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## Myxomycete diversity and ecology in arid regions of the Great Lake Basin of western Mongolia

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Novozhilov, Y.K. and Schnittler, M. (2008). Myxomycete diversity and ecology in arid regions of the Great Lake Basin of western Mongolia. *Fungal Diversity* 30: 97-119.

A systematic survey for myxomycetes in winter-cold deserts and steppes of western Mongolia resulted in a total of 333 records belonging to 36 species from 13 genera and 7 families. *Physarum notabile* as the most common species was recorded 72 times, but about one third of all species was classified as rare for the whole study area. Due to the very arid climate of the region, all specimens were obtained by applying the moist chamber culture technique. Maximum values for diversity and species richness were recorded in dry steppe/shrub and mountain steppe/tall shrub communities, whereas extrazonal grasslands and alpine steppes had the most depauperate myxomycete biota. Among three different groups of substrata (bark of shrubs, ground litter, and dung of herbivores) diverging trends in species richness and substrate specificity of the species were found: bark had the richest but least specific, dung the poorest but most specific myxomycete assemblage. A hierarchical cluster analysis carried out on the incidence-based Chao-Sørensen index clearly indicates a separation between myxomycete biotas of Eurasian, western North American and South American deserts, supporting the moderate endemism model postulated for various other groups of microbes and protists.

**Key words:** biogeography, deserts, distribution, steppes, plasmodial slime moulds, species inventory

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### Article Information

Received 26 August 2007

Accepted 15 March 2008

Published online 31 May 2008

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### Introduction

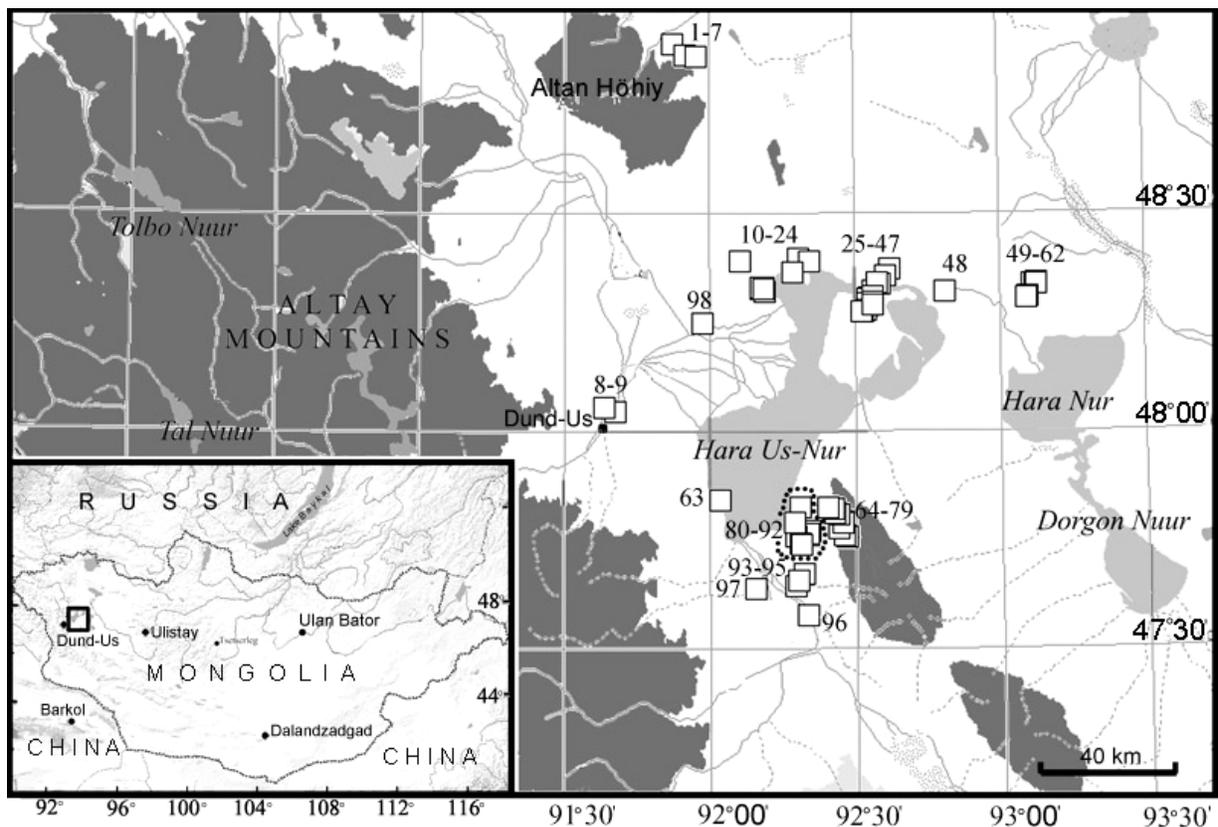
Since plasmodia and myxamoeba of myxomycetes require moist, humid conditions, arid regions would seem to be an extreme habitat for myxomycetes. Due to the apparent absence of fructifications in the field, desert myxomycetes are indeed poorly known. Published species lists include the Sinai peninsula (Ramon, 1968), the Sahara (Faurel *et al.*, 1965), the Sonoran desert of Arizona (Evenson, 1961; Blackwell and Gilbertson, 1980, 1984), semiarid regions of the Colorado Plateau of the western United States (Novozhilov *et al.*, 2003), arid zones of Mexico (Lado *et al.*, 2002) and Chile (Lado *et al.*, 2006), arid regions of the Caspian Lowland in Russia (Novozhilov *et al.*, 2006), the Mangyshlak peninsula, western Kazakhstan (Schnittler and Novozhilov, 2000),

and the Gobi desert of Mongolia (Novozhilov and Golubeva, 1986). However, myxomycetes are often surprisingly abundant in desert habitats, as reported for in western Kazakhstan and the Caspian Lowland (Schnittler, 2001; Novozhilov *et al.*, 2006). The primary objective of the present study was to assemble taxonomic and distributional data on myxomycetes for the southwestern part of the Great Lake Basin of western Mongolia.

