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The Resilience Index: Assessing Aquaculture's Adaptive Capacity for Informed Decision-Making

Developed for the mussel aquaculture in the Arousa estuary, Galicia, Spain

The Resilience Index equips decision-makers with a tool to assess the adaptive capacity of the aquaculture sector, enabling informed governance decisions and the formulation of new targeted policies. The Resilience Index's versatility facilitates its use in various sectors and regions.

Key Learnings

- **Stakeholder engagement and awareness:** Involving mussel farmers, local communities, and key stakeholders from the beginning has increased project acceptance and raised awareness about climate change impacts on mussel aquaculture, ensuring that solutions meet real needs.
- **Collaborative innovation:** Collaboration between regional authorities, the mussel industry, academia, and civil and environmental organisations has fostered innovative strategies to tackle climate challenges. Inclusivity and shared responsibility drive sustainable outcomes.
- **A comprehensive risk assessment:** A comprehensive framework for assessing climate risks, vulnerabilities, and resilience factors has provided actionable insights, helping to prioritise effective adaptation measures for the long-term sustainability of the mussel sector in the Arousa estuary.

About the region

Galicia, located in the northwest of Spain, covers just 5.8% of the country's territory but holds 32.8% of its coastline (1,659 km) due to its intricate Atlantic coast and multiple estuaries known as Rías. Galicia supplies 40% of Europe's mussels with over 3,000 rafts. The Ría de Arousa, on the southwest coast, stands out as the largest and most productive estuary, hosting about 70% of the Galician mussel rafts. Mussel aquaculture directly employs 3,890 people in the region.

Climate hazards

Extreme Temperatures,
Droughts, Sea Level Rise,
Flooding, Storms

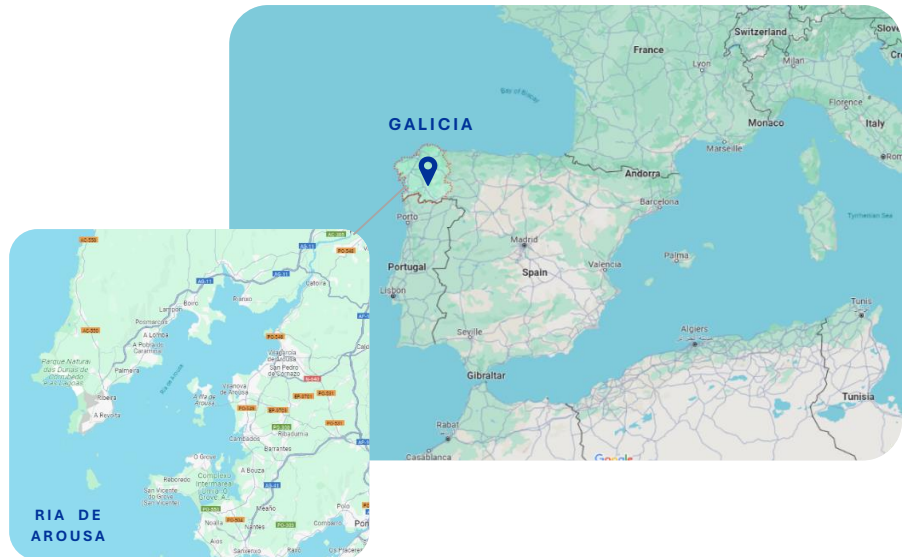
Sector

Coastal Areas
Marine and Fisheries

Key system

Ecosystem and Nature Based
Solutions

Local Economic System



Climate Threats

Galicia faces increasingly extreme weather conditions, with more frequent and intense winter storms causing damage to mussel rafts and port infrastructure. In summer, heat waves raise water temperatures, triggering harmful algal blooms that reduce the availability of mussel seed. Ocean acidification, due to the oversaturation of carbonates in the waters off the Galician coast, can also affect the growth and survival of shellfish species. These hazards significantly threaten the mussel aquaculture sector and the broader socioeconomic stability of the region.

