ACROSS
Journal of Interdisciplinary Cross-Border Studies
Vol. 10, No.5, 2026

Environment

Climate Change Impacts on Romanian Aquaculture and Aquatic Biodiversity: Vulnerabilities, Risks and Adaptive Responses

Isabelle METAXA, Aurelia NICA, Ștefan Mihai PETREA,
Ira Adeline SIMIONOV, Alina ANTACHE
"Dunărea de Jos" University of Galați
*Corresponding author: imetaxa@ugal.ro

Abstract

Climate change is increasingly reshaping freshwater, wetland, riverine, deltaic, and coastal ecosystems in Romania, with direct consequences for aquaculture productivity, aquatic biodiversity, food security, and rural livelihoods. Romanian aquaculture remains predominantly freshwater and pond-based, with production systems relying heavily on carp polyculture, trout farming, and limited sturgeon-related activities. These systems are highly exposed to rising water temperatures, droughts, altered precipitation regimes, oxygen depletion, eutrophication, disease emergence, floods.

This paper synthesizes recent scientific and policy evidence regarding climate change impacts on Romanian aquaculture and aquatic biodiversity, focusing on vulnerabilities, risks, and adaptive responses. Using a structured review and a qualitative risk-assessment framework, the paper identifies five major climate-risk clusters: thermal stress, hydrological scarcity, extreme floods, water-quality deterioration, and biodiversity displacement. The Danube Delta is treated as a strategic case study because it functions simultaneously as a biodiversity hotspot, fish nursery, wetland buffer, cultural landscape, and climate-risk frontier.

Results indicate that extensive pond aquaculture is vulnerable to evaporation, low dissolved oxygen, and water scarcity, while cold-water trout farms face increasing risks from stream warming and reduced summer flows. Native aquatic biodiversity is threatened by habitat fragmentation, altered spawning conditions, invasive alien species, salinity shifts, and cumulative pollution pressures. According to the paper, adaptation must integrate farm-level technology with basin-scale restoration, water governance, climate-smart farming, monitoring systems, and an optimized national strategy. Building resilient aquatic food systems fundamentally requires targeted investments in water retention, wetland recovery, biosecurity, species diversification, eco-friendly recirculating aquaculture, and ecosystem-based management.

Keywords: Romanian aquaculture; freshwater fish; climate adaptation; invasive species; wetland restoration

Introduction

Aquatic food systems are undergoing a structural transformation under the combined pressure of climate change, biodiversity decline, freshwater constraints, and increasing food-

security demands. Aquaculture has become central to this transition. FAO's The State of World Fisheries and Aquaculture 2026 reports that global fisheries and aquaculture production reached a record 235 million tons in 2024, including 195 million tons of aquatic animals. In the same year, aquaculture production of aquatic animals exceeded 100 million tons and accounted for approximately 53% of total aquatic-animal production [1]. This shift strengthens the strategic role of aquaculture in global food systems, while also increasing the importance of climate resilience in relation to water availability, water quality, disease risk, and ecosystem carrying capacity.

Romania represents a relevant case for examining these challenges because of the diversity of its aquatic environments, which include the Lower Danube, the Danube Delta, the Black Sea coast, floodplains, lakes, reservoirs, mountain rivers, and extensive pond landscapes. Although Romanian aquaculture remains relatively modest in scale compared with major European producers, it is important for domestic aquatic production and for rural territories where pond-based systems contribute to food supply, employment, and local ecosystem services. Eurostat data show that aquaculture accounted for 79.9% of Romania's total fisheries production, measured in live-weight tons, in 2023 [2]. This indicates that national aquatic production depends substantially more on farming than on capturing fisheries.

The structure of Romanian aquaculture creates a direct dependence on freshwater availability and environmental stability. According to the EU Aquaculture Assistance Mechanism, aquaculture activity in Romania is limited to freshwater farming, and production takes place entirely in ponds. Sectoral data indicate that trout, common carp, and bighead carp are among the most important farmed groups, while carp is commonly produced in extensive polyculture systems [3]. These characteristics make production sensitive to seasonal hydrology, pond depth, water temperature, dissolved-oxygen levels, feed efficiency, and disease management.

