Chapter 21
Actual Changes of Mountainous Landscapes in Inner Asia as a Result of Anthropogenic Effects

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Abstract Mountain landscapes' reactions on global changes are of particular interest since they reproduce long-term trends contributing to generation of forecasts and scenarios for sustainable regional development. The series of observations in mountainous Inner Asia over the climate, the glacier balance, river runoff lasting for about half a century allowed us to clarify the spatial gradients of the geosystem structure and functioning characteristics, and, therefore, resulting in parameterizing their spatial and temporal variability. Digital elevation models (DEM) with the grid points determining the qualitative and quantitative attributes of geosystems, enabled us to analyze the modern landscape structure, to establish probabilistic relationships between the distributions of geographic components, and to estimate the ranges of climatic characteristics within which these components' balance can be realized. Among the tundra geosystems, the most cold-resistant are the cobresia and dryad ones; herbal species are the least dependent on air temperature, while dwarf shrub tundra tends towards warmer environment. However, grass-sedge and dwarf shrub tundra spreading evidences the critical contribution of geological and geomorphological impacts. Ecological and climatic niches of the normal geosystem functioning can be used in forecasting the landscape transformation under climate changes. The application of statistical methods allows evaluating the contribution of landscape genesis' various factors to the formation of the high-altitude territory structure.

Keywords Landscape dynamics · Anthropogenic load · Climatic changes

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21.1 Introduction

One of the tasks of landscape research at the current stage is to study the dynamics and evolution of ecosystems under a changing climate and growing man-induced impact. The relevance of spatiotemporal landscape dynamics research under the influence of natural and anthropogenic factors is caused by the increased concern of mankind with the intensification in the rates of global changes, thus entailing a noticeable accumulation of dangerous natural disasters provoking serious damage to the population and the economy.

Mountainous landscapes are characterized by high sensitivity to environmental impacts. Responses of these landscapes to the effect of spontaneous and anthropogenic factors do not reflect just random variations, but directional changes in geographical environment, which makes it possible to justifiably develop forecasting and projecting sustainable development of vast areas, such as Inner Asia. By Inner Asia we consider the landscapes of the Altai-Sayan mountainous country (Southern, Central and Mongolian Altai, Western and Eastern Sayan, Tsagan-Shibetu, Western, Eastern and Peaked Tannu-Ola), as well as other neighboring ridges and orographic formations belonging to the drainless areas of the continent (Fig. 21.1). A characteristic feature of the regional landscape is the wide spread of intermountain basins (the Great Lakes Depression, the Valley of Lakes, etc.) and relatively low isolated mountain massifs.

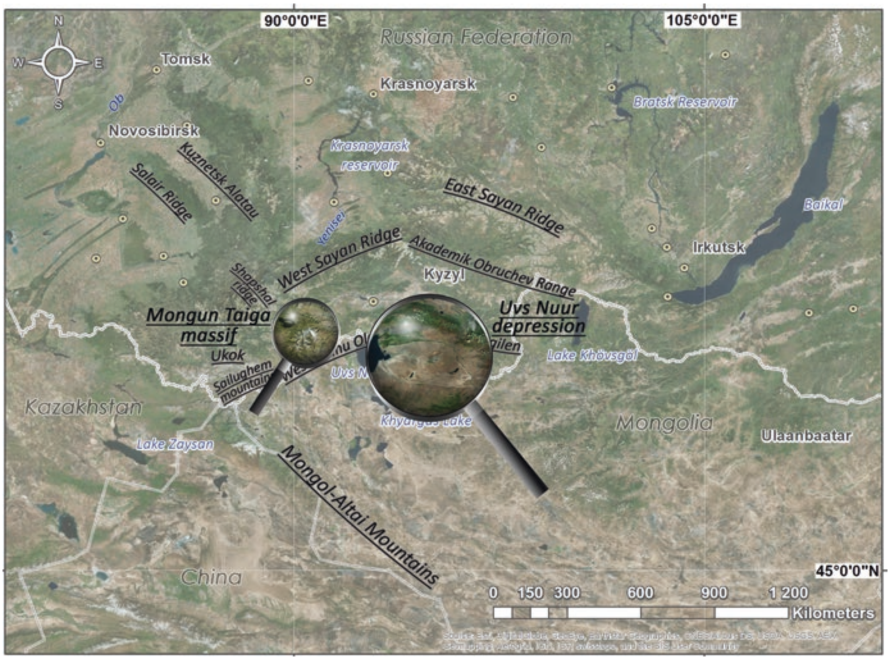

Fig. 21.1 Location of key sites in the research region

Being sparsely populated and hard-to-reach, the territory of Inner Asia still remains underexplored as far as its physicogeographical, paleogeographic, glaciological, and permafrost features are concerned.

