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ORIGINAL ARTICLE

The human impact on the transformation of juniper forest landscape in the western part of the Pamir-Alay range (Tajikistan)

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Abstract Detailed analyses were conducted of human impact on juniper forest landscapes occurring within the Zarafshan Range (Pamir-Alay). *Juniperus seravschanica* and *J. semiglobosa* belong to forest-forming species in Central Asia. At present, juniper forests all over Tajikistan are seriously threatened as a result of excessive logging and cattle grazing. The aim of this paper is to present juniper forest transformation as a result of human activities as well as the diversity of soil properties in the organic and humus horizons in the altitudinal system of soil zonation. Three groups of phytocoenoses were distinguished: those with a dominant share of *Juniperus seravschanica*; those with a dominant share of *J. semiglobosa*; and mixed. Associations with *Juniperus seravschanica* and *J. semiglobosa* feature several variants of phytocoenoses with dominant species: *Artemisia lehmanniana*, *A. dracunculus*, *Eremurus olgae*, *Festuca sulcata*, *Ligularia thomsonii*, *Stipa turkestanica*, *Thymus seravschanicus*, and *Ziziphora pamiroalaica*. The collected soil samples differ in their granulometric composition. Gravelly cobble fractions >2 mm are dominant; the share of sandy particles <2 mm is much lower (about 10–20%). Fraction 0.5–0.05 attains 35% on average. The Corg content of the soil varied from 0.26 to 11.40% in the humus horizon (A) and from 4.3 to 25% in the organic (O). Similar relationships were reported in the case of Ntot concentration. A clear relationship can be observed between concentrations of Corg and Ntot. Soil pH varied, ranging from very low acidic (pH 5.5) to neutral (pH 8.5). The content of available P varied; high concentrations were noted in organic (O) (40.46–211 mg kg^{-1}) and mixed horizons (OA) (2.61–119 mg kg^{-1}). Maximum accumulations of Pavail (1739.6 mg kg^{-1}) and Ptot (9696 mg kg^{-1}) were observed at a site heavily affected by intense grazing. Concentrations of Mgavail varied from 116 to 964 mg kg^{-1}. Most of the analysed soil profiles lacked an organic horizon; only thin humus occurred.

Keywords Landscape changes · Human impact · Juniper landscapes · *Juniperus semiglobosa* · *Juniper seravschanica* · Soil-vegetation link

Introduction

Junipers are an important component of forests in the mountains of Central Asia and constitute the only forest-forming species on the ridges of the Pamir-Alay and western Tian Shan mountain ranges. Representatives of *Juniperus* species can be found, as saplings or accompanying species, in various landscape zones. As a result of diversification of ecological requirements, species of this

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kind can grow in various biotopes, from seashores to dry regions. Some species occur only in alpine conditions in some regions of North America and Central Asia, at altitudes up to 4000 m a.s.l. In the Pamir-Alay (Ismailov 1974; Xu et al. 2011), these species include *Juniperus seravschanica* Kom., *J. semiglobosa* Regel, and *J. turkestanica* Kom. These species grow mainly on steep slopes in places where soil water and debris-mud creeks (*seli in russian*) occur. Juniper forests serve an important habitat-forming function, as they control hydrographic conditions, protect soils from erosion, and slow the formation of debris-mud creeks. Warming of the climate over the past 80 years has caused major disturbances in alpine ecosystems in the Pamir-Alay. In conditions of global climate change, understanding and exploration of the impact of such change on the productivity and diversity of ecosystems, especially the mountain environments of Pamir-Alay, are of great significance and topicality. Among the relevant environmental consequences of climate change in this region are: degradation of the forest ecosystem due to decreased river flows; increases in temperature; increased risk of fire; changes in flora composition due to climate warming; degradation of biotopes; reduction of forage resources for cattle; and shifting of juniper forest vegetation to higher elevations (Makhmadaliev et al. 2008). Moreover, increasing intensive and uncontrolled land use has initiated the process of destruction of juniper forest landscapes (Kayumov 2006; Ismailov et al. 2010).

Juniper species in Central Asia make up a specific formation of vegetation, referred to as Central Asian archa forests (the name *archa* means juniper in Tajiki). Studies of their typology and distribution date back to the early twentieth century (Goncharov 1937; Ovchinnikov 1940; Zakirov 1955; Konnov 1973) and are still being carried out (Safarov 2013a, b). Many articles regarding Central Asian juniper formations were elaborated as parts of various phytogeographic papers published in the former USSR (Mukhamedshin and Talancev 1982 and references cited therein). Thorough phylogenetic, palaeobotanical, geobotanical, and ecological research on *Juniperus* species was carried out by Ismailov (1974). It is worth pointing out that all of these publications, regardless of their character, addressed the issue of degradation of vegetation in reference not only to junipers, but to entire geosystems of Central Asia (Kharin 2002; Niu et al. 2014).

Following the thinning of archa forests in the discussed regions, research was carried out in order to monitor the natural processes of juniper restoration in various conditions in terms of surface features in the Turkestan (Murzakulov 2015) and Zerafshan (Ismailov 1974) ranges. Central Asian junipers are sensitive to climatic conditions, particularly to temperatures, and are among species which take a long time to grow. Their growth rate corresponds to their long maturation period: trees can live 400–600 years, and sometimes up to 1,000 or more (Nikitinskiy 1960; Opala et al. 2017).

Anthropopressure was pointed out at the end of the early part of the twentieth century as another factor causing the shrinkage of juniper forest landscapes and making their restoration almost impossible. Since then, junipers have been grown and propagated in nurseries so as to rebuild the archa forest landscapes, but these actions have met with little success (Ismailov 1974; Shamshiev et al. 2013).

Significant destruction of archa forests in Central Asia was reported as early as the end of the nineteenth century and has continued until the present. Intensified destruction, especially in Tajikistan, took place at the end of the early part of the twentieth century (Ismailov et al. 2010). In spite of widespread degradation, to date there has been no assessment and analysis of human impact on juniper forest transformation. The environmental consequences of human impact on the degradation of plant cover including rare and endemic species, as well as issues regarding nature protection, geobotanics, and soil science in the Fann Mountains, which are part of the Pamir-Alay system, have been presented in several papers: Rahmonov et al. (2011a, b, 2013, 2014), Sadikov (2012), and Rahmonov et al. (2016). So far, these papers are the only available botanic references regarding the region under discussion. The most significant work on the botany, ecosystem, and landscape of the discussed region and of Tajikistan in general is the multi-author monograph *Flora of Tajikistan* (see Rahmonov et al. 2013 and references therein). Soil research carried out along with phytocoenosis analyses does not indicate changeability of the soil cover in particular regions or throughout the country (Kuteminskiy and Leontyeva 1966).

Among the negative effects of juniper landscape transformation are changes in soil cover and in vegetation generally. The aim of this paper is to present juniper forest landscape transformation resulting from human activities as well as the diversity of soil features in the organic layer and topsoil according to the altitudinal soil zonation system in areas subject to intense anthropopressure.

Materials and methods

Study area

The research was carried out in a region situated within the Zarafshan Range, which is part of the extensive Pamir-Alay system, the link connecting the major mountain ranges of Central Asia. The Zarafshan Mountains extend in an east–west direction for about 300 km in the north-western part of Tajikistan; the average width of the range is 50 km.

The range is separated from the Turkestan Mountains by the Zarafshan River Valley in the north, and from the Gissar Range by the Yagnob River Valley in the south (Fig. 1a).