### Materials and methods

#### Study sites

The general study area, situated in western Mongolia's Khovd province, centres around the lake Khara-Us-Nuur and includes the northern part of the Agvash Uul peninsula at 1150 m a.s.l. (desert steppe), the northwest-



**Fig. 1.** Map of the Great Lake Basin of western Mongolia. All 98 localities checked for the presence of myxomycetes are indicated by white rectangles. Mountainous regions are shaded dark grey; lakes and rivers are marked pale grey. Numbers refer to the localities listed in the text. A dotted black line indicates the border between two groups of localities in the north-western part of the Jargalant ridge, with localities 80-92 situated in the fan-like erosion rubble fields, and 64-79 on the slopes of the ridge. Insert: geographical position of the study area (delimited by the rectangle). Source: Microsoft Encarta Reference Library, 2002, modified.

ern part of the Jargalant ridge (a part of the Mongolian Altai mountain chain, mountain and alpine steppe) and the Altan Hohiy hills (dry steppe, Fig. 1). The major portion of the study area belongs to the Great Lake Basin. Elevations above sea level comprise an altitudinal gradient stretching from 1088 to 1650 m in lake depressions and 1780 to 3238 m in the mountains. The dominating vegetation are various steppe communities, ranging from desert over dry to mountain and alpine steppe (Rachkovskaya and Volkova, 1977; Volkova, 1994; Rachkovskaya *et al.*, 2007). In erosion valleys and gullies collecting water during the rare precipitation events, shrubs up to 3 m height occur additionally; only the alpine steppe is entirely devoid of shrubs. The region has an extreme continental arid climate and is characterised by long, cold and dry winters alternating with short but hot summers, during which 70-90% of all precipitation falls.

Situated on the lee side of the Altai Mountains, the study area receives only 5-140 mm annual precipitation with a high inter-annual variability. Mean monthly temperatures fluctuate between  $-20^{\circ}\text{C}$  in January as the coldest and  $+23^{\circ}\text{C}$  in July as the warmest month. The average annual temperature is  $0.3-4^{\circ}\text{C}$ . Spring and autumn seasons are very short. Extreme daily and annual temperature fluctuations are typical for the region (Buyan-Orshikh, 1988).

The prevailing type of soil of extrazonal grasslands and desert steppe around the lakes is a sandy weakly alkaline Burozem (light brown soil) with a low content of organic matter. The foothills of the mountains are dominated by granite gravel weathered from coarse red granite and these soils tend to become rocky and shallow in alpine regions. Solidified soils and sands are very typical throughout the general study area.

### Localities and vegetation types

The lower parts of the study area are situated in the dry steppe (semidesert) zone (Rachkovskaya and Volkova, 1977; Volkova, 1994). Here, edaphic moisture, salinity, and grazing pressure are the most important factors determining the vegetation (Rachkovskaya, 2001; Zemmrich *et al.*, 2007) which often changes over short distances, therefore a number of different communities can be recognised (Zemmrich, 2006). For the following ecological analysis of myxomycete assemblages only the main vegetation types were distinguished. The whole area is primarily treeless, and shrubs taller than 0.2 m occur only on slopes and especially in erosion valleys with higher edaphic moisture. Only extrazonal grasslands around lakes, being basically weakly saline meadows, and alpine steppes have no shrubs. The whole area is grazed by camels and horses, but especially mixed herds of sheep and goat, sometimes exhibiting a strong destructive influence on vegetation. Their droppings were found to be an important microhabitat for a whole assemblage of myxomycetes. Small rodents also occur at high population densities; most prominent among these are Mongolian rabbits, called Pika (*Ochotona pallasi* Gray). Locality numbers written in bold in the following brief descriptions refer to Fig. 1; all localities (1 to 98) are assigned to the respective major vegetation types. After the locality number follows the number of substrate samples collected in parentheses, with 16 localities only surveyed for field collections of myxomycetes.

**I. Treeless extrazonal grasslands** around lakes can be differentiated into herb-rich, weakly alkaline meadows around lake-shores and an outer ring of chee-grass, the Poaceae *Achnatherum splendens* (Trin.) Nevski., growing in large tussocks with culms up to 2 m tall, both together providing the richest pastures in the region. Due to intense grazing, saline meadows are devoid of ground litter and may be flooded after major rains. The five sampled localities are chee-grass stands, all situated in Khovd Aimag, Dörgön Sum within the depression of the Great Lakes.

**Dörgön Sum** Locality **22** (4), **23** (0), **24** (0): large sand dunes, partly loose sand, dry, between reed stands,

very shallow depression, sands over alluvial silt, at the northern tip of the lake Khara-Us-Nuur, 1170 ± 10 m a.s.l., 48°21'55" N 92°17'12" E; **30** (4), **32** (0): heavily grazed chee-grass stands around jurtes, sandy, fixed alluvial soils, around the Khara-Us river ca. 5.5 km WSW Seer, between lakes Khara-Us-Nuur and Dalai-Nuur, 1159 ± 10 m a.s.l., 48°18'34" N 92°33'54" E; **31** (2), **45** (0): heavily grazed chee-grass stands ca. 500 m from jurtes, sandy, fixed alluvial soils around the Khara-Us river ca. 5.5 km WSW Seer, between the lakes Khara-Us-Nuur and Dalai-Nuur, 1159 ± 10 m a.s.l., 48°18'34" N 92°33'54" E; **51** (1), **52** (0): chee-grass stand around a broken well, Argalant hills, in a valley with two broken wells ca. 45 km E Seer, between the lakes Khara-Us-Nuur and Dalai-Nuur, 1410 ± 10 m 48°20'23" N 93°07'03" E; **63** (2): chee-grass stands, sandy shoreline, near a bird-watching tower overlooking a reed swamp at the western shore of lake Khara-Us-Nuur, 1179 ± 10 m a.s.l., 47°50'22" N 92°02'00" E.

