Next-generation monitoring & mapping tools to assess marine ecosystems & biodiversity

Deliverable D4.3

Guidelines for developing NEMO-Tools CS projects

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Executive Summary

This deliverable presents comprehensive guidelines for developing and managing citizen science (CS) projects aligned with NEMO-Tools principles, addressing the critical need for standardized methodologies that uphold scientific rigor, policy relevance, and environmental standards while effectively engaging diverse stakeholder communities in marine conservation monitoring. Drawing on established best practices, knowledge exchange with the Aristotle University of Thessaloniki (AUTH) Citizen Science Hub, and operational experience from three innovative pilot projects, this work provides a structured framework supporting the establishment of robust citizen science initiatives capable of generating credible scientific knowledge and fostering meaningful public participation in addressing Mediterranean marine conservation challenges. This deliverable fulfills Task 4.3 objectives by providing methodological guidance highlighting main aspects of establishing and running citizen science projects, mapping the national citizen science landscape to identify good practices revealing success factors and barriers, documenting pilot project design and implementation through AUTH CS Hub, and establishing foundations for supporting selected initiatives with technical expertise ensuring compliance with NEMO-Tools operational principles. The guidelines, pilot projects, and landscape analysis collectively constitute a comprehensive resource supporting development of effective, inclusive, and impactful citizen science programs advancing marine conservation through novel methods, technologies, and stakeholder engagement approaches.

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1. Introduction

Citizen science has emerged as a transformative approach to environmental research and monitoring, offering new opportunities to bridge the gap between scientific knowledge production and public engagement (Bonney et al., 2009). Defined as the involvement of non-professional volunteers in scientific research, from data collection and analysis to interpretation and dissemination, citizen science makes scientific research accessible to the general public while expanding the spatial and temporal scales of data acquisition (Shirk et al., 2012; Hecker et al., 2018). Citizen science programs have increased dramatically in recent years (Conrad & Hilchey, 2011), as a mechanism for addressing complex environmental challenges that require large-scale, sustained monitoring efforts beyond the capacity of traditional academic or governmental research (Dickinson et al., 2012).

The marine realm presents a compelling case for citizen science engagement, given both the critical importance of ocean and coastal ecosystems and the significant challenges inherent in their monitoring and conservation (Thiel et al., 2014). Marine and coastal environments support diverse habitats and provide essential ecosystem services, including climate regulation, food provisioning, carbon storage, nutrient cycling, and coastal protection (Worm et al., 2006). Yet these systems face unprecedented pressures from climate change, pollution, overfishing, habitat destruction, and invasive species (Halpern et al., 2008; IPCC, 2019). Developing and implementing robust marine biodiversity monitoring programs is paramount for assessing ecosystem health, quantifying human impacts, and guiding evidence-based conservation strategies. The vastness of marine environments, combined with their dynamic nature and the technical complexity of marine research, creates substantial logistical and financial barriers to comprehensive scientific monitoring (Cigliano et al., 2015). Citizen science offers a pragmatic solution to these constraints by mobilizing networks of volunteers who can contribute observations across broad geographic areas and extended time periods, generating datasets that would be prohibitively expensive or logistically impossible for professional researchers to collect independently (Thiel et al., 2014; Pocock et al., 2017).

Beyond data collection, marine citizen science serves multiple interconnected functions that enhance both scientific outcomes and societal benefits. Participation in citizen science projects has been shown to increase environmental literacy, foster stewardship attitudes, and strengthen the role of communities in addressing environmental problems (Haywood et al., 2016; Cerrano et al., 2017). In the marine context, citizen scientists contribute to monitoring biodiversity, tracking invasive species, assessing pollution levels, documenting climate change impacts, and evaluating the effectiveness of conservation interventions (Thiel et al., 2014; Martin et al., 2016). Furthermore, citizen science can strengthen the science-policy interface by generating locally relevant data that informs marine spatial planning, fisheries management, and conservation policy (McKinley et al., 2019; Hyder et al., 2015).

Despite its considerable potential, marine citizen science faces several challenges that must be addressed to ensure scientific rigor, participant engagement, and meaningful conservation outcomes. Data quality remains a primary concern, as variations in observer experience, sampling effort, and species identification skills can introduce biases and uncertainties that compromise dataset validity (Kosmala et al., 2016; Aceves-Bueno et al., 2017). Ensuring adherence to standardized protocols, providing adequate training, and implementing quality assurance mechanisms are therefore essential but resource-intensive requirements (Wiggins et al., 2011). Volunteer recruitment and retention present additional challenges, particularly for marine projects that may require specialized skills such as SCUBA diving, boat operation, or taxonomic expertise, or that demand sustained participation over extended periods (Thiel et al., 2014; Martin et al., 2016). Geographic and demographic biases in participant recruitment can result in spatially or temporally uneven sampling, limiting the representativeness and analytical utility of collected data (Dickinson et al., 2012).

Addressing these concerns has become a primary focus in the field, leading to substantial advancements. These include the development of frameworks that encompass clear research objectives aligned with conservation priorities, robust and standardized data collection protocols, accessible training materials and ongoing support mechanisms, transparent data management and quality control procedures, effective communication strategies that provide feedback to participants, and pathways for translating findings into policy and management applications (Bonney et al., 2009; Shirk et al., 2012). These steps have substantially improved the quality and consistency of data, strengthened the academic credibility of marine citizen science projects (Sandahl & Tøttrup, 2020), and facilitated their integration into conservation management frameworks and policy development (Cheung et al., 2022). By synthesizing best practices from existing initiatives, evaluating novel engagement methods and technological tools, and systematically assessing both success factors and barriers, it becomes possible to establish citizen science projects that generate scientifically credible data, foster meaningful public participation, and contribute substantively to marine conservation objectives.

2. Guidelines for initiating and managing a citizen science project

Successfully establishing and managing a citizen science project requires careful consideration of multiple interconnected dimensions that span the entire project lifecycle, from initial conceptualization through implementation to long-term sustainability and impact assessment. The guidelines for establishing and managing a citizen science initiative created within the Nemo-Tools project present a comprehensive framework organized into seven core thematic areas: Basics, Participation, Engagement, Data Collection, Data Management, Technical Tools, and Evaluation, each addressing critical questions that project coordinators must consider to ensure their initiatives uphold scientific rigor, maintain policy relevance, meet environmental standards, and effectively engage diverse stakeholder communities.

2.1. BASICS (FOUNDATIONAL PROJECT DESIGN)

The foundation of any successful citizen science initiative rests upon clearly articulated objectives that align scientific research questions with societal needs and conservation priorities. Project designers must begin by defining the initiative's primary aim and specific research questions while explicitly identifying the environmental or scientific issues being addressed. This foundational clarity serves multiple purposes: it provides direction for methodological choices, facilitates communication with potential participants and stakeholders, and establishes criteria against which project success can ultimately be evaluated (Wiggins et al., 2011; Shirk et al., 2012).

Equally important is articulating how the project contributes to broader scientific understanding or generates societal benefits, and identifying who will benefit from project outcomes. Marine citizen science projects, for instance, may simultaneously contribute to biodiversity monitoring, inform marine spatial planning decisions, enhance participants' environmental literacy, and strengthen community connections to coastal ecosystems (Cigliano et al., 2015; McKinley et al., 2019). The spatial and temporal scale of the project must be deliberately chosen based on available resources, target audience characteristics, research objectives, and the ecological scale at which the phenomenon of interest operates.

Resource planning constitutes another critical foundational element. Project coordinators must realistically assess the financial, human, and technological resources required throughout the project timeline, from inception through data collection, analysis, dissemination, and archiving. This includes not only core research team capacity but also resources needed to support participant recruitment, training, ongoing engagement, data management infrastructure, and quality assurance mechanisms (Bonney et al., 2009). Understanding what benefits participants will gain, whether educational opportunities, skill development, social connections, or contributions to meaningful conservation outcomes, helps shape engagement strategies and ensures that projects deliver value to volunteers who donate their time and effort (Haywood et al., 2016).

2.2. PARTICIPATION

The architecture of citizen participation fundamentally shapes project feasibility, data quality, geographic coverage, and ultimate impact. Projects must clearly define their target participant demographics, determining whether recruitment will be open to anyone or focused on specific communities, age groups, or individuals with particular skills or access to certain environments (Thiel et al., 2014). Marine citizen science projects involving SCUBA diving, for instance, necessarily target participants with diving certification, while coastal monitoring programs can engage broader audiences including families and school groups (Martin et al., 2016).

Central to participation design is specifying the roles citizens will play throughout the research process. The spectrum of participation models ranges from contributory projects, where volunteers primarily collect data according to researcher-designed protocols, to collaborative projects involving citizens in multiple stages including question refinement and data interpretation, to co-created projects where communities participate in most or all aspects of project design and implementation

(Shirk et al., 2012). Each model presents distinct advantages and challenges regarding data quality, participant learning outcomes, project complexity, and resource requirements.

Practical participation parameters must be explicitly defined, including the specific activities citizens will perform, their frequency, the time commitment required, and any associated costs or resource requirements. Transparency about these expectations helps potential participants make informed decisions about joining while enabling project coordinators to develop appropriate support mechanisms (Dickinson et al., 2012). Projects should also establish systems for recognizing and valuing participant contributions, whether through acknowledgment in publications, feedback on how their data contributes to findings, certificates of participation, or opportunities for skill development and networking.

Understanding and addressing barriers to participation is essential for ensuring inclusive and representative volunteer engagement. Barriers may include financial constraints (equipment costs, travel expenses), temporal limitations (work schedules, other responsibilities), physical accessibility challenges, language barriers, or lack of relevant knowledge or skills (Cigliano et al., 2015). Successful projects proactively identify potential barriers and implement strategies to reduce them, such as offering flexible participation schedules, developing multilingual materials, or creating varied participation opportunities accommodating different expertise levels.

