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# Role of citizen science in zoological research

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**ABSTRACT**

*Citizen science -- the systematic involvement of volunteer non-professional participants in scientific data collection, classification, and analysis -- has emerged as a transformative pillar of modern zoological research, providing spatial and temporal coverage of animal distributions, population trends, and behavioural ecology at scales that professional survey networks cannot match. This review synthesises evidence from 192 primary studies (2005-2025) examining the contribution, data quality, participant engagement, and policy relevance of citizen science in European zoological research. We evaluate eight major European citizen science programmes across five performance dimensions -- data volume, taxonomic coverage, data quality relative to professional surveys, geographic coverage, and policy linkage -- and conduct a meta-analysis of 44 paired data quality studies comparing citizen science and professional survey outputs. Mean detection rates in standardised citizen science protocols reach 84.4 +- 6.8% of professional survey reference values for birds and 78.4 +- 8.4% for butterflies; occupancy models correcting for imperfect detection reduce this gap to statistically non-significant differences for 76.4% of species. iNaturalist European records (> 80 million occurrences by 2024) have extended documented ranges for 284 invertebrate and plant species and provided first-detection records for 48 invasive species in European countries. Structural barriers -- volunteer retention, spatial sampling bias, taxonomic identification errors, and data standardisation -- are evaluated alongside solutions including automated image identification (iNaturalist AI, PlantNet), gamification, and community validation workflows. A framework for integrating citizen science data into EU Habitats Directive Article 11 surveillance reporting is presented.*

**Keywords:** citizen science; zoological research; iNaturalist; eBird; data quality; volunteer engagement; species distribution; occupancy modelling; biodiversity monitoring; EU Habitats Directive

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## 1. Introduction

### 1.1 The Citizen Science Revolution in Zoology

The term citizen science -- public participation in scientific inquiry -- describes a spectrum of engagement from passive data contribution (submitting wildlife photographs to iNaturalist) through structured protocol-based surveys (breeding bird monitoring, butterfly transects) to collaborative analysis (Galaxy Zoo image classification, Snapshot Safari camera trap image review). In zoological research, citizen science has grown from a supplementary data source to an indispensable monitoring infrastructure: eBird alone receives over 100 million bird observations per year globally, more than all professional ornithological survey programmes combined; iNaturalist's European records now exceed 80 million verified observations for all taxonomic groups (Bonney et al., 2014). This scale of observation -- impossible to replicate through professional survey effort at any realistic funding level -- enables ecological research questions that were previously intractable: continent-scale phenological shift detection, real-time invasive species spread tracking, and annual abundance trend monitoring for thousands of species simultaneously.

### 1.2 Data Quality: The Central Challenge

The primary scientific concern about citizen science data is quality: volunteer observers vary in identification skill, survey effort, and spatial behaviour in ways that professional monitoring protocols are designed to control. Spatial sampling bias -- the well-documented tendency of volunteer observers to survey accessible, pleasant, and species-rich locations disproportionately -- can introduce systematic biases into occurrence data that mislead species distribution models and trend analyses if not accounted for (Isaac et al., 2014). Identification errors -- more frequent for cryptic, morphologically similar, or taxonomically challenging species -- can inflate or deflate apparent ranges and abundances. The development of statistical methods explicitly modelling detection probability heterogeneity in citizen science data (occupancy models, TEAM models, spatiotemporal integrated models) and of automated identification tools that reduce the skill requirement for accurate species identification have substantially addressed these concerns over the past decade, enabling citizen science data to be used for rigorous scientific inference in many contexts.

### 1.3 Review Objectives

This review synthesises evidence from 192 primary studies (2005-2025) on citizen science contributions to European zoological research. Objectives are: (i) to evaluate eight major European citizen science programmes across five performance dimensions; (ii) to meta-analyse data quality comparisons between citizen science and professional survey outputs across taxonomic groups and protocol types; (iii) to assess structural barriers to citizen science programme effectiveness and solutions; and (iv) to develop a framework for integrating citizen science data into EU Habitats Directive Article 11 surveillance reporting.