**II. Desert steppe/dwarf shrub** communities are represented by three plant communities classified by Hilbig (1990) as (i) *Artemisia xerophytica* Krasch. dry desert (semi-desert) shrub steppe mostly on light Burozem (light brown) soils, (ii) *Anabasis brevifolia* C.A. Mey. / *Allium mongolicum* Regel desert steppe with *Ephedra przewalskii* Stapf on gravelly soils, and (iii) *Krascheninnikovia ceratoides* (L.) Gueldenst. shrub desert steppe in dry erosion gullies. Dominating and steadily occurring perennial species are *Stipa glareosa* P. Smirn., followed by *Artemisia xerophytica* and *Anabasis brevifolia* (Zemmrich, 2006). All these plants produce only occasionally very thin mats of twiglet litter. Besides herbivore dung, the main substrate collected was fibrous bark of sagebrush and various small *Chenopodiaceae* shrubs, proven in previous studies to be productive for corticolous myxomycetes (Schnittler, 2001; Novozhilov *et al.*, 2003; Novozhilov *et al.*, 2006). Desert steppe is the main vegetation of the plains. Fourteen localities situated in Dörgön Sum within the depression of the Great Lakes, twelve in Chandman Sum, and one in Myangad Sum were sampled.

**Buyant Sum** Locality **9** (0): semidesert with *Cleistogenes* and *Artemisia*, sandy plains around the airstrip 5 km E Khovd, 1100 ± 50 m a.s.l., 48°03'00" N 91°38'00" E; **Dörgön Sum** **10** (1): *Artemisia*-dominated desert steppe, fixed soil on the margin of a wetland, very shallow depression, alluvial silt, at the northern tip of the lake Khara-Us-Nuur, 1293 ± 5 m a.s.l., 48°23'55" N 92°18'30" E; **19** (1): *Artemisia*-dominated desert steppe, red basalt and fixed, loamy sands, moderately grazed,

stony plain, northern part of Agvash-Uul island, 1088 ± 10 m a.s.l., 48°17'24" N 92°33'44" E; **20** (2), **21** (0): fixed sand dunes, overgrown with *Nitraria* thickets, temporarily wet depressions, at the northern tip of the lake Khara-Us-Nuur, 1165 ± 10 m a.s.l., 48°23'08" N 92°20'35" E; **28** (6): *Ephedra*-dominated *Anabasis* desert, small sand accumulations over basalt pebble, near the Dalantai hills, 1211 ± 25 m a.s.l., 48°21'21" N 92°36'13" E; **29** (3): *Artemisia*-dominated desert steppe, fixed, somewhat silty sand and basalt pebble, plain SW of the Dalantai hills, around the Khara-Us river, 1184 ± 10 m a.s.l., 48°20'16" N 92°35'05" E; **33** (6): stony *Anabasis* desert, red basalt and fixed, loamy sands, stony plain, northern part of Agvash-Uul island, 1171 ± 25 m a.s.l., 48°18'11" N 92°32'58" E; **34** (7): *Artemisia*-dominated desert steppe, fixed, somewhat loamy sand, 1212 ± 25 m a.s.l., 48°17'21" N 92°32'48" E; **37** (7): stony *Anabasis* desert, red basalt and fixed, loamy sands, stony plain, northern part of Agvash-Uul island, 1190 ± 25 m a.s.l., 48°18'00" N 92°32'30" E; **38** (7): *Artemisia*-dominated desert steppe, fixed, somewhat loamy sand, 1206 ± 25 m a.s.l., 48°17'36" N 92°32'32" E; **43** (1): *Artemisia*-dominated desert steppe, fixed, somewhat silty sand and basalt pebble, heavily grazed plain N of Khara-Us river, 1165 ± 10 m a.s.l., 48°19'14" N 92°33'42" E; **44** (1): *Artemisia*-dominated desert steppe, fixed, somewhat silty sand and basalt pebble, moderately grazed, plain N of the Khara-Us river, 1206 ± 10 m a.s.l., 48°20'21" N 92°34'42" E; **47** (1): *Artemisia*-dominated desert steppe, red basalt and fixed, loamy sands, grazed, stony plain, northern part of Agvash-Uul island, 1162 ± 25 m a.s.l., 48°17'58" N 92°33'44" E; **49** (5): stony *Anabasis* desert, valley of the Argalant hills, 1410 ± 10 m a.s.l., 48°20'23" N 93°06'38" E; **59** (5): stony *Anabasis* desert, fixed soil with pebble and many stones, plains in the foreland of the Argalant hills, 1302 ± 10 m a.s.l., 48°18'49" N 93°05'42" E; **Chandman Sum 79** (0): stony *Anabasis* desert, rubble field of the Jargalant Range; valley of the Zagan-Burgast river, 1785 ± 20 m a.s.l., 47°49'23" N 92°24'15" E; **81–97** plains at the southeastern edge of lake Khara-Us-Nuur; **81** (4): *Krascheninnikovia*-dominated shrub desert steppe on sandy soil; 1188 ± 10 m a.s.l., 47°45'36" N 92°18'15" E; **82** (2): *Stipa*-dominated desert steppe on sandy soil, 1193 ± 10 m a.s.l., 47°45'36" N 92°18'31" E; **83** (2): *Krascheninnikovia* desert steppe on sandy soil with larger stones, 1223 ± 20 m a.s.l. 92°19'14" N 47°45'40"; **88** (1): small, sandy salt pan, 1165 ± 10 m a.s.l., 47°45'34" N 92°17'40" E; **89** (2): *Artemisia* desert steppe on sandy soil, 1185 ± 10 m a.s.l., 47°44'25" N 92°18'41" E; **91** (2): *Anabasis* desert steppe, 1247 ± 10 m a.s.l., 47°49'24" N 92°18'33" E; **93** (1): *Krascheninnikovia* desert steppe, 1214 ± 10 m a.s.l., 47°40'23" N 92°19'03" E; **94** (3): stony *Anabasis* desert steppe, fixed, stony sands at the Bajan-Khuschu hills, 1270 ± 10 m a.s.l., 47°38'50" N 92°17'43" E; **95** (3): *Artemisia* desert steppe, 1216 ± 10 m a.s.l., 47°39'25" N 92°18'15" E; **96** (1): herb-rich meadow with old shrubs of *Caragana spinosa*, slightly salty meadows on sandy soil, 1219 ± 10 m a.s.l., 47°34'43" N 92°20'10" E; **97** (1): dry *Artemisia*-dominated desert steppe on sandy soil, 1234 ± 10 m a.s.l., 47°38'09" N 92°09'05" E;

