



Co-created citizen science as an approach to sustainable coastal monitoring and governance

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ABSTRACT

Environmental information remains insufficient across many coastal regions characterized by small settlements, limited institutional presence, and fragmented environmental governance. In such contexts, citizen science offers a promising strategy to strengthen local monitoring capacities, generate management-relevant data, and support decentralized environmental management. This article analyzed the experience of the Citizens for the Coastal Environment project, a co-created citizen science initiative implemented along the coast of Buenos Aires Province, Argentina, as an empirical case to examine the potential of community-based coastal monitoring in data-poor settings. The objective was to analyze the methodology employed, the outcomes achieved, and the factors that enabled sustained community participation over three consecutive years under conditions of limited resources and institutional support. Through a four-phase participatory process, 24 localities distributed along approximately 1500 km of coastline established community-based environmental monitoring systems addressing morphological, oceanographic, meteorological, and coastal litter variables. The methodological design was adapted to local contexts and supported the long-term engagement of more than 200 volunteers, even after the conclusion of institutional funding. The results showed that co-created citizen science could function as a low-cost, decentralized coastal monitoring approach capable of complementing formal environmental monitoring systems. Key outcomes included strong community ownership of the knowledge produced, the technical quality of the collected data, and the strategic use of information by local actors. The experience also identified conditions and limitations relevant to sustaining and adapting similar initiatives in other coastal regions.

1. Introduction

Coastal areas host a high diversity of ecosystems and human activities and are subject to increasing pressures stemming from urban expansion, tourism, pollution, and climate change (OECD, 2021; Cavazos et al., 2024; Zuo et al., 2025). These complex dynamics demand robust, locally responsive environmental monitoring systems that are sustainable over time and capable of informing public policies and adaptive management processes (Suškevičs et al., 2025; Wehn et al., 2025). However, in many regions worldwide, the availability of systematic and locally relevant environmental data remains uneven (Lameira et al., 2025). In many Latin American countries, significant gaps in environmental information persist, particularly in smaller localities or areas with limited institutional presence (Ruiz-Luna et al., 2021; Cavazos et al., 2024). Reliance on centralized monitoring systems, which typically entail high technical and budgetary requirements,

restricts territorial coverage and contributes to inequalities in access to data (Lameira et al., 2025).

In this context, citizen science has emerged as a complementary approach for expanding observational capacity, involving communities in knowledge production, and strengthening environmental governance (Bonney et al., 2009b; Skarlatidou et al., 2024). In coastal and marine settings, these approaches are increasingly recognized as a way to extend monitoring coverage in data-poor and resource-constrained contexts (Wehn et al., 2025). At the same time, citizen science initiatives vary substantially in how participation is organized across the research process. A widely used distinction identifies contributory projects, in which citizens mainly contribute data; collaborative projects, in which participants may also help refine methods, analyze information, or disseminate findings; and co-created projects, in which researchers and social actors jointly shape key stages of the process, from problem definition and study design to interpretation and communication of

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results (Bonney et al., 2009a; Shirk et al., 2012). This distinction is particularly relevant in coastal management contexts, where the value of participatory monitoring depends not only on data generation but also on the capacity of monitoring approaches to incorporate locally defined priorities, site-specific knowledge, and long-term stewardship concerns (Conrad and Hilchey, 2011; Frøelng et al., 2024).

Recent literature suggests that co-created and community-based monitoring initiatives can offer advantages that are especially relevant for coastal governance. Coastal areas pose particular monitoring and governance challenges because they are dynamic land–sea interfaces where geomorphological, oceanographic, meteorological, ecological, and human processes interact over short spatial and temporal scales. These challenges are often intensified by seasonal tourism, urban expansion, infrastructure development, erosion, storm impacts, pollution, and fragmented institutional responsibilities. As a result, coastal management requires information that is not only technically reliable but also spatially distributed, frequently updated, and sensitive to site-specific environmental and social conditions. Beyond expanding the spatial reach of monitoring, co-created and community-based initiatives may improve the local relevance of environmental information, strengthen trust between scientific and community actors, and support forms of environmental management that are more participatory and territorially grounded (Khair et al., 2021; Coppari et al., 2024; Suškevičs et al., 2025). In this sense, their value lies not only in producing additional data, but also in linking scientific knowledge with local experience and in creating conditions for the social appropriation and public use of environmental information. This is particularly important in socially and environmentally heterogeneous coastal regions, where monitoring systems must respond to uneven institutional capacity, variable resource availability, and multiple local concerns (Skarlatidou et al., 2024; Wehn et al., 2025; Corbau et al., 2025).

From a theoretical standpoint, these initiatives align with a pluralistic understanding of scientific knowledge, one that recognizes the value of local epistemologies and the need to produce relevant, context-specific data to support collective action (Eitzel et al., 2017; Skarlatidou et al., 2024). Within this framework, community appropriation of knowledge involves not only participation in data generation but also the capacity to use, reinterpret, and strategically project that knowledge within their territories (Pateman et al., 2025). Moreover, various studies have emphasized that trust-based relationships between local actors and technical teams are central to ensuring the continuity of these processes over time, particularly in contexts with limited institutional presence or scarce resources (Golumbic and Oesterheld, 2023; Leach et al., 2010a).

In Argentina, the institutionalization of environmental citizen science remains nascent. Recent national mappings indicate that many environmental citizen science initiatives have been promoted by academic institutions, civil society organizations, or mixed actor networks, but only a limited number have become integrated into official environmental monitoring or management programs (PNUD, 2022; 2023). These initiatives include, for example, projects focused on biodiversity observations, urban environmental issues, water quality, and environmental awareness, whereas long-term participatory coastal monitoring systems remain scarce. Furthermore, there are no specific public policies for funding or institutional strengthening that formally recognize citizen science as a valid tool for producing environmental information (PNUD, 2022). In coastal settings in particular, monitoring has largely relied on short-term scientific field campaigns led by academic teams, often based on periodic site visits, instrument-based measurements, and externally defined research agendas. These efforts have frequently coexisted with isolated awareness-raising actions, such as beach cleanups or educational activities, but have rarely developed into long-term participatory monitoring processes or sustainable community-based coastal observing systems (PNUD, 2023). Within this context, the co-created project Ciudadanos por el Ambiente Costero (CiuPAC) represents a pioneering initiative, not only because of its territorial scale and multi-site implementation, but also because it provides an opportunity to examine how

co-created citizen science can support more participatory and decentralized forms of coastal management.

This study therefore aimed to evaluate the methodology developed within CiuPAC, examine the outcomes achieved, and identify the key factors that enabled sustained community participation over three consecutive years. Drawing on this experience, the study explores how a co-created, multi-site citizen science initiative can contribute to the design of participatory coastal monitoring systems and to more inclusive, territorially grounded, and trust-based coastal management. Although these issues have often been discussed conceptually, empirical evidence from long-term, multi-site coastal monitoring experiences remains limited, particularly in Latin American contexts.

Because this study examines the development and evaluation of a co-created monitoring process, rather than the analysis of a single environmental dataset, the manuscript adopts an integrated structure. After describing the study area and evaluation framework, the design and implementation of the CiuPAC monitoring program are presented together with the evidence used to assess its main outcomes. This organization allows methodological decisions, operational results, and evaluation findings to be linked to each phase of the project, before discussing the implications, limitations, and transferability of the experience for participatory coastal monitoring and governance.