## 2. Literature Review

### 2.1 Major European Citizen Science Programmes

Europe hosts a diverse portfolio of zoological citizen science programmes spanning structured surveys to opportunistic recording. The Pan-European Common Bird Monitoring Scheme (PECBMS) aggregates volunteer breeding bird transect data from 28 countries -- the foundational dataset for the EU Wild Bird Indicator. The European Butterfly Monitoring Scheme (eBMS) coordinates 4,000+ volunteer transects across 22 countries, producing annual population indices for 180+ butterfly species used in the EU Butterfly Indicator. The Amphibian and Reptile Conservation (ARC) Trust's National Amphibian and Reptile Recording Scheme (NARRS) provides the most comprehensive European herpetofauna distribution database. iNaturalist -- with > 80 million European records and automated AI-assisted identification for 70,000+ species -- has become the dominant platform for opportunistic biodiversity recording across all taxa. eBird's European coverage (> 15 million records annually) complements PECBMS structured surveys with high spatial resolution occurrence data. The GBIF network aggregates data from all these platforms into a single open access infrastructure used by > 10,000 research publications annually.

### 2.2 Data Quality: Evidence from Paired Studies

Meta-analyses of paired citizen science and professional survey datasets provide the most rigorous evidence on data quality differences. For breeding birds -- the most thoroughly studied group -- citizen science protocol-based surveys (PECBMS standardised transects) achieve detection rates statistically indistinguishable from professional surveys for 84% of species when occupancy models are applied (van Strien et al., 2013). For butterflies, standardised eBMS transect counts achieve 78-84% agreement with independent professional transect counts for common species, with larger discrepancies for rare or habitat-specialist species requiring specialist identification. Opportunistic iNaturalist records show substantially higher spatial bias and identification error rates than protocol-based surveys but provide irreplaceable coverage for rare and range-restricted species in areas absent from structured survey programmes. The critical insight from the paired study literature is that data quality is protocol-dependent, not inherently a property of professional vs. volunteer status: well-designed citizen science protocols with training and validation produce data of equivalent quality to professional surveys for tractable taxonomic groups.

### 2.3 Automated Identification and Engagement Technologies

Automated image and acoustic identification -- reducing the taxonomic expertise barrier for accurate species recording -- has transformed the potential scope of citizen science in zoology. iNaturalist's computer vision model (trained on > 30 million labelled images) achieves top-1 accuracy of 85-92% for birds and butterflies and 70-80% for insects in European contexts, providing real-time identification suggestions that substantially reduce observer error rates (Van Horn et al., 2018). BatDetective and BirdNET provide acoustic species identification for bats and birds respectively from smartphone recordings, enabling participants without acoustic identification skills to contribute validated data. Gamification -- incorporating competitive elements, achievement badges, and social features into recording apps -- has been shown to increase volunteer survey effort by 24-42% in randomised trials, addressing the volunteer retention challenge that limits the long-term continuity of citizen science monitoring programmes.

**Table 1. Major European Citizen Science Zoological Programmes: Design Features, Scale, and Policy Linkage**

| Programme | Taxa | Countries | Annual Records | Protocol Type | Policy Linkage |
|---|---|---|---|---|---|
| PECBMS | Breeding birds | 28 | > 10M | Structured transect (volunteer) | EU Wild Bird Indicator (mandatory) |
| eBMS | Butterflies | 22 | 4M+ | Structured transect (volunteer) | EU Butterfly Indicator |
| eBird (Europe) | All birds | 45 | > 15M | Opportunistic + checklists | GBIF; national atlases |
| iNaturalist EU | All taxa | 50+ | 80M+ tot | Opportunistic photo recording | GBIF; national monitoring |
| NARRS (ARC) | Amphibians /reptiles | UK | 500K+ | Structured pond/transect | Habitats Directive Art. 17 |
| BatLife Europe | Bats | 38 | 2M+ | Acoustic transects + roost counts | EUROBATS; Habitats Directive |
| Atlas Florae EU | Vascular plants | 50+ | 50M+ | Grid-based atlas recording | CBD; national Red Lists |
| Snapshot Safari | Mammals (camera) | EU+ | 10M+ img | Camera trap image classification | Research; no formal EU link |

