Formation of Forest Biogeocenoses on Disturbed Lands of the Northern Caspian Region

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Abstract—The features, trends, and rates of formation of new forest biogeocenoses on anthropogenically disturbed lands, in particular, on an unused pond created on heavy loamy soils in the semidesert of the Northern Caspian region are analyzed. At the early stage of spontaneous pond colonization by vegetation, the development of the pond was most significantly influenced by a seed source (300 m from the pond) in the Arboretum of the Dzhanybek Research Station of the Institute of Forest Science, Russian Academy of Sciences, in which 120 species of introduced tree and shrub plants grow. Thirty-four pioneer species initially colonized the lower part of the unused pond, and 29 of these species had survived into 2018. The formation of intrazonal willow—oleaster—poplar communities of the quasi-tugai type with a weed—wet-meadow herbage has been revealed. Their development was influenced by geographical isolation, self-regulation under rather unstable moisture conditions due to occasional flooding by melt snow waters and bogging. The upper part of the soil-forming rock brought to the surface has been differentiated. A forest leaf litter has been formed from slightly decomposed tree leaves and twigs with a thickness of 1–2 cm; the stock of this litter is currently quite substantial, reaching 0.953 ± 0.196 kg/m², and the ash content has reached 13.85%. Ca absolutely prevails in the ash, while the amounts of Mg, Fe, and K are significantly lower. A humus horizon has been formed, and the soil effervescence depth has changed. On the whole, the previously infertile substrate has acquired features of immature soil over the almost 40 years of its colonization: the manifestation of humus-accumulative process, gradual humification of organic matter, and decarbonization of the matter. On the whole, a compact, structurally diverse, spontaneously emerging self-developing forest biogeocenoses may significantly transform disturbed semidesert areas. The features of their structure and the composition of emerging species make it possible to choose species properly that are the most suitable for landscaping.

Keywords: formation of biogeocenoses, disturbed lands, intrazonal conditions, quasi-tugai, immature soil
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INTRODUCTION

The agricultural development of semidesert lands between the Volga and Ural rivers in the Caspian Lowland has significantly transformed the landscapes in this area; however, in addition to its purposeful cultural use, abandoned artificial depressions (quarries, canals, ponds, trenches, etc.) are increasingly common here. These topographic lows are often overgrown with trees and shrubs because of their better moisture supply in this zone than in the surrounding treeless area. These sites are interesting objects for studying processes of primary successions and soil formation. The time of their emergence (start-moment) is usually known, which makes it possible to observe the features, trends, and rates of formation of soil and vegetation cover on an initially lifeless substrate over many years (Sizemskaya et al., 1995; Sizemskaya and Sapanov, 2002; Dimeeva, 2007; Sizemskaya, 2013; Akhmedenov and Azhakhova, 2018). In this context, we provide the results of almost 40-year-long continuous monitoring of the formation of soil and vegetation cover in the Arboretum of the Dzhanybek Research Station of the Institute of Forest Science, Russian Academy of Sciences.

MATERIALS AND METHODS

This paper presents some results of studying the formation of the natural forest biogeocenosis and primary soil profile in the lower part of a depression with a size of $35 \times 45$ m and a depth of 3 m, which was excavated in 1979. This place was initially planned to be used for creating a pond; however, it was artificially filled with water only once in 1980 and was then abandoned and gradually began to be overgrown with vegetation (Fig. 1).

The object is on the territory of the agroforestry complex of the Dzhanybek Research Station of the
Institute of Forest Science, Russian Academy of Sciences, in the clay semidesert of the Northern Caspian region on the border of Volgograd oblast and the Republic of Kazakhstan. Almost one-third of its area was covered by soils of the solonetz complex (microrelievations with solonchakous solonetzes containing up to 3% of readily soluble salts in the soil profile); the area is dominated by semishrub communities: Kochia prostrata and Artemisia pauciflora (the Latin names of plants are given according to K.S. Cherepanov (1995)). The topographic lows with nonsaline meadow–chestnut soils are dominated by grasses and forbs, while the microslopes with solonetzic light-chestnut soils are dominated by Tanacetum achilleifolium, Leymus ramosus, and Agropyron desertorum (Kamenetskaya, 1952; Rode and Polskii, 1961; Olovyanikova, 2004; Novikova et al., 2004).