The Zarafshan Mountains achieved their present form during the Alpine Orogeny. The geological structures include Upper Palaeozoic and, to a lesser extent, Carboniferous, Cretaceous, and Neogene rocks. Deposits from the Middle Devonian and Carboniferous predominate. The northern foothills are partially built of Lower Silurian rocks, whereas in the western part of the mountains Neogene deposits predominate, among which the Lower Silurian is also represented (Vinnichenko and Tadzhibekov, 2010). These rocks are represented by thick terrigenous sandstone, quartzites, schists, limestone, marls, dolomite, clay, gneiss, loess cover (often on steep slopes), salt-bearing deposits (often in the area of outflows and river valleys), and conglomerates. There are also

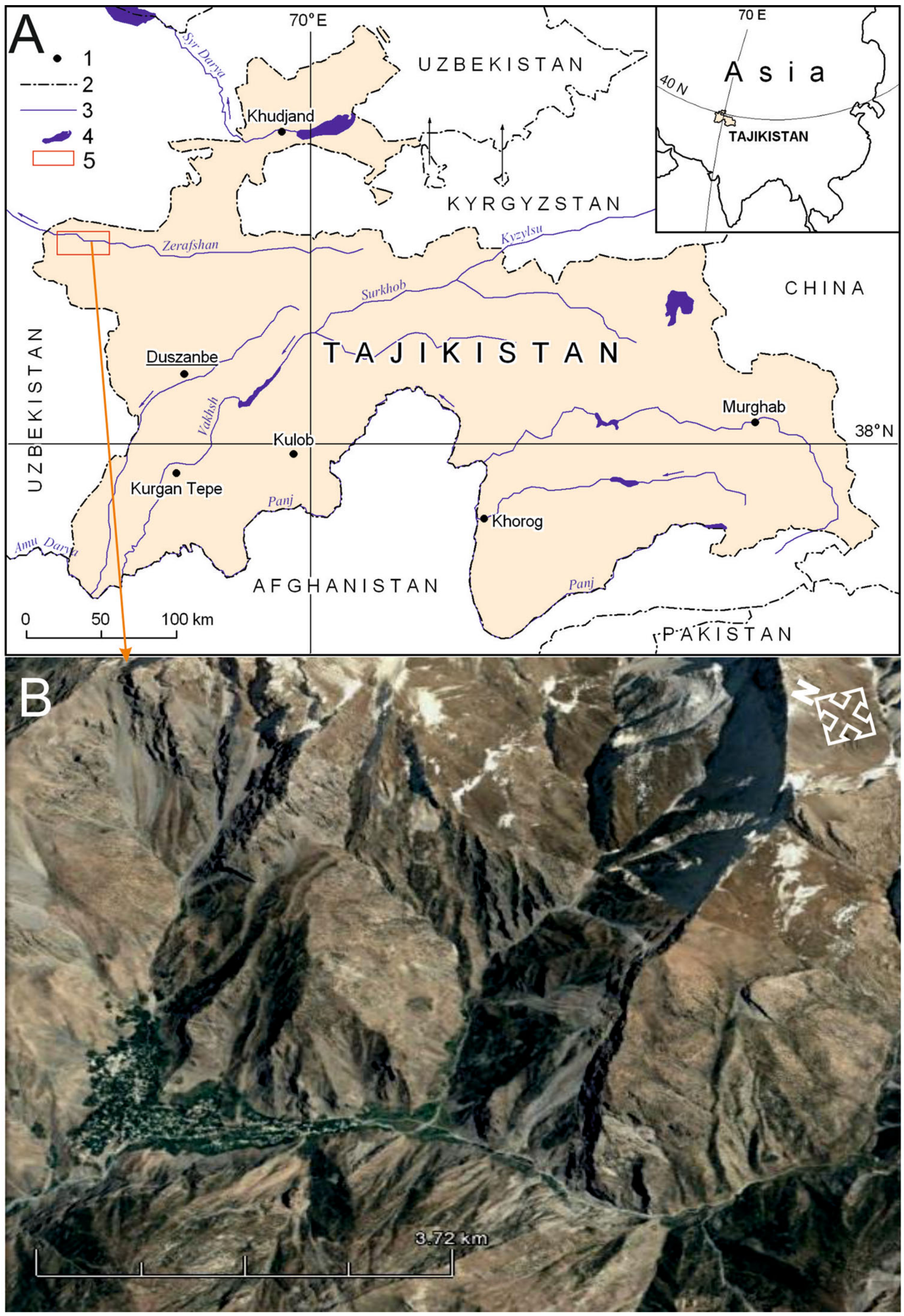

Fig. 1 Location of the research area within the borders of Tajikistan: **a** 1—major cities, 2—state borders, 3 and 4—hydrographic network, 5—research areas, **b** fragment of the investigated area (*source*: Google Earth Image ©2016 CNES/Astrium, 39°20′09.41″N, 68°06′41.97″E)

widespread covers of Quaternary (Pleistocene and Holocene) deposits.

The Zarafshan Mountains are characterised by sharp hypsometric contrasts resulting from large height amplitudes over relatively short distances. Both high steep ridges and deep narrow valleys occur in the region (Fig. 1b). This kind of relief is favourable for the development of slopewash processes (Rahmonov et al. 2016). Small valley and cirque glaciers occur in the mountains. The length of these glaciers was greater in the Pleistocene, as can be seen in numerous frontal moraine ramparts (Kotlyakov et al. 1993). Characteristic features of the relief include deep U- and V-shaped valleys with numerous gaps and vast debris-block layers of gravity cones. These formations and processes have a direct impact on the diversity and mosaic nature of the landscape. Archa forests are the main element of the entire landscape of the Turkestan, Hissar, and Zarafshan ranges. In the Fann Mountains, only small areas have remained unaffected by human economic activities (Sadikov 2012).

The climate conditions of the Zarafshan Range are diverse, depending on altitude, which reaches up to 5489 m a.s.l at Chimtarga Peak in the Fann Mountains. The authors used available mean temperature and precipitation data (Trohimov 1968; Williams and Konovalov 2008; Opala et al. 2017), based on a long period (40–60 years), from three meteorological stations nearest the Urej River Valley (Fig. 2).

Mean yearly precipitation for the discussed area is 400–500 mm on peaks and slopes at altitudes of about 3000–3400 m a.s.l. (418 mm at Anzob Pass, 3373 m a.s.l). In basins and deep valleys (altitudes in the range of 2200–2500 m a.s.l.), precipitation drops to 250–300 mm (271 mm in Iskanderkul, 2204 m a.s.l). Most precipitation occurs in the spring season (60–70 mm in April or May), while winter is characterised by low rates of snowfall.

Mean temperatures reach about 15–16 °C (maximum: 25–26 °C) in summer and −5 to −8 °C (minimum: −25 to −26 °C) in winter. The period without ground or air frost lasts for 90–100 days a year (Sadikov 2012). Air temperatures tend to depend strongly on altitude. The temperature drops from about 10.5 °C at 1680–1700 m a.s.l. at the mouth of the Urej River at the Kshtut River to 0 °C at 3200 m a.s.l. near the Kulikalon Lakes and about −5 °C at about 4000 m a.s.l. at the lower glacier and snow line (Fig. 3). At the highest peak, Chimtarga (5489 m a.s.l), it is estimated at about −15 °C.

The warmest month of the year is July (or, less frequently, August). July temperatures range from about 21 °C at 1700 m a.s.l. to 10 °C at 3300 m a.s.l. near the upper line of juniper forests. July temperatures drop under 0 °C at altitudes over 4750 m a.s.l and reach a low of about −4 °C on Chimtarga Peak. The coldest month is January. The mean temperature in January is 2.1 °C in Dushanbe (about 800 m a.s.l.) and drops below 0 °C in the mountains at 1200 m a.s.l. It falls under −10 °C at the altitude of 3000 m a.s.l., drops as low as −15.5 °C at 4000 m, falls to −21 °C at 5000 m, and reaches a low of −23.5 °C on Chimtarga Peak.