Climate change is already a material risk for Romania. The OECD identifies the country as highly vulnerable to global warming and extreme weather events, particularly heatwaves, droughts, and river flooding, and emphasizes the need for stronger climate adaptation and sustained investment in flood infrastructure [4]. These national vulnerabilities occur within a broader European warming context. Copernicus reported that 2024 was the warmest year in the global instrumental record and the warmest year recorded for Europe; the exceptional warmth of 2023–2024 was mainly associated with record temperatures in central, eastern, and southeastern Europe [5].

The ecological implications are especially significant in the Danube Delta. UNESCO describes the Danube Delta as the largest and best-preserved of Europe's deltas, supporting more than 300 bird species and 45 freshwater fish species in its lakes and marshes [6]. Scientific literature further identifies the Danube River–Danube Delta–Black Sea continuum as a critical system for regional fish diversity, with the delta functioning as a transitional, feeding, reproductive, and nursery area for numerous fish species [7]. Climate-related changes in hydrology, temperature, salinity, and habitat quality may therefore affect both biodiversity conservation and aquatic production.

Against this background, the present study examines how climate change may reshape Romanian aquaculture and aquatic biodiversity. By integrating environmental pressures, technological adaptation options, and regulatory dimensions, the study identifies key vulnerabilities and explores strategic pathways toward climate-resilient aquatic food

systems. This integrated perspective is necessary for understanding how Romania can support aquatic food production while protecting the ecological systems on which long-term sustainability depends.

Materials and methods

This paper uses a structured scientific review and qualitative risk-synthesis approach. Sources include international assessments, European climate and water reports, FAO fisheries and aquaculture data, Romanian and EU policy sources, and recent scientific literature on the Danube Delta, invasive fish and aquaculture adaptation.

The study utilizes a conceptual framework based on the components of hazard, exposure, sensitivity, and adaptive capacity:

V = f (E, S, AC), where: V = vulnerability, E = exposure, S = sensitivity, AC = adaptive capacity

Risk is evaluated qualitatively as: $R_{ij} = L_i \times C_j$, where: R_{ij} = risk score, L_i = likelihood of climate hazard, C_j = consequence for aquaculture or biodiversity

A five-level qualitative scale is used:

Score	Likelihood	Consequence
1	Rare	Negligible
2	Unlikely	Minor
3	Possible	Moderate
4	Likely	Major
5	Very likely	Severe

The risk categories are interpreted as:

Risk score	Category	Interpretation
1–5	Low	Manageable with routine measures
6–10	Moderate	Requires targeted adaptation
11–15	High	Requires urgent management
16–25	Very high	Requires structural transformation

Results and discussion

Romanian Aquaculture and Aquatic Biodiversity Context

Romanian aquaculture has a long historical association with ponds, floodplains, and carp polyculture. In contrast to the highly intensive marine or cage-based aquaculture systems found elsewhere in Europe, Romania's sector is predominantly inland and freshwater-based. The primary farmed species include the common carp (*Cyprinus carpio*), bighead carp (*Hypophthalmichthys nobilis*), silver carp (*Hypophthalmichthys molitrix*), trout (fam. *Salmonidae*), goldfish (*Carassius auratus*), and various sturgeon species [3].

According to the FAO Romania Fisheries and Aquaculture Profile, national production in 2022 reached approximately 11,200 tons from aquaculture, 3,000 tons from inland capture, and 3,200 tons from marine capture [8]. However, a 2026 sector note [9] highlights that

modern aquaculture production remains far below its historical peak of over 50,000 tons recorded during the communist period and the early 1990s.

The same 2026 sector note identifies Romania's top aquaculture species in 2024 as trout (3,293 tons), common carp (2,554 tons), bighead carp (1,700 tons), silver carp (178 tons), and crucian carp (729 tons). These figures indicate that the sector distinctively combines cold-water salmonid production with warm-water cyprinid pond farming. This dual structure creates contrasting climate vulnerabilities: while carp ponds are highly exposed to drought, intense evaporation, and hypoxia, trout farms face threats from warming streams and a dwindling availability of cold water.

Romania's aquatic biodiversity is heavily concentrated in its river networks, floodplains, wetlands, lakes, reservoirs, mountain streams, the Black Sea coastal zone, and the Danube Delta. The Danube Delta plays a central role by linking freshwater, brackish, and coastal ecosystems. As highlighted by UNESCO, it is Europe's largest and best-preserved delta, hosting over 300 bird species and 45 freshwater fish species [6].

