Rocznik Świętokrzyski. Ser. B – Nauki Przyr. 36: 55-63, 2015

Polska Akademia Nauk – Oddział w Krakowie,
Kieleckie Towarzystwo Naukowe

Biodiversity of phytogenic aeolian landforms in the Gobi desert (China)

Bioróżnorodność fitogenicznych form eolicznych na pustyni Gobi (Chiny)

JANINA BORYSIAK[2]

Zarys treści: Niniejszy artykuł zawiera przegląd literatury dotyczącej roślinności fitogenicznych form eolicznych wykształconych w wydmowych krajobrazach pustyń Tengger i Badain Jaran, leżących z obrębie Gobi, w Chinach. Uwzględniono jedynie prace opublikowane w języku angielskim w pliku *open access*. Szczególną uwagę zwrócono na wyniki badań nad bioróżnorodnością roślinną.

Słowa kluczowe:

Key words:

Janina Borysiak, *Zakład Geografii Kompleksowej, Instytut Geografii Fizycznej i Kształtowania Środowiska Przyrodniczego, Wydział Nauk Geograficznych i Geologicznych, Uniwersytet im. A. Mickiewicza w Poznaniu, 61-680 Poznań, ul. Dzięgielowa 27; janina.borysiak@amu.edu.pl.*

The crucial factors that shape the morphodynamics of semiarid and arid areas are vegetation and wind. Owing to them, the unique types of landscape with very distinct identity features of the surface morphology are formed in specific conditions. Among these types are areas with phytogenic aeolian landforms, called as, among others: cone, coppice dune, nebkha, phytogenic mound, shadow dune and vegetated dune (Mycielska et al., 2008; Du et al., 2010b). Such landforms are made of wind-transported sands, accumulated within and around plants. Their distribution and morphology depend, among others, on the developmental characters of plants, speed and direction of wind, sand resources and local hydrogeological conditions (El-Bana et al., 2002). Life forms, which most effectively accumulate sand, are shrubs, as well as small and medium size trees (Qong et al., 2002; Xiong et al., 2003; Liu et al., 2008; Mycielska et al., 2008; Li et al., 2010; Zhang et al., 2011; Pool et al., 2013; Zhou et al., 2015). It was proved that vegetation of nebkhas enriches accumulated sand in biogenic elements, while the nebkha groupings form so called fertile islands with microclimate and soil properties different from surrounding areas (Hesp and McLachlan, 2000; Zhang et al., 2011; Yang et al., 2014). When these landforms are not exposed to degradation, e.g., due to browsing and trampling by farm animals, they are safe sites for species that in the same climatic conditions, but without protection of other plants, would not survive (Brown and Porembski, 1997). El-Bana et al. (2002) named such sites 'vegetation islands'. Landforms of aeolian accumulation were recognized as good geoindicators of aeolian erosion and land cover degradation (Tengberg and Chen, 1998; Du et al., 2010a, b; Quets et al., 2013), as well as rapid desertification caused by extensive desiccation (Wang et al., 2006). The knowledge of mechanisms of their formation was used in environmental bioengineering and activities against desertification (El-Bana et al., 2003; Wang, 2004; Lavaine et al., 2015). The works by Yue et al. (2005) and Wang et al. (2006) contain the literature review (starting from the 80s) on the nebkhas occurring in

Photo 1. Sand accumulation around the *Nitraria tangutorum* (Nitrariaceae) shrub, Badain Jaran Desert (Gobi), China (photo by Janina Borysiak)

Fot. 1. Akumulacja piasku wokół krzewu *Nitraria tangutorum* (Nitrariaceae), Pustynia Badain Jaran (Gobi), Chiny (fot. Janina Borysiak) the dessert areas of China – their origin, spatial distribution, formation control, textural features of accumulated sand, morphology, internal structure, morphodynamics, soil, as well as their role in the controlling desertification.

