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Forum Paper

Empowering national capacity for DNA-based approach to species identification and biodiversity monitoring

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Abstract

DNA barcoding has become a cornerstone for species identification and biodiversity monitoring, enabling applications from ecological research to conservation and environmental policy. The International Barcode of Life (iBOL) provides global coordination, but national nodes are essential for implementing barcoding at scale, building local capacity and translating scientific advances into practice. This paper synthesises experiences from 20 countries (17 in Europe), drawing on a survey and a workshop conducted under the Horizon Europe Biodiversity Genomics Europe project. We examine how national nodes are initiated, governed and sustained and identify common challenges, such as defining scope, securing funding, harmonising methods and engaging stakeholders. Most nodes were initiated by research communities and operate as informal networks with heterogeneous governance and staffing models. Key priorities include constructing comprehensive DNA barcode reference libraries, aligning activities with biomonitoring needs and promoting FAIR and CARE data principles. We highlight strategies for capacity building, methodological standardisation and stakeholder engagement, alongside approaches for diversifying funding and strengthening communication. Based on these insights, we present ten practical recommendations to guide the establishment and long-term success of national DNA barcoding nodes. Strengthening these infrastructures will enhance Europe's ability to deliver robust DNA-based biodiversity monitoring, underpin metabarcoding and metagenomic studies and contribute to global efforts in species discovery, conservation and environmental management.

Key words: Capacity building, DNA (meta) barcoding, national barcoding nodes, reference libraries, science-policy interface, scientific infrastructure

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Introduction

DNA barcoding has been widely adopted for species identification and biodiversity assessment with applications ranging from fundamental research to species management and conservation (Antil et al. 2023). Recent reductions in sequencing costs and the advent of high-throughput metabarcoding pipelines have further lowered the barriers and increased the impetus for national teams to generate and share largescale DNA barcode reference libraries. Since DNA barcoding was proposed by Hebert et al. (2003), it has become a global research collaboration coordinated by the International Barcode of Life consortium (iBOL). The current programme of iBOL focuses on building a DNA-based reference library of eukaryotic life to accelerate species identification and discovery, studying the ecological interactions amongst species and laying the foundations for global DNA-based biomonitoring programmes (Box 1).

Box 1. DNA barcoding glossary.

DNA barcoding is a method of specimen-based species identification using short, standardised DNA sequences. Ideally, every species should have reference DNA barcode sequences deposited in open access repositories. Unidentified specimens can then be identified by comparing their DNA sequences with the DNA barcodes in the reference databases. The most commonly used DNA barcoding marker for animals is a ~ 658 base pair 5' fragment of the mitochondrial cytochrome *c* oxidase I (COI) gene. Standard DNA barcoding markers for other taxonomic groups, such as plants or fungi, include nuclear ribosomal genes (e.g. ITS, 18S) or plastid genes, such as *rbcL*, *matK* and *trnH-psbA* (Hollingsworth et al. 2009; China Plant BOL Group 2011; Schoch et al. 2012).

iBOL (International Barcode of Life Consortium, iBOL, http://www.ibol.org/) is a non-profit corporation and international research alliance aiming to provide a global, open-access system for the DNA-based discovery and identification of eukaryotic species by building DNA barcode reference libraries, sequencing facilities, informatics platforms, analytical protocols and the international collaboration required to inventory and assess biodiversity on a planetary scale.

iBOL Europe (iBOL-E, https://iboleurope.org/**)** is the European node of iBOL (previously named Bioscan Europe). It brings together national networks, scientists and projects working on biodiversity characterisation and monitoring in Europe and supports iBOL's vision of a comprehensive Earth observation system for biodiversity.

Barcode of Life Data Systems (BOLD) (https://www.boldsystems.org/) is a web portal and a workbench, developed to support the deposition, curation and application of DNA barcode data. BOLD is the main globally accessible platform for submitting, analysing and sharing DNA barcode data.

DNA barcoding in Europe

Since the outset of DNA barcoding, Europe has been deeply involved in DNA barcoding research developments and applications (Savolainen et al. 2005; Chase et al. 2007; Valentini et al. 2009). The early establishment of large research initiatives enabled rapid development of DNA barcode reference resources (Bonants et al. 2010; Dincă et al. 2011, 2021; Oliveira et al. 2016). The barcoding community in Europe has applied the concept across various biological contexts and disciplines, such as taxonomy (Grabowski et al. 2017, Copilaș-Ciocianu et al. 2023), phylogeography (Bozáňová et al. 2020; Rendoš et al. 2023; Rewicz et al. 2023; Dapporto et al. 2024; Królikowska et al. 2024; Mamos et al. 2024) or different subdisciplines of ecology, such as pollination or food-web ecology (Wirta et al. 2014, 2015; Roslin and Majaneva 2016; Rewicz et al. 2024). There has also been considerable activity in the field of DNA barcode biomonitoring to deliver high-throughput, cost-effective monitoring of species diversity (Buchner et al. 2025), including of species of conservation concern (Johnsen et al. 2020) and invasive species, pests and pathogens (Blackman et al. 2020; Mata et al. 2021; Rossmann et al. 2021). Moreover, DNA barcoding is increasingly applied for water quality monitoring to support the delivery of the EU Water Framework Directive (Pont et al. 2018; Kuntke et al. 2020; Blancher et al. 2022; Macher et al. 2025).

