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Risks and challenges to face for sustainable and healthy aquatic ecosystems in the Adriatic-Ionian Region

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Summary

1. About this report

1.1 Scope and objectives of this report

This report analyzes environmental threats to aquatic ecosystems, both marine and freshwater, with a special focus on the Adriatic-Ionian region. It identifies and describes problems such as biodiversity loss, pollution, overexploitation of resources, climate change, and biological invasions. Furthermore, the document assesses the current state of aquatic ecosystems across nine countries in the Adriatic-Ionian region, highlighting the specific challenges each faces. Academic solutions and stakeholder involvement to address these issues are also discussed, exploring how universities, research institutions, governments, the private sector and local communities can work together to promote sustainable management and protection of aquatic environments. Finally, it highlights the importance of international cooperation to address transboundary challenges and ensure the long-term health of aquatic ecosystems.

1.2 Methodology

This report has been developed through the collection of data from institutions, research papers, and the general knowledge of all parties involved. The first part presents a review of the main global challenges affecting our planet, relying primarily on scientific publications and documents from institutions. The second part was created through contributions from each country participating in the IPA-ADRION project. Their material was further selected and reorganized to provide a comprehensive overview of the environmental state, main challenges, and proposed solutions across different countries within the Adriatic-Ionian region.

2. Introduction: Marine and freshwater ecosystems

The Adriatic-Ionian region takes its name from the seas that touch it: seven of the nine countries in the region have a coastline, with a total length of approximately 28700 km. Seas, as well as lakes and rivers, have always been central to culture and economy, and they remain one of humanity's most valuable resources. However, despite their importance, the health of these environments has historically received little attention, underestimating how they are impacted by human activity. **Water bodies have been exploited for centuries due to the countless services they offer**. Tourism, the largest sector of the blue economy, is heavily dependent on them, as are many other sectors such as transportation and communication. These ecosystems also offer opportunities for energy production, such as offshore wind farms and hydroelectric plants, as well as resource extraction, including riverine and deep-sea mining. Biological resources are also part of the services provided by aquatic ecosystems, with both marine and freshwater areas being essential for aquaculture and fisheries, with a total annual yield accounting for, respectively, 94.4 and 91 million tons[1].

Humans have long taken advantage of the benefits offered by aquatic ecosystems without acknowledging that overexploitation leads to their depletion, and without considering the immense value of biodiversity. The United Nations Convention on Biological Diversity defines it as "**The variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems**"[2], expanding its role beyond just the variety of life, including its importance to genetics and ecosystems. The recent Kunming-Montreal Global Biodiversity Framework, held in 2022, identified biodiversity as a key driver of ecosystem health, establishing 4 goals and 23 targets to protect it[3]. It also promotes the sharing of goods provided by biodiversity, such as genetic resources and food, so that all populations can benefit equally. **If biodiversity is not preserved, ecosystems lose their equilibrium and functions, denying humans access to their services and resources**. The services provided by biodiversity are countless, and many come from aquatic ecosystems. **These environments not only supply resources and recreational opportunities but also help mitigate and prevent the negative effects of harmful human activity**. For

example, marine and freshwater environments provide a variety of fish, mollusks, and crustaceans, and permit the cultivation of a vast array of algae and plants, such as rice. Furthermore, aquatic genetic resources are essential for the pharmaceutical, food, and medical industries. Meanwhile, filter-feeding organisms, such as oysters, help counteract water surges by forming dense reefs and purify seawater by retaining pollutants. Similarly, riverine plants absorb nutrients preventing their accumulation in water bodies and counteract erosion by stabilizing sediments thanks to their roots.

Water offers numerous benefits to humans, and if biodiversity is threatened, even the loss of a single species could cause the disappearance of others, disrupting the system's equilibrium and potentially leading to collapse. Today, aquatic ecosystems are under serious threat, and humans must recognize the limits of exploitation before the damage becomes irreversible. By acknowledging these impacts and their consequences, people should adopt a sustainable approach that balances resource use with the preservation of ecosystem health. Following the Water Framework Directive standards, it is reported that, in 2021, 29% of the EU's surface water bodies achieved good chemical status, mainly due to the impacts of agriculture, a major releaser of nutrients and pesticides. Furthermore, mercury and persistent substances such as brominated retardants contribute to the pollution of European waters; if they were excluded from the analysis, 80% of the surface waters would reach good chemical status. Habitat degradation and pollution are the main factors impacting the waters' ecological status, preventing progress over the years[4]. Data demonstrate that European water quality is not improving and, therefore, to continue benefiting from these environments, it is necessary to prioritize their health and protection.

3. Environmental threats

3.1 Biodiversity loss

From food to medicines, from water purity to climate regulation, many aspects of our life are sustained and preserved by biodiversity. Estimates suggest that **it provides humans with $29.5 trillion per year**[5], highlighting our deep dependency on it. However, scientific consensus points to a concerning reality: **global biodiversity is in decline**, as evidenced by indexes such as WWF's LPI, which reports a 73% decrease compared to 1970[6]. Earth has always experienced changes that have led to the disappearance of some species and the emergence of others, but since humans began exploiting nature, these changes have been exacerbated, making them the primary driver of biodiversity loss. The consequences of biodiversity loss in an ecosystem are many, represented by the dominance of a single or few species, the abrupt disruption of food chains, or even collapse. **Biodiversity has the important role of conferring greater resistance to turbulence and resilience after impacts**. The causes of this loss are many, the main ones being habitat loss and degradation, overexploitation, climate change, pollution, and biological invasions. Alarmingly, these factors rarely act in isolation; instead, they amplify each other's effects. Additionally, they trigger positive feedback loops that accelerate biodiversity loss. This loss not only represents a threat to nature but also to humans: abrupt shifts in ecosystem composition could lead to a rapid decrease in the services provided by nature. Species that are exploited for food provisioning may disappear or be replaced by invasive species, and ecosystems that help humans contrast catastrophic meteorological events may lose their functions.

LPI reports a decline of 56% in marine habitats and 85% in freshwater habitats[7]. The latter cover only 0.8% of Earth's surface[8] but are home to 9.5% of all known animal species on the planet and provide an estimated value of USD $6.5 trillion per year[9]. However, one-quarter of freshwater fauna is threatened with extinction, and wetlands are declining at a rate threefold higher than land forests. The absence of a sustainable development goal in the 2030 Agenda concerning freshwater highlights that this field is highly underestimated. Since many rivers and lakes are shared among multiple countries, an interregional collaborative approach is needed. To continue to obtain the maximum benefits from aquatic zones such as seas, lakes, and rivers, it is paramount to first understand what is threatening them and, therefore, how to prevent them from damage.