2.3. ENGAGEMENT STRATEGIES

Sustained participant engagement represents one of the most significant challenges in citizen science, with many projects experiencing substantial participation decline over time (Rotman et al., 2012). Effective engagement begins with strategic recruitment that employs diverse channels (e.g. social media, community organizations, educational institutions, environmental groups, local media) to reach target audiences with compelling messaging about the project's purpose, importance, and opportunities for meaningful contribution (Thiel et al., 2014).

Comprehensive training and ongoing support systems are fundamental to maintaining data quality while empowering participants to contribute confidently and competently. Training approaches may include in-person workshops, online learning modules, instructional videos, field demonstrations, mentoring relationships, and reference materials such as species identification guides or equipment operation manuals (Bonney et al., 2009). The depth and format of training should align with the complexity of tasks, the expertise levels of participants, and the project's data quality requirements. Marine projects involving species identification, for example, may require extensive training in taxonomic characteristics, whereas projects using automated sensors primarily need training in proper equipment deployment and data upload procedures.

Retention strategies extend beyond initial training to encompass ongoing communication, feedback loops, community building, and opportunities for participants to see the impact of their contributions (Haywood et al., 2016). Regular updates on project progress, research findings emerging from collected data, and stories highlighting how citizen-generated information influences conservation decisions help maintain motivation and demonstrate that volunteer efforts are valued. Creating communities of practice through online forums, regular meetups, or social media groups fosters peer support, knowledge sharing, and social connections that enhance the participant experience beyond individual data collection activities.

Standard protocols and guidelines serve dual purposes of ensuring methodological consistency while providing participants with clear instructions for their activities. Well-designed protocols balance scientific rigor with accessibility, breaking complex procedures into clear steps, using visual aids and examples, and anticipating common questions or challenges (Wiggins et al., 2011). For marine monitoring projects, protocols might specify survey timing, transect lengths, identification criteria, recording formats, and quality control procedures. Making protocols available in multiple formats, such as printed field guides, mobile applications and video demonstrations, accommodates diverse learning preferences and field conditions.

2.4. DATA COLLECTION

The scientific value of citizen science initiatives depends fundamentally on the quality, relevance, and utility of collected data. Projects must clearly specify what types of data will be collected (e.g. quantitative measurements, species observations, photographic documentation, environmental parameters, temporal patterns) and explicitly connect these data types to research objectives (Kosmala et al., 2016). This alignment ensures that volunteer efforts generate information capable of addressing the project's scientific questions while avoiding unnecessary data collection that burdens participants without analytical purpose.

Tool and technology selection profoundly influences data quality, participant experience, and project scalability. Options range from traditional paper datasheets and field guides to smartphone applications, GPS-enabled devices, underwater cameras, portable water quality sensors, and other specialized equipment (Bonney et al., 2009). Technology choices should consider participant access and digital literacy, data collection environments (including connectivity constraints in marine and coastal settings), required data precision, and integration with data management systems. Providing clear guidelines or templates for data submission, including data format specifications, required fields, acceptable value ranges, and submission procedures, reduces errors and facilitates efficient data processing.

Data validation and quality assurance mechanisms are essential for ensuring dataset credibility and scientific utility. Multi-layered approaches to quality control may include automated validation checking for impossible values or inconsistent entries, expert review of submitted observations (particularly for rare species or unusual findings), cross-validation through multiple observers or repeated measurements, photographic verification, statistical outlier detection, and calibration exercises comparing volunteer and expert measurements (Wiggins et al., 2011; Kosmala et al., 2016). Designating clear responsibility for data quality oversight, whether through dedicated project staff, expert volunteers, or automated systems, ensures systematic attention to validation throughout the data collection period.

Establishing control measures that ensure objectivity and reproducibility strengthens the scientific credibility of citizen science data. These may include standardized observation conditions, calibrated equipment, blind validation procedures, random resampling by experts, and comprehensive metadata capture documenting observation circumstances, observer identity, environmental conditions, and any factors potentially affecting data quality (Aceves-Bueno et al., 2017). Transparent reporting of validation results, including measures of inter-observer reliability and known sources of uncertainty, allows data users to appropriately interpret findings and assess fitness for particular analytical purposes.

Progress tracking and reporting mechanisms serve both internal project management functions and external accountability requirements. Regular monitoring of participation rates, geographic coverage, data submission volumes, validation outcomes, and emerging patterns enables adaptive management, identifies training needs or protocol refinements, and documents project activities for funders and stakeholders (Shirk et al., 2012). Determining how updates and findings will be shared with participants and the broader public (e.g. through newsletters, social media, community meetings, scientific publications, policy briefs, interactive visualizations, or other formats) ensures that knowledge generated through citizen science reaches diverse audiences and fulfills commitments to transparency and reciprocal communication.

2.5. DATA MANAGEMENT

Robust data management systems are fundamental to citizen science projects, ensuring that volunteer-generated data are appropriately stored, processed, analyzed, and preserved for long-term accessibility and reuse (Bowser et al., 2014). Data management planning must address technical infrastructure for secure storage with appropriate backup systems, workflows for data ingestion and quality control, analytical capabilities aligned with research objectives, and archival solutions ensuring long-term preservation. The anticipated volume and formats of accumulated data should guide infrastructure choices, as projects may generate hundreds to millions of records in formats ranging from structured databases to images, audio recordings, or sensor time series.

Data ownership and intellectual property considerations require explicit articulation, particularly given that citizen science involves collaborative knowledge production across diverse contributors. Clear policies should specify who holds rights to collected data, how citizen scientists will be acknowledged in publications and derivative products, what permissions are granted for data reuse, and how attribution will be managed. Many projects adopt open data principles that make datasets publicly accessible while ensuring appropriate credit to contributors, though some contexts may require restricted access for sensitive information such as endangered species locations.

Accessibility policies should define the degrees to which data will be publicly available, including options for direct download, visualization through web interfaces, API access for programmatic queries, and integration with broader data repositories or biodiversity databases (Bowser et al., 2014). Protocols concerning data availability duration are particularly important for ensuring long-term scientific utility, with best practices advocating for permanent archiving in established repositories rather than project-specific websites that may become inaccessible after funding ends.

Compliance with FAIR principles (Findable, Accessible, Interoperable, Reusable) enhances the value of citizen science data for ongoing research, education, and policy applications (Wilkinson et al., 2016).

2.6. TECHNICAL PLATFORM

For projects employing digital platforms or mobile applications, careful attention to technical design directly affects participant experience, data quality, and project sustainability. Platform purpose must be explicitly defined, whether focused primarily on data collection, participant engagement and communication, data visualization and exploration, educational content delivery, or combinations of these functions (Sturm et al., 2017). Understanding primary user groups either citizen scientists, professional researchers, policymakers, educators, or the general public, helps prioritize features and design user interfaces appropriate for diverse technical competencies and access contexts.

Functional requirements for marine citizen science platforms often include geolocation capabilities for spatially explicit data collection, offline data collection with subsequent synchronization to accommodate field environments with limited connectivity, mapping and geotagging features for visualizing observation locations and spatial patterns, image upload and annotation tools, species identification aids, real-time data validation feedback, and social features enabling participant interaction and community building (August et al., 2015). Technical implementation decisions regarding programming languages, frameworks, database systems, hosting infrastructure, and security protocols should be informed by development team expertise, anticipated user volumes, integration requirements with external tools including AI models for image recognition or data validation, scalability needs, and long-term maintenance considerations.

User onboarding and support mechanisms significantly influence participant adoption and sustained engagement. Effective platforms incorporate intuitive interfaces requiring minimal instruction, contextual help features and tooltips, comprehensive tutorials or FAQs, demonstration videos, and responsive technical support channels (Newman et al., 2012). Accessibility considerations are essential, including compatibility across devices (smartphones, tablets, computers), responsive design adapting to different screen sizes, language localization options, and accommodation of users with disabilities through features such as screen reader compatibility and alternative text for images.

Examining existing citizen science platforms provides valuable insights into design patterns, technological solutions, and lessons learned. Successful marine citizen science platforms such as iNaturalist for biodiversity observations, Marine Metre Squared for coastal biodiversity monitoring, and REEF's fish survey programs demonstrate diverse approaches to engaging volunteers while generating scientifically valuable datasets (Thiel et al., 2014). Analyzing comparable platforms helps identify best practices, anticipate technical challenges, and avoid reinventing solutions to common problems, while still allowing for innovations addressing project-specific needs.

2.7. EVALUATION

Comprehensive evaluation frameworks are essential for assessing project success, identifying areas for improvement, demonstrating impact to stakeholders, and contributing to broader understanding of citizen science effectiveness (Kieslinger et al., 2018). Evaluation should encompass multiple dimensions including data outcomes (volume, quality, spatial and temporal coverage, scientific insights generated), participant outcomes (learning gains, attitude changes, continued engagement in science or conservation), social outcomes (community capacity building, policy influence, public awareness), and operational outcomes (efficiency, sustainability, innovation in methods or technologies).

Defining specific indicators for measuring success enables systematic assessment while acknowledging that citizen science projects often generate diverse types of value that may be difficult to quantify. Data quality metrics might include validation pass rates, inter-observer reliability measures, or comparisons with professionally collected reference data (Kosmala et al., 2016). Participant engagement indicators could track recruitment numbers, retention rates, activity levels, volunteer hours contributed, or diversity of participant demographics. Scientific impact can be evaluated through peer-reviewed publications, integration into assessments or management decisions, or contributions to species distribution databases and conservation prioritization.

