was before" (Rocha et al., 2014).

In this context, the present work aims to discuss the perils of documenting biodiversity and describing new species based on photographs alone but considering the recent advances in artificial intelligence image generation (generative adversarial networks – GANs; see Göring et al. (2023)). The reliability of the use of images from "citizen science" to document biodiversity and describe new species is discussed, as well as desired standard procedures relative to registering associated data and photograph details. To avoid biodiversity documentation errors caused by images that have been altered or adulterated, intentionally or not, or even generated by artificial intelligence, here we suggest important procedures that should be adopted as norms by reviewers and editors and be incorporated into journal policies.

2 Species records and description based on images

2.1 The case of the goblin shark – *Mitsukurina owstoni* (Jordan, 1898) (Lamniformes: Mitsukurinidae)

The goblin shark *Mitsukurina owstoni* (Jordan, 1898) is the single extant species in the family Mitsukurinidae and was most recently assessed by the International Union for Conservation of Nature (IUCN) Red List in 2017 as least concern (Finucci and Duffy, 2018). In 2020, a photograph of what appeared to be a goblin shark on a beach in Greece taken by a citizen was posted on social media; 2 years later, Kousteni et al. (2022) published a survey of new records of rare species in the Mediterranean Sea, with 20 different new occurrences of taxa distributed in 10 countries bordering the Mediterranean. However, five of these occurrences were based only on image records (*Ancistrocheirus lesueurii* (d'Orbigny, 1842), *Carcharodon carcharias* (Linnaeus, 1758), *Kyphosus* sp., *Scyllaea pelagica* (Linnaeus, 1758)), including the rare and mysterious goblin shark *Mitsukurina owstoni* in Sect. 4.4 of Kousteni et al. (2022), whose evidence was the photograph provided by the abovementioned citizen (Anastasiadis et al. (2022), in Kousteni et al. (2022)).

As soon as the survey was published, experts questioned the records after noticing several morphological inconsistencies in the photographed specimen. Then Pollerspöck and Straube (2023), who organize the Shark References forum, raised doubts about the validity of the record, pointing out in a rebuttal the low image quality and many inconsistencies between the photographed specimen and the species' known meristic and morphological characters (e.g., the number of gill slits, lack of teeth, body proportions), and raised questions about the circumstances behind the record. Given the criticism, and the repercussions of the comment on forums and groups on social networks, such as Facebook (https://archive.ph/0IEM3, last access: 21 April 2023) and X (formerly Twitter) (https://archive.vn/eN6Lc, last access: 21 April 2023, almost 300 000 views up to 21 April 2023), the authors of the section (Anastasiadis et al., 2022) responded to the rebuttal made by Pollerspöck et al. (2023), complementing information on the dimensions of the specimen, which "should be considered an embryo" (17–20 cm in length) (Anastasiadis et al., 2023a), but then retracted both the section and the reply, thus ending the discussion (Anastasiadis et al., 2023b).

2.2 Citizen science: challenges, recommendations, and solutions for the use and verification of images

Based on the scientific literature, it is evident that the use of images plays an increasing role in the documentation, taxonomy, and expansion of knowledge about species distribution (Barahona-Segovia et al., 2017; Tiralongo et al., 2019; Heard et al., 2019; Werenkraut et al., 2020; Wangyal et al., 2020; Tiralongo et al., 2021; Martinou et al., 2021; Terán-Sánchez et al., 2021; Ehemann et al., 2022; Demetriou et al., 2022; Webb et al., 2022; Antúnez-Fonseca et al., 2022; Barahona-Segovia et al., 2023; Gorleri et al., 2023; Krell and Marshall, 2017). Regarding taxonomic consequences, a classic case involves Hume's owl, *Strix butleri* (Hume, 1878), initially known to be only from eastern Egypt, Sinai, Israel, the Palestinian territories, Jordan, and the Arabian Peninsula, with possible records on the island of Socotra and in southern Pakistan (Mikkola, 2012; Jennings, 2010; Dickinson and Remsen, 2013). In 2013, a group of ornithologists recorded the call of and photographed a possibly undescribed owl species in the region, which was later described as *Strix omanensis* Robb, van den Berg, and Constantine, 2013, based on acoustic evidence and photographs, without depositing physical material as evidence (Robb et al., 2013).

However, a more in-depth analysis conducted by Kirwan et al. (2015) revealed both morphological and molecular differences between the specimens previously identified as *Strix butleri* and the type series of *S. butleri*, which more closely resembled *S. omanensis*. Additionally, they described *Strix hadorami* Kirwan, Schweizer, and Copete, 2015, as the morphotype previously misidentified as *S. butleri* and recommended considering *Strix omanensis* to be a junior synonym for *Strix butleri* due to the lack of available material for analysis, as the type series of *S. butleri* was found to be morphologically similar to *S. omanensis* (Kirwan et al., 2015).

Subsequently, the group of authors who proposed *Strix omanensis*, along with other collaborators (Robb et al., 2016), based on new molecular data to clarify the taxonomy and nomenclature of the *S. butleri* complex, confirmed the hypothesis of Kirwan et al. (2015). They also considered *Strix omanensis* a junior synonym for *S. butleri* based on molecular data. This series of events illustrates how the use of molecular data can resolve complex taxonomic situations. It is important to note that various similar cases of species descriptions from different animal groups based on photographs (without depositing physical material as a holotype) or direct observations in nature have already occurred and are compiled in Krell and Marshall (2017), highlighting how technological innovations, such as the ease of obtaining high-resolution images, high-quality audio recordings, and high-resolution videos, among others, can have consequences for taxonomy.

