TRANSEATION

BLUE IS THE NEW GREY · NATURE-BASED SOLUTIONS

Advancing Ecosystem-Based Management through Hybrid Blue-Grey Infrastructures in Marine and Coastal Areas

DELIVERABLE 3.2
Criteria and guidelines for systemic risk assessment in project demonstrators

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Symbols, abbreviations and acronyms

EBM	Ecosystem-Based Management
EU	European Union
Hybrid NbS	Hybrid blue-grey Nature-based Solutions
IPCC	Intergovernmental Panel on Climate Change
IRGC	International Risk Governance Council
LBUs	Life Boosting Units
M	Milestone
MPA	Marine Protected Area
NbS	Nature-based Solutions
PPE	Personal Protective Equipment
SRUs	Saitec Reef Units
Sys-RA	Systemic Risk Assessment
T	Task
UN SDGs	United Nations Sustainable Development Goals
WP	Work Package

EXECUTIVE SUMMARY

The Deliverable D3.2. "Criteria and guidelines for systemic risk assessment in project demonstrators", contributes to WP3 "Ecosystem-Based Management (EBM) framework for hybrid blue-grey infrastructures", and specifically to Task 3.2, which aims to evaluate systemic risk reduction linked to the implementation of hybrid Nature-based Solutions (hybrid NbS) in marine and coastal areas (Objective OB3.2). The deliverable presents and summarizes the most relevant information on climate change risk assessment. This information serves as guidelines for designing local-scale Systemic Risk Assessment (Sys-RA) frameworks and presents those developed within the TRANSEATION project demonstrators. The demonstrator regions comprise two coastal protection infrastructures (Coastal Protection Infrastructure Demonstrators I and II), two artificial reefs that form part of the same offshore wind energy infrastructure (Offshore Wind Farm Infrastructure Demonstrator), and two low-trophic infrastructures (i.e., biobased ropes, rafts, and longlines; Low-Trophic Aquaculture Infrastructure Demonstrator). A thorough evaluation of the ecological and socio-economic risks to which these demonstrators are vulnerable is necessary in order to establish the effectiveness, as well as the potential for adaptation and mitigation, of these hybrid NbS in the context of climate change and from an integrated social-ecological perspective. To this end, the reported risk assessment approach integrates multiple risk dimensions - hazard, exposure, vulnerability, and response - while identifying key drivers of change in marine and coastal ecosystems under climate variability. It explores cumulative impacts, cause-effect relationships, feedback loops, and trade-offs between environmental and socio-economic risks in each demonstrator area, enabling the identification of the multiple interrelated hazards affecting the zones, as well as their specific vulnerabilities and priorities for action. The aim is to provide local communities and policymakers with a solid knowledge base, both theoretical and local scale, to help them understand the risks associated with multiple hazards. The basis will support the challenges posed by climate change by providing guidelines and criteria to improve coastal and marine NbS planning and assessment while supporting ecosystem services and biodiversity from an applied and systemic approach, in this sense, it can serve as a supporting tool within the System Design step of the Systems Approach Framework.

Keywords: climate change; risk assessment; multi-hazard; hybrid NbS

1. INTRODUCTION

Over recent decades, the risks associated with climate change have been intensifying, impacting various regions and ecosystems globally (IPCC, 2022). The coastal and marine regions are particularly vulnerable due to their unique physical, environmental, and socio-economic characteristics (EUCRA, 2024). Rapid climate change is anticipated to significantly affect the natural environment and anthropic activities in these areas, with chronic hazards such as coastal erosion, floods, water temperature increase, and marine heatwaves becoming more severe due to both climatic changes and human activities (EUCRA, 2024).
Understanding these dynamics is crucial for the sustainable management of environmental systems and resources and effective decision-making. Social and environmental agents are interconnected, and their complex dynamics can operate across various scales, leading to unpredictable impacts (Lenton et al., 2008).

In the marine environment, according to the International Union for Conservation of Nature (IUCN), biodiversity is in a severe risk. According to the IUCN Red List[2], more than 1550 marine species are threatened with extinction. The IUCN Red List reports that 44% of reef-building coral species are threatened with extinction, along with 37% of sharks and rays and 25% of marine mammals, such as whales and dolphins. Additionally, 86% of sea turtle species are classified as endangered.
The main causes of this biodiversity crisis include:

- Climate change: rising water temperatures and ocean acidification compromise marine ecosystems.
- Pollution: chemicals, plastics, and other waste damage marine fauna and flora.
- Overfishing: excessive fishing drastically reduces populations of many species, and creates ecological imbalances
- Habitat destruction: the degradation of critical habitats, such as coral reefs and seagrass beds, threatens the survival of numerous marine species.

Parallelly, coastal erosion in the Mediterranean Sea is a growing environmental concern driven by both natural processes and human activities. Rising sea levels, intensified storms, and reduced sediment supply, partly due to dam construction on rivers, are accelerating the retreat of many shorelines. Urban development, tourism infrastructure, and the removal of coastal vegetation have further weakened natural defences like dunes and wetlands. As a result, beaches and heritage sites are increasingly at risk, threatening local economies and ecosystems (Zanin et al., 2024).
In this situation, hybrid NbS represent an innovative and integrative approach to managing marine and coastal areas. These solutions combine natural elements, such as seagrasses, wetlands, mangroves, and oyster reefs, with traditional grey infrastructure like seawalls, breakwaters, and piers. The goal is to enhance the resilience of coastal and marine zones while supporting ecosystem services and biodiversity. In marine and coastal settings, hybrid NbS can:

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[2] The IUCN Red List is a critical indicator of the health of the world's biodiversity. Far more than a list of species and their status, it is a powerful tool to inform and catalyse action for biodiversity conservation and policy change, critical to protecting the natural resources we need to survive. It provides information about range, population size, habitat and ecology, use and/or trade, threats, and conservation actions that will help inform necessary conservation decisions.

(i) protect coastlines from erosion and extreme weather events, such as storms and sea-level rise, by dampening wave energy and stabilizing sediments; (ii) promote habitat restoration, for example by integrating eco-engineered structures that mimic natural habitats (like artificial reefs or “biowalls”) to support marine biodiversity; (iii) improve water quality by enhancing natural filtration processes (e.g., via oyster beds or seagrass meadows);(iv) support sustainable blue economy practices, such as eco-tourism, aquaculture, or fisheries, by maintaining healthy ecosystems.

Unlike purely grey infrastructure, hybrid NbS emphasize ecosystem-based management (EBM). This involves a systemic perspective that integrates ecological, social, and economic factors. In the TRANSEATION project, this approach is strengthened through digital monitoring tools and stakeholder engagement, enabling adaptive management and long-term effectiveness.

In summary, hybrid NbS represent an innovative approach that blends engineering and nature for the sustainable management of marine and coastal environments. But **are these hybrid NBS adaptable to all climatic changes where hazards can trigger multiple risks?** In this frame, climate change assessment should fully address the challenges at the coastal-marine interface (Schlüter et al., 2020). The objective of deliverable D3.2. “Criteria and guidelines for systemic risk assessment in project demonstrators” is to collect and summarize the most relevant information on climate change risks and provide a systemic assessment encompassing multiple risks affecting the biodiversity, ecosystem, and socio-economic activities in the hybrid NbS demonstrators’ areas, Sys-RA. The project proposes four use cases at different stages of the marine and coastal infrastructure life cycle to demonstrate the scalability and replicability of these hybrid solutions, while also assessing trade-offs and short- and long-term benefits. In particular, two demonstrators implementing infrastructures for the coastal protection (demonstrators 1 and 2), two NbS infrastructures implemented to an offshore wind farm (demonstrator 3), and a low-trophic aquaculture infrastructure (demonstrator 4).

Building upon the definition of risk and its components provided by the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), this deliverable is designed to be a quick reference source for stakeholders and decision-makers to better integrate climate resilience in climate and environmental planning and policymaking. The development of effective strategies for mitigating and adapting to climate change risks in the demonstrators’ areas requires the identification and systems analysis of all key components of risk. Accordingly, a comparative review of risk terminology is conducted, and demonstrator areas are analysed to highlight the challenges and strategies adopted to address climate risks in the two different contexts (coastal and marine).

Following this introduction, Section 2 provides an overview of the key risk concepts to present the standards and instructions that define how the risk assessment should be performed. These guidelines offer step-by-step procedures for carrying out the assessment and enable the subsequent multi-hazard risk assessment for the demonstrator areas (Section 3). Finally, Section 4 provides a summary of the main findings of the presented analysis, highlighting future developments and possible connections with other project activities.

2. GUIDELINES ON THE MAIN RISK CONCEPTS AND TERMINOLOGIES

In recent decades, the risks linked to climate change have intensified, affecting regions and ecosystems worldwide (IPCC, 2022). Coastal regions and marine ecosystems are especially vulnerable due to their distinct physical, environmental, and socio-economic characteristics (EUCRA, 2024). Understanding these characteristics is essential for informed decision-making and the sustainable management of marine and coastal systems. Accordingly, advancing in climate change risk assessment is essential to fully capture the challenges at the terrestrial-coastal-marine interface, where multiple hazards can trigger cascading effects (Schlüter et al., 2020). To carry out a multi-hazard risk assessment is fundamental to first define the terminologies underpinning the assessment. Multiple definitions of risks were introduced during the years; the most relevant from 2002 to 2022 are summarized in Figure 1.

