

Scale for Assessing the Impact of Operational Stress on the Resource Potential of Medicinal Plants: A Case Study of Southern Uzbekistan

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Abstract This article discusses the development of a scale for assessing the impact of exploitation stress on the resource potential of medicinal plants. The scale assesses the degree of exploitation impact, taking into account the life form of the plant and the type of harvested raw material, based on certain criteria. According to this scale, for perennial herbaceous plants harvested for their underground part, one-year exploitation in a given area is assessed at 2 points (β), and repeated exploitation over two years is assessed at 3 points (α). For perennial herbaceous plants and subshrubs harvested for their aboveground part, the assessment varies depending on the intensity of harvesting and is assessed at 1 point (γ), 2 points (β) or 3 points (α). In this regard, it is recommended to harvest the aboveground part of perennial herbs in one area no more than once every 4 years. With a one-time harvesting of raw materials from the underground part of perennial herbaceous plants, the number of exploitable individuals is reduced by approximately 44%. This is confirmed by the dynamics of the decrease in the resource potential of southern Uzbekistan during the collection of the root resin of *Ferula tadshikorum* and the roots of *Inula grandis*. In this regard, after a single procurement of raw materials of such species, it is necessary to withstand a three-year

period without exploitation. According to the scale, this load is estimated at 2 points (β), and repeated two-year exploitation at 3 points (α). With the systematic collection of raw materials of the aboveground part of semi-shrubs for three or more years in one area, an irreversible decrease in the resource potential of plants also occurs. This is confirmed by a decrease in the number of exploitable individuals of *Ajuga turkestanica* by 55% after two-year procurement. Two-year exploitation requires 6-7 years for restoration and is estimated at 2 points (β), and three-year or more at 3 points (α). Thus, the collection of the aboveground part of semi-shrubs in natural conditions is also recommended to be carried out once every 4 years in one area. The proposed scale can also be used to assess the resource potential of other types of medicinal plants not studied within the framework of this study. To do this, it is necessary to take into account the life form of the plant, the type of raw material and the time of its restoration according to the established criteria.

Keywords Scale of Exploitation Impact, Sustainable Harvesting, Medicinal Plants, Resource Potential, Southern Uzbekistan

1. Introduction

Currently, recent ecological perspectives emphasize the role of biodiversity conservation in human well-being. The fundamental principle of this worldview is the preservation of the planet's biodiversity, which is essential for ensuring a high quality of life for humans. From this perspective, research into the effects of anthropogenic factors on biological entities—especially wild resource plants subjected to various stressors, with human economic activity playing a particularly significant role, including operational stress and technogenic pollution—is highly relevant [1].

At present, approximately half of all medications are derived from plant materials, with over 50% of these sourced from wild plants. Interest in phytotherapy and herbal remedies has grown significantly among both healthcare practitioners and the general population. This rising demand has led to the depletion and often unsustainable use of natural medicinal plant resources. Addressing this issue requires solving environmental problems and developing sustainable harvesting methods that promote the regeneration of medicinal plant populations [2].

Recent analyses indicate that nearly two-thirds of the world's plant species are either threatened with extinction within the 21st century or experiencing a significant decline in their populations. The loss of plant species and the reduction in taxonomic diversity are linked to a number of factors, including population growth, rapid habitat transformation, overexploitation, the spread of invasive species, pollution, and climate change. In recent years, approximately 60% of natural ecosystems have been degraded or are being used unsustainably. In most cases, anthropogenic activity is considered the primary driver of ecosystem degradation. The Global Strategy for Plant Conservation (2002) outlines five main goals and sixteen specific targets. Notably, the third goal focuses on the "sustainable use of plant resources" [3]. However, in the countries of Central Asia, the unregulated and excessive exploitation of plant resources has led to a severe decline in the natural habitats of many valuable species.

For example, in Tajikistan, the annual collection of up to 150 tons of *Ferula tadshikorum* has led to the near-total disappearance of its resource-bearing populations. Similarly, in Afghanistan, annual harvesting of up to 200 tons has resulted in such drastic declines that the species has been listed in the Red Data Books of both countries. A comparable situation has been observed in Uzbekistan, where the resource area for *Ferula tadshikorum* has been reduced by 96%, and raw material reserves have declined by 83%. Consequently, this species has also been included in the Red Book of the Republic of Uzbekistan [4].

The primary cause of these changes is the uncontrolled and unsustainable exploitation of plant resources. In response to this critical situation, our previous studies have developed a classification system for resource plant species in the flora of Uzbekistan [5].

To date, numerous studies have been conducted to examine the impact of operational stress on medicinal plant populations in the Kirov region, as well as the influence of anthropogenic factors on forest cover in mountainous areas [1]. These investigations have primarily focused on the effects of operational stress on the aboveground parts of medicinal plants and have assessed the recovery time of coenopopulations.

However, there is still a lack of scientifically validated methods for assessing the impact of operational stress on the condition of medicinal plant coenopopulations. In light of this, the development of a standardized scale to evaluate the effects of operational stress on coenopopulations of rare, endemic, and highly valued medicinal plants is both timely and highly relevant.

Thus, the developed scale for assessing exploitation stress on the resource potential of medicinal plants serves as a tool that enables a quantitative evaluation of the impact of harvesting on natural populations, taking into account the biological characteristics of species and the type of harvested raw material. The application of this scale contributes to the development of scientifically grounded approaches to the sustainable use and conservation of medicinal plants. The proposed methodology is particularly relevant for the conditions in southern Uzbekistan and other regions of Central Asia, where natural phytocenoses are under high anthropogenic pressure.

2. Materials and Methods

2.1. Research Objects

To develop a scale for assessing the impact of operational stress, species were selected based on the types of raw materials and annual volume requirements. Therefore, two Red Book species were selected for the study: *Ungernia victoris* (raw material – leaves), with an average annual demand of 22.5 tons, and *Ferula tadshikorum* (raw material – root resin), with an average annual demand of 106.5 tons. In addition, two highly demanded species: *Ajuja turkestanica* (raw material – aboveground part), 19.25 tons, and *Inula grandis* (raw material – roots), 52.75 tons per year [5] (Fig. 1).

The necessity of developing a scale for assessing exploitation stress on the resource potential of medicinal plants is determined by a combination of ecological, biological, and economic factors. An analysis of the state of natural resources has shown a declining trend in population size and habitat degradation for several species actively used in pharmaceutical and traditional medicine. This is particularly true for *Ungernia victoris* and *Ferula tadshikorum*, which are listed in the Red Data Book of Uzbekistan, as well as for the highly demanded species *Ajuja turkestanica* and *Inula grandis*, which are subject to intensive harvesting.

*Ungernia victoris**Ferula tadshikorum**Ajuga turkestanica**Inula grandis***Figure 1.** Research objects

The absence of a unified quantitative approach to assessing the degree of harvesting impact on plant resource potential complicates the development of measures for their rational use and conservation. In this regard, the development of an exploitation stress assessment scale is a scientifically grounded necessity aimed at establishing objective criteria for species resilience to anthropogenic pressure. Such a scale makes it possible to determine the maximum allowable levels of raw material collection without threatening the recovery of natural populations and serves as a tool for planning the sustainable use of medicinal plants in the conditions of southern Uzbekistan and other regions of Central Asia.

2.2. Research Methods

To determine the natural resources of plants within the Republic of Uzbekistan, the manuals on “Resource Science and Standardization of Medicinal Plant Raw Materials” [2] were used. Raw material reserves were determined during the growing season of each plant.

To analyze the impact of operational stress on the resource potential of medicinal plants, four parameters were selected: the number of operational individuals (pcs.) in 10x10 meter accounting plots; raw material yield (g); the length of the aboveground part of the plant (cm); the length

of the underground part of the plant (cm). The experiments were carried out for five years (2021–2025) at each of the monitoring sites. Five monitoring sites were selected for each plant species. A comparative analysis of the parameters was carried out before and after harvesting plant raw materials at each monitoring site for five years.

A three-level (point) scale has been developed to assess the impact of exploitation stress on the resource potential. The main parameters of this scale are indicators for monitoring sites, namely: the number of exploitation individuals (pcs.), raw material yield (g) and plant recovery time. To assess the impact of exploitation stress on the underground organs of plants, raw material collection was carried out in the following volumes: for *Ferula tadshikorum*, 50 g of root resin was collected from each model specimen; for *Inula grandis*, 50% of the rhizome mass of the model specimen was removed. To evaluate the impact on the aboveground organs, sampling was conducted as follows: for *Ungernia victoris*, 50% of the leaves of the model specimen were collected; for *Ajuga turkestanica*, 50% of the aboveground part, including the flowering leafy shoot tops, was harvested. An increase in points on the scale reflects the degree of destruction of plant populations. At the same time, regular collection of plant raw materials in the same area for 3 years allows us to assess the level of damage to the population of a given

species and its ability to recover. Thus, a score of 1 to 3 points for a species in a certain area reflects the state of its resource potential and populations. In addition, when assigning points, the life form of the plant and the type of harvested raw materials are taken into account. According to the evaluation criteria, 1 point is designated as gamma (γ), 2 points as beta (β), and 3 points as alpha (α) (Table 1).