In China, nebkhas were studied in the regions of: Alaxa Plateau, Bashang grassland, Hexi Corridor, Hotan River Basin, Lop Nor, Ordos Plateau, Taklamakan Desert and Ulan Buh Desert. The landforms of the aforementioned areas were built mainly by such species as: *Caragana microphylla* (Fabaceae), *Nitraria tangutorum* (Nitrariaceae) – Photo 1, and *Tamarix ramosissima* (Tamaricaceae). These scrubs attained the height of 0.4–1.8 m, 0.13–4.4 m and 1.0–15.0 m, respectively. They occurred most frequently around oases, in river valleys, lake catchments, on the alluvial fans at the foot of mountains, on degraded pastures and abandoned arable lands, as well as in the ecotones between oases and areas of mobile dunes. The areas with nebkhas, formed by the three mentioned species were characterised by the annual sum of precipitation of 22–330 mm. The average level of groundwater surface was located at the depth of 1.5–17.0 m and an annual wind speed ranged from 2.1–5.0 m/s. Nebkhas had cone-like or hemispherical shape. The former were formed by plants with vertical structure and numerous, densely branched shoots, while the latter – within plants with lodged, sparse shoots (Du et al., 2010b). Wang et al. (2006) mentioned several plant species that, besides *Caragana microphylla*, formed vegetation in the Huade County region, such as: Poaceae – *Cleistogenes squarrosa*, *Leymus chinensis*, *Stipa grandis* and *Stipa caucasica* subsp. *glareosa*; and Caragana stenophylla. The nebkhas that have developed in this region are approximately 0.4–1.8 m in height and 1.0–5.0 m in length. All nebkhas are covered by vegetation in approximately 45–100%.

On the Alaxa Plateau, nebkhas were studied in the area of a dry riverbed, with a mean annual precipitation of about 36 mm (1954–2003), potential evapotranspiration of 3,500 mm and dust storms occurring on more than 67 days year-1. They were formed mainly around *Tamarix chinensis* shrubs. They were not degraded because of the vegetation cover > 80% (Wang et al., 2008).

In the vast areas of shifting dunes of Taklamakan Desert, He et al. (2003) conducted research on the effects of aeolian erosion on the development and degeneration of *Tamarix taklamakanensis* community. This tamarisk is a Chinese endemic and threatened species, found only in the Taklamakan area. In the developing stage of community, sand burying stimulated vigorous growth of tamarisk shrubs. The community coverage was 8–22% in the southern and southeastern parts of Taklamakan Desert, 1–7% in its central part, and was sparsely distributed in most parts of the area (<0,5%). The cited authors did not mention any plant species that composed this community.

Only a few publications on the Chinese desert areas, emphasized a role of nebkhas in the development of biodiversity. It was found that these landforms provide a favourable microenvironment for the formation of a seed bank – less exposed to direct solar radiation, with cooler and moister soil than in internebkha spaces (Liu et al., 2006; Du et al., 2010b).

In Yanchi County (E 107025'11.68", N 37055'46.79", 1600 m a.s.l.), Zhou et al. (2015) studied plant cover of 397 nebkhas with *Nitraria tangutorum* and its connection with environmental gradients. These authors, in the introduction to their article, stated that, until 2015, the Chinese nebhkas were not investigated relative to the biodiversity of their flora, as well as structure and spatial distribution of plant communities. Thus, the study results of the cited authors are the only ones that determine a role of Chinese phytogenic aeolian landforms in the development of biodiversity.