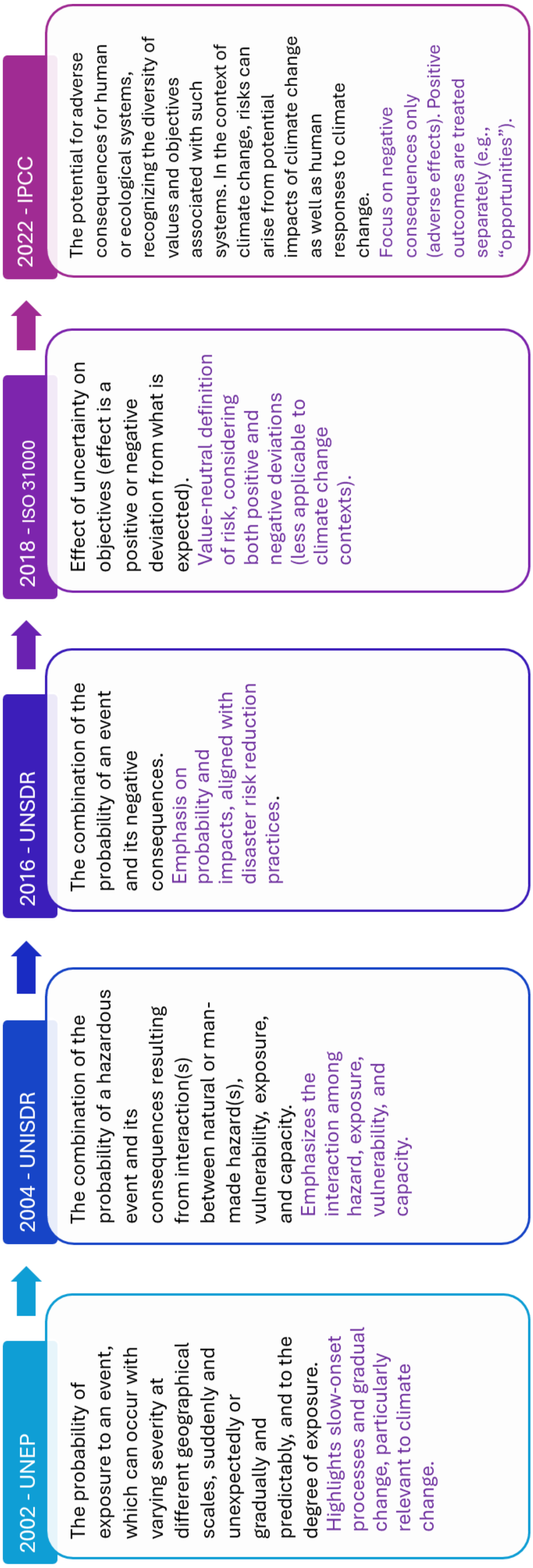

Figure 1. Most relevant climate change risk definitions across the 2002-2022 timeframe. In purple, the focus of the definition is specified.

Among all the definitions, the risk framework inspired by the climate risk model of the IPCC was applied in the demonstrators' areas. This report provides an updated overview of the main terminologies to assess multiple risks (IPCC, 2023), and it builds upon Milestone 7 (according to grant agreement) / Milestone 3.4 (according to the TRANSEATION proposal). The IPCC framework is based on four main components:

- **Hazards** – Climate and environmental factors that can cause damage.
- **Exposure** – The extent to which elements (ecosystems, infrastructure, and communities) are exposed to these hazards.
- **Vulnerability** – The sensitivity and adaptive capacity of the exposed systems.
- **Response** – Actions taken to mitigate, adapt to, or manage the identified risks.

Table 1 reports the specific definitions of each factor.

Table 1 Definitions underpinning multi-hazard risk assessment as defined by the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2023).

Term	Definition (https://www.ipcc.ch/srocc/chapter/glossary/)
Risk	Potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social, and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems, and species.
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
Response	The nature of climate risk also involves risks from responses themselves. The risks of climate change responses include the possibility of responses not achieving their intended objectives or having trade-offs or adverse side effects for other societal objectives. In particular, human responses may create novel hazards and unexpected side effects and entail opportunity costs and path dependencies. Response risks can originate from uncertainty in implementation, maladaptation, action effectiveness, technology development or adoption, or transitions in systems. Interactions across responses can importantly involve co-benefits for other objectives, such as human health and well-being, which may be improved from both reduced air pollution (e.g., AR6 WGI Chapter 6, Szope et al., 2021; WGIII, IPCC, 2022) and enhanced adaptation to climate change. The nature of risk also entails residual impacts that will occur even with ambitious societal responses, given limits to adaptation at sectoral and regional levels. In some cases, the losses will be irreversible.

2.1. CAPTURING MULTI-HAZARD RISK INTERACTIONS

The concept of multi-hazard risk entails the assessment of various hazards that may occur simultaneously or in close succession. This can happen due to their interdependence, being triggered by the same event, or posing a threat to the same vulnerable elements, even if they do not occur at the same time. Recognizing interactions among multiple risks shifts the focus of risk assessment from isolated climate hazards or single-event hazard interactions to a dynamic system where multiple events continuously interact with evolving social and economic conditions (Simpson et al., 2021).

However, when hazards interact across different spatial and temporal scales, whether by triggering each other or by affecting the same vulnerable elements, they are classified as compound hazards.
In risk assessment, three different approaches can be distinguished based on the degree of interaction considered (Hochrainer-Stigler et al., 2023) (Figure 2):

- *Multi-layer single-hazard Risk:* Assessment of multiple hazards in a region, but without considering interactions between hazards or between vulnerabilities. This approach helps understand the relative importance of different risks but does not capture cascading effects.
- *Multi-hazard Risk:* Assessment that includes interactions among hazards but assumes no interaction at the level of vulnerability (i.e., exposure to one hazard does not change vulnerability to others).
- *Multi-risk:* The most comprehensive assessment, considering both hazard interactions and vulnerability interactions (i.e., when damage caused by one hazard increases the vulnerability to another).

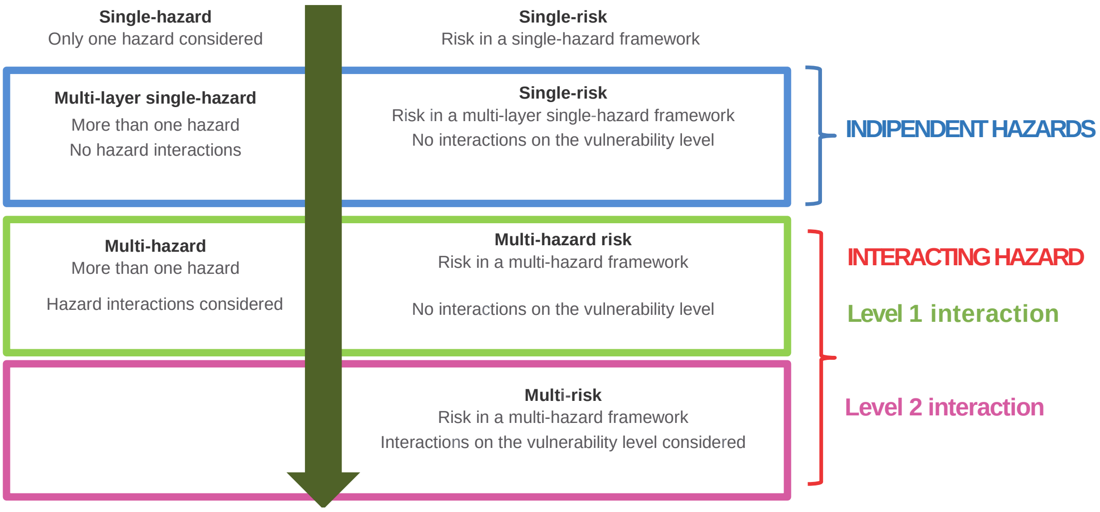

Figure 2. Multi-risk levels interactions diagram.

This perspective is particularly important as the frequency and intensity of atmospheric and marine extreme events increase due to climate change. The Sixth Assessment Report (AR6) of the IPCC highlights the necessity of integrated risk management strategies to effectively address these challenges (IPCC, 2023). Understanding multi-risk requires acknowledging the complex interconnections and cascading effects of multiple hazards (Figure 3), emphasizing how their interactions can amplify overall impacts beyond what would be expected if each hazard were considered in isolation.

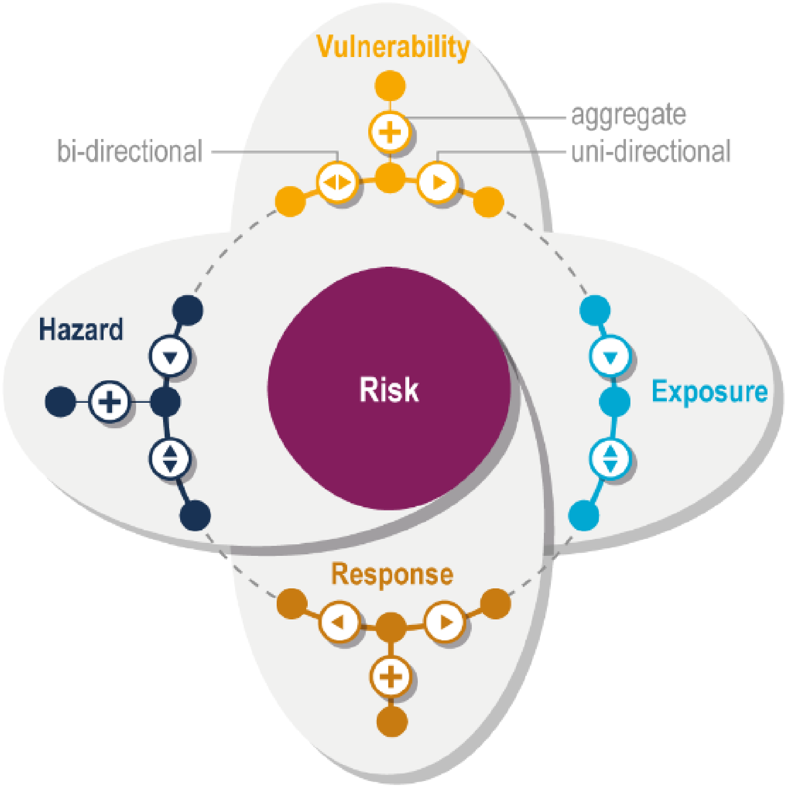

Figure 3. Framework for complex climate change risk interaction, adapted from Simpson et al. (2021) and IPCC (2023).

The interplay between various hazards forms a complex network of risks that demands a holistic systems approach for effective management. Due to their interconnected nature, addressing one risk can trigger cascading effects on others, underscoring the need for integrated solutions, collaboration, and co-creation. Given the critical importance of these issues, the following sections will delve deeper into multi-hazard interactions, thoroughly examining the framework and challenges while exploring present and future opportunities.

The notion of **systemic risk** emerges when hazards, vulnerabilities, and exposures interact dynamically across sectors and scales, potentially leading to cascading effects and irreversible changes.

In complex social-ecological systems, risk can arise from:

- Tipping points, where small changes push the system into a different state.
- Feedback loops, where the effects of an event reinforce the original hazard or vulnerability, amplifying the overall risk.
- Cascading effects, where the impact of one hazard leads to the triggering or intensification of other hazards.

Capturing the interactions between multiple hazards is a complex yet essential task that requires a thorough understanding of various challenges and methodologies (IPCC, 2023; Simpson et al., 2021). Many regions worldwide are increasingly exposed to multiple hazards occurring simultaneously, highlighting the need for a nuanced approach to risk assessment, analysis, and management (Šakić Trogrlić et al., 2024).

Types of multi-hazard interactions include:

- *Concurrent hazards:* hazards that occur simultaneously or overlap for a certain period
- *Successive hazards*:
  - Successive triggering: where one hazard triggers another
  - Successive alteration: where one hazard modifies the probability or characteristics of another hazard

As recommended by European guidelines, recognizing multi-hazard interactions is critical because cascading events can amplify impacts and losses far beyond what would be estimated through single-risk analyses.
Thus, evaluating multi-hazard risk is necessary to make informed decisions on risk management priorities; avoid underestimating cascade and amplification effects not captured by isolated hazard assessments; support better territorial planning by understanding how hazards interact over time and space.