Participatory evaluation approaches that involve citizen scientists and other stakeholders in assessment design, data collection, and interpretation enhance both the credibility and utility of evaluation findings (Kieslinger et al., 2018). Participant surveys, focus groups, interviews, and feedback forums provide insights into volunteer experiences, learning outcomes, perceived value, barriers encountered, and suggestions for improvement, all insights that cannot be captured through administrative data alone. Stakeholder consultations with researchers, policymakers, conservation practitioners, and community organizations assess broader impacts and relevance to decision-making contexts. Mechanisms for collecting and integrating feedback throughout the project lifecycle enable adaptive management that responds to emerging challenges, capitalizes on unexpected opportunities, and continuously improves project design and implementation (Williams and Brown, 2014). Creating pathways for continued citizen involvement beyond initial project phases, whether through follow-up initiatives, expanded roles for experienced volunteers, or integration into long-term monitoring networks, maximizes return on training investments while building sustained capacity for community-based science.

2.8. OVERALL FRAMEWORK

The framework presented provides a structured approach to designing, implementing, and evaluating citizen science projects that generate credible scientific knowledge while fostering meaningful public engagement with marine conservation challenges. By systematically addressing questions across the core thematic areas, from foundational project design through participation architecture, engagement strategies, data collection protocols, data management infrastructure, technical platforms, to comprehensive evaluation, project coordinators can develop initiatives that uphold scientific standards, meet policy needs, advance environmental objectives, and deliver value to all participants. The accompanying visual guide (Figure 1) includes these considerations (except the technical platform considerations, which are optional for designing a citizen science initiative) into an accessible reference framework supporting the establishment of robust citizen science programs aligned with best practices and the principles of open, inclusive, and impactful science.

Figure 1. Overview of key methodological components for establishing and managing a Citizen Science (CS) project.

3. AUTH CS Hub knowledge exchange

The development of robust citizen science initiatives requires not only theoretical frameworks and methodological guidelines but also practical insights derived from operational experience in establishing and managing citizen science projects. As part of the deliverable objectives to design, implement, monitor, and evaluate pilot projects through the Aristotle University of Thessaloniki (AUTH) Citizen Science Hub, knowledge exchange activities were undertaken to understand existing practices, evaluation frameworks, and operational templates that inform effective citizen science project implementation (Figure 2).

3.1. Context and Approach to Knowledge Exchange

The knowledge exchange process focused on extracting valuable lessons, methodological approaches, and practical tools from AUTH CS Hub's existing operational framework and pilot project experiences, rather than co-designing new pilot initiatives from inception. This approach recognized that the AUTH CS Hub had already developed functional systems for event organization, participant engagement, data collection, and impact evaluation through its establishment under the INCENTIVE project, a European Union Horizon 2020 initiative aimed at establishing citizen science hubs in research performing and funding organizations to drive institutional change and ground responsible research and innovation in society.

The knowledge exchange centered on reviewing documentation that captures AUTH CS Hub's operational approach, including standardized templates for event reporting and participant evaluation questionnaires. These materials provide concrete examples of how citizen science principles are operationalized in practice, offering insights into participant recruitment strategies, event organization protocols, data collection methodologies, evaluation frameworks, and mechanisms for assessing both participant outcomes and broader project impacts.

3.2. Evaluation and Impact Assessment Framework

A particularly valuable component of the knowledge exchange involved examining AUTH CS Hub's approach to participant evaluation and project impact assessment, as embodied in their standardized event questionnaire. This questionnaire reflects a sophisticated understanding of the multiple dimensions through which citizen science projects generate value, extending beyond data collection outcomes to encompass participant learning, attitudinal shifts, network building, and broader societal impacts.

The evaluation framework addresses several critical dimensions. First, it assesses networking and partnership formation by examining whether event participation led to new partnerships or networks promoting responsible research and innovation, a crucial metric for evaluating how citizen science catalyzes collaborative capacity beyond individual projects. Second, it measures shifts in social engagement by evaluating increased interest in collaborating to solve local or global problems and participating in relevant discussions and debates, thereby capturing the project's contribution to developing an engaged community capable of contributing to science-informed decision-making. Third, the framework evaluates science trust and legitimacy by assessing whether participation increased trust in science and research, and how participants perceive citizen science as a legitimate and ethical approach to research. Fourth, it examines perceptions of citizen science utility, specifically whether participants view citizen science as capable of achieving better research results addressing social challenges and producing outputs relevant to local societal needs.

The framework also incorporates metrics for sustained engagement, using scaled questions to quantify increases in interest in engaging with science following event participation, and assessing willingness to participate in future research and innovation decision-making processes. Additionally, demographic data collection enables analysis of participant diversity and identification of potential gaps in engagement. By capturing gender identity, age ranges, stakeholder group affiliation (academic staff, students, governmental bodies, business, civil society organizations, local communities), and educational levels, the questionnaire supports equity-focused evaluation that can reveal whether projects successfully engage diverse communities or inadvertently reinforce existing inequalities in science participation (Cigliano et al., 2015).

3.3. EVENT REPORTING AND DOCUMENTATION FRAMEWORK

AUTH CS Hub's standardized event reporting template demonstrates a systematic approach to documenting citizen science activities that balances comprehensive record-keeping with operational efficiency. The template systematically captures essential project metadata including event titles, dates, venues, organizers, and audience composition with stakeholder categorization. This demographic documentation enables aggregated analysis of engagement patterns, identification of underrepresented groups, and assessment of whether projects successfully convene diverse stakeholder communities. Documentation of event organization processes, including steps taken to set up activities, location selection rationale, target group selection criteria, and promotional strategies, creates institutional memory that supports knowledge transfer to future project developers. The outcomes documentation framework captures multiple dimensions of project results including main outcomes achieved, data and information gathered, new ideas generated, and partnerships established. This multi-dimensional outcome assessment recognizes that citizen science projects generate value through multiple pathways beyond primary research objectives (Kieslinger et al., 2018). Lastly, the reporting framework incorporates reflective evaluation components asking project organizers to identify challenges encountered, articulate main takeaways, specify success factors, consider alternative approaches for future implementation, and summarize participant feedback.

The knowledge exchange with AUTH CS Hub provided several concrete insights that informed the development of the Guidelines for Establishing and Managing a Citizen Science Project presented in Section 2, namely:

- the importance of aligning citizen science activities with participants' existing interests, skills, and activities,

- the central role of partnerships with relevant stakeholders, particularly those who can facilitate access to participant communities and implementation sites,
- the value of standardized, yet flexible, documentation frameworks that capture both quantitative metrics and qualitative insights,
- the practical challenges of data validation and retrieval, and
- the multi-layered evaluation approach examining not only data collection outcomes but also participant learning, attitudinal shifts, partnership formation, and broader societal impacts.

The knowledge exchange process revealed several points of alignment between AUTH CS Hub practices and the operational principles of NEMO-Tools products. The emphasis on developing standardized yet accessible monitoring protocols, creating educational materials tailored to diverse target group characteristics, providing training and support systems for participants, establishing clear data processing and management protocols, and implementing multi-dimensional evaluation frameworks all resonate with NEMO-Tools' objectives of providing methods, techniques, and equipment for effective citizen science implementation in marine contexts. The documentation reviewed through knowledge exchange can inform technical expertise and know-how provision to support compliance with NEMO-Tools operational principles across broader initiatives. The templates, questionnaires, and organizational frameworks developed by AUTH CS Hub represent replicable tools that can be adapted for use by other marine citizen science projects, thereby facilitating standardization while allowing contextual customization.

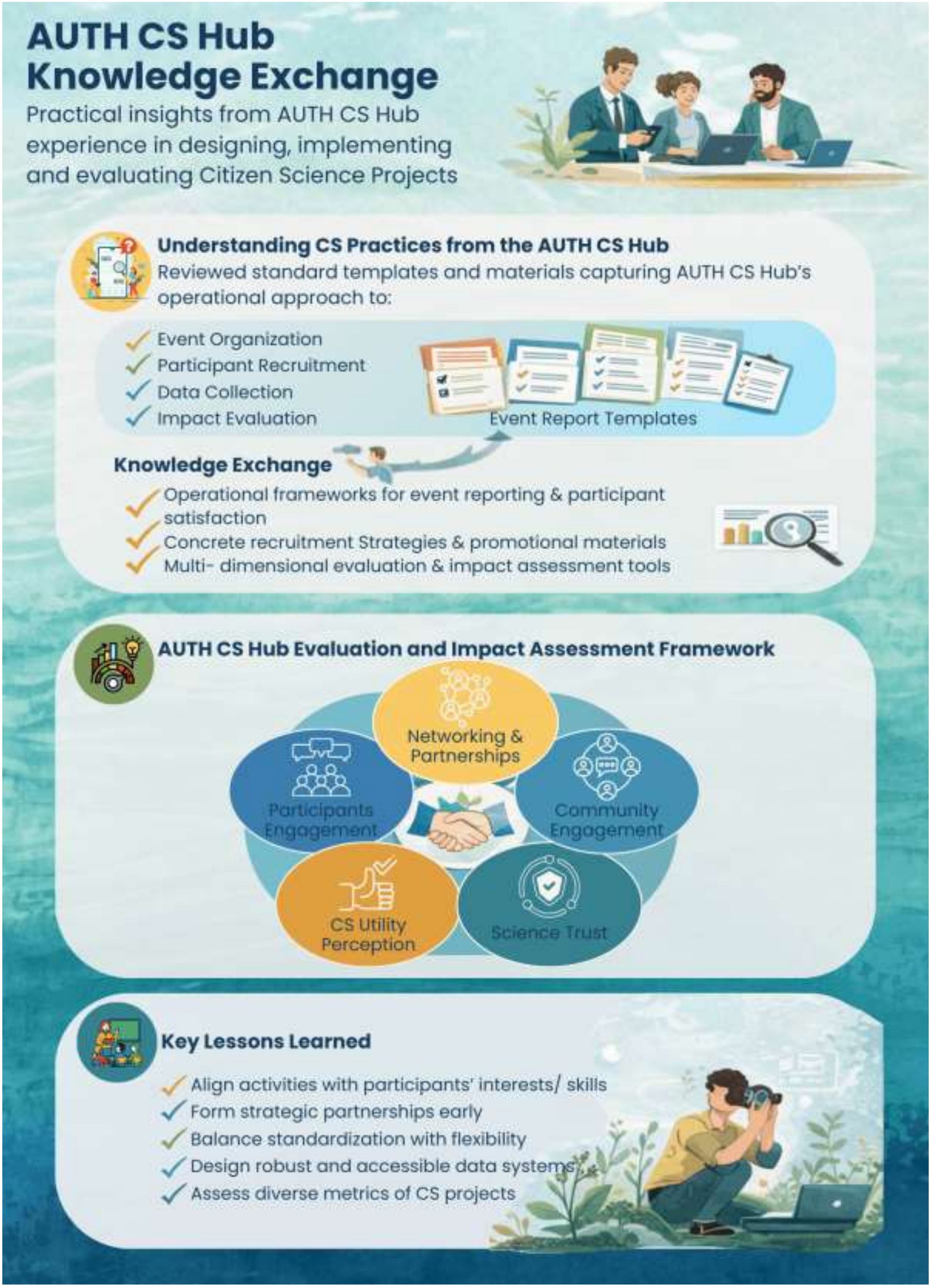

Figure 2. Synthesis of the AUTH CS Hub knowledge exchange process, illustrating how operational experience, evaluation frameworks, and documentation practices inform best practices for designing, implementing, and assessing citizen science projects.