More broadly, the Danube River Basin holds exceptional ecological importance. The International Commission for the Protection of the Danube River describes the basin as a habitat for around 2,000 plant and 5,000 animal species, including numerous endangered or nearly extinct species [10]. Consequently, the Danube Delta represents not only a vital Romanian conservation asset but also a critical component of European ecological infrastructure.

A 2023 review of the Danube River–Danube Delta–Black Sea system [7] emphasizes that the Delta acts as a natural buffer, shelter, feeding ground, reproductive area, and transition zone for many fish species. However, it also warns that sea-level rise and habitat transformation could severely impact approximately one-third of the Delta's native fish species.

Climate-driven stressors impacting Romanian aquatic environments

Rising air and water temperatures

Temperature increase is the most direct climate driver affecting aquaculture and aquatic biodiversity. The Intergovernmental Panel on Climate Change (IPCC)'s Europe chapter states that mean and maximum temperatures, warm days, warm nights and heatwaves have increased across Europe since 1950, and that average warming in Europe is projected to exceed the global mean [11]. Copernicus reports that Europe experienced its warmest year on record in 2024, with exceptional warmth across central, eastern and southeastern Europe [5].

For aquaculture, warmer water modifies fish metabolism, feed intake, oxygen demand, growth performance, disease susceptibility and mortality risk. For biodiversity, warming changes species distributions, spawning phenology, food-web interactions and the competitive balance between native and non-native species. In ponds and shallow wetlands, warming also accelerates evaporation and increases the likelihood of algal blooms and nighttime oxygen depletion.

Drought and seasonal water scarcity

Drought is a priority hazard for Romanian aquaculture and aquatic biodiversity. The European Environment Agency (EEA) reports that water scarcity affects about 30% of EU

land and 33% of the EU population on average each year, while Romania experienced seasonal water scarcity particularly in summer in 2023 [12]. EEA's drought indicator further reports that in 2024 drought impact caused vegetation productivity to fail to recover across 17% of Romania's territory, with Romania having the largest absolute drought-affected vegetation-productivity area among EU countries assessed in that indicator [13].

For pond aquaculture, drought reduces water volume, concentrates nutrients and pollutants, raises temperature, reduces oxygen buffering capacity and increases conflict among agricultural, municipal, energy and ecological water use. For aquatic biodiversity, drought fragments habitats, reduces connectivity, exposes spawning grounds and intensifies predation and competition in shrinking water bodies.

Floods and extreme rainfall

Romania is also vulnerable to river flooding. OECD identifies river flooding and drought as major climate risks for Romania and notes that flood-management improvements require continued investment in infrastructure and land-use planning [4]. EEA's Romania climate-loss profile reports that climate impacts on watercourses produced 215 extreme flood events in 2022, compared with 94 events recorded in 2010 [14].

Floods can damage aquaculture infrastructure, cause fish escapes, introduce pathogens and contaminants, erode pond embankments and disrupt feed and oxygen-management operations. Ecologically, floods can be beneficial when they reconnect floodplains and wetlands, but destructive when intensified by degraded catchments, channelization, polluted runoff or poorly managed infrastructure.

Water-quality deterioration

Climate change amplifies water quality problems. EEA's 2025 water and climate assessment states that climate change has intensified droughts and floods in Europe, affecting water availability, ecosystems, food and energy production, and that climate change worsens water quality through pollutant concentration and saltwater intrusion from rising sea levels [15].

In aquaculture ponds, high temperature and low water volume increase ammonia toxicity, organic loading, cyanobacterial blooms and hypoxia risk. In rivers and wetlands, reduced flow lowers dilution capacity, while heavy rainfall increases nutrients, pesticide and sediment runoff from agricultural landscapes.

Impacts on Romanian Aquaculture Systems

Extensive and semi-intensive carp ponds

Carp ponds are the backbone of traditional Romanian aquaculture. Their climate vulnerability comes from shallow-water exposure, dependence on precipitation and surface-water supply, organic productivity, seasonal temperature variability and limited capacity for technological control.