In this regard, we recommend that studies involving citizen science (records or species descriptions) should adhere to rigorous search criteria for the validation of available information (such as social networks, taxonomic group pages, online image databases, among others). These restrictions, including the use of different keywords and filters in combination, are recommended by us to narrow down the search area (filters). These measures are aimed at enhancing scientific output by making it more difficult to employ fake images, particularly when they are complemented by expert analysis, and the decision to discard low-quality images that hinder the observation of diagnostic characteristics.

Recently, Fraisl et al. (2022) conducted a review that raised concerns about the quality of data generated by citizen science and proposed strategies to mitigate them. They emphasize the importance of training and clear procedures to empower participants, as well as structured protocols to guide them and data validation by taxonomy experts. It is also crucial to address participants' behaviors, including potential conflicts of interest, biases, and lack of neutrality.

The following criteria should also be considered by the guidelines of most citizen science platforms: location (as precise coordinates as possible); date and time of the photograph; original photo (raw image); behavior at the time of observation; and, in some cases, reaching out to the photographer for additional information and material submission (e.g., Barahona-Segovia et al., 2017; Wangyal et al., 2020; Antúnez-Fonseca et al., 2022; Ehemann et al., 2022; Demetriou et al., 2022; Barahona-Segovia et al., 2023).

In our opinion, if these criteria are not followed, inaccurate and questionable information may be presented, which could be detrimental to species conservation. The cases of the goblin shark and Hume's owl highlight how the implementation of cross-verification layers can be effective in validating information. In taxonomically complex and species-rich groups, similar cases may go unnoticed for longer periods. Therefore, the rigorous implementation of verification procedures is crucial for ensuring the integrity and reliability of species records or descriptions based on images or observations.

3 AI-generated images

3.1 The case of the pope's puffer jacket

An example of the power of synthetic images was the global "meme" effect of an alleged photo of Pope Francis wearing a stylish white puffer jacket. The deepfake image was created on Midjourney, a text-to-image AI (artificial intelligence) platform, and was first published on Reddit (https://archive.vn/HVT7L, last access: 22 April 2023). The image quickly spread across social media in March 2023, with many believing it to be a new style adopted by the pontiff. *Time* magazine (https://archive.vn/2qkCt, last access: 21 April 2023) called it "the first truly viral misinformation event fueled by deepfake technology", while web culture expert Ryan Broderick, cited by *New Scientist* (https://archive.vn/RPG9o, last access: 22 April 2023), labeled it "the first real mass-level AI-misinformation case". This incident highlights concerns about the potential misuse of AI-generated images and their impact on public perception of the truth. It also shows how synthetic images can deceive the public without proper verification and warning mechanisms.

3.2 AI-generated image detection – does it leave clues?

Wang et al. (2022) found that it is still possible for advanced computational tools to differentiate GAN (generative adversarial network)-generated images from real ones, but they emphasize that this does not guarantee that people can perfectly distinguish synthetic images. The authors also add that time is on the side of deep learning models, as the strengths of current fraud detection methods are entirely dependent on the weaknesses of current GAN models and may therefore be surpassed by the rapid improvement in this area. A year later, Göring et al. (2023) wrote an essay evaluating the realism and appeal of images generated by different AI text-to-image generators, such as DALL-E 2, Midjourney, and Craiyon, using various text prompts and their own images, to compare the results of an online subjective study with image quality models and features. The paper concluded that some of the generators can produce realistic and appealing images, but this depends on the approach and the text prompt, which tends to rank up continuously.

By means of comparison, we used DALL-E 2 and Midjourney to generate some fictional species and specimens (Fig. 1) in various situations that can be representative of the average type of pictures used in records made by both specialists and the general public: a picture of a red-eyed dark-spotted guppy, taken from an aquarium (Fig. 1a); a macro photograph of a hummingbird flying (Fig. 1b); our special synthetic photo of a seagull gliding overseas as if the photo was taken from a bird observer on a boat (Fig. 1c), which can be contrasted with the series of variations in Fig. 19 from Göring et al. (2023) in terms of realistic appeal; and a picture of the dorsal view of a fly standing over a leaf (Fig. 1d). Figure 1e and f simulate what could be accidental findings of a rare deep-sea shark (Fig. 1e), and a white-skinned black-striped leopard (Fig. 1f). We also prompted something improbable, like a polar bear eating bamboo (Fig. 1g). To illustrate the main concern about realistic appeal, we used a dead shark as photographed from a smartphone by a citizen walking on the beach (Fig. 1h) and a specimen of a preserved catfish, deposited in a scientific collection (Fig. 1i).

3.3 AI-generated images and the trust in science

AI generative models can produce realistic images known as deepfakes or synthetic images, which can have various applications from entertainment to scientific research, and for biological interest, generate images of known species and even create "artificial species". Sofia Crespo's Critically Extant project (https://www.criticallyextant.com/, last access: 22 April 2023) is a good example of artistic use with a positive impact on nature conservation. The project uses artificial intelligence to illustrate critically endangered species and is the first deep learning art show to be shown on the famous Times Square big screens in New York (https://archive.vn/wip/rFTcA, last access: 22 April 2023).

However, like images modified by photo editing software (see this case: https://archive.vn/wip/M3yVX, last access: 26 April 2023), the misuse of AI-generated images can also undermine trust in science by facilitating evidence falsification, data manipulation, and public deception. Therefore, scientists (authors, reviewers, and editors) must be able to authenticate and verify these images, and ethical and legal regulations must be in place to govern their use, which could involve the abovementioned practices proposed in Sect. 2.2.