The ground-based observation data in Inner Asia are lacking due to the sparsity of hydrological and weather stations and the insufficient duration of observation series. The use of contemporary equipment (automatic hydrometeostations and loggers connected to sensors, etc.) makes it possible to shift from unsystematic records of landscape states to continuous series of universal characteristics reflecting the functioning modes of geosystems. However, no remote studies can solve all the problems of regional ecogeographical forecasting. These circumstances increase the importance of expeditionary research; otherwise the interpretation of rapidly increasing remote survey data remains problematic.

21.2 Study Area

Geographers of St. Petersburg State University conduct research in various areas of Inner Asia following the best expeditionary traditions of the Russian Geographical Society dating back to the middle nineteenth century. When choosing research methods, semi-stationary observations of monitoring type are preferred, at which testing grounds are denoted with benchmarks. Repeated measurements are performed at model areas according to a standard procedure. The most detailed works were carried out on the massifs of Mongun-Taiga (Republic of Tuva, Russia), Tabyn-Bogdo-Ola (Republic of Altai, Russia; Mongolia), and Turgani-Nuru, Kharhira-Nuru, Tsambagarav (Mongolia). Climate, glacier balance, runoff, and other attributes of high and mid-mountain landscape component were obtained in research expeditions during the last four decades. They provide opportunity for specifying the values of regional gradients to identify various aspects of geosystem activity and, therefore, contribute to a relevant forecast of space-time landscape changes.

The formation of the climate in a region located in the continental sector of the mid-latitude zone is greatly influenced by a number of factors as follows: the western air mass transport prevailing throughout the year at altitudes of 1000–2000 m; the circulation processes developing over West Siberia; remoteness from the oceans, and the proximity of the territory to arid spaces of Central Asia. The peak annual values of the radiation balance were recorded in intermountain basins. The total input of radiation on mountain slopes is determined by their aspect.

For most of the year, the region is dominated by the continental air, characterized by low temperatures, dryness, and a stable meteorological regime in winter. The vertical temperature gradient in January does not exceed −0.3 °C/100 m, but due to inversions in the depressions, the temperature drops below −50 °C. In spring, foehns in the mountains and sandstorms in the depressions are common.

Rainfall distribution in the region is in extreme contrast: in the western Altai, annual precipitation reaches 2000 mm and in the Tuva and Ubsu-Nur depressions it is less than 200 mm. In the annual course, precipitation peak is observed commonly in July; however, in the mountains, much of the winter precipitation is caused by the intervention of cyclones of the Arctic front, while the summer rainfall is mostly influenced by the cyclones of the polar front. The snow accumulation decreases southeastward. For instance, in the southeastern Altai, locally it hardly ever exceeds 5 cm. The growth of the snow accumulation with the altitude is observed only up to the altitude of 2000 m.

The considerable longitude-latitude outstretch of the region results in a wide variety of local climates, which, in its turn, leads to the formation of specific landscape structure due to the inherent diversity of edaphic mountainous conditions, such as slope gradients and Sun exposure, tectonic structures, geologic substrate, matter migration modes, etc.

Geosystems of Inner Asia are represented by boreal semi-humid, semi-arid, and arid landscapes, which differ dramatically from spectra of high-altitude belts (Ogureeva 1980; Kuminova 1960; Sobolevskaya 1950). Glacial-nival and mountain-tundra landscapes prevail in highlands; mid- and low mountains are covered by forests, mainly by taiga, as well as by various steppes; intermountain depressions and hollows are dominated by steppes and semi-deserts. The boundaries between altitudinal belts are frequently indistinct; numerous ecotone formations appear, such as forest-steppe, tundra-steppe, forest-tundra. Southward and eastward gradients in heat and water availability affect the snowline position, the upper and lower boundaries of the forest belt, and also the altitude belt range related to the increasing climate continentality.

Modifications in mountain landscapes, determined by the joint action of natural and anthropogenic factors, manifest themselves in different ways, depending on the sustainability of geosystems and on the type, intensity, and duration of the environment impact. Climate change is one of the most important natural factors of landscape dynamics.