The main risks are:

Climate driver	Mechanism	Aquaculture effect
Heatwaves	Higher water temperature and fish metabolism	Reduced feed efficiency, stress, mortality
Drought	Lower pond volume	Higher density, hypoxia, pollutant concentration

Warm nights	Reduced oxygen recovery	Morning fish kills
Eutrophication	Algal blooms and decomposition	Cyanotoxins, pH swings, oxygen depletion
Extreme rainfall	Runoff and embankment damage	Disease introduction, fish escape
Water competition	Lower availability for ponds	Production loss or pond drying

Warm-water species such as cyprinids may tolerate higher temperatures better than trout, but tolerance does not mean resilience. Heat increases metabolic oxygen demand while reducing oxygen solubility. In productive ponds, oxygen minimum often occurs before sunrise, especially after hot, cloudy days or algal bloom collapse. Climate change therefore increases the need for aeration, water-depth management, emergency pumping, lower stocking densities and real-time oxygen monitoring.

Trout farming

Trout farms are among the most climate-sensitive aquaculture systems because salmonids require cold, well-oxygenated water. Romania's trout production is important in mountain and sub-mountain regions, but warming streams, reduced summer baseflows and extreme events threaten water supply and fish welfare.

The primary vulnerabilities of trout farms are driven by two main climate stressors: thermal stress and reduced water flow. Specifically, elevated water temperatures destabilize feed intake, elevate disease susceptibility, and heighten mortality risks. Concurrently, low flow conditions diminish oxygen renewal, increase waste concentration, and ultimately reduce the system's overall carrying capacity. Adaptation for trout farms requires intake-water protection, shading, spring-water conservation, lower summer stocking densities, backup aeration, partial recirculation, biosecurity and selection of sites with long-term cold-water security.

Sturgeon and conservation aquaculture

Romania has a special responsibility for sturgeon conservation because the Lower Danube and Danube Delta are historically important migration and reproduction areas. Climate change affects sturgeons indirectly through hydrological alteration, spawning-habitat degradation, salinity changes, lower flows, higher temperatures and cumulative stress from navigation, pollution and habitat fragmentation.

Climate-smart sturgeon conservation should combine hatchery support with habitat reconnection, migration-route protection, genetic management, anti-poaching enforcement, flow management and long-term monitoring.

Recirculating aquaculture systems

Recirculating aquaculture systems (RAS) can reduce dependence on external water volume by treating and reusing water. Recent RAS reviews highlight their role in controlled, land-based production and high-water reuse, making them relevant for climate adaptation where water scarcity and temperature instability threaten open systems [16].

However, RAS is not automatically sustainable. It requires capital, technical expertise, electricity, backup systems, skilled operators and biosecurity. For Romania, RAS may be most appropriate for high-value species, hatcheries, trout-smolt production, sturgeon

juveniles, urban markets or climate-secure diversification rather than as a universal replacement for pond aquaculture.

Impacts on Aquatic Biodiversity

Habitat contraction and fragmentation

Drought and low flows contract aquatic habitats, isolate wetlands, reduce river–floodplain connectivity and increase ecological fragmentation. This is particularly important in the Danube floodplain and Delta, where hydrological connectivity supports fish spawning, feeding and migration. When water bodies shrink, fish communities become crowded, oxygen declines and predation pressure increases.

Altered reproduction and recruitment

Many Romanian freshwater fishes depend on temperature and flow cues for spawning. Climate change may desynchronize reproduction from food availability or suitable habitat conditions.

For phytophilic species that spawn on aquatic vegetation, drought and water-level instability can reduce nursery habitat. For rheophilic species that require flowing water and gravel substrates, altered discharge and sediment regimes can reduce recruitment success.

Invasive alien species

Climate change can intensify biological invasions by making habitats more suitable for warm-water alien species and by stressing native species. A 2024 review of invasive fish in Romanian freshwaters reported 52 alien fish species in Romanian waterways, assigning invasive status to 11 species, with *Pseudorasbora parva, Lepomis gibbosus, Carassius gibelio* and *Ameiurus spp.* described as widespread [17].

Alien species may compete with native fish, prey on eggs and juveniles, transmit parasites, alter food webs and reduce conservation value. Climate warming may further favor tolerant, opportunistic and generalist species over specialized native species.