The state of the vegetation cover was annually monitored since 1981; the soil cover on the bottom was studied on an interval of 7–10 years in 1992, 2002, 2011, and 2018. We used field research methods generally accepted in forestry, soil science, and ecology.

RESULTS AND DISCUSSION

During the creation of the pond, the entire fertile layer and soil stratum were removed and a soil-forming rock without nutrients and with a humus content of not more than 0.1% was brought to the surface; therefore, the soil-ground was initially an unsuitable substrate for vegetation colonization. The pond slopes were formed from displaced soil and contained a significant amount of readily soluble salts (up to 3%). Additional moisture from snow accumulation subsequently formed a favorable water regime for moisture-loving vegetation on the infertile substrate in the lower part of this topographic low. Periodic monitoring of the moisture content revealed a good moisture supply for the soil ground on the bottom: here, the average moisture content of the upper strata is 20–23% and corresponds to the lowest moisture capacity, while the productive moisture reserve in the 0–2 m layer reaches high values (400 mm). The depth of ground water is 1.8–2.0 m and its salinity does not exceed 0.9 g/L; its composition is hydrocarbonate–calcium. This contributed to the spontaneous colonization of pioneer woody and herbaceous vegetation species.

Vegetation cover formation. From the first year after the cessation of pond filling with artificial water (1980), the surface of the lower part and slopes began to be colonized actively not only by the common reed (Phragmites australis Trin. ex Steud.), but also by some tree and shrub species. These species included the self-sown oleaster (Elaeagnus oxyccarpa Schleiht.), black poplar (Populus nigra L.) and white poplar (Populus alba L.), Caspian willow (Salix caspica Pall.), etc. In 1985–1986, the pond began to be intensively colonized by vegetation. Self-sown anemophorous and zoonchorous woody and shrub species annually colonized the lower part of the pond; their seeds were distributed from the Arboretum of the Dzhanybek Research Station (at a distance of about 300 from the pond), where over 120 tree and shrub species grow (Senkevich and Olovyanikova, 1996). Since 1993, the most widespread species in the lower part of the pond was oleaster. It formed a fragmentary 5–6 m high canopy. The domination of oleaster is explained by its wide ecological amplitude, salt tolerance, and good adaptability to variable environmental conditions (Nikitin, 1966; Svyazeva, 1986). In the southern part of the bottom, the second most widespread species was the Caspian willow, represented by shrubs from ten to 18 shoots with a height of 4–5 m. A few black poplar specimens with a height of 4–6 m and one black poplar specimen with a height of 8 m and a diameter of 12 cm were recorded. Three-to five-year-old individuals of green ash (Fraxinus pennsylvanica Marsh.), common hackberry ( Celtis occidentalis L.), field elm (Ulmus carpinifolia C. Koch.), plumleaf crab apple (Malus prunifolia Borkh.), Siberian elm (Ulmus pumila L.), black and white poplars, bitter-berry (Padus virginiana (L.) Mill.), and three hawthorn species (Crataegus monogyna Jacq., C. submollis Sarg., and C. korolkowii L. Henley) occurred occasionally. A 1–2 m high underbrush was formed from golden currant (Ribes aureum Pursh.), common barberry (Berberis vulgaris L.), Tatarian honeysuckle (Lonicera tatarica L.), brier (Rosa sp.), European buckthorn (Rhamnus cathartica L.), and low juneberry (Amelanchier spicata Koch.). A total of 34 woody and shrub species were recorded. Almost all of them are confined to the lower parts of the slopes. Five–seven species were recorded on the lowermost part of the pond (Sizemskaya et al., 1995).

In the early 1990s, the woody and shrub vegetation was at the stage of formation; this was indicated, among other things, by a clear vertical closure of plants, which

Fig. 1. View of the pond overgrown with trees and shrubs, 2018.
of different ages and compositions, which together formed thicket communities.

The grass cover of these woody and shrub thickets had an uneven composition and was represented mainly by meadow—bog species, which here formed tall grass clumps from reed, wood small-reed (Calamagrostis epigejos (L.) Poth), hoarhound (Amagrostis epigejos) tall grass clumps from reed, wood small-reed (Calamagrostis epigejos (L.) Poth), hoarhound (Epilobium nervosum Boiss. et Buhse), and aster (Aster salignus Willd.). Trees and shrubs were often densely intertwined with bed-drain Galium pseudovirelze Tzel. and bittersweet Solarum dulcamara L.).

