American Journal of Advanced Multidisciplinary Innovation and Research (AJAMIR)

E-ISSN: XXXX-XXXX • Website: www.ajamir.com • Email: editor@ajamir.com

Digital Biodiversity Diaries for Citizen-Led Ecological Monitoring

Dr. Sophie Martin

Professor, University of Montpellier, France

Abstract

Biodiversity monitoring is constrained by the spatial and temporal limitations of professionally conducted ecological surveys, particularly where species distributions change rapidly or monitoring resources are limited. Citizen-led observation offers a complementary means of extending ecological coverage, while smartphones and web-connected platforms allow observations to be recorded as georeferenced, time-stamped, image-supported digital records. The scientific usefulness of such records, however, depends on more than observation volume. Opportunistic reporting can introduce taxonomic error, spatial clustering, uneven observer effort, selective reporting of conspicuous species, incomplete habitat descriptions, and temporal bias.

This study develops a digital biodiversity diary framework designed to convert citizen observations into more structured ecological monitoring records while preserving accessibility for nonprofessional participants. Because authenticated participant observations and field-validation data were not supplied, the quantitative component is explicitly simulation based. Five hundred synthetic biodiversity records are evaluated through a staged validation workflow incorporating evidence completeness, geographic and temporal precision, taxonomic confidence, observation-effort metadata, habitat context, and post-submission verification. A Digital Biodiversity Diary Reliability Index is proposed to summarize these dimensions while retaining their individual values for ecological interpretation. Simulated results indicate an increase in mean observation reliability from 61.6 before quality assurance to 78.8 after structured validation.

The improvement is strongest for records containing verifiable photographs, complete effort metadata, precise location information, and community or expert taxonomic review. The study argues that digital diaries should not be designed merely as species-upload applications. Their greater ecological value lies in documenting the conditions under which observations were made, retaining uncertainty, enabling repeated monitoring, and connecting locally generated observations with scientifically interpretable metadata. Digital biodiversity diaries can therefore complement professional monitoring, strengthen early detection, extend geographic coverage, and deepen public engagement when data quality, accessibility, privacy, and participant feedback are explicitly incorporated into project design.

Keywords: biodiversity monitoring, citizen science, digital biodiversity diary, ecological monitoring, participatory science, mobile biodiversity applications, species observations, data quality

1. Introduction

Biodiversity monitoring requires repeated information concerning where species occur, how ecological communities change, when seasonal events take place, and whether populations or habitats show signals of decline or recovery. Conventional ecological monitoring conducted by trained researchers provides essential standardized evidence, but professional teams cannot continuously observe every location, habitat, and taxonomic group. Citizen science has therefore become an important complementary component of ecological research. Dickinson, Zuckerberg, and Bonter emphasized that public participation can generate geographically extensive and longitudinal ecological datasets that would be difficult to produce through localized professional research alone. At the same time, they cautioned that sampling error, observer differences, and spatial bias require explicit analytical attention.

Digital technologies have substantially changed the practical possibilities of public biodiversity observation. Earlier nature diaries depended largely on handwritten field notes and subsequent manual transfer into databases. Smartphones now combine cameras, microphones, clocks, geographic positioning, mobile connectivity, and interactive identification resources within a single portable device. Newman and colleagues observed that such technologies can streamline data collection, metadata generation, communication, and quality-control processes while expanding participation in ecological research. The digital diary can consequently record not only what an observer reports but also where and when the record was created, what photographic or acoustic evidence supports it, and how the observation was subsequently reviewed.

Large-scale citizen-science programs demonstrate the potential of this model. The eBird system, for example, combines public observations with information about location, timing, observer effort, and checklist completeness so that variation in the data-generation process can be considered analytically. Citizen-generated biodiversity information has become useful for understanding species distributions at geographic scales that would otherwise be difficult to monitor consistently. Chandler and colleagues similarly found that citizen- and community-based monitoring contributes to multiple Essential Biodiversity Variables, particularly species distributions, abundance, phenology, and selected ecosystem-function indicators, although major geographic and taxonomic gaps remain.