4. Nemo-Tools CS Pilot Projects

The NEMO-Tools project has developed three innovative citizen science pilot initiatives that apply the methodological guidelines presented in Section 2 to address critical marine conservation challenges using novel technological approaches. These pilot projects focus on passive acoustic monitoring, AI-powered fish identification and environmental DNA (eDNA) biodiversity assessment, and demonstrate how emerging technologies can expand the spatial and temporal scope of marine monitoring while meaningfully engaging diverse public audiences in scientific research. Each initiative employs distinct technical approaches and engagement strategies while sharing fundamental commitments to accessibility, data quality, and long-term sustainability.

4.1. Low-Cost DIY Hydrophones for Passive Acoustic Monitoring

Project Overview and Scientific Rationale

The passive acoustic monitoring initiative addresses a fundamental challenge in marine biodiversity research: collecting sound data across the extensive spatial and temporal scales needed to understand marine species distributions, behaviours, and responses to anthropogenic noise pollution. Traditional passive acoustic monitoring relies on expensive commercial hydrophones and recording equipment, limiting deployment to well-funded research programs and resulting in spatially and temporally sparse data coverage, particularly in coastal and nearshore environments. The NEMO-Tools DIY hydrophone initiative fundamentally differs by developing very low-cost underwater listening devices that can be freely distributed to citizen scientists, enabling easy access to acoustic monitoring technology while expanding data collection to previously under-sampled locations.

The project's scientific objectives encompass multiple dimensions: enhancing biodiversity monitoring through detection and identification of vocally active marine species, characterizing underwater noise pollution across diverse habitats and temporal scales, filling data gaps from under-sampled marine areas where traditional research infrastructure is absent, and strengthening public scientific literacy regarding the importance of sound to marine species and the adverse effects of anthropogenic underwater noise.

Participation Architecture and Accessibility Design

The initiative employs an inclusive participation design by eliminating demographic restrictions and technical barriers that typically constrain marine acoustic research. All age groups, educational backgrounds, and affiliations are eligible to participate, including fellow scientists, students, recreational boaters, fishermen, divers, and coastal residents. This broad inclusivity reflects recognition that valuable acoustic data can originate from any marine location where participants have access, and that diverse participant communities contribute complementary spatial and temporal coverage patterns shaped by their varied relationships to marine environments.

The initiative targets Greek waters to facilitate easy distribution of low-cost DIY hydrophones. While all Greek waters are eligible for monitoring, operational constraints such as boat availability and summer vacation patterns will likely result in most acoustic data originating from shallow-water, nearshore areas during non-winter months. Citizen scientists are primarily involved with data collection, recording not only underwater sounds but also metadata such as recording location and timestamp. The main activity involves deploying DIY hydrophones and recording passive acoustic data by submerging them underwater. Participants use simple handheld recorders or smartphone recording applications, requiring only the ability to press a "record" button, deliberately designed to minimize technical expertise requirements. No specific duration or time frequency is suggested. Citizens can record for as long as desired and repeat sessions opportunistically during leisure travel, fishing expeditions, diving excursions, or dedicated field trips. This flexible, self-directed participation model accommodates varying levels of commitment while enabling both occasional contributions and sustained engagement from enthusiastic participants.

Recognition and acknowledgment of individual contributions constitute core design principles addressing known challenges of volunteer retention in citizen science (Rotman et al., 2012). The project's central web platform, currently under construction, is designed to display all acoustic recordings on an interactive map attributed to contributing participants, provide visual summaries of collected data, and implement a leaderboard showcasing top contributors. At this stage of implementation, there is no clear projection of participant numbers, though the initiative can easily scale to hundreds depending on DIY hydrophone distribution. Resource requirements for participants are deliberately minimized. All hydrophone equipment is manufactured and provided by NEMO-Tools at no cost, eliminating financial barriers to participation. The only requirement is access to marine waters, which citizens can access during their regular activities without additional travel expenses. Recording devices are assumed to be already owned by most participants, further reducing participation costs.

Engagement Strategies and Community Building

The main strategies for recruiting and motivating participants include NEMO-Tools outreach activities, social media announcements and engagement campaigns, and strategic synergies with other established citizen science projects including those coordinated through the AUTH CS Hub. This multi-faceted approach recognizes that different participant demographics respond to different recruitment mechanisms, and that integration with existing citizen science communities can accelerate adoption by building on established trust and engagement patterns. Rather than requiring formal training sessions, the project distributes layperson leaflets with each DIY hydrophone package, providing accessible guidance on equipment operation, data collection protocols, and submission procedures. Participants will receive continuous remote support throughout implementation through FAQs, interesting acoustic case studies, and troubleshooting guidance that will be available on the central web platform.

To sustain engagement and mitigate participant fatigue, the program emphasizes meeting participant expectations and providing visible feedback on progress and results. The project webpage will serve not only as a data collection and storage platform but also as an active communication and engagement tool. Participants will receive visual summaries of collected data, highlighted case studies demonstrating interesting acoustic phenomena captured by citizen scientists, and dedicated sections acknowledging individual contributions. Recordings will be displayed on an interactive map showing geographic coverage and temporal patterns, allowing participants to contextualize their contributions within the broader data landscape, while a leaderboard showcasing top contributors will further incentivize sustained participation.

Data Collection, Validation, and Scientific Utility

The technical specifications for data collection balance scientific utility with accessibility constraints. Participants use only a single hydrophone plugged into a handheld recorder or cell phone for data collection. They then submit uncompressed audio files in WAV format (16-bit) recorded at sampling rates determined by their recording devices, typically 44.1 kHz for standard consumer electronics, though more capable recording devices can be employed by participants choosing to invest in enhanced equipment. These recordings can promote the understanding of marine biodiversity, species distribution, and underwater noise pollution.

Guidelines for data submission are displayed in the leaflet distributed with the hydrophone and on the central web platform. The workflow from citizen submission to evaluation follows a structured pipeline designed to ensure data quality while providing timely feedback to participants. When citizens upload WAV files to the central web platform, recordings will automatically be transferred to a dedicated acoustic data server where processing and evaluation occur. Files will be initially marked as "under processing" to manage participant expectations regarding feedback timing. Expert acoustic analysts will review recordings, conduct quality control and extract scientifically relevant features. Automated acoustic processing algorithms will complement expert review, enable efficient analysis of large data volumes and maintain quality standards. Following analysis, results will be returned to the web platform for public display. Each recording will be accompanied by a spectrogram image and one or two easily understandable acoustic metrics, making scientific findings accessible to citizen contributors regardless of their technical expertise. Data quality assurance will be overseen by at least two acoustic experts.

Impact Measurement, Project Sustainability and Timeline

Project success will be evaluated through multiple complementary indicators capturing different dimensions of impact. Scientific metrics will include the number of audio submissions, total duration of acoustic records, number of localities or regions covered, and number of unique species or species groups identified in acoustic data. These quantitative measures provide objective assessment of data volume, spatial coverage, and biodiversity information content, all fundamental to determining the project's contribution to marine science. Engagement metrics will track the number of unique citizen scientist users, webpage visits, and social media shares, providing insight into project reach and public interest. Participant satisfaction feedback, assessed through surveys and platform interactions, will offer qualitative understanding of the volunteer experience and identify opportunities for improving engagement strategies or technical systems. The suitability of collected data for scientific purposes will be evaluated through analysis of data quality metrics, comparison with professionally collected reference recordings where available, and ultimately through the number and reach of scientific publications produced using citizen-contributed acoustic data.

The project's design deliberately emphasizes long-term sustainability by automating data collection and management processes after initial development investment. The project employs Nemo-Tools resources for manufacturing hydrophones and building the platform, then automates data collection so it becomes a self-feeding process continuing after the project's completion, requiring minimal ongoing intervention beyond server maintenance, periodic expert review, and community management. This sustainability model recognizes that short-term project funding cycles often undermine citizen science initiatives that require extended temporal coverage to generate scientifically meaningful datasets (Dickinson et al., 2012).

4.2. AQUAID: AI-Powered Fish Species Identification

Project Overview and Scientific Rationale

The AQUAID (Artificial Intelligence for Quality Underwater Assessment and Identification) initiative aims to address critical challenges in Mediterranean marine biodiversity monitoring by combining citizen science data collection with advanced machine learning for automated species identification. The primary objective of this citizen science initiative is to empower citizens, divers, and marine enthusiasts to contribute to marine biodiversity monitoring by uploading underwater images of fish species that are automatically identified using advanced AI models trained on the MEDFISH101 dataset, a comprehensive collection of Mediterranean fish images. The key research questions addressed are whether citizen-contributed underwater images can improve species recognition and monitoring in the Mediterranean Sea, how accurate and generalizable AI-based fish classifiers are in uncontrolled, in-the-wild underwater conditions, and what role participatory science can play in long-term surveillance of marine ecosystems.