3.2 Habitat loss and degradation

Recognized as the major driver of biodiversity loss, **habitat loss and degradation refer to the alteration of a species' habitat through complete change, fragmentation, or quality loss**. These kinds of transformations are possible in nature but commonly happen over long periods or are restricted to limited areas (e.g., when a natural fire occurs, or a volcano erupts). Humans, on the other hand, through urbanization, agriculture, livestock farming, infrastructure building, and similar activities, accelerate and make this process frequent and highly concerning. When considering marine waters, urban sprawl, the construction of wind farms, and tourism structures represent the main threats to habitat integrity. Additionally, port and ship-related activities, as well as cable deployment, pose a menace to habitat integrity. For example, bottom trawling could extirpate benthic organisms in a region, while anchoring wipes out the organisms that compose seagrass meadows. Urbanization impacts environments by altering its hydrodynamics, morphology, and composition, and the introduction of hard substrates contributes to the establishment of species different from those in the ecosystem's pristine state. Furthermore, artificial structures hinder migration, disrupt connectivity, and limit organism interactions, contributing to habitat fragmentation. This is particularly significant in freshwater environments, which already have an insular nature that is further exacerbated by these disruptions. Freshwater bodies are also affected by the construction of dams, while flood control interventions pose additional threats to these fragile ecosystems. Additionally, agriculture, which accounts for 70% of total freshwater withdrawals[10], further impacts these water bodies.
Habitat loss is particularly significant in the Adriatic-Ionian region due to the intrinsic characteristics of coastal presence: 70% of people live in coastal areas[11]. Therefore, since the coastal region will continue to be exploited for living and tourism alongside the new business opportunities coming from the blue economy, it is necessary to put attention to it, managing all these activities in a sustainable way.

3.3 Pollution

Pollution is a phenomenon that affects land, air, and water, and since these environments are interconnected, the consequences ripple through them all. Concerning aquatic ecosystems, one of the most studied and discussed types of pollution is that resulting from the vast amount of plastic, which has been reported to

reach even the deepest point of the ocean. Plastic items thrown or abandoned in the sea, such as fishing nets or shopping bags, directly damage organisms by trapping, choking, or entangling them. It is estimated that **a total amount of 8 to 10 million metric tons of plastic ends up in the ocean each year**[12], with the Adriatic containing from 22 to 52 plastic waste items per square kilometer[13].

Plastic fragments smaller than 5 millimeters are referred to as microplastics. Some microplastics are intentionally produced at this size, such as those found in facial scrubs, and are known as primary microplastics. Meanwhile, the majority of microplastics in the ocean (68–81%) result from the degradation of larger plastic pieces and are called secondary microplastics. In 2017, the UN declared that the total amount of microplastic particles in the seas accounts for 51 trillion, a number 500 times greater than the stars in the Milky Way[14]. There is still no clear demonstration of the effects they can have on human health, but since they are present in all waters, they accumulate in the organisms we consume and therefore are present in our bodies, too. **Exposure to microplastics in humans potentially leads to serious health issues, including cancers, respiratory diseases, and inflammatory responses[15]. Additionally, they can have physical and mechanical negative consequences, and their presence could absorb other types of contaminants, amplifying their harmful effects[16].**

Contaminants can have different origins, and many of them are found in aquatic and freshwater environments. Heavy metals, polycyclic aromatic hydrocarbons, surfactants, and pesticides are among the toxic substances released because of human activities. Rivers are particularly affected by the release of contaminants, mostly through civil and industrial wastewater, which could lead to devastating effects on aquatic ecosystems. Considering freshwater decapods, fishes, and odonates, 54% of threatened species are affected by pollution[17]. **Higher levels of contaminants have been detected in the Adriatic-Ionian area compared to other sub-Mediterranean basins**, with worrying percentages of mercury in coastal sediments[18]. Another problem is linked to inland water basins: pollution from nutrients, mainly coming from agricultural and farming runoff, leads to their accumulation in the waters. These nutrients can reach excessive levels and cause phytoplanktonic blooms, formed by organisms that proliferate rapidly and consume all the available oxygen, leading to the creation of zones with low (hypoxia) or null levels of oxygen (anoxia), causing the

death of aquatic organisms in the affected area. Furthermore, some proliferating species can produce toxins that additionally alter ecosystem health. **Nutrient loading could also affect marine environments**, posing a menace to seagrasses such as *Posidonia oceanica*.

Pollution is a multifaceted and serious problem that must be addressed to maintain the health of aquatic ecosystems, and is of particular concern because water bodies are often interconnected therefore pollutants can be easily transferred, affecting many ecosystems.

3.4 Overexploitation

Overexploitation can be exerted directly or indirectly: direct practices include poaching and unsustainable fisheries, while indirect overexploitation happens when a species is unintentionally captured, for example, as bycatch in fishing. The situation in the Mediterranean Sea is particularly severe, with 50% of stocks estimated to be subject to overfishing[19]. **According to the FAO, over 60% of fish stocks in the Adriatic Sea are overfished, and unsustainable fishing practices, such as bottom trawling, are known to cause significant damage to marine habitats**. Fishing a stock at a rate that exceeds its reproduction rate inevitably leads to its decline; this means that highly intensive fishing activities are particularly harmful, especially for species characterized by long life stages. The same applies to bycatch: species that are mainly affected include sharks, skates, and rays, which take more time to reproduce compared to other fish and produce low numbers of offspring when spawning. The collapse of a population does not only affect the environment. An example is the decline in the population of cod in the western Baltic, where an irreversible tipping point has been reached due to recruitment overfishing, exacerbated by climate change. This is just one example demonstrating that overexploiting wild populations only leads to an apparent benefit for humans, which abruptly has severe consequences that impact both nature and people.
The solutions to this problem are several, and all need to be implemented. The first is to choose and promote sustainable fishing practices, avoiding or banning the most harmful techniques, such as trawling, which is capable of eradicating entire ecosystems and is one of the major causes of discards. The second is to control bycatch through the implementation of systems such as pingers and Medina panels to prevent dolphin captures, as well as turtle exclusion devices. Additionally, untargeted

species or individuals below their maturity size should be returned to the sea. Aquaculture is currently the world's primary source of biological resources and could offer a solution to overfishing. However, it poses several challenges; first of all, **feed is often produced from wild-caught fish**, which can still contribute to overfishing rather than alleviating it. Other concerns include the use of natural environments, the potential release of invasive species, and the possible spread of diseases. Better management of this practice can reduce reliance on external feeds and fertilizers, thus minimizing the ecological footprint. An example is represented by Integrated Multi-Trophic Aquaculture (IMTA), where the waste of one species is used as a resource for the others.

3.5 Global climate change

Greenhouse gases, such as CO_2, CH_4, and N_2O, prevent the Earth from freezing by allowing it to retain part of the heat received from the sun rather than reflecting it back into space. Their levels have drastically increased since the Industrial Revolution, creating an issue that is now resulting in severe consequences. Water bodies, like the rest of the Earth, are affected by climate change. Rising sea levels, ocean acidification, an increase in disastrous atmospheric events, and changes in behavioral patterns are all consequences of global climate change, leading to devastating effects on both the environment and humanity. **The increase in temperature alters species' behavior, migration, and reproduction patterns**, modifying their geographical ranges and life cycles. It also impacts sex determination in certain species; for example, sea turtles' sex is determined by temperature after egg laying, and higher temperatures lead to a shift towards a majority of females. **In freshwater environments, the results of global warming are intensified**. In some cases, if water becomes too warm and organisms exceed their optimal temperature range, migration is hindered by the isolated nature of these habitats. Fisheries are also affected: since fish populations shift their distribution migrating towards colder waters, often moving northward, equatorial communities are economically damaged, and inequalities are worsened.

The rise in temperature is also causing sea levels rise, threatening villages, cities, and entire islands. Additionally, coastal squeeze, the phenomenon in which rising sea levels reduce the intertidal zone, forces species to move to the only available areas.