**Myangad Sum 98** (1): species-rich shrub desert steppe on stony fixed sands, ca. 5 km E Myangad, 1176 ± 25 m a.s.l., 48°14'56" N 91°58'30" E.

**III. Dry steppe/shrub communities** occur at all sites with slightly better water supply, resembling the fan-like, gravely erosion dumps of mountain valleys (called in Mongolian "bel"), foothill slopes or erosion gullies. A rich steppe alternates with shrubby vegetation characterized by *Caragana leucophloea* Pojark. and *Caragana bungei* Ldb. on light clayish and sandy brown soils containing a high proportion of gravel and granite crumbs. These shrubs are up to 70 cm tall and have usually smooth, later furrowed and curly bark. Additionally, the wild almond *Amygdalus pedunculata* Pall. and the *Polygonaceae* *Atraphaxis frutescens* (L.) K. Koch (the latter with a soft, peeling bark) grow at higher elevations in erosion gullies. These shrubs provide thicker mats of leaf litter, being a suitable microhabitat for myxomycetes. Sampled localities include the districts Buyant Sum near Khovd (1); Myangad Sum (7), Dörgön Sum (18), and Chandman Sum (5).

**Buyant Sum Locality 1** (4): poor *Caragana* shrub desert, stony fixed sands, ca. 10 km W Lake Khara-Us-Nuur (western shore), 1647 ± 25 m a.s.l., 48°53'05" N 91°52'50" E; **Myangad Sum 11** (6): *Caragana-Atraphaxis* shrub desert on sandy soil, plain shrub desert near a holy mound (Owoo) at the NW tip of lake Khara-Us-Nuur, 1212 ± 10 m a.s.l., 48°19'03" N 92°11'16" E; **12** (5): species-rich *Caragana* shrub desert on somewhat fixed, sandy soil, NW edge of lake Khara-Us-Nuur, 1530 ± 10 m a.s.l., 48°23'12" N 92°06'21" E; **13** (3): *Caragana* shrub on sandy soil over granite rubble, eastern fringe of the hills, near NW tip of lake Khara-Us-Nuur, 1254 ± 25 m a.s.l., 48°19'27" N 92°10'54" E; **14–17** Ujan-Unet hills near the northwestern tip of lake Khara-Us-Nuur; **14** (5): *Atraphaxis* shrub on deep sandy, loose soil over granite rubble, 1307 ± 15 m a.s.l., 48°19'55" N 92°11'02" E; **15** (6): *Caragana-Atraphaxis* shrub on deep sandy, loose soil over granite rubble, 1286 ± 40 m a.s.l., 48°19'51" N 92°10'56" E; **16** (3): *Amygdalus* shrub thicket, small sand dune blown over granite rock, 1286 ± 40 m a.s.l., 48°19'51" N 92°10'56" E; **17** (3), **18** (0): *Krascheninnikovia* shrub steppe, sandy, somewhat fixed soil over granite, 1260 ± 30 m a.s.l., 48°19'31" N 92°11'00" E; **Dörgön Sum 25** (7): *Caragana* shrub, basalt pebble, some stones, fixed sand, base of the Dalantai hills, 1256 ± 25 m a.s.l., 48°22'14" N 92°37'04" E; **35** (8): *Caragana* shrub desert, fixed, somewhat loamy sand, 1227 ± 25 m a.s.l., 48°17'03" N 92°32'32" E; **36** (4): *Caragana*-dominated shrub desert, loose sands blown over red basalt rocks, 1227 ± 25 m a.s.l., 48°17'03" N 92°32'32" E; **39** (6): *Caragana* shrub desert, loose sands over red basalt, 1258 ± 25 m a.s.l., 48°16'44" N 92°32'07" E; **40** (7): *Caragana* shrub