2. Study area

The project was carried out along the coast of Buenos Aires Province, Argentina, which extends for approximately 1500 km from the Partido de la Costa district in the north to Villarino in the south. This coastal strip includes a wide variety of ecosystems and geomorphological settings, such as sandy beaches, dune fields, cliffed coasts, estuarine environments, tidal flats, coastal wetlands, and low-lying flood-prone areas (Diez et al., 2007; Isla et al., 2018). It also encompasses localities with contrasting socio-economic and tourism dynamics, ranging from highly visited seaside towns with strong seasonal economies to small settlements with lower population density, more limited infrastructure, and less institutional capacity for environmental monitoring (Isla, 2013; Rojas et al., 2014). Because this is a temperate region, tourism is concentrated mainly in only a few months of the year, particularly during summer. This marked seasonality results in large numbers of visitors over short periods, followed by a pronounced decline in local economic activity during the rest of the year, a situation that is especially significant in smaller localities. Across this territory, coastal communities face multiple environmental challenges, including beach and cliff erosion, storm impacts, sediment redistribution, flooding and runoff-related processes, pressures associated with tourism and urban expansion, and, in several sites, increasing concern over coastal litter accumulation (Diez et al., 2007; Rojas et al., 2014; Isla et al., 2018). This environmental and socio-territorial heterogeneity makes the Buenos Aires coast a particularly relevant setting for evaluating participatory monitoring approaches capable of producing locally relevant information under diverse coastal management contexts.

The coastal areas selected for the implementation of monitoring activities correspond to 24 localities (Fig. 1) distributed across 12 municipalities, including both urban centers and small coastal communities. Most of these localities lack formal environmental monitoring systems and do not benefit from the consistent presence of state coastal management agencies.

3. Project evaluation

The overall aim of CiuPAC was to develop a co-created coastal environmental monitoring network in Buenos Aires Province capable of producing locally relevant information on coastal processes and, through that information, supporting the understanding and participatory management of environmental issues in coastal localities. To evaluate the project's development and scope, we designed an

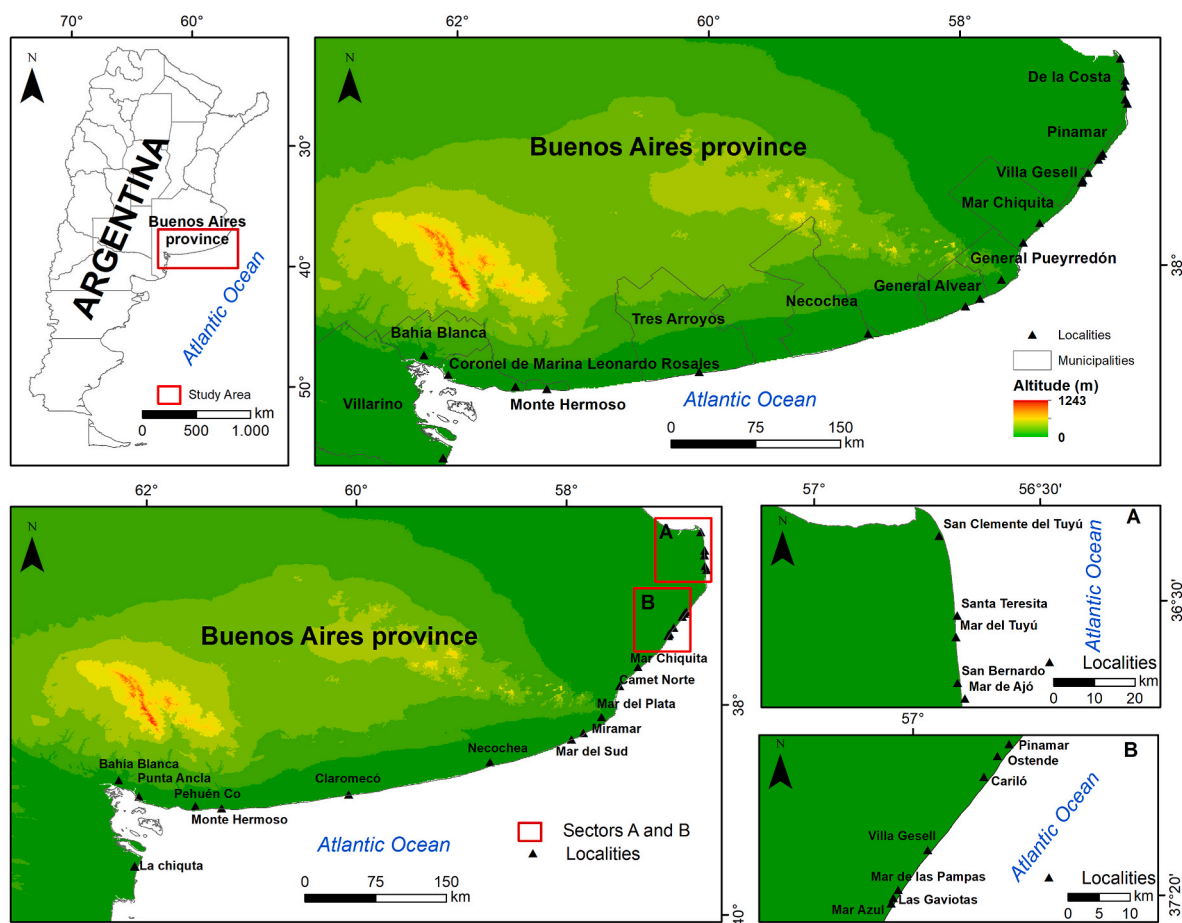


Fig. 1. Geographical distribution of the localities in Buenos Aires province that participated in the CiuPAC project.

evaluation matrix based on the open framework proposed by Kieslinger et al. (2018), which assesses citizen science initiatives across three core dimensions and considers both implementation processes and resulting outcomes and impacts. Because CiuPAC was a multi-site participatory coastal monitoring initiative, this framework was adapted to the project's context and objectives.

Based on this approach, three analytical dimensions were defined: (1) learning and capacity building, (2) the scientific and technical impact of the monitoring program, and (3) socio-environmental, institutional, and management-related impact. For each dimension, guiding questions were developed to examine both the processes involved and the outcomes and impacts observed. The matrix was then applied to CiuPAC using multiple sources of evidence generated throughout the project. These sources included project records, training materials, monitoring databases, reports produced by the scientific team, ongoing exchanges with local leaders, and concrete examples of how the information generated was used, interpreted, and shared. Particular attention was given to how locally identified environmental concerns were translated into monitoring variables and to how the information generated was used to interpret, communicate, or discuss coastal problems.

4. Design and implementation of the monitoring program

The CiuPAC project was developed using a co-created citizen science approach (Shirk et al., 2012; Eitzel et al., 2017). This approach seeks to generate context-specific, relevant, and socially meaningful knowledge by integrating scientific and community-based ways of knowing (Skarlatidou et al., 2024; Pateman et al., 2025). In line with international recommendations on data verification and credibility in citizen

science, the methodological design incorporated quality assurance procedures tailored to different stages of the monitoring cycle, from field measurement and data recording to validation and subsequent review (Freitag et al., 2016; Balázs et al., 2021).