Furthermore, it is crucial to take into account **transient risks** (i.e., risks arising from the transformation of systems due to climate change) and **residual risks**, even when adaptation measures are in place (IPCC, 2022).
Understanding and addressing multi-hazard interactions is critical to inform the design, implementation, and long-term effectiveness of hybrid NbS, especially in demonstration areas exposed to multiple and overlapping hazards.

2.1.1. MARINE AND COASTAL RISKS

Marine and coastal hazards, including coastal erosion, flooding, marine heatwaves, eutrophication, harmful algal blooms, and deteriorating water quality, pose escalating risks to ecosystems, coastal infrastructure, economies, and communities. These hazards are often interrelated, with compounding effects that are shaped by a mix of natural dynamics and human activities.
Extreme event analyses (Lange et al., 2020) show that such hazards are frequently driven by multiple, interacting factors acting across different temporal and spatial scales. For example, a marine heatwave can intensify eutrophication by boosting algal growth, which in turn depletes oxygen levels and harms marine biodiversity. Similarly, coastal flooding combined with storm surges can exacerbate erosion and salinization of freshwater resources. In regions where multiple hazards coincide, their interplay can lead to nonlinear and amplified impacts, often beyond what would be expected from individual hazards alone.
Understanding marine and coastal hazards requires attention to both acute events, such as hurricanes, tsunamis, or storm surges, and slow-onset processes, including sea level rise, ocean acidification, coastal subsidence, and changes in sediment transport. Human interventions, such as coastal development, shoreline hardening, and dredging, can further alter natural dynamics, increasing exposure and reducing adaptive capacity.
Moreover, these hazards are influenced by broader drivers such as population growth in coastal areas and the degradation of natural buffers like wetlands, dunes, and seagrasses. The loss of such ecosystems can significantly reduce coastal resilience by removing natural defences that buffer storm impacts or filter pollutants.

This complex web of multi-hazard risks underscores the necessity of a holistic, integrated approach to coastal risk assessment and management. A comprehensive understanding of these hazards must incorporate the interactions among hazard types, levels of exposure, vulnerability of systems and populations, and existing response capacities.

This approach aligns with the IPCC AR6 risk framework and is further supported by complementary models such as the UNDRR/Sendai Framework, which emphasizes the interlinked nature of hazard, vulnerability, exposure, and capacity, and the IRGC systemic risk model, which highlights the importance of identifying interdependencies, cascading effects, and potential tipping points in complex systems.

3. CHARACTERIZING RISK COMPONENTS ACROSS THE TRANSEATION DEMONSTRATORS

Understanding and characterizing the components of risks related to climate change in coastal and marine areas requires a careful distinction between extreme **events** and slow-developing **processes**, an example is reported in Figure 4.

These two categories of hazards differ not only in their temporal and spatial dynamics but also in the way they influence the exposure, vulnerability, and response capacity of socio-ecological systems (La Viña et al., 2022; van der Geest & van den Berg, 2021).

Extreme events, such as coastal floods, storm surges, and heat waves, are acute and sudden phenomena, characterized by well-defined thresholds and immediate impacts that are often devastating. Their assessment is strictly linked to the crossing of critical thresholds, which are a central element for early warning systems and emergency management. However, the definition of threshold itself is influenced by multiple technical, ecological, and social factors, and can significantly impact the quantification and communication of risk (Lehner et al, 2006; Seneviratne et al., 2021).

In contrast, slow-onset events, such as sea level rise, salinization, ocean acidification, or biodiversity loss, evolve gradually and continuously, without an identifiable beginning or end. Their assessment is based on the observation of long-term trends and variations, rather than on specific events. These processes can produce non-linear transformations and generate persistent pressures on ecosystems and local socio-economic systems (van der Geest & van den Berg, 2021).

It is important to underline that, due to the increasing trends of climate change and the scenarios predicted for the future, the statistical properties of these processes will tend to diverge significantly compared to the past (Foster et al., 2023).

Within the analysis of the risk components made for the demonstrators in the context of the TRANSEATION project, the coexistence and interaction between extreme and slow onset events have been taken into account and analysed to reinforce the need for an analysis that goes beyond the logic of isolated risks and considers instead compound, cumulative, and systemic dynamics in a multi-temporal and multi-scale perspective.

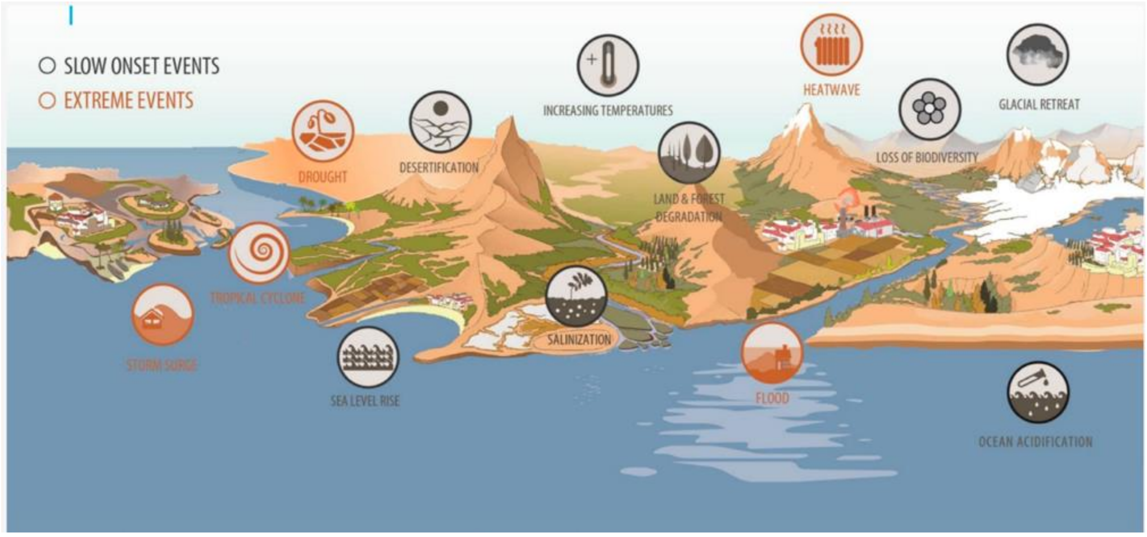

Figure 4. Coexistence of extreme events (orange logos) and slow-developing events (black logos) (from La Viña et al., 2022).

3.1. METHODOLOGY UNDERPINNING THE DEMONSTRATORS' RISK FRAMEWORK

The development of the risk frameworks followed a co-development approach. This approach involves making choices collaboratively and, due to its advantages (e.g., offering holistic, equitable, and effective analysis), is becoming increasingly important in climate science (Fleming et al., 2023). Thus, the methodology included a co-designed process with the demonstrator leaders. The framework was implemented through three steps: 1) theoretical background underpinning the main risk concepts and presentation to the demonstrators' leaders, 2) understanding of the state of play through an explorative questionnaire, and 3) reflecting and designing the risk frameworks during an in-presence workshop (see Milestone 7).

In line with the latest IPCC framework, the first step was to present to the demonstrators' leaders the risk assessment approach, which highlights the linkages between climate hazards, exposure, vulnerability, and response factors, and promotes adaptation and risk reduction strategies. The main definitions were introduced to the project demonstrators in the online workshop held on 13 November 2024.

The second step was carried out by means of a questionnaire in which demo leaders had to select one or more options for several selected questions, to obtain an initial screening of the main risk factors for hybrid blue-grey infrastructure in marine and coastal areas. The questions are listed in Box 1.

BOX 1: QUESTIONNAIRE ON SYSTEMATIC RISK ASSESSMENT FOR HYBRID BLUE-GREY INFRASTRUCTURES IN MARINE AND COASTAL AREAS

- Which **visible changes** due to climate change do you experience in your demo area?

E.g., Seasonal shifts, Beaches loss, Alien species introduction, Loss of biodiversity, Ecosystems change or degradation, Eutrophication and/or hypoxia events frequently occurring.

- Which **main natural hazards** occur in your demo area?

E.g., Storm surges, Changing in weather trends, Sea Level Rise, Coastal erosion, Pluvial flood, Mean water temperature increase, Marine heatwaves, Ocean acidification, Ocean deoxygenation

- Which **anthropic hazards** occur in your demo area?

E.g., Plastic pollution, Ship traffic, Oil pollution, Sewage disposal, Waste disposal, Heavy metals/toxic contaminations, Overtourism, Overfishing, Trawling, or other invasive techniques

- Within the area of your demo, which are the **environmental receptors** of interest?

E.g., Beaches, River months, Wetlands and saltmarshes, Marine Protected areas, Marine ecosystems, Offshore ecosystems, Degree Protection of water bodies

- Which **socio-economic** systems are affected?

E.g., Housing, Infrastructures, Tourist accommodation, Historical and cultural sites, Green urban areas, Primary sector, Secondary sector, Service sector

- Within the area of your demo, which are the **principal vulnerable habitats/species**?

E.g., Seagrass beds, Maërl beds, Kelp forests, *Cladocora caespitosa*, Coral reefs, Marine mammals, Red List of Threatened Species, Vulnerable marine ecosystem.

- What social, economic, and infrastructural weaknesses make your region and community more vulnerable to these climate hazards?

E.g., Lack of Legislation, Low level of preparedness or capacity of population, Vulnerable population (e.g., low-income, elderly, young, disabilities), Small-scale commercial activities (e.g., fishing, aquaculture, recreational, artisanal), and highly populated areas

- Within the area of your demo, which are the **principal responses to adapt to or mitigate** climate change?

[Open answer]

Following the questionnaire, the third step was carried out during a face-to-face workshop with the demonstrator leaders, which was held during the consortium meeting on March 12, 2025. The aim of the workshop was to finalize the risk framework for each demonstrator. In particular, for each demonstrator, two frameworks were developed: one addressing **risks to ecosystems and biodiversity**, and the other focusing on **risks to socio-economic activities** associated with the demonstrators. Risks related to ecosystems, biodiversity, and socio-economic aspects were identified as the most relevant during the co-development approach. These are consistent with the elements monitored and assessed throughout the project (WPs 3, 8, and 14). The only exception was the offshore wind farm demonstrator, where only the risk to ecosystems and biodiversity was assessed. This is because there are no direct socio-economic activities associated with the SRU and LBU that could be damaged by climate change. Rather, these infrastructures should be seen as measures to address and adapt to climate change while enhancing biodiversity.