Vegetation analysis

Research and field observations were carried out in areas subject to intensive human activity. The analysed region is mainly used for grazing, logging for firewood, and, to a lesser extent, agriculture. The catchment of the Urej River was selected as the key area for the research. This region features one of the largest groups of juniper forests in the western Pamir-Alay. Juniper forest communities characterised by a natural tree stand structure have remained at relatively low elevations (1900–2600 m a.s.l.). As the absolute altitude rises towards the upper section of the Urej River, the effects of present-day human activity can increasingly be observed in the form of changes in the structure of juniper forest ecosystems. It is worth mentioning that the area around the middle section of the Urej Valley was used for agriculture as part of the collective farm system until the 1990s. State control and forestry surveys protected the area from degradation and guaranteed obligatory protection of valuable ecosystems. This socio-economic system protected juniper forest ecosystem habitats from degradation resulting from human interference. After this period, as a result of the collapse of the collective farm system, relatively rapid changes were initiated in the ecosystem. Lack of monitoring resulted in impetuous interference with the environment. For these reasons, the Urej River Valley represents and documents various stages of juniper forest evolution under rapidly growing anthropopressure over the past 20 years resulting from changes in land use due to the transformation of the political-economic system after 1991. Knowledge of the history of the region made it possible to trace the stages of growing anthropopressure. To some extent, the valley can be considered a model for this kind of research on mountain ecosystem transformations. Thus, the results of research carried out in the Urej catchment are representative of the larger area of the Pamir-Alay region.

Geobotanic research was carried out based on field observations made in 2010–2014 within juniper forest phytocoenoses at altitude gradients ranging from 2000 to 3600 m a.s.l. The diversity of the juniper forests was assessed based on dominant species according to commonly adopted methods (Ismailov 1974; Ismailov et al. 2010). Also, maps presenting vegetation distribution in the Urej Valley were drawn up based on research from 2009 to

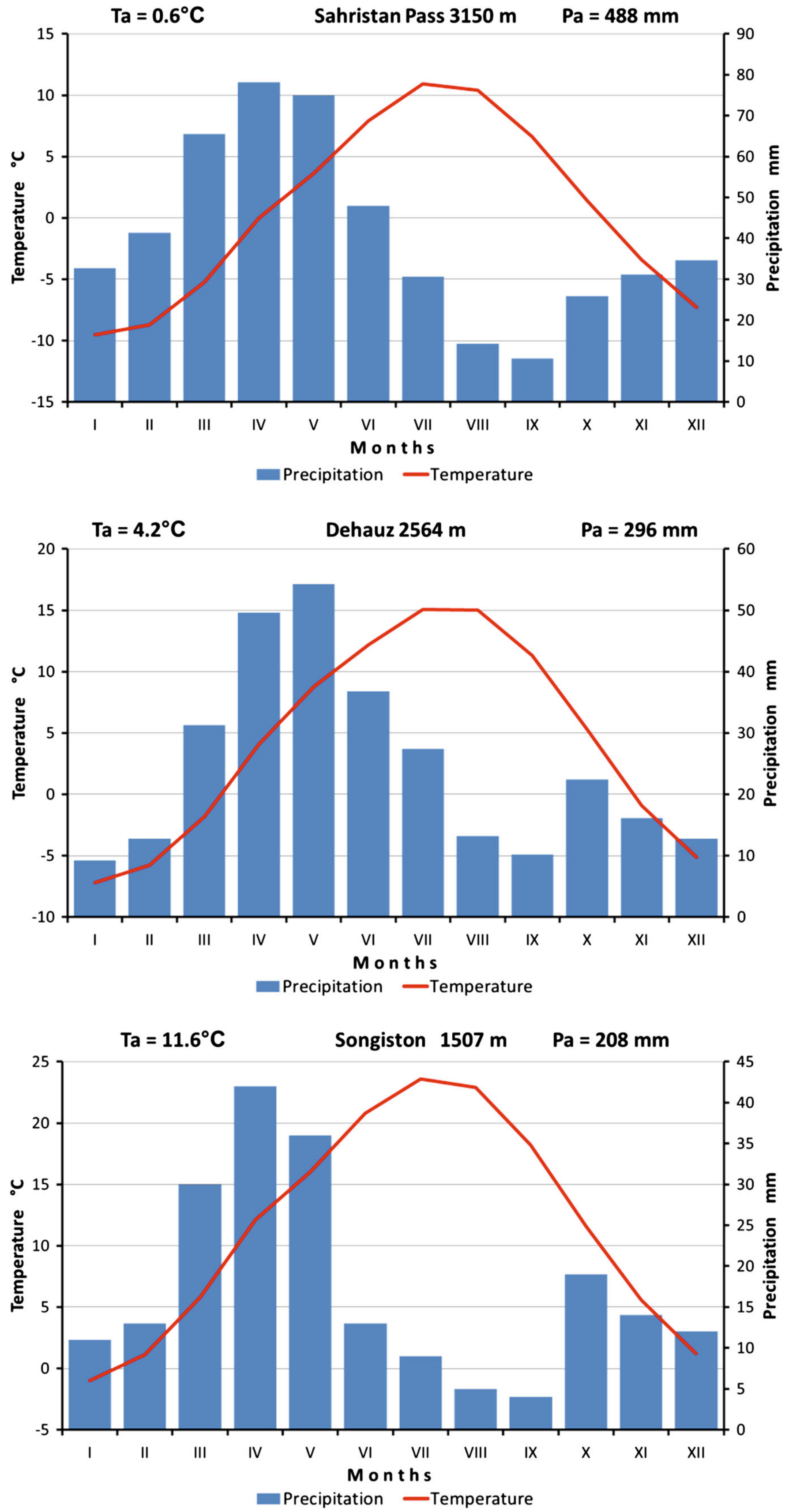

Fig. 2 Climatic diagram for selected stations in Pamir-Alay. T_a average annual temperature, P_a average annual precipitation total (after data of Williams and Konovalov (2008), partly updated)

