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Approaches and Principles for the Restoration of Tugay Forests in Azerbaijan

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Abstract. *Tugay (riparian) forests are among the rarest and most functionally important ecosystems in Azerbaijan's arid and semi-arid lowlands. They provide bank stabilization, microclimate regulation, habitat connectivity, and biodiversity support along the Kura and Araz river corridors. Yet tugay forests have been strongly degraded and fragmented by hydrological regulation, reduced floodplain inundation, groundwater decline, grazing pressure, land conversion, and technogenic impacts. Restoration in this context cannot be treated as ordinary afforestation; it requires re-establishing the coupled river–floodplain–groundwater processes that sustain recruitment and long-term stand persistence. This paper synthesizes national ecosystem assessment findings, official reporting, and peer-reviewed restoration ecology frameworks to produce a restoration framework tailored to Azerbaijan. The core proposition is a driver-based restoration logic linking pressures to geomorphic and hydrological processes, expected ecological responses, measurable indicators, and priority interventions. The paper emphasizes environmental flows, floodplain connectivity, protected-area anchors, and adaptive monitoring supported by remote sensing and field inventories. A set of restoration principles and an intervention sequence are proposed for implementation under realistic constraints, with success criteria aligned to internationally recognized ecological standards and adaptive governance principles.*

Keywords: *tugay forests, riparian restoration, Kura River, Araz River, environmental flows, floodplain connectivity, groundwater, protected areas, adaptive management, Azerbaijan*

Introduction

Tugay forests (also spelled "tugai") are riparian forest ecosystems in arid and semi-arid river valleys whose structure and regeneration are strongly dependent on river flow regimes, sediment dynamics, and shallow groundwater availability. In continental desert regions, tugay systems form linear corridors of floodplain forests and shrublands that create biodiversity "islands" in otherwise steppe or semi-desert landscapes. The ecological significance of tugay forests derives from their role as habitat, migration corridors, bank-stabilizing vegetation, and microclimate moderators.

In Azerbaijan, riparian forests occupy mainly floodplains and banks of the Kura and Araz rivers, where groundwater can remain within reach of deep-rooted phreatophytes under natural or semi-natural conditions. However, regulation of flows, water withdrawals, floodplain fragmentation, and land conversion have reduced the frequency and duration of overbank flooding, limited sediment deposition, and lowered groundwater recharge.

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These changes disrupt the recruitment of floodplain trees and the persistence of multi-layered riparian communities. National policy and reporting documents also provide a baseline for restoration relevance within broader land-use and climate frameworks. Official reports include forest restoration and planting activities, and identify the restoration and reconstruction of tugay forests as a direction of work in the Kura and Araz valleys (Republic of Azerbaijan, 2015). More recent climate reporting continues to frame forest expansion within mitigation commitments (Republic of Azerbaijan, 2023). The national ecosystem assessment provides additional ecosystem-service context and explicitly describes tugay forests as dependent on shallow groundwater and floodplain space, with flow regulation identified as a mechanism reducing floodplain extent and degrading tugay systems (Azerbaijan National Ecosystem Assessment, 2024).

Protected-area leverage is a practical entry point for tugay restoration because it concentrates governance tools (restrictions, monitoring, enforcement) and provides a spatial anchor for ecological recovery. In Azerbaijan, protected areas such as the Garayazi/Qarayazi State Nature Reserve protect remnant tugay fragments and can serve as restoration nuclei (Administrative Department of the President of the Republic of Azerbaijan—Presidential Library, n.d.).

This paper develops a restoration-oriented synthesis for tugay forests in Azerbaijan that is intended to be implementable under real constraints: regulated flows, competing land and water demands, and climate aridification risks. The objective is not to restate generic riparian restoration guidance, but to translate evidence into a driver-based prioritization logic, measurable success criteria, and an adaptive intervention sequence suitable for the Kura–Araz lowlands and associated protected tugay fragments. (Beechie et al., 2010; Palmer et al., 2005; Pahl-Wostl et al., 2012).

Methods

This study is a synthesis-and-framework paper that combines (i) official national reporting and ecosystem assessment documents, (ii) peer-reviewed riparian and restoration ecology literature (prioritizing Scopus-indexed sources with DOI records where available), and (iii) the reference list extracted from the source manuscript provided by the author (see Appendix mapping table). The analytical method follows a driver → process → response → intervention chain, which is consistent with widely used restoration planning logic (e.g., linking stressors to mechanisms and then to actions and monitoring) (Beechie et al., 2010; Hobbs & Harris, 2001).