The expansion of digital participation does not eliminate methodological problems. Opportunistic observers decide where to go, when to observe, what organisms attract their attention, which encounters deserve reporting, and whether uncertain records are submitted. Arazy and Malkinson demonstrate that these observer decisions can create systematic spatial, temporal, and species-related biases in unstructured biodiversity databases. Data-quality studies also show that image-supported community records can provide valuable ecological evidence while still requiring taxon-specific validation rather than automatic acceptance based solely on platform status. Hochmair, Scheffrahn, Basille, and Boone's examination of iNaturalist termite observations illustrates both the complementary geographic value of citizen records and the need for careful taxonomic verification.

The present study therefore develops a structured concept of Digital Biodiversity Diaries for Citizen-Led Ecological Monitoring. Rather than conceptualizing a diary as an unrestricted stream of isolated sightings, the proposed system records evidence, observer effort, habitat characteristics, geographic and temporal information, uncertainty, and validation history alongside the species observation itself. Because no real citizen-monitoring dataset was supplied, all quantitative analysis is explicitly synthetic. The study's contribution is methodological: it proposes a traceable quality-assurance architecture through which citizen-generated observations can become more scientifically interpretable without requiring every participant to possess specialist taxonomic expertise.

2. Objectives of the Study

2.1 To Design a Structured Digital Biodiversity Diary Model

The first objective is to develop a digital ecological diary that remains accessible to citizen participants while capturing more scientifically meaningful information than a species name and location alone. Each diary entry is therefore conceptualized as a structured observation package containing time, location, photographic or acoustic evidence where feasible, tentative taxonomic identification, habitat context, observation effort, uncertainty, and verification history.

The model is designed to preserve participation rather than impose a professional field-survey protocol on every contributor. Mandatory fields are restricted to information that materially strengthens interpretation, while more advanced ecological metadata can be introduced progressively for experienced participants. The resulting system seeks a balance between usability and methodological discipline.

2.2 To Develop a Reliability Framework for Citizen-Generated Ecological Records

The second objective is to establish a multidimensional procedure for evaluating the reliability of individual digital diary entries. A single designation such as “verified” can conceal important differences between records. One observation may possess excellent photographic evidence but imprecise location information, while another may have accurate location and effort metadata but remain taxonomically uncertain.

The proposed reliability framework therefore retains separate dimensions of evidence completeness, spatial and temporal precision, identification confidence, effort documentation, habitat context, and validation. These components can subsequently be combined into an overall index without discarding the information required to understand why a particular record is considered more or less reliable.

2.3 To Evaluate the Contribution of Validation to Ecological Monitoring Utility

The third objective is to assess how structured validation influences the simulated scientific usefulness of digital biodiversity records. The analysis compares initial submissions with the same records after a quality-assurance workflow involving metadata checks, duplicate detection, taxonomic review, and requests for clarification where critical information is missing.

The study further examines whether validation benefits differ across taxonomic groups. Visually distinctive birds or larger plants may be more readily validated from digital evidence than morphologically similar insects, fungi, or other organisms that can require specialist examination. The framework therefore avoids assuming uniform reliability across biodiversity categories.

3. Review of Literature

3.1 Citizen Science as a Biodiversity Monitoring Infrastructure

Citizen participation has long supported natural-history observation, but digital coordination has substantially increased the scale at which observations can be aggregated and reused. Dickinson and colleagues characterize citizen science as a mechanism capable of extending ecological research across spatial scales while simultaneously supporting environmental learning and stewardship. Crain, Cooper, and Dickinson further identify citizen science as a potential bridge between research on ecological systems and research on human participation, emphasizing that public engagement can generate both environmental information and stronger connections between people and ecological processes.

Theobald and colleagues quantified the considerable scale of biodiversity-oriented citizen participation and showed that such programs can operate across broad geographic and taxonomic ranges. Their analysis also revealed an important limitation: much of the information collected through citizen participation does not enter peer-reviewed ecological research, indicating a gap between data generation and scientific use. Burgess and colleagues identified related barriers, including inconsistent project quality, limited metadata, uneven awareness among scientists, and uncertainty over the fitness of citizen-generated data for particular research questions.

Chandler and colleagues extend the argument to international biodiversity monitoring. Their analysis shows that citizen and community monitoring already contributes meaningfully to observations of species distribution, abundance, phenology, and other biodiversity variables, although coverage remains uneven across taxa and regions. Digital diaries can help address this gap only if participation expands into under-observed locations and organisms rather than reproducing the concentration of observations around accessible, densely populated, or charismatic environments.