3.2. RISK FRAMEWORKS FOR THE PROJECT DEMONSTRATORS

The demonstrators' regions are characterized by a diverse array of multi-risk hazards, where the interactions between different hazards substantially amplify the vulnerability of the regions to environmental and socio-economic risks. This section provides a thorough examination of how coastal and marine climate and anthropogenic hazards can interact simultaneously in the context of hybrid NbS and coastal communities within the TRANSEATION demonstrators, enhancing the understanding of the compounded risks faced by the regions and their implications.

3.2.1. COASTAL PROTECTION INFRASTRUCTURE DEMONSTRATOR I

The CCell artificial barriers are an innovative solution to combat coastal erosion, an alternative to traditional breakwaters, based on a steel mesh structure on which a rock crust is formed through electrolysis.

This process reduces the porosity of the mesh and increases the barrier's ability to dissipate wave energy by inducing breakage and/or turbulence, thus contributing to the protection of the coast and the accumulation of sand between the barrier and the shore. The system is designed to become progressively autonomous, aiming to reduce or eliminate electricity use within 18 months.

A preliminary experimental phase has already been carried out to optimize the rock growth parameters in specific conditions of Israeli waters. The subsequent phases include anchoring tests on sandy seabeds, assessment of the impact on waves and erosion, and monitoring of ecological effects.

For this demonstrator, it was decided to focus on two different risks; the first related to ecosystems and biodiversity connected to the demonstrator (Figure 5), while the second related to the socio-economic activities on the coast. The protection of these coastal activities is one of the primary functions of the demonstrator (Figure 6).

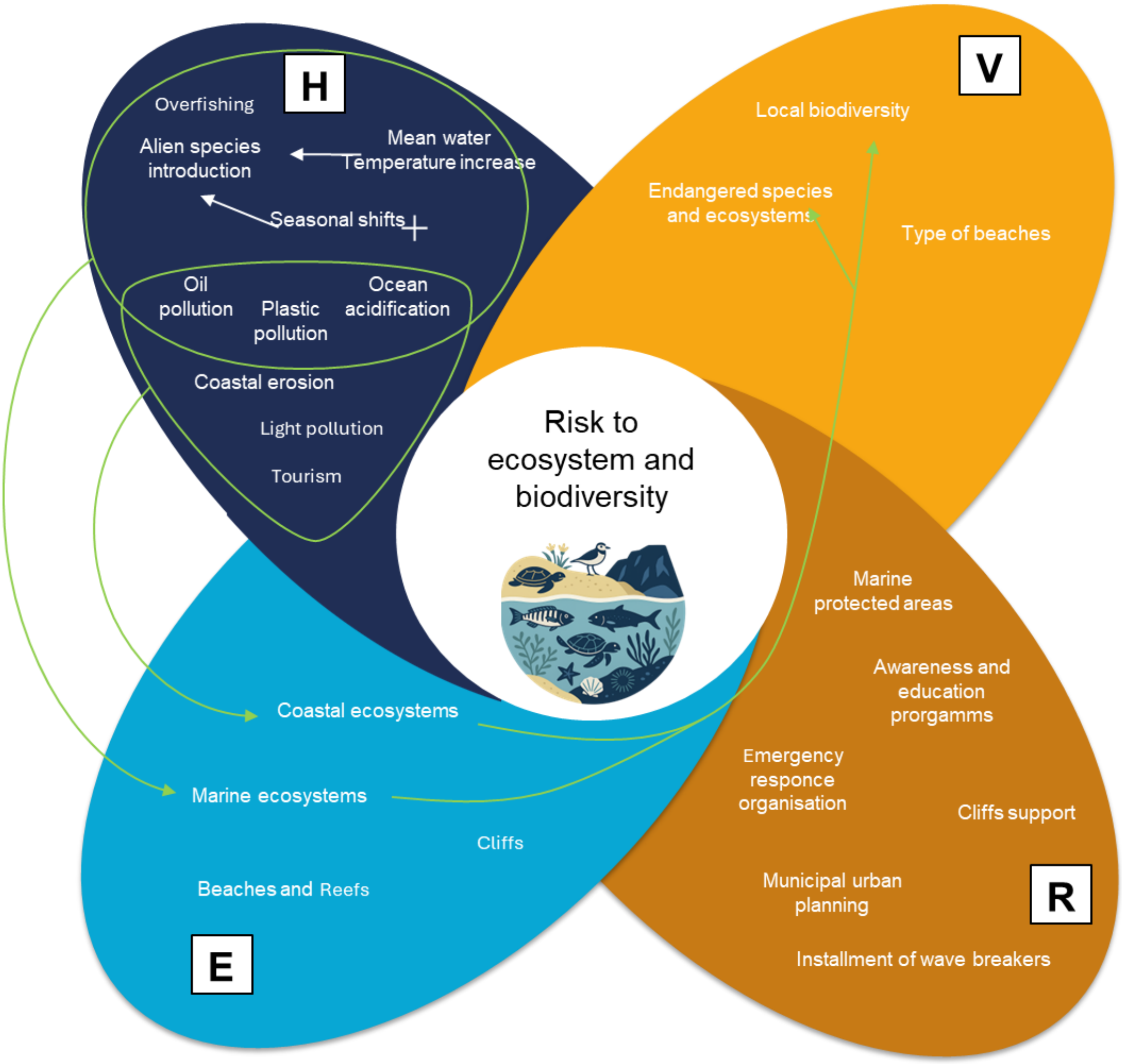

Figure 5. Risk to ecosystems and biodiversity for the Coastal protection infrastructure demonstrator I.

As regards the analysis of risks on ecosystems and biodiversity, the category of hazards has been divided into two subgroups, thus making explicit which hazards affect marine biodiversity, which affect coastal biodiversity, and finally, which ones impact both categories.

Among the hazards that affect the marine environment, the most significant is the increase in average water temperature, which, together with changes in seasonal patterns, can damage marine habitats and influence water quality and the ideal conditions for local ecosystems.

These two mentioned hazards are among the causes of the spread of invasive species within the waters of the area and the zone where the demo is located, which alters the trophic webs, causing the displacement or elimination of native populations.

As regards the **hazards** impacting coastal ecosystems, slow-onset events such as coastal erosion and human-induced hazards such as tourism and light pollution are those with the greatest impact. In particular, the latter has an often underestimated effect on the alteration of hormonal, metabolic, and behavioural rhythms of many species.

Finally, among the hazards that affect both habitats, ocean acidification and anthropogenic factors related to plastic pollution and oil spills have been identified.

The elements exposed to the combination of natural and human factors previously described are coastal and marine ecosystems, beaches, barriers, and cliffs.

Their **vulnerability** is described and defined based on the presence of local biodiversity, elements that are particularly important when we analyse the impacts of the introduction of alien species and the presence of endangered species.

In the specific analysis of risks for beaches, the elements of vulnerability are the type of beach, for example, whether it is a sandy or rocky beach.

The **response** component includes both structural and non-structural strategies to reduce vulnerability, minimize exposure, and mitigate the impacts of hazards. As shown in the diagram, designating marine protected areas (MPAs) has been identified as a measure that can improve biodiversity status and increase ecological resilience.

Education and awareness programs support community engagement and promote adaptive behaviour, while emergency response organizations provide preparedness and timely response during extreme events.

Structural interventions such as the installation and reinforcement of breakwaters and cliff support provide engineered protection that, in the case of coastal ecosystems, can reduce the risk associated with coastal erosion.

On a larger scale, municipal urban planning plays a critical role in integrating risk considerations into coastal development and land use decisions.

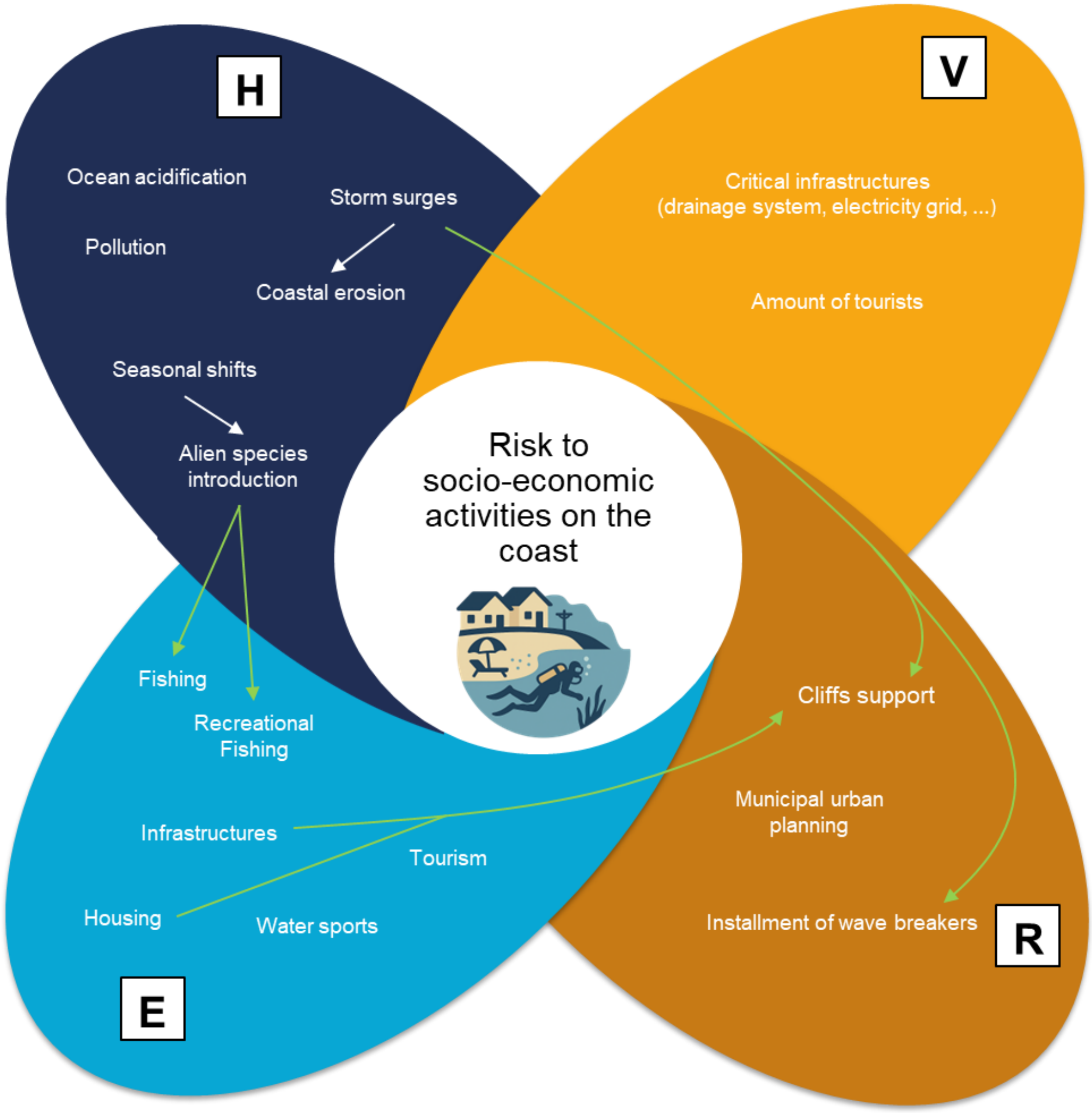

Figure 6. Risk to infrastructures and socio-economic activities on the coast for the Coastal protection infrastructure demonstrator I.