In more illuminated areas, small clumps of creeping buttercup (Ranunculus repens L.), water germander (Teucrium scordium L.), bushy cinquefoil (Potentilla supina L.), and knotweed (Polygonum mite Schrank) could be found under the sparse woody and shrub canopy, and groups of mesohilous meadow species (couch grass (Elytrigia repens (L.) Nevski.), willowleaf yellowhead (Inula salicina L.), and catnip (Nepeta cataria L.) occurred on microelevations. Arable and pasture weeds (field milk whistle Sonchus arvensis (Sónchus arvensis L.), creeping thistle (Cirsium arvense (L.) Scop.), barnyard millet (Echinochloa crusgalli (L.) Beauv.), green foxtail (Setaria viridis (L.) Beauv.), rough cocklebur (Xanthium strumarium L.), etc.) also occurred here rather often; their sprouts are brought by cattle from pastures adjacent to the pond and from nearby arable lands (Sizemskaya et al., 1995). The herbaceous vegetation on the lower part of the pond was characterized by its clump distribution, tall-weed herbage, and abundant weed species, which is typical for pioneer groups and often observed at the initial stages of vegetation formation.

It was too early to observe the formation of communities both on the slopes and on the lower part of the pond 10–15 years after the beginning of pond overgrowth, since the vegetation of the slopes was extremely sparse by that time and represented by almost undifferentiated thickets with poor composition on the lower part. Some predictions could only be made on the development paths of these thickets. It was assumed that vegetation on slopes would develop according to the steppe zonal pattern, depending on exposure (Sizemskaya et al., 1995), which is usually characteristic of recovery successions in this region (Dzhapova, 2007, Novikova et al., 2018). However, the natural complex of the lower part of the pond “followed” the path of development of so-called tugais (intra-zonal desert formations of near-river woody shrub thickets combined with meadow bog groups) back at that time (Rastitel’nyi pokrov..., 1956). They are characterized by species recorded on the lower part: reed, wood small-reed, greater plantain, creeping buttercup, and soft buckwheat. We recorded 34 herbaceous plant species, half of which were represented by weeds (Sizemskaya et al., 1995). In true natural tugais, the dominant species are poplars with an admixture of willow (several species), oleaster, and tamarisk. Barberry, buckthorn, honeysuckle, brier, and reed penetrate under the forest canopy (Korovin, 1961). Large-grass wet-meadow willow oleaster forests occur in some areas of the desert zone (Nikitin, 1966). We recorded these species on the lower part of the former pond.

In 1994, the snowy winter and intense snow melting caused pond flooding. The water was 1 m above the ground for more than four months, which led to the overwetting and death of many species. Some forb representatives, as well as certain species of woody and shrub vegetation that cannot withstand long-term flooding (Semenov’s maple, tamarix, elder, white dogwood, etc.) disappeared. It is this period that marked a sharp depletion of the biological diversity of new biogeocenoses and, at the same time, an acceleration of the weedy stage of vegetation cover formation.

There were about 30 species by the early 2000s; the dominant species among them were oleaster, white and black poplars, and Caspian willow; golden currant, common barberry, Tatarian honeysuckle, brier, hawthorns, Juneberry, and buckthorn prevailed on the slopes of the pond. A native species, blackthorn Prunus spinosa L., occurring in local ravines and lake basins, appeared in this period. White poplar became particularly stable in the lower part of the pond; it formed a canopy clone stand with trees of different ages, which occupied about 50% of the site area. The average height of the clumps is 13 m; some specimens reach 20–22 m at a diameter of 55 cm. Oleaster and willow occupy 10% of the area each; 30% of the area is covered by “windows” with a single one- to three-year-old self-sown black and white poplars. The ground cover is represented by wet—meadow vegetation groups with the involvement of reed, wood reed, and (less often) bugleweed (Fig. 2).

