

Biodiversity and conservation challenges in the Kura–Caspian aquatic system and their implications for ecosystem services and the green economy

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Keywords

aquatic biodiversity, ecosystem services, green economy, Kura–Caspian system, sturgeon conservation

ABSTRACT

The Kura River, its riparian habitats, the Kura delta and the Caspian Sea form an interconnected ecological system that supports freshwater and marine biodiversity while also providing ecosystem services with economic and social value. This study integrates two independently prepared 2026 research projects on riverside flora and fauna and on fish and other aquatic animals, and develops their observations within an ecosystem-services and green-economy framework. The source projects identified Tugai riparian vegetation, riverine fish communities, sturgeons and the Caspian seal as important components of regional biodiversity and emphasized pollution, overfishing, habitat degradation, plastic waste and climate-related water change as major pressures. A structured qualitative synthesis was combined with targeted verification against recent peer-reviewed literature and institutional sources. The analysis shows that biodiversity loss cannot be treated as a separate conservation issue because ecological degradation can weaken fisheries, habitat regulation, bank stability, nature-based recreation and other services on which water-dependent economic activity relies. Recent Caspian research further indicates that cumulative stressors and falling water levels threaten sturgeon and seal habitat as well as fisheries and coastal infrastructure. Conservation therefore has a green-economy dimension: sustainable harvest rules, habitat restoration, pollution prevention, circular waste systems, responsible aquaculture and adaptive protected-area planning can protect natural capital while supporting resilient livelihoods. The study concludes that biodiversity protection in the Kura–Caspian system should be integrated with water, fisheries and economic planning rather than addressed through isolated species-level interventions.

INTRODUCTION

River and inland-sea ecosystems are not only reservoirs of biological diversity; they are forms of natural capital that support water regulation, food production, fisheries, recreation, habitat connectivity and local livelihoods. In Azerbaijan, the Kura River links inland freshwater habitats and riparian landscapes with the Caspian Sea. Its ecological condition therefore matters beyond the river channel itself. Changes in water quantity, pollution, habitat structure and biological communities can be transmitted downstream and can influence the condition of the Kura delta and the wider Caspian system.

The two source research projects used in this article examine complementary parts of this continuum. Djumayeva focused on flora and fauna along the Kura riverside, identifying fish, riparian shrub communities and Tugai forest habitats as characteristic elements and emphasizing pollution and declining water conditions as ecosystem pressures. Sadikhova focused on fish and other aquatic animals, with particular attention to Caspian sturgeons, the Caspian seal, plastic pollution, overfishing, habitat destruction and conservation measures. Her research also highlighted the social and economic consequences of declining aquatic biological resources.

This combined perspective is relevant to the green economy because biodiversity underpins services that conventional economic accounting often treats as free inputs. Riparian vegetation stabilizes banks, regulates microclimates and supports habitat connectivity, while aquatic food webs sustain fisheries and other ecosystem

functions. In the Kura–Aras basin, earlier ecosystem-services analysis explicitly connected freshwater biodiversity and ecosystem condition with hydropower, irrigated agriculture, drinking-water supply, nature-based tourism and natural-hazard regulation (Flores & Abbasov, 2015). Biodiversity degradation can therefore transfer ecological costs into production systems and public infrastructure.

The objective of this study is to synthesize the original research materials into an academic assessment of biodiversity and conservation challenges in the Kura–Caspian aquatic system and to interpret their implications for ecosystem services and green economic resilience. Three questions guide the analysis: (1) which biodiversity components are emphasized by the source projects; (2) which interacting pressures most directly threaten those components; and (3) which conservation responses can protect both ecological functions and the economic benefits derived from natural capital? No population census, fish-catch dataset or monetary valuation was generated by the source projects, so the paper does not estimate species abundance, fishery revenue or the monetary value of ecosystem services.

LITERATURE REVIEW

Recent research confirms the ecological importance of riparian Tugai forests in Azerbaijan. Gurbanov et al. (2026) describe these forests as high-diversity, multilayered ecosystems whose composition is strongly shaped by hydrological regime, groundwater conditions and soil salinity. They also identify grazing, deforestation and hydrological

alteration as important drivers of degradation. Ahmadova (2026) similarly emphasizes bank stabilization, microclimate regulation, habitat connectivity and biodiversity support as key functions of Tugai forests and argues that restoration must recover river–floodplain–groundwater processes rather than rely on simple tree planting.