Göring et al. (2023) assessed the quality and appeal of images generated by AI models from text prompts, utilizing both computational models and subjective evaluation by a random audience through an online platform. Participants were presented with the images and assigned realism scores on a scale from 1 to 5. We conducted a survey following a modified methodology from that employed by Göring et al. (2023), reducing the survey questions to the realistic appeal of AI-generated species images. Similarly to the survey by Göring et al. (2023), participants were randomized from both the university community and the general public. The primary objective of the survey was not to compare models but solely to assess the general perception by the public of how realistic an image of an animal species could be. No subject variables were added, and no personally identifiable information was collected or stored, in compliance with Brazil's General Data Protection Law (LGPD; law no. 13.709/2018). The questionnaire was made available online and was distributed among academic groups and the general public for 48 h, receiving a total of 621 responses (see supplementary file S1 (Campos et al., 2023) in the "Data availability" section). Participants were asked to rate the images as 1 – completely false; 2 – false but convincing; 3 – not sure if it is real or not; 4 – real but highly modified; and 5 – real, only processed. The images used in the questionnaire were the same as those presented in Fig. 1 of this article. The results showed that image credibility is predominant, with six of the nine images having a mean score of 4 with a very low variation considering the confidence interval of 95 %, i.e., believed to be real by the public (Table 1 and Fig. 2).

Figure 1. Realistic AI-generated images of some species that actually do not exist in nature, using text-to-image prompts created by the authors of this paper. The prompts were as follows: **(a)** "red-eyed + Poeciliidae fish + guppy"; **(b)** "photo of hummingbird with black spots flying"; **(c)** "a full side view of a seagull gliding oversea, as the picture was taken from a bird observer on a boat"; **(d)** "a fly over a leaf, dorsal view, spread wings, close focus on wing nervures"; **(e)** "goblin shark + caught by fisherman"; **(f)** "trap cam recorded a rare striped wild leopard walking, the species has white skin with only horizontal line stripes all over the body"; **(g)** "polar bear in the forest eating bamboo"; **(h)** "a dead small shark on the beach, as photographed by a smartphone"; and **(i)** "'catfish' as preserved in a glass jar of alcohol at a scientific collection". AI engines used: **(b)** Midjourney; all other images: DALL-E 2, Bing interface.

Table 1. Descriptive statistics for the realistic appeal survey about animal species images. Variance, Var; coefficient of variation, C.V.; confidence interval (95 %), C.I. The percentage in "% mode" is calculated against the total number of responses (n). The letters between parentheses are the same as those used to identify the species in Fig. 1 in this article.

Species' picture	(n)	Mean	SD	Var	C.V.	Median	Mode	Mode (n)	% mode	C.I.	Mean ± C.I.
(f) Leopard	621	4.65	0.84	0.71	18.11	5	5	507	82 %	0.07	4.65 ± 0.07 [4.58–4.72]
(a) Guppy	621	4.24	1.06	1.13	25.08	5	5	369	59 %	0.08	4.24 ± 0.08 [4.15–4.32]
(i) Catfish in a jar	621	4.09	1.28	1.63	31.19	5	5	363	58 %	0.10	4.09 ± 0.1 [3.99–4.19]
(c) Seagull	621	4.07	1.23	1.51	30.19	5	5	335	54 %	0.10	4.07 ± 0.1 [3.97–4.16]
(d) Fly	621	4.06	1.24	1.54	30.51	5	5	334	54 %	0.10	4.06 ± 0.1 [3.96–4.16]
(e) Shark and fisherman	621	3.79	1.42	2.02	37.5	5	5	312	50 %	0.11	3.79 ± 0.11 [3.68–3.9]
(h) Stranded shark	621	3.45	1.47	2.15	42.52	4	5	235	38 %	0.12	3.45 ± 0.12 [3.33–3.56]
(b) Hummingbird	621	3.15	1.51	2.29	48.09	3	5	174	28 %	0.12	3.15 ± 0.12 [3.03–3.27]
(g) Polar bear	621	2.89	1.54	2.36	53.14	3	1	165	27 %	0.12	2.89 ± 0.12 [2.77–3.01]

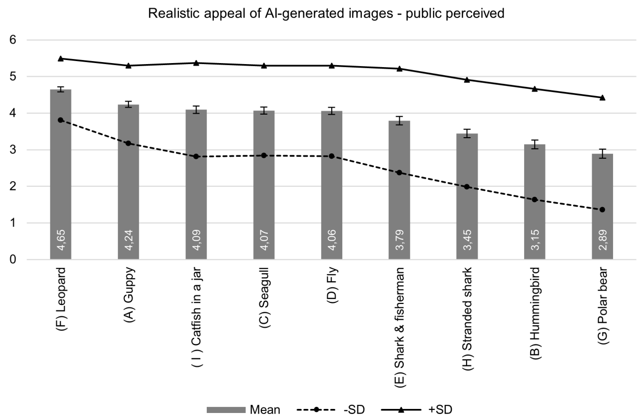

Figure 2. Realistic appeal of AI-generated images of some species, rated by the people interviewed in the survey ($n = 621$). The scale represents the values from 1 – completely false; 2 – false but convincing; 3 – not sure if it is real or not; 4 – real but heavily modified; and 5 – real, only processed. The species are arranged in descending order of mean values. The error bars represent the 95 % confidence interval. The dashed black line with round markers shows the value of mean minus standard deviation (−SD), and the continuous black line with triangle markers shows the values of mean plus standard deviation (+SD). The letters between parentheses are the same as those used to identify the species in Fig. 1 in this article.

The performance of the leopard image was remarkable (Fig. 1f) and worth mentioning, as 82 % of the respondents rated it as real (see Table 1), only processed. Due to its unusual species and landscape characteristics, this image could be mistaken for a new record and would be highly credible for most people in general and perhaps only recognized by experts in the field and in identifying images obtained through image capture tools such as trap cams (only 3 %, $n = 21$ classified it as fake). Furthermore, it is worth mentioning the significant improvement in the degree of realism observed in Fig. 1c in this article compared to Fig. 19 from Göring et al. (2023) (both show a seagull gliding in the sky, generated in DALL-E, only a few months apart), highlighting the rapid improvement of these image generation models.