Some global climate scenarios, based on estimations of anthropogenic greenhouse gases emissions into the atmosphere, suggest a significant increase in the global temperature of the Earth's surface. The EGISS model predicts a rise of 1–1.5 °C in the average July temperature in the region by mid-twenty-first century (Schmidt et al. 2006). This corresponds to the computation data of the RCP 8.5 scenario, widely applied for prediction calculations in numerous glaciological, meteorological, and other studies (Riahi et al. 2011). It should be noted that the dissected mountain relief always gives a much more diverse picture of potential climate change. The results of long-term weather data analysis in the study area show that, since the mid-1980s, there has been a significant increase in the average summer air temperature. Precipitation trends in the region have also been revealed. In low-mountain areas (below 900 m a.s.l.), the average annual and average summer precipitation remains stable or changes insignificantly over half a century (Kyzyl, Toora-Khem, Sosnovka weather stations), while in the mid-mountains, the precipitation is gradually decreasing (Erzin, Mugur-Aksy weather stations). However, it would be incorrect to infer decrease in moisture from this data, since observations in adjacent territories often show different trends. Thus, if the climate change remains the same in future, the most probable scenario is an increase in the average summer temperature against a slight decrease in precipitation.

The cumulative data of integrated study describing the functioning mechanisms of mountain geosystems make it possible to assess the landscape transformation trend and amplitude due to the environmental impact, first and foremost, due to the observable climatic changes. Contemporary transformations of intact arid high-mountainous landscapes are considered through an example of the Mongun-Taiga massif, the Ubsunur Biosphere Reserve cluster.

The Mongun-Taiga massif (3970.5 m a.s.l.) is located to the southeast of the linkage between the ridges of the Altai and Tannu-Ola system. The massif is surrounded by multilevel intermontane troughs. The stepped relief results from the wide occurrence of areas with gentle (2–3 °) slopes – remnants of planation surfaces lifted to different heights due to a considerable amplitude of vertical tectonic movements. Traces of glacial activity are wide-spread here: kars, cirques, moraine-pondage lakes, trough river valleys, etc. A unique feature of the massif glaciation is a diversity of glaciers morphology: dome-shaped peak complexes, sloping, hanging, cirque, and valley glaciers. The climatic snow line corresponds approximately to the level of 3600 m a.s.l.

Based on long-term expedition studies, thematic maps, and space images, we composed a unique landscape map (1: 100,000) covering an area of more than 1500 km^2.

The total area of the massif glaciation amounts to about 20 km^2. Above 3200 m plateau geosystems with a scarce soil-vegetation cover (*Waldheimia tridactylites, Saxifraga oppositifolia, S. melaleuca, Crepis nana, C. chrysanta,* etc.) dominate. The soil cover consists of nutrient-poor Cryosols (cryozems) and Leptosols (lithozems), where the average depth of permafrost is 0.3–0.4 m.[1]

Mountain tundra, occupying almost a third of the massif area, is represented by several types: kobresia (*Kobresia myosuroides* prevailing); dryad (*Dryas oxyodonta* with cryophyte herb species of *Bistorta viviparum, Papaver nudicaule, Pedicularis uliginosa,* etc.); moss-dwarf shrub (*Betula rotundifolia*, green and *Polytrichum* mosses); grass-sedge tundra (*Carex melanantha, C. orbicularis, C. sempervirens, C. stenocarpa, Eriophorum polystahion*, etc.). The tundra soil cover consists of Cryosols, Leptosols, and (in hollows) taiga Gleysols.

Alpine meadows (*Saxifraga sibirica, Draba sibirica, Aster alpinus, Trollius asiaticus, Dracocephalum grandiflorum, Gentiana grandiflora*, etc.) are distributed sporadically on Mollic and Folic Leptosols. Meadows with dominance of *Kobresia myosuroides* are combined with cryophyte mixed herb sedge meadows in moister habitats (with the predominance of *Carex melanantha*). Mixed grass meadows on Umbrisols are characterized by a wide variety of species (Festu*ca ovina, F. kryloviana, Poa altaica, Galium verum, Bistorta viviparum, Dracocephalum grandiflorum, Sajanella monatrosa, Tephroseria praticola, Campanula rotundifolia*, etc.),

[1]The Latin names of plants are summarized in S.K. Cherepanov (1995) classification of soils according to Shishov (2004).

and significant presence of shrubs and small shrubs (*Betula rotundifolia, Juniperus pseudosabina, Spiraea alpina, S. media, Salix reticulata, S.glauca*).