However, within Europe, considerable challenges remain. Europe is home to at least 200,000 animal and plant species (MEMO/04/27, European Commission 2004), with hundreds of species being described every year since 1950 (Fontaine et al. 2012), but still many more awaiting discovery and scientific description (Srivathsan et al. 2023). Species diversity and endemism are particularly high in southern Europe, where complex ecosystems and glacial refugia allowed the long-term persistence and accumulation of biodiversity through time (Hewitt 2000; Dapporto et al. 2024). Overall, there is a general increase in species diversity at lower latitudes (Hillebrand 2004), but this is poorly reflected in the density of DNA barcode data across Europe (Fig. 1). The effective development and growth of barcoding initiatives across Europe is therefore essential to support the construction of comprehensive reference libraries, to accelerate the discovery of new species and underpin comprehensive biomonitoring programmes.

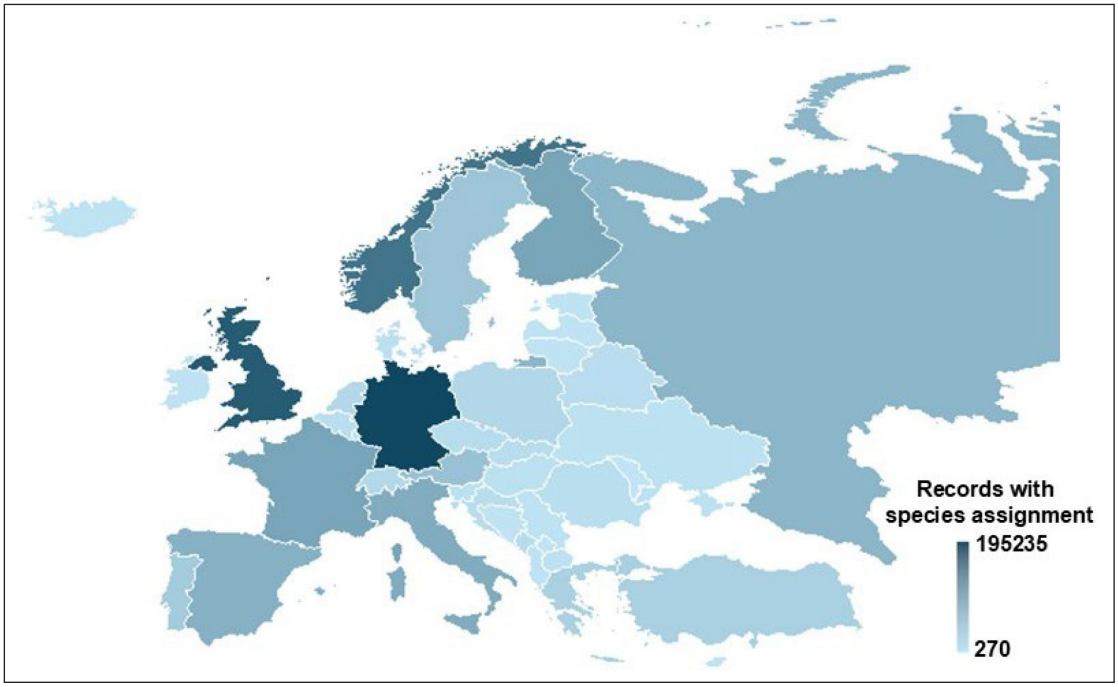

Figure 1. Heat map illustrating the heterogeneity in the number of available DNA barcode records with species assignment. Data were retrieved from the BOLD Systems data portal in November 2025 (Suppl. material 1).

National barcoding initiatives in Europe

National DNA barcoding initiatives serve as foundational pillars for organising, coordinating and scaling barcoding activities at the national level (Wirta et al. 2016; Zangl et al. 2020). In Europe, some well-established national DNA barcoding nodes have made substantial contributions to the global DNA barcode reference library, including, for example, the Finnish Barcode of Life, the Norwegian Barcode of Life (NorBOL) and the German Barcode of Life (GBOL) (Box 2). However, progress across Europe has been uneven; some countries and biodiverse regions lack established barcoding programmes and many taxonomic and geographic gaps remain in the continental DNA barcode reference library (Weigand et al. 2019; Csabai et al. 2023). Recent analyses reveal that southern and eastern European biodiversity hotspots remain particularly under represented, limiting the utility of metabarcoding for conservation assessments in these regions (Gaytán et al. 2020). This heterogeneity in progress across European states, coupled with the benefits that could arise from coordinating efforts amongst neighbouring countries, led to the development of the iBOL Europe initiative as a continental nexus for the European DNA barcoding community. One of the aims of iBOL Europe is to support the widespread development of national DNA barcoding nodes and promote complementarity in their contributions, whether through specialisation in particular workflows, technical expertise or scientific focus across taxa and habitats. Moreover, recent European Union directives — including the EU Biodiversity Strategy for 2030 (European Commission 2020) and the EU Nature Restoration Law (European Commission 2024) — as well as the upcoming EU Soil Monitoring Law (European Commission 2025), explicitly call for continent wide biomonitoring frameworks, providing additional impetus for national governments to invest in structured barcoding initiatives.

Box 2. Examples of well-established national barcoding nodes.

The **Finnish Barcode of Life** (FinBOL) is Finland's national DNA barcoding initiative and systematic efforts to build a national reference library began in 2007. FinBOL has received funding from several major national foundations and, since 2014, it has been almost continuously supported by the Research Council of Finland as part of the Finnish Biodiversity Information Facility (FinBIF) research infrastructure project. FinBOL functions primarily as a network of species experts, working towards its central goal to generate DNA barcode references for all animals, plants and fungi in Finland. To date, FinBOL has processed 155,064 samples, representing 25,037 species. Its current focus is on "dark taxa" - groups for which species-level identifications often remain uncertain.