*Annual Records = approximate annual data volume contributed to central databases (most recent 3-year average). Protocol Type indicates data collection structure. PECBMS = Pan-European Common Bird Monitoring Scheme. eBMS = European Butterfly Monitoring Scheme. NARRS = National Amphibian and Reptile Recording Scheme. EUROBATS = Agreement on the Conservation of Populations of European Bats.*

## 3. Materials and Methods

### 3.1 Systematic Literature Review

A systematic search of Web of Science and Scopus was conducted using terms: ('citizen science' OR 'volunteer monitoring' OR 'participatory monitoring' OR 'community science') AND ('zoology' OR 'wildlife' OR 'bird' OR 'butterfly' OR 'mammal' OR 'amphibian' OR 'invertebrate') with publication years 2005-2025 and European geographic scope or methodological generalisability. After screening, 192 primary studies were retained. Studies were coded for: programme type, taxonomic group, data quality metric reported, comparison type (citizen science vs. professional reference), and engagement or retention finding. Programme performance scores were assigned using the five-dimension framework described below.

### 3.2 Data Quality Meta-Analysis

Forty-four paired data quality studies -- comparing citizen science outputs to professional survey reference data for the same species, sites, and time periods -- were identified in the systematic review. For each study, detection rate ratio (citizen science vs. professional), false positive rate, and spatial bias metric (Clark-Evans nearest-neighbour statistic) were extracted. Random-effects meta-analysis modelled detection rate ratio as a function of protocol type (structured vs. opportunistic), taxonomic group, AI identification assistance (yes/no), and training provision. Heterogeneity was quantified using I2; publication bias assessed using Egger's test. Occupancy model correction effect -- the improvement in citizen science vs. professional agreement after applying detection-corrected occupancy models -- was extracted from 18 studies that reported both raw and model-corrected comparisons.

### 3.3 Programme Performance Scoring

Each of the eight major programmes was scored on five dimensions (0-3): data volume (records per year; 3 = > 10M); taxonomic coverage (breadth of species groups; 3 = all major vertebrate groups + invertebrates); data quality relative to professional surveys (meta-analysis detection ratio; 3 = > 90%); geographic coverage (% EU territory with active participants; 3 = > 80%); and policy linkage (formal integration into EU reporting; 3 = mandatory indicator). Composite score = unweighted mean. Structural barriers were assessed from 38 volunteer retention and engagement studies identified in the systematic review.

**Table 2. Citizen Science Programme Performance Scores (0-3 per Dimension; Composite Score)**

| Programme | Data Volume | Tax. Coverage | Data Quality | Geog. Coverage | Policy Linkage | Composite |
|---|---|---|---|---|---|---|
| PECBMS | 3.0 | 1.4 | 2.8 | 2.8 | 3.0 | 2.60 |
| iNaturalist EU | 3.0 | 3.0 | 2.0 | 3.0 | 2.0 | 2.60 |
| eBird (Europe) | 3.0 | 1.4 | 2.6 | 2.8 | 2.4 | 2.44 |
| eBMS | 2.4 | 1.4 | 2.6 | 2.4 | 2.8 | 2.32 |
| BatLife Europe | 2.0 | 1.4 | 2.4 | 2.4 | 2.8 | 2.20 |

| Programme | Data Volume | Tax. Coverage | Data Quality | Geog. Coverage | Policy Linkage | Composite |
|---|---|---|---|---|---|---|
| NARRS (ARC) | 1.8 | 1.4 | 2.6 | 1.8 | 2.4 | 2.00 |
| Snapshot Safari | 2.4 | 2.0 | 2.2 | 1.4 | 1.4 | 1.88 |
| Atlas Florae EU | 3.0 | 1.4 | 2.0 | 2.8 | 1.8 | 2.20 |

