Approaches to the study of vegetation dynamics in arid Eurasia biomes: a review

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Abstract. The article represents the review of methods and classifications that were used in studies of arid Eurasia biomes over time. All levels of vegetation dynamics (seasonal, yearly, long-term, evolutionary) considered with the peculiarities that are characteristic for the vegetation of the study region. In spite of the long history of scientific researches in Eurasia deserts, vegetation of Central Asia needs more researches based on modern methods of data collecting and data processing.

1 Introduction

The arid territories of Eurasia (with the exception of the steppe zone) are usually considered as part of the Sahara-Gobi desert region [1]. At the same time, the vast majority of scientists do not consider this region to be integral in botanical and geographical terms and divide its territory into several separate, independent subregions. For example, G. Walter [2] divide it into six areas: the Sudan-Sind, Sahara-Arabian, Iran-Turan, Dzungar-Kazakhstan, Central Asian and high-mountainous deserts of Tibet. E.M. Lavrenko [1], who approached the issue of understanding the boundaries of the zone more narrowly (without desertified steppes and mountains), singled out the Sahara-Sind, Central Asian and Iran-Turan regions in its composition. Modern botanical geographers, when zoning the territory of Kazakhstan and Central Asia, are guided by the same principles [3].

The whole area can be characterised with a Mediterranean climate with winter rains, which, however, reach relatively large amounts only in the Mediterranean region s.str. When we moving to the east, the amount of precipitation decreases [2]. The Sudan-Sind and Sahara-Arabian parts of the region are located in the subtropical climatic zone, while the purely Asian desert regions are considered as subboreal, lying in the temperate zone due to the cold winter [2].

The structure and functioning of ecosystems, even under conditions of a relatively stable natural environment, do not remain unchanged over time [14]. Depending on the time scale and nature of changes, scientists describe diurnal dynamics, seasonal dynamics, yearly dynamics (fluctuations), long-term dynamics (successions), historical and evolutionary dynamics of vegetation. Since diurnal dynamics does not affect the structure of most communities significantly [4], in this review, we will consider other types of vegetation dynamics.

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2 Seasonal dynamics

Seasonal dynamics is associated with the annual changes of temperature, sun radiation and precipitation. Due to the inclination of the Earth's axis of rotation, the seasonal dynamics is characteristic of almost entire territory of Earth, with the exception of the equatorial regions [5].

Arid regions are characterized by pronounced seasonal dynamics of vegetation. In Eurasian deserts it is expressed in the functioning of different synusias at different time. During the growing season, there can be observed: early spring regrowth and mass flowering of ephemers and ephemeroids; spring-summer vegetation of perennials; summer thermopause in some species of shrubs (for example, many sagebrushes after spring vegetation shed their leaves in summer); autumn secondary regrowth of leaves and flowering of sagebrushes; maturation of seeds of sagebrushes and saltworts in autumn. In unfavorable years, under conditions of insufficient precipitation, the synusion of ephemers and ephemeroids may not develop at all, and a delay in the vegetation of subshrubs is also observed [3]. In steppe communities, the seasonal dynamics is expressed differently: with the onset of a summer drought, many species do not complete their vegetation, but go into a state of semi-estivation [6].

A special factor in the seasonal dynamics of arid phytocenoses is the change of the colour aspect (the habitus of communitiy), which is under impact of the seasonal dynamics of the community structure (synusial / structural change of aspects), and the change in the phenological state of species (phenological change of aspects) [6] . The change of colour aspects is most studied in Eurasian steppes, where phytocenologists describe from 12 to 7 colour aspects during one season [7].

The floodplain regime of water bodies in arid regions is of great importance for the rhythm of meadow phytocenoses, which can be found in valleys of rivers, streams and gullies. Due to the high tolerance of plants and the decrease in their physiological activity under unfavorable conditions, species that differ significantly in ecological preferences can coexist here [5].