Hydrological and ecological reasoning is anchored in the “natural flow regime” paradigm and the environmental flow literature, emphasizing that variability in magnitude, timing, frequency, duration, and rate of change of flows underpins river–floodplain ecosystem integrity (Poff et al., 1997). In tugay contexts, these flow attributes translate into floodplain inundation opportunities, groundwater recharge, and sediment disturbance regimes needed for recruitment and vegetation succession.

The paper also integrates principles from riparian zone ecology, emphasizing that riparian corridors are land–water interfaces where ecological processes are shaped by both watershed-scale drivers and local floodplain conditions (Gregory et al., 1991; Naiman & Décamps, 1997).

Remote sensing is treated as a complementary monitoring tool rather than a stand-alone assessment method. Evidence from high-resolution imagery analysis of tugay vegetation in Central Asia demonstrates the value of object-based change detection for identifying vegetation dynamics and monitoring restoration outcomes, particularly when coupled with field verification (Gärtner et al., 2014).

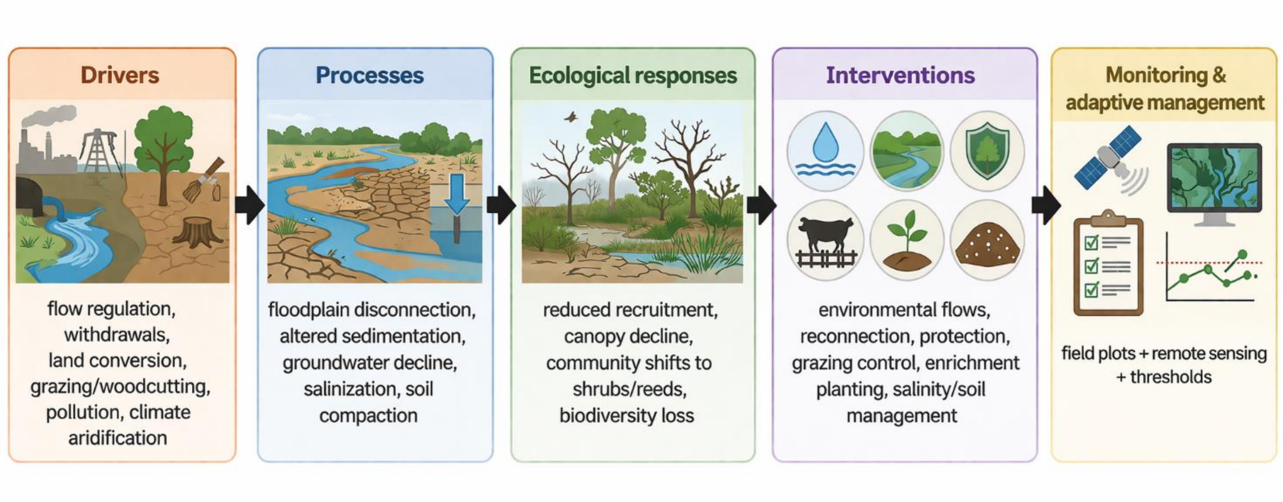

Figure 1
Conceptual framework of ecosystem processes and adaptive management

Results

National-level sources indicate that Azerbaijan's forests are not evenly distributed: they are concentrated in mountain regions but also occur along the lower Kura and Araz as a belt, and restoration/reconstruction of tugay forests in these valleys has been identified as an ongoing direction of work. Reported figures in national communication include forest area estimates and annual restoration/planting activities (Republic of Azerbaijan, 2015). In the most recent ecosystem assessment synthesis reviewed here, tugay forests are explicitly characterized as dependent on shallow groundwater and floodplain space, with flow regulation in the Kura identified as a mechanism shrinking floodplain area and stressing tugay systems (Azerbaijan National Ecosystem Assessment, 2024).

Table 1
Driver groups affecting tugay forests and restoration implications

Driver group	Typical pressures in Azerbaijan tugay contexts	Dominant processes	Expected ecological response	Practical indicators	Priority interventions
Hydrological regulation and withdrawals	Reservoir operations, irrigation abstraction, reduced overbank flooding	Reduced floodplain inundation; lowered groundwater recharge; altered sediment regime	Recruitment failure; canopy thinning; compositional shifts	Inundation frequency; groundwater depth/salinity; seedling density	Environmental flow thresholds; floodplain reconnection; groundwater-sensitive site selection
Land conversion and fragmentation	Floodplain agriculture, infrastructure, channel constraint	Loss of floodplain area; disconnection of side channels	Reduced habitat continuity; simplified structure	Floodplain width; corridor continuity	Spatial zoning; buffer enforcement; targeted corridor restoration
Grazing and woodcutting pressure	Livestock browsing, fuelwood harvest, understory disturbance	Reduced regeneration; soil compaction	Seedling suppression; erosion	Browsing intensity; grazing pressure	Controlled grazing regimes;