The **Norwegian Barcode of Life** (NorBOL) is Norway's national research infrastructure for DNA barcoding and was established in 2007 and operates as a collaborative network of 16–17 biodiversity institutions. NorBOL's focus includes both Norway and the Arctic, across freshwater, marine and terrestrial ecosystems. Its taxonomic scope includes arthropods, chordates, plants, fungi, lichens and other metazoans. By the end of 2024, BOLD holds records of approximately 193,000 specimens representing 28,500 species from Norway. NorBOL's activities include hosting international conferences, publishing scientific outputs and serving as a knowledge hub for stakeholders, such as the Norwegian Environment Agency.

The **German Barcode of Life** (GBOL) was launched in 2011 as a consortium-based initiative to establish a DNA barcode reference library for Germany's biodiversity and has evolved into a comprehensive biodiversity platform that integrates taxonomy, conservation, genomics and public engagement. Its geographic focus includes Germany and neighbouring countries of Central Europe, covering freshwater, marine and terrestrial ecosystems. Over its 14-year history, GBOL has generated large volumes of barcode records, and developed robust data infrastructures and workflows for specimen curation and long-term storage. The project also serves as a hub, enabling funding for several major biodiversity monitoring projects relying on DNA metabarcoding routines. DNA barcodes have been generated for more than 650,000 specimens.

Across Europe, there are 11 countries with national DNA barcoding nodes. Although the term 'national node' has been widely used in the DNA barcoding community, it remains a loosely defined concept. The working principle is to have some mechanism for coordination, involving a chair or co-chairs taking on responsibility for coordinating activities across research institutions and acting as a point of contact between the national-level DNA barcoding activities and broader scale initiatives, such as iBOL Europe and the global iBOL programme. Beyond this principle, there has been considerable heterogeneity in how national nodes are initiated and organised, as well as the practicalities of how they operate.

Supporting the further development of national barcoding nodes in Europe

The aim of this paper is to distil the experiences and expertise from different European countries on how they established and run their national DNA barcoding nodes. This work was performed as part of the Horizon Europe-funded Biodiversity Genomics Europe project (https://biodiversitygenomics.eu/). Our motivation is to facilitate the establishment and further development of national DNA barcoding activities and networks, thus promoting communication and collaboration amongst researchers, as well as amongst researchers, research-users and other stakeholders. While acknowledging the cultural differences amongst nations and asymmetries in access to funding and institutional support, we have worked to identify key factors influencing the success of establishing a national DNA barcoding initiative. Our over-riding aim is to provide general recommendations for establishing functional national DNA barcoding nodes across diverse economic conditions and varying levels of research infrastructure. By providing such support, we envisage a progressive and phased build-up and cross-country support for the use of DNA-based species identification in Europe.

Methodology

To bring together experiences and share expertise from different European countries on how they established and sustain their national DNA barcoding nodes, we employed a two-step process. The first step involved the collation of experiences through a structured questionnaire. The second consisted of an in-person workshop, to derive key principles from the questionnaire findings.

Step 1 Survey

The questionnaire included 26 questions designed to gather information in three key areas: (i) aspects related to the establishment of a national DNA barcoding node; (ii) all the practices currently implemented to ensure effective operation and support its growth and (iii) insights into which of these practices proved most effective, as well as the challenges encountered (see Appendix 1 for the list of questions).

Our survey targeted as many countries as possible, primarily in Europe, encompassing diverse research landscapes and funding environments. The list of intended respondents included one representative from each national initiative associated with iBOL and, when more than one national lead was actively involved in coordination efforts, the survey was sent to multiple representatives. We also included representatives of initiatives in countries where barcoding programmes were still in early stages of development and not yet formalised as national BOL nodes. In total, the questionnaire was sent to 31 recipients and 20 responses were received representing 17 countries (Fig. 2). The primary target area was Europe, but we also sought input from a small number of non-European nations (please see Fig. 2). Based on the themes that emerged in responses to the survey, we partitioned the findings into five topics: i. Initiation of national nodes; ii. Governance of the nodes; iii. Scientific nature of the nodes; iv. Funding and v. Communication / dissemination actions.

Step 2 Workshop

The findings from the questionnaire were used to inform and shape the concept and key thematic areas of a three-day workshop held in 2023 at the University of Lodz field station in Spała, Poland. The event brought together 21 participants — nine of whom also completed the questionnaire— from 12 countries, along with two additional attendees who joined remotely from other countries. The workshop also included an online presentation by Paul Hebert from the University of Guelph, representing iBOL, which provided participants with valuable information on the wider strategy of iBOL in relation to national nodes. During the workshop, the survey results were presented, discussed and further complemented with new insights and ideas shared amongst the participants. The workshop included breakout groups focusing on the five aforementioned primary topics. Each breakout group identified key steps and issues for establishing and developing a functional national DNA barcoding node, based on their experiences and reflections across the different countries.

Figure 2. Countries are highlighted whose representatives of a national initiative responded to the questionnaire (yellow), attended the workshop (green) or both (yellow–green stripes). Peru and South Africa are not displayed on the map; however, representatives of their national nodes took part in the survey and the workshop, respectively.

Presentation of the findings

As the survey responses and workshop discussions included some sensitive information (e.g. funding sources and amounts, working relationships, personal data), we have distilled their findings into aggregated anonymised summary responses. The findings regarding each of the five primary topics are presented and discussed below. Where there was an overlap in the response to different topics, we nevertheless included these responses in each of the separate sections because messages that repeatedly occur underscore their importance.

Results and discussion

Since the survey included national nodes, more localised nodes and even nodes that were not yet formally established, some questions were either left unanswered or marked as 'Not applicable/I don't know.' As a result, not every question received 20 responses, which explains the inconsistencies in the total number of replies.

