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Human Impacts on Forest Stand Structure and Ecosystem Resilience: A Focus on Afghanistan

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Abstract

Forests are essential for biodiversity, climate regulation, and ecosystem services. However, anthropogenic activities such as deforestation, agriculture, grazing, and changes in species composition have altered forest stand structures, leading to biodiversity loss, soil degradation, and reduced ecosystem resilience. This narrative review synthesizes the literature to examine the impacts of human activities on forest dynamics and ecosystem resilience, highlighting the role of stand structural complexity in mitigating these effects. National assessments in Afghanistan reveal significant land-use and land-cover (LULC) changes, with declines in forest cover, grasslands, and water bodies. The review also identifies research gaps, including limited field data and the underrepresentation of socio-economic factors. Future research should incorporate long-term monitoring, standardized methods, and advanced technologies to strengthen conservation strategies. The study emphasizes adaptive forest management, including reforestation, selective species management, and agroforestry, as essential approaches to maintaining ecosystem resilience under ongoing human pressures.

Key words: Afghanistan, Chilgoza, Community-based Forest Management; Overgrazing, Pistachio, Resilience

د ځنګلي ټولنو په جوړښت او ایکوسیستم زغم باندې د انساني کړنو اغیزې: په افغانستان تمرکز

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لنډیز

ځنګلونه د بیولوژیکي تنوع، د اقلیم تنظیم او د ایکوسیستم د خدمتونو لپاره بنسټیز ارزښت لري. اما د انسانانو په وسیله ترسره کیدونکې کړنې لکه د ځنګل پرېکول، کرنه، د کورنیو اهلي ژویو څرول او د نوعو د ترکیب بدلون د ځنګلي ټولنو د جوړښت (Stand structure) د بڼې د بدلون سبب ګرځي. د دغه کړنو په پایله کې بیولوژیکي تنوع له منځه ځي، د خاورې تخریب او د ایکوسیستم د زغم کمېدل رامنځ ته کیږي. دا روایتي بیاکتنه (Narrative review) شته ادبیات سره یو ځای کوي تر څو د انساني کړنو اغېزې د ځنګلي ټولنو په دینامیک په ځانګړي ډول د ځنګلي ټولنو په ساختماني پېچلتیا (Stand structural complexity) او د ایکوسیستم پر زغم وڅېړي. په افغانستان کې ملي ارزونې د ځمکې د کارونې او پوښښ په اړه د پام وړ بدلونونه ښیي، چې پکې د ځنګلي پوښښ، نباتي پوښښ او د اوبو د زېرمو کموالی او په ټوله کې د ایکوسیستم خدماتو له منځه تلل شامل دي. دغه بیاکتنه د څېړنې په برخه څو تشې، لکه د ساحوي معلوماتو کموالی او د ټولنیزو–اقتصادي فکتورونو لږ استازیتوب هم په ګوته کوي. په همدې اساس لازمه ده چې په راتلونکو څېړنو کې د اوږدمهاله څار، معیاري تګلارې او پرمختللو ټکنالوژیو کارونه شامل

شي ترڅو د ساتنې ستراتیژۍ پیاوړې شي.په همدې ترتیب دغه مطالعه د انطباقي (Adaptive) ځنګلي مدیریت پر ارزښت په ځانګړي ډول د ځنګل بیارغونې (Reforestation)، د نوعو ټاکنیز مدیریت او اګروفارسټري باندې هم ټینګار کوي چې د روانو انساني فشارونو تر سیورې لاندې د ایکوسیستم زغم لوړ وساتل شي.

کلیدی ټکي: افغانستان، جلغوزي، د ټولنې پر بنسټ د ځنګل مدیریت، له حده ډیر څرول، پسته، مقاومت

Introduction

Forests are vital biological resources, supporting a wide array of species and delivering essential ecosystem services, such as nutrient cycling, water regulation, erosion prevention, and carbon sequestration (Mackey, 2002; Montagnini & Nair, 2004). The spatial arrangement of trees and canopy layers, referred to as stand structure, is a critical component of forest ecosystems. Stand structure influences water availability, nutrient cycling, light distribution, and overall ecosystem functioning (Atkins et al., 2018; Ray et al., 2023). Moreover, structurally complex stands enhance biodiversity by creating ecological niches, providing shade, and fostering favorable microclimates (LaRue et al., 2019; Zellweger et al., 2020).