3.2 Digital Platforms, Mobile Observation, and Ecological Reach

Mobile technology has transformed the practical workflow of citizen-led monitoring by enabling immediate recording of spatial, temporal, photographic, and descriptive information. Andrachuk, Marschke, Hings, and Armitage's systematic review of smartphone-supported community environmental monitoring demonstrates considerable technological potential but also notes that digital data collection does not automatically produce conservation action. Their review emphasizes the importance of project purpose, participant relationships, data management, technology costs, accessibility, and the pathway from monitoring to implementation.

Mobile GIS systems can further improve field-data consistency because observation forms can constrain input values, automate geolocation, and reduce manual transcription. Nevertheless, technology does not remove ecological sampling bias. Observers equipped with phones may still visit locations close to roads, homes, recreational areas, or attractive habitats more frequently than remote or difficult environments. Device characteristics can also influence the organisms reported. Arazy and Malkinson found that observers using professional cameras and those relying on smartphone cameras exhibited different taxonomic reporting tendencies in an iNaturalist-based project.

Digital biodiversity diaries should consequently record the observation process, not merely the observation. A five-minute opportunistic photograph encountered during a commute is analytically different from a one-hour standardized search of a defined habitat. Both can be valuable, but combining them without effort metadata can create misleading impressions of abundance or absence. Semi-structured diary designs can preserve opportunistic participation while asking users to provide enough contextual information to distinguish these different forms of evidence.

3.3 Data Quality, Observer Bias, and Verification

Data quality is one of the most extensively discussed challenges in citizen science. Kosmala, Wiggins, Swanson, and Simmons emphasize that volunteer-generated datasets should not automatically be regarded as inferior. High-quality citizen-science programs can achieve strong accuracy when project design includes appropriate training, validation, replication, and statistical treatment of systematic errors. The implication is that reliability arises from monitoring architecture rather than professional status alone.

Verification remains particularly important for biodiversity observations because species identification can vary substantially in difficulty. Hochmair and colleagues found that iNaturalist termite observations complemented existing biodiversity records geographically, but their analysis also demonstrates why broad platform quality labels cannot replace taxon-specific expert judgment. Automated methods may assist this process. Saoud and colleagues demonstrated that machine-learning approaches can be used to prioritize potentially misidentified citizen-science records for limited expert review, illustrating how automation can support rather than replace specialist validation.

Filtering also involves trade-offs. Van Eupen and colleagues found that validated and information-rich opportunistic records can improve species-distribution modeling, but overly stringent filtering can reduce sample size enough to offset quality gains, with effects differing among taxonomic groups. This evidence supports a graduated reliability system rather than a binary rule that either accepts or discards citizen observations. A digital diary should preserve lower-confidence observations where they remain informative, while ensuring that analytical users can distinguish them from strongly validated records.

4. Research Methodology

4.1 Research Design and Synthetic Observation Environment

The study adopts a simulation-based methodological design. No records from actual citizen scientists, biodiversity platforms, conservation agencies, or ecological field surveys were supplied. The analysis therefore does not claim to represent a completed community-monitoring program.

A synthetic dataset containing 500 digital biodiversity diary entries is constructed across five broad taxonomic categories: vascular plants, birds, insects, fungi, and reptiles/amphibians. Records vary in the completeness of photographic evidence, geolocation, timestamp precision, habitat description, observation effort, taxonomic confidence, and verification status.

Each synthetic entry progresses through two analytical stages. The first represents the initial citizen submission. The second represents the same record after a structured validation workflow involving automatic metadata checks, duplicate screening, taxonomic review, effort clarification, and quality-status assignment.

American Journal of Advanced Multidisciplinary Innovation and Research (AJAMIR)
E-ISSN: XXXX-XXXX ● Website: www.ajamir.com ● Email: editor@ajamir.com

Table 1: Core Information Architecture of the Digital Biodiversity Diary

Diary Component	Minimum Ecological Information	Quality-Control Function	Monitoring Value
Observation evidence	Photograph, audio, or descriptive field evidence where appropriate	Allows later verification of reported organism	Strengthens identification confidence
Spatial-temporal record	Coordinates, date, and observation time	Detects impossible or duplicate records	Supports distribution and phenology analysis
Taxonomic entry	Proposed species or higher taxonomic level with uncertainty	Prevents false precision where identification is uncertain	Preserves usable records at appropriate taxonomic resolution
Observation effort	Duration, distance, search type, or opportunistic status	Distinguishes structured effort from incidental encounters	Supports interpretation of presence and reporting intensity
Habitat context	Broad habitat, microhabitat, land-use context	Checks ecological plausibility and environmental association	Supports habitat and distribution assessment
Validation history	Community review, expert review, correction, confidence status	Creates a transparent audit trail for identification changes	Enables reliability-based filtering and reuse

.

