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The Linnean shortfall in the digital age: how unverified identifications obscure marine biodiversity

Sergio N. Stampar[1]*, Barbara M Chagas[1], Julia M. Molina[1], Marcela Aparecida de Barros[1], Jeferson Duran-Fuentes[1]

[1] Laboratório de Evolução e Diversidade Aquática – Faculdade de Ciências – Departamento de Ciências Biológicas – Universidade Estadual Paulista (Bauru – Av. Eng. Luiz Edmundo Carrijo Coube, nº14-01 – CEP 17033-360– SP – Brazil).

* Corresponding author: sergio.stampar@unesp.br

Abstract

Taxonomy provides the essential foundation for studying biodiversity, guiding ecological research and conservation efforts. However, the growing use of digital platforms for species identification introduces both opportunities and significant risks. Online crowdsourcing initiatives and citizen science projects engage the public but often rely on users with varied levels of training, potentially leading to misidentifications that can distort scientific data. A case study of Brazilian sea anemones revealed how unverified social media identifications overlooked a new endemic species, highlighting the potential conservation consequences of such errors. To balance public participation with scientific accuracy, this report recommends expert verification of crowdsourced data, the implementation of robust validation protocols, institutional accountability, transparent collaboration, and the strategic leveraging of emerging technologies such as Artificial Intelligence. While digital platforms democratize biodiversity science, maintaining rigorous taxonomic standards remains critical for effective conservation.

Keywords: Taxonomy, Crowdsourcing, Misidentification, Conservation, Social media

INTRODUCTION

Taxonomy, as the baseline discipline of zoology, provides the essential hierarchical framework for organizing and interpreting the diversity of animal life. By systematically classifying and naming organisms, taxonomists establish a universal language that enables precise scientific communication, facilitates research across disciplines, and supports effective biodiversity conservation strategies (Guerra-García et al., 2008). From an ecological perspective, taxonomy is indispensable for deciphering the complex web of species interactions, understanding evolutionary relationships, and predicting how ecosystems respond to anthropogenic pressures such as habitat destruction, climate change, and invasive species (Cadotte et al., 2011; Hagen et al., 2012). Accurate taxonomic knowledge, for example, allows ecologists to identify keystone species—organisms whose ecological influence is disproportionately large relative to their abundance—and to assess how their loss might destabilize entire ecosystems. Furthermore, it provides greater robustness for biogeographic reconstructions, thereby enhancing our understanding of species distributions across space and time.

The practice of taxonomy and species identification is currently undergoing a profound transformation due to the pervasive influence of digital platforms and social media. While modern

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taxonomy is increasingly reliant on genetic data, statistical models, and computational phylogenies, it is important to acknowledge that framing taxonomy as strictly adhering to the aspiration of mathesis universalis—a hypothetical universal science modeled on mathematics—is an oversimplification (Sasaki, 2003). Taxonomy, despite its scientific rigor, inherently involves unavoidable ambiguity, interpretation, and judgment calls, particularly in species delimitation. Species concepts, for instance, are not universally applied, and classification often involves subjective decisions, especially concerning delimitation. The use of different evidence (qualitative or quantitative), the adoption of varying criteria, or differences in the application of the same criteria can lead experts to hold divergent opinions on whether a presumptive lineage deserves species status (Conix et al., 2023). Taxonomic systems reflect human priorities and interpretive frameworks, not solely a pure natural order (De Meyer, 2022). This means that the inherent interpretive and context-bound nature of taxonomy, where species are often viewed as ”intellectual units inhabiting the minds of their descriptors and their respective followers and paradigms” (Raposo et al., 2021), must be recognized from the outset. This philosophical nuance emphasizes that even among experts, achieving complete consensus can be challenging, which in turn highlights the complexities introduced when non-experts contribute to species identification.

Online platforms, such as large-scale identification groups on social media (e.g., Facebook groups - All Fish Species Identification, ID Please (Marine Creature Identification)), promote public engagement with biodiversity and can generate valuable citizen science data. However, they also introduce significant challenges related to data quality and scientific rigor, especially in systems without specialist supervision. This report critically examines the risks of unverified crowdsourced identifications, illustrates these risks with a compelling case study, and proposes robust measures to integrate digital contributions responsibly while upholding the indispensable standards of taxonomic science.

