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ADAPTATION TO CLIMATE CHANGE

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Monitoring water quantity and quality for climate change adaptation

Enhancing ecosystem resilience in the Black Sea region

How can the fragile Black Sea region adapt to climate change-related pressures? Research teams in Bulgaria, Greece, Romania and Türkiye aim to find feasible solutions within a virtual watershed framework in the Black Sea.

Key Learnings

- **International Approach**: Climate change knows no boundaries. A collaborative, interregional strategy is crucial for addressing the shared challenges the Black Sea countries face.
- **Stakeholder Engagement**: The project team effectively identified key issues and established common ground by engaging stakeholders from diverse backgrounds, including the public and private sectors, industry, academia/research, and citizens from the outset. This inclusive approach enabled a thorough understanding of the issues at hand and fostered broad acceptance of the project. It also facilitated the development of innovative pathways to address key regional issues.
- **Improved monitoring**: Both project stakeholders and research teams emphasised the need for improved monitoring. Their shared goal was to use sensors to track environmental parameters and identify necessary measures for better climate change adaptation.

About the region

The Black Sea, a major inland sea spanning 436,000 km², is nestled between Europe and Asia and bordered by Bulgaria, Romania, Ukraine, Russia, Georgia, and Türkiye. Known for its unique biodiversity, the Black Sea supports an array of marine life, including dolphins, sturgeon, and various fish species. A mosaic of cultures, languages, and histories characterises the region. Its coastal population engages in a variety of activities, including fishing, tourism, and trade, which are vital to the local economies. The Danube Delta is located in the Northwest of the Black Sea and is one of the largest and most well-preserved deltas in Europe, covering approximately 4,150 km². Rich biodiversity and stunning landscapes mark the UNESCO World Heritage site, with the Danube shaping the Black Sea's environment and supporting its valuable ecosystem.

Climate Hazards

Flooding, Sea Level Rise,

Extreme Heat,

Droughts, Storms

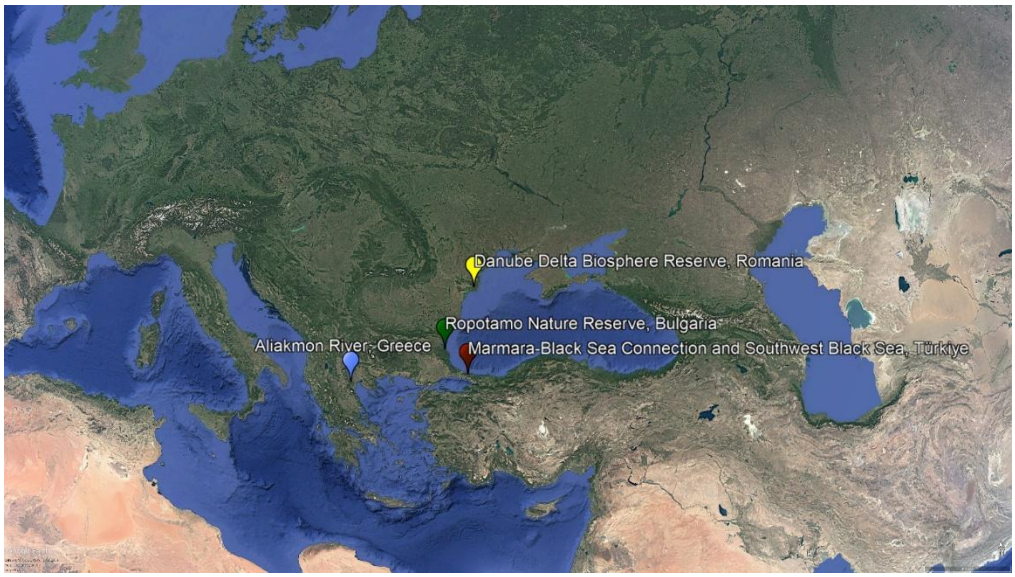
Sector

ICT, Water Management,

Marine and Fisheries,

Coastal Areas,

Biodiversity protection



Key system

Water Management, Ecosystems and Nature Based Solutions

Climate Threats

Climate Change is severely impacting the Black Sea, causing coastal erosion and flooding due to rising sea levels and temperatures. These changes disrupt marine ecosystems, altering species distribution and abundance whilst also leading to ocean acidification and oxygen deficiency. Higher temperatures further facilitate the spread of invasive species, harming native ecosystems and reducing CO_2 absorption. Additionally, extreme weather events, such as the powerful storms in Türkiye in August 2021, have severely damaged coastal ecosystems and infrastructure. The catastrophic flooding due to a series of severe thunderstorms claimed 97 lives and caused widespread destruction, including the collapse of buildings and bridges.