desert, loose sands over red basalt, 1278 ± 25 m a.s.l., 48°16'26" N 92°31'41" E; **41** (4): stony shrub community, red basalt rocks, ridge of the second Sagon hill, 1319 ± 25 m a.s.l., 48°16'27" N 92°31'33" E; **42** (3): *Artemisia* shrub dry steppe, deep sandy slope, coordinates very close to loc. 41, 1300 ± 25 m a.s.l.; **48** (6): *Caragana* shrub, rocky granite slope, canyon of the Tschono-Kharyaichyn Gol river, 1177 ± 50 m a.s.l., 48°19'13" N 92°48'40" E; **50-57** valleys and rocky gullies of the Argalant hills over gneiss and or basalt; **50** (5): *Caragana* shrubs and *Artemisia*, small gully between rubble fields, 1410 ± 10 m a.s.l., 48°20'23" N 93°06'38" E; **53** (5): broad gulch with *Caragana* shrubs and *Artemisia*, boulder-rich valley bottom, 1420 ± 10 m a.s.l., 48°20'29" N 93°07'02" E; **54** (5): small gully with *Caragana* shrubs and *Artemisia*, 1455 ± 25 m a.s.l., 48°20'40" N 93°07'19" E; **55** (8): steep, rocky gully with *Amygdalus* shrubs, 1484 ± 50 m a.s.l., 48°20'43" N 93°07'18" E; **56** (3): steep, rocky upper slope of a small summit, 1568 ± 50 m a.s.l., 48°20'44" N 93°07'25" E; **57** (7): steep, rocky upper part of a valley, 1460 ± 50 m a.s.l., 48°20'26" N 93°07'17" E; **58-62** Argalant hills; **58** (5): *Caragana* shrub and *Artemisia*, small gulch between rubble fields, 1417 ± 10 m a.s.l., 48°20'23" N 93°07'09" E; **60** (7): small gully lined with various shrubs, sand, pebble and some larger stones, 1302 ± 10 m a.s.l., 48°18'49" N 93°05'42" E; **61** (4): as 60 but 1294 ± 10 m a.s.l., 48°18'46" N 93°05'42" E; **62** (8): shallow valley with shrubs, 1293 ± 10 m a.s.l., 48°18'37" N 93°05'28" E; Chandman Sum **80** (3): *Artemisia* dry steppe on sandy soil, plain shrub semidesert at the southern end of lake Khara-Us-Nuur, 1175 ± 10 m a.s.l., 47°45'35" N 92°17'52" E; **84** (3): *Caragana* shrub, small gully, W-exp. lowermost slopes of the Jargalant ridge, 1250 ± 20 m a.s.l., 47°45'43" N 92°19'54" E; **85** (3): *Caragana* shrub, larger gully, W-exp. lowermost slopes of the Jargalant ridge, 1250 ± 20 m a.s.l., 47°45'43" N 92°20'0" E; **86** (3): *Caragana* shrub, small gully, 1310 ± 20 m a.s.l., 47°46'03" N 92°20'37" E; **87** (0): stony shrub semidesert at the fringe of a larger gully, 1268 ± 20 m a.s.l., 47°45'59" N 92°20'6" E; **90** (2): *Caragana* shrub on sandy soil, plain shrub semidesert, 1190 ± 10 m a.s.l., 47°44'17" N 92°18'51" E.

**IV. Mountain steppe / tall shrub.** The xerophilous tussock grasses *Stipa krylovii* Roshev. and *Agropyron cristatum* (L.) Beauv. are dominant components of these communities. The tufts of these species are densely covered by dead leaf sheaths that accumulate snow, water and fine soil which improves water retention (Zemmrlich, 2006). If sheltered from grazing, tall shrub communities with *Caragana bungei*, *Atraphaxis frutescens*, and *Ribes acicularis* Lindl. occur sporadically on stony slopes. Sampled were three localities in Buyant Sum and eleven localities in the Jargalant mountain ridge in Chandman Sum.

Buyant Sum Locality **2** (2), **3** (0), **4** (0): *Caragana* shrub, stony summit, near a TV pole at the hill Ucha-Obo, red basalt with some finer soil ca. 10 km W the lake Khara-Us-Nuur (western shore), 1647 ± 25 m a.s.l., 48°53'05" N 91°52'50" E; **5** (7): *Caragana* shrub, stony slopes, canyon Dwamt Khongil, coarse red granite with sandy fissures, ca. 7 km W the lake Khara-Us-Nuur (western shore), 1566 ± 35 m a.s.l., 48°51'52" N 91°55'11" E; **6** (0), **7** (1): dwarf shrubs and various annual plants, alluvial sands in the canyon Dwamt Khongil, 1346 ± 10 m a.s.l., 48°51'35" N 91°57'28" E; Chandman Sum **69-78** and **92**: Jargalant ridge, valley of the Zagan-Burgast river; **69** (0): rubble field with larger boulders and some fine soil, N-exp. slope, saddle ca. 4 km NNW of the summit Khan-Batar-Ula, 2600 ± 50 m a.s.l., 47°46'50" N 92°26'40" E; **70** (4): *Ribes acicularis* thickets, rubble field with larger boulders and fine soil, W-exp. lower slope, ca. 50 m above the valley bottom, 2230 ± 50 m a.s.l., 47°47'32" N 92°27'21" E; **71** (3): sparse *Caragana bungei* shrub, rubble field with boulders and gravel, E-exp. steep, middle slope, ca. 250 m above the valley bottom, 2281 ± 50 m a.s.l., 47°47'22" N 92°27'12" E; **72** (2): rubble field with larger boulders and some fine soil, *Ribes acicularis* thickets, W-exp. lower slope, ca. 50 m above the valley bottom, 2261 ± 50 m a.s.l., 47°47'19" N 92°27'14" E; **73** (1): small willow stand, small, canyon-like sector of the valley, along the river, 2245 ± 20 m a.s.l., 47°47'17" N 92°27'16" E; **74** (4): sparse *Caragana bungei* shrubs, broad valley bottom with larger stones and rubble created by the river, middle part of the valley, 2042 ± 20 m a.s.l., 47°48'26" N 92°26'37" E; **75** (2): sparse *Caragana* and *Atraphaxis* shrubs, W-exp. rocky lower slope of the middle part of the valley, 2028 ± 20 m a.s.l., 47°48'35" N 92°26'24" E; **76** (4): sparse *Caragana bungei* shrubs, broad valley bottom with larger stones and rubble created by the river, lower part of the valley, 2005 ± 10 m a.s.l., 47°48'56" N 92°25'54" E; **77** (1): *Caragana* and *Atraphaxis* shrubs, SE-exp. rocky lower slope of the lowermost part of the valley near its mound, 1890 ± 20 m a.s.l., 47°49'09" N 92°25'14" E; **78** (3): *Caragana* shrubs, broad rubblefield at the mound of the valley to the plains, 1780 ± 20 m a.s.l., 47°49'23" N 92°24'15" E; **92** (3): rubble field with larger boulders and some fine soil, *Ribes acicularis* thickets, E-exp. lower slope, ca. 150 m above the valley bottom, 2259 ± 50 m a.s.l., 47°47'23" N 92°17'15" E.