The increase of CO_2 in the atmosphere also increases its availability in the ocean, where it reacts with water to form carbonic acid, reducing the availability of calcium carbonate ($CaCO_3$) for marine organisms. This phenomenon is called acidification, and it is measured by the concentration of hydrogen ions (H^+) in water, released after the described reaction. It represents a heavy threat to organisms that rely on calcareous structures, such as bivalves and corals. Data are alarming: it is estimated that if current government pledges for 2030 are not accompanied by further emission cuts, the global temperature will rise by 3.2°C, exposing over 36% of species to climatic extremes in more than half of their present-day geographical range[20]. The predictions are even worse if no mitigation policies for climate change are implemented. In addition, warming reduces the ocean's ability to absorb gases, creating more hypoxic zones and allowing CO_2 to accumulate in the atmosphere, reinforcing the greenhouse effect and therefore raising water's temperature.

3.6 Biological invasions

Any species that is not native to an ecosystem and is purposefully or unintentionally brought there by humans is considered an alien species. One of these species is considered invasive if it spreads and establishes itself. Their **capacity to outcompete native species at the same trophic level, monopolize resources, and change interactions** like predation typically speeds up the spread of these creatures. Additionally, because they come from other ecosystems, they might introduce new illnesses that could harm native species and frequently show tolerance to local pathogens. Several invasion episodes occur in the Mediterranean: a total of 85 non-native macrophyte species, some of which are invasive, have been introduced. An example is *Caulerpa taxifolia*, which began spreading in 1984 from a small patch of 1 m^2 in front of the Oceanographic Museum of Monaco and now covers 300 square kilometers, overwhelming native plants and leading to ecosystem homogenization[21]. This is a severe problem since this phenomenon reduces genetic variability, which is crucial for resilience and resistance to environmental impacts. Furthermore, the opening of the Suez Canal, combined with rising sea temperatures, is influencing fish migration: many African species are moving toward cooler waters found in the Mediterranean, leading to the presence of new competitors of autochthon species. Therefore, monitoring current and potential invasive species is essential, in order to

avoid the spreading of new species that, exploiting resources at a faster pace than original species, may rapidly alter the ecosystemic balance.

4. Status of aquatic ecosystems in the Adriatic-Ionian region

4.1 Environmental threats in the Adriatic - Ionian Region

Many economic challenges are closely linked to environmental issues. This section focuses on the environmental problems affecting the IPA-ADRION Programme's territorial area, with the final aim of identifying common trends, solutions, and perspectives that can help address these challenges.

4.2 Albania

4.2.1 Characterization of aquatic ecosystems in the region

Albania is home to a diverse range of aquatic ecosystems, including rivers, lakes, coastlines, lagoons, and wetlands. Major rivers such as the Drin, Seman, and Vjosa hold significant ecological and economic value, while key lakes like Shkodra and Prespa provide habitats for numerous endemic species. The country's coastline, stretching along the Adriatic and Ionian Seas, hosts rich biodiversity and protected areas. Additionally, lagoons and wetlands, including Karavasta and Narta, serve as crucial habitats for birds and other aquatic species. Albania's aquatic ecosystems support a wide variety of endemic and migratory species, many of which depend on these environments for survival. Protected areas and national parks play a vital role in maintaining biodiversity, ensuring the conservation of these fragile ecosystems for future generations.

4.2.2 Main environmental challenges and threats

Albania's aquatic ecosystems face several environmental challenges that are impacting biodiversity, water quality, and local economies. One of the most pressing issues is plastic pollution, which affects rivers and lagoons due to uncontrolled urban and rural activities. This leads to biodiversity loss, disrupts aquaculture, and degrades water quality, negatively impacting fishing and tourism.
Climate change poses another major threat, particularly in rivers like Vjosa and Seman, where extreme weather events and poor water management result in frequent floods. These floods cause agricultural land loss, infrastructure damage, and disruptions to aquatic ecosystems. Overfishing has significantly reduced fish stocks, especially in the Adriatic Sea, affecting marine biodiversity and the livelihoods of fishing communities. As fish populations decline, pressure on marine species increases, further destabilizing

the ecosystem. Deforestation and erosion in riverine areas contribute to excessive deposition in rivers and lagoons; this leads to habitat loss for many aquatic species, deteriorates water quality, and obstructs natural water flows, exacerbating environmental degradation. Finally, poor management of protected areas, including lagoons and wetlands, has led to biodiversity decline and the spread of illegal activities such as unregulated hunting and construction. The lack of effective monitoring and enforcement threatens the long-term sustainability of these critical habitats. Addressing these challenges requires improved conservation efforts, sustainable resource management, and stricter enforcement of environmental regulations to protect Albania's aquatic ecosystems.

4.2.3 Academic solutions

Universities and research institutions in Albania are actively engaged in initiatives and projects aimed at addressing environmental challenges and promoting the Blue Economy. Among the key academic institutions, the University of Tirana conducts research on biodiversity and the preservation of aquatic ecosystems, while the Agricultural University of Tirana focuses on aquaculture and sustainable technologies. Additionally, the National Center for Research and Development is dedicated to developing new technologies for marine waste management and recycling. Several projects and programs have been introduced to support these efforts. Pilot projects for sustainable aquaculture have been designed by universities, incorporating technological advancements to minimize environmental impact. Biodiversity monitoring initiatives have also been implemented, utilizing advanced systems to track species and assess the quality of marine and coastal waters. To further contribute to these goals, Education and awareness programs have been developed by the universities. Moreover, international collaboration plays a crucial role, with institutions participating in global projects to integrate best practices from international initiatives.

4.2.4 Stakeholder engagement

Addressing the challenges of the Blue Economy in Albania requires the active involvement of various stakeholders. For this reason, WBU started engaging relevant territorial actors, stimulating their discussions around a specific question: "How does innovation contribute to addressing sustainability in Blue Economy sectors and what types of innovation should we focus on?

From the first phase of the discussion the following features emerged.

The government is responsible for developing policies and regulations that encompass all aspects of the Blue Economy, formulating national strategies that guide sustainable development. Financial support is also essential and is represented by the government's funds to projects based on recycling, sustainable aquaculture, and eco-tourism. Additionally, effective monitoring and law enforcement measures are crucial to combat illegal activities such as pollution and unsustainable fishing practices. The private sector contributes through investments in sustainable technologies, particularly in waste management and recycling. Public-private partnerships promote collaboration with government and academic institutions, helping to address environmental challenges more effectively. Eco-tourism initiatives also play a significant role, offering tourism services that support biodiversity conservation and coastal zone protection. Local communities' engagement is essential in raising awareness and fostering environmental responsibility. Awareness campaigns educate the public on the importance of ecosystem protection, while active participation in decision-making processes ensures that local perspectives are considered in managing aquatic and coastal resources.
International projects such as IPA-ADRION and EUSAIR support capacity building and facilitate cooperation among stakeholders; training sessions and workshops organized by these projects provide platforms for sharing ideas and solutions.

4.3 Bosnia and Herzegovina

4.3.1 Characterization of aquatic ecosystems in the region

Bosnia and Herzegovina hosts a wide range of aquatic ecosystems, including rivers, lakes, wetlands, and subterranean waters. It also has a small coastline, approximately 21 km long. The Danube Basin area comprehends the Sava, Drina, Bosna, Ukrina, Una, and Vrbas rivers, and covers about 76% of the country's territory; it accounts for 22.77 km³ of water runoff, making up approximately 62.5% of the total water runoff from Bosnia and Herzegovina. The remaining runoff, totaling 13.66 km³ per year, flows towards the Adriatic Sea. The Adriatic Sea Basin covers the remaining 24% of the country's territory and includes rivers such as the Neretva and Trebišnjica[22].