4 Ethical issues

A relevant ethical aspect can be intellectual property, as who owns the authorship of an image generated by an AI model? This can generate ethical and legal conflicts (Appel et al., 2023; Mahendra, 2023). In this regard, we also raise the following question: who would be responsible for errors or unwanted results generated by the use of artificial intelligence in the production of images in scientific articles? We believe that in addition to synthetic images having an impact on the scientific community, this also applies broadly to other areas and can reach public figures such as civil and religious authorities, as in the case of the pope illustrated in this article. Therefore, the platforms that provide these AI models have been making successive updates to their usage control policies (Appel et al., 2023).

According to Sha et al. (2023), one of the bottlenecks that limit the potential of the output is the ability to convert the text prompt used to request the image (which, due to the characteristics of GANs, are not repeatable), where the size of the characters and classes of descriptors can significantly affect the behavior of the model. The authors' appeal sounds reasonable: "We appeal to the community's consideration of the counterpart solutions, like ours, against the rapidly-evolving fake image generation".

5 The effect of images on people's perception of species and threats to conservation

The prospect of being preyed upon by animals threatens our sense of control over our lives and disrupts our perception of being separate from nature (Fuchs, 2015; Milatovic, 2015). In this context, various animals are often portrayed in horror movies due to their differences in appearance and behavior, as well as their ability to symbolize dangers to humans, especially crocodilians, snakes, and sharks (Nelson, 2016; Shiffman et al., 2020). In this way, manipulated or synthetic images of these specimens can influence people's perception and attitude toward the species, often diminishing their sense of value and respect (Thomas-Walters et al., 2020).

Casola et al. (2022), aiming to understand the role of social media in shaping public perceptions and attitudes toward sharks, identified trends in which negative messages and news headlines about shark attacks, often linked to shark-related movies as threats to humans, can increase public anxiety regarding these animals. They found that negative content increased fear and the perception of danger and intentionality of shark bites, while positive content decreased support for lethal responses (fishing) and increased support for research-based, education-based, and nonintervention responses.

In a study addressing how popular media portrays shark conservation, Shiffman et al. (2020) conducted a comprehensive analysis of approximately 1812 English-language articles over a decade (2008–2017). The results revealed that this media coverage is often inaccurate and biased, posing a threat to the sustainability of shark conservation. Furthermore, the authors noted that many of these popular articles contain incorrect, biased, or misleading information regarding the threats sharks face and the most effective solutions to protect them. They also contain imprecise or misleading information about the behavior, intelligence, and intentions of sharks, as seen in this excerpt: "Sharks' negative public image, and the associated idea that sharks are threatened at least in part because they frighten people, was mentioned in 288 articles (15.9 % of articles) with the movie 'Jaws' [Steven Spielberg, 1975] being specifically referenced in 136 articles (7.5 % of articles)" (Shiffman et al., 2020).

In this context, it is important to emphasize that tools like AI-image generative models can be readily utilized to create images with a high potential for widespread dissemination in mass media, as demonstrated in the case of the pope's jacket episode; this can occur in situations where realism may not be as critical as the image's appeal. Therefore, it is important to mention our concern that this could lead to a misinterpretation of species conservation issues by the public and potentially impact the support for evidence-based policies.

From another perspective, we remark that applications based on image processing models can also be used for the benefit of species conservation. The application of machine learning models, especially convolutional neural networks, can save a significant amount of time for researchers by automating the extraction of information from images (Norouzzadeh et al., 2018). Furthermore, data extraction from photographic images through AI contributes to the reduction in costs associated with information collection, making projects more accessible to those without large teams of human volunteers, enabling more cost-effective and, in some cases, real-time monitoring, and the productivity gains and time reduction provided by the integration of AI can be positive factors, expediting studies related to wildlife documentation and conservation (Norouzzadeh et al., 2018; Curran et al., 2022; Dhillon and Verma, 2022).

For example, one application with the potential for significant impact, which can be expanded to cover more groups, was the development of an image identification model (convolutional neural network) for pangolins in online image repositories. This serves as a tool to expedite the detection of illegal trade in the species by identifying images of whole specimens and even body parts that are being traded (Cardoso et al., 2023).

6 Conclusions

Modern ways of collecting biodiversity information are growing in use and popularity. One of these is the use of images as evidence of a species' occurrence in nature, which has already also been widely accepted. In this context, the integrity of information becomes even more critical, considering that there is a tradeoff between publishing new findings swiftly and the quality of data validation that can only be controlled with wide verification by the scientific community, for example, through greater integration of scientific societies, with facilitated communication with the body of reviewers and editors of journals. This enables the safety of authorship of an imminent discovery by defining the recording reliability, even before the final publication, and this can be one of the mitigating factors of risks of mistakes caused by the use of unknown source images as evidence for new records, rediscoveries, expansions of distribution, or even descriptions.

Another trend that has gained significant popularity is the case of the citizen science projects, where biodiversity documentation can involve the participation of both experts and non-experts, recording species data in nature, primarily through images. We appreciate initiatives like these, which can be highly valuable for accelerating biodiversity knowledge and promoting nature conservation, as long as certain precautions regarding the reliability of the data obtained are observed. Some procedures should be encouraged in the case of using images alone to record biodiversity, such as a requirement for the authors to provide the raw image (without any type of editing) as a supplementary file for the reviewers. In addition, a statement, preferably a document signed by the author(s) of the photograph or image, should be presented as a supplementary file by the author(s) of the paper, declaring that the photograph is authentic and providing information about the ownership over the rights of the image; identification; the contact details of the photographer; the most precise location where the photograph was taken (with coordinates, preferably); the date and time (at least approximate); the photographic equipment used; the type of lens; and other relevant metadata related to the photograph.