Despite their ecological importance, forests worldwide are under mounting pressure from anthropogenic activities. Poor land-use policies, weak legislation, insecure property rights, agricultural expansion, ineffective law enforcement, and increasing demand for food and commodities are driving deforestation and degradation (Geist & Lambin, 2002). Deforestation disrupts stand dynamics, resulting in biodiversity loss, reduced carbon sequestration, altered microclimates, and declining soil quality, all of which negatively affect plant growth and ecosystem stability (Roy et al., 1999; Nilus et al., 2011). In Global South, unsustainable harvesting, overgrazing, nuts collection, and fuelwood dependency have emerged as primary drivers of forest decline, mirroring the challenges faced in Afghanistan (Khurram et al., 2024).

Forest stand structural complexity is particularly important for maintaining ecosystem resilience. Forests with greater vertical and horizontal diversity show stronger resistance to drought, pests, and disease, and lower rates of tree mortality (Li et al., 2023; Atkins, 2018). Studies relvead that resilience measures in terms of survival and stability increase sharply as structural complexity rises on the relative scales (Messier et al., 2013; Mori et al., 2013). Such findings highlight the importance of preserving and restoring complex forest structures to enhance adaptive capacity under climate change and anthropogenic pressures.

Ecosystem services derived from forests are fundamental to human well-being, supporting livelihoods, regulating environmental processes, and sustaining cultural values (Skewes et al., 2016; Costanza et al., 1997). These services are commonly categorized into provisioning, regulating, cultural, and supporting functions, all of which are highly sensitive to land-use and land-cover (LULC) changes (Millennium Ecosystem Assessment, 2005; de Groot et al., 2010; Najmuddin et al., 2022). The degradation of these services not only diminishes ecological integrity but also directly undermines socio-economic resilience in fragile states such as Afghanistan (Khurram et al., 2024).

Secondary forests and natural regeneration play an important role in buffering ecological functions and promoting biodiversity recovery after disturbance (Guariguata et al., 1998). However, natural regeneration alone has proven insufficient in Afghanistan, where high extraction rates and weak governance systems impede recovery (Shalizi et al., 2018, Shalizi et al., 2020). Intensified human activities such as mining, road construction, and agricultural expansion further exacerbate LULC changes, accelerating biodiversity loss and weakening ecosystem resilience (Alcamo et al., 2005; Ellis & Pontius, 2007; Deng et al., 2015; Quintas et al., 2016; Najmuddin et al., 2022).

In Afghanistan, the socio-economic importance of forests and rangelands is amplified by the population's reliance on natural resources. Approximately 80% of Afghans depend directly or indirectly on ecosystems for their livelihoods (Saidajan et al., 2012). Agroecosystems employ 40–60% of the labor force and contribute roughly one-fourth of national GDP (MAIL, 2016; World Bank, 2014). Grasslands and forests support rural communities by preserving soils, maintaining water resources, and supplying critical goods for energy, construction, and agriculture (Milbrandt et al., 2011). They also play a key role in reducing vulnerability to natural disasters and socio-economic shocks (Khalid et al., 2018). Yet, the value of these ecosystem services remains underestimated by policymakers due to limited awareness, insufficient research, and decades of political instability (Saba et al., 2001; Gouhari et al., 2021; Najmuddin et al., 2022).

This narrative review examines the anthropogenic impacts on forest stand dynamics and ecosystem resilience, with a particular focus on Afghanistan. It explores how human-induced disturbances including agricultural expansion, unsustainable harvesting, grazing, and mining alter forest composition, density, and spatial distribution. The review highlights the role of stand structural complexity in mitigating the negative effects of deforestation and emphasizes the benefits of multilayered, diverse forest stands in enhancing resilience against environmental stressors. Furthermore, it evaluates sustainable forest management strategies, including selective harvesting, agroforestry, reforestation, and community-based management, as key pathways to restore degraded ecosystems and maintain ecosystem services. By synthesizing ecological and socio-economic evidence from Afghanistan and comparable regions, this review provides insights into the challenges and opportunities for biodiversity conservation and long-term ecosystem sustainability under intensifying anthropogenic pressures.