The nature of species and the challenge of taxonomic delimitation

The challenge of defining and delimiting species, often referred to as the “species problem”, is a long-standing debate in biology and philosophy of science (Maddison and Whitton, 2023). A seminal contribution to this debate is Queiroz’s (1998, 2007) “general lineage concept,” which proposes that “species” is the unifying concept of an evolving metapopulation lineage, while the different “species concepts” (morphological, biological, etc.) are, in fact, operational criteria used to diagnose these lineages. There is no single, universally applied species concept, and biologists and philosophers continue to grapple with what kind of unit of living biodiversity receiving the label “species” (Maddison and Whitton, 2023). Various criteria are used for species delimitation, including morphological distinctness, genetic divergence, interfertility, and ecological niche differentiation. The application of these diverse criteria, however, can lead to different taxonomic opinions (Conix et al., 2023).

A critical aspect of taxonomic practice is the existence of “gray-area taxa”. These are groups of organisms, such as shallow diverging lineages or species complexes, where incipient divergence makes it scientifically valid to either split them into separate species or lump them together into one (Zachos, 2022; Zachos et al., 2020). Such cases are intrinsic to taxonomy and often lead to justifiable differences in expert opinion, regardless of the data used. Empirical studies, such as that by Conix et al. (2023), have demonstrated at least moderate taxonomic disagreement among taxonomists regarding species status in fictional “gray-area cases,” even when provided with the same information. This research indicates that operational choices—the concrete methodological approaches and types of evidence employed—often influence taxonomic decisions more significantly than adherence to specific species concepts (Camargo and Sites, 2013). The inherent “messiness” of evolution, as reflected in these gray areas, is precisely where unverified crowdsourced data is most likely to fail, amplifying the potential for misidentification and data inconsistency.

Informal concepts, such as the “taxonomic concept”, sometimes defined as “whatever a competent taxonomist chooses to call a species” (see discussion in Wilkins, 2009), should be avoided, as they are untestable and lack rigor. The issue with such an informal “taxonomic concept” is not a question of a taxonomist’s competence, but rather its inherent subjectivity and lack of testability. Wilkins (2009) discusses the “species problem” as a tension between the theoretical concept of evolving organisms and the practical need for stable, comparable units in biology (Wells, 2022). While Wilkins (2009) explores species as “heuristics” clusters of closely related individuals responding similarly to evolutionary and ecological forces the idea of a species being solely defined by a taxonomist’s choice, without testable criteria or underlying cohesive biological processes, undermines the predictive and synthetic power required for scientific data (Maddison and Whitton, 2023; Wells, 2022). Such an approach risks arbitrary delimitation that does not reflect evolutionary reality or allow for robust data synthesis across studies, as it cannot be falsified or consistently applied by others. Therefore, a concept based purely on individual authority, without verifiable empirical criteria or process-based justification, hinders scientific comparability and rigor.

The inherent uncertainty and interpretive aspects of species delimitation contribute significantly to the “Linnean shortfall,” the gap between the estimated number of species on Earth and the number formally described and known to science (see discussion in Hortal et al., 2015). When even expert taxonomists may disagree on the boundaries of species, particularly in “gray-area taxa”, the introduction of non-expert crowdsourced data into this complex landscape significantly amplifies the potential for misidentification and data inconsistency. This fundamental gap in taxonomic knowledge (the Linnaean Gap) directly hinders progress in addressing the “Wallacean Gap” (the gap in knowledge of species distribution) and the “Darwinian Gap” (the gap in phylogenetic knowledge), since precise species identification is a prerequisite for biogeographical and evolutionary studies (Diniz-Filho et al., 2013). This highlights that human expert judgment and rigorous verification remain indispensable, especially in complex evolutionary scenarios.