Regarding the risk identified in socio-economic activities on the coast (Figure 6), the hazard component includes a wide range of factors related to climate and human activities. Regarding climatic **hazards**, ocean acidification, shifts in seasonal patterns, and coastal erosion are identified as key threats. Exacerbated by wave action and storm surges, these processes contribute to the physical degradation of coastal zones, endangering infrastructure and diminishing land value. Finally, the introduction of alien species, facilitated by global trade and sea warming, can destabilize local food webs.

The **exposure** elements identified are housing, infrastructure, and sectors that are highly dependent on stable coastal conditions, such as tourism and recreational water sports very popular in the demonstrator coast, sectors that can be affected both by physical damage and by a decrease in environmental attractiveness.

As regards the introduction of alien species, this appears to be specifically connected to the exposure elements of human activities such as both commercial and recreational fishing.

In this context, **vulnerability** is shaped by multiple factors, particularly the condition of critical infrastructure such as access roads, drainage systems, and power networks. When these systems are outdated or poorly maintained, they significantly increase the overall sensitivity to external shocks. Furthermore, the number of tourists in coastal regions is an important element to consider in the vulnerability analysis for elements of the tourism sector itself, water sports, but also infrastructures, since during the high season, local services, water resources, and waste management systems can be overloaded.

Finally, with regard to the **response** component, in addition to measures such as the installation of breakwaters and cliff support systems, aimed at stabilizing the coast by protecting against erosion and storm surges, adequate municipal urban planning plays a key role in ensuring that the management of economic activities and the development of infrastructures takes into account future risk scenarios, integrating new adaptation measures and limiting construction in highly exposed areas such as the plain positioned above the cliff.

3.2.2. COASTAL PROTECTION INFRASTRUCTURE DEMONSTRATOR II

The Geocorail system will be installed directly onto the structures of various breakwaters composed of metal gabions, which will be deployed in Lavandou, France, and filled with small-sized riprap. This demonstrator aims to validate and integrate an innovative hybrid blue-grey NbS as an alternative to traditional breakwaters. The goal is to facilitate the scaling up of this or similar solutions for mitigating coastal erosion in other locations with comparable conditions and challenges.

For this demonstrator it was decided to focus on two different risks; the first related to ecosystems and biodiversity present in the demo site (Figure 7), while the second related to the infrastructures and tourism sector which results to be a key economic segment of the city of Lavandou and the broader geographic area (Figure 8).

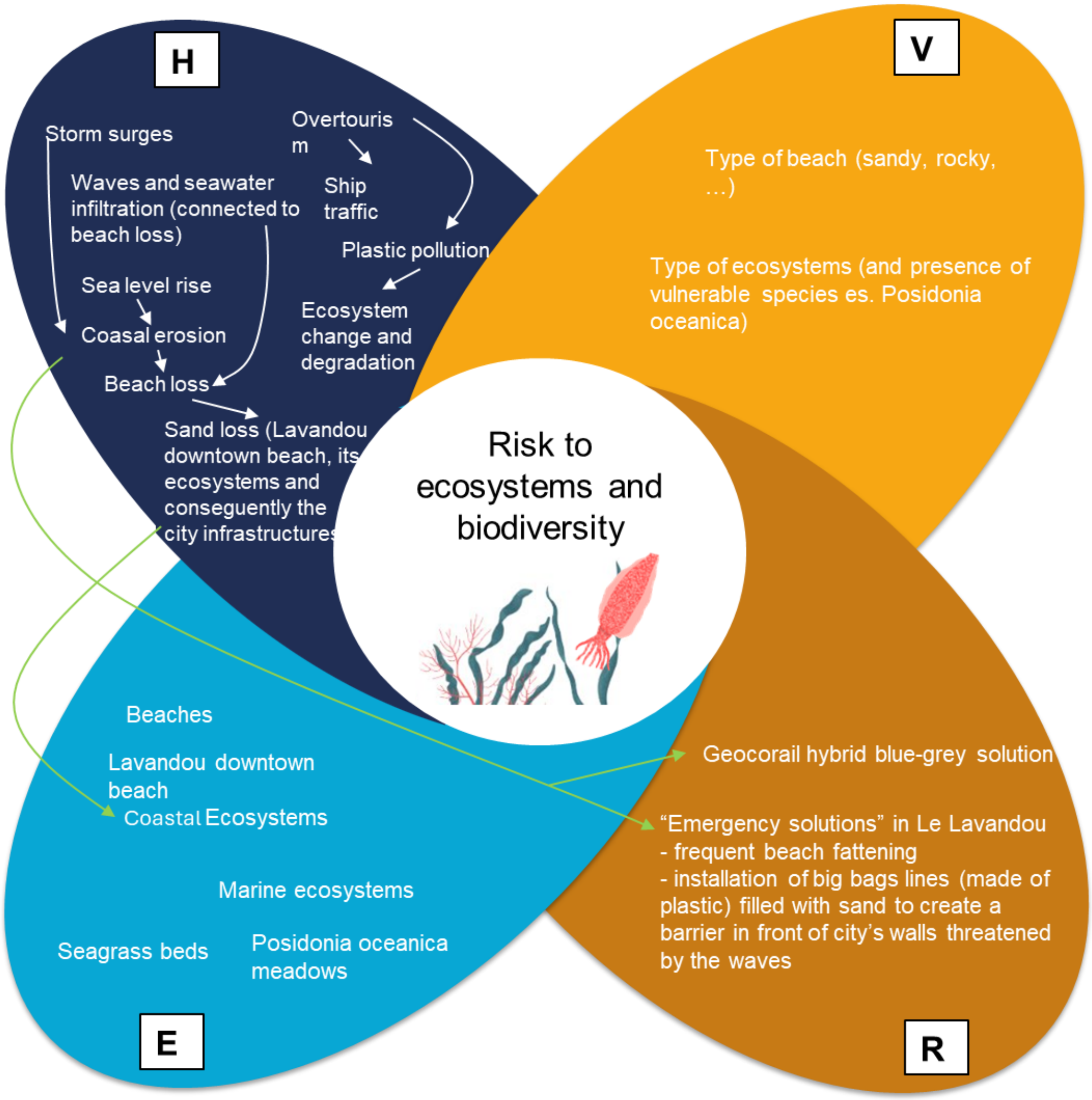

Figure 7. Risk to ecosystems and biodiversity for the Coastal protection infrastructure demonstrator II.

The hazard component highlights both direct climate-related threats and indirect anthropogenic factors.

Climate **hazards** include storm surges and sea level rise, wave activity, and increased seawater intrusion. These pressures are deeply interconnected, as indicated by the arrows in Figure 7. Sea level rise and storm surges are the main drivers of coastal erosion, which, by creating a compounded effect with seawater intrusion, leads to beach loss and degradation.

This culminates in sand loss, with a particularly significant impact in urban areas such as the beach in the centre of Lavandou, where not only ecosystems but also city infrastructures are exposed to increasing risks.

In parallel, human activities such as excessive tourism and the resulting naval traffic exacerbate ecosystem degradation. These factors intensify plastic pollution and contribute to a broader process of ecosystem change and deterioration.

The **exposure** domain includes several environmental units directly affected by these hazards, both at the coastal and marine levels. As regards the coastal domain, beaches have been identified, in particular the beach in the centre of Lavandou, and coastal ecosystems that are particularly exposed to the phenomenon of beach and sand loss.

As regards the marine context, among the various marine ecosystems, seagrass meadows are exposed, and in particular *Posidonia oceanica* meadows, a critical species for its role in providing ecosystem services such as the creation of habitats for marine species, combating coastal erosion, and carbon sequestration.

As regards the **vulnerability** elements that define the identified exposure elements, the type of beach (for example, whether sandy or rocky) and the type of ecosystem have been identified, with emphasis on the presence of vulnerable species such as *Posidonia oceanica*, as determining factors. These intrinsic properties not only influence what could be the extent of the damage that could be suffered, but also its capacity to recover.

In terms of **response**, the diagram distinguishes between short-term emergency solutions and more integrated hybrid approaches. In Le Lavandou, emergency measures include frequent beach nourishment and the installation of sand-filled plastic bags that are used to create barriers in front of urban walls threatened by wave action. Although these measures offer rapid protection, they are reactive and temporary. In contrast, the blue-grey hybrid Geocorail solution represents a sustainable approach that combines ecological principles and engineering to stabilize sediments and protect and support natural habitat functions in the long term.