Driver group	Typical pressures in Azerbaijan tugay contexts	Dominant processes	Expected ecological response	Practical indicators	Priority interventions
				indices; regeneration rates	enforcement; alternative fuel programs
Invasive species and disturbance	Colonization by non-native taxa; disturbance-mediated spread	Competitive displacement; altered succession	Reduced native diversity	Invasive cover; species composition metrics	Early detection/rapid response; mechanical removal; replanting native guilds
Climate aridification and heat stress	Increased drought frequency; higher evapotranspiration	Increased water stress; reduced growth	Mortality during drought; decline in vigor	Drought indices; canopy condition	Drought-resilient species selection; hydrological buffering; adaptive monitoring
Pollution and technogenic pressure	Industrial/agricultural runoff; localized contamination	Toxic stress; reduced soil/leaf function	Reduced vigor; decline in sensitive species	Water/soil contaminants; leaf condition	Source control; riparian buffers; targeted remediation

This driver structuring is consistent with the causal mechanisms emphasized by riparian ecology: flow and groundwater regimes are first-order controls on riparian vegetation composition and recruitment, and human modifications can propagate through multiple pathways (Allan, 2004; Naiman & Décamps, 1997; Merritt et al., 2010). Moreover, national syntheses specific to Azerbaijan explicitly link shallow groundwater, floodplain space, and flow regulation to tugay condition (Azerbaijan National Ecosystem Assessment, 2024).

A key operational implication of the driver analysis is that tugay restoration in Azerbaijan should be treated as a flow–groundwater–land-use coupled problem rather than a tree-planting problem. Where floodplain area is reduced and groundwater declines, planting without hydrological correction is likely to produce short-lived stands or repeated failures. Empirical work in arid tugay analogues demonstrates strong relationships between groundwater depth/salinity, soil conditions, and tugay species diversity and distribution, reinforcing the need for threshold-based site selection and water management integration (Zeng et al., 2020).

Restoration prioritization can be strengthened by explicitly incorporating environmental thresholds into water-withdrawal decisions in tributaries and headwaters that affect downstream tugay forests. For Azerbaijan’s Kura basin, peer-reviewed work has proposed environmentally relevant limits for exploitation of mountain streams, which is directly aligned with a downstream tugay protection logic when combined with floodplain management (Abbasov & Smakhtin, 2009).

Protected-area anchors are practically important because they support enforcement and reduce competing land-use pressures. Official guidance describing protected area categories in Azerbaijan indicates how sanctuaries/reserves function as conservation instruments, which can be operationalized to protect tugay fragments and support restoration nuclei (Administrative Department of the President of the Republic of Azerbaijan—Presidential Library, n.d.; Azerbaijan National Ecosystem Assessment, 2024).

Monitoring and adaptive management should integrate remote sensing with repeated field inventories. Local studies along the Kura River in the Agjabadi district illustrate how phytocoenological characterization can inform the selection of restoration diagnostics and indicators (Gurbanov & Ahmadova, 2024). Combining such local field approaches with remote sensing change detection creates a defensible monitoring system for decision cycles. (Gurbanov & Ahmadova, 2024; Gärtner et al., 2014).

Implications for national policy alignment

Official reporting indicates that Azerbaijan has ongoing forest restoration activities and that tugay restoration in the Kura and Araz valleys is an explicit direction of work, while recent climate reporting frames forest expansion and sequestration within national commitments. Tugay restoration can therefore be positioned as both adaptation (ecosystem resilience, bank stabilization, microclimate buffering) and mitigation (carbon storage within riparian corridors), but only if hydrological constraints are addressed and success is measured transparently (Republic of Azerbaijan, 2015; Republic of Azerbaijan, 2023).

Conclusion

Tugay forest restoration in Azerbaijan should be defined as the recovery of a hydrologically connected floodplain forest system, not merely the re-establishment of tree cover. The evidence supports a basin–landscape restoration strategy built around (i) environmental flow and groundwater thresholds, (ii) protected-area anchors (especially Garayazi/Qarayazi), (iii) integrated land-use controls and grazing/woodcutting management, and (iv) adaptive monitoring that blends repeated field inventories with high-resolution remote sensing. This approach aligns national ecosystem assessment findings—highlighting the dependence of riparian forests on shallow groundwater and the negative effects of flow regulation—with international standards for ecologically successful river restoration and integrated governance under climate uncertainty.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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