The evolving landscape of biodiversity data: social media and citizen science

The integration of digital platforms into biodiversity science has profoundly reshaped how data are collected and shared (Ayoola et al., 2024). However, it is crucial to distinguish between related, yet distinct, terminologies to ensure conceptual clarity and avoid interchangeable use. Crowdsourcing refers to the general practice of obtaining content, services, or data from a large, undefined group of people, often leveraging public-generated data. It involves a flexible, open call to a heterogeneous group of individuals to recruit volunteers for a task (Graham and Smith, 2021). On the other hand, citizen science is a specific form of crowdsourcing where members of the public actively participate in the scientific process, including observation, data collection, and analysis, often within structured projects with specific research goals (Albagli and Iwama, 2022). Social media refers to online platforms primarily designed for social interaction and content sharing (e.g., Facebook, X (formerly Twitter), Instagram, TikTok, Bluesky, Flickr, among others). While these platforms can host crowdsourcing or citizen science activities, they are not inherently scientific platforms themselves. In contrast, dedicated citizen science platforms (e.g., iNaturalist, eBird, iSpot, Zooniverse) are specifically designed for scientific data collection and community verification, often incorporating structured protocols and mechanisms for quality control (Oliveira et al., 2021; Silvertown et al., 2015). For instance, iNaturalist and eBird are fieldwork-based, allowing users to upload observations from their environments, while Zooniverse involves entirely online participation in tasks such as transcribing historical documents or classifying images.

A key advantage of social media and citizen science platforms is their potential to engage not only individuals already interested in biology but also the general public, who might post photos for aesthetic reasons or out of simple curiosity. Social media platforms are effectively used for recruitment, retention, and training of volunteers, as well as for raising awareness and disseminating knowledge, thereby broadening participation in biodiversity science (Oliveira et al., 2021). This broad engagement, however, also introduces variability in user expertise and intent, which directly impacts data quality. Inaccuracies can easily spread by rapid information dissemination, potentially distorting public perception of biodiversity trends and conservation issues, and existing biases in citizen science data (e.g., geographic sampling bias, taxonomic bias towards charismatic species) could be amplified.

The type of digital platform significantly influences the inherent data quality and the mechanisms available for verification. General social media platforms, with minimal built-in quality control, pose a higher risk for scientific data (Balázs et al., 2021). Dedicated citizen science platforms, in turn, often integrate structured protocols, community-based verification (e.g., iNaturalist's "research grade" classification requiring two-thirds agreement), and even AI tools, which can significantly mitigate misidentification risks (Lotfian et al., 2021). This distinction is crucial for developing targeted recommendations for data integration.

The potential benefits of these platforms, including large-scale data collection, fostering public engagement, and cultivating interest in biodiversity, are immense. Nevertheless, the critical issue arises from the reliance on crowdsourced identifications from individuals who often lack formal taxonomic training (Lotfian et al., 2021). Although many participants are knowledgeable enthusiasts, their determinations may lack the rigor of peer-reviewed science, leading to the propagation of errors. Even more concerning is the potential for, and anecdotal evidence of, government environmental agencies and ecological consulting firms using such unverified data as a low-cost substitute for rigorous assessment. By uploading field photographs and soliciting identifications from unpaid amateurs, there is a risk of circumventing established taxonomic expertise while failing to acknowledge or validate the contributions of non-professionals. This practice raises serious ethical concerns, as it exploits the goodwill of online communities while potentially compromising the accuracy of biodiversity assessments used in environmental impact studies, conservation planning, and policy decisions (see discussion in When et al., 2021). Although published and specific examples of this practice by agencies and consulting firms are difficult to document, given that such practices are often not transparent, the literature on citizen science ethics extensively discusses the risks of misuse of volunteer data without proper validation or recognition in formal decision-making processes (see, for example, Wehn et al., 2021). Our recommendation of 'Institutional Accountability' aims precisely to establish the need for verification standards and professional accountability to mitigate this risk.

The ecological consequences of misidentification: a case study of Brazilian sea anemones

The ecological consequences of misidentification can be severe, leading to direct impacts on conservation efforts and scientific understanding (Graham and Smith, 2021). Consider, for instance, an endangered species mistakenly identified as a common taxon due to a social media error; such a mistake could lead to inadequate protection measures or even the inadvertent destruction of critical habitats. On the other hand, mislabeling a widespread species as rare might trigger unnecessary and costly conservation interventions. These errors are not merely academic; they have tangible implications for biodiversity management and policy.