At the aquatic end of the system, Caspian sturgeons illustrate the connection between biodiversity and economic incentives. Pueppke et al. (2023) describe Caspian sturgeons as ecologically and economically important but critically threatened by illegal and unregulated fishing, loss of spawning and feeding habitat, pollution and climate-related environmental change. The authors also note growing interest in aquaculture as one tool for reducing harvest pressure on wild stocks, while stressing that recovery of self-sustaining populations requires coordinated habitat and fisheries governance.

Caspian biodiversity is affected by multiple stressors rather than a single driver. Bodini et al. (2024) examined the decline of kilkas, sturgeons and seals through a cumulative-stressor framework and showed that interacting perturbations can produce system-wide depletion. Lahijani et al. (2024) likewise identify physical alteration, pollution, overfishing and climate change as concurrent drivers of declining bioresources. This evidence supports the broad structure of the source projects, but it also requires caution: individual percentages and causal claims reported in educational dossiers should not be treated as measured regional statistics unless supported by traceable datasets.

Climate-driven changes in the Caspian Sea add a further conservation and economic dimension. Court et al. (2025) show that continued sea-level decline can disrupt habitats used by sturgeon and the endemic Caspian seal, reduce the effectiveness of static protected-area boundaries and create serious risks for fisheries, ports and other coastal infrastructure. Their analysis demonstrates that biodiversity policy and economic adaptation cannot be separated: conservation areas, fishing grounds and infrastructure may all shift as shorelines retreat.

The green-economy perspective therefore extends beyond species protection. It includes sustainable fisheries, pollution prevention, circular material systems that reduce plastic leakage, restoration of riparian natural capital, adaptive spatial planning and forms of aquaculture that reduce pressure on depleted wild stocks. The original Sadikhova project proposed deposit-return approaches, stronger quota control, protected spawning areas and aquaculture, while the Djumayeva project emphasized river clean-ups, reduced chemical pollution and public awareness. These proposals provide a practical basis for linking biodiversity conservation to resource efficiency and low-impact economic activity.

MATERIALS AND METHODS

The study applied an integrative qualitative design based on two author-prepared research dossiers completed in 2026. Djumayeva's project, 'Fauna and flora diversity in riverside area', examined Kura riverside species, Tugai vegetation, fish communities, pollution and visible ecosystem change using online sources, research papers and image-based comparison. Sadikhova's project, 'The status, problems, and conservation ways of fish and other aquatic animals', used literature and document analysis, qualitative and quantitative comparison of reported trends, and visual observation of solid waste and plastics along Absheron coastal areas. The present article retains the thematic content of both works while restructuring it into a unified analytical framework.

The source materials were coded into five categories: biodiversity components; ecosystem services; anthropogenic pressures; climate and

hydrological pressures; and conservation or green-economy responses. Claims from the source projects were separated into descriptive observations, proposed solutions and quantitative statements. Quantitative claims that lacked a reconstructable dataset or traceable source were not repeated as findings. Targeted literature verification was then conducted using peer-reviewed research and institutional material on Tugai forests, Caspian sturgeons, Caspian seals, cumulative ecosystem stress, sea-level decline and freshwater ecosystem services.

The study is a synthesis rather than a biological survey. No new fish sampling, vegetation plot, laboratory water-quality analysis, catch assessment or economic valuation was conducted. Accordingly, the results describe relationships and policy implications rather than estimating population sizes or causal effect magnitudes. This approach is appropriate for preserving the original research contribution while avoiding unsupported numerical precision.

RESULTS AND DISCUSSION

Biodiversity structure across the Kura–Caspian continuum

The source projects portray biodiversity as a connected river–riparian–marine system. Djumayeva identifies fish such as carp, catfish, pike and barbel alongside mammals and riparian shrub and forest communities, with particular emphasis on Tugai vegetation. These observations align with recent research showing that Tugai forests along the Kura basin contain diverse *Populus*, *Salix*, *Ulmus*, *Alnus* and *Tamarix* communities and depend strongly on hydrological connectivity (Gurbanov et al., 2026). Their value is not limited to species lists: riparian vegetation contributes to bank stabilization, habitat continuity and local environmental regulation.