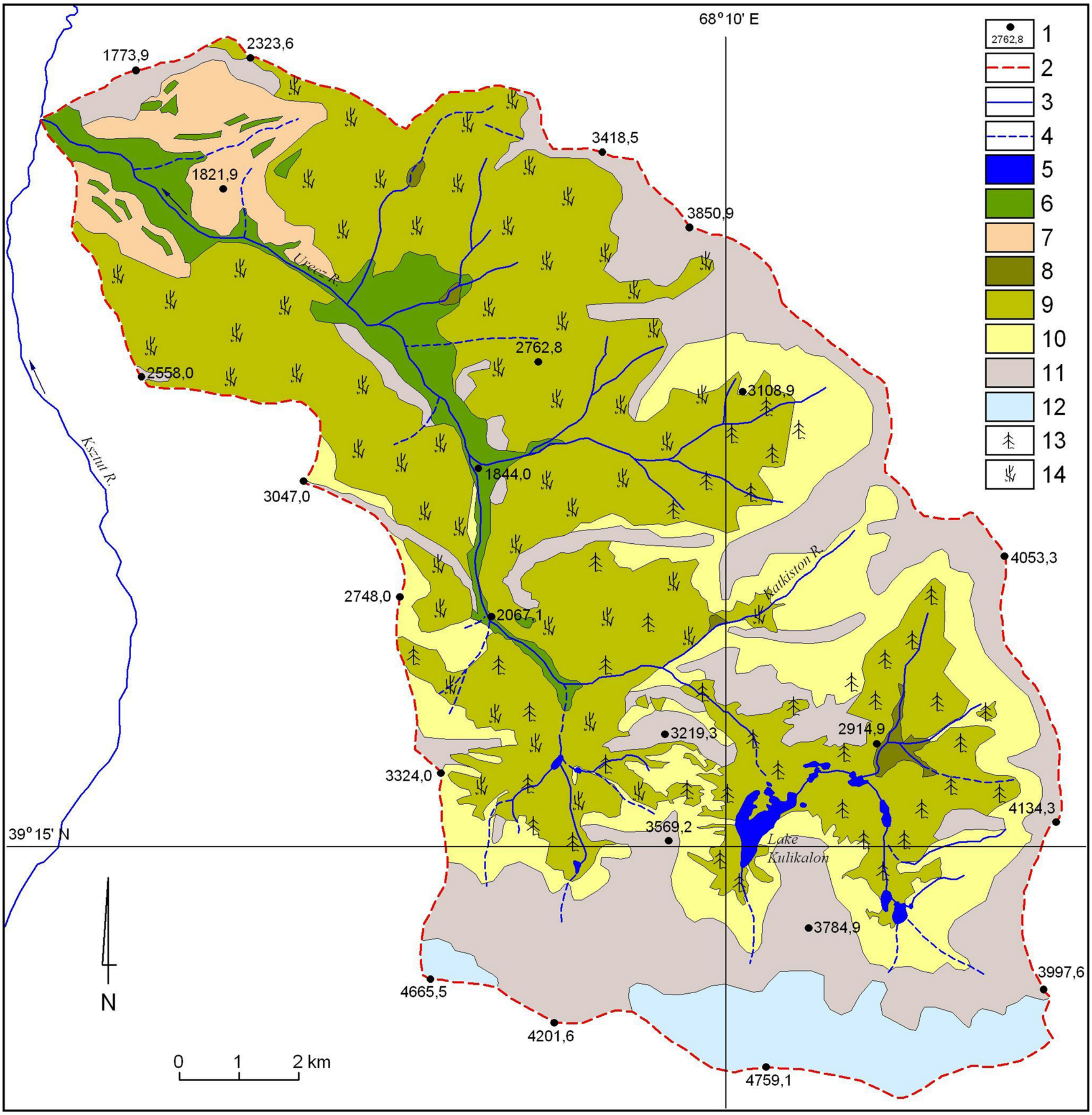

Fig. 3 Distribution of contemporary types of vegetation in the catchment of the Urej River: 1—altitude points, 2—catchment boundary, 3 and 5—hydrographic network (permanent, seasonal, water reservoirs), 6—irrigated farmland 7—steppified farmland after felling of junipers, 8—peat bogs, 9—juniper forests, 10—alpine meadow-steppe vegetation, 11—rocky surface and scree with scarce vegetation, 12—glaciers and permanent snow, 13—*Juniperus semiglobosa*, 14—*Juniperus seravschanica*

2012, using the itinerary method (Konnov 1973; Sadikov 2012).

Soil analysis

In order to assess the vertical diversity of soil properties within the juniper forest landscapes and directly above their upper boundary (Photograph 1), where grazing takes place (Photograph 2), soil samples were taken from organic (where present) and humus horizons (Table 1). The area of sample collection included both former and present sites of juniper occurrence. The samples were connected with the main mass of the rhizosphere. The material taken from depths to 10 cm was organic (O) or organic-mineral (OA);

Table 1 Characterisation of soil sampling locations

No. of samples	Soil horizons	Morphological description of soil horizons	Mean sea level (MSL)	Geographical coordinates
1	AC	Mineral horizon, thick matter, under dense scrub (*Rosa lutea*), slope about 45°	3470	39°15′19.00″N 68°13′14.40″E
2	C	Parent rock horizon, degraded topsoil horizon, stone-gravel fraction, eroded soil cover, dominant cushion vegetation, adjacent to juniper forests, slope to 60°	3546	39°15′36.65″N 68°13′27.51″E
3	Olh	Organic horizon, poorly decomposed, dense, sodded, alpine meadow with a share of *Geranium regelii*, intensive grazing, slope 25°	3511	39°15′32.88″N 68°13′23.83″E
	AB	Mixed topsoil and enrichment horizon, high share of herbaceous plant roots, dense structure, dominating fine fractions, alpine landscape		
4	OC	Organic horizon, loose, mixed with bedrock, mixed fraction matter, upper forest line, thickset specimen of *J. semiglobosae,* forest landscape, slope 40°	3119	39°15′30.18″N 68°12′11.02″E
5	OA	Organic-humus horizon, presence of farm animals, very hard crust, clearly layered surface, slope 35°	3416	39°15′41.37″N 68°13′04.56″E
6	OA	Organic-mineral horizon, loose structure, within a typical alpine belt of *Acantholimon* sp., slope 45°	3536	39°15′23.51″N 68°13′12.82″E
7	A/C	Humus horizon with features of parent rock, loose structure, various fraction composition, under a meadow with *Geranium regelii* dominant on the northern slope, directly within the glacier melting zone, slope 45°	3536	39°15′23.51″N 68°13′12.82″E
8	OA	Organic-topsoil horizon, loose structure, non-consolidated mineral and organic matter, under *Astragalus* sp, slope 45°	3536	39°15′23.51″N 68°13′12.82″E
9	Olh	Organic horizon, clearly divided into sub-horizons, sub-horizons interspersed with mycelia, built from remains of juniper	2883	39°15′20.57″N 68°11′44.19″E
	AB	Mixed topsoil and subsoil, soil develops on a bottom moraine, coarse-grained limestone matter, soil range is limited by the canopy, slope 5° m a.s.l., juniper landscape		
10	O	Organic horizon built from bark, shells, and juniper berries in various stages of decay, on top of a moraine, under *J. semiglobosa*	2858	39°15′25.19″N 68°11′08.61″E
	AB	Mixed topsoil and subsoil, various grain fractions with dominant stone material, slope 5°		
11	A	Humus horizon, various fraction material with dominant gravel, in bush-scrub community within steppified forests, slope 40°	2026	39°15′56.07″N 68°11′02.09″E
12	A	Humus horizon, dominating rock fraction, loose structure, numerous roots, under *Cerasus verrucosa*, slope 60°	2113	39°19′56.07″N 68°07′02.09″E
13	AC	Mixed horizon, material of various grain sizes with dominant gravel fraction, loose structure, under *J. seravshanica*, slope 70°	2008	39°19′47.83″N 68°06′52.15″E
14	AB	Mixed horizon with dominating subsoil horizon, rock fractions, under biogroup *Ephedra* sp., *J. seravshanica*, slope 35°	2524	39°21′28.43″N 68°06′84″E
15	AB	Mixed horizon, dominant fine sand, high share of rock fraction, under *Juniperus seravshanica,* slope 25°	2428	39°19′52.40″N 68°07′41.69″E
16	Ol	Organic horizon, built mainly from juniper litter, poorly decayed, animal excrement, slope 10°	2680	39°19′47.22″N 68°07′08.21″E
	AB	Mixed topsoil and subsoil horizon, fine grain fraction, dense structure, overgrown with herbaceous plant roots, gradual transition		
	Bbr	Subsoil horizon, fine fraction material, proliferation of roots, dense structure		
	C	Parent rock built mainly from fine fraction material, share of limestone		
17	AB	Mixed topsoil and subsoil horizon, dense structure, mixed fraction material, under *Artemisia dracunculus*, steppified landscape, slope 35°	2593	39°20′05.82″N 68°08′03.248″E
18	AB	Mixed horizon with subsoil features, dominant rock fraction, under *Juniperus seravshanica, Rosa ecea,* slope 30°	2419	39°20′20.08″N 68°07′46.85″E

below that, it possessed features of the cambic horizon (B) and frequently of parent rock (C), generally not processed chemically. Apart from areas under canopies, these soils are generally very shallow.