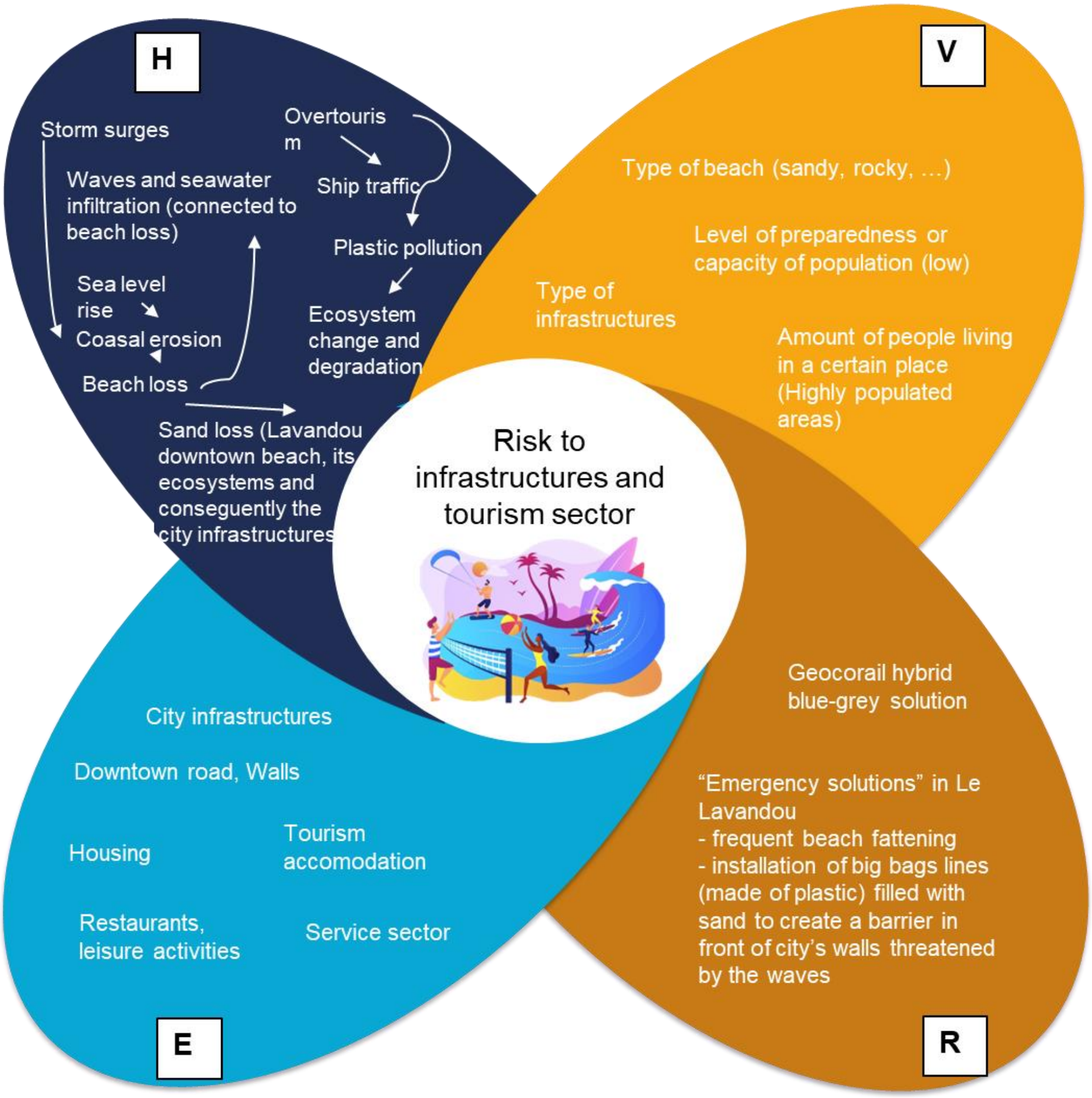

Figure 8. Risk to infrastructures and the tourism sector for the Coastal protection infrastructure demonstrator II.

As regards the risk analysis on infrastructure and the tourism sector (Figure 8), both climatic and anthropic factors are included in the **hazard** component without differences compared to those specified for the risk on ecosystems and biodiversity.

The **exposure** elements include tangible and socio-economic elements located in the risk areas. Among the main exposed assets are urban infrastructure (in particular roads taking downtown, and walls), housing, restaurants, recreational activities, tourist accommodation facilities, and the service sector.

While infrastructure such as roads and city walls are directly threatened by physical erosion processes, recreational activities, tourist accommodation facilities, and the service sector are not always physically located in areas threatened by the listed hazard elements but are also deeply interconnected with the local economy and seasonal population flows, which inevitably strongly depend on the environmental quality and attractiveness of the coast.

The **vulnerability** component includes contextual and structural characteristics such as the type of beach (sandy, rocky, etc.), which influences the natural resistance of the system to erosion, and the type of infrastructure and its degree of robustness and maintenance.

A further critical aspect highlighted in this context is the population density in the area, which increases systemic vulnerability, especially where a large number of people reside or gather in areas exposed to coastal hazards, and the related level of preparedness or adaptive capacity, in particular in the face of increasing climate threats, which is defined as low.

As in the previous risk diagram, the response dimension includes a mix of short-term (e.g., beach nourishment and temporary wave barriers) and long-term (e.g., the hybrid blue-grey Geocorail solution) interventions.

3.2.3. RISK FRAMEWORK FOR OFFSHORE WIND FARM INFRASTRUCTURE DEMONSTRATOR

This demonstrator consists of the installation and implementation of two NbS technologies, SRUs and LBUs, on a floating offshore wind platform aimed at increasing the biodiversity of the area.

SRUs consist of a set of elements, joint together, made of sections of wind turbine blades; each element surface is covered with mollusc shells, to boost invertebrate settlement on it. The hollow sections provide caves of different sizes, which provide shelter to different species. All together serve as an artificial reef that facilitates the proliferation of marine organisms of different nektonic and benthic communities' species of vertebrates and invertebrates. Those elements should serve both as protection against anchors or fishing gear and as biodiversity-enhancing artificial reefs for offshore wind farms.

LBU devices provide a natural substrate for colonisation and development of fully functional ecosystems. Through effective monitoring, with this NbS, we can better understand the changes in an ecosystem, the biodiversity generated, and the CO2 sequestered by the artificial reef of the offshore windmills.

In the case of this demonstrator, the risk framework based on the IPCC structure is reported in Figure 9. As anticipated in the methodology section (Section 3.1) for this demonstrator, only the risk to the functioning in enhancing ecosystems and biodiversity richness and the risk to the structural integrity of the infrastructures were assessed. This is because there are no direct socio-economic activities associated with the SRU and LBU NbS that could be directly damaged by climate change. Rather, these infrastructures should be seen as positive response measures to address and adapt to climate change. The diagram in Figure 9 outlines key interrelated factors that contribute to the risk to SRUs and LBUs' functioning and structural integrity. Understanding the systemic stressors contributes also to improving the understanding of the multiple roles of this hybrid NbS in the marine-coastal system.

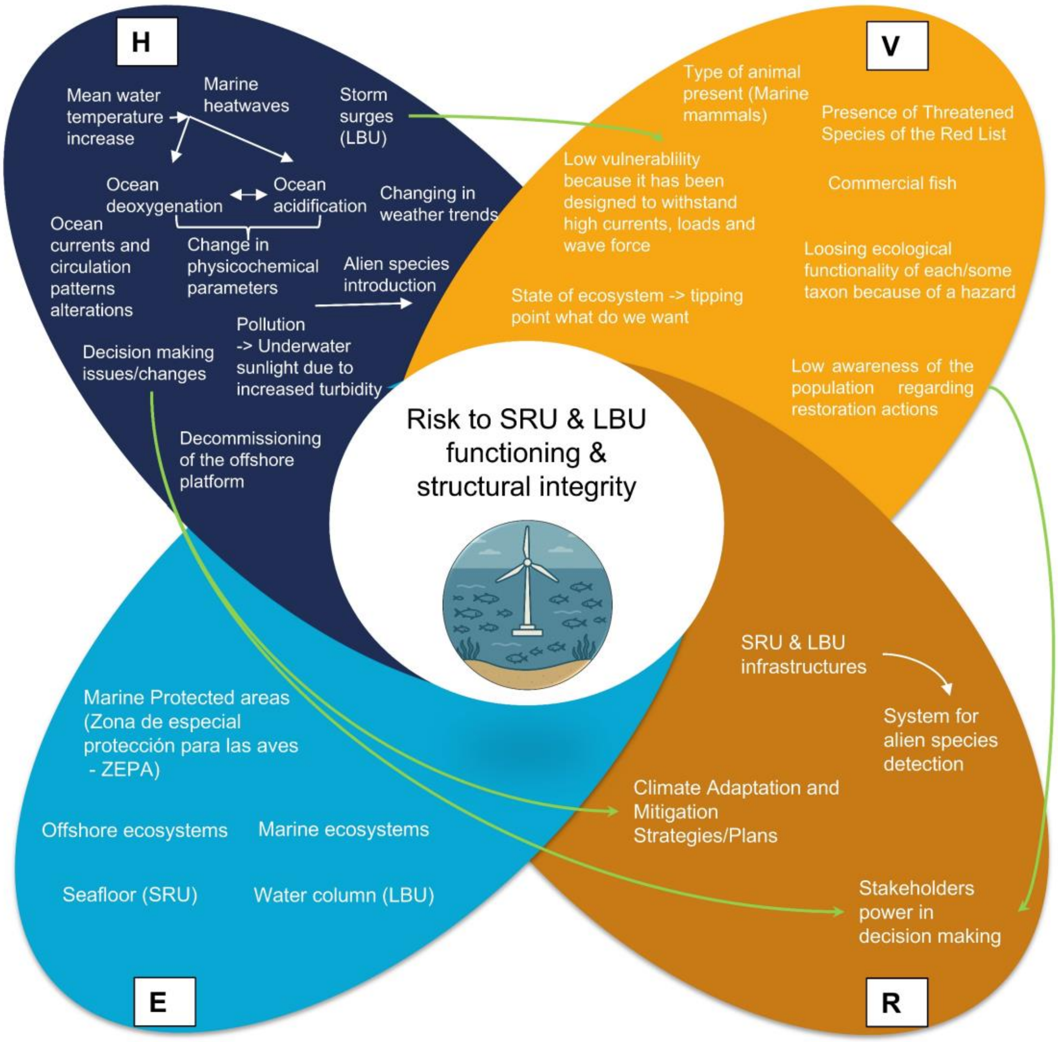

Figure 9. Risk framework for the offshore wind farm infrastructure.

Figure 9 underlines that multiple climate-related stressors contribute to the **hazard** component. One of the most significant is the increase in mean water temperature, which during the summer can lead to marine heatwaves. These, in turn, can trigger cascading effects such as ocean deoxygenation and, in combination with increasing CO2, acidification. These changes impact physicochemical parameters, ultimately disturbing the balance of marine ecosystems. Simultaneously, climate change can cause physical disruptions. Storm surges and shifting weather patterns can damage both marine habitats and built infrastructure. Additionally, changes in ocean currents and circulation patterns influence water quality and nutrient distribution.

Human-induced pressures compound these challenges. For example, pollution from increased turbidity can reduce underwater sunlight, affecting water column and seabed photosynthetic organisms like seagrasses and algae. Moreover, the introduction of alien species can disrupt native ecosystems. Finally, the decommissioning of offshore platforms may disrupt completely the new eco-engineering habitat, decommissioning also the newly created artificial reefs.

Beyond these environmental and anthropic challenges, the instability of political and administrative decision-making adds further pressure, influencing whether hybrid NbS are implemented.

Different areas of the marine space experience these hazards in different ways. Offshore and marine ecosystems are particularly affected, especially the seafloor, where SRUs are located, and the water column, where LBUs operate. Itis important to consider that the floating wind farm is also located in a MPA and a special bird protection zone ("Zona de Especial Protección para las Aves" - ZEPA[3]), making it even more sensitive to climate-related hazards.

Among the **vulnerabilities**, the presence of marine mammals and threatened species (as listed by the IUCN Red List[4]) makes this region highly susceptible to hazards that affect biodiversity, water quality, and physical conditions. Moreover, commercial fish is more vulnerable because of overfishing risk.