The implementation of these recommended procedures may avoid image adulteration or even the use of false or fake images since the photographer or image creator and/or the paper's author(s) would be held accountable. In the case that research misconduct of image manipulation is discovered, penalties could be applied to the people directly responsible after a proper examination of the circumstances and after the due right of clarification has been safeguarded. Such consequences should not be drastically different from those that are applied in cases of general types of definitely proven research misconduct and should include severe restrictions on those responsible. Scientific societies, editorial groups, and representatives of the journals need to update their policies and address these types of research misconduct, implementing constraints and penalties that can include banning the researcher from publishing in the scientific journal where the "fake" photograph was published, banning the researcher from scientific societies, excluding the researcher from the scientific journal's editorial board, or even implementing administrative penalties such as those that already exist in institutions for cases like plagiarism or scientific fraud. We believe that the procedure suggested above, as well as the action of making both the photographers of the images and the researchers who are using the photographs accountable for them, will reduce the possibility of image fraud or adulteration and consequently reduce the risk of fake photograph publications in biodiversity documentation. Furthermore, the abovementioned statement would already ensure a secure peer-review process, where editors and reviewers will already have confidence in the accuracy of the data, eliminating the need for additional verification. Additionally, they absolve themselves of any potential liabilities in cases of publishing papers with fake or altered images.

The *M. owstoni* case in the Mediterranean Sea was quite demonstrative of two concerns addressed in this paper. First, the geographic distribution data may affect the calculation of the extent of occurrence and the area of occupancy, criteria used to classify the conservation status of species according to the IUCN Red List of Threatened Species. Although the assessment of the threat level is conducted by experts and researchers who may occasionally exclude some records they deem dubious and/or imprecise, there are also other threat estimation policies established by each country, for example in Brazil, where officially recognized categorization is carried out by the Instituto Chico Mendes de Conservação da Biodiversidade, at least in part taking into account some of the IUCN's criteria (ICMBio, 2023). Therefore, the record or expansion of the geographic distribution of species to a location where it does not occur (either through modified or created images) may lead to classifying them as least concern or considering them to be less threatened than they actually are. Second, there are factors affecting the difficulty of identifying species only by pictures. The goblin shark *M. owstoni* is the only species in the genus and has clear external taxonomic traits. However, in groups including cryptic species (rich and complex groups), mainly small sized, this is even more worrying, and therefore the photographs alone cannot serve as a basis for accurate species identification and must be completely discouraged.

Certainly, the most critical scenarios would involve situations such as registering the rediscovery of a species or even describing a new species solely based on a fake image. While specific instances of this occurring may not be documented in the literature, it remains a hypothetical possibility. These scenarios could create the false impression that a species still exists (in the case of rediscovery) or artificially inflate the number of known species in nature (in the case of newly described species). Consequently, it is imperative that we establish, promote, and recommend mechanisms and procedures to prevent the utilization and proliferation of fake images in biodiversity documentation.

Data availability. The datasets generated and/or analyzed during the current study are available in supplementary file S1 at https://doi.org/10.6084/m9.figshare.24428047 (Campos et al., 2023).

Supplement. The supplement related to this article is available online at: https://doi.org/10.5194/we-23-135-2023-supplement.

Author contributions. Conceptualization: DSC, RFdO, and FPO. Writing (original draft as well as review and editing): DSC, RFdO, LdOV, PHNdB, JLSN, ECG, and FPO.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Disclaimer. Publisher's note: Copernicus Publications remains neutral with regard to jurisdictional claims made in the text, published maps, institutional affiliations, or any other geographical representation in this paper. While Copernicus Publications makes every effort to include appropriate place names, the final responsibility lies with the authors.

Acknowledgements. We express our gratitude to the anonymous reviewers for their valuable contributions to the paper. This work was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES – finance code 001), Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPQ), and Fundação Amazônia de Amparo a Estudos e Pesquisas (FAPESPA) in the form of scholarships within the scope of their programs. Specifically, we acknowledge the following grants: the FAPESPA grant (no. 028/2021) to Erick Cristofore Guimarães, the CNPQ grant (no. 307974/2021-9) to Felipe Polivanov Ottoni, and the CAPES grant to Rafael Ferreira de Oliveira (no. 88887.808704/2023-00). We also thank the providers of the DALL-E 2 and Midjourney services used to generate artificial images for this article. The ownership of the images generated by both services was designated to the authors in accordance with the terms of service, automatically in the case of DALL-E 2, and through a paid license by DSC in the case of Midjourney (invoice no. 73AE6B83-0002).

Financial support. This research has been supported by a Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) grant (grant no. 88887.674455/2022-00) to Diego Sousa Campos.

Review statement. This paper was edited by Ricardo Rocha and reviewed by Manuel Biscoito, Frank Krell, and Raquel Vasconcelos.

References

Anastasiadis, A., Papadimitriou, E., and Küpper, F. C.: [Retracted 20 March 2023] 4.4 First record of the goblin shark *Mitsukurina owstoni* Jordan, 1898 (Lamniformes: Mitsukurinidae) in the Mediterranean Sea [see Retraction Note], Mediterr. Mar. Sci., 23, 417–446, 2022.

Anastasiadis, A., Papadimitriou, E., and Küpper, F. C.: [Retracted 20 March 2023] Reply to Comment on "First record of the goblin shark *Mitsukurina owstoni* Jordan, 1898 (Lamniformes: Mitsukurinidae) in the Mediterranean Sea" by Jürgen Pollerspöck, Simon Weigmann, Bernard Seret and Nicolas Straube. Medit. Mar. Sci., 24, 101-103, Mediterr. Mar. Sci., 24, 104–108, 2023a.