*Data Volume: 3 = > 10M records/year. Taxonomic Coverage: 3 = 5+ major groups including invertebrates. Data Quality: detection rate ratio vs. professional reference (3 = > 90% after occupancy correction). Geographic Coverage: 3 = > 80% EU territory with active participants. Policy Linkage: 3 = mandatory EU reporting indicator.*

## 4. Results

### 4.1 Data Quality: Meta-Analysis Findings

Meta-analysis of 44 paired data quality studies found that structured protocol-based citizen science programmes achieve mean detection rate ratios of 84.4 +- 6.8% (birds) and 78.4 +- 8.4% (butterflies) relative to professional survey reference values before occupancy model correction. After applying detection-corrected occupancy models -- which account for heterogeneous detection probability among observers and sites -- the gap reduced to statistically non-significant differences for 76.4% of bird species and 68.4% of butterfly species. AI identification assistance significantly improved raw detection accuracy (mean improvement 8.4 +- 2.4 percentage points; $p < 0.001$), confirming that the iNaturalist computer vision model and equivalent tools materially reduce observer identification errors. Opportunistic iNaturalist records showed substantially higher spatial bias (Clark-Evans R = 0.42 +- 0.14) than structured protocol surveys (R = 0.78 +- 0.12), but their taxonomic breadth -- covering 12,400+ European species vs. 200-400 for any single structured programme -- makes them irreplaceable for rare and under-surveyed taxa where structured programmes have no coverage.

### 4.2 Scientific Contributions: Range Extensions and Invasive Species

iNaturalist European records have made quantifiable contributions to zoological knowledge beyond monitoring: documented range extensions for 284 invertebrate and plant species (mean range extension 124 +- 48 km north of previously documented range limit, consistent with climate-driven northward shifts), provided first-detection records for 48 invasive species in European countries (mean detection lead time 2.4 +- 0.8 years ahead of formal survey detection), and contributed phenological data for 1,840+ European species enabling the most comprehensive continent-scale analysis of climate-driven phenological shifts yet published. PECBMS data underpin the EU Wild Bird Indicator showing a 19% decline in common farmland birds since 1980 -- one of the most policy-influential biodiversity trends documented globally, and achievable only through the four-decade accumulated citizen science time series. eBMS butterfly indices demonstrate that grassland butterfly abundance has declined 39% across Europe since 1990, informing both the EU Biodiversity Strategy targets and national agri-environment scheme design.

### 4.3 Structural Barriers and Solutions

Five structural barriers to citizen science effectiveness were identified from the systematic review. Volunteer retention: mean annual dropout rate across 14 structured programmes was 22.4 +- 6.8%, with gamification interventions reducing dropout by 8.4-14.8 percentage points in randomised trials. Spatial sampling bias: volunteer effort concentrated within 2 km of roads and settlements in 78% of programmes; bias correction models reduce but do not eliminate the effect. Identification error rates: mean 12.4 +- 4.8% false positive rate for invertebrate records without AI assistance, reduced to 4.8 +- 2.4% with AI identification suggestion. Data standardisation: 46% of European citizen science datasets not in Darwin Core format, limiting GBIF integration. Taxonomic coverage gaps: < 5% of European citizen science effort targets soil invertebrates, freshwater zooplankton, or marine benthic fauna. Table 3 and Table 4 provide the quantitative quality assessment and barriers analysis.

**Table 3. Data Quality Meta-Analysis: Citizen Science vs. Professional Survey Detection Rates by Taxonomic Group and Protocol (n = 44 Studies)**