Sadikhova extends the biodiversity frame downstream to the Caspian Sea, where sturgeons, kilka and the endemic Caspian seal are used as examples of species embedded in wider food-web and habitat relationships. Pueppke et al. (2023) confirm the severe conservation status of Caspian sturgeons, while IUCN (2021) identifies fishing-gear mortality, habitat degradation, disturbance and climate-related loss of breeding ice as major concerns for the Caspian seal. The Kura–Caspian perspective is therefore useful because river condition, spawning access, delta habitats, coastal change and marine food webs are ecologically connected even when individual species occupy different parts of the system.

Figure 1 organizes this relationship as a qualitative pathway. It does not represent measured flows or monetary values. Instead, it shows how biodiversity components can be affected by common pressures and how ecological change can propagate into ecosystem-service and green-economy outcomes.

Table 1 summarizes the principal biodiversity-service relationships retained from the source research and strengthened through recent literature. The table illustrates why a conservation strategy based only on charismatic species would be incomplete: the same interventions that support sturgeon or seal conservation can also protect fisheries, riparian functions, water-dependent livelihoods and resilience.

Multiple pressures and cumulative ecosystem risk

Pollution is the most consistently identified pressure across both source projects. Djumayeva discusses municipal wastewater, industrial contaminants and river pollution, while Sadikhova emphasizes plastics, industrial discharges and oil-related pollution. The scientific literature supports treating these pressures cumulatively rather than independently. Lahijani et al. (2024) show that bioresource decline in the Caspian is linked to a combination of pollution, physical alteration, overexploitation and climate change; Bodini et al. (2024)

similarly demonstrate that multiple concurrent stressors can help explain simultaneous depletion of kilkas, sturgeons and seals.

Overexploitation and habitat alteration add direct pressure to biological populations. Sturgeon recovery is especially difficult because migratory fish require functioning spawning routes and because high commercial value creates persistent incentives for illegal harvest (Pueppke et al., 2023). The source projects' recommendations for stronger control, protected spawning periods and reporting of destructive fishing are therefore consistent with contemporary conservation priorities. At the same time, reduced river flow, dams, shoreline development and falling Caspian water levels can alter habitat even when fishing pressure is controlled.

Climate and hydrological change further complicate management. Court et al. (2025) project that substantial sea-level decline can reduce shallow habitats important to sturgeon and Caspian seals and can shift or eliminate current conservation areas. These changes create a moving-target problem: fixed protected boundaries may cease to cover the ecosystems they were intended to protect. Adaptive conservation planning is therefore needed alongside pollution control and fisheries enforcement.

Table 1. Biodiversity, ecosystem-service and green-economy relationships in the Kura–Caspian system

Biodiversity component	Ecosystem-service and green-economy relevance
Tugai riparian forests	Bank stabilization, habitat connectivity, microclimate regulation, carbon storage and support for nature-based recreation
River and reservoir fish communities	Food resources, recreational and commercial fishing, food-web function and indicators of aquatic ecosystem condition
Kura delta and spawning corridors	Nursery and spawning habitat, biodiversity connectivity and support for renewable fishery resources
Caspian sturgeons and food web	High-value renewable biological capital, fisheries, aquaculture development and cultural value
Caspian seal and coastal habitats	Flagship biodiversity, ecosystem integrity, conservation tourism and justification for adaptive spatial protection

Ecosystem services and green-economy implications

The economic meaning of biodiversity in the Kura–Caspian system is best understood through ecosystem services rather than through unsupported monetary estimates. Healthy riparian forests help stabilize banks, regulate local hydrology and maintain habitat; functioning rivers support water supply, agriculture and reservoirs; and aquatic biodiversity supports fisheries, food webs and nature-based recreation. Flores and Abbasov (2015) explicitly assessed freshwater ecosystem services in the Kura–Aras basin in relation to hydropower and also considered drinking-water supply, irrigated agriculture, nature-based tourism and natural-hazard regulation. Ecological degradation can therefore impose indirect economic costs by weakening these services.