Anastasiadis, A., Papadimitriou, E., and Küpper, F. C.: Retraction Note: "4.4 First record of the goblin shark *Mitsukurina owstoni* Jordan, 1898 (Lamniformes: Mitsukurinidae) in the Mediterranean Sea" by Athanasios Anastasiadis, Evangelos Papadimitriou and Frithjof C. Küpper in: Kousteni, V. et al. (2022). New records of rare species in the Mediterranean Sea (May 2022). Medit. Mar. Sci., 23, 417–446, https://doi.org/10.12681/mms.28372 and Reply to Comment on "First record of the goblin shark *Mitsukurina owstoni* Jordan, 1898 (Lamniformes: Mitsukurinidae) in the Mediterranean Sea" by Jürgen Pollerspöck, Simon Weigmann, Bernard

Seret and Nicolas Straube. Medit. Mar. Sci., 24, 101–103, https://doi.org/10.12681/mms.34033, 2023b.

Antúnez-Fonseca, C. A., Hofmann, E. P., Reyes-Barahona, A. A., Ordoñez-Mazier, D. I., Dubón, F. J., Reyes, H. D., and Townsend, J. H.: New records and range expansion of *Norops sagrei* (Squamata: Dactyloidae) in Honduras highlight the importance of citizen science in documenting non-native species, Caldasia, 44, 325–331, https://doi.org/10.15446/caldasia.v44n2.94568, 2022.

Appel, G., Neelbauer, J., and Schweidel, D. A.: Generative AI Has an Intellectual Property Problem, Harvard Business Review: Intelectual Property, https://archive.ph/zQsaj (last access: 9 September 2023), 2023.

Barahona-Segovia, R. M., Tapia, R. C., and Monsálvez, L. P.: First record of *Myopa metallica* Camras, 1992 (Diptera: Conopidae: Myopinae) in Northern Chile after 46 years: A case study of the success of citizen science programs, Journal of Insect Biodiversity, 5, 1–8, https://doi.org/10.12976/jib/2017.5.13, 2017.

Barahona-Segovia, R. M., González, C. R., and Pañinao-Monsálvez, L.: Citizen science meet South American tachinids: new records of feather-legged fly *Trichopoda* (*Galactomyia*) *pictipennis* Bigot (Diptera: Tachinidae) from Chile, Neotrop. Entomol., 52, 227–239, https://doi.org/10.1007/s13744-022-00979-2, 2023.

Campos, D. S., Oliveira, R. F. d., Vieira, L. d. O., Bragança, P. H. N. d., Nunes, J. L. S., Guimarães, E. C., and Ottoni, F. P.: Supplementary file S1 - Realistic appeal of AI-generated images, figshare [data set], https://doi.org/10.6084/m9.figshare.24428047.v2, 2023.

Cardoso, A. S., Bryukhova, S., Renna, F., Reino, L., Xu, C., Xiao, Z., Correia, R., Di Minin, E., Ribeiro, J., and Vaz, A. S.: Detecting wildlife trafficking in images from online platforms: Atest case using deep learning with pangolin images, Biol. Conserv., 279, 109905, https://doi.org/10.1016/j.biocon.2023.109905, 2023.

Casola, W. R., Beall, J. M., Peterson, M. N., Larson, L. R., and Price, C. S.: Influence of social media on fear of sharks, perceptions of intentionality associated with shark bites, and shark management preferences, Frontiers in Communication, 7, 1033347, https://doi.org/10.3389/fcomm.2022.1033347, 2022.

Curran, B., Nekooei, S. M., and Chen, G.: Accurate New Zealand Wildlife Image Classification-Deep Learning Approach, in: AI 2021: Advances in Artificial Intelligence, Lecture Notes in Computer Science, edited by: Long, G., Yu, X., and Wang, S., Springer, Cham, 13151, 632–644, https://doi.org/10.1007/978-3-030-97546-3_51, 2022.

Demetriou, J., Díaz-Calafat, J., Kalaentzis, K., Kazilas, C., Georgiadis, C., Turrisi, G. F., and Koutsoukos, E.: The alien Black-and-yellow Mud Dauber, *Sceliphron caementarium* (Drury, 1773) (Hymenoptera, Sphecidae), continues its spread: new citizen-science records from Eastern Europe and the Balkans, Check List, 18, 535–543, https://doi.org/10.15560/18.3.535, 2022.

Dhillon, A. and Verma, G. K.: Fusion of Deep Learning Features for Wild Animal Detection, in: Advances in Deep Learning, Artificial Intelligence and Robotics, edited by: Troiano, L., Vaccaro, A., Tagliaferri, R., Kesswani, N., Díaz Rodriguez, I., Brigui, I., and Parente, D., Lecture Notes in Networks and Systems, Springer, Cham, 249, 15–24, https://doi.org/10.1007/978-3-030-85365-5_2, 2022.

Dickinson, E. C. and Remsen, J. V.: The Howard and Moore Complete Checklist of the Birds of the World, Vol. 1, 4th edn., Aves Press, Eastbourne, 461 pp., ISBN 9780956861108, 2013.

Ehemann, N., Acosta-Rodríguez, E., Tagliafico, A., Pelletier, N., and Stevens, G.: Manta and devil ray species occurrence and distribution in Venezuela, assessed through fishery landings and citizen science data, J. Fish Biol., 101, 213–225, https://doi.org/10.1111/jfb.15088, 2022.

Finucci, B., and Duffy, C. A. J.: *Mitsukurina owstoni*, The IUCN Red List of Threatened Species 2018: e.T44565A2994832, https://doi.org/10.2305/IUCN.UK.2018-2.RLTS.T44565A2994832.en, 2018.