The nebkhas with *Nitraria tangutorum*, studied in Yanchi County (Zhou et al., 2015), were convex, oval, or almost circular, free-standing mounds of 0,06-4,84 m in height, with the mean of 1,77 m. An average area, length and width were 36,76 m2, 7,15 m, 5,92 m, respectively. The vegetation cover ranged from 10,33–89.00% (the mean 34,84%), with an average cover of *N. tangutorum* – 22,41%. When nebhka was ≤ 2.0 m in heigh, the structure of its vegetation and vegetation of an internebkha space were similar. In total, 48 species , including 20 annuals and 28 perennials, were noted. They belonged to 16 families and 38 genera, which proves a high taxonomic diversity. The most numerously represented were: Poaceae, Chenopodiaceae and Asteraceae. The number of plant species increased linearly with an increase in the height and area of nebkhas, while for several calculated indices of species diversity (Simpson index, Pielou index, Shannon-Wiener index) – logarithmically. The study showed the relationship between the plant occurrence and nebkha differentiation into five types of microhabitats: crest, midslope, bottom, edge and internebkha space. *Chloris virgata* and *Eragrostis pilosa* (Poaceae) dominated within an internebhka space, while *Salsola collina* and *Corispermum chinganicum* (Chenopodiaceae – on a crest and midslope. An even distribution within microhabitats had *Artemisia sieversiana* (Asteraceae). The species diversity of internebkha spaces was higher than nebkhas, especially, far away from active dunes. Four groups of vegetation (I-IV) were distinguished based on dominating and subdominating species: I/ *N. tangutorum-Chloris virgata+Eragrostis pilosa*, II/ *N. tangutorum-Artemisia scoparia*, III/ *N. tangutorum-Salsola collina+Bassia dasyphylla* and IV/ *N. tangutorum-Agriophyllum squarrosum*. The first two groups (I, II) were characterised by a distinct contribution of halophytes and steppe species and, simultaneously, a large distance from mobile dunes. Two other groups (III, IV) were characterized by a dominating role of psammophytes. They were connected with the areas situated close to mobile dunes. The nebkhas with vegetation of the *N. tangutorum-Chloris virgata+Eragrostis pilosa* type were distinguished by the highest mean values of such parameters as: height (2,21 m), length (8,82 m), width (6,84 m) and area (55,39 m^2). The highest number of species (35 on average) and vegetation cover (38,5% on average) had vegetation of the group *N. tangutorum-Artemisia scoparia*. Communities of *N. tangutorum-Agriophyllum squarrosum* (IV) had the lowest species diversity. In the article's conclusion, Zhou et al. (l.c.) stated that nebkhas were habitat of many functional groups of plants and their characteristics (length, width, height and area) substantially affected floristic diversity.

Previously, nebkhas were studied by Liu et al. (2008) in Jinta County and Ejin Banner, on the Gobi dessert. They examined landforms formed around *Tamarix ramosissima* and listed several accompanying species: *Elaeagnus angustifolia* (Elaeagnaceae), *Haloxylon ammodendron* (Chenopodiacea) and *Populus euphratica* (Salicaceae). The majority of nebkhas represented free-standing landforms. They formed a chain along the axis reflecting the prevailing wind direction. The spatial diversity of nebkhas was shown – it was higher on the dessert in Ejin Banner than in Jinta County.

Qong et al. (2002) conducted research on phytogenic aeolian landforms of the Taklamakan Desert, in north-west China. In this desert, mobile dunes covered 85% of the area, while the remaining 15% was occupied by permanent or relatively permanent landforms, called by these authors – *Tamarix cones*. This article provided some data about a role of cones in the plant diversity development of Taklamakan. Within the seven studied cones, the following species had the highest cover: *Tamarix ramosissima*, *Phragmites australis* (Poaceae), *Alhagi sparsifolia* (Fabaceae), *Calligonum mongolicum* (Polygonaceae), *Nitraria sibirica* and *Scorzonera divaricata* (Asteraceae). The occurrence of sticky glands along tamarisk leaves was emphasized. Owing to these glands, the falling leaves stick together and form cohesive litter, not dispersed by wind, on the nebkha surface.

In the north-west part of Gobi Desert, 229 nebkhas were studied, mostly, in their early phase of development. Apart from Nitraria ramosissima, nebkhas are frequently built also by *N. sphaerocarpa* (Su et al., 2012). It is thought that *N. sphaerocarpa* plays a significant role in stabilizing desert sands. This role results from its biological features, i.e., its capability for abundant branching and intensive vegetative reproduction. *N. sphaerocarpa* was accompanied by, among others: *Reaumuria soongorica* (Tamaricaceae) and terophytes – *Suaeda glauca* (Chenopodiaceae) and *Zygophyllum orientale* (Zygophyllaceae).

Some data on the species diversity of nebkhas were provided by Zhang et al. (2011) for the north-west part of Ordos (NE of Langzhou), located on the Inner Mongolia Plateau. The nebkhas in this region were studied on the area of 4.5 ha, in the plant formation of *Caragana tibetica*, which forms an ecotone zone of 20 km in width and 500 km in length, situated between a steppe (from the east) and desert (from the west). They were formed from sand carried by winds from the deserts: Badain Jaran, Tengger Desert, Ulan Buh and Bayinwenduer. The nebhka vegetation was dominated by: *Caragana tibetica*, *Reaumuria soongorica*, *Potaninia mongolica* (Rosaceae) and *Tetraena mongolica* (Zygophyllaceae). The amount of sand accumulated by *C. tibetica* per unit of area was 0.0313 m^3m^{-2}. It was found that a nebkha becomes a fertile island gradually, in the course of its formation, and, at the same, time, its heterogeneity is developed.