It should be noted that the studied pond is not the only one in this area between the Volga and Ural rivers: other similar abandoned objects occur rather often here. We recorded a widespread distribution of oleaster, willow, and poplar in artificial topographic lows, especially in those containing water (ponds and canals). In particular, the colonization of tugai-like trees and shrubs dominated by white willow (Salix alba L.) and two poplar species (black and white poplars) was described in a similar topographic low in western Kazakhstan (Akhmedenov and Azhakhova, 2018). The species composition is determined by the distance of this object from the floodplain forests of the Urals River (40 km), which indicates natural factors for the colonization of native species, growing here under intra-zonal hydromorphic conditions. In addition, poplars and willows often appear along the low-water line of numerous canals and ponds, which prevents their normal use.

As can be seen, the above-described key site is not unique, since similar vegetation often occurs through—

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out the studied area, which indicates a single mecha-
nism of colonization of artificial wet sites by anemo-
and zoochorous woody and shrub vegetation.

The intrazonal pattern and quasi-tugai appearance
of the forest biogeocenosis have been preserved at this
site for almost 40 years against the background of
increased intraspecific and interspecific competition
with an increase in the age of main forest-forming spe-
cies. At the current stage, there is no reason to believe
that the life cycle of this spontaneously formed forest
biogeocenosis will be transient, despite the dominant
influence of the water factor, which is determined by
the special hydrological regime of the site (significant
fluctuations in the groundwater level due to the peri-
odic flooding of this depression with melt water).

**Soil cover formation.** The spontaneous emergence
of vegetation, in particular, woody and shrub vegeta-
tion, significantly influenced the transformation of
the initial substrate, which had a medium loamy gran-
ulometric composition, a poorly defined lumpy struc-
ture, and pale brown color and rapidly effervesced
under the action of HCl. Signs of primary soil (litter
accumulation and some differentiation of the mor-
phological profile) began to be observed ten years after
the beginning of the colonization of the lower bottom
of the pond by vegetation. Processes of accumulation
and transformation of organic matter subsequently
became more intensive.

At the current stage, the following features of the
structure of the morphological profile of the embry-
onic soil are observed (Table 1).

A litter horizon from slightly decomposed tree
leaves and twigs with a thickness of 1–2 cm is clearly
distinctive from above; its stock is currently quite sub-
stantial, reaching 0.953 ± 0.196 kg/m² at an ash con-
tent of 13.85%. The ash composition is absolutely
dominated by Ca (26015 mg/kg); the content of Mg,
Fe, and K is much lower. A brownish–dark-gray
humus horizon, W, with a depth of 1–2 cm was
formed under the litter; this humus has a well-defined
lumpy–powder-like structure, does not effervesce,
and is densely intertwined by plant roots. The C₉ₒᵣg
content is 0.67%. This horizon is characterized by the
humus accumulation of coarse organic modern-type
matter, as well as by active zoogenic structuring under
the effect of all forms of microorganisms (bacteria,
fungi, actinomycetes, diatoms, and other soil algae
cyanobacteria, as well as nematodes and some
protozoa (Lebedeva et al., 2014). Here, the fungal
component prevails over the bacterial one at a ratio of
2.1 : 1 (Prikhod’ko and Sizemskaya, 2015). This is
consistent with the statement that an increase in the
amount of fungi in soil promotes the sequestration
(storage) of soil carbon (Bailey et al., 2002).

The litter horizon is followed by a fragmental
lumpy—powdery—fine-grained and grayish–light
brown horizon, C1ca, which is 2–3 cm thick, has signs
of eluviation (clarification of mineral matter), and is
characterized by strong effervescence and fine-cryst-
talline gypsum growth. At a depth of 5–7 cm, it
changes to a pale brown platy—nuciform—granulated
medium loam, which is transformed into the original
soil-forming rock with gypsum druse bands at a depth
of 15–17 cm. The processes of biogenic transforma-
tion of the mineral and organomineral soil matter
revealed covered the upper 15 cm layer (Lebedeva
et al., 2014).

With respect to the structural features of the mor-
phological profile, this soil layer can be assigned to the
humus-accumulative, weakly alkaline carbonate type
(Abakumov, 2012), division of immature soils,