Fraisl, D., Hager, G., Bedessem, B., Gold, M., Hsing, P. Y., Danielsen, F., Hitchcock, C. B., Hulbert, J. M., Piera, J., Spiers, H., Thiel, M., and Haklay, M.: Citizen science in environmental and ecological sciences, Nature Reviews Methods Primers, 2, 1–20, https://doi.org/10.1038/s43586-022-00144-4, 2022.

Fuchs, M.: 'They are a fact of life out here': The Ecocritical Subtexts of Three Early-Twenty-First-Century Aussie Animal Horror Movies, in: Animal Horror Cinema, edited by: Gregersdotter, K., Höglund, J., and Hållén, N., Palgrave Macmillan, London, UK, 37–57, https://doi.org/10.1057/9781137496393_3, 2015.

Göring, S., Rao, R. R. R., Merten, R., and Raake, A.: Analysis of Appeal for realistic AI-generated Photos, IEEE Access, 11, 3899–39012, https://doi.org/10.1109/ACCESS.2023.3267968, 2023.

Gorleri, F. C., Jordan, E. A., Roesler, I., Monteleone, D., and Areta, J. I.: Using photographic records to quantify accuracy of bird identifications in citizen science data, Ibis, 165, 458–471, https://doi.org/10.1111/ibi.13137, 2023.

Heard, J., Chen, J. P., and Wen, C. K.: Citizen science yields first records of *Hippocampus japapigu* and *Hippocampus denise* (Syngnathidae) from Taiwan: A hotspot for pygmy seahorse diversity, ZooKeys, 883, 83–90, https://doi.org/10.3897/zookeys.883.39662, 2019.

ICMBio: Sistema de Avaliação do Risco de Extinção da Biodiversidade – SALVE, ICMBio, https://salve.icmbio.gov.br/ (last access: 8 September 2023), 2023.

Jennings, M. C.: Atlas of the breeding birds of Arabia, in: Fauna of Arabia, King Abdulaziz City for Science & Technology & Fauna of Arabia, Riyadh & Frankfurt, Vol. 25, 751 pp., ISBN 9783929907834, 2010.

Kirwan, G. M., Schweizer, M., and Copete, J. L.: Multiple lines of evidence confirm that Hume's Owl *Strix butleri* (A. O. Hume, 1878) is two species, with description of an unnamed species (Aves: Non-Passeriformes: Strigidae), Zootaxa, 3904, 28–50, https://doi.org/10.11646/zootaxa.3904.1.2, 2015.

Kousteni, V., Anastasiadis, A., Bariche, M., Battaglia, P., Bonifazi, A., Ćetković, I., Chimienti, G., Colombo, M., Constantinou, C., Corsini-Foka, M., Dalyan, C., Dogrammatzi, A., Domenichetti, F., El Zrelli, R., Fernández-Alías, A., Kampouris, T. E., Kesici, N. B., Küpper, F. C., Lipej, L., Mancini, E., Manunza, B., Marcos, C., Mavrič, B., Mavruk, S., Mutlu, E., Özvarol, Y., Papadimitriou, E., Pešić, A., Pérez-Ruzafa, A., Pey, A., Poursanidis, D., Rizgalla, J., Samaha, Z., Stipa, M. G., Trkov, D., Türeli, C., Ventura, P., Yacoubi, L., Zacchetti, L., and Zava, B.: New records of rare species in the Mediterranean Sea (May 2022), Mediterr. Mar. Sci., 23, 417–446, https://doi.org/10.12681/mms.28372, 2022.

Krell, F. T. and Marshall, S. A.: New species described from photographs: Yes? No? Sometimes? A fierce debate and a new declaration of the ICZN, Insect Systematics and Diversity, 1, 3–19, https://doi.org/10.1093/isd/ixx004, 2017.

Krell, F. T. and Wheeler, Q. D.: Specimen collection: Plan for the future, Science, 344, 815–816, https://doi.org/10.1126/SCIENCE.344.6186.815, 2014.

Mahendra, S.: Who Owns Art Created By AI? Can AI Art Be Copyrighted?, Atificial Intelligence +, https://archive.ph/aF552 (last acess: 9 September 2023), 2023.

Martinou, A. F., Fawcett, J., Georgiou, M., Angelidou, I., Philippou, M., and Schaffner, F.: Occurrence of *Aedes cretinus* in Cyprus based on information collected by citizen scientists, Journal of the European Mosquito Control Association, 39, 31–38 https://doi.org/10.52004/JEMCA2021.0002, 2021.

Mikkola, H.: Owls of the World: A Photographic Guide, Christopher Helm, London, 512 pp., ISBN-13: 978-1-77085-136-8, 2012.

Milatovic, M.: Consuming Wildlife: Representations of Tourism and Retribution in Australian Animal Horror, in: Animal Horror Cinema: Genre, History and Criticism, edited by: Gregersdotter, K., Höglund, J., and Hållén, N., Palgrave Macmillan, London, UK, 73–93, https://doi.org/10.1057/9781137496393_5, 2015.

Minteer, B. A., Collins, J. P., Love, K. E., and Puschendorf, R.: Avoiding (Re)extinction, Science, 344, 260–261 https://doi.org/10.1126/science.1250953, 2014.

Nelson, D., L.: Herpetology Horror Show: A Brief Exploration of Reptiles and Amphibians in Horror Films, https://www.researchgate.net/publication/318505950 (last access: 8 September 2023), 2016.

Norouzzadeh, M. S., Nguyen, A., Kosmala, M., Swanson, A., Palmer, M. S., Packer, C., and Clune, J.: Automatically identifying, counting, and describing wild animals in camera-trap images with deep learning, P. Natl. Acad. Sci. USA, 115, E5716–E5725, https://doi.org/10.1073/pnas.1719367115, 2018.

Pollerspöck, J. and Straube, N.: Bibliography database of living/fossil sharks, rays and chimaeras (Chondrichthyes: Elasmobranchii, Holocephali), World Wide Web electronic publication, Version 2023, https://www.shark-references.com/ (last acess: 20 April 2023), 2023.