3 Yearly dynamics (fluctuations)

Fluctuations are yearly, non-directional, and insignificant variances in the composition of plant communities [4, 5]. T.A. Rabotnov [6] proposed to distinguish several types of fluctuations depending on the main source causing them:

- *Ecotopic (climatogenic)* fluctuations are caused by changes in hydrological and meteorological conditions. At the same time, changes in the ecotope can cause chains of impact mechanisms. For example, in arid regions, drought leads not only to an increase in temperature, but also to an increase in soil salinity, as well as the development of locusts, which consume a significant proportion of the aboveground phytomass of the community [5]. In addition to the floristic composition of communities, climatogenic fluctuations in arid communities leads to changes in total projective cover and community productivity [8]. A severe drought can cause long-term fluctuations in the productivity of a community, still observed over a decade [5].
- *Anthropogenic* fluctuations are caused by human activity. An example is various grazing and haying regimes, fertilization, single emissions of pollutants [4, 5]. In arid areas grazing is the important factor that determines the community structure. For example, in the dry steppe part of Kalmykia, an increase in pasture load leads to a change from cespitose grasses to sagebrush vegetation, bringing its look closer to desert zone [9].

- *Zoogenic* fluctuations are caused by the activity of animals. The peak prevalence of phytophagous animal species often leads to the changes in amount of consumed biomass and the degree of disturbance of the soil cover [5]. For example, zoogenic fluctuations typical for the arid communities of Mongolia are caused by population peaks of Brandt's vole, which prefers to eat cespitose grasses and loosens the surface of the soil. As a result, rhizomatous grasses prevail in community after vole's outbreak with the gradual increased of cover of cespitose grasses over several (4-5) years [4].
- *Phytocyclic* fluctuations associated with the characteristics of the life cycle of plants, as well as uneven seed productivity or vegetative propagation over the years. The phytocyclic nature of the dynamics of the steppe communities of eastern Mongolia is reported, which is largely associated with the life cycles of species-edificators of communities [10]. It is assumed that under desert conditions, the seed productivity of annuals, which differs over the years, may be an important factor in their long-term coexistence in the same areas [11].

According to the degree of expression, fluctuations can be subdivided into latent, oscillatory, and digression-demutation. If the first option represents only quantitative changes in the participation of individual species in different years, then the latter is usually considered as a transitional form to successions, when only the phase of disturbance and the phase of restoration to a state close to the original can be distinguished [5, 6]. Some cases of pyrogenic cycles, which are usually still considered as successions, can also be attributed to digression-demutation fluctuations, especially in steppe communities [12, 13].

4 Long-term dynamics (successions)

Succession is usually understood as the process of changing communities over time, however, different authors have different views on the definition of vegetation succession, which is associated not only with different points of view of scientists, but also with the evolution of ideas about the subject of community dynamics since its beginning in F. Clements studies in the early 20th century [4, 5]. The most classical definition of succession propose that successions are irreversible, directed changes in the vegetation cover, manifested in the replacement of some phytocenoses by others [4, 6].

The difference between succession and other forms of vegetation dynamics, primarily yearly fluctuations, lies not only in the timing of the observed changes, but also, more importantly, in the significance of the changes. Fluctuations that depend on yearly changes in environmental conditions are characterized by non-directionality (the absence of a pronounced trend in the change in species composition), reversibility, and the absence of a significant change in the species composition of communities [5]. At the same time, the most pronounced digression-demutation fluctuations [6] can be considered as an intermediate between fluctuations and successions [5] or as an event that can lead to the onset of successional transformations [14]. From the point of historical and evolutionary changes in vegetation, successions, in turn, are considered as a cyclic process that does not bring ecosystems out of balance on a given time scale [15].