Mixed herbs larch forests are characterized by high stand density of *Larix sibirica* and diversity in the grass-shrub layer, which consists not only of the boreal herbs but of tundra species as well. *Laricetun nano-betulosum* forests (*Betula rotundifolia, Lonicera altaica, Juniperus sabina, Dryas oxyodonta, Salix sp.*), are characterized by a sparser stand (the projective cover does not exceed 30%). At altitudes below 2000 m, the presence of steppe species among boreal herbs in the soil cover is noticeable (*Artemisia tanacetifolia, Eritrichium pectinatum, Pentaphylloides fruticosa, Potentilla pensylvanica*). A few species of *Salix* brushwood with hygrophytic herbs are distributed in the river floodplains.

Mountain steppes, occupying about a third of the massif area, are represented by several types as follows: forbs steppes (*Festuca valesiaca, F. kryloviana, Setaria viridis, Poa attenuate, Erigeron krylovii, Potentilla astragalifolia* etc.), wormwood steppes (*Artemisia depauperata, Festuca lenensis, Ephedra fedtschenkoae,* etc.), and shrubby steppes (genera *Caragana, Berberis, Dasiphora fruticosa, Artemisia* types).

21.3 Methods

High-resolution (30 m) digital terrain model enabled us to use a novel approach for analyzing the present-day landscape structure. We established the probability correlation between the occurrence of geographic components and estimated the ranges of climatic attributes which allow the existence of these components and their combinations.

The vegetation cover patchiness assessment was carried out based on the concept of *landscape site*[2] determined by mesorelief homogeneity, surface deposits, matter, and moisture migration modes (Isachenko and Reznikov 1996). The accuracy of classifying into landscape sites at the selected scale is confirmed by good correspondence of the GIS thematic layer with the digital slope model. This is important when analyzing the conditions for geosystem formation and for modeling their potential transformations.

The comparison of binomial distributions for the phytocoenosis groups using Wald's method (Cox and Snell 1981) revealed the dependence of their formation on altitude and soil factors. To estimate the determination rate, the criterion χ^2 (Volkenshtein 2006) was applied. Ranking particular factors, which drive the development of phytocoenosis groups, was carried out by comparing the calculated deviations of the dependence measures.

[2] See Chap. 17, this volume, for details.

21.4 Results

Our estimates showed that distribution of dryad tundras and forb-bunchgrass steppes is determined mainly by the climatic factor, with altitude being an integrated climatic driver, while the distribution of grass meadows, floodplain forests, and shrub steppes is influenced by geologic and geomorphologic factors. In general, it was shown that the lower is the sensitivity of phytocoenosis groups to one of the considered factors, the higher is its sensitivity to another one.

The combined effect of various landscape genesis factors determines the formation of an ecotone in the altitude range of 2200–2800 m with approximately equal proportions of mountain tundra, mountain meadow, and mountain steppe geosystems. Similar vegetation cover of neighboring altitudinal steps, confirmed by close values of the integrated occurrence index, illustrates the mutual adaptation and relative equilibrium between vegetation communities. In case of a high patchiness of vegetation cover due to contrast topography in the ecotone, a diffuse type of phytocoenosis contact prevails. This type is characterized by blurring boundaries of the territorial units, gradual transitions between geosystems in space and by the increase in phytocoenosis species diversity (Zelepukina et al. 2018). A similar phenomenon has been observed in the adjacent arid regions of the southeastern Altai and southwestern Tuva: in the altitude range from 2100 to 2400 m meadow and gramineous steppes are enriched with cryophilic species (Makunina 2014).

To detail and analyze the conditions for the geosystems formation, we performed simulation of fields of spatial patterns for the main meteorological indices. The simulation was based not only on time series obtained from the weather station Mugur–Aksy (1830 m), which is the nearest to the massif under study, in the years of 1963–2012 (FGBU VNIIGMI-WDC), but also on data collected from seasonal field weather observations at altitudes of 2260, 2620, 3140 m. At each pixel of DEM, we calculated the average summer air temperature and summer precipitation with due regard to vertical gradient values: −0.69 °C/100 m, as well as 7 mm/100 m and 12 mm/100 m for altitudes above and below 2200 m, respectively (Chistyakov and Kaledin 2010).

The imposition of spacing areas with calculated meteorological data values on the landscape map made it possible to identify the ranges of climatic features with the highest and the lowest geosystem occurrence rate. Distribution analysis of different geosystem types depending on their heat and moisture availability regime revealed that several plant communities can exist under similar conditions.