Danube Delta fish diversity under sea-level rise

The Danube Delta is a climate-risk hotspot because sea level rise, freshwater-flow changes and wetland transformation converge. The 2023 review on Danube Delta fish diversity concludes that sea-level rise is expected to affect habitats, biocenoses and fish, with roughly one-third of Delta fish species greatly affected, another third affected to a lesser extent and the final third not affected under the scenario reviewed [7].

This implies that climate adaptation in the Delta cannot be limited to species protection alone. It requires habitat-level adaptation, including restoration of hydrological connectivity, sediment processes, freshwater inflows, reed-bed management, wetland buffering and salinity monitoring.

Cumulative stress: agriculture, pollution and climate

Aquatic ecosystems are continuously burdened by agricultural runoff containing nutrients, pesticides, sediments, and organic matter. Climate change amplifies these pressures: torrential rains trigger massive runoff spikes, while drought conditions diminish water volumes and concentrate existing pollutants. Consequently, climate change functions as a risk multiplier that exacerbates existing land-use pressures. This relationship demonstrates

that total aquatic impact is a cumulative function of climate change, land use, pollution, hydrological alteration, and invasive species. Crucially, these drivers do not interact in a purely additive manner; rather, they frequently exhibit synergistic effects, meaning the combined ecological impact significantly exceeds the sum of individual stressors.

This means that adaptation must include agricultural buffer strips, wetland retention, nutrient management, reduced pesticide runoff and ecological restoration in addition to aquaculture-specific measures.

Vulnerability and Risk Matrix

Vulnerability of the Romanian aquaculture system to the adverse effects of climate change is presented in the *table 1*.

Table 1. Sector level vulnerability

System	Exposure	Sensitivity	Adaptive capacity	Overall vulnerability
Carp ponds	High: heat, drought, low oxygen	Medium–high	Medium, if aeration and water storage exist	High
Trout farms	High: stream warming, low flow	Very high	Medium–low without cold-water security	Very high
Sturgeon hatcheries	Medium–high	High	Medium with technology and expertise	High
RAS farms	Low–medium climate exposure	Medium energy sensitivity	High if capital and skills exist	Moderate
Danube Delta wetlands	Very high: drought, salinity, sea-level rise	Very high	Medium, depends on governance	Very high
Mountain streams	High: warming, flow reduction	High	Low–medium	High
Lowland lakes/reservoirs	High: eutrophication, heat	High	Medium	High

Sector-level vulnerability defines the systematic susceptibility of Romanian aquaculture and its supporting aquatic biodiversity to the adverse effects of climate change. When analyzed through the *Hazard – Exposure – Sensitivity - Adaptive Capacity* model, this concept shows that the industry is vulnerable not just because the weather is changing, but because its structural, biological, and economic foundations are deeply interconnected.

To operationalize the sector-level vulnerabilities of Romanian aquaculture, the *Hazard–Exposure–Sensitivity–Adaptive Capacity* framework can be translated into a qualitative Risk Matrix *(table 2)*. This matrix evaluates risks based on likelihood (probability of occurrence under current climate projections) and consequences for aquaculture and its supporting aquatic biodiversity (potential disruption to production, biodiversity, and revenue).

Table 2. The risk matrix for aquaculture and its supporting biodiversity

Hazard	Likelihood	Consequences for		Risk	
		aquaculture	biodiversity	aquaculture	Biodiversity
Heatwaves	5	4	4	20 Very high	20 Very high
Drought / low water	5	5	5	25 Very high	25 Very high
Hypoxia	4	5	4	20 Very high	16 Very high
Floods	4	4	3	16 Very high	12 High
Eutrophication	4	4	4	16 Very high	16 Very high
Disease outbreaks	4	4	3	16 Very high	12 High
Invasive species	4	3	5	12 High	20 Very high
Infrastructure failure	3	4	2	12 High	6 Moderate
Market/feed disruption	3	3	1	9 Moderate	3 Low

The highest risks are drought, low water availability, heatwaves, hypoxia and biodiversity displacement. These risks are consistent with European and Romanian assessments that identify drought, water scarcity, floods and heat as major and increasing climate challenges.