Methodology

We conducted a narrative review targeting peer-reviewed journals, books, and agency reports (e.g., FAO, World Bank), emphasizing Afghanistan and ecologically similar dry-montane systems (Hindu Kush–Karakoram–Zagros). Searches focused on terms including stand structure, structural complexity, resilience, Afghanistan, pistachio woodlands, chilgoza pine, juniper, overgrazing, fuelwood, NTFP, and community-based forest management. Inclusion criteria prioritized studies that (i) reported structural metrics or stand-level responses (e.g., size-class distributions, layering, regeneration), (ii) analyzed disturbance or management drivers, or (iii) assessed resilience proxies (mortality, drought responses, recovery). Information was thematically coded (drivers, mechanisms, outcomes, management) to identify patterns, consistencies, and gaps. Limitations include data scarcity, uneven geographic coverage, and reliance on gray literature for Afghanistan.

Results

Afghanistan's Forest Stand dynamic

Afghan forests face illegal logging, fuelwood extraction, chronic grazing, expansion of rainfed fields, and conflict-weakened governance that jointly reduce regeneration, skew size structures, and elevate disturbance risk (Bader et al., 2013; Daiyoub et al., 2024; Khurram et al., 2024). In the eastern conifer–oak belt, timber harvest and fragmentation have lowered basal area and altered size distributions, increasing exposure to pests and fire. Policy reforms have had localized success, but enforcement gaps persist in fragile settings (Khurram et al., 2024).

Northern pistachio woodlands (analogous to Iran's Zagros) show truncated diameter distributions and suppressed seedling/sapling cohorts near settlements due to browsing, fuelwood cutting, and plot encroachment producing "stalled" stands symptomatic of resilience loss (Mahmoodi et al., 2020; Salehi et al., 2013). Where Forest Management Associations reseed hillslopes, protect seed sources, and limit open grazing, recruitment rebounds (Mahmoodi et al., 2020).

In *Pinus gerardiana* forests, intensive cone harvesting reduces seed escape and seedlings. Partial-harvest rules that retain seed trees restore regeneration and gradually rebuild layering (Khurram et al., 2023; Shalizi et al., 2018, Shalizi and Khurram, 2016, Khurram and Shalizi, 2016), mirroring regional experience in Afghanistan's dry-temperate conifers.

Across the Hindu Kush–Karakoram–Balochistan arc, high-elevation junipers exhibit weak regeneration and simplified vertical profiles under cumulative cutting/grazing and drying trends, conditions linked to higher mortality in extremes (Ahmed et al., 2015; Khan et al., 2016). These patterns are relevant for Afghanistan's highlands. Conflict multiplies ecological stressors; displacement, livelihood collapse, and rule breakdown drive spikes in logging effort and market-driven extraction, leaving long-lasting legacies in stand density, composition, and fuel continuity (Bader, 2013; Daiyoub et al., 2024).

These anthropogenic pressures manifest as measurable changes in structure (e.g., inverted-J curves flattening, seedling/sapling bottlenecks), composition (loss of slow-growing, mast-producing species; expansion of browse-tolerant shrubs), and processes (reduced litter inputs, soil exposure, and altered hydrology). Evidence from Afghanistan and adjacent semi-arid woodlands shows that grazing near settlements and along stock routes eliminates cohorts <5 cm DBH and seedlings ≤ 0.3 m height—effectively breaking the regeneration loop and lowering stand-level resilience to drought (Salehi et al., 2013). Where governance improves and extraction is moderated, stands recover multi-cohort structure, improving resistance and post-disturbance recovery.