The climatic niches (ranges of climatic feature values with occurrence of affine geosystems) characterize optimal conditions for the functioning of geosystems. Dense intersection of geosystem climatic niches in the altitude interval of 2200–2800 m, indicating equiprobable development and coexistence of communities belonging to different ecological groups under similar climatic conditions, illustrates not only the absence of prominent dominating landscapes but also the priority of geological and geomorphological factor in vegetation dispersal. This is most clearly manifested through the availability in the altitude zonation structure of arid highlands with larch forests and swamped sedge tundras at extremely low precipitation totals (about 110–150 mm per summer) in overmoistened locations due to surface runoff and seasonal thawing of frost soil.

The study of factors affecting the dynamics of environmental conditions, and trigger mechanisms of these factors, is based on the concept of long-lasting landscape states, i.e. such properties "of its structure that are being preserved for more or less prolonged period of time" (Mamay 1992). The reasons for changing the states can be both, factors external to the system and the circumstances of its self-development and self-organization. The life span of geographic complexes is comparable with the lifetime of the core system elements, first of all, of plant communities. Within the homogeneous geomorphological contours, significant transformations of the dominant plant communities of mountain steppe and alpine landscapes occur within the period of 40–50 years, and in mountain taiga – for about 100–150 years (Puzachenko and Skulkin 1981).

The similarity of the climatic niches for different geosystems implies not only the possibility of transmutation, but also indicates the transformation trend under a definite change in climatic conditions. For instance, with rise in temperature availability, the processes of increasing in the proportion of mesophytic species in the structure of tundra seem to be the most expected, resulting in transformation of cryophylic cushion plants into graminaceous or *Dryas* and *Cobresia* associations, and also a growth in the proportion of *Festuca*-forbs species groupings in *Cobresia* tundras, as well as prairiefication in the structure of high mountain meadows (Dirksen and Smirnova 1997).

However, it should be remembered that the formation of contemporary combinations of meso-, hygro-, xero-, and cryophyte plant communities took a long period of time due to the evolution of both environmental conditions and plant communities with their various adaptive capacity. Therefore, modifications in the ratio of the heat-moisture supply parameters expected by the middle of the twenty-first century seem to be not sufficient to change the landscape invariant. High sensitivity of plant communities to climate variations (dryad tundras and forb-graminaceous steppes especially) is somewhat leveled out by the influence of orographic and geomorphological factors, thus manifesting in a certain geosystem inertia.

Nowadays we face a reduction in the areas of snow and ice formations and a rise of their lower boundary. The glaciation degradation process is taking place in an irregular manner: on the one hand, there are significant differences in the glacier retreat rates, depending on their size, morphological type, exposure timing, etc.; however, since 2009, there has been some slowdown in the retreat of glaciers. During the last 40 years most of the valley glaciers retreat with an average speed of 7–11 m/year (Ganyushkin et al. 2017).

To estimate the scope of potential changes in the massif landscapes, a scenario-based space modeling of meteorological data values was carried out, with an expected increase by the year of 2050 in the mean summer air temperature by 2 °C versus a decrease in precipitation by about 15%. The consequences of such changes are thought to be most noticeable at the foot of the massif and in its highest parts, where glaciation at present is formed. Calculations predict a gradual increase in temperature resulting in a two-fold snow and ice formation area reduction (Ganyushkin et al. 2015).

Based on the concept of spatiotemporal analysis and synthesis of geographical landscapes (Beruchashvili 1986), in a general way and with regard to transition periods, conceivable trends in massif landscape transformations can be viewed as follows:

- Occupation of new locations (deglaciated rockbeds, rockslides, and moraine) by discrete petrophyte clusters
- An increase in vegetation cover shading of cobresia tundra on flat parts of the highlands, with their partial replacement by ground-shrub communities
- A gradual replacement of dryad tundras on mid-steep slopes by some kinds of mountain steppes or Cobresia associations and on undulating moraine surfaces by grass-mixed meadows
- A small reduction of moss-dwarf shrub tundras on morainic deposits cemented by permafrost, and a more noticeable one on slopes
- Increase in the proportion of xerophytic sod grasses in meadows on river valley terraces and drain slopes at the bottom stages of the massif; however, in some hollows, mixed-grass communities are expected not only to maintain their availability, but to raise their productivity as well
- Embedment and spread of larch new growth at the top of the forest boundary; strengthening of the xerophytic species in the undergrowth at the bottom forest boundary, followed by the separation of larch forests into areas or groups with patches of steppe meadows in-between
- Extended spaced grass and sagebrush steppes dispersal at the foot of the massif, followed by semi-desertic steppe replacement.