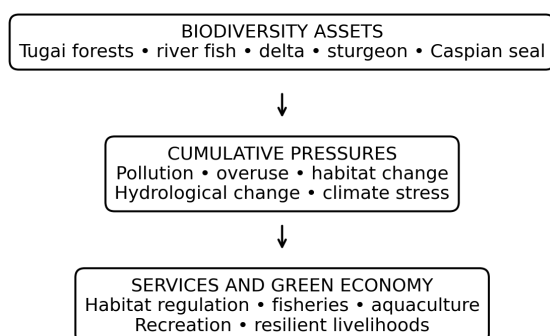


Figure 1. Conceptual biodiversity, pressure and green-economy pathway in the Kura–Caspian aquatic system

Fisheries provide the clearest direct economic link. Sturgeon conservation is not only a biodiversity issue because these species have historically carried high commercial value, while overexploitation and illegal trade have contributed to their decline (Pueppke et al., 2023). A green-economy approach changes the objective from maximizing extraction to maintaining renewable biological capital. Sustainable quotas, traceable supply chains, seasonal protection and enforcement can preserve future resource value, while responsible aquaculture may provide production without placing equivalent pressure on wild populations. However, aquaculture should complement rather than substitute for habitat recovery.

Conservation instruments for natural capital and circular resource management

The two source projects contain several measures that can be organized into a green-economy policy package. First, habitat restoration and environmental-flow management can protect Tugai forests and river–floodplain connectivity. Second, pollution prevention and modern wastewater treatment reduce ecological damage before it enters the river and sea. Third, deposit-return and other circular material systems can reduce leakage of bottles and packaging into aquatic environments. Fourth, fisheries governance should combine monitoring, anti-poaching enforcement, protected spawning areas and scientifically informed harvest rules. Fifth, education and community clean-up activities can strengthen stewardship and lower local litter pressure.

Economic resilience, implementation priorities and study limitations

Conservation investment can also be interpreted as risk reduction. Court et al. (2025) show that Caspian sea-level decline threatens both ecological areas and human infrastructure, illustrating how environmental deterioration can create simultaneous biodiversity and economic losses. For Azerbaijan, priority should therefore be given to interventions with multiple benefits: restoring riparian buffers, reducing untreated discharges, protecting spawning corridors, improving fishery traceability and developing adaptive protected areas. These measures protect natural capital while supporting fisheries, water-dependent production and resilient local livelihoods.

The study has important limitations. The underlying research projects are educational dossiers, not standardized biodiversity surveys. Species lists were not generated from systematic sampling, and the coastal observations did not include quantified litter density or biological abundance. Several numerical statements in the source files could not be independently reconstructed and are therefore excluded. No monetary ecosystem-service valuation or fishery revenue analysis was undertaken. Future research should combine field biodiversity inventories, water-quality monitoring, fishery and aquaculture statistics, habitat mapping and ecosystem-service valuation so that ecological and economic priorities can be assessed within a common decision framework.

CONCLUSIONS

This study integrates two original research projects into a unified assessment of biodiversity and conservation challenges across the Kura–Caspian aquatic system. The combined evidence highlights a connected natural-capital base composed of riparian Tugai habitats, freshwater fish communities, delta and spawning areas, Caspian sturgeons and the wider marine food web that includes the endemic Caspian seal. Pollution, overexploitation, habitat alteration, hydrological change and climate-driven water-level decline act together and can weaken both biodiversity and the ecosystem services on which economic activity depends. The green-economy implication

is that conservation is an investment in productive natural capital rather than a cost external to development. Habitat restoration, sustainable fisheries, responsible aquaculture, pollution prevention, circular waste systems, adaptive protected areas and public stewardship can jointly protect ecological functions and support resilient livelihoods. Because the present study is qualitative, the next step should be a monitored Kura–Caspian biodiversity and ecosystem-services assessment that combines biological indicators with fishery, tourism, water-management and restoration-cost data.

AUTHOR CONTRIBUTIONS

K.D. and A.S. contributed the original research materials, topic development, source collection and preliminary assessment of riverside biodiversity, aquatic species, ecological pressures and conservation options. A.M. contributed supervision of manuscript integration, methodological framing, ecosystem-services and green-economy interpretation, review and editing. All authors contributed to interpretation, reviewed the final manuscript and approved the submitted version.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY

This study is a qualitative synthesis of two author-prepared research dossiers and published literature. No new biological sampling, water-quality dataset, fish-catch dataset or monetary ecosystem-service valuation was generated. The descriptive source materials supporting the synthesis are contained in the authors' original research files.

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