The project was structured into four successive and interconnected phases (Fig. 2). These phases were designed in dialogue with the capacities, interests, and time availability of member organizations, with the aim of fostering ownership of the process, supporting continuity over time, and enhancing the practical usefulness of the information generated.

4.1. Community engagement and co-design of the monitoring program

CiuPAC emerged from a prior trajectory of collaboration between the scientific team and coastal organizations that later became part of AREDAC. This relationship began in 2012, when an environmental group from Villa Gesell contacted the scientific team seeking support to better understand local coastal dynamics and to carry out basic measurements in the context of opposition to a large-scale coastal development project. Between 2012 and 2016, this exchange gave rise to training activities, technical support, and the gradual building of trust between both parties (Fig. 3). During the same period, environmental organizations from different coastal localities in Buenos Aires Province, including the organization from Villa Gesell, became connected through shared concerns about coastal protection and later formed Asamblea Regional en Defensa del Ambiente Costero (AREDAC). Building on these previous relationships, the scientific team and AREDAC member organizations agreed in 2021 to jointly apply to a national call focused on marine sciences, through which CiuPAC was formally established (Fig. 3).



Fig. 2. Overview of the methodological phases of the CiuPAC project.

Participation in CiuPAC was restricted to organizations belonging to the AREDAC. This decision reflected the project's aim of working with pre-existing, locally rooted organizations that already had experience in environmental advocacy and strong ties to their territories. Although AREDAC does not hold legal status, it was formally recognized as the project's institutional counterpart by Argentina's Ministry of Science, Technology and Innovation, which funded the initiative in 2022. Its members interpreted this recognition as a symbolic milestone that strengthened their legitimacy as actors involved in the production and public use of environmental knowledge.

The co-created character of the project was expressed in its design, implementation, interpretation of results, and circulation of

information. The scientific team contributed the overall monitoring framework, methodological criteria, and minimum quality requirements needed to ensure technical consistency. AREDAC member organizations contributed their knowledge of local environmental problems, helped define observation priorities, selected locally relevant monitoring sites, and identified the operational and communication formats that were feasible in each community. As a result, the monitoring design was not imposed as a uniform external scheme, but developed through the articulation of scientific criteria with locally defined concerns and conditions.

During the first year of the project, local teams in 24 coastal localities were visited and trained in coordination with 14 AREDAC member organizations. Between 2022 and 2025, a total of 211 individuals participated in in-person workshops held within their own communities. Although theoretical and practical training was provided in all localities, not all of them moved into sustained implementation. In Monte Hermoso (Fig. 1), for example, monitoring activities were not initiated after training because the local organization had only a few active members and no stable group leader could be identified to coordinate the process. These activities included introductory meetings, co-design sessions, and methodological training tailored to local conditions. During these workshops, priorities were agreed by linking the main environmental concerns identified by each group with variables and monitoring strategies that were methodologically feasible within the project. At the request of participating organizations, mobile applications were not used during beach measurements, and paper data sheets were adopted instead in order to ensure operational autonomy. The organizations also requested that project outreach be limited to the social media platforms they considered most appropriate, and this was incorporated into the communication strategy. When tensions arose between methodological preferences and local feasibility, they were addressed through discussion with the local teams, seeking solutions that preserved minimum technical consistency while remaining workable for participants. These adaptations were an observed outcome of the co-design process, showing that methodological decisions could be adjusted to local capacities, time availability, and preferences without abandoning minimum technical criteria (Table 1).

The size of the volunteer teams varied widely across localities, from

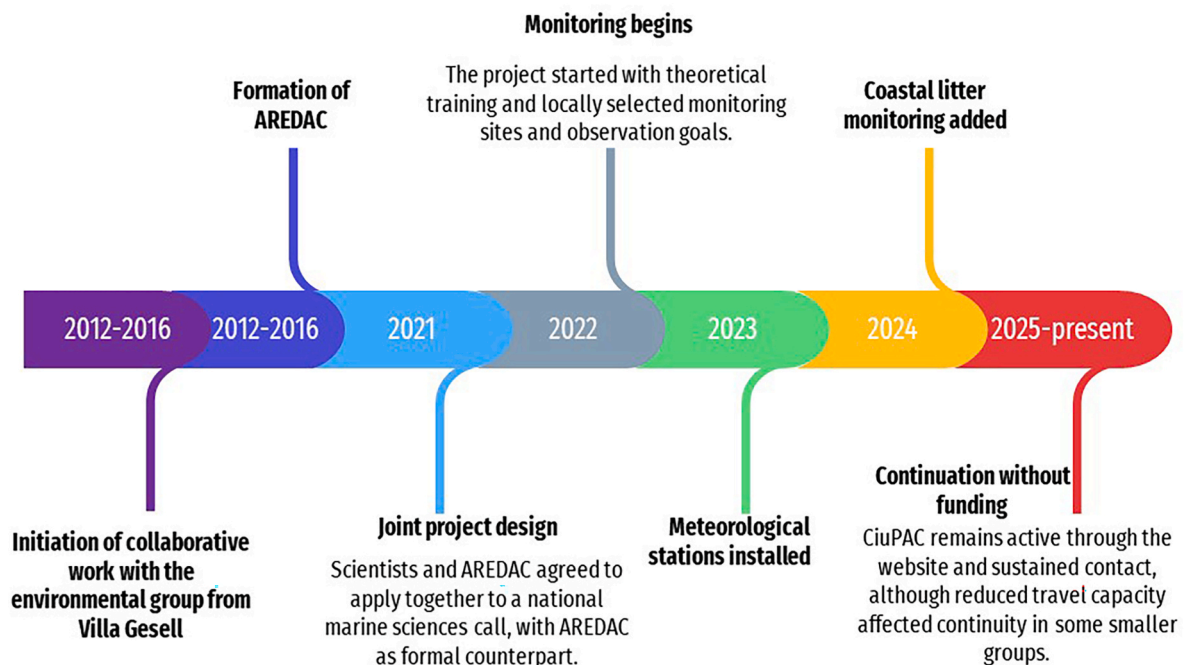


Fig. 3. Timeline of the co-creation and development of the CiuPAC project.

Table 1
Dimensions and guiding questions used in the evaluation matrix applied to the CiuPAC project.