Resilience Index: Addressing Adaptation Challenges in the Mussel Aquaculture

One key challenge in climate adaptation governance is decision-making. In the Galician mussel aquaculture sector, stakeholders must manage a range of interconnected environmental factors, making it difficult to predict how climate change will affect mussel production in the long term.

Additionally, decision-makers in Galicia often struggle with limited or fragmented data, making it challenging to assess the sector's vulnerabilities accurately and to implement timely and effective strategies. Without a clear framework, prioritising climate change adaptation actions becomes a reactive rather than proactive process, potentially compromising the sector's resilience.

The Resilience Index is a mathematical formula that assesses the relationship between key climate scenarios, potentially negatively impacting the mussel sector's productivity, and the resilience factors

available to mitigate negative effects. The framework integrates diverse data sources, including historical climate data, climate projections and the potential of the resilience factors. The Resilience Index highlights sector performance and areas for improvement. It enables decision-makers to identify vulnerabilities, prioritise actions, and allocate resources effectively, supporting a comprehensive assessment of the sector's adaptive capacity. This makes it an essential tool for ensuring the mussel sector in Galicia remains resilient and sustainable in the face of climate uncertainty.

Stakeholder and Expert Engagement: Towards a Common Decision-making Support Tool



Figure 1: Stakeholders workshop. Image Credits: REDE research group, University of Vigo.

Strong collaborative engagement with regional stakeholders and experts, including representatives from the regional government, academia, the mussel production sector, and social and environmental organisations from the beginning characterised the development of the Resilience Index. Workshops ensured that the index was scientifically rigorous, practically applicable and widely accepted by potential users.

The stakeholder contributions were essential to identifying priority-risk scenarios for mussel aquaculture, calculating the potential to mitigate those risks, and assessing the sector's adaptive capacity. These inputs were integrated as variables and values to the Resilience Index formula.

"The development of the Resilience Index is built on constructive collaboration between scientific knowledge and industry expertise. This synergy enables progress in enhancing the management of mussel production, resulting in improved efficiency and sustainability."

Alfonso Villares, Minister of the Sea for the regional government, Xunta de Galicia.

Calculating the Resilience Index: A Health Check for Adaptive Capacity

Consultations with key players in mussel aquaculture identified and prioritised vulnerabilities, risks, and resilience factors crucial for adapting production to climate change. The Resilience Index is a "health check" for the sector's adaptive capacity. It pinpoints where climate change adaptation requires targeted efforts and resources to significantly increase the sector's resilience.

Figure 2 summarises the Resilience Index results for the entire mussel sector in the Ría de Arousa estuary. The estuary is located in the region of Galicia and hosts around 70% of the Galician mussel rafts. Risk management is the least developed resilience dimension, with an adaptive capacity level of 36%. Within this dimension, emergency action plans are the least developed resilience factor. However, to define a strategic roadmap for improving adaptive capacity, it is essential to consider the performance level of the resilience factors and their weight within the overall resilience model. The project team considered resilience factors with a performance level below 50% and a total resilience weight above 5%.

Resilience dimensions	Adaptive capacity performance level	Weight of the resilience dimension in total resilience	Resilience Factors	Weight of the resilience factor in total resilience	Adaptive capacity performance level
1. Governance	49%	● 16,50%	1.1 Training programs	● 3,50%	69%
			1.2 Flexible management	● 4,80%	42%
			1.3 Marine spatial planning	● 4,50%	49%
			1.4 Management of public-private funds	● 3,70%	38%
2. R&D&I	47%	● 22,30%	2.1 Advanced scientific research	● 6,70%	52%
			2.2 Improvement of exposure forecast	● 5,70%	47%
			2.3 Applied biotechnology projects	● 5,00%	44%
			2.4 Development of new technologies	● 4,90%	43%
3. Risk Management	36%	● 17,90%	3.1 Multitrophic aquaculture	● 3,70%	35%
			3.2 Adapted insurance coverage	● 2,90%	41%
			3.3 Ecosystem Approaches to Aquaculture	● 5,80%	38%
			3.4 Emergency action plans	● 5,40%	28%
4. Collaboration	43%	● 20,10%	4.1 Intersectorial collaboration	● 4,90%	49%
			4.2 Interdisciplinary cooperation	● 6,60%	45%
			4.3 International cooperation networks	● 4,70%	45%
			4.4 Intra-sectoral collaboration	● 3,90%	33%
5. Operational management	48%	● 23,20%	5.1 Adaptation of infrastructure	● 4,40%	45%
			5.2 Monitoring and warning systems	● 6,10%	56%
			5.3 Improvement of production techniques	● 6,00%	50%
			5.4 Flexible procedures	● 6,70%	42%