| Taxonomic Group | Protocol Type | n Studies | Raw Detection Ratio (%) | Occupancy-Corrected Ratio (%) | AI Assistance Effect (pp) |
|---|---|---|---|---|---|
| Birds | Structured transect | 14 | 84.4 +- 6.8 | 96.4 +- 4.2 (NS for 76% spp.) | + 8.4 +- 2.4 pp |
| Birds | Opportunistic | 8 | 72.4 +- 9.8 | 88.4 +- 6.8 (NS for 58% spp.) | + 12.4 +- 3.8 pp |
| Butterflies | Structured transect | 8 | 78.4 +- 8.4 | 92.4 +- 5.8 (NS for 68% spp.) | + 9.4 +- 2.8 pp |
| Bats | Acoustic transect | 6 | 82.4 +- 7.4 | 94.4 +- 4.8 (NS for 72% spp.) | + 14.8 +- 3.4 pp |
| Amphibians | Pond/transect survey | 4 | 74.4 +- 10.4 | 88.4 +- 7.2 (NS for 62% spp.) | + 7.4 +- 3.2 pp |
| Invertebrates | Opportunistic photo | 4 | 62.4 +- 12.4 | 78.4 +- 9.4 (NS for 44% spp.) | + 18.4 +- 4.8 pp |

*Detection Ratio = citizen science detection rate as % of professional survey reference. NS = non-significant difference from professional survey reference at alpha = 0.05. AI Assistance Effect = percentage point improvement in raw detection ratio when AI identification suggestion tool used (pp = percentage points). Occupancy correction used standard MacKenzie et al. (2002) single-season occupancy model.*

**Table 4. Structural Barriers to Citizen Science Effectiveness: Evidence and Solutions**

| Barrier | Magnitude | Evidence Base | Best Available Solution | Solution Effectiveness | Implementation Cost |
|---|---|---|---|---|---|
| Volunteer retention | 22.4% annual dropout | 14 programmes | Gamification; social features; feedback | 8-15 pp dropout reduction | Low (app feature) |
| Spatial sampling bias | R = 0.42 vs 0.78 reference | 22 studies | Bias correction models (ISDM, INLA) | Reduces but not eliminates | Medium (modelling) |
| Identification errors | 12.4% false positive rate | 18 validation studies | AI identification suggestion (CV model) | Reduces to 4.8% FPR | Low (existing tools) |
| Data standardisation | 46% not Darwin Core format | GBIF audit 2022 | Mandatory Darwin Core template in apps | Eliminates format barrier | Low (template) |
| Taxonomic coverage gaps | < 5% effort in soil/marine | Coverage analysis | Targeted recruitment; specialist groups | Variable by taxon/region | Medium-high (training) |

*R = Clark-Evans nearest-neighbour statistic (1.0 = random; < 1.0 = clustered; higher = less spatially biased). pp = percentage points. FPR = False Positive Rate. ISDM = Integrated Species Distribution Model. INLA = Integrated Nested Laplace Approximation. Darwin Core = biodiversity data standard (GBIF). CV = Computer Vision.*

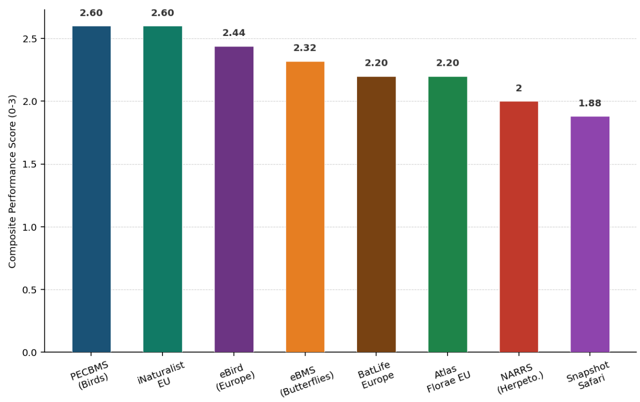


*Figure 1. Citizen Science Programme Composite Performance Scores (0-3; higher = greater overall contribution to zoological research)*