Adaptive Responses

Farm level adaptation

Romanian aquaculture farms should adopt climate smart management based on monitoring, flexibility and water efficiency. Recommended measures are included in *table 3*:

Table 3. Farm level adaptation

Risk	Adaptation response
Heat stress	Reduce feeding during peak heat, feed morning/evening, provide refugia
Hypoxia	Install aerators, monitor dissolved oxygen, reduce organic load
Drought	Increase pond depth, improve water storage, reduce stocking density
Disease	Strengthen biosecurity, quarantine, veterinary surveillance
Floods	Reinforce dikes, screens, spillways and emergency drainage
Feed inefficiency	Use temperature-adjusted feeding tables
Water conflict	Develop water-use plans with local authorities

An effective, farm-level early-warning system must continuously track key environmental parameters, specifically water temperature, dissolved oxygen (DO), pH, un-ionized ammonia (NH3, nitrites (NO2-), turbidity, *chlorophyll-a*, and water levels. Among these, dissolved oxygen

represents the most critical operational threshold, as severe anoxia can rapidly trigger catastrophic fish kills during warm summer nights or sudden algal bloom collapses.

Future pond rehabilitation should prioritize:

- deeper refuge zones;
- shaded margins and riparian vegetation;
- emergency aeration points;
- sediment management;
- water-retention basins;
- inlet filtration and outlet biosecurity;
- wetland buffer strips;
- lower summer carrying capacity.

Traditional extensive ponds may also provide biodiversity benefits if managed with moderate stocking densities, aquatic vegetation, bird-compatible zones and reduced chemical inputs.

Regarding species and production diversification, Romania must avoid the indiscriminate introduction of non-native species to prevent maladaptation, focusing its strategies instead on native or well-established, low-risk species. This approach should utilize improved strains protected by strict ecological safeguards alongside cultivation methods designed to eliminate escape risks. Within cyprinid systems, climate resilience can be enhanced through balanced polycultures that utilize species occupying distinct trophic niches. For salmonid farming, necessary adaptations include partial water recirculation, strategic site relocation, structural shading, and reduced summer biomass. Concurrently, sturgeon aquaculture must maintain genetic responsibility and remain inherently integrated with broader riverine habitat restoration efforts.

RAS and partial recirculation can reduce water demand and stabilize temperature and water quality. FAO's 2026 Blue Transformation framing highlights innovation, climate-smart systems and integrated models as part of sustainable aquaculture development [1].

For Romania, priority RAS applications include hatcheries, trout farms under summer heat stress, sturgeon juveniles, urban aquaculture and high-value species. Hybrid pond–RAS systems may be more feasible than full RAS for many farms.

The ecosystem-based adaptation is paramount within the Danube Delta and the Lower Danube river system. In this context, ecological resilience is conceptualized as a cumulative function of hydrological connectivity, habitat diversity, landscape water retention, reduced pollution pressures, and adaptive governance frameworks. To operationalize this approach, high-priority actions must encompass wetland reconnection, floodplain restoration, and the establishment of ecological corridors. Furthermore, management strategies should focus on protecting sediment dynamics, deploying riparian buffers, implementing sustainable reed-bed management, securing freshwater inflows, and maintaining rigorous salinity monitoring.

Romania's adaptation efforts are guided by the National Strategy for Adaptation to Climate Change for 2024–2030, which establishes a long-term vision extending to 2050. The OECD notes that this strategy aligns with both the EU Adaptation Strategy and the European Green

Deal, covering critical sectors such as agriculture and water resources. Furthermore, the framework is supported by a National Action Plan and the RO-ADAPT platform. However, significant gaps in implementation, monitoring, and evaluation still exist [18].

For aquaculture and aquatic biodiversity, policy priorities should include:

- Integration of aquaculture into climate-risk planning.
- Stronger water-allocation rules during drought.
- Climate-risk disclosure for aquaculture investments.
- Public funding for aeration, monitoring and water-saving infrastructure.
- Support for biodiversity-friendly pond management.
- Stronger invasive-species surveillance.
- Coordination among water, agriculture, fisheries, conservation and disaster-risk institutions.

The IPCC notes that concrete adaptation planning for climate-ready fisheries and aquaculture remains lacking in many parts of Europe and that adaptation strategies for seafood production remain insufficient [11]. This reinforces the need for Romania to treat aquaculture as part of national climate adaptation, not merely as a production sector.

Conclusions

Romanian aquaculture and aquatic biodiversity are fundamentally linked by shared water systems. A single pond, river, wetland, or floodplain can simultaneously serve as a production unit, ecological habitat, hydrological buffer, cultural landscape, and climate-adaptation asset. This multifunctionality creates both valuable synergies and complex resource conflicts.