Policy experiments in Afghanistan point to levers that rebuild resilience alongside livelihoods. Community-based Forest Management (CBFM) can reduce illegal harvest, formalize harvesting rules for NTFPs like chilgoza, and re-establish protection of seed trees, while national REDD+ readiness and forest reference levels (FREL) aim to align finance with avoided degradation (Khurram et al., 2023; Khurram et al., 2024; Teimoory et al., 2022). FAO-supported restoration in pistachio belts re-seeding degraded hillsides, safeguarding old-growth seed stands, and limiting open grazing, demonstrates early regeneration gains where local institutions hold (FAO, 2019). These cases underscore that resilience in Afghanistan's forests hinges on curbing pressure (logging, grazing), protecting regeneration windows, and restoring structural complexity through community-anchored rules and incentives.

The buffering role of stand structure complexity

Stand structural complexity is a variation in tree sizes, vertical layering, crown architecture, deadwood legacies, and spatial heterogeneity mitigates the ecological damage typically associated with deforestation and degradation by stabilizing microclimate, sustaining demographic processes, and distributing risk across functional groups. Complex canopies buffer understory temperature and humidity, reducing heat extremes and desiccation that follow canopy loss; such microclimate insulation slows thermophilization and helps maintain sensitive understory communities even as macroclimate warms (Zellweger et al., 2020; De Frenne et al., 2019, 2021). In practical terms, maintaining multi-layered canopies, irregular gap mosaics, and coarse woody debris (CWD) conserves cool, moist microsites that enhance seedling emergence and survival after disturbance, thereby supporting resistance and recovery at stand scale.

Complex structure also improves resource capture and hydraulic stability. Across broad forest gradients, structural diversity increases light interception efficiency beyond what leaf area alone predicts, supporting higher productivity and carbon uptake that can offset degradation-related losses (Atkins et al., 2018; LaRue et al., 2019, 2023). By packing crowns more efficiently and partitioning light and space, mixed and uneven-aged stands reduce asymmetric competition and dampen growth declines during droughts; complementary rooting depths and mycorrhizal associations further spread risk ("response diversity") under climatic stress (Jucker et al., 2015; Mori et al., 2013). Globally, higher tree-species diversity is consistently associated with greater productivity and, in many dry forests, better drought resistance implying that structurally and compositionally diverse stands hold greater functional insurance against disturbance (Liang et al., 2016; Grossiord, 2020).

For Afghanistan's dry-temperate conifer, juniper, and pistachio systems, these mechanisms are especially relevant. Canopy simplification from fuelwood cutting, intensive nut and cone harvest, and chronic grazing removes seed sources, reduces vertical layering, and exposes regeneration to heat and vapor-pressure deficits, compounding the effects of drought. Evidence from Afghanistan's chilgoza pine (*Pinus gerardiana*) forests shows that adjusting harvest practices to retain seed trees and limit cone removal can restore natural regeneration and gradually rebuild structure; community preferences already favor partial-harvest rules that leave enough cones for seed dispersal (Khurram et al., 2023; Shalizi et al., 2018). In analogous high-elevation juniper woodlands of the region, cumulative cutting and grazing have simplified diameter distributions and suppressed saplings, patterns diagnostic of resilience loss highlighting the need to protect mid-story cohorts and structural legacies during recovery.

Proposed strategies to enhance forest ecosystems resilience

(i) Structural retention and variable-retention harvesting: Retaining biological legacies such as live seed trees, veteran trees, cavity trees, and CWD at felling or during post-disturbance interventions preserves habitat networks, seed sources, and microclimate refugia that accelerate natural regeneration and maintain ecosystem functions. The retention approach is widely recognized as an integrative pathway to reconcile production with biodiversity and resilience outcomes (Gustafsson et al., 2012, 2020; Lindenmayer et al., 2012). In Afghanistan context, structural retention translates to explicit cone-bearing tree retention in chilgoza forests, dispersed reserves in pistachio woodlands, and the protection of juniper seed trees on drought-prone slopes.