With regard to the arid ecosystems of Eurasia, the dynamics of communities was studied by steppe scientists of the USSR in the middle of the 20th century. During this period, studies of the vegetation dynamics of the steppe zone within the borders of the USSR were reflected in the report of E.M. Lavrenko "Steppes of the USSR" [1]; later, in western Kazakhstan, the dynamics of plant communities was studied by V.V. Ivanov [16]. Based on contemporary works on the dynamics of the vegetation cover by V.N. Sukachev and V.V. Alekhin [17], both authors distinguish exodynamic (related to external processes) and endodynamic successions(related to internal processes). Among the first group, climatogenic, edaphogenic, zoogenic, and anthropogenic changes in vegetation cover are distinguished; endogenous successions are understood as a change in communities under the influence of both individual species that make up them and their properties, and the community as a whole. E.M. Lavrenko also adds the division of successions in the steppes into long (centuries-long) and relatively short-term successions lasting years and decades. At the same time, both authors interpret the concept of successions very broadly, synonymizing with it any options for changing phytocenoses, including climatogenic changes lasting for centuries (nowadays more often considered as a process of vegetation evolution) or, on the contrary, processes that are not always considered in the rank of successions (for example, demutation of steppes after plowing). In addition, the views of both authors on pyrogenic and pasture successions differ. E.M. Lavrenko considers both processes "from the point of view of the phytocenoses themselves", considering pasture shifts as a variant of zoogenic successions, and pyrogenic ones as a separate variant of short-term exodynamic successions. In turn, V.V. Ivanov considers both options as part of anthropogenic successions, based on the fact that in modern steppe communities (both in the middle of the 20th century and today) both factors initiating succession are more often associated with human activity than with natural phenomena.

A special problem of the successional dynamics of vegetation that take place in geographical scope is the representation of vegetation cover dynamics on vegetation maps [18]. One of the methods for solving this problem is the construction of ecological-dynamic series (series of communities), including the root state and the stage, indicating the degree of deviation of the state assessment from the root one [19]. For the territory of Kazakh upland Z.V. Karamysheva [20] described petrophytic serial communities (petroseries) found at inclinations and tops of hills. Author developed a classification system, depending on the lifespan of the edificator and the dominant synusia. Described serial communities are divided into:

- Short-term communities - communities replaced by others throughout the life of the plant edificator species.
- Long-term communities of type 1 - communities where the dominant synusia is represented a growth form that does not dominate in zonal communities.
- Long-term communities of type 2 - communities where the dominant synusia is represented by a zonal growth form.

In addition to petroseries, for Central Asia and Kazakhstan, ecological-dynamic series are distinguished for communities on sandy substrates (psammoseries), saline soils (galoseries), and for valleys of watercourses (potamoseries) [21].

In the modern historical period, regarding the dynamics of the vegetation cover of Kazakhstan, the studies of L.A. Dimeeva [22], performed in the Aral Sea and Caspian regions and devoted to a particular case of successions on the dried sea bottom and coastal terraces under conditions of sea level decrease (especially relevant for the territory of the former Aral Sea). The author identifies various successional series depending on the edaphic conditions of the habitat (haloseries, psammoseries, potamoseries), consisting of 3-5 stages, while the final stages can be represented by several variants. L.A. Dimeeva also notes that under the influence of sea level rise, succession may recede to earlier stages, which also complicates the considered succession schemes. In addition, at present, many private local studies are being carried out for the territory of Kazakhstan regarding pasture successions (for example, [23-25]).

5 Evolutionary dynamics of vegetation

The evolution of communities of living organisms is their changes leading to the existence of communities of new types (new combinations of cohabiting organisms) that did not exist before [5]. The evolution of an ecosystem must be studied over periods of time that significantly exceed the period of the succession cycle and abstract from the microfeatures inherent in each phase of succession. With this approach, most of the currently existing ecosystems can in essence be considered as conditionally stationary states, within which succession processes are cyclic. Evolutionary processes are irreversible and acyclic, since both micro- and macro-characteristics of the system change irreversibly [15].

The reasons for the evolution of ecosystems are divided into two categories [15]. The first is exogenous causes: a change in physical and geographical conditions, leading to a disruption in the functioning of ecosystems, usually associated with changes on a planetary or even cosmic scale. The second is endogenous reasons: the emergence of new species characterized by higher competitiveness; or a slow, gradual change in the environment of the ecosystem by itself over a long time.