The granulometry of the soil material was determined mainly in the laboratory, but partly on site. Standard methods were used to determine the following parameters: soil colour according to Munsell; pH in water and in 1 M KCl, total organic carbon and $CaCO^3$ using the CS-530 Carbon/Sulphur Analyser (Eltra) method; total nitrogen (Ntot) using the Kjeldahl method; available phosphorus (Pavail) and magnesium (Mgavail) using the Egner–Riehm method (Bednarek et al. 2004); and total phosphorus (Ptot) using Bleck's method, as modified by Gebhardt (1982). Each measurement concerning the physico-chemical properties of soils was repeated three times; mean values were compiled in Table 3.

Results

Most frequently, juniper forest landscapes occupy alpine areas (Fig. 3). In the highest parts of the mountains, forests of the phytocoenosis with *Juniperus semiglobosa* are based on a single species. Dry and dead high trees, which can often be found within the area, are removed for firewood, disturbing the natural biogeochemical cycle of the ecosystem. Forests with *J. seravschanica* dominate on steep slopes. The areas at the mouth of the Urej River are covered by xerophilous shrubs in habitats formerly overgrown by forests.

Juniper forest landscape

The research distinguished three groups of phytocoenoses: those with a dominant share of *Juniperus seravschanica*, those with a dominant share of *J. semiglobosa*, and mixed, combining both of the species (Fig. 3). Distribution of these species in terms of altitude is a function of their ecological tolerance to temperature fluctuations. Species diversification within these landscapes depends on slope exposition and surface relief. Hence, associations with both *Juniperus seravschanica* and *J. semiglobosa* feature several varieties of phytocoenoses related to dominant species.

The association *Juniperus seravschanica,* growing at 1200–2400 m a.s.l., creates biocoenoses which are comparatively rich in terms of species composition. Landscape physiognomy is determined by habitat and climatic conditions, relief forms, and, currently, by the presence of humans. This association is most commonly found on northern and north-eastern slopes. Based on the species which dominate and shape their physiognomy, several varieties with *J. seravschanica* were distinguished within this landscape. These include: dominant *Festuca sulcata*, *Scorzonera acanthoclada*, *Stipa turkestanica*, *Artemisia lehmanniana*, *Scutellaria hissarica*, *Cousinia hissarica*, *Artemisia dracunculus*, *Ziziphora clinopodioides*, and *Thymus zeravschanicus*.

Shrubs play an important part in juniper forests with *J. seravschanica*. The most common species include *Cotoneaster oliganthus*, *C. multiflora*, *C. hissarica*, *Rosa fedtschenkoana*, *R. ecae*, *Ephedra equisetina*, *Astragalus variegates*, *Spiraea hypericifolia*, *Lonicera bracteolaris*, *L. simulatrix*, and *Berberis oblongata*, among others.

It should be emphasised that the highly fragmented relief, mosaic-like land-soil conditions, and humidity all have a strong impact on vegetation. These factors justify the division of landscapes based on the most common facies of archa forests with dominating species.

The association *Juniperus semiglobosa* favours higher altitudes (2400–3500 m a.s.l.) and is characterised by well-preserved tree stand structures resulting from relatively weak human pressure (regions with little or no access for humans). The domination of particular species, related to ecological and topoclimatic conditions and the prevailing relief, can be observed in different parts of these forests. Hence, various facies resulting from a dominant species making up the undergrowth can be distinguished within the phytocoenosis with *J. semiglobosa*. Dominant species are represented by *Artemisia lehmanniana*, *A. dracunculus*, *Ligularia thomsonii*, *Poa litvinoviana*, *P. relaxa*, *Ferula kokanica*, *Hypericum scabrum*, *Ziziphora pamiroalaica*, *Gentiana oliveri*, *Campanula glomerata*, *Scabiosa songorica*, *Polygonum coriarium*, *Eremurus olgae*, *Onobrychis echidna*, *Cousinia franchetii*, *C. verticillaris*, *Acantholimon velutinum*, and others. The share of the mentioned species in the undergrowth often reaches 60–80% of a given patch, which generally is characterised by a small area. In higher parts of the mountains, these are single-species forests in which, compared to the association *J. seravschanica*, shrubs occur individually as deciduous species due to unfavourable bioclimatic conditions. *Rosa fedtschenkoana*, *R. ecae*, and *Berberis oblongata* can be found here individually as well as, more often, *Sorbus tianschanica* and others.

The ecoclines between the *Juniperus semiglobosa* and *J. seravschanica* formations create a mixed phytocoenosis of the two species, which occurs between 2450 and 2800 m a.s.l. and is characterised by an intermediate composition with a large share of bushes and undershrubs of species of the genera *Rosa*, *Lonicera*, *Berberis*, *Cotoneaster*, *Ephedra*, *Sorbus*, and *Cerasus*.

Human impact on juniper landscape transformation

The results of our research on juniper forest transformation are derived from direct field observations. First of all,