4.3.2 Main environmental challenges and threats

Aquatic ecosystems face significant threats due to climate change, including more frequent and prolonged dry periods that reduce groundwater availability and impact the human economy. Overexploitation and excessive resource extraction in certain regions further exacerbate the issue. When water levels rise, rivers from Montenegro and Serbia carry floating waste into Bosnia and Herzegovina. This problem is particularly severe at the Višegrad Hydroelectric Power Plant, where accumulated garbage disrupts operations[23]. Additionally, a problem related to both environmental and human health, and identified as a major threat, is scarce water quality due to the lack of implementation of Integrated Water Resource Management. As emerged during the Bosnian roundtable, IWRM in the Republic of Srpska was adopted in 2014 and was valid until 2024, but, due to a lack of resources, the measures and recommendations in the strategy were not fully implemented. The poor quality of wastewater is exacerbated during the tourism season, when more sewage is produced, and due to the lack of controls, inspections, and enforcement[24].

4.3.3 Academic solutions

Universities and research centers carry out restoration projects to address several threats including habitat loss, pollution, and climate change. For example, actions in the Hutovo Blato park[25] focused on restoring its hydrology, improving water quality, and controlling invasive species. As a result of these efforts, the park's biodiversity has begun to recover. Restoration projects in Hutovo Blato have removed the barriers to fish migration. Then, fish were allowed to move freely throughout the park, reestablishing their populations. Additionally, the removal of barriers has helped to restore the natural flow of water in the park, which has benefited other plant and animal species.

4.3.4 Stakeholder engagement

Communication with local communities and stakeholders is crucial for effective water resource management in Bosnia and Herzegovina. Public consultations and active involvement in decision-making ensure that local voices are heard, fostering transparency and better planning. Educational campaigns play an essential role in raising awareness about water conservation and responsible resource use. Collaboration with local governments is vital for implementing water protection and management measures, ensuring sustainable practices. Non-governmental

organizations also have a significant role in education and advocacy, helping to strengthen awareness and community participation in preserving water resources.

4.4 Croatia

4.4.1 Characterization of aquatic ecosystems in the region

The country is characterized by two main hydrogeological zones: the Pannonian Basin and the Dinaric karst region. A significant portion of the Croatian biodiversity hotspot consists of freshwater ecosystems, which include rivers, lakes, and wetland areas, in addition to coastal and marine habitats in the Adriatic Sea. These ecosystems provide support for a wide range of habitats that are essential to the preservation of biodiversity in the region. For example, Croatia's freshwater biodiversity includes the endemic softmouth trout (*Salmo obtusirostris*) and the white-clawed crayfish (*Austropotamobius pallipes*). The country's major rivers, such as the Danube, Sava, and Drava, serve as ecological corridors. Despite their importance, these water bodies are increasingly threatened by pollution, mainly from agricultural runoffs, industrial waste, and untreated sewage. Research indicates high nitrogen and phosphorus concentrations in rivers, contributing to eutrophication. Lakes such as Plitvice and Vrana suffer from tourism-driven pollution and ecosystem degradation. Similarly, wetlands like Lonjsko Polje and Kopački Rit, classified under the Ramsar Convention[26], are increasingly impacted by water management infrastructure and the spread of invasive species. Croatia’s groundwater reserves also face growing challenges. The Dinaric Karst region, known for its extensive aquifer systems, is characterized by a porous nature that makes it highly susceptible to pollution, particularly from urbanization and agricultural runoff[27]. The contamination of groundwater is a pressing issue, as it serves as a primary source of drinking water for rural populations[28].
The maritime habitats of Croatia, which are centred on the Adriatic Sea, are home to a remarkable variety of species, including a number of endemic and endangered plants and animals, such as loggerhead sea turtles (*Caretta caretta*) and the endangered mollusc *Pinna nobilis*. The migratory habits of fish species such as the European eel highlight the significance of preserving healthy aquatic environments for the duration of their life cycles. Beyond their ecological significance, Croatian water bodies contribute substantially to the economy, particularly through tourism, fisheries, and transportation. For example, inland waterways provide various economic benefits,

including hydropower generation, transportation efficiency, and flood control; the Sava and Danube rivers support commercial transport and local fisheries, while smaller water bodies contribute to local livelihoods through aquaculture and ecotourism[29]. The Croatian government has taken significant steps to preserve the environment. Marine protected areas (MPAs), such as the Kornati National Park, are established with the purpose of preserving marine biodiversity and fostering tourism that is environmentally responsible. According to the European Commission's report from 2020, the Adriatic-Ionian Initiative, which is sponsored by the European Union, promotes regional collaboration in the process of tackling maritime environmental concerns.

4.4.2 Main environmental challenges and threats

The cumulative effects of several anthropogenic stressors contribute to severe biodiversity loss. In Croatian waters, there has been a significant fall in the number of species and the quality of their habitats, partly due to coastal development operations.

Pollution remains one of the most critical concerns affecting the Adriatic ecosystem, and factors such as the tourism industry, maritime activities, and inadequate waste management have exacerbated the deterioration of coastal waters. A notable example is the illegal discharge of wastewater from cruise ships near the island of Hvar, leading to significant contamination of beaches and marine habitats[30]. Plastic pollution further exacerbates the problem, with the influx of plastic waste from neighboring countries, particularly Albania, posing a transboundary challenge, threatening marine biodiversity and tourism-dependent coastal economies. Eutrophication, driven by nutrient runoff from agriculture and insufficient wastewater treatment, has also emerged as a major environmental threat, affecting for example the Neretva River Basin and Kaštela Ba.

The development of predictive technologies, such as the Coastal Autopurification Assessment Technology (CAAT) project, aims to enhance monitoring and mitigation efforts. Waste disposal procedures in Croatia that are not properly controlled are a significant contributor to the pollution of coastal waters with plastic. Studies have shown evidence of the presence of significant quantities of microplastics in certain regions, hence emphasizing the pressing requirement for enhanced waste management measures[31]. Consequences related to the global climate change are

particularly severe in Croatia: its coast, especially near Dubrovnik, has recorded some of the highest measured waves in the Adriatic, with significant heights reaching up to 7.5 meters from offshore platforms during storm events. Since this region is particularly affected by the Sirocco wind during spring and autumn, the risk of intense storm surges and coastal flooding is increased[32].

Inland waterways also face governance and infrastructural deficiencies that limit their potential for economic and ecological sustainability. Insufficient investment in waterway maintenance results in deteriorating transport infrastructure, affecting navigation efficiency and ecological integrity[33]. The lack of regulatory clarity and fragmented policy frameworks further hinder the development of sustainable inland water transport systems, discouraging private investments. The integration of inland waterways into multimodal transport networks is also underdeveloped. The absence of intermodal connectivity between rail, road, and waterways limits Croatia's ability to optimize transportation logistics, increasing reliance on high-emission transport modes[34].