One-way analysis of variance (ANOVA) was applied to test the effect of harvesting intensity (factor “Intensity of influence (year)” with five levels: Control, 1st year, 2nd year, 3rd year and 4th year) on morphological and resource-related characteristics of four species: *Ungernia victoris*, *Ferula tadshikorum*, *Ajuga turkestanica* and *Inula grandis*. For each species, the following dependent variables were analyzed separately: number of exploitable individuals (pcs.), raw material yield ($\text{kg}\cdot\text{ha}^{-1}$), main morphometric parameters (leaf or aboveground length, root diameter or underground length), and dynamics of yield reduction (%). ANOVA was performed using ordinary least squares (factor as fixed effect); assumptions of the ANOVA model (homogeneity of variances) were inspected, and pairwise post-hoc comparisons were conducted using Tukey’s Honest Significant Difference test at $\alpha = 0.05$. Group means and standard errors (SE) are reported. Statistical calculations were performed in a computational environment and the results are presented in tabular form.

The results were statistically processed in Excel, Past3, and Origin Pro programs.

These methods provided the basis for evaluating the degree of operational stress on medicinal plants and for developing a scale applicable to Southern Uzbekistan.

2.3. Research Area

Southern Uzbekistan includes the Kashkadarya and Surkhandarya regions, which are located in the

southernmost part of the republic. The region borders the Samarkand and Bukhara regions to the north, Tajikistan to the east, Turkmenistan to the west, and Afghanistan to the south. The southern border of the region runs along the Amu Darya River, which is also the border between Uzbekistan and Afghanistan (Figure 2).

In the study, five main monitoring sites were identified for each plant. *Ungernia victoris* - Surkhandarya region: Padang, Kushtut, Khankasu, Xanaka and Sharasay massifs. *Ferula tadshikorum* - Kashkadarya region: Buztepa, Xujaipok massifs and Surkhandarya region: Xujaaxsar, Xamkan, Xazratbobo. *Ajuga turkestanica* - Kashkadarya region: Pachkamar, Langarota massifs and Surkhandarya region: Xujamayxona, Darbant and Pasurxi. *Inula grandis* - Kashkadarya region: Tarkapchigay, Karadaxana, Akbash massifs and Surkhandarya region: Chagam, Duxona massifs (Figure 2).

In botanical and geographical terms, the territory of the Kashkadarya region belongs to the Urgut district of the Kuhistan district, the Kashkadarya and Tarkapchigay districts of the West Gissar district of the Central Asian Mountain Province and the Karshi-Karnabchul district of the Bukhara district of the Turan province. The Surkhandarya region belongs to the Kashkadarya, Tarkapchigay, Baysun, Kugitang and Surkhan-Sherabad districts of the West Gissar district of the Central Asian Mountain Province and the Sangardak-Tupalang district of the Gissar-Darvaz district and the Babatag district of the Panj district [6, 7].

Simultaneously, several studies have been carried out within our republic aimed at investigating the diversity, ecological conditions, and potential for sustainable utilization of medicinal plant species, emphasizing their effective use in both traditional and contemporary medical practices [8, 9].

Table 1. Project scale for assessing the impact of operational stress on the state of the resource potential of medicinal plants

Life form of plants	Type of raw material	Intensity of influence (year)	Number of operating individuals (pcs.)	Yield (kg/ha)	Recovery time (year)	Ball
Perennial	Underground part	1	16.1 ±0.35	371 ±5.67	3-4	$\gamma / 1$
		2	12.6 ±0.75	97 ±4.07	5-6	$\beta / 2$
		more than 3	5.6 ±0.45	0	Not recoverable	$\alpha / 3$
Perennial	Aboveground part	1	14.5 ±0.73	223.2 ±16.81	2-3	$\gamma / 1$
		2	7.9 ±0.52	154.8 ±11.21	4-5	$\beta / 2$
		more than 3	4.5 ±0.34	0	Not recoverable	$\alpha / 3$
Semi-shrub	Aboveground part	1	30.4 ±1.19	59.78 ±4.82	3-4	$\gamma / 1$
		2	27.1 ±1.81	39.85 ±3.21	5-6	$\beta / 2$
		more than 3	11.8 ±0.55	0	Not recoverable	$\alpha / 3$

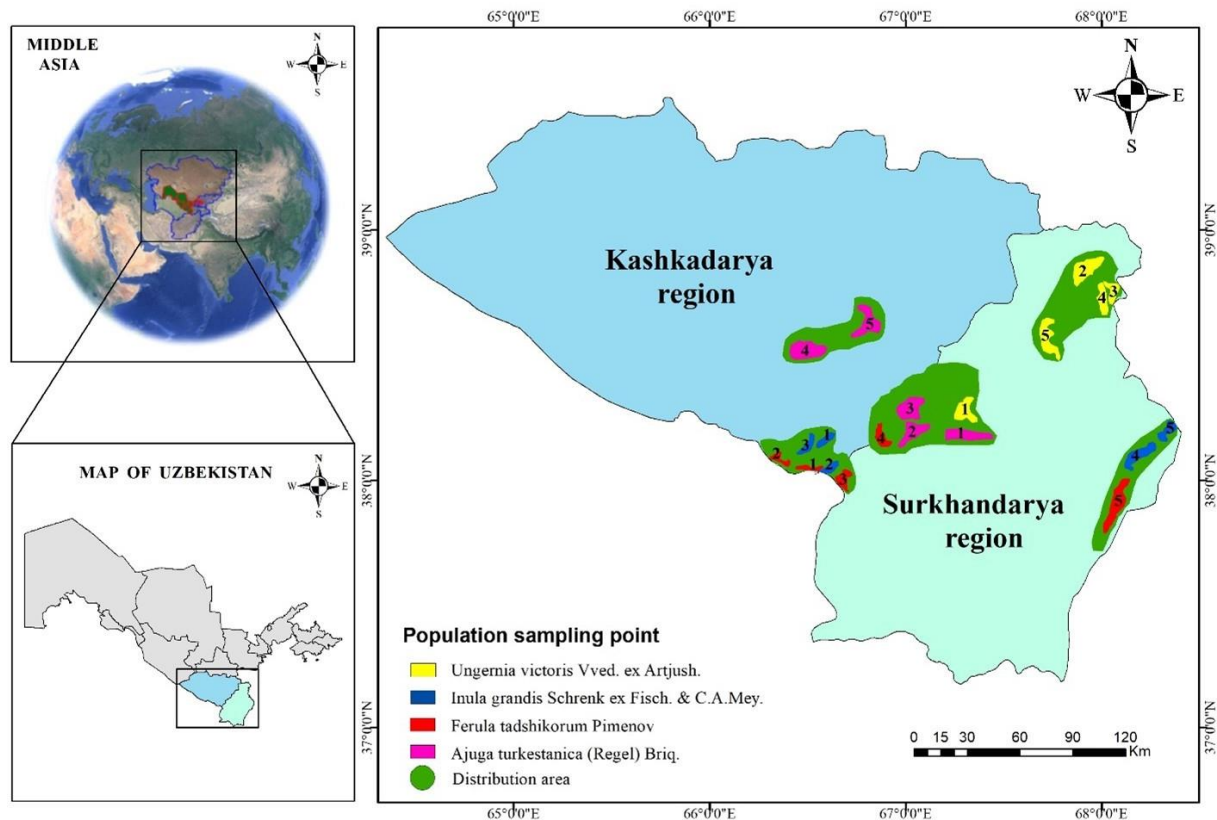


Figure 2. Research area

3. Results

3.1. Dynamics of the Reduction of the Resource Potential of Medicinal Plants under the Influence of Operational Stress

Ungernia victoris – on the Padang monitoring site (10x10 m) at the control (without exploitation) stage the following indicators were recorded: the number of exploitable individuals was 8.5 ± 0.58 pcs., the raw material yield (leaves) was 51.77 ± 3.69 kg/ha, the length of the aboveground part of the model specimens was 36.9 ± 0.78 cm, the length of the underground part was 16.4 ± 0.21 cm. After the first year of exploitation, a significant decrease in productivity was revealed. The following indicators were recorded: the number of exploitable individuals was 6.9 ± 0.52 pcs., the raw material yield was 42.0 ± 3.32 kg/ha, the length of the aboveground part of the model specimens was 31.9 ± 0.47 cm, and the length of the underground part was 12.2 ± 0.29 cm. The decrease in productivity was 18.7%. After the second year of operation, a decrease in yield to 43.3% was recorded. This decrease significantly correlates with a decrease in the number of exploitation specimens (4.8 ± 0.24 pcs.), raw material yield of 29.3 ± 1.84 kg/ha, the length of the aboveground part of model specimens of 25.1 ± 0.27 cm and the length of the underground part of 9.43 ± 0.24 cm. After the third and fourth years of operation, a sharp decrease in raw material yield by 55–80% was observed.