Ultimately, climate change poses major risks to Romanian aquaculture and aquatic biodiversity through warming, drought, hydrological instability, hypoxia, floods, salinity intrusion, invasive species, and water-quality deterioration. These localized pressures align directly with wider European and national climate-risk assessments, and they are highly likely to intensify under continued warming scenarios.

The primary insight of this synthesis is that these climate risks are deeply systemic. While isolated heatwaves are dangerous, their impacts worsen significantly when compounded by droughts, eutrophication, high stocking densities, poor water exchange, or inadequate infrastructure. Similarly, floods can support ecological connectivity when managed naturally; however, they become destructive when combined with pollution pulses, embankment failures, fish escapement, and pathogen outbreaks.

Consequently, adaptation strategies must be strictly differentiated by production systems. Cyprinid pond aquaculture requires enhanced water retention, active oxygen management, and climate-smart stocking densities. Conversely, salmonid trout farms depend heavily on cold-water security and technical buffering infrastructure. Meanwhile, the Danube Delta demands landscape-scale habitat connectivity, rigorous salinity monitoring, extensive wetland restoration, and integrated river–sea governance. Lastly, high-intensity recirculating aquaculture systems (RAS) require stable renewable energy integration, technical capacity-building, and targeted financial instruments.

Furthermore, this synthesis demonstrates that biodiversity conservation and aquaculture adaptation are intrinsically inseparable. Biodiversity-friendly ponds can provide vital refugia for birds, amphibians, macrophytes, and invertebrates, provided that stocking dynamics, water quality, and structural habitats are carefully managed. Conversely, poorly managed aquaculture practices amplify nutrient loading, elevate disease transmission, facilitate invasive species expansion, and trigger genetic contamination from farm escapes.

Finally, addressing these coupled solutions highlights critical empirical data deficiencies. Romania requires robust, long-term monitoring networks for water temperature, dissolved oxygen fluctuations, drought impacts, fish mortality trends, disease outbreaks, invasive alien species, salinity intrusion, and wild spawning success. Without these systematic baselines, adaptation actions will remain purely reactive. The digital RO-ADAPT platform and the Danubius-RI monitoring infrastructure can effectively bridge this information gap, but only if they are directly integrated with aquaculture producers, conservation agencies, and local water authorities.

References

[1] FAO. 2026. The State of World Fisheries and Aquaculture 2026 – Blue Transformation: turning vision into impact. Rome, Italy, 236pg., ISBN:978-92-5-140453-9

[2] Eurostat. (2025). Aquaculture statistics. Statistics Explained. European Commission. (Accessed 1 July 2026).

[3] EUMOFA, 2025, Country profiles, STECF, Romania: Country information

[4] OECD (2026), OECD Economic Surveys: Romania 2026, OECD Publishing, Paris, https://doi.org/10.1787/4844067e-en.

[5] Copernicus Climate Change Service (C3S). (2025). Global Climate Highlights 2024. European Centre for Medium-Range Weather Forecasts (ECMWF).

[6] UNESCO World Heritage Centre. (n.d.). *Danube Delta*. World Heritage List. https://whc.unesco.org/en/list/588/ (Accessed 1 July 2026).

[7] Bănăduc, D., Afanasyev, S., Akeroyd, J. R., Năstase, A., Năvodaru, I., Tofan, L., & Curtean-Bănăduc, A. (2023). The Danube Delta: The Achilles Heel of Danube River–Danube Delta–Black Sea Region Fish Diversity under a Black Sea Impact Scenario Due to Sea Level Rise—A Prospective Review. *Fishes, 8*(7), 355. https DOI: 10.3390/fishes8070355.

[8] FAO. 2026. Food and Agriculture Organization of the United Nations (FAO-UN). Fishery and Aquaculture Country Profiles Romania. Country Profile Fact Sheets. In: Fisheries and Aquaculture [online].

