Stakeholder-Driven Prioritisation of Nature-Based Solutions in a Volcanic Lake Basin

Chiara Iavarone[1], Raffaele Pelorosso[1], Giulia Mancini[1], Perla Rivadeneyra[2], Federico Cornacchia[3], Sebastian Raimondo[4], Fabio Recanatesi[1], Carlo Giupponi[2], Maria Nicolina Ripa[1].

1 Università degli Studi della Tuscia, Department of Agricultural and Forestry Sciences, Viterbo, Italy

2. Fondazione Eni Enrico Mattei, Venice, Italy; Ca' Foscari University of Venice, Department of Economics, Venice, Italy

3 Fondazione Eni Enrico Mattei, Venice, Italy; Ca' Foscari University of Venice, Department of Environmental Sciences, Informatics and Statistics, Venice, Italy

4 Fondazione Eni Enrico Mattei, Venice, Italy

1. Background and objective

Freshwater ecosystems are increasingly affected by nonpoint source pollution driven by intensive land use, creating trade-offs between agricultural production and ecosystem conservation. While Nature- Based Solutions (NBS) such as buffer strips, cover crops, and retention basins offer effective strategies to mitigate these pressures, their success depends not only on biophysical performance but also on stakeholder acceptance, long-term maintenance, and social feasibility. Growing evidence shows that participatory approaches are essential to enhance the adoption, scalability, and durability of NBS.

Within the framework of the **Horizon Europe EUROLakes project**, this study presents a case application of a participatory decision-making approach in a lacustrine system (Lake Vico), combining the **4 Returns Framework** (Natural, Social, Economic, Inspirational) with **Participatory Multi-Criteria Analysis (PMCA)**. The approach integrates stakeholder mapping, co-evaluation of alternatives, criteria weighting, and multi-criteria aggregation to move beyond purely technical assessments.

The objective is to demonstrate how structured science–society interaction can support the co-design and prioritisation of NBS while simultaneously fostering a community of practice. By integrating diverse knowledge systems and stakeholder perspectives, the process enables the identification of more shared, context-adapted solutions and strengthens the conditions for their effective implementation within complex socio- ecological systems

3. Methodology:

Landscape Partnership creation:

- **Stakeholder mapping**
- **Workshops & social** (Facebook group) to align science with place-based knowledge and sharing information

Participatory Multi-criteria Analysis (PMCA)

- co-creation and co-evaluation of NBS scenarios using the **4 Returns Framework** and a dedicated **Decision Support System (pDSS)**

Results

- **Enhanced Community of Practice**
- **Prioritised NBS:** Socially accepted and biophysically effective restoration pathways for Lake Vico.

Objective

This first phase serves as the foundation for collaborative governance by fostering trust, transparency, and shared ownership of the restoration processes.

Stakeholder Mapping Process

1. Initial Mapping (Jan–May 2025): All relevant stakeholders were identified, considering both those located within the catchment and those outside but exerting influence over it.

The mapping was conducted in multiple iterations, systematically recording each stakeholder's name, contact details, email, and a short description of their role.

Stakeholder Mapping Process

2. Scoring and Validation: Each stakeholder was positioned in the matrix by assigning a score from 1 (low) to 5 (high) for both their **interest in the project** and their **capacity to influence its outcomes.**

The scoring was discussed and jointly validated by all authors, incorporating feedback from stakeholders.

Workshops & social (Facebook group)

to align science with place-based knowledge and sharing information

2 workshops in presence (May25 and Nov25)

1 Facebook group (97 members)

1 Formulate alternative solutions to the current ones

Current Management (BAU)

- Measures defined in the Agricultural Use Plan (PUA), including spontaneous grassing and erosion control practices

2. Grassing Optimization

- Better management of vegetative cover in hazelnut groves to intercept runoff during critical periods.

3. Environmental Conservation

- Dry stone walls, vegetated buffer strips, retention basins, and restoration of riparian vegetation.

4. Nature Trail

- Partial removal of hazelnut groves along the bank, creation of a vegetated coastal buffer, and development of an ecotourism path.

5. Crop Renewal

Replacement of hazelnut groves with better-adapted varieties or more conservative crops in at-risk areas.

6.Other Interventions

Selective wildlife control, support for organic farming, and regulation of water levels.

2. Share them with a group of experts to assess their feasibility.

Experts Consulted

- Agronomist
- Experts with direct knowledge of the Lake Vico context
- Natural Reserve authorities

Share and Assess Feasibility

- Technical Feasibility
- Economic Feasibility
- Social Feasibility

Selected alternative :

Alternative NBS evaluated

1. **Current Management (BAU)** Measures defined in the Agricultural Use Plan (PUA), including spontaneous grassing and erosion control practices.
2. **Grassing Optimization** Better management of vegetative cover in hazelnut groves to intercept runoff during critical periods.
3. **Environmental Conservation** Dry stone walls, vegetated buffer strips, retention basins, and restoration of riparian vegetation.
4. **Nature Trail** Partial removal of hazelnut groves along the bank, creation of a vegetated coastal buffer, and development of an ecotourism path.