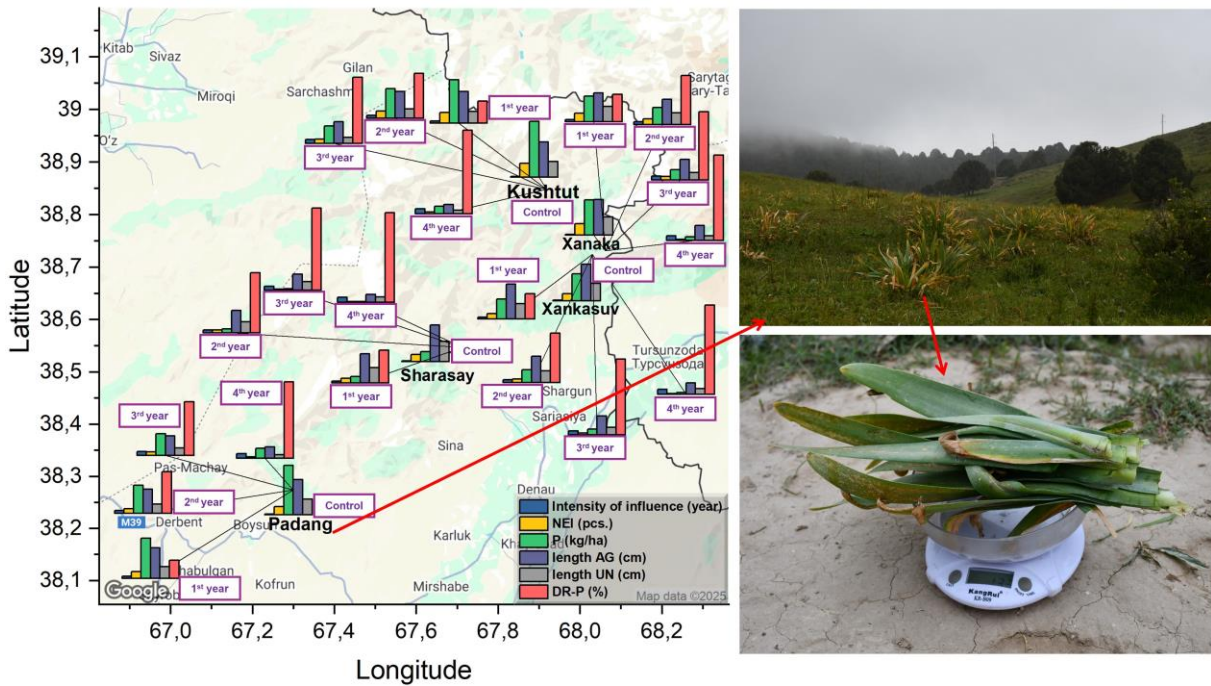
In the monitoring areas of Kushtut, Xankasu, Xanaka and Sharasay, a significant reduction in the number and yield of raw materials with regular exploitation was also observed. According to the indicators, the number of exploitable specimens decreases from 22.7% in the first year to 94.2% by the fourth year. These data significantly correlate with the reduction in the length of the underground and aboveground parts of the plant. These data indicate that regular harvesting of raw materials for three or more years significantly reduces the plant's ability to restore its resource potential (Figure 3).

Ferula tadshikorum – on the Buztepa monitoring site (10x10 m) at the control (without exploitation) stage, the following indicators were recorded: the number of exploitable individuals was 14.6 ± 1.21 pcs.; the yield of raw materials (root resin) was 4.38 ± 0.36 kg/ha; the length of leaves of model specimens was 84.03 ± 1.36 cm; and the root diameter was 14.08 ± 0.56 cm. After the first year of exploitation, a significant decrease in productivity was revealed. The following indicators were recorded: the number of exploitable individuals was 8.2 ± 0.65 pcs.; the yield of raw materials was 2.46 ± 0.19 kg/ha; the length of leaves of model specimens was 71.31 ± 0.58 cm; and the root diameter was 10.61 ± 0.33 cm. The decrease in yield was 43.8%. After the second year of exploitation, a decrease in yield to 55.4% was recorded. This decrease significantly correlates with a decrease in the number of exploited individuals (6.5 ± 0.17 pcs.), raw material yield of 1.95 ± 0.05 kg/ha, leaf length of model specimens of

66.65 ± 0.91 cm and root diameter of 9.32 ± 0.28 cm. After the third and fourth years of exploitation, a sharp decrease in raw material yield by 69–82% was observed.

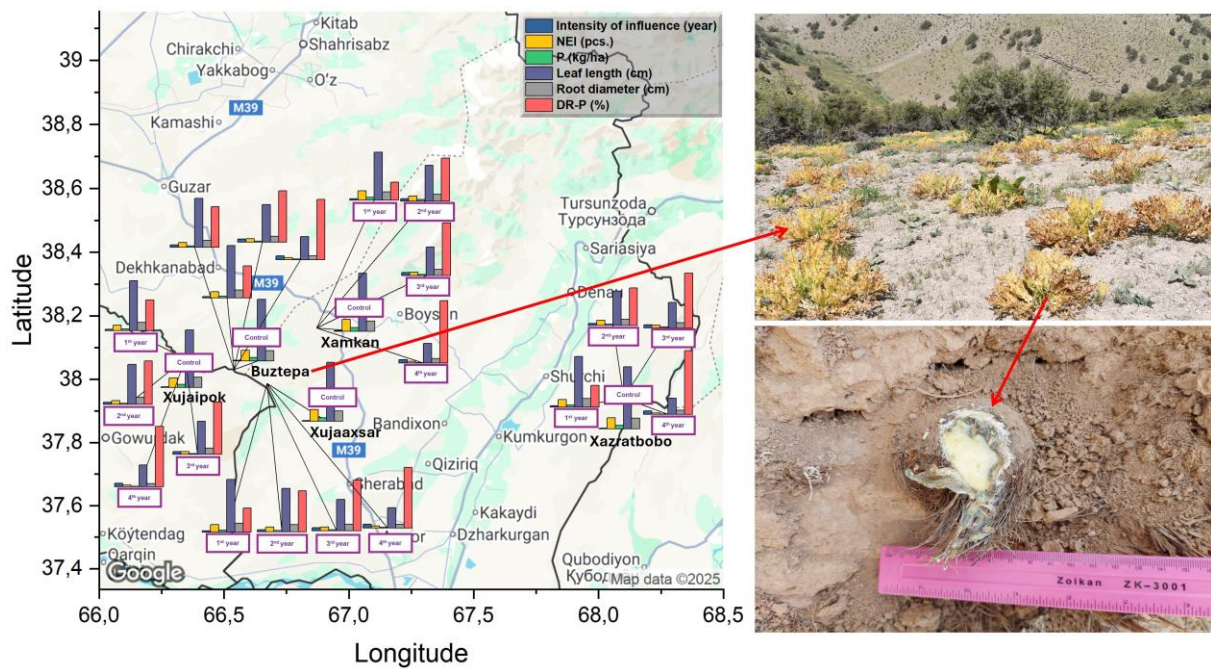
In the monitoring areas of Xujaipok, Xujaaxsar, Xamkan, Xazratbobo, a significant reduction in the number and yield of raw materials with regular exploitation was also revealed.

According to the indicators, the number of exploitation specimens decreases from 41.9% in the first year to 85.4% by the fourth year. These data significantly correlate with the reduction in the length of the leaves of model specimens and the diameter of the plant roots.



Note: NEI (pcs.) – number of exploitable individuals; P (kg/ha) – raw material yield; length AG (cm) – length of aboveground part of model specimens; length UN (cm) – length of underground part of model specimens; DR-P (%) – dynamics of yield reduction.