The initiative addresses specific scientific issues including the decline of marine biodiversity in the Mediterranean due to overfishing, pollution, invasive species, and climate change, the lack of high-resolution, species-level monitoring data across time and space, and the difficulty of scaling expert-based image annotation for large-scale underwater datasets. The project contributes to broader scientific understanding by providing real-time, geo-referenced data on species distribution and abundance, enriching marine biodiversity databases, monitoring invasive species, and tracking population dynamics over time. By enabling anyone with access to underwater imagery to participate meaningfully in species monitoring, the platform dramatically expands the spatial and temporal resolution of biodiversity data while reducing dependency on scarce expert taxonomic capacity.

The initiative simultaneously increases environmental awareness, literacy, and engagement among the public regarding marine ecosystem health. Main beneficiaries include marine researchers and ecologists who gain access to a growing repository of annotated fish images from across the Mediterranean, and policymakers and conservationists who can base decisions on up-to-date distribution maps and biodiversity trends. Citizen scientists benefit through enhanced scientific literacy, a sense of community, and satisfaction from active engagement in environmental protection and monitoring. Participants learn to identify fish species, understand marine food webs, and use AI-assisted tools while engaging with a growing network of marine enthusiasts, divers, and scientists.

Participation Model and Technical Accessibility

AQUAID initially operates at a regional scale, covering the Eastern and Central Mediterranean, with plans for pan-Mediterranean expansion. Scale is determined by two main factors: availability of high-quality training data (the MEDFISH101 dataset) primarily for Mediterranean species, and the network of collaborators, diving centers, NGOs, marine research institutions, willing to support outreach and engagement.

AQUAID embraces an open participation model welcoming anyone with access to underwater imagery. Primary target groups include recreational and professional divers, underwater photographers, marine tourism operators, fishermen, coastal community members, and educational institutions. Schools and environmental education programs are explicitly encouraged to participate through structured activities that integrate biodiversity monitoring with curriculum learning objectives. Participation involves uploading underwater images through web or mobile interfaces, tagging photos with location, date, and optional metadata such as depth and habitat characteristics, and reviewing AI-predicted species identifications. Optionally, participants may engage in data validation by flagging uncertain predictions or confirming species names when known, contributing to continuous model improvement through human-in-the-loop learning. Community feedback mechanisms allow participants to correct misidentifications, building collective knowledge while refining algorithmic performance.

The platform is deliberately designed for inclusivity, requiring no minimum educational qualifications or formal training in marine biology or AI systems (https://huggingface.co/spaces/AndrewKof/NEMO-Tools). Users follow simple guidelines on ethical data collection, community conduct, and image licensing. Technical barriers are minimized through intuitive interfaces and built-in prompts guiding metadata submission. The time commitment is designed to be low-barrier and asynchronous. Submitting an image with optional metadata takes approximately one to two minutes and can happen opportunistically anytime. There is no minimum commitment threshold, allowing both occasional contributors who upload a single dive's images and dedicated participants who regularly submit observations to engage meaningfully. This flexibility accommodates varying levels of interest and availability while building a diverse contributor community. The initiative aims to engage hundreds of citizen participants in the first full year post-launch, dozens of marine experts for dataset validation, outreach, and community moderation, plus diving clubs and academic partners.

Resource requirements are limited to access to marine waters, a smartphone or camera capable of underwater photography, and internet connection for image upload. The platform supports both web and mobile access, requiring no specialized software installation. All participation is voluntary and cost-free, with citizens using existing photographic equipment (GoPros, smartphones, underwater cameras). This elimination of financial barriers ensures equitable participation opportunities across socioeconomic contexts.

Engagement Architecture and Community Recognition

Recruitment strategies will leverage established partnerships with diving centers, marine protected areas, schools, and environmental organizations, building on existing networks where target participants are already gathered. NEMO-Tools outreach activities, social media campaigns, and synergies with other citizen science initiatives extend reach beyond these core networks. Motivation is designed to be sustained through multiple recognition mechanisms including digital badges and leaderboards based on contribution volume and validation accuracy, certificates of participation for schools and NGOs, and emphasis on the scientific impact of contributions through communication of how citizen data informs conservation decisions. The web platform will eventually be formatted to host personal dashboards allowing participants to track their contributions, view identification results for their images, and see how their observations compare with broader patterns, creating individualized engagement experiences that maintain interest over time.

The platform provides accessible guidance on image upload procedures, AI prediction review, and metadata contribution. These functions will be supplemented by FAQs and case studies demonstrating how citizen images have contributed to scientific discoveries or conservation actions. Seasonal campaigns, such as focused efforts to document spawning aggregations or monitor invasive species during peak abundance periods, are under design to create temporal engagement peaks while addressing priority information needs. Newsletters featuring contributor highlights and scientific updates are methods considered for maintaining ongoing communication with the participant community, strengthening social connections and demonstrating continued project vitality. Educational content, though optional, will provide learning opportunities for participants interested in deepening their understanding of Mediterranean ichthyofauna, marine ecology, or artificial intelligence systems. This optional educational layer will allow the platform to serve diverse participant motivations, from casual contributors primarily interested in contributing photographs to dedicated learners seeking substantive knowledge development.

Data Management, AI Integration, and Quality Assurance

Collected data include underwater images of fish along with metadata such as location, date, and depth, informing understanding of marine biodiversity, species distribution, and invasive species. This visual data supports core research goals of improving AI-based species identification and mapping biodiversity trends in the Mediterranean. Participants submit data via web or mobile platform, which guides users through image upload and metadata tagging using built-in templates and quality prompts. The technical infrastructure combines a user-facing web platform with backend GPU-based AI inference servers and scalable image storage systems. When participants upload images, AI models trained on MEDFISH101 process submissions to generate species predictions with associated confidence scores. High-confidence predictions are immediately returned to users, while uncertain classifications are flagged for expert review by marine biologists or ichthyologists who validate or correct identifications. This hybrid human-AI system balances the efficiency of automated processing with the accuracy assurance that expert review provides. Random samples of all submissions, including high-confidence predictions, are periodically verified by specialists to detect systematic model errors or drift. Statistical checks identify anomalies or duplicate submissions, and model versioning ensures reproducibility by tracking which algorithm version processed each image. Standardized tagging protocols and transparent documentation of classification methods provide additional quality control layers.

Data storage employs standard image formats (JPEG) with structured metadata in CSV and JSON formats, ensuring interoperability with existing biodiversity databases and analytical tools. The platform anticipates accumulating 10,000–50,000 images within the first two years, a substantial dataset volume that would be infeasible to generate through traditional expert-led surveys alone. Contributor ownership is respected while data is shared under open licenses for scientific and educational use, with appropriate attribution maintained throughout data lifecycle stages. Validated datasets are shared in open formats (CSV, JSON) through an accessible online repository. Data are publicly accessible through the platform, with some early-stage data reserved for project partners and reviewers. Data will remain accessible for a minimum of five years, with plans for long-term archiving and periodic backups.

Technical Platform and Evaluation

The central web platform serves as the main tool for data collection and visualization of marine biodiversity using AI-powered species recognition, but will further be updated to also serve public engagement. Primary users include citizen scientists (divers, photographers), marine researchers, educators, and conservation stakeholders. New users will be introduced via onboarding tutorials and optional live support for educators or partner organizations. The platform is web-based, accessible via any browser, and optimized for both desktop and mobile devices with no installation needed. The platform supports responsive design for various screen sizes and compliance with usability standards.

Potential risks include image metadata leaks, misuse of AI predictions, and image copyright issues, mitigated through anonymization, proper licensing, and user agreements. The platform tracks and reports project progress through auto-counts of user submissions, localities covered, and visual summaries of collected data, allowing citizens to monitor use of their submissions and scientists to measure engagement and data volume. Success indicators considered include total number of images uploaded, diversity of species captured, geospatial coverage across the Mediterranean, and accuracy of AI predictions after expert validation. Participant engagement will be tracked through user retention rates, frequency of contributions, and feedback activity. Additional indicators will include number of active users, schools or organizations involved, and growth in user base over time. These multi-dimensional indicators will enable assessment of both the platform's technical performance and its success in mobilizing citizen participation. Impact assessment will track number of related publications, size of created datasets, improvements in prediction accuracy, media coverage, and educational uptake. The use of platform data by conservation stakeholders, such as integration into marine spatial planning, fisheries assessments, or protected area monitoring, will provide the most direct evidence that citizen science contributes meaningfully to evidence-based decision-making.

Scientific Outputs and Conservation Applications

The ultimate measure of AQUAID's impact lies in its contributions to marine biodiversity understanding and conservation effectiveness. Validated datasets will be shared publicly through accessible repositories, enabling use by researchers, managers, and policymakers who may not be directly involved in the project. The creation of large, georeferenced image databases will support species distribution modeling, population trend analysis, habitat association studies, and invasive species tracking, all priority information for Mediterranean marine management. The platform's real-time data generation enables rapid detection of distribution shifts or invasive species establishment, providing early warning capacity that traditional monitoring programs, constrained by sampling schedules and processing delays, cannot match. This temporal responsiveness represents a distinctive advantage of continuously operating citizen science platforms over periodic survey efforts.

4.3. Environmental DNA Biodiversity Monitoring in Multi-stressed Coastal Environments

Project Overview and Scientific Rationale

The eDNA initiative represents a complementary approach to marine biodiversity monitoring, focusing on microbial and eukaryotic communities that are largely invisible to visual observation methods yet play fundamental roles in marine ecosystem function. Traditional microbial and eDNA monitoring requires laboratory infrastructure, specialized expertise, and substantial per-sample costs, limiting sampling intensity and geographic coverage. The NEMO-Tools eDNA project addresses these constraints by developing frugal sampling tools and simplified protocols that enable local communities, students, and stakeholders to collect water samples and document environmental conditions. By distributing accessible monitoring capacity to coastal populations who interact regularly with marine environments, the project dramatically expands temporal and spatial resolution while building local environmental stewardship capacity.