Some ecosystems in the area are already in a fragile state, and exposure to further hazards may lead to loss of ecological functionality or even tipping points. While the area has low vulnerability to storm surges, thanks to engineering designed to withstand strong currents and wave forces.

Concerning the population point of view, low public awareness about marine restoration actions increases the vulnerability of NbS initiatives.

The SRU and LBU hybrid NbS are part of a **response strategy** that supports both adaptation and mitigation to the aforementioned hazards. Important is also to underline that within the hybrid NbS, an alien species detection system is in place, which permits monitoring and responding to alien species introductions.

To further address these pressures, engagement with local and broader stakeholder communities is crucial. Within the TRANSEATION project, key stakeholder activities aimed at raising awareness among the general public and decision-makers are planned and will be carried out within WP14. Ultimately, developing effective Climate Adaptation and Mitigation Strategies/Plans is essential for reducing risk and building resilience.

[3] ZEPAs, in Spain, are designated through a European Directive: The Birds Directive (Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds). The purpose of this regulation is to protect all European wild birds and the habitats of several species, particularly through the designation of ZEPAs (https://www.aveprotected.com/).

[4] The IUCN Red List is a critical indicator of the health of the world's biodiversity. Far more than a list of species and their status, it is a powerful tool to inform and catalyze action for biodiversity conservation and policy change, critical to protecting the natural resources we need to survive. It provides information about range, population size, habitat and ecology, use and/or trade, threats, and conservation actions that will help inform necessary conservation decisions (https://www.iucnredlist.org/).

- **IN-DEPTH RISK ASSESSMENT ASSOCIATED WITH THE INSTALLATION AND DECOMMISSIONING OF THE LBUS.**

In addition to the climate-related and ecological risks already considered in the framework, it is essential to recognize that the demonstrator also carries inherent risks associated with the operational phases of **installation and future decommissioning**. These activities, although limited in duration, have the potential to cause both environmental disturbance and safety hazards if not carefully planned and executed. Given that six LBUs will be deployed on DemoSATH within a MPA, it becomes particularly relevant to evaluate the risks associated with these discrete yet critical interventions.

The installation phase involves marine operations close to sensitive infrastructure and habitats. These operations require the presence of support vessels, lifting equipment like onboard cranes, and professional divers. In this context, various factors may contribute to the emergence of risks: the proximity of the vessels (and crane) to the DemoSATH platform and the exposure to adverse sea and weather conditions, leading to unintended contact with the DemoSATH structure or with other submerged assets. Moreover, even though the duration of installation is relatively short, the complexity of offshore manoeuvres introduces a risk of mechanical failure, accidental release of fluids (such as hydraulic oil or lubricants), or even minor collisions that could damage the LBUs or the floating platform itself. A failure in handling or securing the LBUs could result in material losses, prolonged installation times, or compromised safety conditions.

From a human safety perspective, offshore operations always entail a degree of occupational hazard. The handling of LBU structures on deck, particularly in a moving and unstable environment, demands rigorous adherence to safety protocols. One of the most critical moments is the lifting of the LBUs using the vessel's crane, which poses inherent risks both to personnel and equipment. Improper rigging, sudden movements due to sea swell, or a malfunction in the lifting system could result in dropped loads, swinging structures, or unexpected impact, all of which can cause injury or material damage. Fatigue, human error, or unexpected shifts in sea state can further increase the probability of operational incidents. Diving tasks, in particular, add a layer of complexity and risk, exposing personnel to underwater currents, entanglement hazards, and pressure-related health issues. Coordination between the marine crew, crane operator, and diving teams must be seamless, as any miscommunication can lead to dangerous situations in an already complex operational setting.

The decommissioning phase, though often underestimated, presents similar or even heightened risks. After months or years of exposure, the LBUs may be colonized by marine life or partially embedded in biofouling, making their removal more difficult and potentially hazardous to both equipment and surrounding habitats. The removal process might release attached species into the water column. If not conducted with caution, the decommissioning phase could undo some of the ecological benefits generated during the operational life of the LBUs, especially if marine biodiversity has developed around them. In areas of high conservation value, any unintended impact during removal could pose a setback to restoration objectives, particularly if species of interest or protected organisms are affected.

Given the above, it is considered good practice to anticipate a set of precautionary measures that could be activated in the event of unforeseen incidents during installation or

decommissioning. These early considerations reflect a proactive approach to operational planning and contribute to reinforcing the robustness of the demonstrator. Contingency thinking may include identifying alternative time windows in case sea conditions delay offshore activities, preparing backup equipment for critical lifting tasks, and ensuring clear communication protocols among teams to deal with unexpected situations. For tasks involving cranes and heavy lifting, particular attention should be paid to load stability and the mechanical condition of hoisting systems, as well as to the secure handling of LBUs during transfer from deck to sea. The use of certified Personal Protective Equipment (PPE) is essential for all personnel on deck and underwater, including helmets, flotation devices, harnesses, and diving suits with integrated safety systems, depending on the role and exposure.
From an environmental standpoint, vessels may be equipped with basic spill response kits, and procedures for the prompt containment and notification of any accidental release could be outlined in advance. For operations involving divers, basic emergency response protocols, such as evacuation readiness, surface monitoring, and first-aid capacity on board, can significantly enhance safety in dynamic conditions.

These elements reflect a practical and responsible approach to anticipating challenges in offshore operations. By outlining basic response strategies, enforcing PPE use, and integrating key safety considerations, the project demonstrates awareness of the operational context and a commitment to minimising disruption. This mindset strengthens the capacity of the team to adapt to changing conditions and contributes to ensuring that the intervention is carried out with due care and consideration, particularly in a setting as sensitive as a MPA.

3.2.4. LOW-TROPHIC AQUACULTURE INFRASTRUCTURE DEMONSTRATOR

The low-trophic aquaculture demonstrator is aimed at managing the growth of mussel and seaweed cultures by including a new nature-based raft and long-line infrastructures based on biodegradable ropes. Mussel productions are assessed as nature-based sustainable infrastructure, enhancing the local economy while providing environmental benefits (e.g., water quality). At the same time, it has the potential to serve as an emission, capture, and utilization GHGs technology while also contributing to human development along several UN SDGs (SDGs 2, 3, 7, 13, and 14).
Under the IPCC risk framework, the risk to ecosystems and biodiversity from hybrid NbS aquaculture systems arises from the intersection of multiple hazards, climatic, biological, and pollution-related, their interaction with vulnerable and exposed ecological components, and the varying capacity of the system to respond and adapt. By promoting design resilience and implementing integrated monitoring, these risks can be mitigated while enhancing the environmental compatibility of aquaculture infrastructure.
Figure 10 reports the risk framework for ecosystems and biodiversity; indeed, Figure 11 represents the risk to the socio-economic sphere related to the aquaculture activity.

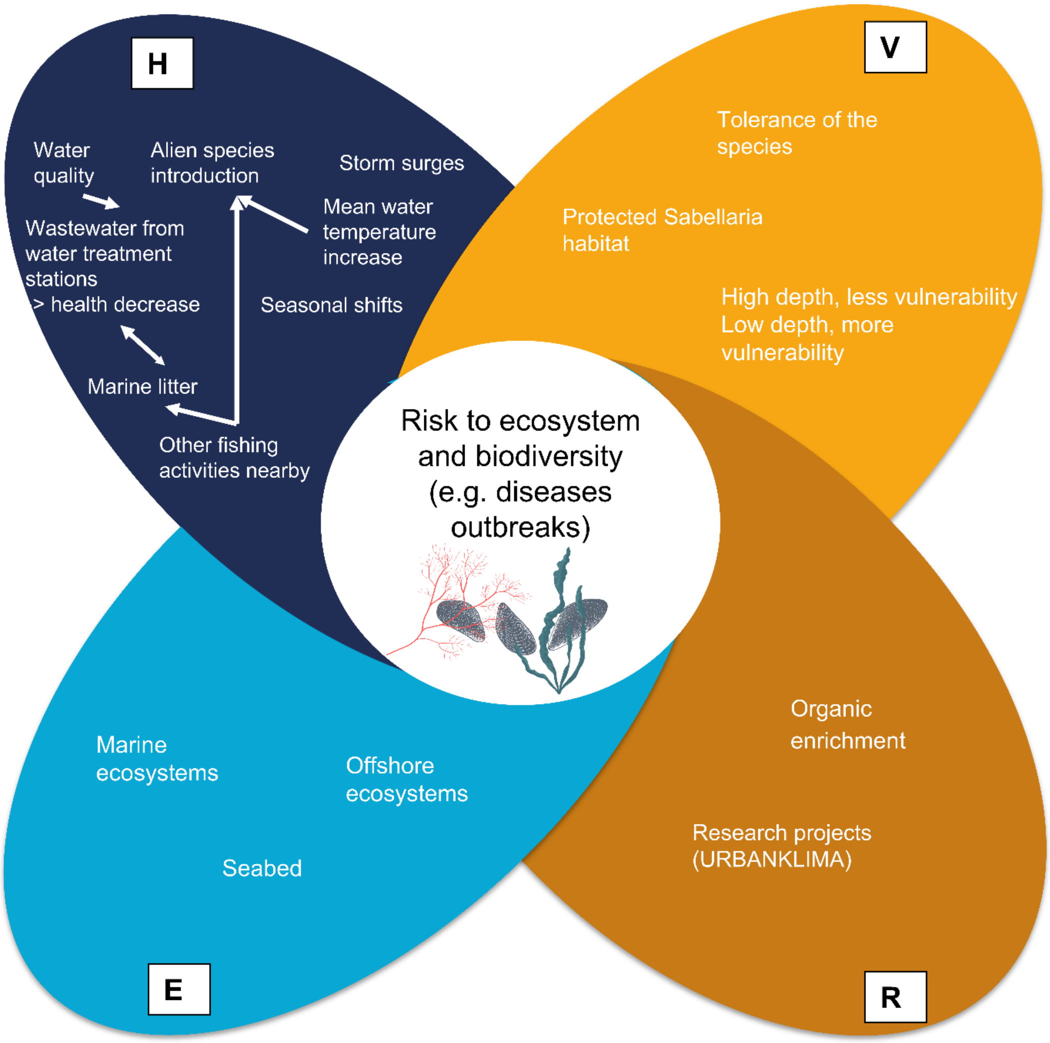

Figure 10. Risk to ecosystems and biodiversity for the low-trophic aquaculture infrastructure demonstrator.