Figure 3. Dynamics of the reduction of resource potential of *Ungernia victoris* over four years



Note: NEI (pcs.) – number of exploitable individuals; P (kg/ha) – raw material yield; Leaf length (cm) – length of leaves of model specimens; Root diameter (cm) – diameter of roots of model specimens; DR-P (%) – dynamics of yield reduction.

Figure 4. Dynamics of reduction of resource potential of *Ferula tadshikorum* over four years

These data indicate that regular harvesting of raw materials over three or more years significantly reduces the plant's ability to restore its resource potential (Figure 4).

Ajuga turkestanica – at the Pachkamar monitoring site (10x10 m) at the control (without exploitation) stage, the following indicators were recorded: the number of exploitable individuals was 11.4 ± 0.47 pcs.; raw material yield (aboveground part) was 69.3 ± 2.64 kg/ha; the length of the aboveground part of model specimens was 40.2 ± 0.62 cm; and the length of the underground part was 20.98 ± 0.96 cm. After the first year of exploitation, a significant decrease in productivity was revealed. The following indicators were recorded: the number of exploitable individuals was 7.2 ± 0.38 pcs.; raw material yield was 44.1 ± 2.86 kg/ha; the length of the aboveground part of model specimens was 34.09 ± 0.74 cm; and the length of the underground part was 18.97 ± 0.68 cm. The decrease in yield was 36.37%. After the second year of operation, a decrease in yield to 55.24% was recorded. This decrease significantly correlates with a decrease in the number of exploitation specimens (5.1 ± 0.45 pcs.), raw material yield of 31.02 ± 2.74 kg/ha, the length of the aboveground part of model specimens of 25.76 ± 0.63 cm and the length of the underground part of 16.38 ± 0.36 cm. By the third and fourth years of exploitation, a sharp decline in raw material yield was recorded, reaching 77–87% compared to the control level. This marked reduction strongly correlates with decreases in the number of exploitable specimens and in both aboveground and underground biomass dimensions.

The monitoring sites of Langarota, Xujamayxona, Darbant and Pasurxi also revealed a significant reduction in the number and yield of raw materials with regular exploitation. According to the indicators, the number of exploitable specimens decreases from 26.3% in the first year to 90.6% by the fourth year. These data significantly correlate with the reduction in the length of the underground and aboveground parts of the plant.

These data indicate that regular harvesting of raw materials over three or more years significantly reduces the plant's ability to restore its resource potential (Figure 5).

Inula grandis – on the Tarkapchigay monitoring site (10x10 m) at the control (without exploitation) stage the following indicators were recorded: the number of exploitable individuals was 42.7 ± 2.16 pcs., raw material yield (root) 236.6 ± 15.2 kg/ha, leaf length of model

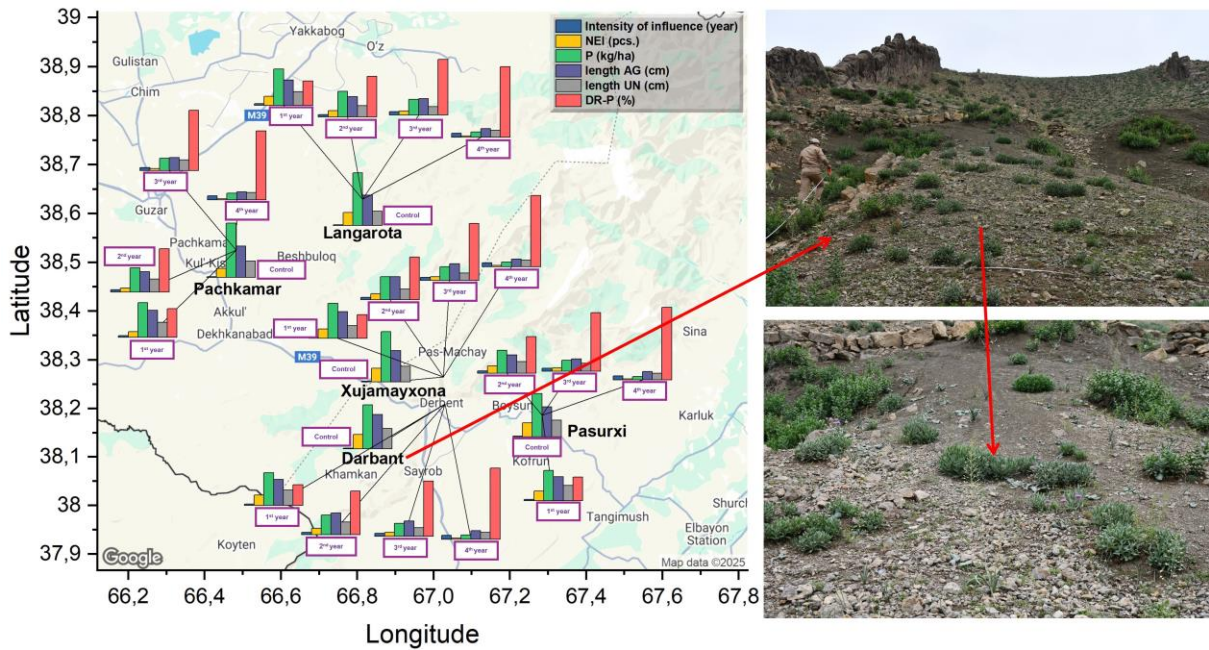
specimens 37.16 ± 0.71 cm and root diameter 24.69 ± 0.89 cm. After the first year of exploitation, a significant decrease in productivity was revealed. The following indicators were recorded: the number of exploitable individuals was 36.1 ± 1.25 pcs., raw material yield 199.8 ± 10.06 kg/ha, leaf length of model specimens 30.37 ± 0.59 cm, and root diameter 19.42 ± 0.42 cm. The decrease in yield was 15.56%. After the second year of operation, a decrease in yield to 27.31% was recorded. This decrease significantly correlates with a decrease in the number of exploitation individuals (30.9 ± 1.26 pcs.), raw material yield of 172 ± 11.2 kg/ha, leaf length of model specimens of 24.1 ± 0.41 cm and root diameter of 15.09 ± 0.59 cm. After the third and fourth years of operation, a sharp decrease in raw material yield by 51–69.5% is observed.

In the monitoring areas of Karadaxana, Akbash, Chagam, and Duxona, a significant reduction in the number and yield of raw materials was also revealed with regular exploitation. According to the indicators, the number of exploitation specimens decreases from 19.29% in the first year to 83.4% by the fourth year. These data significantly correlate with the reduction in the length of the leaves of model specimens and the diameter of the plant roots.

These data indicate that regular harvesting of raw materials for three or more years significantly reduces the plant's ability to restore its resource potential (Figure 6).

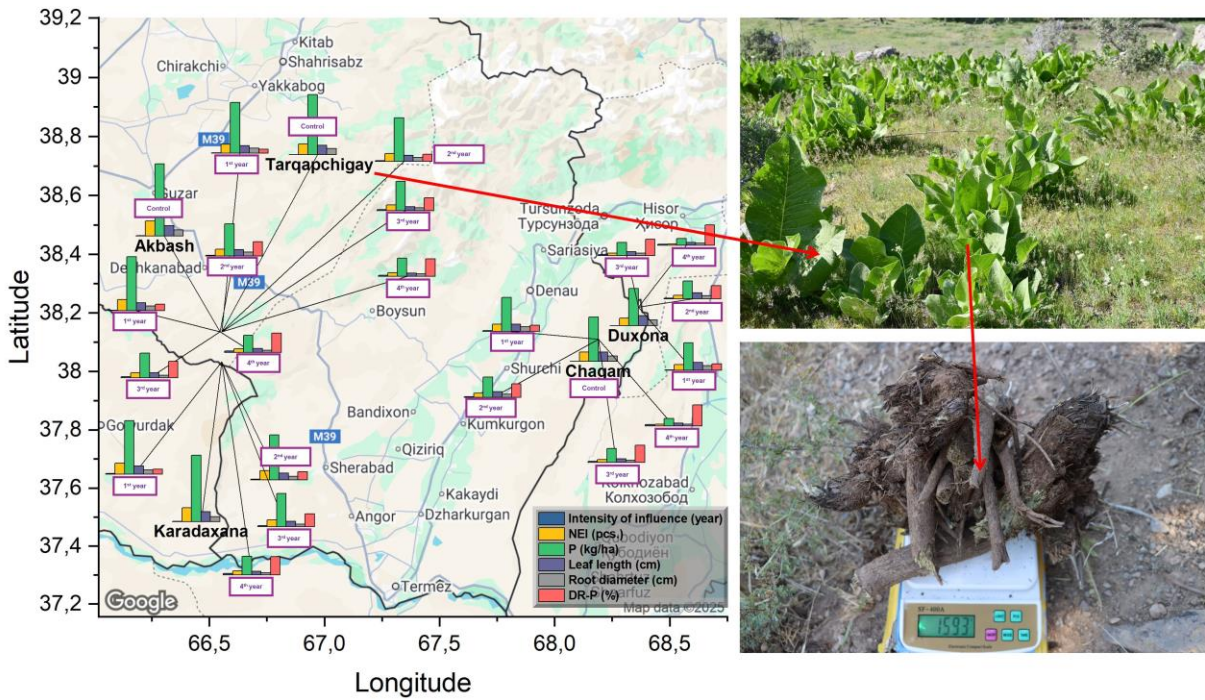
The study revealed significant quantitative changes in the structural and productive parameters of four studied medicinal plant species under different intensities of exploitation. One-way ANOVA confirmed that the intensity of influence (year of harvesting) had a statistically significant effect on all analyzed variables ($p < 0.001$). Below are the detailed results for each species.