Dimension	Processes and feasibility: guiding questions	Outcomes and impacts: guiding questions	Observed evaluation outcomes in CiuPAC
Learning and capacity building	Does the project address issues and concerns that are relevant to the participating groups? Are adequate opportunities for training, support, and feedback provided? Do participants engage in different stages of the monitoring process?	Did participants strengthen their understanding of coastal dynamics and the variables being monitored? Did they develop the capacity to measure and interpret local processes? Was methodological appropriation and continuity of engagement observed?	Improved understanding of the monitored coastal processes (Sections 4.1 and 4.2). Development of practical skills to apply coastal monitoring protocols (Section 4.2). Adaptation of procedures to local capacities, time availability, and preferences (Section 4.1). Increased operational autonomy among local teams (Sections 4.2 and 4.5). Volunteer participation in the contextual interpretation of data (Sections 4.1 and 4.3). Uneven but sustained monitoring in several localities after the end of project funding (Section 4.5).
Scientific and technical impact of the monitoring program	Are the monitoring objectives and protocols clear and appropriate? Are mechanisms for follow-up, validation, and adjustment incorporated throughout the project? Does the design allow emerging needs to be incorporated during the process?	Did the project generate environmentally relevant information that was methodologically consistent and context-specific? Did it expand the territorial coverage of coastal monitoring? Did the information produced help interpret relevant coastal processes and strengthen the technical credibility of the data?	Expansion of coastal monitoring coverage across multiple localities (Sections 4.3 and 4.5). Production of environmental information on morphological, oceanographic, meteorological, and coastal litter variables (Section 4.3). Application of simple, standardized, and reproducible protocols for data collection (Section 4.3). Implementation of validation and traceability mechanisms adapted to each type of variable (Section 4.3). Generation of methodologically consistent information for interpreting coastal processes and site-specific environmental problems (Section 4.3). Incorporation of new monitoring variables in response to emerging participant demands (Sections 4.1 and 4.3).
Socio-environmental, institutional, and management-related impact	Does the project strengthen coordination between the scientific team and AREDAC member organizations? Are opportunities for information sharing and communication among actors promoted? Are issues raised by participating organizations incorporated into the project?	Were the data and reports used to understand, communicate, or discuss coastal problems? Did participation in CiuPAC strengthen the public legitimacy of the organizations involved? Was the network able to remain active, at least partially, after the end of the funding period?	Variable use of project data, reports, and materials to communicate coastal processes and local environmental problems (Sections 4.1 and 4.4). Strengthened public legitimacy of some participating organizations as actors involved in producing and using environmental knowledge (Section 4.1). Incorporation of citizen-raised concerns, such as coastal litter, into the monitoring program (Sections 4.1 and 4.3). Support for community participation in public discussions on coastal problems and infrastructure works (Sections 4.1 and 4.4). Consolidation of communication, feedback, and exchange channels between the scientific team and local organizations (Section 4.4). Partial continuity of the network after the end of funding, shaped by local leadership, organizational capacity, and continued involvement of the scientific team (Section 4.5).

Note: Section numbers in parentheses indicate where each observed evaluation outcome is further developed in the manuscript.

groups with more than 20 active participants to others sustained by only 2 or 3 people. This variation occurred within a network of organizations already united by a shared commitment to protecting the coastal environments in which they lived. Within that common framework, participants repeatedly expressed, during workshops and follow-up exchanges, a strong interest in expanding their understanding of coastal processes and valued the opportunity to generate reliable data that could support the protection of their local environments.

Co-creation also extended beyond data collection. Local participants contributed to the interpretation of the information produced by providing contextual knowledge about site-specific processes. For example, once beach profiles had been graphed by the scientific team, participants helped interpret whether the observed changes reflected generalized erosion or more localized processes, such as runoff or gully formation affecting a specific sector. In addition, some monitoring components were introduced in response to priorities raised by the

organizations themselves. Coastal litter monitoring, incorporated in 2024, was not part of the project's initial design but emerged from participant demand. Similarly, the use of the information generated went beyond simple feedback to volunteers: organizations used project reports, rainfall and wind data, and other outputs to communicate local environmental processes, disseminate CiuPAC activities, and support their interventions in public discussions related to coastal problems and infrastructure works. These practices provided evidence of methodological and social appropriation, as participants were not only involved in data collection but also contributed to the contextual interpretation, adaptation, and public circulation of the information produced.

Overall, CiuPAC can be understood as a co-created coastal environmental monitoring experience built on prior trust, territorial knowledge, and the joint definition of monitoring priorities. This collaborative construction enabled not only the production of environmental data, but also the generation of contextualized information, the social

appropriation of results, and the strengthening of local capacities with potential relevance for participatory coastal management.

4.2. Volunteer training and coordination

To support implementation across diverse coastal settings, the project combined locally delivered training with a decentralized organizational structure. Training was conducted through theoretical and practical workshops held in each locality and adapted to local conditions. Workshop duration ranged from two to three days depending on the number of participants and included classroom sessions, beach-based practical exercises, and the distribution of standardized low-cost kits containing manuals, data sheets, and basic monitoring instruments.

Training was organized in two main stages. The first, carried out in 2022, focused on coastal environmental dynamics, the identification of key environmental variables, and the application of monitoring methodologies. The second, implemented in 2023, introduced meteorological and climatic monitoring, including the installation, use, and maintenance of manual rain gauges and automatic weather stations. In this phase, the people responsible for operating these instruments were selected by the local teams themselves and trained in situ by the scientific team. In some localities, rain gauges were distributed door to door, together with personalized guidance on installation, use, and data recording.

To strengthen continuity and facilitate implementation under uneven local conditions, the project also developed a three-level participation structure inspired by the ranking system proposed by Freitag et al. (2016) (Table 2). This structure recognized differences in availability, experience, and degree of commitment among participants while allowing responsibilities to be distributed without losing methodological coherence.

The first level consisted of local coordinators, identified during the initial meetings in each locality through participatory observation (Spradley, 1980). These individuals stood out for their organizational initiative, their ability to connect with others, and the recognition they received from their peers. Their role was informally validated within each group, which helped ensure community legitimacy and strong territorial embeddedness, consistent with participatory action research principles (Cornish et al., 2023; Leach et al., 2010b). Local coordinators acted as a bridge between the scientific team and their communities by organizing field campaigns, maintaining group engagement, facilitating communication, and helping sustain activities over time.

The second level was composed of methodological guarantors: participants who completed the technical training, received certification, and assumed responsibility for the correct application of monitoring protocols in the field. Their role was to support methodological consistency during each campaign and help ensure that recorded data met the agreed quality standards. The third level included occasional contributors, who joined specific campaigns without prior technical training and provided logistical or operational support during monitoring activities.

Together, this combination of place-based training and differentiated participation roles made it possible to adapt the monitoring program to local conditions while maintaining operational continuity across the network. Its functioning was further supported by the ongoing presence of the scientific team, which remained accessible and closely engaged throughout the project. This organizational structure provided evidence that in-person training, differentiated roles, and continued support fostered practical monitoring skills and varying degrees of operational autonomy among local teams.

4.3. Implementation of the monitoring program and data quality assurance

Monitoring activities were carried out by local teams at monthly, daily, or continuous intervals depending on the variable considered (Table 3). The participatory protocols were adapted from existing

methodologies (Bustos et al., 2013; Vallarino and Urrutia, 2021) and were designed to be simple, reproducible, and suitable for community-based settings. The variables monitored included coastal morphology, oceanographic features, meteorological parameters, and coastal litter. These variables were selected because they were directly related to the main environmental concerns raised by local groups, including shoreline and beach change, storm and runoff impacts, local weather variability, and coastal litter accumulation. For each variable, accessible instruments and standardized recording procedures were defined (Table 3).

All data were initially recorded on paper forms and later digitized by the local teams using restricted-access accounts on the project's web platform. This procedure, which was collectively agreed at the start of the project, ensured both traceability and operational autonomy. Data quality was supported through multiple validation mechanisms, including photographic evidence, cross-checking, differential GPS measurements, comparisons with official meteorological stations, and laboratory analyses in specific cases, in line with recommendations from the citizen science literature on data verification and credibility (Freitag et al., 2016; Balázs et al., 2021; Lin Hunter et al., 2024) (Table 4).