"Climate change and its direct and indirect consequences are here. We need to restructure our way of thinking and how we deal with climate change's impacts, requiring a multidisciplinary regional approach. We need to convince people that the current practices are not sustainable.",

Nicolaos Theodossiou, Coordinator of ARSINOE CS6

A participatory approach for international climate change adaptation

In response to the climate challenges, the ARSINOE project is developing a cross-border watershed management plan involving Bulgaria, Romania, Türkiye, and Greece, with stakeholders playing a pivotal role. The team began by identifying a broad list of stakeholders, categorising them into five groups: industry/business, government/policymakers, associations/NGOs, research/academia, and local citizens.

After assessing each group's interest in the Black Sea Case Study – which builds on the project framework – and their potential to influence the planned activities, the team invited them to participate in a series of engagement activities. These activities included working groups and living labs as part of a participatory approach, ensuring that stakeholders' perspectives were heard and incorporated into decision-making.

This collaborative approach brought together diverse organisations and individuals to develop a shared vision for the Black Sea region in 2050. It also helped identify innovation pathways for building climate resilience and securing funding for regional climate change adaptation measures. This effort secured funding for three innovative companies, selected through an official tender, to implement their solutions in Bulgaria, Romania, and Türkiye, as well as for a research team in Greece to develop a solution to improve water management along the country's longest river. The following sections show how these regional climate adaptation actions are taking shape on the ground.

Regional climate change adaptation measures

Bulgaria – Natural Reserve

In Bulgaria, the ARSINOE project focuses on the Ropotamo Reserve, a strictly protected ecosystem with limited human access. To assess the river basin, the team conducted unmanned aerial vehicle-based surveys and geospatial analyses, using national and international datasets. They included climate projections for RCP4.5 and RCP8.5, meaning moderate and highest emission scenarios. Based on these findings, the team identified potential sensor locations within the reserve. Meanwhile, a selected innovator initiated a separate monitoring programme outside the reserve along the Ropotamo River, implementing real-time water quality monitoring at three key sites:

- A reference site in the upper course,
- A settlement-adjacent site before the reserve to measure human impact on the area,
- A lower-course site near the estuary to assess the river's self-cleaning capacity before reaching the Black Sea.

In mid-September 2024, the project team installed the first set of sensors and established a demonstrator site, integrating the necessary infrastructure

Figure 1: The Ropotamo River. Image Credit: © ENOVA H2O / ARSINOE Project.

for real-time water quality monitoring. These sensors measured key parameters such as nitrates, pH, and temperature.

Throughout the implementation, the team collected water samples every month and analysed them in a laboratory using standard methods to calibrate, validate, and verify sensor data. This analysis covered key water quality indicators, including chlorophyll and blue-green algae. Additional lab tests measured nutrient levels, while on-site tests focused on pH and temperature, critical factors for assessing climate impacts.

Monitoring continued until the end of June 2025 to thoroughly assess the reserve's ability to self-purify – its natural capacity to clean itself under different seasonal conditions. The final analysis will compare water quality before and after the river flows through the protected area, offering valuable insights into how the reserve mitigates human impacts and enhances ecosystem resilience in the face of climate change.

The innovation at Ropotamo River plays a direct role in climate change adaptation by providing high-frequency, site-specific water quality data that helps detect environmental stressors linked to climate variability, such as elevated temperatures, nutrient loads, and pollution spikes. The system's ability to detect these changes almost in real-time is critical for assessing how ecosystems respond to chronic and extreme climate-related events, such as droughts, heatwaves, or flooding. Identifying water quality patterns via sensors supports early-warning systems and adaptive water management, helping local authorities prepare for and mitigate the effects of shifting climate baselines. By offering a cost-efficient, low-footprint alternative to traditional lab-heavy approaches, the system enhances river ecosystem resilience while strengthening the scientific basis for regional climate adaptation policies.

Romania – Danube Delta

In Romania, the study site is located in the Danube Delta. The selected innovator, ProVerse, has developed a demonstrator to address challenges in integrating data from various sources, including on-site sensors, historical records, satellite data, and other relevant datasets. Using advanced data processing and modelling tools, the system analyses and forecasts changes in water quality.

The demonstrator contains four separate systems, all built on the ProVerse platform:

i) A data pipeline for accepting and processing time-series data,

ii) Databases for long-term storage of the raw and processed data,

iii) World state service that allows state changes in the time-lapse of simulation models,

iv) Metaverse technology.

A river buoy protects the instruments from natural hazards and allows reliable monitoring.

During the first phase, the project team and the innovator set up a data pipeline to receive and process time-series data. They also co-developed databases for storing both raw and processed data over the long term. Additionally, the water quality sensors were purchased and calibrated at the ProVerse facilities.

The metaverse platform is now ready to collect real-world data from the buoy. The project team will use this water quality data to visualise, simulate, and analyse how climate change affects the Danube Delta's

natural biofiltration capacity. By leveraging metaverse technology, the platform will support the development of targeted adaptation strategies.