For *Ungernia victoris*, at the control stage (without exploitation), the number of exploitable individuals averaged 8.5 ± 0.58 pcs., raw material yield was 51.77 ± 3.69 kg·ha⁻¹, the length of the aboveground part was 36.9 ± 0.78 cm, and the underground part 16.4 ± 0.21 cm. After one year of exploitation, these values decreased to 6.9 ± 0.52 pcs., 42.0 ± 3.32 kg·ha⁻¹, 31.9 ± 0.47 cm, and 12.2 ± 0.29 cm, respectively, corresponding to an 18.7% productivity loss. By the fourth year, yield reduction exceeded 80%, accompanied by a pronounced depletion of natural populations (Figure 7).



Note: NEI (pcs.) – number of exploitable individuals; P (kg/ha) – raw material yield; length AG (cm) – length of aboveground part of model specimens; length UN (cm) – length of underground part of model specimens; DR-P (%) – dynamics of yield reduction.

Figure 5. Dynamics of the reduction of resource potential of *Ajuga turkestanica* over four years



Note: NEI (pcs.) – number of exploitable individuals; P (kg/ha) – raw material yield; Leaf length (cm) – length of leaves of model specimens; Root diameter (cm) – diameter of roots of model specimens; DR-P (%) – dynamics of yield reduction.

Figure 6. Dynamics of the reduction of resource potential of *Inula grandis* over four years

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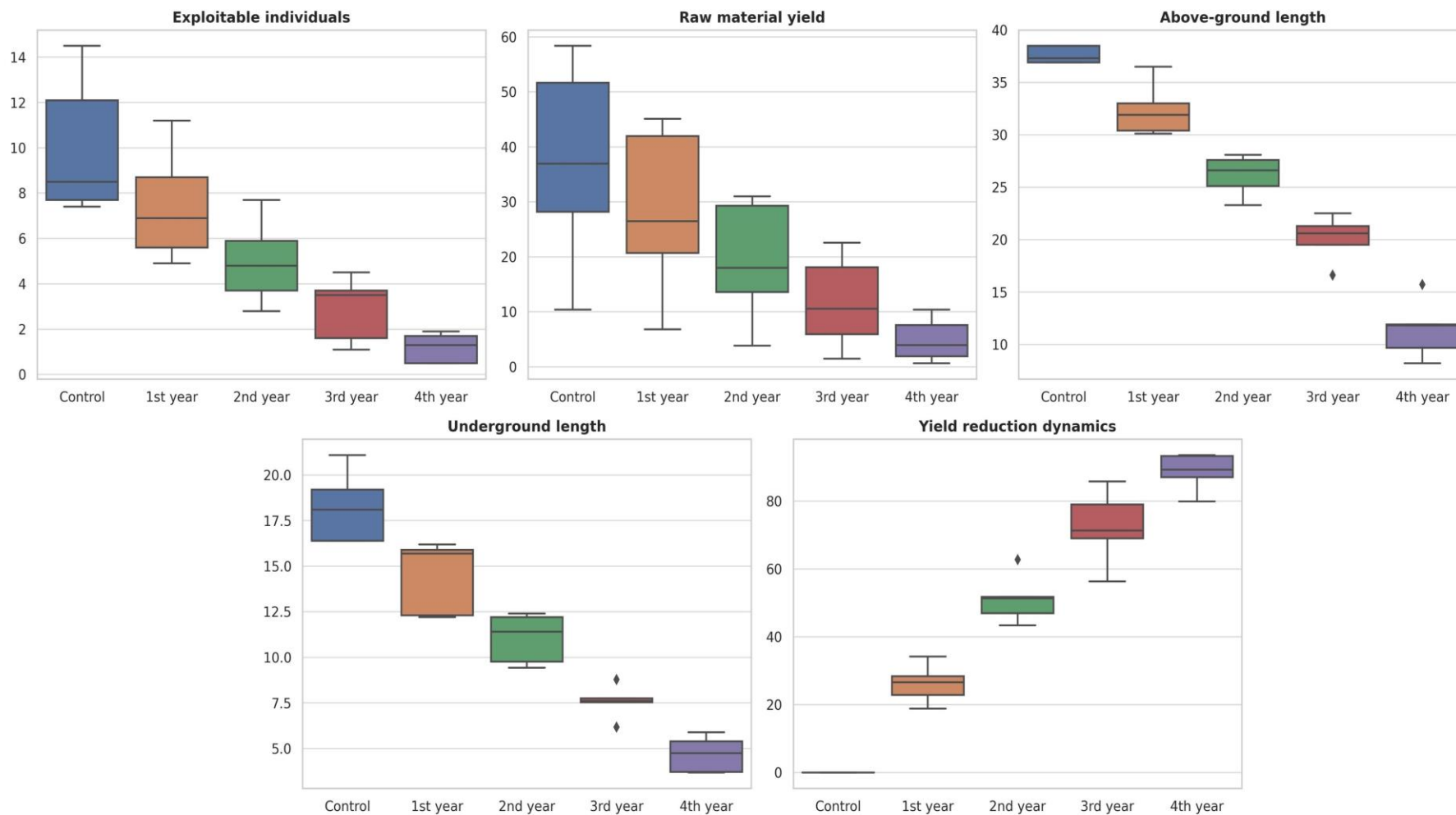


Figure 7. Results of one-way analysis of variance of *Ungermia victoris* under different exploitation intensities

For *Ferula tadshikorum*, control plots recorded 14.6 ± 1.21 individuals and $4.38 \pm 0.36 \text{ kg} \cdot \text{ha}^{-1}$ of root resin yield. After the first year, yield declined by 43.8% to $2.46 \pm 0.19 \text{ kg} \cdot \text{ha}^{-1}$, with a further reduction to 82% after four years. Morphometric indicators (leaf length and root diameter) followed similar declining trends. ANOVA results ($F_{3,16} = 45.16\text{--}88.41$, $p < 0.001$) confirmed significant dependence on the duration of harvesting, particularly for raw material yield and root diameter (Figure 8). *Ajuga turkestanica* exhibited pronounced sensitivity to harvesting pressure. Under control conditions, the number of exploitable individuals was 11.4 ± 0.47 pcs. and yield $69.3 \pm 2.64 \text{ kg} \cdot \text{ha}^{-1}$. After one year of exploitation, yield declined by 36.4%; after four years, the reduction exceeded 87%. One-way ANOVA indicated significant effects of exploitation intensity on all variables ($F_{3,16} = 34.91\text{--}91.12$, $p < 0.001$), confirming the cumulative negative impact of continuous harvesting on both aboveground and underground (Figure 9).

Inula grandis also showed strong dependence of productivity on harvesting duration. The initial yield was $236.6 \pm 15.2 \text{ kg} \cdot \text{ha}^{-1}$, decreasing by 15.6% after one year and by 69.5% after four years. Both morphometric traits (leaf length and root diameter) decreased significantly with exploitation time. ANOVA revealed significant differences among all treatments ($F_{3,16} = 39.92\text{--}86.05$, $p < 0.001$), indicating strong depletion effects after prolonged use (Figure 10).

3.2. Occupational Stress Impact Rating Scale

Based on the obtained results, it was established that with annual and systematic collection of raw materials from the aboveground part of perennial herbaceous plants for three or more years in one area, the resource potential of plants is not restored. This fact is confirmed by the example of *Ungernia victoris*: with systematic collection of raw materials for four years, the number of exploitable individuals decreased by almost 80%. After the first year of raw material procurement, a reduction in exploitable individuals by more than 18% was observed; in the second year - by more than 43%, and in the third - over 56%.