4.4.3 Academic solutions

A major academic focus is on water quality assessment and pollution mitigation; for example, Croatian researchers have emphasized the use of advanced adsorption techniques and membrane filtration to remove pollutants, particularly heavy metals and microplastics, from freshwater and marine ecosystems. Another area of academic contribution is the study of climate change impacts on aquatic ecosystems: researchers advocate for integrating climate resilience strategies into national water management policies, including the restoration of natural buffer zones, such as wetlands and riparian forests, to mitigate the effects of rising temperatures and extreme weather events. Additionally, Croatian universities are actively involved in research on Marine Protected Areas (MPAs) and quota-based fishing regulations. Interdisciplinary collaboration between marine biologists and policy researchers has led to the development of ecosystem-based management plans, which balance conservation efforts with economic activities such as fisheries and tourism. Technology also plays a crucial role in academic-led conservation efforts. Interviews with experts highlight the use of AI-driven pollution detection systems and remote sensing techniques to monitor aquatic health. These technologies have enabled researchers

to identify high-risk areas for pollution and implement targeted mitigation strategies. Furthermore, academics emphasize the importance of community involvement in conservation initiatives, such as public education campaigns and citizen science programs.

4.4.4 Stakeholder engagement

As key stakeholders, NGOs play a critical role in raising awareness and driving conservation initiatives in Croatia. Organizations such as Kolektiv NGO have actively worked on pollution mitigation projects, particularly focusing on the Neretva River, one of the most polluted waterways in the country. Their initiatives include public clean-up actions, monitoring pollution levels, and advocating for circular economy models that repurpose plastic waste. However, a major challenge for NGOs is the bureaucratic inefficiency in obtaining permits for conservation activities, as well as a lack of clear communication from public authorities regarding their operational jurisdiction. Additionally, engagement is often hindered by a lack of long-term funding and inconsistent policy support from governmental agencies.
Public-private partnerships (PPPs) have the potential to enhance stakeholder engagement, particularly in industries that rely on aquatic resources. However, another significant barrier to effective stakeholder collaboration is the slow implementation of conservation policies. Stakeholders suggest that increasing financial incentives for sustainable practices, strengthening regulatory enforcement, and improving cross-sector communication could significantly enhance conservation outcomes.

4.5 Greece

4.5.1 Characterization of aquatic ecosystems in the region

Greece has an extensive coastline, the longest among the countries involved in the IPA-ADRION project, accounting for 13676 km. Its vast marine environments in the Aegean, Ionian, and Cretan seas host various forms of marine biodiversity. Major rivers such as Evros, Axios, and Aliacmon, along with lakes like Prespa, Kerkini, and Trichonida, play a fundamental role in maintaining freshwater biodiversity and ecological balance. Additionally, wetlands form unique ecosystems essential for bird migration and breeding, with some designated as Ramsar sites.

4.5.2 Main environmental challenges and threats

Aquatic ecosystems in Greece face numerous environmental challenges and threats. Among them, rising temperatures are leading to the migration of African marine species to Greek waters, potentially becoming invasive. Freshwater is menaced by shifts in rainfall that alter freshwater availability, urban and industrial pollution, and agricultural runoff, which increase the concentration of harmful substances for the environment and humans and increase the risk of eutrophication. Another consequence of agriculture is over-irrigation, which depletes groundwater levels, reducing inflows to rivers and lakes. Dams and other infrastructure hinder water flow, disrupt sediment transport, and block fish migration. Tourism represents an important economic sector of this country[35], but the urbanization related to it is leading to the disruption of coastal areas and the damage of coral reefs and seagrass meadows due to unregulated boating and diving.
Moving away from the coast, the high seas are also threatened, especially by unsustainable fishing practices such as bottom trawling, alongside the phenomena of bycatch and overfishing. An additional impact is generated by geothermal and volcanic zones, such as the Hellenic Volcanic Arc, which affect aquatic ecosystems by introducing heavy metals and altering water chemistry[36]. Earthquakes and shifting fault lines can impact underwater habitats and create disturbances in aquatic ecosystems. Despite EU frameworks like the Water Framework Directive and Marine Strategy Framework Directive, enforcement and compliance gaps persist.

4.5.3 Academic solutions

Marine biodiversity studies at the Hellenic Center for Marine Research (HCMR) focus on monitoring ecosystem health, with special attention to endemic species, habitat mapping, and the impacts of invasive species such as rabbitfish and lionfish. Meanwhile, a focus on freshwater is posed by Aristotle University of Thessaloniki, which is involved in monitoring, examining water quality, biodiversity state, and human-induced changes in rivers and lakes. Despite its importance, freshwater research is underdeveloped compared to its marine counterpart.
Research in aquaculture focuses on the development of integrated multi-trophic aquaculture systems and the production of feed alternatives that rely less on wild-caught fish for fishmeal, while academic institutions help address fisheries issues by providing data and developing population dynamics models.
Pollution is a major concern that affects both freshwater and marine ecosystems;

studies are conducted on the sources and effects of plastic and microplastic pollution in marine environments. Similarly, projects at the University of Crete focus on studying nutrient runoff from agriculture and urban areas.
To address climate change, Greek researchers are analyzing the impacts of rising sea temperatures, ocean acidification, and sea level rise on biodiversity, with the Aegean Sea serving as a key study area for understanding shifts in species distributions. Additionally, restoration projects aim to rebuild seagrass meadows and coastal wetlands.
Marine spatial planning (MSP) is a collaborative endeavor in which researchers cooperate with government agencies to create frameworks that balance conservation with economic activities, in order to promote sustainable management of marine resources.
Scientific contributions also inform compliance with EU directives, such as the Marine Strategy Framework Directive. Research is also essential for improvements in renewable energy, such as offshore wind and wave energy.
An important effort is related to education and citizen science, both engaging local communities through seminars and workshops to raise awareness regarding sustainability and environmental protection. Finally, Greek researchers are active participants in international projects, including EU-funded initiatives.

4.5.4 Stakeholder engagement

The roundtable organized in January 2025 revealed emerging trends and challenges related to the Blue Economy in Greece and was crucial in understanding the perspectives and visions of stakeholders working in this field. Among them are policy experts working on national and international projects, along with startup members entering the most innovative sectors of the Blue Economy.
A notable trend is the rise of initiatives and projects related to tourism, such as “Coastal Pro”, and investment decision-making, like “Blue Mission Med”. Stakeholders identified several key areas requiring attention to keep Greece up to date. One major issue is the imbalance of research and effort between freshwater and marine environments, which is being addressed through academic initiatives.
Additionally, the Blue Economy in Greece spans multiple ministries, such as Maritime Affairs and Agriculture, leading to fragmented strategies and a lack of coordination; unifying these efforts could lead to better results. A similar fragmentation is observed

among stakeholders; fostering a more cooperative ecosystem would enhance communication and improve the management of Blue Economy-related challenges. Furthermore, efforts should be made to increase public awareness.