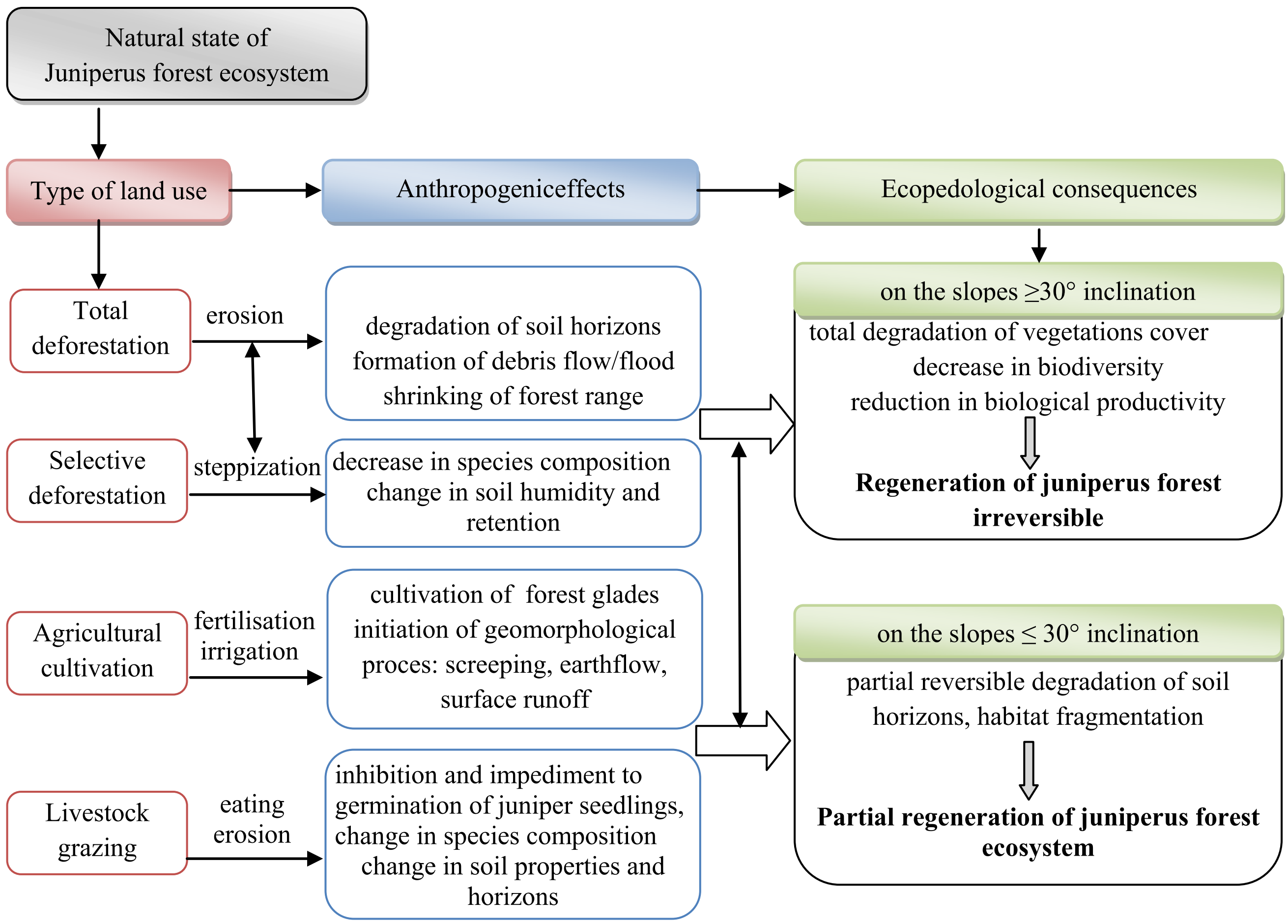

Fig. 4 The general pattern of transforming juniper forests under the influence of human activity and its ecopedological consequences

numerous remains of trunks of the discussed trees, both old (characterised by large circumferences of 1.5 m) and young, can be found. Some are partly decomposed; most have completely dried out. The observations showed that young trunks were covered with bark with living tissue (*cambium*) discovered underneath, proving that these individual trees had been cut down quite recently. The trunks confirm the common occurrence of the species in the past, which can be seen in the etymology of names of certain locations, such as Artuch, which means juniper forests.

Another degradation factor for juniper forests is seasonal pasture from May to August. Grazing within steppified forests on slopes greater than 30° causes the acceleration of erosion processes and degradation of soil horizons. Herds of cattle also eat small young juniper seedlings, significantly inhibiting regeneration.

The consequences of uncontrolled tourism in this area are primarily related to the often unconscious causation of fire. The presence of etheric oils in juniper needles causes them to burn quickly, and thus they increase the range of fire and the shrinkage of forest areas, as has occurred in the central part of the Urej catchment.

Glades within the juniper phytocoenosis (especially on the northern slopes) are exploited for agricultural purposes with the use of fertilisation and irrigation (Photograph 3). This causes changes in species composition. Excessive irrigation has initiated the processes of earthflow within the juniper forest ecosystems. The impact and effect of human activity on juniper forest ecosystems is illustrated in scheme (Fig. 4).

Soil properties

The analysed soil samples differ in their granulometric composition (Table 2). Gravelly cobble fractions >2 mm in the form of mixed limestone grains are dominant (sometimes reaching up to 50%). The share of sandy particles <2 mm is much lower (about 10–20%). The fraction 0.5–0.05 reaches 35% on average.

The pH of each soil sample is neutral or close to neutral, which undoubtedly results from the geological bed, with

Table 2 Granulometric composition of soil-building formations

Nr of samples	Soil horizons	Thickness (cm)	Colour of soil		Rock	Grain size composition mm (%) of fine earth					
			Wet	Dry		Sand					Silt
					>2.0 (mm)	2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.1	0.1–0.05	<0.05
1	AC	0–5	5Y4/1	5Y6/1	34.4	13.8	13.9	11	9.3	6.4	11.2
2	C	0–6	2.5Y5/1	2.5Y7/1	22.8	18.6	9.3	17.4	18.2	3.7	8.1
3	Olh	2–0	2.5Y3/3	2.5Y4/3	n.d	n.d	n.d	n.d	n.d-	n.d	n.d
	AB	0–10	10YR2/2	10YR4/2	12.6	7.3	9.1	8.7	36	13.6	12.9
4	OC	0–4	2.5Y5/2	2.5Y6/2	15.8	11.8	10.5	12.9	17.6	17.3	14.3
5	OA	0–10	2.5Y3/2	2.5Y4/2	28.7	13.9	11.5	12.3	13.8	11.6	8.2
6	OA	0–5	2.5Y3/2	2.5Y6/2	10	5.2	10.4	16.1	24.9	15.6	17.8
7	A/C	0–4	2.5Y3/2	2.5Y4/2	11.5	7.3	14.3	17	19.7	13.4	16.8
8	OA	0–6	2.5Y3/3	2.5Y5/3	14.3	6.6	10.9	20.1	23	15	10
9	Olh	5–0	10YR2/2	10YR2/3	n.d	n.d	n.d	n.d	n.d	n.d	n.d
	AB	0–7	10YR2/1	10YR3/1	26	8.5	9.5	14.1	19.8	13.5	8.6
10	O	8–0	5YR1.7/1	5YR2/1	n.d	n.d	n.d	n.d	n.d	n.d	n.d
	AB	0–6	10YR2/2	10YR3/2	46.6	12.4	8.6	8.2	8.7	6.9	8.6
11	A	0–8	10YR2/2	10YR4/2	20.5	6.3	9.9	17.7	19.5	10.8	15.3
12	A	0–4	10YR2/2	10YR4/2	37.6	9.1	8.8	10.7	16.8	12.4	4.5
13	AC	0–5	2.5Y3/3	2.5Y5/2	19.4	16.4	18.4	17.7	14.1	7.4	6.6
14	AB	0–5	10YR2/2	10YR4/2	19	7.2	9.8	19	17.8	11.8	15.3
15	AB	0–8	10YR2/3	10YR4/3	10.4	8.9	13.8	12.8	14.7	34.1	5.5
16	Ol	4–0	10YR4/2	10YR5/2	n.d	n.d	n.d	n.d	n.d	n.d	n.d
	AB	0–10	10YR2/2	10YR3/2	7.9	14.2	12.9	14.4	15.3	28.7	6.6
	Bbr	10–30	10YR2/2	10YR3/2	7.4	6.2	12.8	22	21.2	13.9	16.5
	C	31–40	10YR5/2	10YR7/2	16.8	3.3	6.3	8.9	27.4	23	14.3
17	AB	0–6	2.5Y3/2	2.5Y4/2	18	6.8	12.3	13.5	16.6	14.9	17.9
18	AB	0–4	10YR2/2	10YR4/2	17.8	9.1	11.5	21.8	14.8	14.4	10.6

the exception of organic horizons related to acidic juniper litter (Table 3). Values of pH range between 6.0 and 8.5 in water and 5.5–8.5 in KCl. All analysed samples show varying concentrations of available potassium. Higher concentrations were detected in organic (O) (40.46–211 mg kg^{-1}) and mixed (OA) (2.61–119 mg kg^{-1}) horizons. Sample 5 represents a site associated with intense grazing and presence of animals. Both available P (1739.6 mg kg^{-1}) and total P (9696 mg kg^{-1}) at this site attain the highest values of all samples (Table 1). Total phosphorus (Ptot) shows a high degree of variability (Table 3); its maximum values are also related to cattle grazing in this area. High concentrations of total phosphorus do not affect concentrations of available phosphorus. Available magnesium ranges from 116 to 964 mg kg^{-1} (Table 3). The highest concentration, as with those of phosphorus and nitrogen, was detected in sample 5.