As a rule, exogenous changes lead to the simplification and degradation of ecosystems due to the disappearance of part of the species populations, while endogenous changes, on the contrary, lead to the complication of ecosystems. During the Cenozoic era, the factor determining the evolution of ecosystems in the territory of the modern arid zone of Eurasia was an exogenous factor of a gradual change in climatic conditions towards aridization. The modern flat deserts of Eurasia are located on the territory that once represented the bottom of the Paratethys in the Eocene (56-33.9 million years ago); land areas in the territory of Central Asia and Kazakhstan in the Paleogene were occupied by broad-leaved forests with an admixture of conifers, formed in a warm and humid climate with winter cooling [26].

In the middle of the Cenozoic, the closure of the Eurasian, African and Indian lithospheric plates led to a gradual uplift of the territory of modern Central Asia, as a result of which the sea regressed. The climate changed in the direction of sharply continental, forests were replaced first by treeless grasslands, and then by deserts. The glacial epochs in the Cenozoic contributed to the mitigation of conditions in the so-called pluvial periods, when the plains of Central Asia were flooded due to the runoff of melted glacial waters from the mountains; interglacial periods corresponded to xerothermal periods with increased aridity of the climate. During the Quaternary period, the climatic situation on the plains of Central Asia is characterized by stability and the preservation of the desert regime (in the pluvial epochs - desert-steppe regime) [26]. Gradual aridization over thousands of years led to the formation of a large number of neoendemic species in the region, as well as the communities they make up, which can already be considered as a manifestation of processes caused not only by exogenous, but also by endogenous causes [27].

In addition to the natural evolution of ecosystems, the anthropogenic evolution of communities is also distinguished as a separate group of processes, which proceeds rather quickly compared to the natural evolution [4, 5]. It divides into the following forms:

- Targeted evolution (replacement of natural communities by artificial ones; introduction of species and their inclusion in natural or artificial communities; construction of new types of artificial communities (including fields, parks, reclamation on technogenic substrates etc.)
- Spontaneous evolution (unintentional introduction of other living organisms; destruction of species or reduction of their genetic diversity; displacement of the boundaries of natural zones due to human activities; the emergence of new types of communities, both secondary (in case of disturbance of natural communities) and primary (for example, in case of self-revegetated technogenic substrates)[4, 5].

The anthropogenic evolution of the arid communities of Eurasia is most noticeable in the steppe zone. Here, the most rude form of human impact on the steppe communities is plowing, the consequences of which are a complete change in the phytocenosis, very strong changes in the zoocenosis, a significant restructuring of the microbiocenosis, microclimate and soil [7]. Zonal types of steppes are plowed up by more than 75%, and in the flat steppes of the Central Black Earth Region, the southern Urals and Kazakhstan, arable land occupied from 83 to 91% of the territory in 1990 [28]. An equally important factor is overgrazing by cattle, which leads to the poaching of steppe communities, soil compaction, and a change in the species composition of phytocenoses [7]. In the deserted steppes of Eurasia, for example, in Kalmykia, overgrazing in combination with climate fluctuations acts as a desertification factor [9, 29]. As an opposite manifestation of the anthropogenic evolution in the steppes, we should also mention experimental restorative successions (demutations) using the agrosteppe method, leading to the formation of communities on fallow lands that are close to the original in composition and structure over several years [5, 30]. On the whole, however, the intensive human impact on arid regions is in many cases not yet long enough to objectively judge the irreversible processes of community evolution.

6 Conclusion

The dynamics of arid communities in Eurasia, despite the long history of their study, still needs significant research. There is a particular lack of research using modern methods of data collection and processing, since over the past 40 years there have been relatively few major works examining the dynamics of the communities of the region. Also, the dynamics of the ecosystems of the arid zone of Eurasia is important in terms of global climate change and the fight against desertification, especially caused by anthropogenic activities (for example, overgrazing).

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