

**MONITORING OF GREEN COVER CHANGES AND FOREST INDICATORS IN THE
BROAD-LEAVED FORESTS OF WESTERN TIEN-SHAN USING MODERN
ANALYTICAL APPROACHES****Nurullo Muxsimov***Research Institute of Forestry, Tashkent, Uzbekistan**E-mail: nurullo.mukhsimov@mail.ru,**ORCID ID: 0009-0007-4995-6221***Nargiza Jo‘rayeva***Research Institute of Forestry, Tashkent, Uzbekistan**E-mail: nargizajorayeva2124@gmail.com**ORCID: 0009-0007-7176-7988*

Abstract: The broad-leaved forests of the Western Tien-Shan, located within the UNESCO World Heritage-listed Ugam-Chatkal Biosphere Reserve, represent relict ecosystems of high ecological importance. However, these forests are increasingly affected by anthropogenic and climatic pressures, including overgrazing, illegal logging, recreational disturbance, rising temperatures, and prolonged droughts, which threaten forest structure, biodiversity, and regeneration processes. This study presents a three-year (2024–2026) integrated monitoring assessment of vegetation dynamics and forest condition in the Qoronqul forest section, Bostanliq District, Tashkent Region, Uzbekistan. The methodological framework combined field phenological observations, biometric measurements, permanent sample plot monitoring, NDVI-based remote sensing, and GIS statistical analysis. The results indicate significant ecosystem degradation. Species richness declined from 52–55 to 8–10 taxa, while herbaceous cover decreased from 90–100% to 20–30%. NDVI classification showed that 64% of the area remained relatively healthy, whereas 20% was open land,

10–11% degraded, and about 5% critically affected. Big topographic differences in regeneration were observed: northern slopes showed higher regeneration (55–60%) and seedling density ($>1,100$ ind./ha), compared to southern slopes (5–10% and ~ 120 ind./ha) due to moisture and thermal stress. Forest productivity indicators confirmed degradation, including low biomass increment (0.25–0.35 t/ha/year), reduced canopy closure (0.6), and poor site quality (Class IV). Phenological shifts of 7–20 days indicated high sensitivity to climate variability. The study highlights hidden degradation processes where structurally altered ecosystems persist despite stable NDVI signals. Results support sustainable forest management through grazing regulation, regeneration enhancement, slope-specific restoration, and long-term GIS monitoring.

Keywords: Western Tien-Shan, broad-leaved forests, NDVI, natural regeneration, phenology, biodiversity, forest degradation, remote sensing, forest management, Uzbekistan