**V. Treeless alpine steppe.** Different perennial grasses (*Festuca lenensis* Drob., *F. sibirica* Hack. ex Boiss.) with sedges (*Carex rupestris* All., *C. pediformis* C.A. Mey.) and cushion plants (*Oxytropis oligantha* Bunge, *Arenaria meyeri* Fenzl) grow on humus-rich soils (dark Kastanozem and Chernozem) between 2300 and 2400 m a.s.l.; higher elevations between 2650 and 3060 m are covered by cryophyte steppe on Dernozem soils dominated by *F. lenensis* and *C. rupestris*

(Volkova, 1994). Four localities of the Jargalant ridge in Chandman Sum were sampled.

Localities 64-68: uppermost valley of the Zagan-Burgast river, WSW-exp. slope near the summit Khan-Batar-Ula, Chandman Sum **64** (3), **65** (0): alpine meadows, ridge towards the summit,  $3238 \pm 75$  m a.s.l.,  $47^{\circ}45'25''$  N  $92^{\circ}28'16''$  E; **66** (2): rather dry alpine meadow, ridge 200 m below the summit,  $3184 \pm 75$  m a.s.l.,  $47^{\circ}45'30''$  N  $92^{\circ}28'11''$  E; **67** (4): rather dry alpine meadow, ca. 1 km NNW of the summit,  $3076 \pm 50$  m a.s.l.,  $47^{\circ}45'44''$  N  $92^{\circ}27'58''$  E; **68** (2): rather dry alpine meadow, a. 2 km NNW of the summit,  $2944 \pm 50$  m a.s.l.,  $47^{\circ}45'55''$  N  $92^{\circ}27'50''$  E.

### **Substrate sampling**

A total of 283 substrate samples from 82 of the 98 visited localities were collected to prepare moist chamber cultures. These included bark from living trees and shrubs (71 samples), plant litter (71 samples), various types of woody debris (40 samples) and dung (101 samples) of herbivorous animals, such as camel, cow, horse, sheep and Pika.

Bark of living plants was classified into texture groups as proposed by Schnittler (2001): type b2 – bark smooth but rupturing with age, sometimes forming curls on dying twigs: *Amygdalus pedunculata*, all species of *Caragana*, *Salix* spec.; type b3 – bark smooth but soon peeling in long, more or less loose strips: *Atraphaxis bracteata*, *A. frutescens*, *Lonicera microcarpa*, *Nitraria sibirica*, and type b5 – fibrous bark, often separating into fine fibres: all species of *Artemisia* and *Oxytropis aciphylla* Ldb. Finally, woody bark (bw) was represented by partly dead woody stems of *Krascheninnikovia ceratoides* and *Chenopodium frutescens*, both *Chenopodiaceae* showing abnormal secondary growth. Litter was classified into two types. The first type was leafy litter (ll) of taller shrubs such as *Amygdalus pedunculata*, *Caragana bungei*, *C. leucophloea*, *Ephedra przewalskii*, *Krascheninnikovia ceratoides*, and *Ribes acicularis*. The second type was represented by tussock grasses (lg), such as *Achnatherum splendens*, *Elymus* spec., *Stipa glareosa* or *S. gobica*. Coarse woody debris (w) of different plants was classified into moderately decayed wood (w3) and strongly decayed wood (w4). Dung samples (d) of various herbivores ranged in size from relatively large and compact droppings (2-20 cm) of cattle, camel and horse until

small pellets (0.5-1.5 cm) of sheep, goat and Pika.

### **Moist chamber cultures**

Moist chamber cultures were prepared in the manner described by Härkönen (1977, 1981). All cultures consisted of moist filter paper in Petri dishes (10 cm diam.) and were incubated under ambient light and at room temperature (ca 20-24°C) for up to 90 days and examined for the presence of myxomycetes on six occasions (days 2-4, 6-8, 11-14, 20-22, 40-44 and 85-90). A record is defined herein as one or more fruiting bodies of a species which originated from one culture. The pH value for all cultures was measured after one day with a pH meter Orion 610 on the surface of three different wet pieces of substrate. Water retention (in mg water per g dry substrate) was calculated by comparing the weight of the dry Petri dishes (before watering) with the weight of the Petri dishes if soaked with water after three days of culture. At this time, excess water was poured off, and a set of Petri dishes prepared with filter paper only was used to account for the water retention of the filter paper alone.

### **Data analysis**

To estimate the extent to which the survey was exhaustive, a species accumulation curve was constructed using the program EstimateS (Colwell, 2006) and subjected to a regression analysis using the hyperbolic function  $y = Ax/(B + x)$ , where  $x$  is the number of samples,  $y$  represents the number of species recorded, and the parameter  $A$  refers to the maximum number of species to be expected (Fig. 48). Species diversity (alpha-diversity) was calculated using Shannon's diversity index  $H' = -\sum P_i \log P_i$ , where  $P_i$  is the relative abundance (the proportion of the number of records represented by a particular species, Shannon and Weaver 1963; Magurran, 2004). To compare myxomycete biotas from different regions, the adjusted incidence-based Sørensen index (Cs) recently developed by Chao *et al.* (2005, 2006) was computed with EstimateS and used for a cluster analysis as weighted pair-group method (WPGMA) with the program Statistica 5.5. Canonical correspondence analysis (CCA) was carried out using PcOrd

4.17 to assess the relative importance of substrate types on myxomycete associations (Schnittler, 2001; Schnittler *et al.*, 2002). Graphs were created with SigmaPlot 8.0 (Fig. 49). The calculated eigenvalues, ranging between 0 and 1, represent a measure of the degree to which species distribution can be explained by the respective ordination axis (Ter Braak, 1986). Only species classified as common (relative frequency > 1.5 % of all records) were included in this analysis, except for *Comatricha laxa* and *Perichaena corticalis* var. *liceoides*, both classified as occasional in the study area (> 0.5-1.5 %) but widely distributed in other arid regions of Eurasia.