Participatory monitoring was conducted between June 2022 and June 2025, across 24 localities. However, the actual implementation of the monitoring scheme varied among localities according to local conditions, community priorities, and organizational capacity (Table 4). In practice, this meant that not all localities monitored the same set of variables or sustained the same sampling frequency throughout the project. While some groups maintained regular measurements across several components of the monitoring program, others prioritized variables that were either more closely related to local concerns or more feasible given their available time, number of participants, and logistical capacity. As a result, the spatial and temporal coverage of the dataset was uneven across the network, reflecting both the flexibility of the co-designed approach and the operational differences among local teams.

In this study, technical quality was understood as the ability to generate methodologically consistent, traceable, and appropriately validated information according to the type of variable being measured. The validation strategies summarized in Table 4 provided evidence that this level of technical quality was achieved across different components of the monitoring program. This did not imply assuming full equivalence with highly instrumented scientific campaigns, but rather recognizing that standardized protocols, prior training, technically guided site selection, repeated observations, and multiple validation procedures made it possible to produce data that were sufficiently robust for environmental interpretation. Management usefulness, in turn, referred to the ability of those data to provide locally grounded evidence on specific coastal issues and to support their understanding, communication, and

Table 2
Participation levels within the organizational structure of the CiuPAC project.

Level	Inclusion Criteria	Role in Monitoring and the Network
Local coordinators	Community recognition (natural leadership, organizational skills, and sustained commitment)	Coordination of field campaigns, liaison with the scientific team, motivation of new participants, conflict resolution, and continuity of the process after funding ends
Methodological guarantors	Participation in theoretical and practical workshops and technical certification	Rigorous application of protocols, field-based methodological supervision, and technical support to the local team
Occasional contributors	Occasional voluntary participation without prior technical training	Operational support in logistical tasks, data collection, and ad hoc assistance during monitoring campaigns

discussion at the local scale. Beach profiles provide a good example: beyond being produced through a common supervised protocol, their interpretation was complemented by the knowledge of local groups, who contributed contextual knowledge that helped determine whether the observed changes reflected generalized erosion or more localized processes, such as runoff or gully formation affecting specific sectors of the profile. In this way, the data were not only technically consistent but also useful for contextualizing coastal dynamics and supporting local discussions around site-specific environmental problems, including erosion, runoff-related changes, storm impacts, sediment redistribution, and coastal litter accumulation. The following sections describe how each monitored variable was implemented in practice and the specific mechanisms used to support data quality.

4.3.1. Coastal morphology

Morphological measurements were conducted monthly, prioritizing spring low tide days to maximize the visibility of the beach profiles. In each locality, the simple topographic profile method proposed by Bustos et al. (2013) was applied, which uses two 150 cm graduated metal rods and either a measuring tape or a graduated rope (Fig. 4c). Measurement sites were selected by local teams according to collectively defined criteria, including proximity to participants' homes, ease of access, and environmental representativeness, while avoiding sectors directly affected by infrastructure or discharge points. In localities with more available volunteers or multiple coastal issues of interest, more than one site was monitored.

Profile validation relied on three complementary strategies: (1) simultaneous measurements using both basic equipment and differential GPS (RTK) during joint technical campaigns; (2) georeferenced photographic records taken from a standardized perspective at the beginning and end of each profile (with the mobile phone placed on the measuring rod facing the sea and then the land); and (3) remote supervision by the technical team through analysis of the images and data sheets submitted.

For surface sediment, three variables were estimated: grain size, sorting, and grain shape. Samples were collected concurrently with the topographic profile measurements, and the exact point of extraction within the profile was recorded (dune toe, berm, and swash zone). A visual technique specifically adapted for this project was used, which

Table 3
Environmental variables included in the participatory monitoring program of the CiuPAC project.

Variable	Proposed Parameters	Recommended Frequency	Instruments and Techniques
Beach morphology	Topographic profile	Monthly	Graduated rulers (adapted from Bustos et al., 2013)
Surface granulometry	Sediment size, shape, and sorting	Monthly	Visual-perceptual field analysis (adapted from Vallarino and Urrutia, 2021)
Oceanographic parameters	Wave height and period, breaker type, longshore current	Monthly	Direct visual observation (adapted from Bustos et al., 2013)
Manual meteorology	Daily precipitation	Daily	Manual rain gauges
Automatic meteorology	Temperature, humidity, pressure, wind, UV index, precipitation	Continuous	Automatic weather stations
Coastal litter	Quantity and type of litter	Monthly	Collection and classification using a guide adapted from OSPAR (2020)

was based on a printed scale template to determine grain size, along with reference charts to identify sorting and shape (Vallarino and Urrutia, 2021) (Fig. 4a and b). Validation of these records included cross-checking by members of the same team, comparison with laboratory analyses, and photographic documentation of the sampled sediments.

4.3.2. Oceanographic parameters

Oceanographic variables were recorded through direct observation from the shoreline using a methodology adapted from the littoral environmental observations (LEO) protocol developed by the Coastal Engineering Research Center (CERC) in the United States and later adjusted by Bustos et al. (2013) for use in community-based contexts.

The technique relies on visual estimates guided by standardized procedures, enabling a systematic and replicable interpretation. The variables recorded included wave height and period, breaker type (spilling or plunging), and the direction and velocity of the longshore current.

These observations were carried out prior to beach profile measurements so that the oceanographic data reflected sea conditions at the time of morphological sampling. Measurements were taken from the shoreline, with at least thirty consecutive waves observed to estimate the average period and height. The longshore current velocity was determined via the controlled drift of a floating object, with the time measured over a known distance between two points (Fig. 4d).

The primary validation strategy consisted of systematic comparisons with open-access oceanographic forecasts, particularly through platforms such as Windy and Windguru. This enabled the identification of major inconsistencies and the adjustment of local estimation criteria. Complementary strategies included photographic documentation of sea conditions at the time of observation and comparisons of estimates among observers from the same team.

4.3.3. Meteorology

Meteorological monitoring included daily precipitation records from manual rain gauges and continuous atmospheric observations from automatic weather stations. Both instruments were managed locally by trained volunteers during the second phase of the project.

A total of 83 manual rain gauges were installed across eight localities selected on the basis of the size and density of their urban areas. The placement of each rain gauge and the designation of those responsible for monitoring were determined by local coordinators and methodological guarantors, following guidelines provided by the scientific team. Efforts were made to represent both central and peripheral areas, ensuring even distribution in open spaces. Precipitation readings were taken daily at 23:59 h, in accordance with a standard protocol established during the training sessions.

In addition to the officially distributed instruments, several individuals voluntarily acquired their own rain gauges and joined the observation network on their own initiative, thereby expanding spatial coverage and strengthening their sense of ownership in the process.

Fifteen automatic weather stations were also installed, each managed by designated volunteers within their communities. These individuals receive specific training on operation, maintenance, and basic troubleshooting. The stations recorded data every 5 min, generating continuous time series for temperature, humidity, atmospheric pressure, precipitation, wind speed, and wind direction. This decentralized approach enabled continuous instrument operation without relying on the physical presence of the scientific team; remote support via video calls was only occasionally needed.

In three localities, particularly in rural areas, participants voluntarily shared the datasets from their personal weather stations, thereby enriching the project's monitoring network.

Validation of the precipitation data collected by manual rain gauges was carried out through comparisons with data from nearby official meteorological stations and with the project's own automatic stations. In

Table 4
Monitored variables, spatial coverage, frequency, number of measurements, and validation strategies (June 2022–June 2025).