The project focuses on coastal marine zones impacted by various stressors including eutrophication, chemical pollution, shipping, and climate-related pressures. It seeks to close data gaps, improve understanding of ecosystem function, and support evidence-based management. The initiative contributes to broader scientific understanding by creating practical monitoring tools and contributing new data to international databases. It raises environmental awareness, provides educational opportunities, and fosters long-term partnerships between scientists and local communities while informing marine conservation policy, restoration priorities, and sustainable development. The initiative benefits citizen scientists by promoting scientific literacy, developing skills, and increasing environmental awareness. Local communities benefit through increased resilience and informed conservation actions. Participants receive hands-on experience with biodiversity monitoring tools and develop a stronger sense of connection to their environment. They benefit from direct collaboration with research teams and training workshops that enhance community capacity in environmental stewardship. Students develop early awareness of environmental issues and are encouraged to engage in sustainability actions.

The initiative focuses on three key Greek marine zones: the Saronic Gulf, the Gulf of Kavala, and the Thermaikos Gulf, selected to represent different environmental and anthropogenic stress gradients. These regions offer ecological relevance, accessibility for participant engagement, alignment with institutional expertise, and stakeholder interest. The geographic focus enables intensive monitoring across diverse conditions while facilitating coordination between research teams and citizen scientists through regional workshops, training events, and feedback sessions. Scientific objectives encompass determining how multiple stressors affect marine microbial and eukaryotic community structure and function, investigating whether citizen-collected eDNA data can support robust biodiversity assessments comparable to professionally collected samples, closing data gaps in regions where routine monitoring is absent, and supporting evidence-based conservation planning and restoration prioritization. By creating practical tools for biodiversity monitoring and contributing data to international databases, the project generates scientific resources extending beyond immediate research objectives.

The project employs resources for protocol development, training material creation, implementation, citizen science activities, interactive summer school activities, data analysis, and stakeholder dissemination, then automates data collection so it becomes a self-feeding process continuing after project completion. Financial resources support field campaigns through provision of consumables (Lugol's solution, microscope slides, cover slips, pH paper) and frugal equipment to enable school and community-level data collection. Human resources include a core team of researchers and educators responsible for designing sampling protocols, coordinating fieldwork, and ensuring data quality.

Participation Design and Requirements

The eDNA project deliberately targets diverse participant demographics. All age groups, affiliations, and educational levels are eligible. Targeted participants include school students at various educational levels, university students, educators, diving clubs, and coastal community members. Activities and materials are carefully tailored to different age groups and expertise levels, recognizing that effective engagement requires matching participation complexity to audience capabilities and interests. Each activity has structured, simplified guidelines developed specifically for citizen engagement.

Primary citizen activities include collecting water samples following standardized protocols, measuring abiotic variables such as temperature, salinity, and pH using provided instruments, documenting visible biodiversity phenomena such as algal blooms, and participating in periodic workshops, summer schools, or community science events. The project provides all necessary consumables, Lugol's solution for sample preservation, microscope slides, cover slips, pH paper, sample containers, and frugal equipment, eliminating financial barriers while ensuring methodological standardization. Participation frequency and duration vary depending on participant group characteristics and local conditions. Some individuals can participate in one-off events such as summer schools or community sampling days, while others engage regularly when unusual phenomena prompt opportunistic observation. Ideally, participants submit samples and observations whenever red tides, phytoplankton blooms, jellyfish aggregations, or other notable events are noticed, creating an early warning system for ecosystem changes. This flexible engagement model accommodates varying capacity and interest levels while building sustained monitoring coverage.

At this implementation stage, there is no clear projection of participant numbers, which will depend on interest and engagement. Usually, ten to thirty participants per activity are engaged. All necessary training is provided through guides, visual tools, and in-person sessions tailored to each target audience's needs. Participation level and involvement are not uniform across all project stages, depending on individual engagement. However, overall participation is expected to increase over time as participants become more familiar with citizen science concepts. Participants need only access to basic consumables and field kits provided by the research team. School labs may use microscopes or basic kits.

The project implements multiple recognition mechanisms to acknowledge citizen contributions, including attribution in datasets and publications, showcase features in outreach materials, feedback on how submitted samples contribute to scientific understanding, and certificates acknowledging participant roles. These recognition practices validate volunteer efforts while demonstrating that citizen contributions generate meaningful scientific value rather than serving merely as educational exercises.

Training, Support, and Capacity Building

Given the greater technical complexity of eDNA sampling compared to photographic or acoustic observation, the project invests substantially in participant training and ongoing support. Printed field guides with visual instructions, step-by-step protocols, and troubleshooting guidance provide ongoing reference materials supporting fieldwork. Workshops and mentoring relationships provide continuous support throughout project implementation, creating pathways for participants to ask questions, troubleshoot challenges, and deepen their understanding. This sustained engagement infrastructure recognizes that one-off training sessions are insufficient for maintaining data quality and participant motivation over extended periods. Regular communication through newsletters, social media updates, and community meetings is expected to maintain project visibility while providing feedback on collective progress and emerging findings.

Main strategies for recruiting and motivating participants include establishing strong networks with schools, local municipalities, NGOs and local stakeholders, along with NEMO-Tools outreach actions, social media announcements and engagement strategies, and synergies with other citizen science projects. Motivation is sustained through relevance to local issues, clear impact, and co-design of activities. To sustain engagement and mitigate participant fatigue, the program emphasizes meeting participant expectations and providing visible feedback on progress and results. This feedback-oriented approach is considered essential for reinforcing motivation and strengthening sense of ownership in the conservation effort.

Data Collection Protocols and Quality Assurance

Data collection combines direct water sampling with observational records and photos, and environmental metadata (temperature, salinity, pH, location, depth, transparency). Water samples collected in provided containers are preserved with Lugol's solution following standardized protocols detailed in visual field guides. Samples are sent to the research team for laboratory analysis, including microscopic examination of phytoplankton communities, molecular analysis of eDNA, and quantification of environmental parameters. This centralized analysis ensures consistency and quality while leveraging specialized equipment and expertise unavailable to most citizen participants.

Concurrently, participants record metadata including location, date, time, water temperature, salinity, pH, visual water clarity, weather conditions, and any notable phenomena observed. Photographic documentation supplements written records, providing visual evidence of sampling conditions and observed phenomena. Mobile phones serve as multipurpose tools, functioning as cameras, GPS units, and potentially as data submission interfaces. Standardized collection methods ensure comparability across participants and sampling events, with detailed protocols specifying sample volumes, preservation procedures, storage requirements, and shipping instructions. Recognition that citizens may use varying equipment for metadata measurement, is addressed by accounting for known standard error ranges in subsequent analysis. This pragmatic approach balances the desire for precise measurements with the reality that requiring calibrated research-grade instruments would create insurmountable participation barriers.

Expert oversight of data quality occurs at multiple stages. Field protocols are designed and refined by the research team based on pilot testing and feedback. Submitted samples undergo expert laboratory analysis ensuring accuracy of biological identifications and measurements. Statistical quality control identifies outliers or inconsistent data points requiring verification or exclusion. This multi-layered validation approach maintains scientific rigor while enabling broad citizen participation.

Dissemination, Impact, and Stakeholder Engagement

Results are disseminated through multiple channels targeting different audiences. Scientific community engagement occurs through peer-reviewed publications, technical reports, and conference presentations, ensuring that citizen-generated data contributes to formal scientific discourse and biodiversity databases. Participant communication includes feedback on how submitted samples informed findings, visual summaries of regional patterns, and acknowledgment of individual and collective contributions.

Public engagement employs social media, press releases, and outreach events translating scientific findings into accessible narratives connecting with broader societal concerns about marine ecosystem health. Periodic stakeholder workshops in each focal region convene local authorities, NGOs, educators, and community leaders to discuss findings, implications for local management, and opportunities for continued monitoring. These workshops serve dual purposes of disseminating results and maintaining stakeholder investment in project continuation beyond formal funding periods.

The project's emphasis on co-design and integration of citizen input into research directions fosters genuine partnership rather than extractive data collection relationships. Participant feedback shapes protocol refinements, geographic priorities, and communication strategies, ensuring that project evolution responds to community interests and concerns. This participatory governance approach enhances project legitimacy while building social capital supporting long-term environmental stewardship.

5. Synergies with Other Projects

The methodological frameworks and operational principles developed through NEMO-Tools have demonstrated practical applicability beyond the project's core pilot initiatives, informing the design and implementation of complementary citizen science programs addressing marine biodiversity monitoring challenges. Members of the NEMO-Tools scientific team have actively applied the project's guidelines and best practices to parallel initiatives, creating opportunities for knowledge exchange, capacity building, and expanded engagement networks that benefit both NEMO-Tools objectives and broader marine conservation efforts.

Alonnisos Marine Biodiversity Monitoring Initiative

A notable example of NEMO-Tools framework application occurred within the National Marine Park of Alonnisos Northern Sporades (NMPANS), Greece's first marine protected area. Members of the NEMO-Tools scientific team, working within the context of a separate project funded by MedFund through the "Highly Protected Mediterranean Initiative," developed and implemented a citizen science program specifically targeting recreational divers and the diving tourism sector during 2025. The initiative's design phase explicitly utilized the methodological guidelines presented in Chapter 2 of this deliverable, systematically addressing the core thematic areas of project basics, participation architecture, engagement strategies, data collection protocols, data management infrastructure, technical platforms, and evaluation frameworks. This application demonstrated the practical utility and adaptability of NEMO-Tools principles across different project contexts, funding mechanisms, and stakeholder configurations.