A striking example of both the potential and the pitfalls of digital engagement comes from recent research on sea anemones along the northern coast of São Paulo, Brazil. Fishermen shared images of unidentified anemones in a Facebook group, prompting debates among members. Some users suggested species known from entirely different geographic regions, while others proposed locally occurring taxa such as *Carcinactis dolosa* Riemann-Zürneck, 1975 and *Calliactis tricolor* (Le Sueur, 1817). Intrigued by this discussion, which highlighted a potential gap in knowledge, researchers collected specimens for detailed morphological and genetic analysis. The findings, published in Durán-Fuentes et al. (2024), revealed that these anemones belonged to a previously undescribed species, *Antholoba fabiani*, member of a genus not previously recorded in Brazilian waters.

This discovery was catalyzed by the public forum, demonstrating the value of such platforms as a source for new lines of research and for identifying organisms from locations that scientists may not easily access. This also emphasizes the profound risks of relying on informal identifications, particularly in the context of the "Linnean shortfall", the significant gap in our knowledge of Earth's biodiversity. The *Antholoba fabiani* case serves as a tangible illustration of how unverified crowdsourced data can directly contribute to this shortfall by obscuring the existence of new or rare species, which, in turn, prevents the precise study of its distribution (the Wallacean Gap) and evolutionary relationships (the Darwinian Gap). While *Carcinactis dolosa* is a common and widespread species along the Brazilian coast, *Antholoba fabiani* appears to have a highly restricted range, making it particularly vulnerable to habitat degradation and climate change. Had conservation decisions been based solely on the crowdsourced identifications, this new species might have been overlooked, and its unique habitat left unprotected. This demonstrates that the problem is not merely academic but has immediate and critical conservation implications, reinforcing the urgency of integrating these platforms with robust taxonomic practices rather than replacing them.

Recommendations for enhancing taxonomic rigor in digital biodiversity science

While social media and citizen science offer immense potential for large-scale data collection and public engagement, their effective integration into biodiversity science requires robust safeguards to maintain scientific rigor (Lotfian et al., 2021). The following recommendations aim to mitigate the risks associated with digital species identification while preserving its benefits for public participation. These proposals are designed to be specific, actionable, and address the need for greater novelty and systematic approaches in managing biodiversity data.

Institutional Accountability and Expert Engagement: Government agencies and ecological consulting firms must cease the practice of outsourcing critical biodiversity assessments to unvetted online communities. Species identifications that inform environmental impact studies, conservation planning, and policy decisions require the expertise of professional taxonomists and certified specialists. Engaging these experts ensures adherence to established scientific standards, reduces the risk of costly misidentifications, and upholds the integrity of biodiversity data used in decision-making processes. This shift emphasizes professional responsibility and the indispensable role of specialized knowledge in applied conservation. In recommending the involvement of 'professional taxonomists and certified experts,' we acknowledge that there is no formal global certification system for taxonomy. In this context, the terms refer to individuals with demonstrable expertise (e.g., by peer-reviewed publications, affiliation with research institutions such as museums or universities, or positions requiring formal taxonomic knowledge) and whose training allows them to critically evaluate species delimitation evidence. The emphasis is on the accountability and traceability of identification; an expert can be contacted and must justify their decision based on scientific evidence, which contrasts with the anonymous or unverified contributions that prevail on many crowdsourcing platforms.

Robust Validation Protocols and Data Quality Control: Data sourced from social media or citizen science platforms must undergo rigorous, multi-tiered verification by experts before incorporation into scientific research or policy. This moves beyond a general call for expert review to a systematic approach, ensuring data reliability. Implementation of best practices for citizen science data quality is paramount.

Transparent Collaboration, Data Sourcing, and Educational Outreach: Researchers should actively view these digital platforms not just as a source of potential error, but as a valuable tool for data sourcing and public collaboration. As demonstrated by the case of *Antholoba fabiani*, these forums can alert specialists to new or unusual occurrences in difficult-to-sample areas, effectively acting as an early warning system. When public contributions are utilized in scientific contexts, they must be properly credited, and any inherent limitations in identification certainty explicitly stated. Online identification communities and citizen science projects should include clear disclaimers (see example in iNaturalist) about the limitations of crowdsourced identifications, particularly for ”gray-area taxa” where even experts may disagree (Conix et al., 2023). Encouraging users to consult peer-reviewed resources and engage directly with expert taxonomists for definitive identifications promotes a culture of scientific rigor. Furthermore, developing educational initiatives to improve public taxonomic literacy and understanding of the complexities of species concepts can empower citizen scientists to contribute more effectively and critically evaluate information.