For determination, sporocarps were preserved as permanent slides in lactophenol and/or glycerol gelatine, to distinguish between limeless and lime-containing structures. Sporocarp structures were studied with a JEOL 35c scanning electron microscope (SEM) at St. Petersburg. Species were identified according to Martin and Alexopoulos (1969) and various original descriptions from the literature, basically applying a morphospecies concept. Determinations considered as uncertain are denoted as "cf." (confer). Nomenclature follows that of Lado (2001) and Hernández-Crespo and Lado (2005) except for the two genera *Collaria* Nann.-Bremek., *Stemonitopsis* Nann.-Bremek. and the conserved names of several other genera (Lado *et al.*, 2005) approved recently by the Committee for Fungi of the IAPT (Gams 2005). Voucher specimens are deposited in the collection of the second author (sc) at the Botanische Staatssammlung Munich (M) and in the fungal herbarium of the Komarov Botanical Institute of the Russian Academy of Sciences, Laboratory of Systematics and Geography of Fungi (LE).

For names of all myxomycete species mentioned in Fig. 49, additional abbreviations are given. Names of vascular plants are those listed by Czerepanov (1995). After each name, an estimate of abundance as described by Stephenson *et al.* (1993) is given in brackets. This estimate is based upon the proportion of a species in relation to the total number of records (333): **R** – rare (< 0.5 % of all records), **O** – occasional (> 0.5-1.5 % of all records), **C** – common (> 1.5-3 % of all records), **A** –

abundant (> 3 % of all records). Abundance and the total number of records for a species is set in brackets. Next, the occurrence of a species in different vegetation types (indicated by Roman numerals) and microhabitats (indicated by letters) is listed. Five vegetation types were differentiated (**I** for extrazonal grasslands, **II** for desert steppe/dwarf shrub, **III** for dry steppe/shrub, **IV** for mountain steppe/tall shrub, **V** for alpine steppe). Abbreviations for substrate types are **b** – bark of living trees and shrubs; **w** – large dead woody debris of trees and shrubs; **l** – ground litter; **d** – dung of herbivorous animals. Finally, all localities where a species was found are given in parentheses.

## Results

### *Annotated species list*

Throughout the following annotated species list the following form is used to present the information (explained for the first species mentioned):

*Arcyria cinerea* (Bull.) Pers. – species name after Lado (2001),

[ARCcin, C, 9] – abbreviation for common species, abundance scale value, total number of records,

**II**: 2, **III**: 5, **V**: 2 / – vegetation types a species was found: number of records per vegetation type,

b: 3, l: 3, w: 3 – substrate types a species was found: number of records per substrate type,

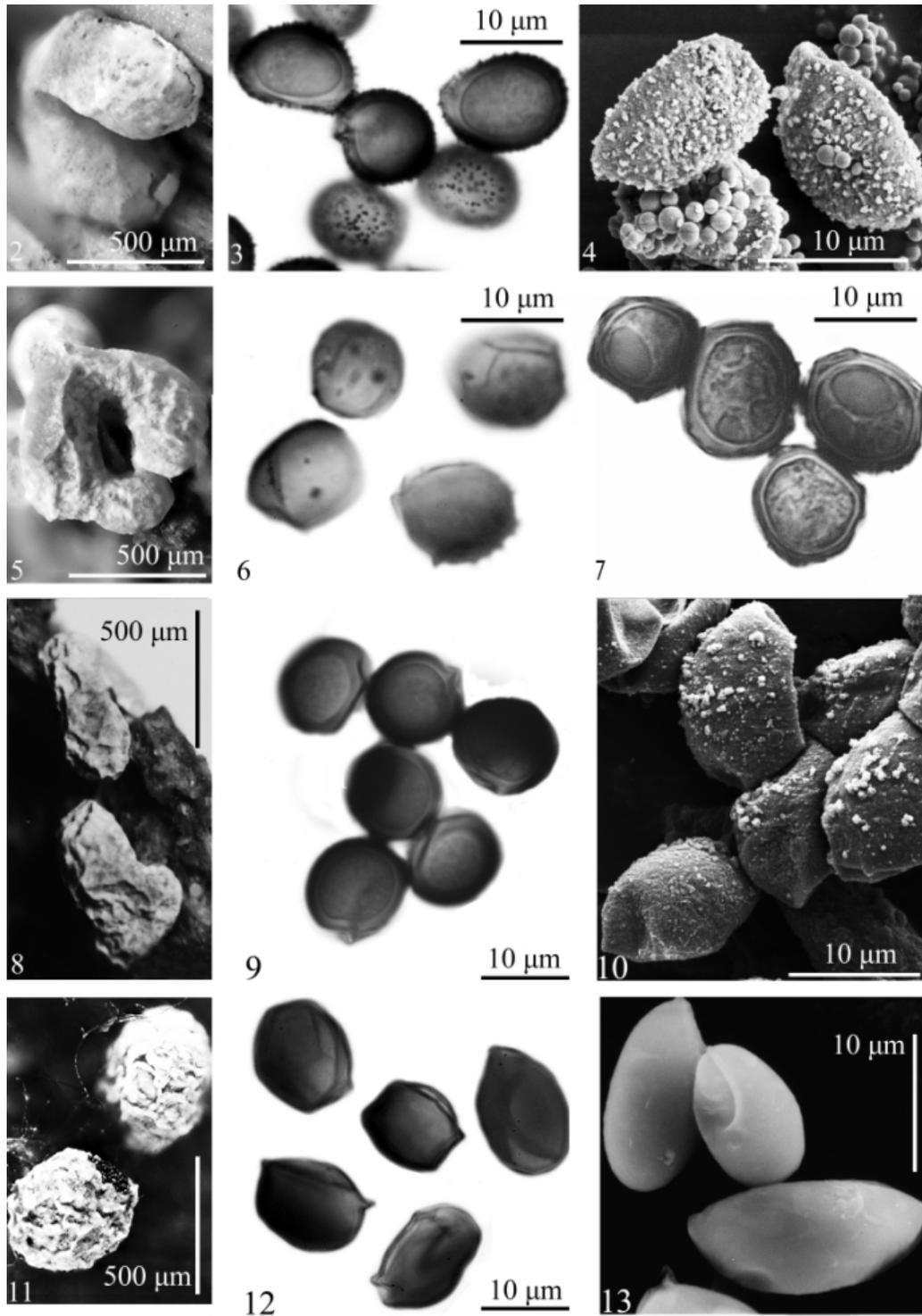
(Loc. 12, 25, 55, 57, 64, 66, 82, 85, 94) – localities a species was recorded from.