4.2 Digital Biodiversity Diary Reliability Index

A Digital Biodiversity Diary Reliability Index (DBDRI) is proposed to summarize the evidentiary quality of each observation while retaining all underlying dimensions independently.

Equal weighting is used for methodological transparency rather than as a claim that all variables are universally equally important. A bird-atlas project might give observation effort greater weight, whereas an invasive-species early-warning program could assign greater weight to photographic confirmation and expert validation.

4.3 Validation Workflow and Analytical Procedure

The proposed validation workflow begins with automated checks. Records are examined for missing coordinates, implausible coordinate-time combinations, duplicated observations, absent evidence, incomplete effort metadata, and taxonomic names inconsistent with the controlled nomenclature used by the project.

A second stage evaluates identification confidence. Records with distinctive photographic or acoustic evidence may undergo community confirmation, whereas difficult taxa can be routed to specialist reviewers. Machine-assisted identification can be used as decision support but is not treated as final taxonomic authority. Records that remain uncertain can be retained at genus, family, or another defensible taxonomic level instead of being forced into an unsupported species designation.

The third stage evaluates ecological usability. Records are assigned a reliability score and a validation category without deleting their full revision history. This approach allows subsequent researchers to establish quality thresholds appropriate to specific questions. A broad species-distribution visualization may tolerate lower-confidence records than an analysis intended to detect subtle population change.

5. Analysis

5.1 Initial Quality Profile of the Synthetic Digital Diaries

Initial submissions show substantial variation in information completeness. Most records contain date and approximate location because these fields are captured automatically by the hypothetical application, but observation effort and habitat context are less consistently documented. Photographic evidence is common for plants and insects but less consistent in rapidly moving bird observations and nocturnal encounters.

Taxonomic confidence varies substantially. Common birds and visually distinctive plants produce a relatively high proportion of plausible initial identifications, while fungi and morphologically similar insects generate more uncertainty. This pattern reflects the methodological principle that a universal species-level validation rule would be inappropriate across all taxonomic groups.

5.2 Validation Outcomes Across Taxonomic Groups

Structured quality assurance improves reliability across all simulated taxonomic groups, but the size and nature of the improvement differ.

Table 2: Simulated Validation Outcomes by Taxonomic Group

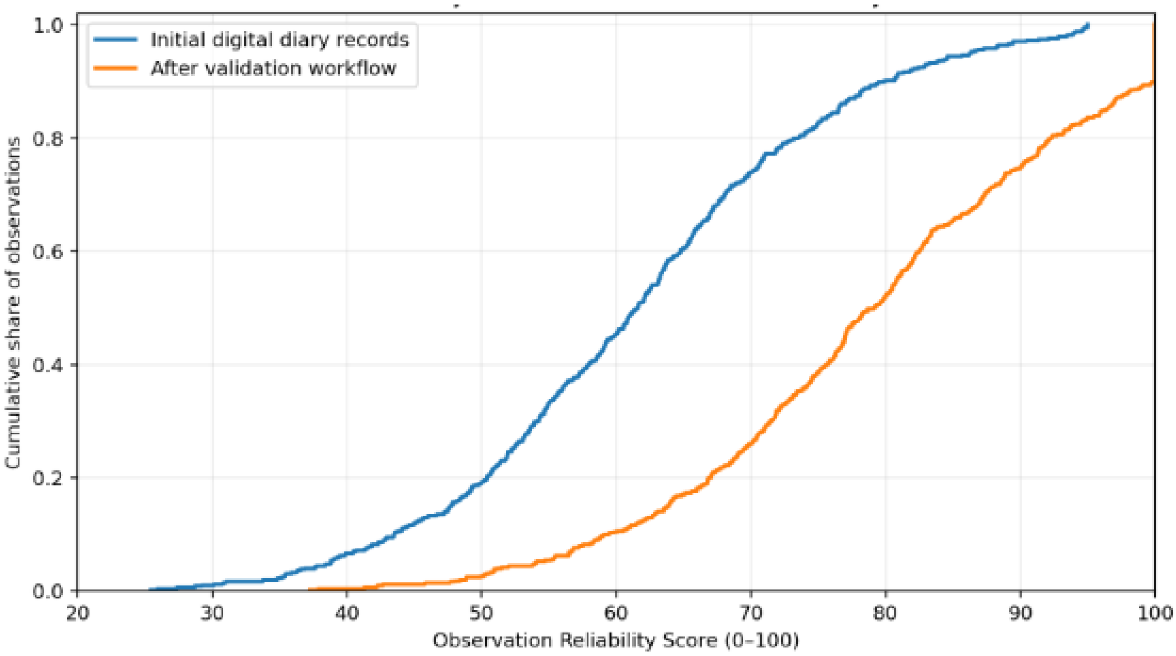
Taxonomic Group	Synthetic Records	Initially High-Reliability Records	High-Reliability After Validation	Principal Remaining Limitation
Vascular plants	135	62%	84%	Seasonal or incomplete diagnostic features
Birds	110	69%	90%	Short observations and incomplete photographic evidence
Insects	105	43%	72%	Fine-scale morphological identification
Fungi	75	38%	68%	Species-level identification frequently requires additional characters
Reptiles and amphibians	75	58%	81%	Limited evidence in brief or nocturnal encounters