Thus, the main trends in the dynamics of high-altitude landscapes in the region under consideration at the present stage can be reduced to a decrease in the total area of glaciers, the disappearance of small glaciation forms, the release of rocky areas and loose sediments from ice cover, activation of thermokarst processes and permafrost degradation. In the long term, despite the low diversity of physicogeographical environments at the place of contact with the glacial-nival belt, one can assume some amplification of the highland belt structure resulting from glacier retreat and soil-vegetation cover formation on graded surfaces.

In the altitude interval 2400–2800 m, where the greatest values of the vegetation cover entropy are observed, the overall stability of the whole complex of various elements (emergence manifestation) is significantly increased; therefore, the consequences of climatic changes are expected to result in a certain structure transformation, for instance, an insignificant change in the reproportioning of the main geosystem areas forming the ecotone, as well as the diffusion of closely located systems and the acquisition of features specific for other ecological group communities. Thus, it was noted that cryozems in tundra areas with pronounced steppe features are characterized by a decrease in the humidity of the cryoturbated horizon and by a greater development of the humus one (Lesovaya and Goryachkin 2007). In the landscape structure of the lower parts of the massif, aridization occurring in the continental part simultaneously with a rise in temperature and a drop in the amount of precipitation is not likely to influence the structure complexity. However, the latter can acquire a more deserted view similar to the southern foothills of the Tannu-Ola ranges with nanophyton communities (Volkova 1994).

A closer look at the changes in low- and mid-mountain landscapes of Inner Asia is represented via data obtained in the Ubsu-Nur depression A bitter-saline drainless Ubsu-Nur (Ubsa) lake is located in the southwestern part of the basin at an altitude of 759 m. The height of the basin mounting reaches 4000 m and more: the depression is surrounded by sub-latitudinal ridges with small glaciers and snowfields coupled with stony placers and rock outcrops at the height of more than 3000 m. The landscape map on a scale of (1: 500,000), compiled from the fieldwork data obtained during the geographic expeditions organized by the St. Petersburg state University, covers an area of about 70,000 sq. km. Geosystem distributive characteristics depending on hypsometric, geological-geomorphological, expositional, and climatic differences formed the basis for identifying the leading factors of geosystem spatial differentiation.

The determining factor in the formation of psammophytic, petrophytic, halophyte, and semi-desert geosystems (*Cleistogenes, Stipa, Ptilagrostis, Artemisia frigida, Kochia,* etc.) is the geological and geomorphological conditions of the basin bottom, i.e. a wide distribution of soils with light mechanical composition and sandy massifs, saline soils, etc. Thus, solonchak geosystems (sedge and grass-sedge meadows) are distributed on saline substrates with close-up groundwater on rivers and lake terraces, lake-river and continental deltas. The distribution of petrophyte and psammophyte (a combination of loose sands and sparse grass and shrub) geosystems is mainly associated with a crystalline basement daylight surface emergence, a large amount of detritus in river deltas, alluvial cones, etc., as well as the spread of eolian relief forms.

The landscape shape of the low-mountain part of the basin (up to 1000 m) is characterized by the predominance of feather grass steppes, solonchaks (mainly on the lakeside hollows), and semi-deserts with insignificant participation of small-leaved valley forests. Steppe geosystems are widely spread throughout the altitudinal basin mounting profile. In the middle altitude the taiga belt with its steppified larch forests, *Pineto(sibirica)-Laricetum herbosum* forests, *Pineto(sibirica)-Laricetum* and *Piceeto-Laricetum herboso-hylocomiosum* forests is quite remarkably distinct. The upper forest boundary (about 2400 m) is represented by sparse larch woodlands coupled with moss-lichen dwarf shrubs. However, above 2200 m, the tundra with lichen and dwarf shrubs forests predominates.

The central and eastern parts of the basin are rich in barchan, hilly, shallow-cellular, and coarse-grained sands, covered with sparse feather grass (*Stipa*), wheat grass (*Agropyron*), oxytropes (*Oxytropis*) and pea shrub (*Caragana*) communities. The traditional model of nature management (grazing) alongside with the increase over the last decades in the air temperature and moisture lack contributed to the drying out of the mantled layers with their feeble cementation, as well as partial or complete root system separation, which resulted in a reinforced blowing, denudation, and desertification. However, to date, we are facing a pronounced tendency to