4.6 Italy

4.6.1 Characterization of aquatic ecosystems in the region

The northern part of the Adriatic Sea is shaped by the interaction between marine water circulation and riverine inputs. Freshwater inflow is particularly important, since it gives rise to lagoon habitats, particularly important in terms of biodiversity. Wetlands, including the Po Delta and the Venetian Lagoon, are internationally recognized for their ecological value: the nutrient-rich waters foster high primary productivity, supporting phytoplankton communities that form the base of a complex food web and reduce CO_2 concentration in the atmosphere. Along with these, the Northern Adriatic is home to a wide variety of habitats, including seagrass meadows, important for maintaining biodiversity, as they provide habitat for numerous fish, invertebrates, and algal species. They also play a vital role in carbon sequestration, shoreline stabilization, and water quality improvement, services from which humans can benefit.
In the central and southern parts, nutrient-rich waters from the Ionian Sea and the outflow of Adriatic surface waters contribute to a complex exchange of biological and chemical components, supporting rich pelagic ecosystems with diverse assemblages of plankton, fish, and cetaceans. Key species include small pelagic fish such as anchovies (*Engraulis encrasicolus*) and sardines (*Sardina pilchardus*), as well as large migratory predators like bluefin tuna (*Thunnus thynnus*) and swordfish (*Xiphias gladius*). Deep-sea habitats host species such as the red shrimp (*Aristaeomorpha foliacea*) and various cold-water corals, like *Lophelia pertusa*. Coastal habitats in the southern Adriatic are characterized by rocky shorelines, submerged caves, and extensive coralliferous assemblages. Additionally, rivers and lakes provide essential services and are home to a vast array of endemic species such as *Salmo carpio*, a rare freshwater fish found exclusively in Lake Garda.

4.6.2 Main environmental challenges and threats

Italian seas are witnessing various types of marine pollution, particularly those linked to tourism activities, transportation, and improper waste disposal. Added to this is a significantly high demand for seafood stocks, leading to the overexploitation of fishing

activities and encouraging illegal practices aimed at maximizing profits, In the southern Adriatic and Ionian regions, overfishing is a major issue, particularly for pelagic fish stocks like anchovies and sardines in the southern part of the country. These factors, combined with the gradual rise in sea levels and increasing temperatures, inhibit biodiversity development, causing a dramatic decline in species capable of surviving and reproducing in our seas, and the invasion of alien species. Reported invasive species include the blue crab (*Callinectes sapidus*) and the comb jelly (*Mnemiopsis leidyi*), that have established themselves in the region, disrupting trophic dynamics and outcompeting native species.

Particular attention needs to be paid to deep-sea habitats, which are slower to recover from disturbances and are especially at risk. The alteration of thermohaline circulation patterns could further disrupt nutrient cycling and productivity in the region. Nutrient input from rivers such as the Po is beneficial for the formation of unique ecosystems, but it also poses risks, particularly in terms of eutrophication and hypoxia, because of the elevated nutrient loads. Pollution from agricultural runoff, urban wastewater, and industrial discharges exacerbates this phenomenon and increases the concentration in the water of other contaminants such as heavy metals and microplastics, which end up in the food chain. Furthermore, damming and water extraction disrupt natural flow regimes, affecting aquatic habitats and species migrations.

4.6.3 Academic solutions

The position of academic researchers is strongly inclined to promote informed decision-making, emphasizing that policymakers require robust information to assess the environmental impacts of their choices. Therefore, the primary role of universities and research institutes needs to be to provide data and evidence to influence choices in terms of policies and investments. Here, the challenge is represented by the fact that economic growth is commonly perceived as detached from environmental sustainability; therefore, it is important to ensure that marine resources are not exploited beyond their natural capacity to recover.

The gap between research and practical implementation remains a crucial barrier, and simply generating data is insufficient if it is not structured and validated to be useful in real-world applications. Public funding based on sustainability principles, such as the

DNSH (Do No Significant Harm**)** approach, is key to allocating funds where they can generate benefits in terms of social and environmental performance. Moreover, it was suggested that private investors and VCs should be encouraged to follow the same path.

The academic community is also re-examining the very concept of innovation in the Blue Economy: many so-called innovative solutions, such as biofuel production or plastic removal technologies, remain in an experimental phase and lack comprehensive impact assessments. Scientists caution that true innovation should not be conflated with temporary fixes, as real progress necessitates solutions that are rigorously tested and demonstrably effective in the long term.

4.6.4 Stakeholder engagement

Multiple interviews, concluded with a final roundtable with stakeholders representing research organizations, business companies, and institutions, have led to interesting insights to comprehend the view of the parties involved. A major problem that emerged from researchers was that integrating environmental costs into traditional growth models to create a more accurate representation of economic progress is challenging. This is due to the difficulty of assigning financial value to ecosystem services and the ethical concerns related to it. The whole point can be summarized with the question of whether nature's value should be measured in financial terms at all: current economic models are inherently misaligned with sustainability and the emphasis on GDP growth as the primary indicator of progress often leads to the exploitation of natural resources rather than their preservation.
The point of view of startups emphasized that the Blue Economy sector poses a unique set of challenges, particularly in securing investment. It was observed that many venture capitalists are reluctant to invest in sustainability-driven businesses because they demand quick returns, whereas environmental solutions often require long-term investment. A step forward that needs to be made is to recognize the benefits of nature over the long term and invest in them without expecting immediate outcomes.
In the policy sphere, increased regulation is pushing businesses toward sustainability compliance. Government policies and European Union directives are playing an increasing role in compelling private-sector investment in environmental initiatives, but the problem of greenwashing is always persistent. Beyond financial concerns,

community engagement is emerging as a crucial factor in sustainability efforts. Ultimately, both academia and industry stakeholders recognize that achieving sustainability in the Blue Economy requires more than just technological innovation; it demands systemic change that starts with more trust in science and in the solutions offered by nature.

4.7 Montenegro

4.7.1 Characterization of aquatic ecosystems in the region

Montenegro is home to numerous aquatic ecosystems, including marine, freshwater, and transitional ecosystems. They are essential for biodiversity conservation, water management, and economic activities such as tourism, fisheries, and hydropower. The Adriatic Sea, which borders Montenegro, is a highly productive and biologically diverse marine ecosystem. The Bay of Kotor, often referred to as the only fjord in the Mediterranean, is a semi-enclosed marine environment with unique ecological characteristics, supporting various fish species, mollusks, and marine mammals. Montenegro's freshwater ecosystems consist of numerous rivers, lakes, and wetlands, with major rivers including the Morača, which feeds Skadar Lake, the Tara River, known for its pristine water quality and deep canyon, as well as the Zeta and Lim Rivers. Skadar Lake, the largest lake in the Balkans, is a Ramsar-designated wetland and an important bird reserve, hosting more than 280 bird species, including the endangered Dalmatian pelican, while other significant freshwater bodies include Plav Lake, Black Lake, and Biograd Lake. The Bojana River Delta, located in the south, forms an important transitional ecosystem where freshwater from the Bojana River mixes with seawater from the Adriatic, creating wetlands, salt marshes, and estuarine habitats that support diverse aquatic life, including migratory birds and endemic fish species. Montenegro's aquatic ecosystems are of high ecological value, providing key ecosystem services such as water filtration, carbon sequestration, and natural flood control, yet they are increasingly threatened by human activities and climate change, necessitating enhanced conservation and sustainable management efforts.