Variable	Localities	Recommended Frequency	Measurements Conducted	Technical Validation Strategy
Beach morphology	19	Monthly (since June 2022)	608	Differential GPS, standardized photographs, cross-checking of data sheets
Surface granulometry	19	Monthly (since June 2022)	523	Visual cross-checking among operators, spot comparisons with laboratory analyses
Oceanographic parameters	19	Monthly (since June 2022)	605	Comparison with open-access forecasts, photographs, consensus among observers
Precipitation (manual)	10	Daily (since June 2023)	1095 records per rain gauge	Comparison with nearby automatic and official stations, photographs of instruments
Automatic meteorology	15	Continuous (every 5 min) since June 2023	–	Comparison with nearby official meteorological stations
Coastal litter	8	Monthly (since March 2024)	89	Photographs of the monitored area and of the sorted litter



Fig. 4. Monthly monitoring activities. A. Sediment characterization; B. Beach profile measurement; C. Reference chart for visual sediment analysis; D. Longshore current observations.

addition, periodic photographs of the rain gauges were requested to verify proper installation and general conditions.

4.3.4. Coastal litter monitoring

Coastal litter was incorporated into the project in 2024 in response to concerns raised by local groups, who identified it as an important environmental issue requiring systematic observation.

The measurements were conducted monthly and on a sustained basis by previously trained volunteers. The continuity of monitoring allowed for the development of local time series of high value, particularly at sites where no prior official monitoring efforts existed.

Surveys were carried out along fixed 20-m transects, covering the full width of the beach down to the low tide line. Litter items were classified following the standardized protocol of the *OSPAR Commission (2020)*, which is widely used in international studies for the characterisation of marine litter in coastal environments. The recording process involved the quantification and typological classification of each item collected via data sheets adapted from the original format.

At this stage, new localities also joined the project, some of which had not participated in previous monitoring activities. The inclusion of this variable acted as an entry point for new groups interested in taking part, expanding both the geographical reach and the diversity of actors involved in the monitoring network.

Data validation was conducted through systematic photographic documentation of both the collected litter and the surveyed area, which enabled verification of the correct protocol application and ensured

comparability across localities.

The process also revealed differences in operational continuity, both during the project and in terms of its future projection. Some localities maintained uninterrupted monitoring activities; others suspended them due to operational difficulties or organizational changes; and a third group expressed the intention to resume in the near future (Fig. 5). This diversity of trajectories reflects both the level of autonomy achieved in each territory and the challenges inherent to long-term participatory processes.

4.4. Science communication and community-level feedback

As an integral part of the methodological strategy, the project incorporated accessible and context-sensitive communication mechanisms to ensure process visibility, facilitate timely access to results, and sustain engagement with participating communities. These mechanisms were conceived not only as dissemination tools but also as spaces for feedback, horizontal exchange, and community appropriation of the knowledge produced.

An open-access web platform was created as a centralized space for data upload, consultation of methodological materials, access to recording sheets and manuals, and publication of preliminary results (<https://ciupac.iado-conicet.gob.ar/>). Each participating organization had personalized user access to upload information and consult project-related content. In addition to centralizing data, the platform also hosted tutorials, scientific outputs related to the project, and interviews with participants, thereby supporting both methodological continuity and the circulation of results within and beyond the network.

Communication through social media was defined in agreement with AREDAC member organizations and adapted to their technological and communication preferences. At their request, the project limited its institutional presence to specific platforms, leading to the creation of official Facebook (<https://www.facebook.com/profile.php?id=100081942772176>), Instagram (<https://www.instagram.com/p.ciupac/>), and YouTube (<https://www.youtube.com/@proyectociupac7377>) profiles, where interviews, field records, and audiovisual materials coproduced with the communities were shared. Operational coordination was supported mainly through instant messaging groups, which functioned as spaces for consultation, troubleshooting, exchange of results, and mutual support between the scientific team and the participating organizations. Because these were tools already in use by local groups, they facilitated agile communication, reinforced a sense of belonging, and helped sustain collective learning throughout the project.

As part of this visibility and ownership strategy, the project also developed a shared visual identity, including a distinctive logo, and a project name agreed upon by participants. These resources were used across social media, field sheets, publications, and educational materials. In addition, infographics and audiovisual materials were designed and subsequently used by the organizations themselves in fairs, talks, educational activities, and community outreach initiatives. In many cases, these materials became local tools for environmental

communication and awareness-raising that extended beyond the original scope of the project.

Overall, this communication strategy was consistent with international recommendations on active feedback, accessibility, and openness in citizen science (ECSA, 2015; Pateman et al., 2025), and it played an important role in strengthening trust among actors, supporting the circulation of project outputs, and reinforcing the visibility and legitimacy of the process. It also provided evidence that communication and feedback mechanisms supported the social appropriation of project outputs, as several local organizations used data, reports, and communication materials to explain coastal processes, raise awareness, and

participate in public discussions on coastal problems.

4.5. Post-funding continuity and limitations

Following the end of institutional funding in April 2025, 15 of the 24 settlements that had actively participated in the project continued to carry out monitoring campaigns autonomously, representing a continuity rate of 62.5%. This persistence was supported by strong local leadership, the continued use of project instruments, and the maintenance of communication channels with the scientific team. In several cases, local organizations also made practical use of the information