(ii) Assisted natural regeneration (ANR) and protection of regeneration windows: Where seed sources remain, ANR protecting and releasing natural seedlings by controlling grazing, reducing browsing, and suppressing repeated cutting, offers a cost-effective path to rebuilding cohorts. FAO-GEF initiatives in Badghis, Herat and adjacent provinces have combined enclosure of replanted/seeded areas, rotational or controlled grazing, and local awareness programs; early results report afforestation/reforestation of ~1,700 ha of pistachio woodland and expanded rotational grazing regimes that lower pressure on young cohorts (FAO-GEF, 2024). These measures directly target the regeneration bottlenecks documented in Afghanistan's dry woodlands.

(iii) Community-based Forest Management (CBFM) and NTFP governance: In fragile-state settings, durable governance often depends on community institutions. Recent work from Afghanistan shows that CBFM can formalize rules for NTFPs (e.g., cone and resin harvest), coordinate patrols, and negotiate grazing schedules, improving regeneration without undermining livelihoods (Khurram et al., 2023; Khurram et al., 2024). Aligning CBFM with REDD+-style finance and national forest reference emission levels (FREL) can channel incentives toward avoided degradation and restoration (Teimoory et al., 2022).

(iv) Silviculture for complexity: Mixed-species enrichment, uneven-aged structures, and fuel-pressure reduction. Enrichment planting with drought-tolerant associates (e.g., oak with conifers; under-sown shrubs that stabilize soils), selective thinning to restore irregular diameter structures, and the deliberate creation/retention of deadwood can recover canopy heterogeneity and response diversity. Complementary investments, fuel-efficient cookstoves, alternative income activities, and assisted agroforestry reduce extraction pressure and shorten recovery times (FAO-GEF, 2024). Where disturbances occur (wind, pest, or stand-replacing fire), limiting salvage intensity and retaining legacies helps keep succession on resilient trajectories.

(v) Landscape-scale planning that couples' forests and rangelands: In much of rural Afghanistan, forest patches interface with heavily used rangelands. Rotational grazing, seasonal exclosures, and corridor protection reduce seedling browses and allow recruitment pulses to pass into sapling stages. FAO programs report seasonal partitioning of tens of thousands of hectares for rotational grazing, an approach that can be coordinated with forest regeneration targets in pistachio belts and juniper foothills.

(vi) Monitoring and adaptive management informed by structural metrics: Routine tracking of structural indicators (e.g., diameter-class distributions, vertical layering indices, canopy rugosity, legacy tree density, CWD volume) provides early warning of regeneration failure and guides silvicultural adjustments. Remote-sensing–based canopy structure metrics now scale from stands to regions (e.g., sub-continental light-absorption/structure relations) and can be paired with community monitoring to evaluate interventions in data-scarce settings (Atkins et al., 2018; LaRue et al., 2019, 2023).

Discussion

Anthropogenic pressures are reshaping forest stand structure and weakening ecosystem resilience in Afghanistan and comparable dry-montane systems across the wider Hindu Kush–Karakoram–Zagros region. In Afghanistan, the principal driver's fuelwood extraction, illegal logging, chronic grazing, conversion to rain-fed agriculture, mining, and road expansion truncate diameter distributions, simplify vertical layering, and fragment seed sources, thereby depressing recruitment and altering successional trajectories. These pressures operate alongside weak enforcement and insecure tenure typical of fragile states, amplifying degradation dynamics and constraining recovery (Bader, 2013; Ellis & Pontius., 2007; FAO, 2019; Geist & Lambin, 2002; Khurram et al., 2024; Milbrandt et al., 2011, Shalizi et al., 2018; Shalizi et al., 2020). As a result, stands exhibit homogenization, higher exposure to heat and moisture stress, and reduced capacity to resist or rebound from droughts, pests, and fire—core facets of diminished resilience.