Pollerspöck, J., Weigmann, S., Seret, B., and Straube, N.: Comment on "4.4 First record of the goblin shark *Mitsukurina owstoni* Jordan, 1898 (Lamniformes: Mitsukurinidae) in the Mediterranean Sea" by Athanasios Anastasiadis, Evangelos Papadimitriou and Frithjof C. Küpper in: Kousteni, V., Anastasiadis, A., Bariche, M., Battaglia, P., Bonifazi, A. et al. (2022). New records of rare species in the Mediterranean Sea (May 2022). Mediterranean Marine Science, 23 (3), 417–446, Mediterr. Mar. Sci., 24, 101–103, https://doi.org/10.12681/mms.31742, 2023.

Robb, M. S., van den Berg, A. B., Constantine, M. A.: New species of *Strix* owl from Oman, Dutch Birding, 35, 275–310, 2013.

Robb, M. S., Sangster, G., Aliabadian, M., van den Berg, A. B., Constantine, M., Irestedt, M., Khani, A., Seyed Babak Musavi, S .B., Nunes, J. M. G., Willson, M. S., and Walsh, A. J.: The rediscovery of *Strix butleri* (Hume, 1878) in Oman and Iran, with molecular resolution of the identity of *Strix omanensis* Robb, van den Berg and Constantine, 2013, Avian Res., 7, 1–10, https://doi.org/10.1186/s40657-016-0043-4, 2016.

Rocha, L. A., Aleixo, A., Allen, G., et. al.: Specimen collection: An essential tool, Science, 344, 814–815, https://doi.org/10.1126/science.344.6186.814, 2014.

Sha, Z., Li, Z., Yu, N., and Zhang, Y.: DE-FAKE: Detection and Attribution of Fake Images Generated by Text-to-Image Generation Models, arXiv [preprint], https://doi.org/10.48550/arXiv.2210.06998, 9 January 2023.

Shiffman, D. S., Bittick, S. J., Cashion, M. S., Colla, S. R., Coristine, L. E., Derrick, D. H., Gow, E. A., Macdonald, C. C., O'Ferrall, M. M., Orobko, M., Pollom, R. A., Provencher, J., and Dulvy, N. K.: Inaccurate and Biased Global Media Coverage Underlies Public Misunderstanding of Shark Conservation Threats and Solutions, IScience, 23, 1–15, https://doi.org/10.1016/j.isci.2020.101205, 2020.

Terán-Sánchez, S., Díaz-Arango, A., Arias-Monsalve, H. F., and Ramírez-Chaves, H. E.: New records of mammals of the Coffee Region, Central Andes of Colombia using citizen science, Neotropical Biology and Conservation, 16, 27–43, https://doi.org/10.3897/neotropical.16.e57932, 2021.

Thomas-Walters, L., McNulty, C., and Veríssimo, D.: A scoping review into the impact of animal imagery on pro-environmental outcomes, Ambio, 49, 1135–1145, https://doi.org/10.1007/s13280-019-01271-1, 2020.

Tiralongo, F., Giovos, I., Doumpas, N., Langeneck, J., Kleitou, P., and Crocetta, F.: Is the mangrove red snapper *Lutjanus argentimaculatus* (Forsskål, 1775) established in the eastern Mediterranean Sea? First records from Greece through a citizen science project, BioInvasions Records, 8, 911–916, https://doi.org/10.3391/bir.2019.8.4.19, 2019.

Tiralongo, F., Kalogirou, S., and Agostini, I.: First records of a new color pattern in the Goldblotch Grouper, *Epinephelus costae* (Steindachner, 1878) (Actinopterygii: Serranidae) and first record of leucism in the European conger, *Conger conger* (Linnaeus, 1758) (Actinopterygii: Congridae): a citizen science contribution, Acta Adriat., 61, 117–123, https://doi.org/10.32582/aa.62.1.11, 2021.

Wang, L., Zhou, L., Yang, W., and Yu, R.: Deepfakes: A new threat to image fabrication in scientific publications?, Patterns, 3, 1–5, https://doi.org/10.1016/j.patter.2022.100509, 2022.

Wangyal, J. T., Bower, D. S., Sherub, Tshewang, S., Wangdi, D., Rinchen, K., Phuntsho, S., Tashi, C., Koirala, B. K., Gyeltshen, Bhandari, G. S., Jamtsho, S., Phuntsho, Y., Koirala, T. P., Ghalley, B. B., Chaida, L., Tenzin, J., Powrel, R. B., Tshewang, R., Raika, O. N., Jamtsho, S., Kinley, Gyeltshen, Tashi, S., Nidup, D., Wangdi, N., Phuentsho, Norbu, L., Wangdi, K., Wangchuk, T., Tobgay, P., Dorji, T., and Das, I.: New herpetofaunal records from the Kingdom of Bhutan obtained through citizen science, Herpetological Review, 51, 790–798, 2020.

Webb, C., Clancy, J., Doggett, S. L., McAlister, E., Williams, C., Fricker, S., van den Hurk, A., Lessard, B., Lenagan, J., and Walter, M.: First record of the mosquito *Aedes* (*Downsiomyia*) *shehzadae* (Diptera: Culicidae) in Australia: A unique discovery aided by citizen science, J. Vector Ecol., 47, 133–137, https://doi.org/10.52707/1081-1710-47.1.133, 2022.

Werenkraut, V., Baudino, F., and Roy, H. E.: Citizen science reveals the distribution of the invasive harlequin ladybird (*Harmonia axyridis* Pallas) in Argentina, Biol. Invasions, 22, 2915–2921, https://doi.org/10.1007/s10530-020-02312-7, 2020.