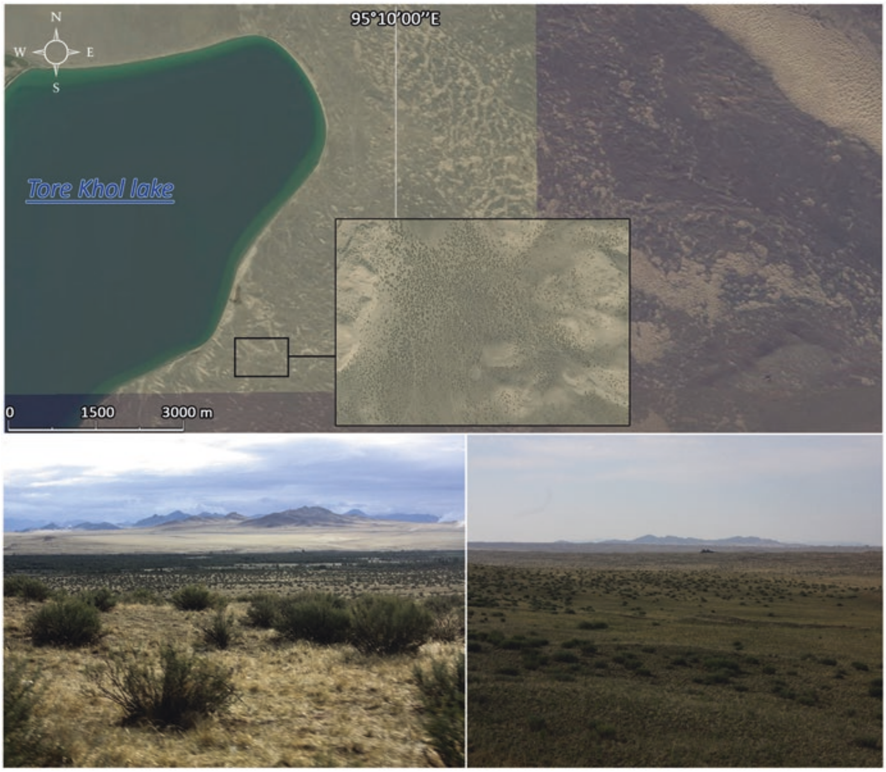

Fig. 21.2 A case of sand fixation by turf forming grasses and caragana in the vicinity of the Tere-Khol lake (at the top – NASA Blue Marble world imagery, 2016, below – Gavrilkina S. photo, 2013)

consolidate sandy ridges and dunes with expanding psammophyte groups (Fig. 21.2). In our opinion, the development of psammophyte communities under conditions of growing aridization is likely to be the consequence of a significant decrease in the unfavorable overgrazing impact owing to the fact that the territory acquired the SPNT (Special Protection National Territory: natural biosphere reserve) status which brought serious changes in the mode of anthropogenic activities.

To evaluate the importance of the climatic factor for the depression landscape differentiation, the ecological and climatic geosystem niches were identified with regard to plant community occurrence frequency within certain limits of estimates for the sums of active temperatures (above 10 °C) and summer precipitation at different types of locations. Simulation of the spatial distribution fields for the main climatic characteristics was carried out on evidence from 15 weather stations through a digital relief model. Due to the sizeable depression, the height difference, as well as the temperature inversions and barrier effects, both vertical and longitude gradients were used in the calculations (Chistyakov et al. 2009).

The patchiness of landscape structure observed in the middle altitude depression, determines numerous overlapping, intersecting, and sometimes, localization of ecological and climatic niches of various geosystems, is above all caused by orographic, geological, and geomorphological factors.

According to the results of expectable landscape transformation modeling under a given climatic scenario (warming versus atmospheric precipitation reduction), a significant increase in semi-desert, halophytic, and psammophyte geosystem areas in the low-mountain belt seems to be quite possible. In the middle altitude, a considerable expansion of the forbs-gramineous steppes seems possible to occur, resulting in a sharp decrease in the areas of cedar-larch and spruce-larch forests. Despite the increasing air temperature at the upper forest boundary (about 2400 m), present-day existing climatic conditions are quite favorable for the reinforcement and spread of the undergrowth, still we can hardly expect the upslope forest movement in at least one stand generation change. Moreover, the potential for tree upgrowth is limited by highland specific features, such as steep slopes, explicit cryogenic processes, strong wind, etc.