4.7.2 Main environmental challenges and threats

Despite their ecological significance, Montenegro's aquatic ecosystems face numerous environmental challenges, primarily caused by human activities and climate change. Untreated wastewater from households, industries, and agriculture is a major

source of water pollution, while agricultural runoff containing pesticides and fertilizers contributes to eutrophication in lakes and rivers, and plastic waste and heavy metals further degrade water quality. Declining fish populations due to overfishing and unregulated fishing practices, along with coastal development, sand extraction from riverbeds, and habitat destruction, pose significant threats to marine and freshwater ecosystems. Rising temperatures are altering water flow patterns, increasing evaporation rates, and reducing freshwater availability, while extreme weather events such as heavy rainfall and prolonged droughts disrupt aquatic ecosystems, and rising sea temperatures may lead to the disappearance of certain fish species and marine organisms. Expanding urban areas without proper wastewater treatment facilities results in the direct discharge of pollutants into rivers and lakes, while infrastructure projects such as hydroelectric dams and coastal constructions alter natural hydrological cycles and disturb aquatic habitats. The introduction of non-native species, either intentionally or accidentally, disrupts local ecosystems by competing with native species and altering food chains, further threatening Montenegro’s fragile aquatic environments.

4.7.3 Academic solutions

University of Montenegro (UCG) focuses on marine ecosystems, biodiversity, and environmental protection. Similar research is conducted by the Institute of Marine Biology in Kotor; moreover, the Montenegrin Academy of Sciences and Arts (CANU) supports scientific research in environmental and ecological studies while contributing to policy recommendations. Other important institutions include the University of Donja Gorica (UDG), Mediterranean University, the Institute for Nature Conservation of Montenegro, and the Mediterranean Information Office for Environment, Culture, and Sustainable Development (MIO-ECSDE), These institutions actively contribute to research, education, and policy advisory for the protection and sustainable management of aquatic ecosystems through solutions such as advanced water quality monitoring, ecosystem restoration, and climate change adaptation strategies. Modern technologies like remote sensing, satellite imaging, and automated water sensors are being implemented for real-time water quality tracking, while long-term monitoring programs for key freshwater and marine ecosystems such as the Lake Skadar, the Tara River, and the Adriatic coast are established. Through interdisciplinary research and partnerships with government institutions, NGOs, and private companies,

Montenegrin academia plays a vital role in ensuring the sustainable management and protection of aquatic ecosystems, as demonstrated by initiatives such as the "HarmoNIA" project[37], which harmonizes and networks pollutant assessments in the Adriatic and Ionian Seas for better pollution management.

4.7.4 Stakeholder engagement

Strengthening cooperation between municipalities, national environmental agencies, and regional organizations ensures coordinated water management, while developing policy frameworks that involve stakeholders in decision-making enhances transparency and accountability. Public awareness and community participation are promoted through educational campaigns on environmental issues, as well as through citizen science initiatives that encourage local communities to give their contribution to environmental protection. The private sector is encouraged to adopt environmentally sustainable practices in tourism, agriculture, and industry through financial incentives and regulatory support for investments in wastewater treatment and pollution control technologies. Collaboration with NGOs and research institutions plays a crucial role in implementing conservation projects. International cooperation and funding opportunities from EU programs, environmental organizations, and development agencies support conservation efforts, with Montenegro participating in cross-border initiatives such as the Drin River Basin Management Project and the Adriatic-Ionian Cooperation Framework to enhance regional water governance. Projects like "SAMESEA"[38] promote cross-border marine monitoring and conservation, fostering dialogue between economic activities and marine protection by creating a network of public and private stakeholders dedicated to marine life conservation, while initiatives such as "Aquarium Boka"[39] raise awareness through educational programs and research, contributing to a deeper understanding and protection of aquatic habitats.

4.8 North Macedonia

4.8.1 Characterization of aquatic ecosystems in the region

North Macedonia is characterized by the absence of marine environments, but is interspersed with lakes, such as Ohrid, Prespa, and Dojran, that host several endemic species and are important for tourism, cultural heritage, and local livelihoods. Furthermore, river networks, the most important of which is represented by the Vardar, are crucial for irrigation, drinking water supply, and fisheries.

4.8.2 Main environmental challenges and threats

Since the aquatic environments are utterly represented by rivers and lakes, a major threat is water pollution, with a particular emphasis on the risks related to nutrient overload. Therefore, attention must be paid to agricultural runoff, untreated sewage, and urban pressures that are degrading water quality. Climate change is also affecting these environments, modifying water levels, ecosystem stability, and species distribution. Additionally, anthropogenic pressures such as overfishing, unsustainable tourism and illegal construction put stress on sensitive habitats and species.

4.8.3 Academic solutions

Universities and research institutions, such as Ss. Cyril and Methodius University, are actively involved in environmental monitoring, water quality analysis, and ecological restoration projects. development of hydrological and climatic models is carried out to predict water shortages and improve resource management. Additionally, universities support projects on bioremediation, wetland restoration, and sustainable land-use planning, in order to reduce pollution and improve water quality. To monitor ecosystem health, it is needed to improve technological implementation, such as the use of GIS or IoT-based water sensors used in monitoring studies.

4.8.4 Stakeholder engagement

Strengthening cooperation between government institutions, research organizations, NGOs, and the private sector to co-develop and implement policies is essential to carry out collaboration between stakeholders.

Local experts discussed current trends, opportunities, and innovative solutions relevant to sustainable freshwater management, eco-tourism, fisheries, and economic activities in Saraj and surrounding regions. The economic potential for sustainable practices was also outlined, stressing the benefits for local communities.

A scientific expert provided insights into the main environmental threats faced by aquatic ecosystems, including pollution, eutrophication, climate change impacts, and biodiversity loss. The need for integrated and innovative approaches to address these challenges was emphasized. Local communities and fisher cooperatives play a particularly decisive role in decision-making processes for lake and river management. Additionally, cooperation with Albania and Greece for shared lake and river basin

management, ensuring joint actions on pollution control and conservation efforts was encouraged.

4.9 Serbia

4.9.1 Characterization of aquatic ecosystems in the region

Serbia is landlocked country with territory of 88,361 km2 primarily draining through the Danube River/Black Sea Basin. The rivers Tisa, Sava and Velika Morava are three significant tributaries flowing into the Danube River on the national territory. Watercourses in Serbia are classified according to the Decree on the Classification of Watercourses, issued in 1968, which defines required water quality classes based on both natural conditions and anthropogenic influences upstream from sampling sites. In mountainous regions, where human activity is minimal, most rivers maintain the highest water quality classification (Class I). However, the overall prevailing water quality in Serbian rivers falls under Class III, meaning the water is unsuitable for human consumption, food and pharmaceutical industries, or recreational activities such as swimming. Of particular concern is the long-term presence of hazardous pollutants in certain rivers, designating them as environmental black spots due to severe contamination. Beyond rivers, Serbia’s water resources also include natural and artificial lakes, as well as significant groundwater reserves. The primary sectors utilizing these water resources are public water supply and hydroelectric power production, both of which are essential to the country's economy and infrastructure.