Annotatsiya. G‘arbiy Tyan-Shanning keng bargli o‘rmonlari UNESCOning Jahon merosi ro‘yxatiga kiritilgan Ugom–Chatqol biosfera rezervati hududida joylashgan bo‘lib, yuqori ekologik ahamiyatga ega relikv ekotizimlar hisoblanadi. Biroq, ushbu o‘rmonlar chorva mollarining me‘yordan ortiq boqilishi, noqonuniy daraxt kesish, rekreatsion bosim, havo haroratining ortishi hamda uzoq davom etuvchi qurg‘oqchilik kabi antropogen va iqlim omillari ta‘sirida tobora kuchayib borayotgan degradatsiya jarayonlariga duch kelmoqda. Mazkur omillar o‘rmon tuzilishi, biologik xilma-xillik va tabiiy tiklanish jarayonlariga salbiy ta‘sir ko‘rsatmoqda. Ushbu tadqiqotda O‘zbekiston Respublikasining Toshkent viloyati Bo‘stonliq tumani Qoronqul o‘rmon bo‘limida 2024–2026-yillar davomida amalga oshirilgan kompleks monitoring natijalari taqdim etilgan. Tadqiqot metodologiyasi doimiy kuzatuv maydonchalari monitoringi, fenologik kuzatuvlar, biometrik o‘lchovlar, NDVI asosidagi masofadan zondlash ma‘lumotlari hamda GIS fazoviy-statistik tahlil usullarini o‘z ichiga oldi. Olingan natijalar ekotizim holatining sezilarli darajada yomonlashganini ko‘rsatdi. O‘simlik turlarining soni 52–55 tadan 8–10 tagacha kamaygan, o‘t-o‘lan qoplami esa 90–100 % dan 20–30 % gacha qisqargan. NDVI tahliliga ko‘ra, tadqiqot hududining taxminan 64 % qismi nisbatan sog‘lom holatda saqlanib qolgan bo‘lsa, 20 % ochiq yer maydonlari, 10–11 % degradatsiyaga uchragan o‘simlik qoplami va qariyb 5 % kuchli degradatsiyalashgan hududlardan iborat ekanligi aniqlandi. Tabiiy tiklanish jarayonlarida relyef omiliga bog‘liq keskin farqlar kuzatildi. Shimoliy ekspozitsiyalarda tabiiy tiklanish darajasi 55–60 % ni, nihollar zichligi esa 1100 tup/ga dan ortiqni tashkil etgan bo‘lsa, janubiy ekspozitsiyalarda ushbu ko‘rsatkichlar mos ravishda 5–10 % va taxminan 120 tup/ga ni tashkil etdi. Bu holat namlik tanqisligi va yuqori harorat stressining kuchayishi bilan izohlanadi. O‘rmon mahsuldorligi ko‘rsatkichlari ham ekotizim degradatsiyasini tasdiqladi. Yillik biomassa o‘sishi 0,25–0,35 t/ga/yil ni tashkil etgan, daraxtlar shox-shabbase qoplanish darajasi 0,6 ga teng bo‘lgan hamda bonitet ko‘rsatkichi IV sinfga mos kelgan. Fenologik fazalarning 7–20 kun oldinga yoki orqaga siljishi ekotizimning iqlim o‘zgaruvchanligiga yuqori darajada sezgir ekanligini ko‘rsatdi. Tadqiqot natijalari shuni ko‘rsatadiki, ekotizimda yuz berayotgan ayrim yashirin degradatsiya jarayonlari faqat NDVI ko‘rsatkichlari orqali to‘liq aniqlanmasligi mumkin, chunki tuzilishi sezilarli darajada o‘zgargan o‘rmonlar ham ma‘lum darajada vegetatsiya yashilligini saqlab qoladi. Tadqiqot natijalari yaylov yuklamasini tartibga solish, tabiiy tiklanishni qo‘llab-quvvatlash, ekspozitsiyaga mos rekultivatsiya choralari ishlab chiqish hamda uzoq muddatli GIS asosidagi monitoring tizimini takomillashtirish uchun ilmiy asos bo‘lib xizmat qiladi.

Kalit so‘zlar: G‘arbiy Tyan-Shan, keng bargli o‘rmonlar, o‘rmon monitoringi, tabiiy tiklanish, NDVI, GIS, fenologiya, biologik xilma-xillik, ekotizim degradatsiyasi, barqaror o‘rmon boshqaruvi.

Аннотация. Широколиственные леса Западного Тянь-Шаня,

расположенные на территории Угам-Чаткальского биосферного резервата, включённого в Список всемирного наследия ЮНЕСКО, представляют собой реликтовые экосистемы, обладающие высокой экологической ценностью. Однако в настоящее время эти леса испытывают возрастающее воздействие антропогенных и климатических факторов, включая чрезмерный выпас скота, незаконные рубки, рекреационную нагрузку, повышение температуры воздуха и продолжительные засухи, что оказывает отрицательное влияние на структуру лесов, биоразнообразие и процессы естественного возобновления. В настоящем исследовании представлены результаты комплексного мониторинга, проведённого в 2024–2026 гг. в Коронкульском лесничестве Бостанлыкского района Ташкентской области Республики Узбекистан. Методологическая основа исследования включала мониторинг постоянных пробных площадей, фенологические наблюдения, биометрические измерения, дистанционное зондирование с использованием индекса NDVI и пространственно-статистический анализ в среде GIS.

Полученные результаты свидетельствуют о существенной деградации лесной экосистемы. Видовое богатство сократилось с 52-55 до 8-10 видов, а проективное покрытие травянистой растительности уменьшилось с 90–100 % до 20-30 %. Согласно результатам анализа NDVI, около 64 % исследуемой территории сохраняет относительно благополучное состояние, тогда как 20 % приходится на открытые участки, 10-11 % - на деградированную растительность и около 5 % - на сильно деградированные территории.

Процессы естественного возобновления характеризовались выраженной зависимостью от экспозиции склонов. На северных склонах уровень естественного возобновления составил 55-60 %, а плотность подроста превысила 1100 экз./га, тогда как на южных склонах соответствующие показатели составили лишь 5-10 % и около 120 экз./га, что обусловлено дефицитом влаги и усилением температурного стресса.