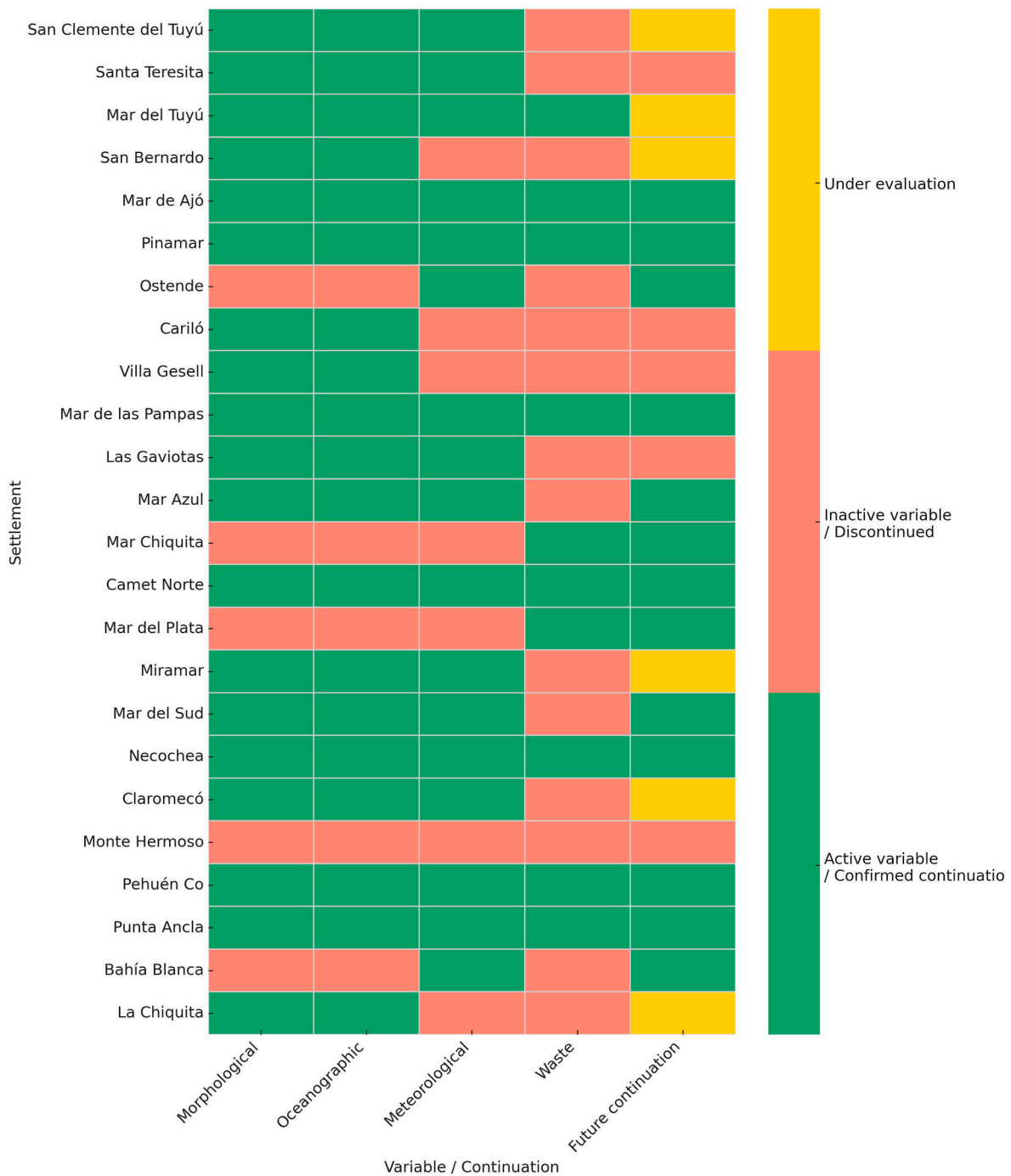


Fig. 5. Distribution of monitored variables and continuity of participating settlements. Green indicates continued involvement in the project, yellow denotes settlements currently evaluating future participation, and red indicates discontinued involvement. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

generated through CiuPAC in community reports, presentations to local authorities, and environmental awareness initiatives, indicating that the project outputs retained value beyond the funded phase.

At the same time, the continuity of the monitoring program was strongly affected by the end of funding. During the funded period, the scientific team was able to conduct annual in-person visits to the 24 participating localities, which helped sustain not only technical support but also the relationship with local groups and the motivation of volunteers. After funding ended, communication continued through phone calls, WhatsApp, and the project website, which helped prevent a complete interruption of activities. However, the absence of continued in-person support reduced the frequency and continuity of the measurements that required greater time investment, local coordination, and technical accompaniment.

This effect was not homogeneous across variables or localities. In the localities that had actively participated in measurements, activities that had initially been carried out monthly often shifted to a seasonal frequency, as occurred with beach profiles, sediments, and some oceanographic parameters, and in some cases to an annual frequency for coastal litter monitoring. By contrast, rain-gauge measurements continued in all localities, and maintenance of the automatic weather stations was also sustained. These differences suggest that continuity depended not only on participant commitment, but also on the operational effort required by each type of measurement and on the degree of continued involvement that could be maintained by the scientific team. In some cases, limitations were linked not only to group size but also to the physical characteristics of the monitored area. In La Chiquita (Fig. 1), for instance, some measurements were initially carried out, but continuity could not be sustained because the monitored site was located more than 70 km from where participants lived permanently, as the area consisted mainly of seasonal housing with no stable resident population. This made regular monitoring logistically difficult despite the group's initial involvement.

These constraints were further amplified by differences in the size and organizational capacity of local teams. Some monitoring groups involved more than 15–20 participants, whereas others relied on only 2 or 3 people. In the latter cases, the limited number of participants increased the individual workload and made it more difficult to sustain certain activities once the period originally planned for the funded project had ended. Although contact with these groups was maintained and interest in the project results persisted, the reduction in face-to-face support had a stronger effect in localities with lower organizational capacity.

These patterns indicate that post-funding continuity was an important but uneven evaluation outcome, shaped by the interaction between local leadership, organizational capacity, operational demands, and the continued involvement of the scientific team. In this sense, while CiuPAC offers transferable elements for the design of participatory coastal monitoring initiatives, its replicability should not be assumed automatically. Sustaining this type of process requires not only clear protocols and technical guidance, but also resources to maintain territorial engagement, strengthen local leadership, and provide continued support to groups with uneven capacities. Rather than a strictly replicable model, CiuPAC should therefore be understood as an experience that helps identify conditions, strategies, and tensions that are relevant for adapting similar approaches to other coastal contexts.

5. Discussion

The discussion focuses on the main evaluation outcomes that emerged from the CiuPAC experience and that are most relevant for understanding its contribution to participatory coastal monitoring and governance. These include the coastal management relevance of co-created monitoring, the credibility and management usefulness of citizen-generated data, the social appropriation of project outputs, and the conditions that shaped continuity after the end of institutional

funding. These topics were selected because they reflect the main strengths and limitations observed during the implementation of a multi-site citizen science initiative in a data-poor coastal context. They also correspond to the main evaluation outcomes identified through the analytical framework presented in Table 1.

5.1. Co-created citizen science and coastal management relevance

The CiuPAC project provides empirical evidence that co-created citizen science can support coastal environmental monitoring in contexts where formal institutional capacity is limited and environmental information gaps persist. While these dynamics have been widely discussed at a conceptual level, empirical evidence from long-term, multi-site coastal monitoring initiatives remains limited, particularly in decentralized governance settings. In line with the participatory framework proposed by Shirk et al. (2012) and further developed by Eitzel et al. (2017), this experience shows that involving local actors throughout the monitoring cycle can strengthen the relevance and legitimacy of the information produced. Beyond its social dimension, the project also demonstrates that community-based monitoring can generate data of practical value for coastal management by expanding spatial coverage and sustaining observations in areas not reached by official monitoring programs, as highlighted in recent assessments of citizen science contributions to environmental monitoring (Wehn et al., 2025). By integrating local knowledge with scientific guidance, CiuPAC functioned as a complementary system rather than an alternative to formal approaches, contributing locally grounded information that can support adaptive management discussions in decentralized coastal settings, consistent with governance-oriented perspectives on participatory environmental data (Skarlatidou et al., 2024; Corbau et al., 2025).

Although CiuPAC was implemented along the coast of Buenos Aires Province, the conditions under which it operated are not unique to this setting. Many coastal regions worldwide are characterized by fragmented settlement patterns, limited institutional presence, and uneven access to environmental information, particularly outside major urban centers. In this sense, the relevance of CiuPAC lies not only in its territorial scope, but also in the way its co-created monitoring framework responds to governance challenges that are common across many coastal systems. By combining local knowledge with simple, validated protocols, the project illustrates how participatory monitoring can extend environmental observation in data-poor and resource-constrained contexts while remaining aligned with broader coastal management goals (Wehn et al., 2025; Corbau et al., 2025).

5.2. Data quality, credibility, and management usability

Concerns about the quality and reliability of citizen-generated data remain a recurring issue in discussions of how citizen science can contribute to environmental management. Several authors have noted that doubts about data credibility often limit the uptake of citizen science outputs in formal decision-making processes, particularly in coastal management contexts where technical standards are well established (Balázs et al., 2021; Soriano-González et al., 2024; Wehn et al., 2025). As Freitag et al. (2016) argue, however, data quality in citizen science does not depend solely on the level of instrumentation or technological sophistication, but also on protocol design, consistency of implementation, and the presence of explicit validation procedures throughout the monitoring process.