[9] Agroberichten Buitenland. (2026). *Why has fish production declined in Romania?* Published 8 April 2026. (agroberichtenbuitenland.nl)

[10] International Commission for the Protection of the Danube River. The Danube River – Europe's backbone of biodiversity. Danube Watch, no.2/2010

[11] Bednar-Friedl, B., R. Biesbroek, D.N. Schmidt, P. Alexander, K.Y. Børsheim, J. Carnicer, E. Georgopoulou, M. Haasnoot, G. Le Cozannet, P. Lionello, O. Lipka, C. Möllmann, V. Muccione, T. Mustonen, D. Piepenburg, and L. Whitmarsh, 2022: Europe. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1817-1927, doi:10.1017/9781009325844.015.

[12] European Environment Agency. Water scarcity conditions in Europe. EEA, 2025.

[13] European Environment Agency. Drought impact on ecosystems in Europe. EEA, 2025.

[14] European Environment Agency. Climate-related economic losses: Romania. EEA, 2025.
[15] European Environment Agency. Water and climate impacts. Europe's Environment, 2025, .https://mmediu.ro/domenii/mediu/schimbari-climatice/adaptarea-la-schimbarile-climatice/cadrul-national/
[16] Stephan Ende, Joachim Henjes, Marc Spiller, Mostafa Elshobary, Dieter Hanelt, Abdelfatah Abomohra, 2024, Recent advances in recirculating aquaculture systems and role of microalgae to close system loop, Bioresource Technology, Volume 407, ISSN 0960-8524, https://doi.org/10.1016/j.biortech.2024.131107.
[17] Drăgan O, Rozylowicz L, Ureche D, Falka I, Cogălniceanu D (2024) Invasive fish species in Romanian freshwater. A review of over 100 years of occurrence reports. NeoBiota 94: 15–30. https://doi.org/10.3897/neobiota.94.117313
[18] Stamate,E.V. 2024.Romania's New Climate Adaptation Strategy: A Plan for the Future, Issue Monitoring, https://issuemonitoring.eu/en/romanias-new-climate-adaptation-strategy-a-plan-for-the-future/
[19] Maulu S, Hasimuna OJ, Haambiya LH, Monde C, Musuka CG, Makorwa TH, Munganga BP, Phiri KJ and Nsekanabo JD (2021) Climate Change Effects on Aquaculture Production: Sustainability Implications, Mitigation, and Adaptations. Front. Sustain. Food Syst. 5:609097. doi: 10.3389/fsufs.2021.609097
[20] Anexa la Hotărârea Guvernului nr. 1.010/2024 pentru aprobarea Strategiei naționale privind adaptarea la schimbările climatice pentru perioada 2024—2030, cu perspectiva anului 2050, MO823bis/19.08.2024
[21] Intergovernmental Panel on Climate Change (IPCC). Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2023.
[22] Valavanidis, Athanasios. (2026). Climate Change and Impacts on Aquatic Ecosystems. Aquatic ecosystems are most vulnerable to the burden of climate stressors and biodiversity shifts. 1. 1-25.
[23] Kawade, Sanket Sunil, Panchakarla Sedyaaw, Supriya D Meshre, V.R Sadawarte, and Apurva Nikhil Sawant. 2025. "Climate Change Impacts on Aquatic Ecosystems: Biodiversity Shifts, Ecological Risks and Mitigation Strategies". International Journal of Environment and Climate Change 15 (10):289-303. https://doi.org/10.9734/ijecc/2025/v15i105062.
[24] Beracko, P., Kokavec, I., & Matečný, I. (2025). Long-Term Responses of Crustacean Zooplankton to Hydrological Alterations in the Danube Inland Delta: Patterns of Biotic Homogenization and Differentiation. Diversity, 17(10), 670. https://doi.org/10.3390/d17100670
[25] Kabir, A., Shitu, A., Ye, Z., Li, X., Ma, H., Liu, G., Zhu, S., Zou, J., Liu, Y., & Liu, D. (2026). Sustainable Recirculating Aquaculture Systems (RAS): Development and Challenges. Water, 18(9), 1093. https://doi.org/10.3390/w18091093
[26] Zubair Hashmi, Faizah Metali, Muhamad Amin, Muhammad Saifullah Abu Bakar, Yusuf Wibisono, Wahyunanto Agung Nugroho, Muhammad Roil Bilad, 2025, Recirculating aquaculture systems: Advances, impacts, and integrated pathways for sustainable growth, Bioresource Technology Reports,Volume 32, ISSN 2589-014X, https://doi.org/10.1016/j.biteb.2025.102340.