Показатели продуктивности лесных насаждений также подтвердили процессы деградации: среднегодовой прирост биомассы составил 0,25-0,35 т/га/год, сомкнутость полога достигала лишь 0,6, а продуктивность древостоев соответствовала IV классу бонитета. Смещение сроков наступления фенологических фаз на 7-20 суток свидетельствует о высокой чувствительности экосистемы к климатической изменчивости. Результаты исследования показывают, что отдельные процессы скрытой деградации экосистем не всегда могут быть выявлены только на основе индекса NDVI, поскольку структурно нарушенные лесные сообщества способны сохранять относительно высокие значения вегетационной активности. Полученные данные создают научную основу для совершенствования устойчивого управления лесами посредством регулирования пастбищной нагрузки, содействия естественному возобновлению, реализации дифференцированных мер восстановления с учётом экспозиции склонов и внедрения долгосрочной системы мониторинга на основе технологий GIS.

Ключевые слова: Западный Тянь-Шань, широколиственные леса, мониторинг лесов, естественное возобновление, NDVI, GIS, фенология, биоразнообразие, деградация экосистем, устойчивое лесопользование.

1. Introduction

Mountain forests of the Western Tien-Shan in Uzbekistan play a pivotal role in maintaining regional ecological balance, providing essential ecosystem services such as watershed regulation,

erosion control, and biodiversity conservation. Although these forests cover only approximately 5% of Uzbekistan's territory, they support disproportionately high ecological and socio-economic functions. Among these, the walnut-fruit (*Juglans regia*-dominated) forests are recognized as relict ecosystems, characterized by high endemism, unique species composition, and global conservation significance. Despite their ecological importance, these forests are increasingly threatened by combined anthropogenic pressures, including illegal logging, overgrazing, and land-use change, as well as climate-induced stressors such as prolonged droughts, rising temperatures, and extreme weather events. Such pressures compromise forest structure, reduce species diversity, and hinder natural regeneration processes, potentially leading to irreversible degradation if not monitored and managed effectively. Previous studies on the Western Tien-Shan forests have largely focused on qualitative descriptions or limited-area assessments, with a notable lack of integrative, quantitative monitoring of degradation and regeneration dynamics. Modern remote sensing indices, such as the Normalized Difference Vegetation Index (NDVI), combined with field-based phenological and biometric observations, offer robust tools for assessing forest health and regeneration efficiency across spatial and temporal gradients [12,13].

This study addresses these gaps by implementing a comprehensive three-year (2024-2026) monitoring program in the Burchmulla State Forest Management area, Qoronqul forest section. The main objectives are: (1) to quantify spatiotemporal changes in green cover using NDVI and field observations; (2) to evaluate natural regeneration across topographic and aspect gradients; (3) to identify key abiotic and biotic factors influencing forest health; and (4) to provide evidence-based recommendations for sustainable management and restoration of walnut-fruit forests. By integrating field and remote sensing approaches, this research aims to enhance understanding of the drivers of forest degradation and regeneration, ultimately supporting conservation and adaptive management strategies in the Western Tien-Shan [6].

2. Methodology

Study Area

The study was conducted in the Qurongqul forestry unit (total area 598 ha; 70 ha intensively studied) of the Burchmulla State Forest Enterprise, Bostanliq District, Tashkent Region, Uzbekistan, situated at 800-1,200 m above sea level within the Western Tien-Shan UNESCO World Heritage property. This region is characterized by rugged terrain, diverse topography, and mixed walnut-fruit and broadleaf forests, representing relict and high-conservation-value ecosystems.

Data Collection

- *Field Surveys*: Monthly phenological observations, species composition inventories, seedling density counts, and biometric measurements (tree height, diameter at breast height [DBH], and age) were conducted in accordance with standardized forestry and ecological protocols.
- *Vegetation Cover Assessment*: Monthly monitoring of green cover was performed using ground-based observations and photographic surveys. Vegetation health and density were classified reflecting healthy, degraded, and sparse areas.
- *Permanent Plots*: Two 300 m² permanent plots were established at 1,100 m a.s.l. on northern and southern slopes to monitor long-term dynamics of forest structure, regeneration, and health.