The study showed that with a single use of the aboveground part of perennial herbaceous plants, the restoration of the raw material resource requires on average 3-4 years, which according to the accepted scale is estimated at 1 point (γ). With two-year use, restoration requires 6-7 years and is estimated at 2 points (β). Collecting raw materials for three or more years in the same area leads to an irreversible decrease in the resource potential of plants and is estimated at 3 points (α). In this regard, it is recommended to harvest the aboveground part of perennial grasses in one area no more than once every 4

years (Table 2).

With a one-time procurement of raw materials from the underground part of perennial herbaceous plants, the number of exploitable individuals decreases by approximately 44%. This is confirmed by the dynamics of the reduction in the resource potential of southern Uzbekistan when collecting the root resin of *Ferula tadshikorum* and the roots of *Inula grandis*. In this regard, after a one-time procurement of raw materials of such species, it is necessary to withstand a three-year period without exploitation. According to the scale, this load is estimated at 2 points (β), and repeated two-year exploitation at 3 points (α) (Table 2).

With systematic collection of raw materials from the aboveground part of semi-shrubs for three or more years in one area, an irreversible reduction in the resource potential of plants also occurs. This is confirmed by a 55% reduction in the number of exploitable individuals of *Ajuga turkestanica* after two years of harvesting. Two-year exploitation requires 6-7 years for restoration and is estimated at 2 points (β), and three years or more at 3 points (α). Thus, collection of the aboveground part of subshrubs in natural conditions is also recommended to be carried out once every 4 years in one area (Table 2).

Based on the obtained results, regular collection of aboveground plant parts for three or more consecutive years led to irreversible decreases in resource potential. For instance, *U. victoris* exhibited an 80% reduction in exploitable individuals after four years of systematic harvesting. One-year exploitation required 3-4 years for natural restoration (1 point, γ), two-year exploitation required 6-7 years (2 points, β), while three or more years resulted in irreversible loss (3 points, α). For species with underground storage (e.g. *Ferula tadshikorum*), the recovery process was even slower.

This scale allows evaluating the state of the resource potential of plants growing in a specific territory, i.e. the state of exploitable individuals. According to the scale, irreversible restoration of the resource is estimated at 3 points (α) and is defined as the ratio of the number of remaining exploitable individuals to their number in the initial (non-exploited) state.

3.3. Statistical Analysis of the Obtained Results

All analyzed traits showed highly significant dependence on harvesting intensity. ANOVA tests confirmed the presence of statistically significant differences ($p < 0.001$) in the number of exploitable individuals, raw material yield, morphological parameters, and yield reduction dynamics. The F-values for the studied species ranged between 34.91 and 91.12, emphasizing the robustness of the effect (Table 3).

Scale for Assessing the Impact of Operational Stress on the Resource Potential of Medicinal Plants:
A Case Study of Southern Uzbekistan

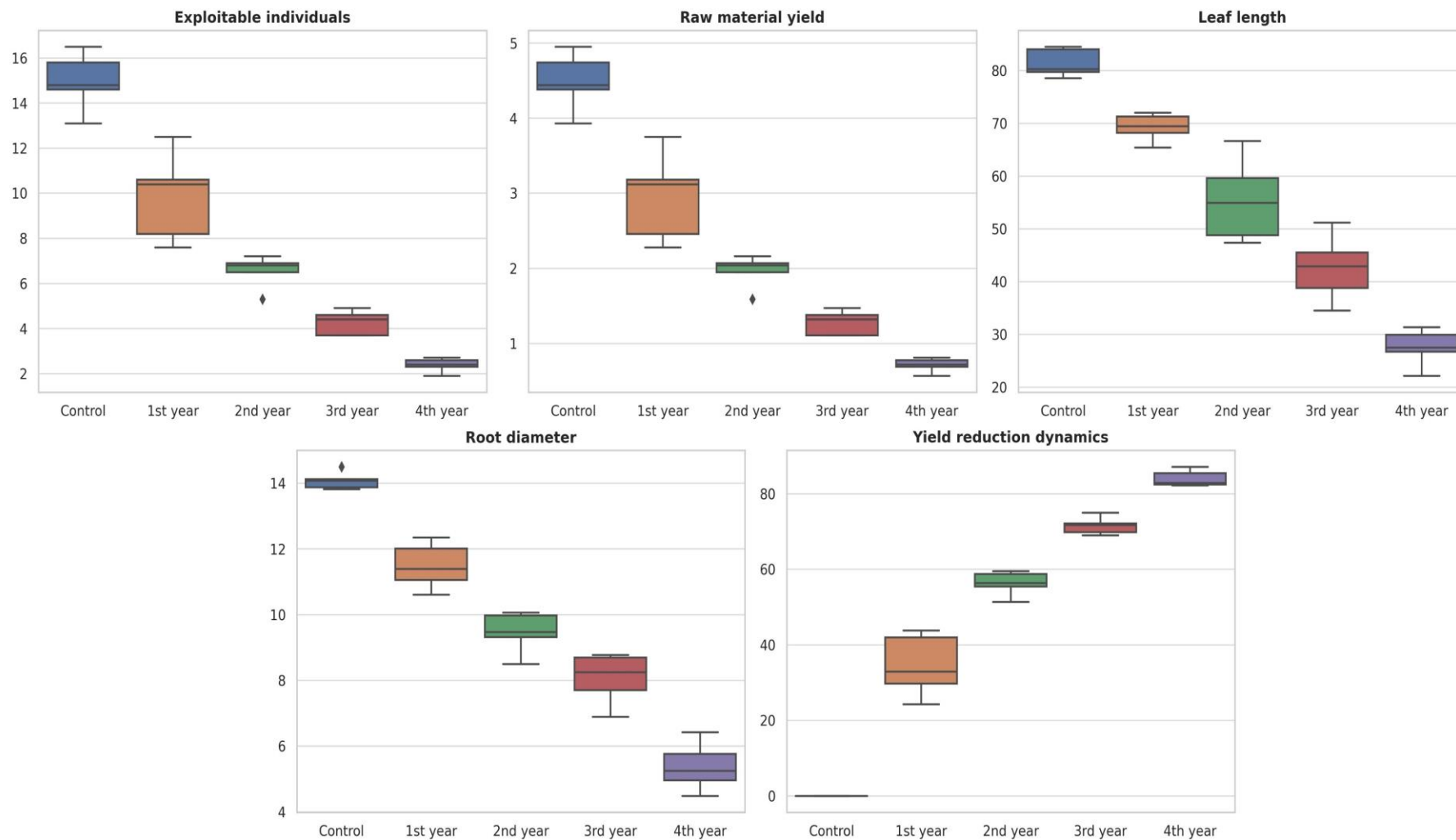


Figure 8. Results of one-way analysis of variance of *Ferula tadshikorum* under different exploitation intensities