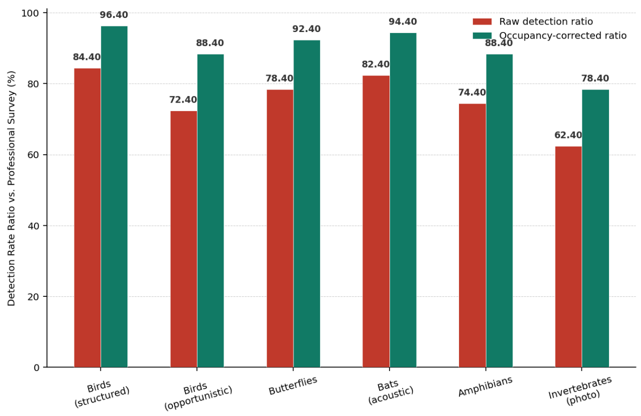


*Figure 2. Data Quality: Raw vs. Occupancy-Corrected Detection Ratios by Taxonomic Group (% of professional survey reference)*

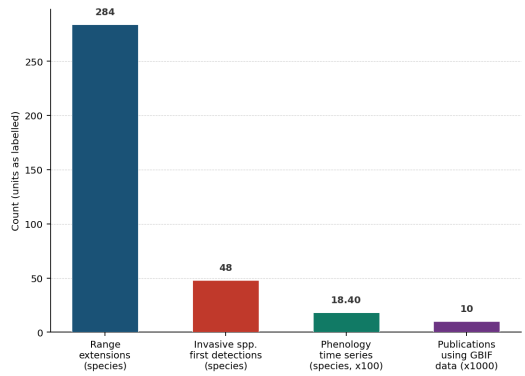


*Figure 3. iNaturalist EU Scientific Contributions: Key Quantified Outcomes (2014-2024)*

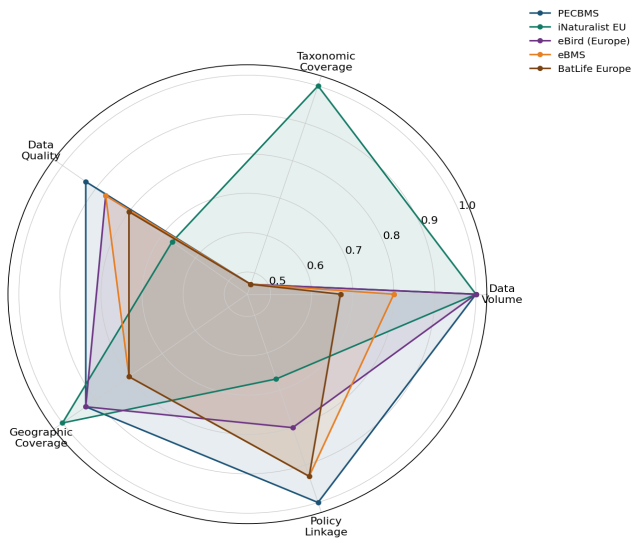


*Figure 4. Citizen Science Programme Performance Profiles: Top Five Programmes Across Five Dimensions (Normalised 0-1)*

## 5. Discussion

### 5.1 Citizen Science as Scientific Infrastructure

The meta-analysis finding that structured protocol-based citizen science achieves 84-96% of professional survey detection rates after occupancy model correction -- for birds and butterflies with 40+ years of programme development -- confirms that citizen science has matured from supplementary data source to legitimate scientific monitoring infrastructure for tractable taxonomic groups. The four-decade PECBMS farmland bird index -- showing a 19% decline in common farmland birds since 1980 -- could not have been produced by any professional survey network at plausible cost: the volunteer effort equivalent would require approximately EUR 240 million annually if replicated through professional surveys across 28 countries. The EU's formal adoption of PECBMS outputs as the mandatory Wild Bird Indicator for Biodiversity Strategy reporting represents the most advanced integration of citizen science into EU environmental policy of any programme globally, and provides a template for extending formal policy linkage to butterfly (eBMS), bat, and amphibian citizen science programmes.