The **hazards** affecting ecosystem and biodiversity integrity in the context of hybrid NbS aquaculture systems are diverse and often interrelated. Climate-induced hazards include rising mean sea temperatures, altered seasonal variability in water currents and thermal stratification, and the increasing frequency and intensity of storm surges and extreme weather events. These are compounded by biological and chemical hazards such as disease outbreaks, exemplified by bacterial contamination like Salmonella, which are closely linked to water quality degradation. The introduction of alien species, potentially facilitated by ballast water or their attachment to floating structures, represents another critical hazard. Additionally, anthropic pollution-related stressors such as marine litter and sewage discharges further compromise water quality, while organic enrichment from aquaculture activities, through feces, pseudofeces, or material degradation from the infrastructure, can alter ecosystem function and structure.

The components most **exposed** to these hazards include offshore and marine ecosystems, particularly those near aquaculture structures. The seabed and benthic communities are especially vulnerable, with protected habitats such as *Sabellaria* sp. reef systems at risk of degradation. Human health and well-being also form part of the exposure landscape, particularly through pathways involving contaminated seafood consumption or recreational contact with polluted waters.

System **vulnerability** is shaped by both environmental and infrastructure-related characteristics. One critical factor in the vulnerability of the benthic system is the depth. Indeed, the effect of a floating artifact on the benthic system, due to losses such as feces and pseudofeces from aquaculture or materials detaching from the infrastructure, can be very impacting. But the vulnerability is reduced when the depth of the water is high, so the bottom is far from the source. Hydrodynamic conditions also influence vulnerability: faster-moving currents can transport and dilute pollutants more effectively, especially in deeper waters, while slower or stagnant flows in shallow areas increase the risk of localized contamination, anoxic zones, and the accumulation of harmful substances. Accordingly, deeper waters tend to lower vulnerability due to the greater capacity for dilution and dispersion of organic material before it can reach and impact the seabed.

The system's **capacity to respond** and its overall resilience depend on both biological tolerance and the implementation of adaptive management strategies. Some habitats may display a degree of tolerance to organic enrichment, though their long-term resilience is contingent on the frequency and severity of disturbances and their intrinsic recovery capacity. Enhancing resilience also requires ongoing scientific inquiry and policy-driven adaptation. Research initiatives such as LIFE IP Urban Klima 2050[5], the Basque Country's largest climate action project, play a key role in informing best practices for infrastructure siting, design, and ecosystem management. By integrating the findings from such projects, stakeholders can enhance decision-making, reduce environmental risks, and support more sustainable and adaptive aquaculture models.

[5] https://urbanklima2050.eu/en/

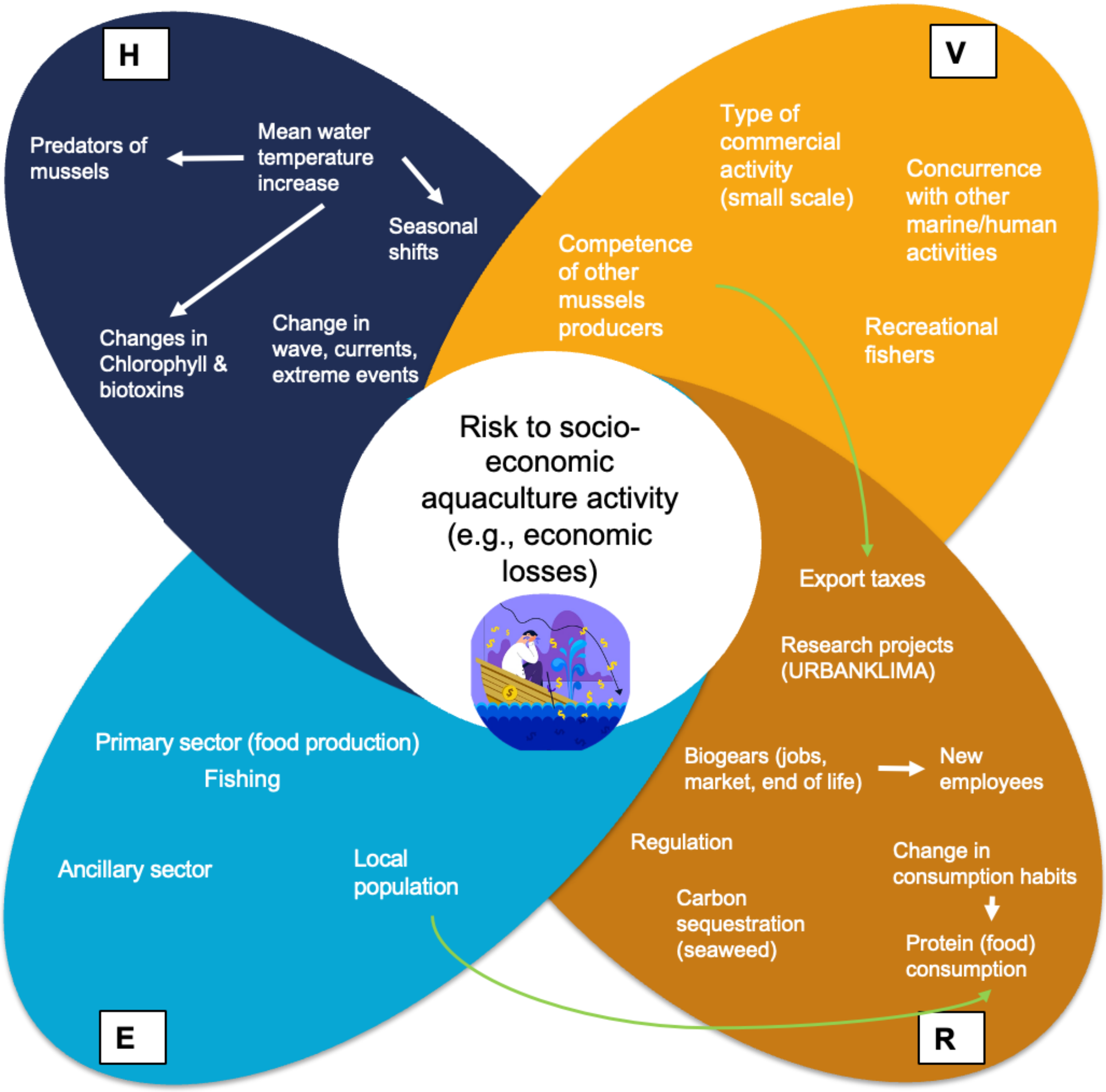

Figure 11. Risk to socio-economic aquaculture activity for the low-trophic aquaculture infrastructure demonstrator.

Low-trophic aquaculture offers sustainable alternatives to high-trophic systems but remains susceptible to multiple socio-economic risks. Given its small-scale, community-anchored model, socio-economic sustainability depends on its resilience to climatic, ecological, and market-driven stressors.

Figure 11 underlines the key **hazards** associated with the implementation of the hybrid NbS aquaculture structure, that include: increases in mean water temperature, seasonal shifts in oceanographic conditions, alterations in chlorophyll concentration and biotoxins, changes in wave dynamics and current regimes, the occurrence of extreme climatic events, and increased predation pressure on mussels.

The sectors most directly **exposed** comprise the primary production sector, particularly aquaculture and fisheries, food production systems, and local communities whose livelihoods are closely tied to marine resources.

Vulnerability is heightened by the small-scale nature of the commercial aquaculture operations, spatial and resource-use competition with other marine human activities (e.g., shipping, tourism), interactions with recreational fisheries, and market competition from other mussel producers. These factors may reduce the system's adaptive capacity and amplify susceptibility to external stressors.

Potential **response strategies** include the implementation of supportive regulatory frameworks (e.g., export taxation policies), promotion of scientific research initiatives (e.g., the UrbaKlima project), job creation in biogear manufacturing and sustainable aquaculture, development of circular economy strategies for gear end-of-life management, carbon sequestration through integrated ecosystem approaches, and efforts to influence consumer behaviours regarding sustainable protein consumption.

4. CONCLUSION AND OUTLOOK

Deliverable D.3.2, *Criteria and guidelines for systemic risk assessment in project demonstrators*, provides a comprehensive overview of multi-hazard climate risks, and a local scale understanding of the systemic risks affecting the four TRANSEATION demonstrators.

The Sys-RA frameworks presented in this deliverable were designed accordingly with the principle of co-development – an approach of growing importance in climate science – where choices are made collaboratively. They build upon the innovative methodology introduced in the IPCC Sixth Assessment Report (AR6) and adapted from Simpson et al. (2021), which captures the complexity of hazard interactions, vulnerability, exposure, and responses.

The analysis shows that all demonstrator areas are subject to a range of climate-related and anthropogenic hazards, including rising sea temperatures, marine heatwaves, water quality degradation, storm surges, and coastal erosion, which together create compounding and systemic risks. These risks impact environmental receptors, socio-economic sectors, and the hybrid NbS implemented. Hybrid NbS, in this context, represent both an impacted element and an adaptive response, showcasing the dual role of such infrastructure in climate resilience.

The assessment also highlights how effective risk mitigation requires integrated responses. These include not only structural measures (e.g., hybrid NbS installations) but also regulatory strengthening, stakeholder engagement, awareness-raising, and participatory governance mechanisms. Active involvement of local communities and coordinated governance frameworks are essential to improving adaptive capacity and long-term resilience. The need for ongoing strategy development and adjustment remains evident as climate pressures evolve.

Overall, the deliverable contributes to identifying both the climate-related risks and the most suitable mitigation and adaptation strategies to reduce potential ecological and socio-economic impacts. By applying the IPCC risk framework, the deliverable offers a structured method to assess and manage risks across diverse marine and coastal settings, supporting long-term sustainability of infrastructure and ecosystems.

Looking ahead, the risk frameworks will also provide critical inputs for the evaluation of the hybrid NbS in terms of effectiveness and performances, and used as the initial input for WP14 "Evidence-based effectiveness evaluation of hybrid blue-grey infrastructures in project demonstrators", where the effectiveness of hybrid NbS will be further evaluated (T14.1).

Moreover, particularly in the frame of the socio-ecological effectiveness evaluation, the Sys-RAs will inform and will serve as a conceptual basis for the modelling of environmental and ecological changes resulting from the implementation of hybrid NbS, including under future climate scenarios (T14.2). The model will assess real-case effectiveness and persistence of such solutions. Furthermore, the risk model will quantify and qualify co-benefits such as service capacity and biodiversity gains in marine-coastal ecosystems, supporting the broader evaluation of blue-grey infrastructure as a climate risk mitigation strategy. Finally, it can serve as a supporting tool within the System Design step of the Systems Approach Framework (T14.4).

This next step will be critical in advancing a sustainable and resilient implementation strategy for hybrid NbS within the TRANSEATION project and beyond.

ANNEX: PHOTOS FROM THE RISK WORKSHOP

Photos from the workshop led during the TRANSEATION Consortium Meeting in Bilbao on March 12, 2025.





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