Initiation of national DNA barcoding nodes

Of the 17 national DNA barcoding nodes/initiatives that provided information, 16 were initiated by the research community — rather than by government agencies — and were later communicated to the relevant authorities.

Only one node was established through a collaborative effort between the scientific community and a government agency. Importantly, the majority of these nodes were initiated and developed by institutions and researchers engaged in taxonomy. This clearly highlights the central and foundational role of taxonomists in both DNA barcoding and the development of reliable DNA barcode reference libraries. In terms of funding, amongst the 18 national nodes that are either fully established or in the process of being established at the time of survey, 11 were initially funded through projects, five received direct governmental support and two were funded through both sources. In some cases, establishing a node took several months (but less than a year), as reported by five of the 14 respondents. Another five respondents indicated that the process took up to two years, while four noted that it required more than three years to establish the national DNA barcoding node. In interpreting these results, it is important to reiterate that the concept of a national node is loosely defined and, as such, the concept of 'establishment' is itself heterogeneous. As noted in the paragraph overviewing national barcoding initiatives in Europe, the minimal requirement for a node is a mechanism for coordinating activities across research institutions and acting as a point of contact between the national-level DNA barcoding activities and broader scale initiatives.

The majority (13 replies) of the national node coordinators were also the national representatives for iBOL (or became immediately after the national node establishment). However, one of the most striking results from both the survey and the workshops was that very few national node coordinators directly sought advice from already established national nodes or international initiatives before setting up their respective nodes. Instead, the decision-making process and steps taken were almost entirely based on intuition and the experience of other within-country activities, as well as their perceptions of the activities of other nations barcoding nodes.

The survey and workshop also highlighted several challenges associated with node initiation, such as: (a) the importance of clarity on the purpose and priorities of the national node; (b) the need to build trust amongst researchers working in the field of DNA barcoding and with the wider pool of taxonomic experts within the country; (c) the need to make the task of node initiation tractable and to avoid the sense of overload at the outset; (d) the difficulties with establishing effective communication to promote node cohesion and (e) the difficulties in establishing contacts and developing working relationships with government agencies and key stakeholder groups. Potential solutions to these challenges are summarised in Table 1.

Governance of national DNA barcoding nodes

There is considerable heterogeneity regarding the governance models adopted by European national DNA barcoding nodes. Of the 16 different nodes where data are available, 10 have been run as informal networks without explicit governance mechanisms, whereas six were operated under formal status (formal consortium, formal scientific network or both). Similarly, we found a great difference in the number of full- or part-time employees

Table 1. Key identified challenges and strategic solutions for establishing a national DNA barcoding node.

Challenges	Potential strategic solutions
Navigating the initial steps	**Tap into existing expertise:** Connect with colleagues from established national nodes in other countries and leverage the iBOL Europe community as a valuable source of advice and good practice.
Defining the node's scope and mission	**Establish a clear focus:** Define a clear measurable goal and initial achievable priorities for the national node. Recognise that this scope may need to evolve and be redefined over time as the initiative develops.
Building trust and an inclusive network	**Foster collaboration and inclusion:** Cultivate an inclusive network by bringing together individuals with diverse expertise, actively involving the wider taxonomic community. Clearly define roles and responsibilities early on. Identify institutional/organisational taxonomic focus areas from the outset and revise periodically. Organise regular meetings and workshops to build momentum and strengthen relationships.
Managing partner hesitation and sense of overload	**Offer flexible entry points:** Provide partners (such as independent institutes, universities or laboratories collaborating with the node) with the option to begin their involvement on a limited basis, allowing them to progressively increase their participation as they become more comfortable and capacity grows, wherever appropriate.
Establishing a cohesive and connected network	**Integrate and communicate:** Link the national DNA barcoding node to existing national biodiversity frameworks and platforms. Ensure consistent communication by keeping people informed through a dedicated website, newsletters or regular online and in-person events.
Engaging and demonstrating value to stakeholders	**Proactive engagement and impact:** Initiate dialogue with potential stakeholders early in forming the national node. Undertake pilot use-case studies to clearly demonstrate the practical value and potential applications of DNA barcoding for the stakeholder community. Be attentive to stakeholders' needs.

(ranging from 0 to 20 persons employed on activities associated with the DNA barcoding node). Overall, most initiatives operated with few staff; three initiatives having a single employee, five having 2–3 employees and five having no dedicated positions. In several cases, there was a lack of clarity about the number of staff and the proportion of their time allocated to running the national node. This uncertainty was primarily due to national nodes being run on a very informal basis. Most respondents noted that cooperation between institutional members and participants in the national DNA barcoding node was the most significant factor for a node's success.

The key challenges linked to the governance of national DNA barcoding nodes and identified during the survey and the workshop included: (a) concerns about conflicts between institutional and network priorities; (b) concerns about decision-making processes within the national node; (c) the strong possibility that the workload may be unevenly distributed amongst partner institutes contributing to the national node and (d) concerns about sample and data ownership and control. Potential solutions to these challenges are summarised in Table 2.

Table 2. Key challenges and proposed solutions for governing and organising a national DNA barcoding node.