During the workshops, the landscape structure studies of the area monitored by the Gansu Minqin National Station for Desert Steppe Ecosystem Studies (geographical coordinates: E 102055'11"/N 38037'44") and Gansu Desert Control Research Institute in the city of Wuwer were carried out. Monitoring covers, among others, a shelterbelt system (10 km in width and 100 km in length), established for the protection of agricultural areas of Minqin oasis. This belt contains the planted species of several trees, including poplar. Zhao et al. (2011) published monitoring results related to the effect of vegetation of both shelterbelt and desert on dust reduction during 19 sandstorms in 2006. The area of the station is surrounded by the Badain Jaran Desert in the west and north and by the Tengger Desert in the east. This area is one of main sources of sandstorms in China. Sand dust events occur 25 days year-1. The cited authors reported that the transportation of sand-dust at the desert site was mainly concentrated in the near ground layer and desert vegetation had an important role in reducing sand-dust flux. This vegetation consisted mainly of *Nitraria tangutorum* community, with an average cover of 7.5% and mean height of 0.31 m, formed within shrub dunes of 1.00 m in height.

A visit was paid to the Minqin Desert Botanical Garden (E 102058'/N 38035', 1378 m a.s.l.). The garden, located at the southeast fringe of Badain Jaran Desert, was established in 1974 and occupies an area of 67 ha. It is the first desert botanical garden in China and was honored with 'A Bright Pearl in Desert'. Research conducted in the garden concentrates on introduction, domestication, cultivation and selection of xerophytes for the needs of environmental bioengineering, including such genera as: *Calligonum*, *Caragana*, *Ephedra* and *Tamarix*. Also, the issues of autoecology and biology of desert plants are studied (e.g. Zhao et al., 2007; Du et al., 2010a; Chang et al., 2012). The garden's collection comprises 620 taxa, including 26 endangered species. It is open to public access and makes it possible to acquire knowledge of desert plant biodiversity, including numerous species that form the vegetation of phytogenic aeolian landforms of Badain Jaran and Tengger deserts .

Names of the plants mentioned in this article follow the taxonomic nomenclature applied in the Flora of China (available from: www.efloras.org, cited 2015 Oct 10).

REFERENCES

Brown G., Porembski S., 1997: The maintenance of species diversity by miniature dunes in a sand-depleted *Haloxylon salicornicum* community in Kuwait. Journal of Arid Environment. 37: 4611–473.

Chang Z.F., Zhu S.J., Han F.G., Zhong S.N., 2012: Differences in response of desert plants of different ecotypes to climate warming: a case study in Minqin, Northwest China. Journal of Arid Land. 4: 140–150.

Du J., Yan P., Dong Y., 2010a: Phenological response of *Nitraria tangutorum* to climate change in Minqin County, Gansu Province, northwest China. International Journal of Biometeorology. 54: 583–593.

Du J., Yan P., Dong Y., 2010b: The progress and prospects of nebkhas in arid areas. Journal of Geographical Sciences. 20: 712–728.

El-Bana M.I., Nijs I., Khedr A.-H.A., 2003: The importance of phytogenic mounds (nebkhas) for restoration of arid degraded rangelands in northern Sinai. Restoration Ecology. 11: 317–324.

El-Bana M.I., Nijs I., Kockelbergh F., 2002: Microenvironmental and vegetational heterogeneity induced by phytogenic nebkhas in an arid coastal ecosystem. Plant and Soil. 247:283–293.

He X.-D., Gao Y.-B., Ren A.-Z., 2003: Role of wind-sand disturbance in the formation and development of *Tamarix taklamakanensis* community. Acta Botanica Sinica. 45: 1285-1290.

Hesp P., McLachlan A., 2000: Morphology, dynamics, ecology and fauna of *Arctotheca populifolia* and *Gazania rigens* nebkha dunes. Journal of Arid Environments. 44: 155–172.

Lavaine C., Evette A., Piégay H., 2015: Europaean *Tamaricaceae* in bioengineering on dry soils. Environmental Management. 56: 221–232.

Li Z., Wu S., Wang X., He M., Ge L., Mu H., Xu G., 2010: Bio-geomorphologic growth process of *Tamarix* nabkha in the Hotan River Basin of Xinjiang. Journal of Geographical Sciences. 20: 205–218.