Evidence from global and regional studies clarifies why structural complexity is pivotal for buffering these impacts. Multi-layered, compositionally diverse canopies moderate understory microclimates, dampening extreme temperatures and vapor-pressure deficits that typically intensify after canopy opening (De Frenne et al., 2019, 2021; Zellweger et al., 2020). At broader scales, structural diversity enhances light capture beyond leaf area alone and stabilizes growth under stress by distributing competition in space and height strata (Atkins et al., 2018; LaRue et al., 2019, 2023). Functional "response diversity" among species, rooting depth, phenology, and mycorrhizal associations further spreads risk, supporting higher productivity and drought resistance (Liang et al., 2016; Mori, 2013; Grossiord, 2020). Where Afghan stands lose mid-story cohorts, seed-tree legacies, and coarse woody debris, they also lose these stabilizing mechanisms, accelerating declines in resistance and recovery.

Afghanistan's pistachio (Pistacia vera complex) woodlands illustrate these processes. Decades of chronic browsing, branch cutting for fuel, and field encroachment near settlements have flattened inverse-J diameter curves, suppressed saplings, and produced "stalled" stands with low recruitment diagnostic of resilience loss (FAO, 2019; Salehi et al., 2013). Where communities have instituted seasonal exclosures, rotational grazing, and protection of seed trees, regeneration has rebounded and structural heterogeneity has begun to recover, indicating that modest governance shifts can re-open "regeneration windows" even under harsh, water-limited climates (FAO, 2019). These results align with dry-montane analogues across the central Zagros, underscoring the transferability of assisted natural regeneration and grazing governance to Afghan pistachio belts.

Chilgoza pine (Pinus gerardiana) forests in eastern Afghanistan reveal a complementary mechanism: non-timber forest product (NTFP) harvesting can either erode or rebuild structure depending on rules. Intensive cone harvest reduces seed escape and seedling cohorts, while partial-harvest rules that retain adequate seed trees restore natural regeneration and, over time, vertical layering (Khurram et al., 2023; Shalizi et al., 2018). Because canopy-forming pines provide microclimatic buffering and structural scaffolding for later-successional associates, safeguarding cone-bearing veterans functions as both a livelihood and a resilience strategy. This highlights a broader lesson for Afghan forests: when management targets legacies (veteran trees, cavity trees, downed wood) and cohort continuity, livelihoods and resilience can be co-produced rather than traded off.

Juniper woodlands in neighboring Pakistan's Ziarat massif, ecologically analogous to Afghanistan's high-elevation junipers, add a cautionary note. There, cumulative cutting and overgrazing, exacerbated by drying trends, have produced stands with poor regeneration and simplified vertical profile conditions linked to increased mortality during climatic extremes (Ahmed et al., 2015; Khan et al., 2016). Afghanistan's highlands share similar exposure and use patterns; without structural retention and regeneration protection, juniper stands may cross thresholds beyond which recovery becomes slow or uncertain. Conflict further multiplies these stressors: wartime breakdowns in rulesets and market shocks can trigger surges in logging effort, leaving durable legacies in stand density, composition, and fuel continuity (Bader, 2013; Daiyoub et al., 2024).

Management implications follow directly from these dynamics. First, retention forestry, the deliberate preservation of live legacies (seed/veteran trees), wildlife trees, and coarse woody debris at harvest or after disturbance helps maintain microclimates, seed sources, and habitat networks that catalyze natural regeneration (Gustafsson et al., 2012, 2020; Lindenmayer et al., 2012). In Afghanistan, this translates into explicit retention of cone-bearing chilgoza trees, dispersed reserves in pistachio stands, and protection of juniper seed trees on drought-prone slopes. Second, assisted natural regeneration (ANR) paired with grazing governance (rotational systems, seasonal exclosures, negotiated corridors) can rapidly reopen recruitment pathways at low cost (FAO, 2019). Third, silviculture for complexity, uneven-aged structures, mixed-species enrichment with drought-tolerant associates, crown-thinning that restores vertical heterogeneity, and deadwood creation rebuilds response diversity that underpins resilience (Messier et la., 2013; Mori et al., 2013). Where disturbances occur, limiting the intensity of salvage operations and retaining legacies helps keep succession on resilient trajectories.