Analytical Framework

- *Annual Growth Rate (K)*: Calculated from height-age relationships using dendrochronological pointer-year analysis.
- *Site Quality (B)*: Evaluated via Mayer's method, based on tree height-to-age ratios.

- *Natural Regeneration Efficiency (R)*: Assessed as post-disturbance seedling recruitment success and density.

- *Integration and Modeling*: Field-based NDVI estimates (from handheld or ground-based sensors) were combined with seedling density and environmental variables (soil, topography, microclimate) to quantify spatiotemporal patterns of forest health and regeneration dynamics.

This methodology allowed a robust evaluation of forest structural integrity, regeneration potential, and the influence of biotic and abiotic drivers across topographic gradients in the Western Tien-Shan.

3. Results

3.1. Biodiversity and Vegetation Cover Dynamics

The results obtained from the monitoring of the Qoronqul forest section revealed significant degradation trends in both biodiversity and vegetation structure over the study period (2024-2026). Species richness declined by approximately 85%, indicating a substantial loss of floristic diversity. Concurrently, herbaceous cover decreased from near-complete conditions (90-100%) to sparse levels (20-30%), reflecting reduced ecosystem productivity and resilience.

Relict and stress-tolerant species, including *Pistacia vera* L., *Crataegus pontica* Koch., *Crataegus turkestanica* Pojark., and *Rosa spp.*, persisted primarily at elevations around 1,030 m a.s.l., suggesting their relatively higher ecological adaptability under degraded conditions.

3.2. NDVI-Based Vegetation Assessment (2026)

NDVI-based spatial analysis demonstrated heterogeneous vegetation conditions across the study area (Table 1):

Table 1. NDVI-based classification of vegetation condition in the Qoronqul forest section

Category	Coverage (%)	Interpretation
Healthy vegetation	64.03	Stable photosynthetic activity
Open areas	20.03	Soil exposure, low biomass
Degraded zones	10.61	Reduced vigor, stress conditions
Critical areas	5.33	High-priority zones for restoration

These findings indicate that although a considerable portion of the area remains vegetated, degradation processes are actively progressing.

3.3. Aspect-Driven Regeneration Gradient

A pronounced contrast in natural regeneration dynamics was observed between slope aspects. Northern slopes demonstrated relatively high regeneration capacity, with natural regeneration rates reaching 55-60% and seedling densities exceeding 1,100 individuals per hectare. In contrast, southern slopes exhibited critically low regeneration levels, with rates of only 5-10% and a seedling density of approximately 120 individuals per hectare.

This disparity is primarily attributed to differences in environmental conditions. Northern slopes benefit from more favorable moisture regimes and microclimatic stability, which support seedling establishment and growth. Conversely, southern slopes are subject to harsher abiotic stressors, including limited soil moisture, elevated temperatures, and increased soil degradation, all of which significantly constrain natural regeneration processes.

3.4. Forest Productivity Indicators

The structural and productivity assessment of the Qoronqul forest section showed generally low forest performance:

Age class: II (25-40 years; active growth stage) [7,10,11]

Canopy closure: 0.6 (sparse stand structure) [5]

Biomass increment: 0.25–0.35 t/ha/year [3]

Site quality: Class IV (low productivity) [4]

Estimated full recovery time: ~31 years under current conditions [8,9]

These indicators confirm that the forest ecosystem is functioning below its ecological potential (Figura 1).



Figure 1. Distribution and composition of tree and shrub species within the study plots

3.5. Phenological Sensitivity to Climate Variability

Phenological observations revealed a high sensitivity of vegetation dynamics to interannual climatic variability:

2024: Cooler and wetter spring conditions delayed vegetation onset to mid-March

2025: Warmer and drier conditions resulted in an earlier onset (early March)

2026: A late frost event caused an approximately 7-day delay in phenological development and led to frost damage in *Amygdalus* spp.

These results highlight the increasing influence of climate variability on forest growth and regeneration processes.