● High contribution to the Resilience Index
 ● Medium contribution to the Resilience Index
 ● Low contribution to the Resilience Index

Figure 2: Summary of the final results of the Resilience Index for the mussel aquaculture in Galicia (Spain). Image Credit: REDE research group, University of Vigo.

Beyond the Numbers: Tailored Prioritisation of Adaptation Actions for a Strategic Roadmap

With the prioritisation criteria established, the project team identified six lines of action to tackle the challenges mussel aquaculture in Galicia is facing. These lines of action should:

- (1) Make production procedures more flexible,
- (2) Open new communication channels among stakeholders,
- (3) Incorporate innovative techniques in the mussel production,
- (4) Integrate mussel aquaculture into the broader ecosystem context in which it takes place,
- (5) Improve models for predicting changes in ocean and meteorological variables, and
- (6) Support designing contingency plans for emergencies caused by the effects of climate change.



Figure 3: Left: stakeholders/experts participating in the prioritisation of solutions. Right: Andrea Ogando (UVigo-REDE) presenting results of the Resilience Index. Image Credits: REDE research group, University of Vigo.

In addition, the project team broke down these lines of action into 24 proposals for action (four for each line). During a stakeholder and expert workshop, the participants used this prioritisation exercise to draft a strategic roadmap for mussel aquaculture, highlighting the most important and urgent actions:

- Emphasis on enhancing systematic, long-term ocean-meteorological and environmental data collection with affordable, easy-to-implement sensors.
- Development and adoption of predictive analytical tools for future event anticipation.
- Improvement of information flows along the supply chain.
- Promotion of innovation through new technologies and collaborative projects.

This collaborative dialogue established an action framework, providing a reference for future programmes integrating scientific advances and long-term consultation processes. In a survey, 72% of participants involved in the strategic roadmap indicated that their awareness of climate change increased after learning about the Resilience Index results. Additionally, 89% stated that they would consider the insights from the Resilience Index in future decision-making processes.

Summary

The development of the Resilience Index has been crucial for advancing climate change adaptation in the mussel aquaculture sector of Galicia's Arousa estuary. With unpredictable weather events and a lack of organised data or strategic guidance, the sector needed a tool to assess its vulnerabilities and improve its adaptive capacity. The development of the Resilience Index highlights the importance of involving stakeholders and experts to ensure scientific accuracy and practical solutions. This collaborative effort translated complex data into clear, actionable insights, making them accessible to a wider audience. Integrating diverse perspectives supported tailoring the Resilience Index to the specific needs of the mussel sector, empowering decision-makers to enhance its resilience and sustainability against climate change.

Further information



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TransformAr

- The TransformAr project: "Accelerating and upscaling transformational adaptation in Europe: demonstration of water-related innovation packages – TransformAr" <https://transformar.eu>
- Galicia demo description in TransformAr project: <https://transformar.eu/demonstrator-5-galicia-region-spain/>
- Detailed information on the development of the Resilience Index for the mussel aquaculture: REDE research group, Ogando-Vidal, A., & Rodríguez-García, C. (2024). Methodology for the development of a climate change resilience index for mussel aquaculture in Galicia (Spain). Zenodo. <https://doi.org/10.5281/zenodo.12800095>
- Detailed information on the development methodology of the Resilience Index for the operability of a port in Galicia (Spain): León-Mateos, F., Sartal, A., López-Manuel, L., & Quintas, M. A. (2021). Adapting our sea ports to the challenges of climate change: Development and validation of a Port Resilience Index. *Marine Policy*, 130. <https://doi.org/10.1016/j.marpol.2021.104573>

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