3. Stakeholder involvement to evaluate alternatives according to criteria

How ? pDSS

pDSS, an online participatory interface developed to facilitate remote completion of structured PMCA questionnaires.

pDSS allows stakeholders to evaluate alternatives against predefined criteria, assign importance weights, provide structured Likert-scale assessments, and contribute qualitative comments.

PDSS stakeholder survey in Italian

pDSS structure

1. Qualitative assessment phase

Alternatives arranged in columns
Criteria (the 4 Returns) arranged in rows
Each cell represents the expected performance of an alternative against a criterion
Participants assessed each alternative using a 5-point Likert scale:
1 = very low contribution 5 = very high contribution

EVALUATION MATRIX

	Alternative 1: Current Management (BAU)	Alternative 2: Grassing Optimisation	Alternative 3: Environmental Conservation and Restoration	Alternative 4: Nature Trail
Natural Returns				
Social Returns				
Financial Returns				
Inspiration Returns				

2. Weighting of assessment criteria

The 4 Returns Framework as core criteria dimensions

Used to weight and evaluate the alternatives
Stakeholders assigned weights to each Return based on their priorities
Weighted scores were aggregated to rank the alternatives.

- **Natural Returns** Benefits to ecosystems, biodiversity and natural capital
- **Social Returns** Benefits to people's health, well-being, equity and livelihoods
- **Economic Returns** Benefits to the local economy and resource efficiency
- **Return of Inspiration** Benefits related to sense of place, cultural identity, landscape value, and people's connection with nature

Weights were normalised (Σ=1) and alternatives evaluated using TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to generate an individual ranking. Individual rankings were aggregated via the Borda rule.

5. Conclusions & Future Outlook

· **Stakeholder mapping** revealed a system dominated by public institutions and agricultural actors, with strong implementation potential but uneven participation.

· **PMCA results** showed a clear preference for **restoration-oriented NBS**, combining high ecological performance with broad stakeholder support.
· **The Nature trail** option occupies a second position, reflecting its perceived potential to integrate ecological restoration with local development and recreational value.
· **Grassing optimisation** emerges as an intermediate solution,
· **BAU** is generally deprioritised in the collective ranking.

· **Engaging** individual farmers and the broader local community remains challenging.

Next step :
· **Quantitative modelling** of NBS :
· spatial and temporal modelling to assess where NBS are most effective
· **Implementation** of the shared NBS

2. Study Area: Lake Vico Basin

Environmental issues

Physical processes

Land use and land management

Soil Erosion and Sediment Transport

Nutrient transport (N and P)

Chemical processes

Oxygen depletion at water-sediment interface

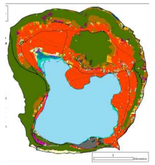
Redox potential drops

"Legacy Phosphorus" unlocked from lakebed

Massive release into water column

Cyanobacterial blooms and accelerated eutrophication

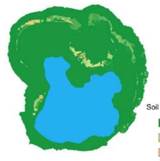
Degradation of Ecosystem



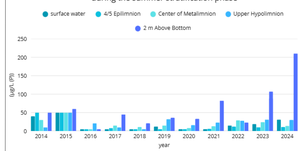
Most relevant land use

- Hazelnut groves: area covered = 35%
- Tree cover: area covered = 42%
- Chestnut groves: area covered = 8 %
- Urban area : 2%

Soil erosion



Temporal evolution of Total Phosphorus concentrations (2016–2024) during the summer stratification phase

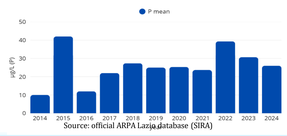


Source: official ARPA Lazio database (SIRA)

Temporal evolution of Total Phosphorus concentrations (2016–2024) during autumn

Source: official ARPA Lazio database (SIRA)

Temporal trend of winter Total Phosphorus concentrations (weighted mean over the water column) from 2016 to 2024.



Source: official ARPA Lazio database (SIRA)

Natural systems

Habitat, water resources, and local biodiversity

Agricultural Production

Crops, cultivation practices, and profitability

Territorial interactions and conflicts

Tourism

Landscape value and accommodation services

Institutions

Regulations, policies, and conflicting objectives

Social & Economic Challenges:

The landscape is dominated by hazelnut cultivation, a deeply rooted cultural heritage and economic pillar that exerts significant pressure on the aquatic ecosystem. The coexistence of a Natural Regional Reserve with agricultural activities creates trade-offs between ecological protection and local livelihoods.