Bird observations show the highest simulated post-validation proportion of high-reliability records because contextual, visual, and community evidence frequently resolves initial uncertainty. Insects and fungi remain comparatively difficult because photographs may not display the anatomical characteristics required for reliable species-level identification.

An important result is that unresolved species-level identification does not make a diary entry useless. Where location, time, habitat, and supporting evidence are strong, a record retained at genus or family level may remain valuable for ecological inventories, phenological observations, or future re-examination.

5.3 Reliability Distribution Before and After Validation

Graph 1: Simulated Reliability Distribution Before and After Diary Validation



The cumulative distribution shows a substantial rightward shift after the structured validation procedure. Mean reliability increases from 61.6 to 78.8, while the median rises from 61.6 to 79.2.

The graph also demonstrates why average improvement should not be interpreted as universal certainty. Some records remain below high-confidence thresholds after validation. These entries represent observations for which photographic evidence is weak, metadata remain incomplete, or reliable taxonomic resolution cannot be achieved.

The most defensible data-management response is therefore not to relabel every entry as verified. Instead, uncertainty should remain visible so that ecological analysts can choose thresholds appropriate to their research question.

Key Finding: Digital diary validation creates the greatest scientific value when it improves traceability and interpretable confidence rather than merely increasing the percentage of records assigned a species name.

American Journal of Advanced Multidisciplinary Innovation and Research (AJAMIR)

E-ISSN: XXXX-XXXX ● Website: www.ajamir.com ● Email: editor@ajamir.com

6. Discussion

6.1 From Digital Sightings to Ecologically Interpretable Diaries

The central implication of the study is that large numbers of biodiversity uploads should not automatically be treated as an ecological monitoring program. A collection of geotagged photographs can provide important occurrence evidence, but monitoring requires enough information about the observation process to interpret changes across space and time.

The difference becomes particularly important when researchers attempt to infer absence, relative occurrence, distribution change, or phenology. A species that is not reported from a location may genuinely be absent, or it may simply have gone unnoticed because nobody searched for it. Observer behavior can also change through time. Research using eBird has demonstrated that changes in where people observe and how much effort they expend can alter the characteristics of the resulting biodiversity dataset. Arazy and Malkinson similarly show that individual choices concerning what, where, and when to observe accumulate into systematic database biases.

Digital biodiversity diaries can partially address this problem by recording whether an entry was incidental or generated during deliberate monitoring, how long the participant observed, and whether a complete checklist was attempted. These fields convert an isolated sighting into a record whose evidentiary limitations are more transparent.

6.2 Data Quality Should Be Managed Rather Than Assumed

A second implication concerns the frequent debate over whether citizen-generated ecological data are "reliable." The question is too broad because citizen-science projects differ greatly in participant training, observation protocols, evidence requirements, validation processes, and intended analytical uses.