Challenges	Potential strategic solutions
Aligning diverse /potentially conflicting institutional priorities	**Foster a collaborative ecosystem**: Establish ways of working rooted in the principle of a network where independent organisations collaborate effectively. Actively seek to maximise the complementarity of activities amongst participating organisations, leveraging unique strengths and resources (e.g. specimen collection, DNA sequencing, bioinformatics, curation, taxonomic expertise).
Setting clear expectations and operational frameworks	**Formalise collaboration**: Develop clear expectations and agreed ways of working. For example, a simple Memorandum of Understanding (MoU) can be highly beneficial in outlining the rights and obligations of partners and providing enough clarity even if the operation is informal.
Managing uneven workload distribution	**Address asymmetry and catalyse engagement**: Acknowledge that informal networks may have an unbalanced distribution of workload, often relying on the dedication of a few individuals. Utilise MoU to define roles and responsibilities clearly, helping to manage expectations. Develop activities that offer genuine benefits to members, which can encourage wider input and participation.
Ensuring effective and compliant data and sample sharing	**Establish transparent sharing protocols**: Define clear terms-of-use for data from the outset and rigorously follow the FAIR (Findable, Accessible, Interoperable, Reusable) and CARE (Collective benefit, Authority to Control, Responsibility, Ethics) data principles. Ensure that reference data are not only publicly accessible, but also enriched with standardised metadata to enhance interoperability and reusability. Clarify ownership of samples and data, ensuring appropriate Material Transfer Agreements (MTAs) are used. Promote understanding and adherence to relevant national and international legislation, such as the Nagoya Protocol on access and fair and equitable benefit sharing.

Scientific direction and approaches of the national DNA barcoding nodes

The development of a DNA barcode reference library for the species found in a country's territory was the initial and sustained focus of almost all national nodes (18/20 responses). In about half of the nodes, there was a clear focus on specific taxa or functional groups, such as pollinators, invasive or endangered species. For the other half of the nodes, all taxa within the territory were targeted without a clear initial prioritisation. The participants reported a primary focus on national representation of taxa, rather than a strong focus on the activities of neighbouring countries with regards to regional reference library representation, although the benefits of coordinated activities amongst neighbouring nations were noted. In addition, the experience of more established national nodes can support the development of emerging initiative in neighbouring countries, for example, through knowledge transfer, training and protocols and even infrastructure sharing. The importance of uploading barcode records to public repositories was stressed by participants, partly from the perspective of ensuring access and use of the data, but also from the standpoint of giving visibility to data, which allows complementarity of activities to be designed and minimising redundancy in data generation within and between countries.

In many, but not all, countries, DNA barcoding applications, such as DNA metabarcoding and environmental DNA (eDNA) research, were also a focus of the national DNA barcoding node. National nodes that were involved in DNA metabarcoding and eDNA applications, as well as reference library construction, noted the benefits in terms of local government and stakeholder interest in participating and collaborating under the initiative when a clear link is made between reference libraries and their applications to biomonitoring and topics of policy relevance.

One of the challenges that was identified was that, despite frequent close collaboration between members of the same node, there were gaps in the sharing of standard operating procedures (SOPs) for acquiring DNA barcode information (Table 3). Instead, the primary source of information for method development was often the wider scientific literature or individual institutional/research group practices. Another fundamental practical challenge identified and discussed at the workshop was the need to build local capacity in countries where DNA-based technologies in general and DNA barcoding approaches specifically, are not widely deployed or accessible. This is part of a broader global challenge in accessibility of technological capacity in biodiversity-rich countries and regions (Table 3).

Funding support for national DNA barcoding nodes

Most nodes were initiated with funding from research projects or with the support of their home universities, research centres and national foundations. In some cases, governmental financial support was provided shortly after the node's initiation. Lack of sustainability of funding was repeatedly reported as a challenge for the long-term operation of the node. Nine national nodes were reported to receive regular funding from the State, while 11 lacked direct national funding support. Furthermore, national nodes generally emphasised that securing funding for the construction of reference libraries is more challenging than obtaining support for applications that depend on these resources, such as DNA metabarcoding and eDNA analyses (Table 4).

Table 3. Setting the scientific direction: key challenges and potential solutions for national DNA barcoding nodes.

Challenges	Potential strategic solutions
Building a comprehensive national DNA barcode reference library	**Strategic library construction**: Prioritise collecting and DNA barcoding taxa of critical importance for national biomonitoring efforts, legal obligations and other high-impact applications. This focused approach helps build a stronger case for investment in reference library construction. Actively align efforts and share data with neighbouring countries and international networks to reduce redundancy and accelerate progress towards a complete national library. Natural history museums and private collections play a critical role in constructing a comprehensive reference library, as they provide access to holotypes and other reference specimens necessary for generating DNA barcodes, thereby ensuring taxonomic accuracy and stability.
Aligning scientific output with stakeholders' needs	**User-centric development**: Recognise that gaps in the reference library are a significant barrier to the broader adoption and effective interpretation of DNA-based biomonitoring. Filling these gaps can form a primary scientific focus. Foster direct connections and maintain ongoing dialogue between the researchers building the reference library and the users (e.g. those involved in DNA-based biomonitoring) to ensure the underlying reference resources meet user requirements and needs.
Ensuring methodological consistency and data standards	**Standardisation and harmonisation**: Implement and widely share Standard Operating Procedures (SOPs) amongst all partners within the national network. This promotes common data standards (e.g. Rimet et al. (2021); Heil et al. (2026)), consistent data protocols and ensures high data quality. Maintain active dialogue with other countries and broader international networks (e.g. iBOL Europe, iBOL) to harmonise methods and approaches. Conduct targeted training events for both researchers and citizen/community scientists on SOPs, covering the entire workflow from sample collection to data analysis.
Strengthening capacity and expertise	**Collaborative capacity building**: Develop strategic partnerships to support training and capacity building. Facilitate the sharing of expertise amongst participating institutions and capitalise on the complementary skills available across the network to elevate overall scientific capability. A stronger emphasis on supporting taxonomy, including dedicated efforts to train and support the next generation of taxonomists should be taken into consideration. Skilled taxonomists are increasingly difficult to find and the field is facing a decline in both expertise and institutional support; thus, this is a pressing concern for the future (Engel et al. 2021; Hochkirch et al. 2022).
Ensuring access to sequencing infrastructure	**Optimising access to facilities**: Develop collaborations and formal agreements amongst institutions to facilitate effective access to sequencing facilities. Explore opportunities for institutions to work together to secure bulk purchase discounts on consumables for national initiatives. Investigate the feasibility of establishing a dedicated national facility, considering the increasing availability and efficiency of low-cost sequencing platforms optimised for DNA barcoding (e.g. as discussed by Hebert et al. (2025)).