Given Afghanistan's energy poverty and heavy reliance on biomass, resilience-positive forestry must be coupled with socioeconomic measures that reduce extraction pressure. Fuel-efficient stoves, alternative livelihoods (e.g., value-added NTFPs), and community benefit sharing can shorten recovery times and improve compliance with retention and ANR rules (FAO, 2019; Khurram et al., 2024). At the policy level, aligning community-based forest management (CBFM) with REDD+ and national forest reference emission levels (FREL) can mobilize finance for avoided degradation and restoration, while embedding locally negotiated harvest and grazing rules (Khurram et al., 2024; Teimoory et al., 2022). Such coupling is particularly important in fragile settings, where centralized enforcement is limited and local institutions are pivotal.

Finally, sustained gains will require monitoring systems that track structural recovery and link it to management feedback. A practical core set includes diameter-class distributions, regeneration densities by height/DBH class, vertical layering indices, canopy rugosity, legacy-tree density, and coarse woody debris volume. Remote sensing products that infer canopy structure at landscape scales (e.g., lidar-derived metrics, structure–light absorption relations) can be paired with community-based plots to guide adaptive management in data-scarce regions (Atkins et al., 2018; LaRue et al., 2019, 2023). Future research in Afghanistan should prioritize long-term plots across disturbance and management gradients, experimental tests of retention and ANR under grazing regimes, and integration of socio-economic metrics (tenure security, fuel use, NTFP dependence) with structural indicators to identify leverage points where stand complexity yields the largest resilience dividends.

Policy and Practice Implications

- Retention forestry: Codify retention of veteran/seed trees and CWD; formalize partial cone-harvest rules in chilgoza to ensure seed escape and cohort continuity (Gustafsson et al., 2012, 2020; Lindenmayer et al., 2012; Khurram et al., 2023).
- ANR + grazing governance: Use negotiated seasonal exclosures and rotational systems around regeneration hotspots; prioritize corridors that channel livestock away from recruitment patches (FAO, 2019).
- Silviculture for complexity: Favor uneven-aged structures, mixed-species enrichment with drought-tolerant associates, crown thinning that restores vertical heterogeneity, and deliberate deadwood creation; constrain salvage intensity to preserve legacies (Messier et al., 2013; Mori et al., 2013).
- CBFM + climate finance: Link community bylaws and benefit sharing to REDD+/FREL payments to fund avoided degradation and Stand Structure Complixity (SSC)-oriented restoration, with transparent monitoring (Khurram et al., 2024; Teimoory et al., 2022).
- Energy and livelihoods: Disseminate fuel-efficient stoves, support value-added NTFPs (e.g., graded chilgoza kernels, pistachio processing), and expand agroforestry niches to reduce biomass pressure.
- Monitoring: Track diameter distributions, regeneration densities, layering indices, canopy rugosity, legacy-tree density, and CWD; pair community plots with remote-sensing proxies of canopy structure (Atkins et al., 2018; LaRue et al., 2019, 2023).

Research Gaps and Future Directison

- Thresholds and recovery kinetics: Identify grazing/harvest thresholds beyond which cohorts fail and quantify time-to-recovery under ANR and retention.
- Microclimate–structure mapping: Deploy logger networks and structure metrics (e.g., canopy rugosity, gap mosaics) to isolate SSC's buffering strength during heat/drought.
- Socio-ecological coupling: Integrate tenure security, fuel use, and NTFP dependence with SSC indicators to locate leverage points for resilience dividends.
- Conflict-sensitive restoration: Design interventions robust to governance volatility, e.g., rules that still function under partial enforcement and deliver near-term livelihood benefits.
- Landscape hydrology: Quantify how SSC and litter/legacy pools affect infiltration/runoff and 81ediment yield at forest–rangeland interfaces common in Afghan watersheds.

Conclusions

Anthropogenic pressures in Afghanistan are simplifying forest structure and weakening resilience, but the same systems exhibit rapid gains when regeneration windows open and legacies are retained. Prioritizing SSC via retention forestry, ANR with grazing governance, silviculture for complexity, and CBFM linked to climate finance offers a pragmatic pathway to co-produce livelihoods and resilience. Embedding adaptive monitoring will be essential to iterate, learn, and scale what works.

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