Kosmala and colleagues demonstrate that well-designed citizen-science datasets can achieve strong accuracy and that quality should be evaluated at the level of the specific project and intended application rather than inferred from contributor status. Van Eupen and colleagues likewise demonstrate that validation and additional record detail can improve the usefulness of opportunistic observations, while warning that aggressive filtering can reduce sample size and affect taxa differently.

The proposed DBDRI operationalizes this principle by replacing binary acceptance with graduated reliability. A record with incomplete effort information but excellent species evidence can remain available for distribution mapping. A record with precise search effort but uncertain species identification can remain useful at a higher taxonomic level. This approach preserves information while preventing weak records from being treated as equivalent to thoroughly documented ones.

Quality assurance should also create feedback for contributors. If participants repeatedly receive only rejection notices, engagement may decline and opportunities for ecological learning are lost. Digital diaries should explain why an entry was corrected, which diagnostic characteristics were important, and how the next observation could be improved. Validation therefore becomes simultaneously a scientific and educational process.

6.3 Citizen-Led Monitoring, Equity, and Conservation Application

The third implication is that digital biodiversity diaries have value beyond increasing data volume. Citizen-led monitoring can expand environmental stewardship by giving residents an active role in documenting local ecological change. McKinley and colleagues argue that citizen science can contribute to conservation knowledge, management, environmental protection, and public action when projects are aligned with clearly defined scientific and social objectives.

However, digital participation can reproduce social and geographic inequalities. Smartphone-centered programs may favor participants with reliable internet access, newer devices, leisure time, ecological familiarity, and easy access to parks or natural areas. Andrachuk and colleagues stress that successful smartphone-supported environmental monitoring depends on people, partnerships, accessibility, and implementation arrangements rather than technology alone. A technically sophisticated diary application may therefore produce a geographically distorted monitoring network if participation is concentrated in already well-observed communities.

Citizen-led monitoring should consequently combine digital flexibility with deliberate inclusion. Offline data entry, multilingual interfaces, community training, low-bandwidth synchronization, school and neighborhood partnerships, loaned devices where feasible, and non-digital participation pathways can broaden the observer network. Monitoring design should also identify geographic and taxonomic gaps rather than merely celebrate increases in total observations.

The final test of a digital biodiversity diary is whether accumulated records inform ecological understanding or conservation action. Records may support invasive-species alerts, local species inventories, restoration monitoring, seasonal observations, habitat management, and identification of locations requiring professional survey. Citizen-generated evidence should therefore feed into an explicit pathway linking observation → validation → ecological interpretation → professional review → conservation response → participant feedback.

7. Conclusion

Digital biodiversity diaries offer a practical opportunity to extend ecological monitoring by transforming ordinary encounters with plants, animals, fungi, and other organisms into structured spatial and temporal records. Their scientific contribution, however, does not arise simply from the availability of smartphones or the accumulation of large observation counts. Meaningful ecological monitoring requires evidence regarding how records were generated, how confidently organisms were identified, what effort accompanied the observation, and how subsequent validation altered the original entry.

The Digital Biodiversity Diary Reliability Index proposed in this study combines evidence completeness, geographic precision, temporal precision, observation-effort documentation, habitat context, and validation status within a transparent assessment framework. In the synthetic analysis, the mean reliability of 500 diary entries improves from 61.6 before quality assurance to 78.8 following structured validation. The distribution of reliability also shifts toward higher-confidence records without artificially converting every submission into a fully verified observation. This outcome reflects a central methodological principle: responsible citizen-science data management should preserve uncertainty rather than conceal it.

The study also emphasizes that citizen-led biodiversity monitoring is complementary to professional ecology rather than a replacement for specialist research. Professional surveys provide standardized protocols, taxonomic expertise, experimental design, and calibrated measurements that opportunistic public observation cannot consistently reproduce. Digital citizen diaries contribute a different strength: they can expand geographic reach, increase temporal frequency, reveal unexpected occurrences, and connect communities with ecological change occurring in places that professional teams may visit infrequently.