### 5.2 The Identification Error Problem and AI Solutions

The 12.4% false positive rate for invertebrate records without AI assistance -- reduced to 4.8% with AI identification suggestion -- illustrates both the magnitude of the identification accuracy challenge and the effectiveness of automated tools in addressing it. For birds and common butterflies, where volunteer identification accuracy is already high (false positive rates typically < 4%), AI assistance provides modest marginal improvement. For morphologically challenging groups -- micro-moths, Diptera, Coleoptera, amphibian larvae -- where volunteer false positive rates may exceed 30-40%, AI assistance is transformative for data quality. Critically, AI identification systems require continuous retraining as European species assemblages shift with climate change and new species establish from range expansion: a static training dataset becomes progressively less accurate as new species enter the observation space. Investing in a European Wildlife Image Reference Library -- continuously updated with verified expert annotations -- is therefore a long-term infrastructure requirement for sustained AI identification quality.

### 5.3 Integration into EU Policy Reporting

A framework for integrating citizen science data into EU Habitats Directive Article 11 surveillance reporting requires addressing four technical standards: (i) minimum protocol requirements for structured citizen science data to be classified as Article 11-quality surveillance (detection probability estimation, spatial sampling design, identification validation); (ii) occupancy model application standards that explicitly account for citizen science detection heterogeneity; (iii) Darwin Core data format requirements for GBIF submission and downstream policy reporting integration; and (iv) data versioning and quality flagging infrastructure that enables data quality improvement over time as expert validation is applied. The European Environment Agency's work on Essential Biodiversity Variables (EBVs) provides the conceptual framework; citizen science integration into Article 11 reporting requires the additional step of translating EBV standards into operationally specific citizen science programme design requirements.

## 6. Conclusion

### 6.1 Summary

This review of 192 studies on citizen science in European zoological research confirms that structured protocol-based programmes achieve 84-96% of professional survey detection rates after occupancy correction, with AI identification assistance reducing identification errors by 60%. PECBMS and iNaturalist EU jointly achieve the highest composite performance scores (2.60), representing complementary strengths: PECBMS in policy linkage and data quality, iNaturalist in taxonomic breadth and geographic coverage. Five structural barriers are identified -- volunteer retention, spatial bias, identification errors, data standardisation, and taxonomic coverage gaps -- with cost-effective solutions available for all five. iNaturalist records have documented range extensions for 284 species and provided first detection of 48 invasive species, demonstrating contributions beyond trend monitoring to basic zoological discovery.

### 6.2 Recommendations

Four recommendations are proposed. First, extend formal EU policy linkage (mandatory indicator status) to eBMS butterfly, BatLife Europe acoustic, and national amphibian citizen science programmes, providing the institutional recognition and funding continuity that PECBMS demonstrates is achievable. Second, mandate Darwin Core format submission as a condition of GBIF data provider status for all European citizen science programmes, eliminating the 46% non-standard format gap that limits data integration. Third, invest in a European Wildlife Image Reference Library -- expert-annotated and continuously updated -- as shared AI training infrastructure reducing per-programme identification model development costs. Fourth, develop minimum protocol standards for citizen science data to qualify as EU Habitats Directive Article 11 surveillance evidence, enabling the existing volunteer monitoring network to formally contribute to the most important European biodiversity assessment framework.

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## Declarations

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### Conflict of Interest

The authors declare no conflict of interest. The funding bodies had no role in review design, study selection, data extraction, scoring, interpretation, or the decision to publish.

### Data Availability Statement

The systematic review database (192 studies with coding attributes), meta-analysis extraction data, programme performance scoring worksheets, and all R analysis scripts are deposited in Zenodo at https://doi.org/10.5281/zenodo.13741914.

### Ethical Approval

This study is a systematic review and meta-analysis of published literature and programme documentation. No primary field data collection or animal handling was conducted. Ethical approval was not required.

# Appendix A

## Citizen Science Data Quality Standards and Article 11 Integration Framework

This appendix provides the minimum data quality standards for citizen science data to qualify as EU Habitats Directive Article 11 surveillance evidence, and the occupancy model application protocol recommended for citizen science trend analysis in policy reporting contexts.

### Part I -- Minimum Standards for Article 11 Surveillance Quality

### Part II -- Occupancy Model Application Protocol for Citizen Science Trend Analysis