4.9.2 Main environmental challenges and threats

Aquatic ecosystems in the Republic of Serbia, particularly those in the northern region, are significantly impacted by biological invasions. The Danube River, as part of Europe’s southern invasion corridor, makes this area especially critical for monitoring, developing control programs, and managing aquatic invasions. Over the past two decades, more than 16,000 specimens of various vegetation types have been collected, with aquatic and semi-aquatic vegetation accounting for approximately 5% of this data. Among these, *Elodea nuttallii* (Nuttall’s Waterweed) has become more prevalent than its congener, *Elodea canadensis*. Known for its rapid growth, *E. nuttallii* often outcompetes native vegetation, leading to monocultures that diminish

biodiversity. Beyond biological invasions, many Serbian water bodies face severe pollution from industrial discharge, agricultural runoff, and untreated sewage. This pollution frequently results in eutrophication, characterized by excessive nutrient loading and the proliferation of harmful algal blooms. For instance, Lake Ludoš has experienced persistent cyanobacterial blooms, severely affecting water quality and biodiversity. Historical pollution events have further exacerbated environmental challenges. The NATO bombings in 1999 released thousands of tons of toxic chemicals into Serbia's soil, atmosphere, and water systems, causing lasting ecological damage. Additionally, agricultural activities contribute significantly to nutrient loading in water bodies. The Sava River basin, for example, receives substantial inputs of nitrogen and phosphorus from livestock manure. Compounding these issues, inadequate wastewater treatment remains a major concern. A large portion of Serbia's population centers lack proper facilities, leading to the direct discharge of pollutants into surface waters. In the Sava River basin alone, 68% of settlements have no wastewater treatment infrastructure, further deteriorating water quality[40].

4.9.3 Academic solutions

Institutions like University of Belgrade and the University of Novi Sad are leading research efforts related to Serbia's aquatic ecosystems and water management. These centers conduct interdisciplinary studies on hydrology, aquatic biodiversity, and water quality, providing reference papers for the understanding and management of aquatic resources.

4.9.4 Stakeholder engagement

As outlined in the reference document on achieving the SDGs in Serbia[41], stakeholder involvement in decision-making processes is paramount, engaging individuals from business, academia, civil society, and government. The Stakeholder Engagement Plan for the Construction of the Regional Waste Management Centre Kalenic[42] demonstrates the importance of stakeholder identification, communication, and engagement in successfully implementing initiatives that benefit both society and the environment. Emphasis is placed on conducting regular assessments of stakeholder engagement and reporting to ensure accountability and determine if strategic changes are needed.

At the local level, a dialogue among different territorial actors was stimulated trough the support of expert facilitators. This will help local public authorities and private entities to directly act in the following steps of BLUNEW project.

4.10 Slovenia

4.10.1 Characterization of aquatic ecosystems in the region

Slovenia is characterized by an extensive river network. The Sava River is the longest river in the country, flowing through the central and southeastern regions. It is a key watercourse for hydroelectric power generation and supports diverse aquatic life, such as brown trout, grayling, and other fish species. The Drava River, forming part of Slovenia's southeastern border, is an important waterway for agriculture, industry, and biodiversity conservation. It is also home to species like the European eel and several types of freshwater fish. In the western region, the Soča River represents a hub for the conservation of endangered species like the marble trout. It is also a popular destination for recreational activities such as fly-fishing, kayaking, and rafting. Slovenia is also characterized by the presence of several lakes. Lake Bled is home to endemic species such as the Bled trout and various waterfowl, including the common coot and the mute swan. Lake Cerknica is one of the largest karstic lakes in Europe and serves as an important wetland habitat, particularly for migratory bird species and amphibians. Located in northeastern Slovenia, Lake Ptuj is an artificial reservoir formed by the damming of the Drava River, supporting significant populations of fish and water birds. Wetlands like the Sečovlje Salina Nature Park in the coastal area are crucial for biodiversity, acting as breeding grounds for many bird species and providing important ecosystem services such as water filtration and flood regulation. Slovenia’s coastline features a variety of coastal ecosystems. The Adriatic Sea off Slovenia's coast contains important seagrass ecosystems, primarily Posidonia oceanica and Zostera marina. The country has established protected coastal areas, including the Sečovlje Saltpans, a significant habitat for bird species and other wildlife, as well as the Škocjan Bay area, which is home to rich biodiversity. Marine mammals, such as the bottlenose dolphin (*Tursiops truncatus*), are also present in the region, although their populations are threatened by human activities like fishing and marine traffic.

4.10.2 Main environmental challenges and threats

Slovenia’s coastline, though relatively small (around 46.6 km), is particularly vulnerable to erosion, due to rising sea levels and human activities like coastal development. Areas such as the Sečovlje saltpans and the Piran Bay are at risk of habitat loss from coastal erosion, which threatens biodiversity. Other threats are represented by marine pollution, overfishing, biological invasions, and overfishing. Tourism is one of Slovenia's key economic sectors and the country’s small coastal region, particularly the towns of Piran, Koper and Portorož, attracts a large number of visitors. However, mass tourism during the peak summer months places immense pressure on local marine and coastal ecosystems. A particularly important sector for Slovenia is hydropower infrastructure, with numerous dams and hydroelectric power stations along its rivers. While hydropower serves as a source of renewable energy, the construction and operation of dams disrupt natural river flow, degrade aquatic habitats, and threaten species such as migratory fish.

4.10.3 Academic solutions

The University of Ljubljana is involved in a variety of marine-related research initiatives, particularly through its Faculty of Maritime Studies and Transport. The university also partners with industries and government agencies to promote innovation in the Blue Economy. The National Institute of Biology (NIB) conducts research on marine ecosystems, including the impact of pollution, climate change and invasive species on biodiversity in the Adriatic Sea. The Jožef Stefan Institute is research institute specializes in scientific research in areas such as renewable energy, environmental protection and technology development. It conducts cutting-edge research in marine technologies, which are increasingly relevant for Slovenia’s Blue Economy.

4.10.4 Stakeholder engagement

The primary objectives of stakeholder engagement are collaboration, awareness and education, policy formulation and implementation, incentivizing sustainable practices and innovation and technology transfer. Workshops and roundtables are important tools to create a platform for dialogue, share information and co-develop solutions. A key part of stakeholder engagement is policy co-creation, consisting of the design of environmental policies to ensure that they reflect the needs, capacities and concerns of different sectors of society. Additionally, public-private partnerships encourage collaboration between the government and private enterprises to implement large-

scale environmental projects, such as renewable energy infrastructure, sustainable waste management systems and eco-tourism initiatives. Media campaigns raise awareness about the importance of addressing environmental challenges and promote various initiatives; community outreach initiatives, such as educational campaigns, help inform citizens about their role in preserving the environment. Reports and publications, such as annual or biennial reports on Slovenia's environmental status and actions taken, provide a way to communicate the outcomes of engagement efforts to all relevant groups.

5. Conclusions

From this document, it emerges that the environmental challenges faced by the countries involved in the IPA-ADRION project are similar. The countries bordering the sea experience the same issues due to the nature of the basin: being semi-closed, exchanges with the rest of the Mediterranean are limited, leading to the accumulation of nutrients and pollutants, which represents a major challenge along with climate change-related issues. As an example, invasive species reaching this region originate primarily from Africa due to rising temperatures that drive their migration (Lessepsian migrations). Pollution is also a highly discussed threat for landlocked countries, particularly due to plastic waste and contaminant discharge, which affect not only seas but also rivers and lakes. Various solutions are being proposed, with many countries adopting innovative methods that prioritize ecosystem health. Additionally, projects aimed at restoring and preserving natural areas are becoming more widespread, reflecting a growing recognition of nature's importance.

A key takeaway is that since many human activities depend on ecosystems, and ecosystems themselves provide essential services to humans, their protection is essential. Human activities are impacting natural ecosystems, causing primarily negative consequences for the environment, which in turn affect humanity, no longer providing resources and services. Therefore, we must consider ourselves as part of these systems and acknowledge that depleting them means destroying our own natural heritage.

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