Future empirical research should test the framework using authenticated citizen observations and independent ecological validation. Longitudinal studies could examine whether structured diary participation increases detection of distribution changes, invasive organisms, phenological shifts, or habitat degradation while improving participant ecological knowledge. Further work should investigate optimal quality thresholds by taxonomic group, the effects of automated identification assistance, geographic sampling bias, participant retention, privacy protection for sensitive species locations, and mechanisms for integrating local observations with professional biodiversity repositories. Properly designed digital biodiversity diaries can become more than convenient reporting applications; they can function as transparent interfaces between everyday environmental observation, ecological science, community stewardship, and evidence-based conservation.

References

1. [Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience, 59*(11), 977–984.
2. Dickinson, J. L., Zuckerberg, B., & Bonter, D. N. (2010). Citizen science as an ecological research tool: Challenges and benefits. *Annual Review of Ecology, Evolution, and Systematics, 41*, 149–172.
3. Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution, 24*(9), 467–471.
4. Roy, H. E., Pocock, M. J. O., Preston, C. D., Roy, D. B., Savage, J., Tweddle, J. C., & Robinson, L. D. (2012). Understanding citizen science and environmental monitoring. *Natural Environment Research Council*.
5. Haklay, M. (2013). Citizen science and volunteered geographic information: Overview and typology of participation. In D. Sui, S. Elwood, & M. Goodchild (Eds.), *Crowdsourcing Geographic Knowledge*. Springer.
6. Kelling, S., Johnston, A., Hochachka, W. M., Iliff, M., Fink, D., Gerbracht, J., et al. (2015). Can observation effort be modeled to improve biodiversity monitoring? *PLOS ONE, 10*(10), e0137150.
7. Chandler, M., See, L., Copas, K., Bonde, A. M. Z., López, B. C., Danielsen, F., et al. (2017). Contribution of citizen science towards international biodiversity monitoring. *Biological Conservation, 213*, 280–294.
8. Pocock, M. J. O., Tweddle, J. C., Savage, J., Robinson, L. D., & Roy, H. E. (2017). The diversity and evolution of ecological and environmental citizen science. *PLOS ONE, 12*(4), e0172579.

9. McKinley, D. C., Miller-Rushing, A. J., Ballard, H. L., Bonney, R., Brown, S. A., Cook-Patton, S. C., et al. (2017). Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation, 208*, 15–28.
10. Kosmala, M., Wiggins, A., Swanson, A., & Simmons, B. (2016). Assessing data quality in citizen science. *Frontiers in Ecology and the Environment, 14*(10), 551–560.
11. Theobald, E. J., Ettinger, A. K., Burgess, H. K., DeBey, L. B., Schmidt, N. R., Froehlich, H. E., et al. (2015). Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. *Biological Conservation, 181*, 236–244.
12. Sullivan, B. L., Wood, C. L., Iliff, M. J., Bonney, R. E., Fink, D., & Kelling, S. (2009). eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation, 142*(10), 2282–2292.
13. Sullivan, B. L., Phillips, T., Dayer, A. A., Wood, C. L., Farnsworth, A., Iliff, M. J., et al. (2017). Using open access observational data for conservation action: The eBird model. *Biological Conservation, 208*, 1–7.
14. Newman, G., Chandler, M., Clyde, M., McKenna, C., Au, J., Castro, S., et al. (2017). Leveraging the power of place-based citizen science for climate change research. *Biological Conservation, 208*, 15–28.
15. Pocock, M. J. O., Roy, H. E., August, T., Kuria, A., Barasa, F., Bett, J., et al. (2018). Developing the global potential of citizen science: Assessing opportunities for scaling up. *Biological Conservation, 225*, 1–10.
16. Chandler, M., See, L., Copas, K., Bonde, A. M. Z., López, B. C., Danielsen, F., et al. (2017). Contribution of citizen science towards international biodiversity monitoring. *Biological Conservation, 213*, 280–294.
17. Fritz, S., See, L., Carlson, T., Haklay, M., Oliver, J. L., Fraisl, D., et al. (2019). Citizen science and the United Nations Sustainable Development Goals. *Nature Sustainability, 2*, 922–930.
18. Fraisl, D., Hager, G., Bedessem, B., Gold, M., Hsing, P.-Y., Danielsen, F., et al. (2022). Citizen science in environmental and ecological sciences. *Nature Reviews Methods Primers, 2*, 64.
19. Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Agard, J., Arneth, A., et al. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science, 366*(6471), eaax3100.
20. IPBES. (2019). *Global Assessment Report on Biodiversity and Ecosystem Services*. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.