The innovation improves the capacity of local stakeholders to monitor and respond to water quality threats, contributing to climate resilience in the Danube Delta. Real-time visualisations and scenario forecasting support earlier detection of conditions linked to harmful algal blooms, salinity increases, or nutrient loading. This can support more targeted conservation efforts and better management of sensitive ecosystems.

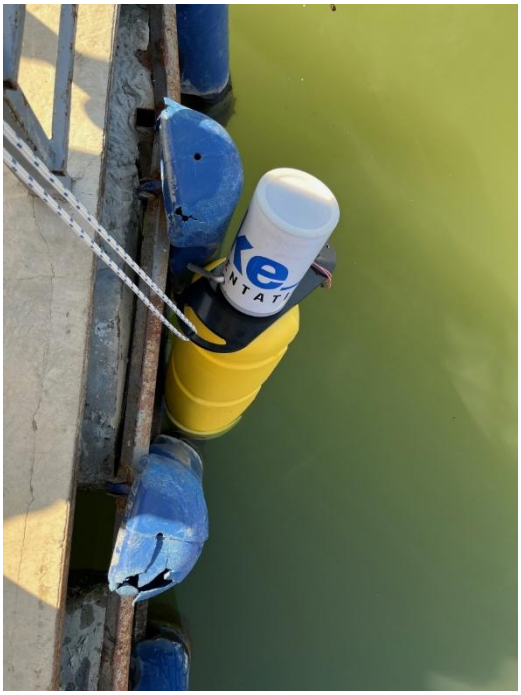


Figure 2: Buoy deployment. Image Credit: © INCSDB, ARSINOE Project.

Türkiye – Marmara and Black Sea Delta

In Türkiye, the team selected the connection between the Marmara Sea and the Black Sea, along with the southwestern Black Sea waters, as a sub-case study. Stakeholders representing this region identified key challenges, such as pollution, declining water quality – particularly oxygen loss – and its impact on fisheries. To address these concerns, regular ship-based marine research expeditions contributed to monitoring and analysing seawater quality parameters.

Figure 3: Expedition in the Black Sea. Image Credit: © METU/ARSINOE Project.

The Turkish team also participated in selecting one of the ARSINOE project innovators to address marine pollution challenges at the site. They chose Polyregnum's "Smart Monitoring Sensors" platform, which is being deployed in the Black Sea for the first time. This platform combines smart sensors with global water quality parameters to remotely monitor air and water pollution, while improving an understanding of air-sea interactions.

Equipped with an AI-powered data processing system, the platform tracks pollution levels in the Black Sea by analysing multiple parameters, including temperature, salinity, pH levels, humidity, and carbon dioxide levels – key indicators for global warming. After completing the corrosion tests, the team integrated all sensors into the platform, which was scheduled for launch in early April 2025.

The SMS platform enhances climate change adaptation in the Black Sea by continuously monitoring key environmental variables and critical indicators of climate-related changes. Better understanding air-sea interactions and detecting signs of ecosystem stress early on supports timely, evidence-based responses. The platform also empowers local authorities and stakeholders to identify long-term climate trends and implement adaptive measures that safeguard environmental quality, public health, and ecosystem resilience in the region.

Greece – Towards a Virtual Watershed Linking to the Black Sea

In Greece, the research team selected the Aliakmon River – the country's longest – for monitoring due to its vital role in energy production, agriculture and water supply. These diverse demands create a complex water management challenge. To address this, the researchers installed low-cost sensors to monitor the river's flow rate, enabling the development of a Digital Twin to support more efficient water management.

Figure 4: Installed sensor. Image Credit: © AUTh, ARSINOE Project.

The Digital Twin operates on a daily basis to generate weekly forecasts about water usage for water supply, irrigation, and electricity generation. It supports predicting water outflow from the river's reservoirs, as it considers hydrological, meteorological, and energy production data. This helps researchers and authorities better understand the complex relationships between different water uses and improve water management efficiency. Considering present and future climate scenarios ultimately strengthens climate resilience.

Exploring four distinct sub-case studies conceptually linked local and regional needs with key processes. It applied the virtual watershed concept to showcase best practices for a comprehensive source-to-sea adaptation approach in water management.

Summary

Addressing today's climate challenges requires an integrated approach to ensure the most effective climate change adaptation solution. Building a climate-resilient Black Sea is only possible through regional collaboration, as emphasised by the stakeholders who participated in the Living Labs envisioning the region's future. Advanced monitoring technologies, real-time data collection, enhanced data-sharing, and a virtual watershed framework all play a crucial role in supporting climate adaptation efforts in the region.

Further information

The work presented in this adaptation story is part of the ARSINOE Mission project.

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Find out more about our Case Study: Case Study 6 – ARSINOE Project

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