For the territory of Inner Asia, nature-use modes and landscapes interaction are of paramount importance. This is due to the extreme living conditions of ethnic groups, their struggle for survival. Generally speaking, landscapes of the region went through weak modifications, which is typical for areas with indigenous nomadic culture. It should be recognized that anthropogenic impact is the main factor limiting the spread of forest geosystems in the areas with a continental climate. Thus, in the lowlands the acute problem of wood shortage for household needs leads to the deforestation of valley forests (*Populus, Salix, Betula*), which are sensitive to external impacts and exist at a very poor atmospheric humifying (below 150 mm of precipitation over summer) only due to auxiliary groundwater feeding. Moreover, the natural renewal of small-leaved forests is hindered by the constant intensive undergrowth trampling and consumption by livestock. In the mid-altitude taiga belt of the continental sector, due to changes in meteorological conditions, a considerable reduction in mesophytic species in the ground cover (prairiefication) is observed leading to a decrease in the habitat forming capacity and, consequently, to forest sustainability, thus, changing their fire resistance and resulting in a more frequent occurrence of both anthropogenic and natural large-scale fires spreading over tens of kilometers and causing significant damage (Fig. 21.3). As for industrial logging, it is more relevant for the semi-humid areas of the Altai and Western Sayan. In this case, the renewal of dark coniferous forests occurs through a series of recovering successions with small-leaved stages (high-grass, small-leaved, small-leaved-coniferous), as well as with the change of the main forest-forming species: in the overwhelming majority of cases *Pinus sibirica* is displaced by *Abies sibirica* (Gavrilkina and Zelepukina 2017). In semi-arid climate, where the light-coniferous taiga predominates, the *Larix* regeneration usually takes place avoiding a small-leaved stage and forest-forming species change. Thus, the taiga belt of the region has been subject to fundamental complication of its structure and growth of its patchiness under the anthropogenic activity impact during the last 50 years. Strongly disturbed landscapes in the region occupy rela-

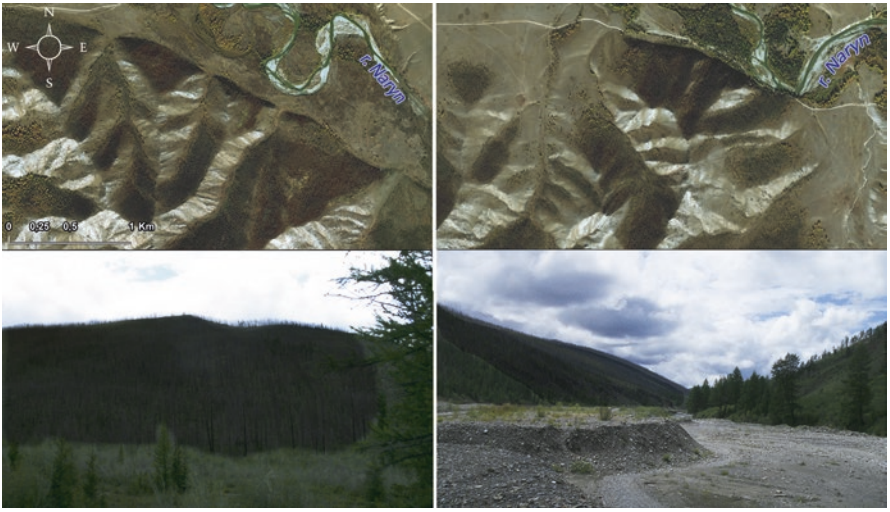

Fig. 21.3 Larch forests after fire disturbance in the Naryn River valley, Erzinsky district, Republic of Tuva. At the top – Landsat 8 imagery, 2017, below – photo Amburtseva N., 2011)

tively small areas and are related to water management and mining activities, occasionally to agricultural industry.

21.5 Conclusion

The research data obtained from long-term field studies of high-mountain landscapes of Inner Asia do not give enough ground for being convinced in the inevitability of global warming and regional landscape transformations resulting from it. All the changes in Inner Asia are of implicit nature: the winter season warming is observed in reality; but the warm half-year does not demonstrate the apparent trends in both: temperature and precipitation changes. Moreover, the multidirectional nature of precipitation fluctuations in the region does not allow one to unambiguously associate the processes of landscape dynamics with changes in external factors. On the one hand, in the highlands glacier and permafrost degradation processes, thawing of ice lenses and veins occur, consequently causing a level decline by 1–1.5 m in most mid-mountain lakes of moraine genesis; and, on the other hand, many large lakes located in the Great Lakes Depression, at the turn of the century, exhibited a rising trend in their level. To sum it up, one can affirm that the dynamics of slightly disturbed high altitude landscapes to a greater degree depends on environmental factors, while the dynamics of low- and mid- altitude landscapes results from anthropogenic impact of various intensity.

The continuation of the investigation depends on the interregional comparison and correlation of the research results, carried out in other mountain regions, as well as using modern remote methods (satellite sounding, electronic tacheometry, aerial survey, and pilotless vehicles etc.) followed by the obligatory verification during field observations.

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