Liu Z., Yan Q., Baskin C.C., Ma J., 2006: Burial of canopy-stored seeds in the annual psammophyte *Agriophyllum squarrosum* (Chenopodiaceae) and its ecological significance. Plant Soil. 288: 71–88.

Liu B., Zhao W., Yang R., 2008: Characteristics and spatial heterogenity of *Tamarix ramosissima* Nebkhas in desert-oasis ecotones. Acta Ecologica Sinica. 28: 1446–1455.

Mycielska-Dowgiałło E., Dłużewski M., Dubis E., Woronko B., 2008: Extorted forms of aeolian accumulation in the Coude du Dra region. Prace Geograficzne. 118: 65–78.

Pool M.R., Pool S.K., Parvaneh I., Dehghani Z., Rostamian M., 2013: Nebkhas of Salvadora persica and their effect on the growth and survival of *Prosopis cineraria*, *Tamarix aphylla*, and *Capparis decidua* trees and shrubs. Flora: 208, 502–507.

Qong M., Takamura H., Hudaberdi M., 2002: Formation and internal structure of *Tamarix* cones in the Taklamakan Desert. Journal of Arid Environments. 50: 81–97.

Quets J.J., Temmerman S., El-Bana M.I., Al-Rowaily S.L., Assaeed A.M., Nijs I., 2013: Unraveling landscapes with phytogenic mounds (nebkhas): An exploration of spatial pattern. Acta Oecologica. 49: 53–63.

Su Y.Z., Yang R., Zhang Z.H., Du M.W., 2012: Distribution and characteristics of *Nitraria sphaerocarpa* nebkhas in a Gobi habitat outside an oasis in Hexi Corridor region, China. Sciences in Cold and Arid Regions. 4: 288–295.

Tengberg A., Chen D., 1998: A comparative analysis of nebkhas in central Tunisia and northern Burkina Faso. Geomorphology. 22: 181–192.

Wang T., 2004: Progress in sandy desertification research of China. Journal of Geographical Sciences. 14: 387–400.

Wang G., Wenzhi Z., Liu H., Zhang G., Li F., 2015: Changes in soil and vegetation with stabilization of dunes in a desert–oasis ecotone. Ecological Research. 30: 639–650.

Wang X., Wang T., Dong Z., Liu X., Qian G., 2006: Nebkha development and its significance to wind erosion and land degradation in semi-arid northern China. Journal of Arid Environments. 65: 129–141.

Wang X., Xiao H., Li J., Qiang M., Su Z., 2008: Nebkha development and its relationship to environmental change in the Alaxa Plateau, China. Environmental Geology. 56: 359–365.

Xiong X., Han X., Bai Y., Pan Q., 2003: Increased distribution of *Caragana microphylla* in rangelands and its causes and consequences in Xilin River Basin. Acta Pratacultural Science. 3: 141–148.

Yang H.T., Li X.R., Liu L.C., Gao Y.H., Li G., Jia R.L., 2014: Soil water repellency and influencing factors of Nitraria tangutorum nebkhas at different succession stages. Journal of Arid Land. 6: 300–310.

Yue X.H., Zhuang Y., Zhang J., 2005: Studies on sandy grassland nebkhas – a review. Journal of Desert Research. 5: 132–139.

Zhang P., Yang J., Zhao L., Bao S., Song B., 2011: Effect of *Caragana tibetica* nebkhas on sand entrapment and fertile islands in steppe-desert ecotones on the Inner Mongolia Plateau, China. Plant Soil. 347: 79–90.

Zhao C.-M., Wang G.-X., Wei X.-P., Deng J.-M., Cheng D.-L., 2007: Effects of groundwater depth variation on photosynthesis and photoprotection of Elaeagnus angustifolia L.. Trees. 21: 55–63.

Zhao M., Zhan K.J., Qiu G.Y., Fang E.T., Yang Z.H., Zhang Y.C., Li A.D., 2011: Experimental investigation of the height profile of sand-dust fluxes in the 0-50-m layer and the effects of vegetation on dust reduction. Environmental Earth Science. 62: 403–410.

Zhou H., Zhao W.Z., Luo W.C., 2015: Species diversity and vegetation distribution in nebkhas of *Nitraria tangutorum* in the desert steppes of China. Ecological Research. 30: 735–744.