Organic carbon (Corg) concentration is variable, with its highest value reported in organic horizons (4.3–25%); in mineral-organic horizons, it ranges from 0.26 to 11.40% (Table 3). Similar relationships were found in the case of total nitrogen concentrations. A clear relationship can be seen between concentrations of organic carbon and nitrogen. The C/N ratio is low in all research profiles, indicating mineralisation of organic matter, which is generally scarce in these ecosystems. Variations in $CaCO_3$ concentrations are presented in Table 3.

Discussion

Functioning of juniper forest vegetation

Juniper forests are of great importance: on one hand, they protect water reserves and serve counter-erosional functions; on the other, they provide high-quality building material and firewood (Photographs 4, 5, 6). At present, juniper forests all over Tajikistan, including the Fann Mountains, have been badly damaged as a result of chaotic,

Table 3 Selected physico-chemical properties of soils

Number of samples	Soil horizons	Thickness (cm)	pH		$CaCO_3$	Corg.	Nt	C/N	Pt	P avail.	Mg avail.
			H_2O	KCl	(%)				(mg kg^{-1})		
1	AC	0–5	7.7	7.6	0.16	0.85	0.168	5	810	14.04	137
2	C	0–6	8.5	8.5	4.70	0.26	0.036	7	816	2.62	732
3	Olh	2–0	5.6	5.4	–	4.3	0.636	7	726	40.46	177
	AB	0–10	6.0	5.5	0.09	3.18	0.284	11	394	9.59	154
4	OC	0–4	7.2	7.2	0.16	1.9	0.189	10	810	37.23	352
5	OA	0–10	7.1	7.0	0.47	11.4	1.072	11	9696	1739.6	964
6	OA	0–5	7.2	7.1	0.60	6.2	0.358	17	764	35.40	230
7	A/C	0–4	6.8	6.6	0.00	1.8	0.257	7	637	13.95	165
8	OA	0–6	6.6	6.4	0.00	3.1	0.321	10	716	44.73	258
9	Olh	5–0	7.0	6.9	–	25.5	1.284	20	1036	207.01	232
	AB	0–7	7.5	7.5	0.79	5.2	1.014	5	779	32.18	460
10	O	8–0	7.0	6.8	0.00	19.0	1.149	17	1214	32.1	223
	AB	0–6	7.3	7.2	22.68	9.5	0.418	23	968	17.09	472
11	A	0–8	7.5	7.3	18.1	2.6	0.549	5	796	20.57	220
12	A	0–4	7.6	7.5	64.53	4.5	0.298	15	760	9.68	271
13	AC	0–5	7.9	7.7	35.78	6.8	0.313	22	1040	12.21	464
14	AB	0–5	7.0	6.8	1.03	4.9	0.551	9	620	57.46	242
15	AB	0–5	7.0	6.9	0.04	0.88	0.426	2	524	24.33	189
16	Ol	4–0	6.7	6.7	–	18	1.246	14	1276	211.3	259
	AB	0–10	7.1	7.0	0.04	5.81	0.415	14	491	58.	234
	Bbr	10–30	7.3	7.1	–	3.83	0.344	11	424	13.53	161
	C	31–40	7.9	7.7	4.67	0.19	0.070	3	679	5.76	116
17	AB	0–6	6.8	6.5	0.00	4.19	0.442	9	598	119.12	223
18	AB	0–4	7.4	7.3	12.95	6.72	0.457	15	640	27.38	568

uncontrolled, and excessive wood cutting and cattle grazing. These activities largely prevent natural restoration of junipers (Brecle and Wucherer 2006). It should be emphasised that all forest ecosystems in Central Asia, including Tajikistan, fall within the first category of protection, as they serve an essential role in terms of nature protection functions in general and soil protection in particular (Zapryagaeva 1976; Kosmynin 1985). Accordingly, wood cutting is strictly forbidden both by custom and by law. Recently, however, as a result of shortage of firewood, intensive wood cutting has been observed, as well as intensified grazing of cattle, goats, and sheep, which can be clearly seen in the Kulikalon Basin (Rahmonov et al. 2011a, b). This, in turn, has a negative effect on forest restoration processes due to increased surface wash on slopes and to soil degradation.

Until the late twentieth century, the local population used much more wood than it does nowadays, mainly due to the lack of electricity. A similar situation could be observed for a few years following the decline of the USSR and during the civil war (in the 1990s) as a result of severe electric power limitations. Deforestation started in this period as a result of the energy crisis of the previous years, during which the population, in the absence of central heating and in view of the limited supply of electricity, was forced to cut down trees for heating. This was true of both cities and villages. The obligatory conservation of energy due to a limited power supply has continued to date throughout Tajikistan (except for strategic facilities) as a result of the insufficient capacities of power stations operating in the country and still unregulated political-economic relations with neighbouring countries (Kayumov 2006; Makhmadaliev et al. 2008).

Generally, juniper forests in Central Asia are characterised by sparse tree stand distribution and low density. Their structure resembles that of open woodland. Another problem related to human activities is the process of steppification of juniper habitats, whereby individual trees occur in small copses and are very scarce due to increased cutting. This leads to the proliferation of open areas in forests and results in the succession of grass species. Juniper forest habitats are transformed into vast forest-steppe landscapes, which are used as grazing land for sheep and goats. Such habitats do not foster the natural

Photograph 1 Animal grazing in the zone of the upper line of juniper ecosystems with visible traces of soil degradation caused by grazing (photograph by O. Rahmonov)

restoration of junipers, as they surrender to herbaceous vegetation, and are additionally consumed by animals. The process of steppification is continuing, and areas already steppified are used as agricultural land regardless of obstacles and unfavourable orographic conditions (Photographs 1, 2, 3). Agricultural use of land in the arid climate which dominates here has little chance of success without artificial irrigation; on the other hand, installation of a water pipeline several kilometres long would soon cause massive degradation of the environment, especially as a result of erosion (Golosov et al. 2015).

The most natural environments, untouched by humans, are preserved in forests situated at altitudes between 2800 and 3300 m a.s.l., especially on steep slopes and situated at least several kilometres away from human settlements. Transporting wood from such areas is difficult or

Photograph 2 Steppified juniper forests in the background of the U-shaped valley (photograph by O. Rahmonov)

Photograph 3 Felled juniper forests are replaced with arable land due to relatively high-quality soils (*source*: Google Earth Image ©2016 CNES/Astrium 39°19′51.35″N, 68°07′20.81″E)

completely impossible, since local residents use mainly donkeys for hauling wood. These landscapes are most commonly associated with *J. semiglobosa* in the research area.

Reforestation processes

According to the UN's FAO, 2.9%, or about 410,000 ha, of Tajikistan is forested. Of this area, 72.4% (297,000 ha) is classified as primary forest and the remainder, 101,000 ha, as planted forest. The changes in forest cover are irrelevant: between 1990 and 2010, Tajikistan lost an average of 100 ha or 0.02% per year. In total, between 1990 and 2010, Tajikistan gained 0.5% of forest cover, or around 2000 ha. The state agency reports different values for the forest cover area (416,700 ha) and percentage (3%) (TajStat 2014).