Table 4. Funding the future: challenges and strategies for sustaining national DNA barcoding nodes.

Challenges	Potential strategic solutions
Securing and sustaining government funding	**Demonstrate national value and relevance**: Focus national DNA barcode node activities on topics and taxa of evident national importance and priority (e.g. endemic species, pollinators, environmental indicators, pests, invasives, threatened species, environmental health indicators, legally protected). Develop "Flagship Projects" showcasing the capacity of DNA barcoding to achieve national goals in biomonitoring, conservation and environmental protection to attract government collaboration and funding support.
Diversifying and expanding funding sources	**Explore a broad funding landscape**: Actively seek funding opportunities across multiple scales (international, national, regional) and from diverse sources. Look beyond traditional government grants to include the private sector, environmental agencies, foundations and philanthropic organisations. Leverage international networks for broader opportunities. Build internal capacity for successful proposal writing through training and mentoring. For applied projects, strategically include costs necessary to support the development and maintenance of essential infrastructure including reference libraries.

Communication/ dissemination actions for national DNA barcoding nodes

The primary means of communication used by most active national DNA barcoding nodes was hosting conferences, symposia and/or workshops, with some nodes running these on an annual basis. Many nodes (10/20) have well-maintained websites which provide information on the node's goals, the people involved and their expertise and opportunities for participation, with a general aim of facilitating involvement and engagement (examples of national DNA barcoding initiative websites include https://bolgermany.de/home/, www.norbol.org, https://www.finbol.org/, https://www.abol.ac.at/en/homepage_en/, https://www.polbol.uni.lodz.pl/ and https://www.ukbol.org/). Participants highlighted the potential of these websites to engage citizen/community scientists in contributing samples for DNA barcode reference libraries, acknowledging that access to expertly verified material is often a key limiting factor in reference library development.

The GBOL (https://gbol.bolgermany.de/en/german-barcode-of-life-2/) and NorBOL (https://www.norbol.org/en/) portals are strong examples of national node web-sites that serve not only as information hubs, but also as active enablers of biodiversity research and outreach (Box 2). Their comprehensive websites effectively support their missions by informing and engaging both researchers and citizen/community scientists. They facilitate communication, enhance collaboration and improve access to biodiversity data not only to the broad scientific community, but also to society. The GBOL webpage acts also as a practical tool for facilitating sample collection and submission by citizen/community scientists. Through the portal, participants can request sampling materials, download and complete standardised collection tables and upload them directly. A cover letter for shipping is automatically generated to be used with the sample package. When available, a prepaid return voucher further streamlines logistics, making the entire process accessible and efficient for contributors.

Social media accounts were used by seven nodes and, in some cases, physical advertising methods (e.g. banners) were occasionally produced to raise the profile of the node at events. An example of a newly-developed national node that effectively combined social media outreach with official institutional announcements during its launch is the Bulgarian node (BgBOL), with a similar approach taken by the Greek node (GrBOL). The iBOL and iBOL Europe websites also played an important role in supporting this outreach and increasing visibility.

Beyond social media and digital platforms, direct engagement is crucial for fostering a robust national barcoding network. This involves organising in-person events and proactively reaching out to potential collaborators. A good example of such a strategy is the recently established Polish node (PoLBOL). PoLBOL actively builds its network by participating in national biodiversity conferences, delivering lectures, coordinating and participating in citizen-science initiatives, including those held in protected areas and organising workshops on DNA-based approaches to biodiversity for the scientific staff of national parks. It further extends its reach by connecting with citizen-science groups composed of non-professional taxonomic experts to build reliable reference libraries.

In general, the communication-related challenges that were identified included: (a) the need to raise the profile of the work of the national node; (b) the challenges of keeping the community updated with news and activities; (c) servicing the communication required to maintain active engagement from participants and (d) a more general challenge around communication strategy and resourcing. Potential solutions to these challenges identified during the survey and workshop are summarised in Table 5.

Summary

We have distilled the findings from the survey and workshop that are outlined and discussed throughout the text into ten key headline recommendations (Box 3). These recommendations are intended to guide both existing and emerging national node teams in the effective establishment and long-term success of DNA barcoding infrastructures across Europe.

Table 5. Communication strategies: challenges for community awareness and connectivity and solutions to overcome them.