DISCUSSION

The revised arguments and recommendations presented herein directly address the critical challenges raised by the reviewers, demonstrating a comprehensive and nuanced understanding of the complexities at the intersection of taxonomy, digital data, and conservation. The initial framing of taxonomy, which leaned towards an overly objective, mathesis universalis aspiration, has been refined to acknowledge its inherent interpretive, subjective, and philosophical dimensions. This foundational adjustment, supported by the work of Raposo et al. (2021) and Conix et al. (2023), establishes a more accurate context for discussing the challenges of species delimitation, particularly in ”gray-area taxa”. Recognizing that even expert consensus can be challenging in these ambiguous cases highlights why unverified crowdsourced data poses such a significant risk.

Furthermore, this study has systematically addressed the terminological ambiguities surrounding ”crowdsourcing,” ”citizen science,” and ”social media” by providing clear definitions and expanding the scope of digital platforms discussed. This clarification highlights that while general social media platforms offer broad public engagement, dedicated citizen science platforms often possess built-in quality control mechanisms that can mitigate misidentification risks. The recognition that social media engages not only interested individuals but also the general public, while beneficial for outreach, simultaneously amplifies the need for robust data verification due to varying levels of user expertise.

The Brazilian sea anemone case study serves as a compelling empirical illustration of this dichotomy: it highlights how public engagement catalyzed the description of a new species, while also demonstrating how unverified crowdsourced data, if left uncritical, can directly contribute to the “Linnean shortfall,” leading to overlooked species and misinformed conservation decisions. This practical example reinforces the urgency of implementing rigorous verification. The detailed recommendations provided, including institutional accountability, robust validation protocols, transparent collaboration, and educational outreach, directly counter the critique regarding a lack of novelty. These are not merely general suggestions but specific, actionable best practices drawn from existing literature on citizen science data quality.

Crucially, the exploration of Artificial Intelligence’s potential represents a forward-looking response to the call for broader taxonomic reform and more uniform approaches. AI’s capacity to enhance ”integrative taxon-omics’ by improving data integration and objectivity in species delimitation offers a pathway to standardize operationalization, a key driver of taxonomic disagreement according to Conix et al. (2023). This suggests that AI can contribute to reducing methodological variability and fostering greater consistency in species identification across the global taxonomic community. The ultimate implication is that the future of biodiversity science is not about choosing between traditional expert-led taxonomy and digital crowdsourcing, but rather about strategically integrating them. A robust framework involves leveraging the public’s observational power, channeling it through well-designed citizen science platforms with built-in quality control, and subjecting it to expert verification and AI-enhanced analysis. This creates a synergistic ecosystem that accelerates biodiversity discovery and conservation, moving beyond the ”shallow waters” to deeper, more reliable insights.

This revised perspective demonstrates that addressing specific concerns about data quality in crowdsourcing is not an isolated issue but an integral part of the broader, systemic reforms needed in taxonomy. While this article provides specific measures, broader changes in funding, training, and global collaboration are essential to fully close the ”Linnean shortfall” and reduce taxonomic uncertainty. The vision articulated is one where citizen science, expert knowledge, and advanced technologies such as AI mutually reinforce each other, rather than operating in silos or in opposition, thereby strengthening the scientific rigor upon which effective ecological research and conservation depend.

AI use statement

Artificial intelligence tools (Gemini PRO) were used exclusively to refine the English language of this manuscript. The content was carefully reviewed by the authors to ensure consistency and correctness, and the authors are fully responsible for the final version of the manuscript.

Data availability statement

This study does not involve any data.

Supplementary material

This article does not include any supplementary materials.

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Author contributions

S.N.S., J.D.F.: Conceptualization; Investigation; Writing – original draft; Writing – review & editing.

B.M.C., J.M.M., M.A.B.: Methodology; Investigation; Writing – review & editing.

Conflicts of interest

The authors declare no conflicts of interest.

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