| Horizon | Depth, cm | C₉ₒᵣg, % | pH_water | Total salts, % | Fraction <1 μm | Ca²⁺ | Mg²⁺ | K⁺ | Na⁺ |
|---------|-----------|-----------|----------|---------------|----------------|-------|-------|-----|-----|
| W       | 0–2       | 0.67      | 7.3 ± 0.2| 0             | 11 ± 3         | 26.6 ± 13.6 | 3.7 ± 0.7 | 0.41 ± 0.02 | 0.10 ± 0.03 |
| C1ca    | 2–7       | 0.50      | 8.0 ± 0.2| 0.41          | 15 ± 1         | 21.9 ± 4.7  | 2.8 ± 1.4  | 0.22 ± 0.07 | 0.09 ± 0.01  |
| C2ca,cs₂| 7–15      | 0.20      | 8.1 ± 0.1| 0.41          | 18 ± 1         | 19.3 ± 1.4  | 6.2 ± 5.8  | 0.09 ± 0.02 | 0.17 ± 0.18  |
| C3ca,cs₂| 15–25     | 0.10      | 8.0 ± 0.1| 0.91          | 16 ± 1         | 17.4 ± 2.9  | 8.0 ± 0.4  | 0.06 ± 0.02 | 0.26 ± 0.13  |

Mean values ± confidence interval at P = 0.9, n = 3.
according to the modern classification of soils of Russia (Klassifikatsiya..., 2000).

Thus, the upper part of the soil-forming rock brought to the surface was differentiated over the period of 30–40 years. Forest litter and a humus horizon were formed and the effervescence depth changed, which results from the humus-accumulative process and gradual humification of organic matter, as well as from decarbonatization of the matter. The humus horizon was formed at a rate of about 0.5 mm per year, while the rate of $C_{org}$ accumulation is estimated to be about 0.01 g/100 g soil per year.

The soil—ground layer to a depth of over 80 cm contains a small amount of nontoxic readily soluble salts composed mainly of sulfates; the amount of exchangeable Na$^+$ does not exceed 1 mmol (eq)/100 g. In the upper horizon, the content of K$^+$ increases in the exchangeable bases as a result of its supply together with melt water. The average pH values do not reach 8.1 in any of the horizons, which indicates the absence of soda salinization (see Table 1). The transformation processes of soil formation covered even the conservative part of the soil—its mineral composition. It was revealed that the upper W horizon was depleted in the silt fraction due to the predominant removal of smectite minerals with partial vermiculitization of chlorites (Sokolova et al., 2013). This shows an increase in the number of exchange positions in the crystal lattice and, accordingly, an increase in the cation exchange capacity. All of this reflects deeper processes of natural regenerative pedogenesis, which leads to the formation of soils (more likely, chestnut soils) without signs of alkalinity under these conditions.

On the whole, the material presented justifies the extension of the lists of species for landscaping under hydromorphic conditions in arid regions and makes it reasonable to recommend the creation of artificial forest plantations of oak, poplars, willows, berry shrubs, and ornamental mesophytic herbaceous plants for recreational purposes in unused depressions (Sposob lesomeliorativnoi rekul’tivatsii zemel’, 2010). These sustainable forest plantations, which are compact and structurally diverse and differ in their functional use and species composition, can significantly transform disturbed areas.

CONCLUSIONS

The development of the originally treeless area in the Volga and Ural interfluve involves the formation of numerous artificial depressions in low-lying areas (canals, ponds, trenches, etc.), which are often spontaneously colonized by trees and shrubs. This colonization has unique patterns, which were observed in the overgrowth of the lower part of the unused pond in the semidesert of the Northern Caspian region, which was colonized by species from the nearby arboretum.

The rate of development of pioneer phytocenoses was initially quite significant: over 60 plant species appeared in this area during the first 10–15 years of spontaneous colonization of the site; 34 of them are representatives of woody and shrub vegetation. Over the course of time, the species diversity decreased slightly (to 29 tree and shrub species) against the background of long-term flooding, fluctuations in the groundwater level, and soil moisture. Species that are highly tolerant to long-term exposure to adverse environmental factors (willows and poplars) or can rapidly gain lost positions owing to their intensive reproduction (both seed and vegetative reproduction) (oak and poplars) survived. On the whole, an intrazonal willow–oleaster–poplar forest stand of the quasi-tugai type with a weed wet-meadow grass cover was formed for almost 40 years. Under these conditions, the infertile substrate acquired the features of immature soil, which is characterized by the accumulative process, gradual humification of organic matter, and decarbonatization of matter.

The object studied made it possible to assess the ecological potential of using some tree and shrub species for creating indefinitely long-term natural forest ecosystems in artificial topographic lows in the originally treeless semidesert of the Northern Caspian region.

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COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

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