Challenges	Potential strategic solutions
Increasing node visibility and profile	**Build online presence**: Develop a website for the national node; even a basic page provides vital information on its existence, participants, status and contact points. **Leverage international networks**: Register with the International Barcode of Life (iBOL) and provide content for the iBOL Europe website and channels to amplify visibility into the broader community. **Create accessible promotion tools**: Prepare easily usable communication materials (e.g. summary slides, graphics) that can be readily shared at scientific conferences and events.
Maintaining community awareness and progress updates	**Ensure consistent information flow**: Organise events and engagement activities, capitalising on cost-effective and inclusive online meetings when in-person events are challenging. Consider producing a regular newsletter or similar communication format to keep the entire community informed about developments and progress.
Fostering continuous engagement of institutions and citizen/community scientists	**Prioritise feedback and recognition**: Recognise that providing timely and consistent feedback to contributors is crucial for maintaining participation. Ensure rapid and thoughtful responses to key participants and collaborators. **Implement Proactive Communication**: Use regular online news postings and updates to keep the community engaged. Pay attention to informing and activating citizen/community scientists. Proactive communication can save time by maintaining engagement and reducing the need for reactive, time-consuming individual responses by email. Ensure contributors' work, including that of citizen/community scientists, is appropriately acknowledged and recognised in all communications.
Addressing resource constraints and communication strategy gaps	**Allocate dedicated resources**: Where possible, within funding proposals, include a specific resource request for essential communication activities. **Develop a tailored strategy**: Create a communication strategy for the national node. This plan should be proportional to the node's activities and budget; even a 'light-touch' strategy is valuable for guiding communication efforts effectively, especially on restricted budgets.

Box 3. 10 key recommendations for success in establishing DNA barcoding national nodes in Europe.

• **Consult experienced nodes and the international community**: Seek advice from established national nodes in other countries and utilise the iBOL Europe community for guidance when starting and developing national nodes.

• **Define scope and mission**: Clearly define the mission and priorities for the national node early on, acknowledging that these may evolve over time. Nodes can start small and scale-up as capacity and needs increase.

• **Build trust and inclusivity**: Foster an inclusive network by bringing together individuals with diverse expertise, including the broader scientific community and citizen/community scientists. Bring the key participants in the national community together to develop a shared vision, including DNA barcoding experts, taxonomists and key national biodiversity infrastructures. Clearly identify roles, responsibilities and expected benefits of participation early-on to build trust.

• **Establish governance (even informally):** Implement clear ways of working, potentially through a basic MoU, to outline partner rights and obligations, even if the node operates informally. This helps manage expectations and addresses potential conflicts or workload distribution issues.

• **Ensure data sharing and FAIR and CARE principles**: Establish clear terms for data use from the outset, adhering to FAIR and CARE data principles and emphasising the goal of producing public reference data. Ensure awareness of sample/data ownership and relevant national and global legislation like the Nagoya Protocol.

• **Prioritise reference library goals**: Focus on building a high-quality curated national DNA barcode reference library, prioritising taxa important for biomonitoring or other national needs to build support for continued investment. Coordinate with neighbouring countries to reduce redundancy.

• **Align with stakeholder needs**: Ensure the node's activities, particularly reference library development, align with the needs of stakeholders, such as regulatory agencies and other users involved in DNA-based biomonitoring and other policy-relevant topics.

• **Standardise methods and build capacity**: Promote the development, sharing and adoption of SOPs amongst partners to ensure data quality, consistency and comparability. Encourage the systematic adoption of common data standards. In parallel, foster strong partnerships focused on training and capacity building, especially where DNA-based technologies are less accessible. This collaborative approach will help standardise methodologies, enhance technical skills and support equitable participation.

• **Secure sustainable funding**: Actively seek funding from diverse sources (State, research projects, international/regional grants, private sector) by focusing activities on topics of national importance and demonstrating value for biomonitoring, conservation or environmental protection. Where possible, embed underpinning costs for reference library development into project proposals that have a focus on applications, such as biomonitoring.

• **Develop a communication strategy**: Create channels like a website, newsletters and events (online or in-person) to raise the node's profile, keep the community updated, maintain engagement and acknowledge contributions. Register the node with international bodies like iBOL and iBOL Europe for wider visibility.

Concluding insights and future directions

DNA barcoding and associated methods have become indispensable tools for biodiversity research and monitoring and sustainable management (Hajibabaei et al. 2016; Elías-Gutiérrez and Valdez-Moreno 2023). In Europe, the DNA barcoding research community has some unique opportunities. Europe hosts a wealth of biodiversity collections across the

numerous national natural history museums, botanical gardens and biodiversity research centres, which provide unprecedented resources to advance the development of barcode reference libraries. Furthermore, the hundreds of years of studies on European biodiversity have resulted in other extensive baseline resources, including checklists and catalogues of flora and fauna in most countries. Thus, Europe benefits from a concentration of taxonomic and ecological expertise that, although heterogeneously distributed, is crucial for reference library development and the interpretation of DNA barcoding data. This expertise is further reinforced by the extensive citizen/community science networks and a pan-European citizen/community science association (Corrales et al. 2025).

The rapid pace of technological developments in DNA sequencing provides further opportunities for DNA barcoding and biodiversity characterisation in Europe. Major sequencing facilities, such as the Centre for Biodiversity Genomics (University of Guelph, Canada), have capitalised on the massive power of high-throughput sequencing machines for extremely high-throughput DNA barcoding, for example, using the PacBio single molecule, real-time sequencing approach (DeWaard et al. 2019). An additional breakthrough for the DNA barcoding community, that is particularly relevant to national DNA barcoding programmes in Europe, is the increasingly widespread use of the low-cost and highly portable nanopore sequencing platforms developed by the Oxford Nanopore Technology (Srivathsan and Meier 2024). This approach allows routine processing of large numbers of samples for DNA barcoding at a low-cost entry point, increasing the accessibility to projects and national initiatives operating on a limited resource base (Hebert et al. 2025). Looking ahead, integrating portable nanopore workflows with automated bioinformatics pipelines and AI-driven species-identification tools, will further reduce turnaround times and enhance real time biodiversity surveillance across diverse European habitats (Munro et al. 2023).