4. Results

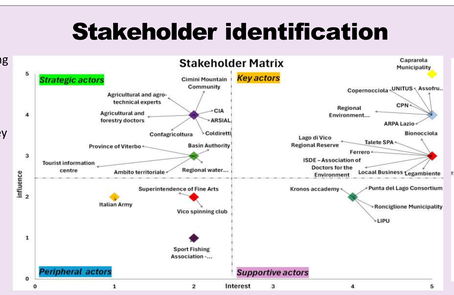
Stakeholder identification

The analysis identified **34 stakeholders**, revealing a complex socio-ecological system with strong institutional influence.

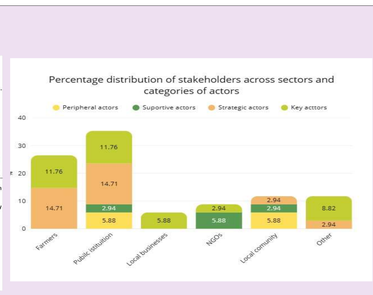
- **Key Actors (41.2%)** High interest & influence (e.g. Natural Reserve, agricultural associations, University of Tuscia). → Main drivers of NBS implementation
- **Strategic Actors (35.3%)** High influence, lower engagement (mainly public institutions and key agricultural sectors). → Crucial for regulation and nutrient management
- **Supportive & Peripheral (23.6%)** NGOs, local communities, small private actors. → Essential for social acceptance and long-term success

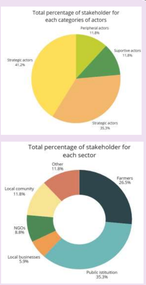
Sectoral relevance:
Public institutions (35.3%) and agriculture (26.5%) dominate.

Stakeholder Matrix

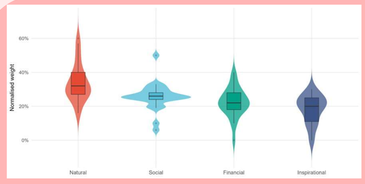


Percentage distribution of stakeholders across sectors and categories of actors





PMCA Results: priorization of NBS

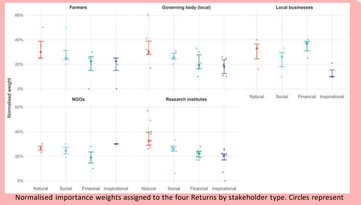


Distribution of normalised importance weights assigned to the four Returns (Natural, Social, Financial and Inspirational) by completed respondents (n = 25). Violin plots represent the overall distribution of weights, while boxplots indicate median values and interquartile ranges.

Criteria Weighting:

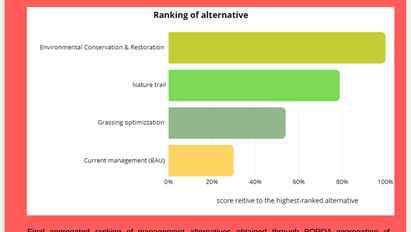
Natural Return is the top priority (highest median score), although it shows the greatest variability, reflecting differing levels of environmental awareness. **Social Return** receives a consistent, intermediate rating; there is a strong consensus on its importance.

Financial & Inspirational Returns, although considered relevant, they have been given lower weightings, suggesting that the protection of the ecosystem and social cohesion are seen as prerequisites for economic sustainability



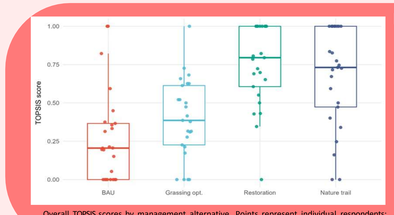
Normalised importance weights assigned to the four Returns by stakeholder type. Circles represent individual respondents, bars indicate the interquartile range (IQR), and diamonds show the median weight for each criterion for each stakeholder group.

Final Prioritisation



Final aggregated ranking of management alternatives obtained through BORDA aggregation of respondent-level TOPSIS rankings. Bars report each alternative's score expressed as a percentage relative to the highest-ranked option (Environmental conservation and restoration actions = 100%).

Distribution of stakeholder preferences



Overall TOPSIS scores by management alternative. Points represent individual respondents; boxplots summarise the distribution of scores across completed respondents.

. **Restoration** shows the **highest and most consistent scores**

. **Nature Trail** presents **high variability** (divergent views)

. **Grassing Optimization** shows **intermediate agreement**

. **BAU** consistently receives **low scores**

TOPSIS scores by stakeholder type. Dots represent respondent-level scores; horizontal bars indicate the within-group median for each management alternative.