The program engaged recreational divers in systematic collection of biodiversity data through two scientifically validated monitoring protocols: the Climate Fish protocol, tracking distribution and abundance changes of coastal fish species as indicators of climate change impacts, and the Reef Check protocol, assessing rocky reef ecological status through monitoring of selected algae, corals, echinoderms, and fish species. Both protocols were designed following NEMO-Tools accessibility principles, minimizing technical complexity while maintaining scientific rigor, and were integrated into routine recreational diving activities through partnerships with local dive centers. Implementation involved comprehensive training of dive center personnel who functioned as facilitators supporting volunteer participation, development of multilingual educational materials including waterproof underwater recording boards, establishment of a dedicated online database for data submission and validation, and organization of targeted engagement events during peak tourism periods. During the first implementation year, the program successfully recruited 20 trained citizen scientists who completed 35 Climate Fish surveys and 12 Reef Check surveys across six monitoring sites.

Knowledge Exchange

Throughout the Alonnisos initiative's implementation, NEMO-Tools pilot projects and technologies were presented to the established network of dive centers, marine protected area authorities, and recreational diving communities. These presentations introduced the DIY hydrophone passive acoustic monitoring approach, the AQUAID

AI-powered fish identification platform, and eDNA frugal sampling methodologies, demonstrating how these complementary technologies could enhance existing visual observation programs. The diving community expressed substantial interest in integrating NEMO-Tools technologies into their monitoring activities. Dive centers recognized that hydrophone deployment during recreational dives could expand data collection to include underwater soundscapes, marine mammal vocalizations, and anthropogenic noise characterization. The AQUAID platform's AI-assisted species identification capabilities were identified as particularly valuable for accelerating image-based monitoring while reducing expert validation workload, potentially enabling broader taxonomic coverage beyond the current protocol-specified target species. Furthermore, the potential for incorporating eDNA water sampling into dive center operations was acknowledged as a mechanism for assessing microbial and planktonic biodiversity complementing visual surveys of macrofauna. The frugal tool approach and simplified protocols align well with the operational constraints and participant demographics characteristic of recreational diving tourism, suggesting high feasibility for integration.

Cross-Project Synergies

The synergies between NEMO-Tools and the Alonnisos initiative exemplify how methodological frameworks developed through one project can catalyze expanded applications addressing diverse but complementary conservation priorities. The Alonnisos program's focus on recreational diver engagement created an established network of trained citizen scientists, institutional partnerships with dive operators, validated training approaches, and functional data management infrastructure, all of which represent valuable assets for potential NEMO-Tools technology deployment. Conversely, NEMO-Tools technologies offer the Alonnisos network opportunities to expand monitoring dimensions, incorporate novel data types, and enhance scientific outputs without requiring fundamental restructuring of existing operational models.

The receptiveness of the diving community to NEMO-Tools technologies, combined with the demonstrated success of applying NEMO-Tools guidelines to a parallel initiative, suggests promising pathways for future collaboration. Joint implementation could enable comparative analyses assessing data quality across different citizen science approaches, pilot testing of integrated multi-method monitoring protocols combining visual observations with acoustic and eDNA data, and development of comprehensive training programs equipping citizen scientists with skills spanning multiple monitoring technologies.

These cross-project synergies ultimately serve NEMO-Tools' broader objectives of demonstrating operational principles, building marine citizen science capacity, and establishing sustainable monitoring models that can be adapted and replicated across diverse Mediterranean contexts. The Alonnisos experience provides concrete evidence that NEMO-Tools frameworks are not merely theoretical constructs but practical tools supporting real-world implementation while creating networks receptive to adopting NEMO-Tools technological innovations for enhanced marine biodiversity monitoring.

6. CS Landscape in Greece

Understanding the existing citizen science ecosystem in Greece provides valuable context for assessing how NEMO-Tools methodologies, technologies, and protocols can support and enhance ongoing initiatives while identifying opportunities for synergy and knowledge exchange. The Greek citizen science landscape comprises diverse initiatives spanning biodiversity monitoring, marine conservation, bird migration tracking, and public engagement platforms. This chapter examines major national citizen science initiatives, analyzing their operational approaches, success factors, and challenges to reveal opportunities for applying NEMO-Tools products and methodologies.

iSea: Multi-Platform Marine Conservation Through Citizen Science

<u>Key Citizen Science Initiatives</u>

iNaturalist Greece Platform: As Greece's national node of the iNaturalist Network, this platform provides accessible infrastructure for documenting all taxa across terrestrial and marine environments. The platform leverages mobile technology, enabling citizens to photograph organisms, submit observations with geolocation data, and receive AI-assisted species identifications subsequently validated by expert reviewers. The integration with the global iNaturalist database ensures data interoperability while maintaining Greek-specific curation and community engagement. iSea serves as the primary contact point for iNaturalist Greece (iNaturalistGR), a collaboration with the Goulandris Natural History Museum that positions Greece within the global iNaturalist Network. This partnership has mobilized over 13,000 volunteers contributing more than 140,000 biodiversity observations, demonstrating remarkable success in volunteer recruitment and sustained engagement.

"Is it Alien to you... Share it!" Program: Launched in 2016, this initiative specifically targets non-indigenous species (NIS) monitoring, addressing the critical threat of biological invasions in the Mediterranean. The project has engaged over 1,400 participants who submit observations of alien species, contributing to improved inventories of NIS distribution and expansion patterns in Greece and contiguous seas. The program produces educational materials including identification guides, informative posters in Greek and English, and promotes sustainable seafood consumption through the complementary "Pick the Alien & Eat Responsibly" campaign.

Mediterranean Elasmobranchs Citizen Observations (M.E.C.O.): The "Sharks and Rays in Greece and Cyprus" project operates within the broader M.E.C.O. Mediterranean network, collecting observations from fishermen, divers, and coastal communities. This initiative addresses the critical conservation status of Mediterranean chondrichthyans, with over half of shark, ray, and chimaera species facing extinction risk. By mobilizing sea users as observers, the project generates distribution and seasonality data that would be prohibitively expensive to collect through traditional surveys alone.

EVMAR (Evaluating Marine Litter in Greece): This comprehensive marine litter monitoring program engages citizens in documenting macro- and microplastic pollution along Greek coastlines. The project's findings, that 89% of Greek coasts exceed EU marine litter threshold values, demonstrate how citizen-generated data can provide policy-relevant information at national scales. The initiative employs standardized protocols aligned with OSPAR and Marine Strategy Framework Directive guidelines, ensuring data compatibility with regulatory frameworks.

obSERVING NATURE Projects: Multiple targeted monitoring initiatives focus on specific conservation priorities, including pen shells (Pinna nobilis and Pinna rudis), Mediterranean cushion coral, and critical coastal ecosystems like the *Erimitis peninsula*. These projects combine professional research with citizen observations, creating hybrid monitoring systems that expand spatial coverage while maintaining data quality through expert validation.

Strengths and Success Factors

iSea's citizen science initiatives exhibit several distinctive strengths that contribute to their effectiveness and sustainability. The organization's multi-platform integration strategy creates synergies across projects, allowing participants engaged in one initiative to easily contribute to others, thereby building a committed volunteer community with diverse expertise. The partnership with iNaturalist provides robust technological infrastructure requiring minimal development investment while offering proven user interfaces, data management systems, and global community connections. The organization demonstrates strong stakeholder engagement capacity, maintaining active partnerships with diving centers, fishing communities, marine protected area authorities, educational institutions, and local municipalities. These collaborations facilitate participant recruitment, ensure local relevance, and create pathways for translating findings into management actions. Communication and outreach approaches include social media campaigns, webinars, festivals, television programs, and traditional media engagement to maintain public visibility and recruit diverse participants. Scientific credibility is maintained through publications in peer-reviewed journals, participation in international research networks, and employment of standardized protocols.

Challenges and Areas for Development

Despite substantial achievements, several challenges constrain iSea's citizen science operations. Data validation resources represent a persistent bottleneck, as expert review of thousands of observations requires significant time investment, potentially creating delays between submission and feedback that may discourage participation. While automated AI-assisted identification on iNaturalist mitigates this challenge for some taxa, marine species, particularly cryptic or rarely photographed organisms, often require manual expert verification. Geographic coverage biases reflect typical citizen science challenges, with observations concentrated in accessible coastal areas, popular diving sites, and regions with active volunteer communities, while remote coastlines and deeper waters remain under-sampled. Participant retention beyond initial engagement requires ongoing investment in communication, feedback, and community building, necessitating sustained personnel capacity that may strain organizational resources during periods of limited funding.

Archipelagos Institute: Integrated Marine and Terrestrial Conservation Research

Key Citizen Science Initiatives

EcoNavigation Platform: This flagship citizen science program targets sailors, tourists, fishermen, divers, and sea enthusiasts, creating a network of observers documenting marine megafauna, invasive species, jellyfish blooms, and pollution incidents throughout the Greek seas and broader Mediterranean. Participants report sightings of marine mammals (dolphins, whales, seals), sea turtles, unusual species occurrences, and environmental degradation via email submissions including date, time, location coordinates, observation type, and photographic documentation where possible.

The program emphasizes opportunistic data collection from individuals already at sea for recreational or professional purposes, thereby minimizing additional effort required for participation. Archipelagos researchers conduct direct recruitment through port visits across Eastern Aegean islands, personally informing boat operators about the project and distributing EcoNavigation booklets and leaflets. Since project inception, over 100 boats from 20+ countries have been informed, with approximately 85% expressing interest in contributing observations. Photo-identification protocols enable individual marine mammal tracking through submitted images, with photographs analyzed against existing databases to establish movement patterns, site fidelity, and population dynamics. This citizen science component complements Archipelagos' professional boat survey program, dramatically expanding observational coverage across spatial and temporal scales impossible for research teams alone.