To maximise the benefits of the opportunities outlined above and to further support the application of DNA barcoding in Europe, building capacity in the national and regional contexts is crucial (Seidl et al. 2021). National nodes play a central role in capacity building, while collaboration amongst nodes — supported by regional initiatives such as iBOL Europe — provides an efficient mechanism for further sharing expertise (Hollingsworth et al. 2026). As DNA-based approaches are increasingly incorporated into routine practice, equitable access to skills and infrastructure will be essential to avoid the emergence of technological divides and to support scalable, standardised biodiversity characterisation. This need is particularly acute in biodiversity-rich countries with limited financial or technical resources. National-level organisation provides a critical foundation for addressing these challenges, complemented by strong cross-border connectivity. A coordinated network of national nodes will enable the sharing of expertise, the development of capacity in sampling, taxonomy and emerging sequencing and informatics technologies, the curation of high-quality barcode reference libraries and the delivery of applied DNA-based monitoring programmes. Beyond these direct capacity benefits, embedding DNA barcoding and biodiversity genomics within the broader European Research Infrastructure landscape will offer significant opportunities for synergy and long-term

sustainability in biodiversity monitoring and assessment (Hollingsworth et al. 2026). We hope that the experiences and observation synthesised in this paper contribute towards this goal and that the resulting recommendations prove useful in serving the community and supporting the development and the growth of national and European DNA barcoding capacity as well as provide inspiration for other regions of the world.

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Appendix 1

Table A1. Questions under each of three categories in the questionnaire.

Section	Question
A	**General information regarding the national node establishment**
A1	What were the things that worked best/that made a positive difference during the node development?
A2	Which were the biggest obstacles to node development progress?
A3	What was the original purpose of creating the node (e.g. building a barcode library of local biota for biomonitoring, formal acknowledgement from the State, application for funding/research projects, popularising DNA-barcode-based research, any other)?
A4	Does the node focus purely on reference libraries, or does it encompass DNA metabarcoding and eDNA applications?
A5	Did the national node initial group become the national representative of international DNA barcoding initiatives (iBOL, BIOSCAN Europe) before starting the initiative?
A6	Did you ask any other already established initiative for advice before setting up the national node and if yes, which one?
A7	What is the formal status and operational structure of the national initiative (e.g. formal consortium or formal scientific network, informal network/group of scientists/institutions or any other)?
A8	What is the requested/real commitment from the partners in the national DNA barcoding initiative?
A9	How did it start (e.g. the research community made the start and then applied for support to the State or the State made the start and asked the support of the research community)?
A10	How much time did it take for the national node to be created (months/years?)
A11	When was the national node created (e.g. date, year)?
A12	How was the initiative funded? Was there any initial financial contribution by the government?
A13	Is there, today, any regular funding from the State or is it possible to apply for such funding from the State?
A14	Does the national node apply as a whole consortium for external financing at EU level or are applications based on the expertise of different research groups?
B	**Information regarding the scientific information of the node**
B1	Are there any SOPs (Standard Operating Procedures) established? If yes, how were they chosen? How does formal cooperation with institutions/universities work (e.g. delivering specimens for DNA barcoding by museums)? Are there any official agreements?
B2	How many people are working for the node tasks permanently (full-time employees or part-time employees)? Are they funded from the node or funded by external sources?
B3	Does the national node announce any projects of its own? Has the node the capability of offering to fund some DNA barcoding-related research (for students/early career scientists etc.)?
B4	Is there an estimated percentage of national biodiversity already covered (barcodes generated in the country, progress since the initiative started), either as whole or for specific taxonomic groups?
B5	Does the node set specific aims regarding specific taxa (e.g. alien species), ecological groups (e.g. pollinators) and total biodiversity coverage?
C	**Scientific community/public awareness of the node - outreach plan**
C1	Are there any national DNA barcoding conferences/symposia/workshops organised?
C2	What is the level of engagement in citizen science? If yes, how do citizen scientists contribute to the initiative?
C3	What is the interaction between the national initiative and the stakeholders (informed, consulted, involved and collaborating)?
C4	Is there a specific website for the national node? Which is the link? What was the rationale behind building this site (who is the predicted user, what content is to be published and how often)?
C5	Were there specific outreach actions to communicate about the national node (e.g. via TV, newspapers, discussion or thematic groups in social media)?
C6	Are there any physical advertisements of the node (e.g. banners in the institution, labels on cars etc.)?
C7	Do you have any other advice on how to attract publicity?

Supplementary material 1

Questions under each of three categories in the questionnaire

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Data type: xlsx

Explanation note: Questions under each of three categories in the questionnaire distributed among the leaders of national DNA barcoding nodes.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Artificial Intelligence (AI) use

Regarding the use of AI in the preparation of this manuscript, the authors declare the following:
Some language editing.

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Conceptualization: EK, AT, MG, KBS, TM, SF, SH, WPGC, TE, BP, EK, BR, LD, BKS, PMH, SK, GD, ŁT, TR, PG. Data curation: SH, PG, KG, EK. Formal analysis: EK, PG, KG. Funding acquisition: GD, PMH. Investigation: EK, AT, MG, PG, PMH. Methodology: EK, WPGC, PMH, PG, MG. Project administration: SH, KF, GD. Resources: GD, AT, MG, PMH. Supervision: MG, AT, PMH. Validation: WPGC, MG, AT, KF, KBS, MM, PMH. Visualization: EK. Writing - original draft: EK, MG, PG, PMH, WPGC, AT. Writing - review and editing: SP, AJ, GT, CB, SK, NUS, BKS, MBDK, BR, LD, BP, SF, EK, TE, RR, ŁT, TR, PG, MK, FOC, WPGC, RLR, FAA, KG, FČ, MG, PDNDH, KBS, TM, KF, MVDB, AH, MG, IK, MM, TL, AT, EK, GB, PMH, GD.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.