Table 2. Monitoring of Broadleaf Forests in the Western Tien Shan (2024–2026)

Monitoring Indicator	2024	2025	2026	Remarks
Number of species	52	50	48	Nut-bearing and associated broadleaf species
Herbaceous ground cover (%)	80	65	70	Decline in vegetation density observed
Natural regeneration (%)	55/5	57/6	60/7	Northern aspect remains stable, southern aspect is under stress
Annual biomass increment (t/ha)	0.30/0.25	0.31/0.26	0.34/0.27	Biometric growth indicators

Phenological onset	17 March	5 March	12 March	Varies according to climatic conditions
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The biomass growth rate and overall forest condition indicators of the Western Tien Shan broadleaf forests remained at a relatively low level in 2026. The mean annual biomass increment ranged between 0.25 and 0.35 t ha⁻¹ year⁻¹, confirming the low productivity characteristic of Site Class IV (Bonitet IV) forest stands. The forest stocking density (canopy closure coefficient) remained at approximately 0.6, indicating that stand thinning and degradation processes are still ongoing. These findings suggest limited productive capacity and emphasize the need for targeted silvicultural measures to enhance forest regeneration and ecosystem stability.

4. Discussion

The results of this study clearly demonstrate that the broad-leaved forests of the Western Tien-Shan are undergoing substantial structural and functional changes driven by both anthropogenic and climatic factors. The observed decline in species richness (by approximately 85%) and the sharp reduction in herbaceous cover indicate a significant simplification of the forest phytocoenosis. Such reductions in biodiversity are widely recognized as early indicators of ecosystem instability and declining resilience, particularly in mountain forest systems where environmental gradients are highly sensitive.



Figure 2. Monitoring process in the Qoronqul forest section of the Burchmulla State Forest Enterprise (Western Tien-Shan, Uzbekistan).

One of the key findings of this research is the presence of “hidden degradation”, where vegetation cover may appear relatively stable (as indicated by 64% healthy NDVI values), yet underlying structural parameters-such as species composition, regeneration capacity, and productivity-are significantly impaired. This confirms that reliance solely on vegetation cover indices can underestimate the true extent of ecosystem degradation. Therefore, integrating field-based observations with NDVI and other spatial indicators is essential for accurate forest condition assessment (Figura 2).

The strong contrast observed between northern and southern slopes highlights the critical role of microclimatic and edaphic factors in shaping regeneration dynamics. Northern slopes, characterized by higher soil moisture availability and lower thermal stress, support relatively stable natural regeneration processes. In contrast, southern slopes are exposed to intense solar radiation, higher evapotranspiration rates, and soil degradation, resulting in severely limited regeneration (5-10%). This pattern is consistent with ecological theory on aspect-driven gradients in mountain ecosystems and underscores the importance of topography in forest management planning.



Figure 3. Phenological monitoring of tree and shrub species in the study area during the vegetation period.

Phenological observations provide additional evidence of the increasing influence of climate variability on forest ecosystems. The interannual shifts in vegetation onset (7-20 days), along with the observed frost damage in *Amygdalus spp.*, demonstrate that even short-term climatic anomalies can significantly affect growth cycles and regeneration success. This sensitivity highlights the vulnerability of mountain forests to ongoing climate change and emphasizes the need for adaptive management strategies that account for phenological variability.

Overall, the combined effects of biodiversity loss, reduced capacity for regeneration, low productivity, and climatic sensitivity indicate that the studied forest ecosystem is undergoing a transition toward a more degraded and less resilient state. Without targeted management interventions, these processes may lead to further ecosystem destabilization and loss of ecological functions.

The findings of this study underscore the importance of implementing integrated and site-specific management strategies. In particular, regulating grazing pressure, reducing illegal logging, and promoting both natural and assisted regeneration are essential for restoring ecosystem structure. Additionally, establishing long-term monitoring systems that integrate GIS and field data will be critical for tracking ecosystem changes and supporting evidence-based decision-making. Special attention should be given to southern slopes, where restoration efforts must address moisture limitations, soil degradation, and thermal stress through adaptive and location-specific approaches.

Conclusion. This study demonstrates that the broad-leaved forests of the Western Tien-Shan are undergoing significant degradation, reflected in reduced species diversity, declining vegetation cover, low productivity, and limited natural regeneration. The results highlight the presence of “hidden degradation”, where stable vegetation cover masks underlying structural and functional decline.

A clear topographic effect was identified, with northern slopes supporting relatively stable regeneration, while southern slopes remain highly vulnerable due to abiotic stress factors. In addition, phenological shifts indicate increasing sensitivity of forest ecosystems to climate variability.

These findings emphasize the need for sustainable forest management, including regulation of grazing, support for natural and assisted regeneration, and implementation of soil and water conservation measures. The establishment of long-term monitoring systems is essential for effective ecosystem management and conservation.

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