The Republic of Tajikistan is currently implementing a programme of forest restoration with the support of international organisations, including the German Federal Ministry for Economic Cooperation and Development (BMZ), represented by the German Society for International Cooperation (GIZ, or *Deutsche Gesellschaft für Internationale Zusammenarbeit*), within the framework of a project entitled 'Adaptation to climate change through sustainable forest management'. The executive agency is the Forestry Agency of the Government of Tajikistan. Tajikistan is among the Asian countries most severely affected by climate change (Kayumov 2006; Makhmadaliev et al. 2008). This is evident from the growing incidence of natural disasters, such as landslides, floods, and droughts, and a general decline in the availability and quality of water. Following the collapse of the Soviet Union, large areas were deforested to meet the above-mentioned need for fuelwood. This now makes the country more vulnerable to climate change and exacerbates its negative impact (Karthe et al. 2015; Niu et al. 2014). Conflicts between forestry offices and the local population over land use also perpetuate the misuse and degradation of forest areas (Kayumov 2006; Makhmadaliev et al. 2008). Forest ecosystems play a key role in the lives of Tajikistan's rural population. Firewood, fodder, medicinal plants, fruit, and nuts can be sold locally at a profit and represent an important source of income (Eisenman et al. 2013). Forests also perform an essential function in regulating the water balance and providing protection against natural disasters. Restoration and protection of forests are therefore of vital importance in the process of adapting to climate change.

Soil conditions

The Fann Mountains are characterised by large differences in altitude within relatively small distances. This undoubtedly has a large impact on scenic diversity and its mosaic-like character. High steep ridges and deep narrow valleys foster processes of intense downwash, which destroy the soil cover down to the bedrock. Specific physiogeographic features of the research area determine the formation of specific types of mountain soils (Kuteminskiy 1960; Kuteminskiy and Leontyeva 1966).

In terms of granulometry, the analysed soil samples are highly diversified, especially in the fraction >2.0 mm

Photograph 4 *Juniperus semiglobosa*. This tree's crooked trunk and branches protect it from being used for timber (photograph by O. Rahmonov)

Photograph 5 *Juniperus semiglobosa*, with traces of human activities (photograph by O. Rahmonov)

(mostly associated with high altitudes; see Table 1). Compare with other fractions, as well as the diversity of output formations (glacial drifts) and their vulnerability to weathering and anthropopressure, material from these fractions is more uniform.

It should be pointed out that vegetation colonises areas where soil parts dominate and, after forming obvious clumps, stores dust transported by wind within these clumps. Typical phytogenic hillocks are formed in this way. Air often carries a great quantity of dust in this area, which causes serious problems for the population.

As was mentioned in "Materials and Methods", the samples were taken from the organic-topsoil horizon of the rhizosphere. Most of these samples lack the organic horizon (O) and their accumulation horizon is not very thick. Mineral formations are mixed with fine organic material (dead thalli of crustose lichens, which are not always separable). Therefore, most samples are marked as mixed horizon (in which mineral material dominates). Directly under this horizon lies bedrock. The topsoil's low thickness values are related to water and wind erosion and mechanical damage caused by animals. Due to lack of vegetation, animals frequently tear out roots, thus degrading soils already characterised by poor compactness. Samples from the AB (partly degraded topsoil) and A horizons occur under dense grass communities and within the phytogenic field and are limited to the areas under canopies.

The results obtained from the test region are close to those from the western Alay Mts. (Glaser et al. 2000) under similar vegetation. The importance of grain size composition, slope angle, porosity of mountain soils, frequent erosion, and land use, all of which are unfavourable for the creation of conditions for nutrient accumulation and soil development, was stated there as well. Other researchers (e.g. Cécillion et al. 2010) attribute important roles in soil development mainly to dynamic geomorphological processes and arid climate changeability at different altitude levels, ignoring the human role in the status of these sensitive mountain ecosystems. The latter, in turn, contributes to the formation of soil mosaic typical of mountain areas on which plant islands are created, along with the phytogenic fields under their canopies. The biocoenotic importance of *Juniperus seravschanica* and *J. semiglobosa* is related to, *inter alia*, the formation of phytogenic field and soil islands; deforestation exposes soil to erosion, resulting in the disappearance of vegetation. Mountain soils of the analysed area are used especially for intensive summer

Photograph 6 Juniper forest thinning as a result of wood cutting (photograph by O. Rahmonov)

grazing. On one hand, grazing determines the soil chemistry, but on the other, it causes the destruction of soil cover and its biological resources (Abbasi et al. 2007; Hagedorn et al. 2010). During the warmest part of the day (when the temperature reaches 30 °C), cattle seek cooler places, including the canopy zones of junipers and larger shrubs. This explains the high concentration of total phosphorus and other soil properties at these altitudes.

Human impact

The history of anthropopressure in the western part of the Pamir-Alay is long and related mainly to the uncontrolled exploitation of natural resources. The management system of protected regions has ceased to function in recent years, especially since the decline of the USSR; *zapovedniki* (protected wild areas) had become a good source of both food and firewood in Tajikistan. This has been a very bad time for the protection of Tajik nature, as well as the time of the greatest degradation of the country's natural environment.

This abuse of the natural environment occurred during times marked by a transitional economy, ethnic conflicts, and the lack of a consistent socio-economic policy. Most of the population of the mountain areas was left on its own, without any help from the state. This forced people to look for new ways to get by, resulting in uncontrolled and irregular wood cutting. For many people from the mountain settlements, the illegal wood trade became the only way to support large families. It should be pointed out that the mountain ecosystems of Central Asia, including forest systems, are considered to be among the most valuable regions of the Earth in terms of biodiversity, referred to as 'hot spots of biodiversity' (Meyers et al. 2000; Mittermeier et al. 2005; Sadikov 2012).

The alpine environment of the Zarafshan Mountains, similarly to other environments of this type, is very sensitive to external factors, both natural and anthropogenic. By virtue of their biomass, volume of fallen needles, shade, and other ecological characteristics, juniper forests are a basic link in the system of biocoenotic relations in the region's ecosystem. The felling of junipers is a mechanism which triggers degradation of the ecosystem along with its endemic species. Archa forests play a protective role within their own and adjacent ecosystems (Rahmonov et al. 2011a, b, 2013; Sadikov 2012).

The surface area contained in the main regions of juniper and other rare forests of Tajikistan decreases by 2–3% every year. About 30% of resident species are in danger of extinction (National Strategy 2003). This process also affects Central Asian healing plants. The main direct causes of the deteriorating quality of juniper forest phytocoenoses include: intensive wood cutting over the past several centuries, a complete lack of biotechnical measures, lack of forest monitoring and care, intensive uncontrolled grazing, the slow growth of junipers, and the current lack of juniper nurseries. There is also an underlying reason, given that the reasons cited above derive from historic, political, cultural, religious, ethnic, and other processes occurring in Tajikistan and neighbouring countries in Central Asia. A detailed diagnosis of the actual sources of these issues, along with the development and implementation of a method to prevent the described negative processes (including the loss of juniper landscapes) and to ameliorate the unfavourable status of the sensitive ecosystems of Central Asia, would require thorough studies encompassing political and cultural geography (Shu, 1999).

Conclusion

Topographic-habitat differences and the specific climate of Central Asia foster the occurrence and development of unique types of juniper forests.

Archa forests are the main element of the entire landscape of the Turkestan, Hissar, and Zarafshan massifs; only small areas of the Fann Mountains have been left unaffected by human economic activities. In most cases, trees of the species *Juniperus semiglobosa* and *J. seravschanica* were cut down for the building industry and, recently, for firewood. This increased soil erosion on steeper slopes, causing overall degradation of the landscape.

The soil cover is heterogeneous in terms of both mechanical composition and chemical properties. Depending on topographic conditions, slope exposition, altitude, and type of vegetation, the soils occurring in the area in question range from fine-grained to poorly developed coarse rock. Debris of various sizes can be observed in the soil profile.

The most destructive forms of anthropopressure in the discussed area include grazing of cattle, sheep, and goats; illegal wood cutting for building and firewood; and non-organised tourism.

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