In this regard, the CiuPAC experience supports the view that community-based monitoring can produce credible environmental information when quality assurance is built into the project from the outset. Rather than relying on highly sophisticated technologies, the robustness of the data generated depended on the combination of standardized protocols, prior training, repeated observations, and multiple validation procedures. This is consistent with recent syntheses emphasizing the role of transparency, traceability, and feedback in

strengthening the scientific value of citizen-generated datasets (Balázs et al., 2021; Lin Hunter et al., 2024).

From a coastal management perspective, the value of the information generated lies not only in its technical consistency but also in its practical usefulness. As noted by Wehn et al. (2025), citizen-generated data are more likely to be taken up when they are transparent, traceable, and aligned with existing information needs. In the case of CiuPAC, management usefulness was expressed through the production of locally relevant evidence on coastal processes that could support understanding, communication, and public discussion of environmental issues at the local scale. This suggests that, in decentralized coastal settings, the contribution of citizen science to management may extend beyond formal institutional uptake and include its capacity to strengthen locally grounded interpretation, communication, and participatory engagement around coastal problems.

5.3. Community appropriation and emerging governance functions

Beyond data production, the CiuPAC experience shows how co-created citizen science can foster processes of community appropriation that extend into coastal governance and management practices. As noted by Pateman et al. (2021), the ability of communities to use, reinterpret, and strategically mobilize knowledge is central to the transformative potential of participatory research. In this case, appropriation was reflected not only in the continued use of monitoring practices and project-generated information, but also in the differentiated trajectories of participation and continuity observed across settlements over time (Fig. 6). These trajectories suggest that the contribution of citizen science to coastal management lies not only in data generation, but also in strengthening the capacity of local actors to engage with environmental issues in informed and territorially grounded ways.

5.4. Conditions and limits of sustained monitoring beyond project funding

Several studies on co-created and community-based citizen science have shown that sustaining long-term participation remains one of the most persistent challenges of these initiatives. Even in well-designed projects, participation often declines over time once initial coordination efforts weaken, particularly where local organizational capacity is uneven (Freitag et al., 2016). Similarly, Golumbic and Oesterheld (2023) argue that continuity in co-created projects depends less on the participatory framework itself than on the presence of stable local leadership and collective organizational routines. In coastal settings, where institutional responsibilities are often fragmented and support structures are discontinuous, these challenges may be further amplified (Corbau et al., 2025).

The CiuPAC experience is consistent with these findings. Although the project was based on a shared methodological framework, continuity varied markedly across localities depending on leadership stability, organizational strength, group size, and the ability to sustain local coordination over time. The results indicate that continued monitoring after the end of funding was made possible not only by the methodological design, but also by the interaction between locally adapted procedures, sustained commitment from participants, and the presence of territorially embedded leaders capable of maintaining group engagement under changing conditions. In this sense, the CiuPAC case reinforces the view that continuity in participatory environmental monitoring depends on socially embedded forms of coordination and trust, rather than on protocol design alone (Golumbic and Oesterheld, 2023; Leach et al., 2010a).

At the same time, the experience also revealed clear limits to that continuity. The reduction of in-person support after the end of funding had a stronger effect in localities with smaller groups and lower organizational capacity, and the frequency of some measurements declined accordingly. This pattern reinforces the argument that sustained engagement in co-created coastal monitoring is context-dependent and

shaped by territorial conditions, rather than guaranteed by the participatory approach itself (Wehn et al., 2025).

Another relevant limitation concerns the social profile of the participants involved. As discussed by Domroese and Johnson (2017) and more recently by Compagnone et al. (2024), initiatives that rely on volunteers with prior environmental engagement often achieve higher levels of continuity and appropriation, but this condition cannot be assumed in all contexts. In this respect, CiuPAC resembles other co-created projects in which activist-oriented participants played a central role in sustaining monitoring efforts, rather than representing a model based on broad, low-commitment participation. This comparison suggests that transferability should not be understood as the replication of specific participant profiles or outcomes, but as the adaptation of co-creation principles to different social and institutional settings.

Scalability represents both an opportunity and a challenge for participatory coastal monitoring. The decentralized structure adopted in CiuPAC made it possible to extend monitoring activities across a large and environmentally diverse coastline without depending on centralized infrastructure, in line with findings reported for other multi-site citizen science networks (Wehn et al., 2025; Corbau et al., 2025). However, this experience also confirms that scaling participatory monitoring requires continued technical coordination, shared data standards, and mechanisms to support comparability across sites. In this sense, the transferability of the CiuPAC approach lies less in its specific national context than in its underlying governance logic: a model in which co-created monitoring can complement formal environmental observation systems in regions with limited institutional reach, provided that implementation prioritizes adaptive design, long-term relationships, and context-sensitive coordination rather than standardized replication.

Based on these findings, future co-created citizen science initiatives in multi-site coastal monitoring should be built around locally defined concerns, supported by simple but standardized protocols, and designed with data quality procedures from the outset. They should also include continuous feedback mechanisms, accessible communication tools, and flexible operational arrangements adapted to local capacities, time availability, and preferences. Finally, long-term continuity should be planned explicitly, since sustained participation depends not only on volunteer commitment but also on local leadership, continued support



Fig. 6. Categories of emerging community-level impacts and participation trajectories identified during the CiuPAC project.

from the scientific team, and resources for periodic in-person engagement.

6. Conclusions

CiuPAC shows that co-created citizen science can constitute a viable form of coastal environmental monitoring in decentralized settings, where institutional presence is limited and available environmental information is insufficient or discontinuous. Through the articulation between the scientific team and the coastal organizations belonging to AREDAC, the project deployed a participatory monitoring network across an extensive and heterogeneous coastal strip, adapting fieldwork to diverse territorial, organizational, and social conditions.

Its value, however, lay not only in expanding environmental observation but also in enabling locally grounded forms of monitoring in which community actors helped define priorities, contextualize records, and circulate the information produced. In this way, the project generated data that were both methodologically credible and socially meaningful, linking monitoring outputs to concrete coastal issues and to locally situated interpretations of environmental change.

From a coastal management perspective, CiuPAC functioned as a complement to formal monitoring systems and as a mechanism for connecting scientific knowledge, territorial experience, and public participation. The project contributed not only by producing locally relevant information, but also by strengthening community actors able to interpret coastal processes, communicate evidence, and engage in public discussions on risks, infrastructure works, and environmental transformations.

At the same time, the experience showed that continuity cannot be explained by methodological design alone. Sustained participation depended on local leadership, organizational capacity, group size, and the possibility of maintaining continued involvement of the scientific team, particularly through periodic in-person engagement. For this reason, CiuPAC should be understood not as a universally replicable model, but as evidence that the transferability of co-created coastal monitoring depends on adapting co-creation principles, methodological flexibility, and continued scientific team involvement to different territorial, social, and institutional contexts.

Consent for publication

Not applicable.

Ethical approval and consent to participate

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available as they are currently under analysis but are available from the corresponding author on reasonable request.

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ORCID iD contribution statement

María Lujan Bustos: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. **Federico Ferrelli:** Conceptualization, Data curation, Formal

analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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