Invasive Fish Species Distribution Research: Building on fisheries monitoring infrastructure, Archipelagos engages fishermen and divers through questionnaire-based surveys documenting invasive species observations and catches. The organization produces educational materials including species identification booklets, informative posters in Greek and English, and leaflets distributed to key target groups. Research findings on species such as *Siganus luridus, Siganus rivulata, Sargocentron rubrum, Lagocephalus sceleratus,* and *Stephanolepis diaspros* inform management recommendations while raising awareness about ecological and economic impacts of biological invasions.

Strengths and Success Factors

Archipelagos' direct field presence and personal recruitment approach creates strong interpersonal connections with participants, fostering trust and sustained engagement that web-based recruitment alone may not achieve. The organization's long-term institutional presence in the Eastern Aegean has built deep relationships with local communities, authorities, and maritime stakeholders, creating social capital that facilitates both research access and citizen participation. The integration of citizen science with professional research programs enables direct validation of citizen observations against systematically collected data, enhancing credibility while identifying training needs or protocol refinements. Marine mammal photo-identification exemplifies this integration, with citizen-submitted images feeding directly into ongoing research databases maintained by specialist teams.

The organization's multimedia communication capacity, including documentary film production, environmental photography, and graphic design, enables sophisticated outreach materials that effectively communicate project goals and scientific findings to diverse audiences. International volunteer programs bring interns, graduate students, and early-career researchers to Archipelagos field stations, creating additional capacity for citizen science coordination, data processing, and participant support while providing educational opportunities for volunteers that enhance retention and skill development.

Challenges and Areas for Development

The EcoNavigation platform's email-based submission system represents a significant limitation compared to modern mobile applications with intuitive interfaces, real-time validation, and automated data processing. Manual data entry and processing of email submissions creates workload bottlenecks, potentially delaying feedback to participants and limiting scalability. The absence of structured digital platforms with user accounts, submission tracking, and data visualization may reduce engagement compared to projects offering participants interactive access to their contributions and collective progress. Geographic concentration of Archipelagos' operations in the Eastern Aegean, while enabling intensive local research, limits capacity for nationwide citizen science coordination. Projects would benefit from expanded recruitment beyond opportunistic port-based approaches to systematic online engagement strategies reaching broader demographics. The organization's research-intensive model requiring substantial expertise and equipment creates higher operational costs than coordination-focused NGOs, potentially constraining geographic expansion or project diversification.

Data standardization across diverse observation types, marine mammal sightings, pollution incidents, invasive species occurrences, jellyfish blooms, requires sophisticated database architecture enabling analysis across disparate data structures. Integration of citizen observations with regulatory monitoring frameworks could be strengthened to ensure compatibility with national and EU reporting requirements. Participant feedback mechanisms beyond project updates would benefit from more systematic approaches to communicating how individual observations contribute to scientific understanding and conservation actions.

HCMR: Research Institution-Led Citizen Science Innovation

Key Citizen Science Initiatives

NAUTILOS Marine Creatures Project: Utilizing the Zooniverse platform, the world's largest crowdsourcing platform for research, IMBBC created the "Marine Creatures" project where citizen scientists annotate underwater photographs to classify benthic communities on rocky substrates. Images from artificial reefs, ports, and natural caves captured during research activities are uploaded to Zooniverse, where volunteers identify sessile fauna including sponges, corals, tunicates, bryozoans, and algae using morphological characters visible in high-resolution imagery.

The project includes tutorials and field guides enabling participants without taxonomic training to contribute meaningful classifications, with multiple volunteers reviewing each image to assess agreement and flag uncertain identifications for expert verification. This approach enables processing of large image datasets that would be prohibitively time-consuming for researchers alone while providing educational opportunities for participants to learn about often-overlooked marine biodiversity.

NAUTILOS Plastic Monitoring Campaigns: HCMR organizes campaigns in touristic coastal areas of Crete engaging schools, citizens, and NGOs in collecting and categorizing macro- and microplastic litter according to type, origin, and environmental lifespan. Participants additionally collect water and sediment samples for microplastic isolation using simple methods (sieving, filtering, density separation). Data are published through dedicated citizen science interfaces with graphical maps indicating locations and quantities, while campaigns are presented at schools and public events to extend educational impact.

Diving Association Sensor Deployment: The NAUTILOS project provides diving associations with novel low-cost sensors measuring and recording environmental parameters (temperature, salinity, chlorophyll). Citizen scientists download data at regular intervals and upload to online platforms serving as visual databases with thematic map generation capabilities. This approach transforms recreational divers into mobile oceanographic observers, expanding spatial and temporal resolution of environmental monitoring.

RECONNECT and Alien Species Monitoring: Programs targeting alien marine species documentation, particularly around Rhodes (a primary entry point for Red Sea species into the Mediterranean), engage beachgoers, divers, and fishermen in photographing and reporting non-native species observations. Educational materials provide safe photography protocols and species identification guidance, with submissions uploaded via web forms or mirrored on iNaturalist. The Hydrobiological Station of Rhodes coordinates these efforts, leveraging its aquarium and public engagement facilities.

<u>Strengths and Success Factors</u>

HCMR's research institution credibility and resources provide substantial advantages for citizen science implementation. Access to EU project funding enables development of technological tools, production of high-quality educational materials, and personnel capacity for citizen science coordination. Integration with professional research programs creates clear scientific utility for citizen contributions, with citizen science data directly informing research questions, complementing systematic surveys, and contributing to peer-reviewed publications. The technological innovation focus distinguishes HCMR initiatives, with novel sensor development, platform prototyping, and methodological experimentation advancing citizen science practice beyond established approaches.

Partnerships with international platforms (Zooniverse) and networks (LifeWatch ERIC, NAUTILOS consortium) provide access to proven infrastructure, best practices, and cross-national collaboration opportunities. The institutional commitment to data preservation and accessibility through LifeWatch Greece infrastructure ensures long-term data availability beyond individual project lifespans, addressing a common citizen science challenge. Educational integration through aquarium facilities (CretAquarium, Rhodes Aquarium), school programs, and science communication events creates diverse engagement pathways reaching audiences beyond typical environmental volunteer demographics. The multi-project portfolio enables testing of different citizen science approaches, technologies, and engagement strategies, generating insights into what works across various contexts.

Challenges and Areas for Development

The complexity of research-driven protocols and technologies may create higher participation barriers compared to simpler observation-based programs. Sensor deployment by diving associations requires equipment distribution, training on device operation and data download, and ongoing technical support, logistical demands that may limit scaling. Image annotation tasks on Zooniverse, while accessible, may appeal primarily to intrinsically motivated participants rather than those seeking direct environmental engagement. Volunteer recruitment beyond project-specific campaigns appears less systematic than NGO-led initiatives with ongoing community-building efforts. HCMR programs benefit from event-based recruitment but may lack continuous outreach and engagement strategies sustaining participation between campaigns. Integration across HCMR's multiple citizen science initiatives could be strengthened to create unified volunteer communities contributing across projects rather than siloed participation. The translation of citizen science data into policy and management actions requires explicit attention, as research institutions' primary outputs are scientific publications rather than policy advocacy. While HCMR maintains relationships with management agencies, ensuring citizen science findings actively inform decisions requires dedicated effort beyond data analysis and publication. Participant feedback mechanisms demonstrating how contributions advance research and conservation could be enhanced to strengthen retention and satisfaction.

7. Conclusions

Citizen science represents a transformative approach to marine biodiversity monitoring and conservation, offering unprecedented opportunities to expand the spatial and temporal scales of data collection while fostering public environmental literacy, stewardship attitudes, and meaningful participation in science-informed decision-making. The guidelines, pilot projects, and landscape analysis presented in this deliverable demonstrate that well-designed citizen science initiatives can generate scientifically credible data addressing critical conservation challenges when they systematically attend to foundational project design, participation architecture, engagement strategies, data quality assurance, robust data management, appropriate technical infrastructure, and comprehensive evaluation frameworks.

The NEMO-Tools pilot projects exemplify how emerging technologies, passive acoustic monitoring, artificial intelligence for species identification, and environmental DNA analysis, can be adapted for citizen science applications through deliberate attention to accessibility, usability, and participant support. By eliminating financial and technical barriers, providing clear protocols and training materials, implementing multi-layered data validation approaches, and creating feedback mechanisms demonstrating impact, these initiatives enable diverse public audiences to contribute meaningfully to marine research while developing skills, knowledge, and connections to marine environments. The projects' emphasis on long-term sustainability through automated data collection processes and archival infrastructure addresses a persistent challenge in citizen science: ensuring that initiatives continue generating valuable data beyond initial funding periods.

Analysis of Greece's citizen science ecosystem reveals a mature and diverse landscape encompassing NGO-led coordination platforms, research institution innovations, strategic partnerships with global infrastructure providers, and field-based community engagement programs. Each organizational model presents distinctive strengths, alongside characteristic challenges related to funding sustainability, geographic coverage, data validation capacity, and policy influence. The diversity of approaches suggests that no single model optimally addresses all contexts; rather, effective citizen science implementation requires matching organizational structures, technologies, and engagement strategies to specific conservation priorities, target audiences, available resources, and institutional capacities.

Substantial opportunities exist for integrating NEMO-Tools products with existing Greek citizen science initiatives, leveraging established volunteer networks, stakeholder relationships, and data management infrastructure while enhancing monitoring capabilities through novel technologies and methodologies. Such integration could accelerate NEMO-Tools adoption, provide real-world validation of tool effectiveness, and strengthen collaborative capacity addressing shared marine conservation priorities. Realizing these opportunities requires proactive coordination, knowledge exchange, and partnership development ensuring that NEMO-Tools offerings align with operational needs and priorities of existing programs while complementing rather than duplicating established efforts.

The guidelines and examples presented in this deliverable provide a foundation for establishing and managing citizen science projects that advance marine conservation while delivering meaningful experiences to participants. By systematically addressing the interconnected dimensions of project design, implementation, and evaluation, and by learning from existing initiatives' successes and challenges, future citizen science programs can maximize their contributions to scientific understanding, environmental stewardship, and collaborative governance of Mediterranean marine ecosystems.

8. References

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