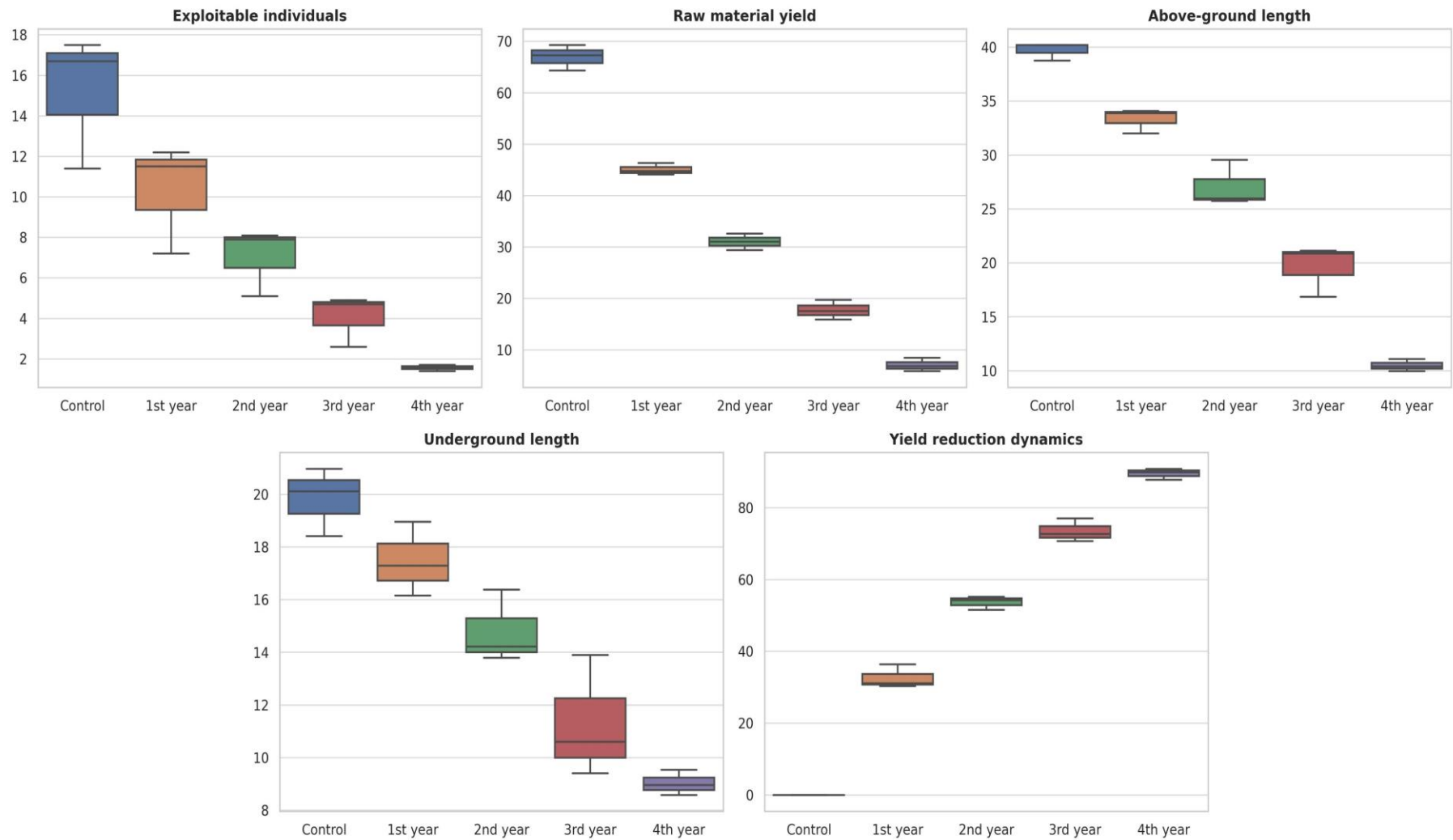


Figure 9. Results of one-way analysis of variance of *Ajuga turkestanica* under different exploitation intensities

Scale for Assessing the Impact of Operational Stress on the Resource Potential of Medicinal Plants:
A Case Study of Southern Uzbekistan

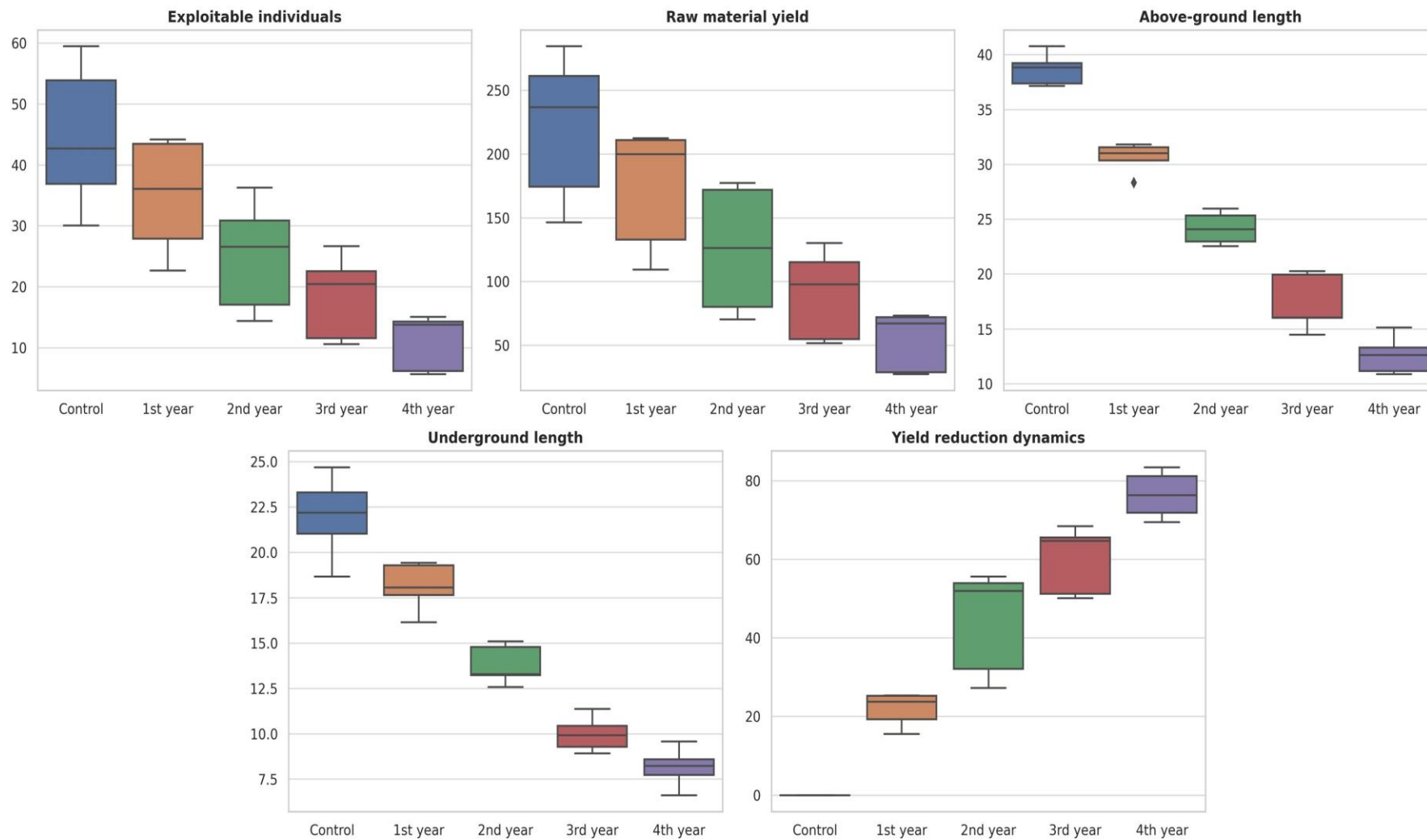


Figure 10. Results of one-way analysis of variance of *Inula grandis* under different exploitation intensities

Table 2. Scale for assessing the impact of operational stress on the state of the resource potential of medicinal plants

Life form of plants	Type of raw material	Intensity of influence (year)	Number of operating individuals 10x10 m (pcs.)	Yield (kg/ha)	Recovery time (year)	Ball
Perennial	Underground part	Without exploitation	14.6±1.21	4.38±0.36	-	-
		1	8.2±0.65	2.46±0.19	3-4	β / 2
		2	6.5±0.17	1.95±0.05	Not recoverable	α / 3
Perennial	Aboveground part	Without exploitation	8.5±0.58	51.77±3.69	-	-
		1	6.9±0.52	42.0±3.32	3-4	γ / 1
		2	4.8±0.24	29.3±1.84	6-7	β / 2
		more than 3	1.7±0.26	10.4±1.72	Not recoverable	α / 3
Semi-shrub	Aboveground part	Without exploitation	11.4±0.47	69.3±2.64	-	-
		1	7.2±0.38	44.1±2.86	3-4	γ / 1
		2	5.1±0.45	31.02±2.74	6-7	β / 2
		more than 3	1.4±0.16	8.46±0.93	Not recoverable	α / 3

Table 3. Results of one-way ANOVA for the studied medicinal plant species under different intensities of exploitation

Indicator	Source of variation	df	F-value	p-value	Significance
<i>Ungernia victoris</i>					
Number of exploitable individuals (pcs.)	Intensity of influence (year)	3	58.42	<0.001	***
Raw material yield (kg/ha)	Intensity of influence (year)	3	76.15	<0.001	***
Length of aboveground part (cm)	Intensity of influence (year)	3	41.27	<0.001	***
Length of underground part (cm)	Intensity of influence (year)	3	36.88	<0.001	***
Dynamics of yield reduction (%)	Intensity of influence (year)	3	84.63	<0.001	***
<i>Ferula tadshikorum</i>					
Number of exploitable individuals (pcs.)	Intensity of influence (year)	3	64.91	<0.001	***
Raw material yield (kg/ha)	Intensity of influence (year)	3	82.77	<0.001	***
Length of leaves (cm)	Intensity of influence (year)	3	49.38	<0.001	***
Diameter of roots (cm)	Intensity of influence (year)	3	45.16	<0.001	***
Dynamics of yield reduction (%)	Intensity of influence (year)	3	88.41	<0.001	***
<i>Ajuga turkestanica</i>					
Number of exploitable individuals (pcs.)	Intensity of influence (year)	3	52.76	<0.001	***
Raw material yield (kg/ha)	Intensity of influence (year)	3	79.53	<0.001	***
Length of aboveground part (cm)	Intensity of influence (year)	3	38.64	<0.001	***
Length of underground part (cm)	Intensity of influence (year)	3	34.91	<0.001	***
Dynamics of yield reduction (%)	Intensity of influence (year)	3	91.12	<0.001	***
<i>Inula grandis</i>					
Number of exploitable individuals (pcs.)	Intensity of influence (year)	3	56.04	<0.001	***
Raw material yield (kg/ha)	Intensity of influence (year)	3	74.82	<0.001	***
Length of leaves (cm)	Intensity of influence (year)	3	44.17	<0.001	***
Diameter of roots (cm)	Intensity of influence (year)	3	39.92	<0.001	***
Dynamics of yield reduction (%)	Intensity of influence (year)	3	86.05	<0.001	***

Note: df – degrees of freedom; F-value – Fisher’s test statistic (ratio of variance between groups to variance within groups); p-value – probability level indicating statistical significance of the observed differences; Significance – level of statistical significance, where p < 0.05 (), p < 0.01 (), and p < 0.001. Highly significant differences (*** p < 0.001) were observed for all studied parameters, indicating a strong dependence of population characteristics on the duration of harvesting pressure.

Overall, repeated harvesting caused a substantial and statistically significant reduction in the resource potential of all studied medicinal plant species. The strongest declines were observed in perennial species with underground raw materials (e.g., *Ferula tadshikorum* and *Inula grandis*), which showed over 70% yield loss after three to four years of continuous exploitation. In contrast, species with aboveground harvested organs (e.g., *Ungernia victoris* and *Ajuga turkestanica*) demonstrated relatively faster but still incomplete recovery. These results confirm that exploitation intensity is the key factor driving the depletion of natural populations and validate the proposed stress rating scale as a reliable tool for assessing long-term sustainability of resource use.

4. Discussions

The recovery dynamics and shrinkage coefficients obtained in this study provide new insights into the post-exploitation regeneration capacity of key medicinal plant species in arid and semi-arid regions of Central Asia. While previous studies offered only fragmentary or incomplete data on resource recovery (e.g., limited information for *Ungernia victoris* and *Inula grandis*, and no data for *Ferula tadshikorum* and *Ajuga turkestanica*), our results present a comprehensive assessment that integrates both quantitative and ecological perspectives.

The observed differences in recovery periods among the studied species can be primarily attributed to their biological and ecological characteristics. Species with underground storage organs such as *Ferula tadshikorum* and *Inula grandis*, require longer recovery periods due to the slow regeneration of root biomass and the depletion of stored reserves following harvesting. In contrast, species with aboveground harvested parts (*Ungernia victoris* and *Ajuga turkestanica*) showed faster, though still incomplete, regeneration, which may be linked to their higher vegetative plasticity and capacity for clonal renewal. Similar regeneration delays under intensive harvesting pressure have been documented for root-bearing medicinal plants in Iran [10] and Nepal [11, 12], supporting the global relevance of our findings. In recent years, extensive botanical research has been conducted in the Central Asian region, focusing on the effects of various external environmental factors on plant species, their ecological stability, and vitality status [13-16]. Changes in environmental conditions—such as climate variability, soil moisture, temperature fluctuations, and biotic interactions—play a significant role in shaping the physiological and morphological responses of plants, ultimately influencing their adaptive potential [17-20]. Under such conditions, the regenerative capacity of plant species emerges as one of the key determinants of population resilience and long-term survival, underscoring its critical importance in plant conservation and ecosystem sustainability [21-23].

Shrinkage coefficients also varied substantially among species, reflecting differences in tissue composition and moisture content. For instance, *Inula grandis* demonstrated a shrinkage coefficient of 60%, which is typical for species rich in secondary metabolites and root polysaccharides, whereas *Ungernia victoris* and *Ajuga turkestanica* showed moderate coefficients of about 50%. These differences emphasize the importance of correcting raw material calculations for moisture loss, as neglecting this factor—as seen in previous assessments of *A. turkestanica* resources in southern Uzbekistan — can lead to significant overestimations of available reserves.

From a resource management perspective, the developed Occupational Stress Impact Rating Scale represents an important methodological advancement. Unlike conventional resource inventories that rely solely on biomass or yield data, this scale incorporates temporal recovery dynamics and ecological resilience, allowing for more accurate classification of resource areas according to their sustainability potential. Its application could extend beyond Uzbekistan to similar ecosystems in Central Asia, where medicinal plant resources face increasing anthropogenic pressure.

Overall, these findings highlight the need for adaptive management strategies based on scientifically validated recovery thresholds and shrinkage coefficients. Integrating such parameters into regional conservation programs and resource certification systems would help ensure the long-term sustainability of medicinal plant exploitation, under the growing demand from both local and international markets.

5. Conclusions

This study quantitatively evaluated the long-term effects of varying harvesting intensities on the resource potential of key medicinal plant species in southern Uzbekistan. The results clearly indicate that repeated harvesting over three or more consecutive years leads to irreversible depletions of exploitable populations and marked reductions in biomass productivity—effects that are particularly pronounced in species possessing underground storage organs (e.g., rhizomes, tubers, or bulbs).

To address this issue, a novel operational stress assessment scale was developed, offering a scientifically robust tool for assessing the sustainability of medicinal plant resource use. This scale facilitates the incorporation of ecological recovery periods into practical resource management and provides a valuable framework for conservation planning, ecological monitoring, and policy development at both national and regional levels.

However, the scope of this study was limited to four target species within specific ecological zones. Broader validation across a wider range of taxa and environmental conditions is necessary to confirm the general applicability of the proposed scale. Additionally, future research should

incorporate socio-economic drivers and climatic variability that may exacerbate resource depletion, and should investigate context-specific, adaptive restoration strategies.

Overall, this research makes a meaningful contribution to the development of sustainable management practices for medicinal plant populations in arid and semi-arid ecosystems. It underpins evidence-based approaches aimed at balancing the sustainable utilization of plant resources with long-term biodiversity conservation objectives.

Supplementary Materials

Ungernia victoris Vved. Ex Artjush (Amaryllidaceae) is an endemic species, distributed only in the Gissar Range and its southern spurs (Tajikistan, Uzbekistan). Today, the problem is not only the insufficiency of the natural raw material base of the plant for obtaining biologically active substances, but also the preservation of the gene pool of this endangered species [24]. It is a rare endemic of the Southwestern Pamir-Alay with a greatly diminishing range. As a result of intensive harvesting of leaves as medicinal raw materials in Uzbekistan over the past 5-10 years, the bulbs of the plant are depleted, and thickets are being restored slowly. The species is listed in the Red Book of Uzbekistan with status 2 [25]. According to modern data on the state of natural resources of medicinal plants in Uzbekistan, the volume of permissible annual procurement of raw materials is 1.72 tons [26].

Ferula tadshikorum Pimenov (Apiaceae) is endemic to Central Asia, and its habitat covers southern Uzbekistan and southern Tajikistan (southwestern Pamir-Alai) [27, 28]. The plant is an endangered herbaceous medicinal plant, the population of which is disappearing in southern Tajikistan. The plant is endemic to southern Uzbekistan (southwestern Pamir-Alai, western spurs of the Gissar Range, Kugitang, Babatag), outside Uzbekistan: southern Tajikistan [29, 30]. According to modern indicators of the resource potential of the plant in Uzbekistan, its reserves are biological and are currently not subject to exploitation. Populations of the species have mainly survived in the border zone - the neutral strip of the state border of the republic, as well as in some forestries [4].

Ajuga turkestanica (Regel) Briq. (Lamiaceae) is a perennial semi-shrub, grayish, slightly blackening when dried. It grows on clayey and rocky slopes in areas of variegated rock outcrops in the foothill and middle mountain belts of Southern Uzbekistan (Kashkadarya and Surkhandarya regions). Due to the intensive exploitation of natural thickets of the plant in recent years, natural populations have suffered significant damage of a critical nature. In view of this, it is recommended to prohibit the collection of raw materials of this valuable, endemic species for some time and to carry out work on its cultivation. According to modern (2025) indicators of resource potential in Uzbekistan, the permissible annual procurement of raw materials is 5.20 tons.

Inula grandis Schrenk (Asteraceae) is a large perennial herbaceous plant. It grows on fine-grained soft slopes in the lower and middle mountain belts. The optimum resource potential is located at altitudes of 1300-1500 meters above sea level. The phytocenotic optimum is distributed in the forb-shrub-juniper community. According to modern indicators of resource potential in southern Uzbekistan, the volume of permissible annual procurement of raw materials is 5.16 tons [31].

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