*Arcyria cinerea* (Bull.) Pers. [ARCcin, C, 9] **II**: 2, **III**: 5, **V**: 2 / b: 3, l: 3, w: 3 (Loc. 12, 25, 55, 57, 64, 66, 82, 85, 94)

*Arcyria minuta* Buchet [O, 2] **II**: 1, **III**: 1 / b: 2 (Loc. 1, 89)

*Badhamia apiculospora* (Härk.) Eliass. & N. Lundq. [BADapi, C, 5] **I**: 3, **II**: 1, **III**: 1 / d: 4, l: 1 (Loc. 30, 37, 62, 63)

The wrinkled white peridium with crème tints, the dark black spore mass, a large and massive limy columella together with the thick-walled apiculoid spores are unmistakable and stable characters of this species shared by all collections from arid regions of the world. However, both spore shape and ornamentation are quite variable. Our collections segregate



**Figs 2-4.** *Badhamia apiculospora* (sc21035, form 1). **2.** Sporocarp as seen by a dissection microscope (DM). **3.** Spores in light microscope under transmitted light (TL), showing coarse and irregular verrucae. **4.** Spores in scanning electron microscope (SEM). **Figs 5-7.** *B. apiculospora* (sc21074, form 2). **5.** Sporocarp (DM). **6.** Spores (TL) showing several large verrucae. **7.** Spores in optical section (TL) with thick walls. **Figs 8-10.** *B. apiculospora* (sc21034, form 2). **8.** Sporocarp (DM). **9.** Spherical spores (TL) with apiculi. **10.** Spore (SEM). **Figs 11-13.** *B. apiculospora* (sc21127, form 3). **11.** Sporocarp (DM). **12.** Smooth elliptic spores (TL) with an apiculus at each end and a ridge. **13.** Smooth spores (SEM).

into three forms. **Form 1** (sc 21035) shows elongated ellipsoid spores ornamented with large, coarsely and irregularly distributed verrucae (Figs. 2-4). **Form 2** (sc 21074, 21034) possesses globose or subglobose spores ornamented with several large verrucae (Figs 5-7 and 8-10). Only **form 3** (sc 21127) with smooth elliptic spores (Figs. 11-13) corresponds exactly with the original description of this species (Eliasson and Lundqvist, 1979). Outside Mongolia, form 1 was recorded in the western US (Colorado Plateau, Novozhilov *et al.*, 2003), form 3 is known from Russia (Caspian Lowland, Novozhilov *et al.*, 2006), whereas form 2 with globose and verrucose spores has not been found before in Eurasian arid regions. We assume that all these “morphotypes” represent cryptic, perhaps asexual strains of one variable morphospecies widely distributed in arid regions. Molecular markers would have to be employed to delimit these strains. Our records are the first for Mongolia, but this species may be common in arid regions of the country.

***Comatricha laxa*** Rostaf. [COMlax,O, 3] **II**: 2, **IV**: 1 / b: 3 (Loc. 75, 81, 82)

All specimens belong to the typical corticolous form of this morphological variable species which seems to be common in arid areas (Schnittler and Novozhilov, 2000; Novozhilov *et al.*, 2003, 2006; unpubl. data from central and western Kazakhstan). The conspicuous characters of this form are the stiff and coarse capillitium threads, branching from the whole length of the columella (Figs 14-15).

***Comatricha pulchella*** (C. Bab. & Berk.) Rostaf. [COMpul, C, 7] **I**: 1, **III**: 6 / l: 7 (Loc. 30, 58, 60, 61, 62, 85)

In other arid regions this taxon prefers the acidic bark of *Tamarix* (Schnittler 2001; Novozhilov *et al.*, 2003; Novozhilov *et al.*, 2006). In our study area it was collected on litter of *Caragana*, *Kraschenninikovia* and *Achnatherum*. All Mongolian specimens have typical sporocarps with reddish-brown, flexuous capillitium (Figs 16-17) and a pinkish-brown spore-mass.

***Cribraria violacea*** Rex [R, 1] **IV**: 1 / b: 1 (Loc. 76)

***Didymium anellus*** Morgan [DDYane, A, 40] **I**: 1, **II**: 9, **III**: 26, **IV**: 4 / b: 14, l: 20, w: 6 (Loc. 11-13, 15-17, 22, 28, 29, 34, 36, 38, 41, 43, 48, 54-58, 60-62, 70, 72, 76, 83-86, 90, 92, 95)

***Didymium difforme*** (Pers.) Gray [DDYdif, A, 17] **II**: 2, **III**: 10, **IV**: 5 / b: 5, d: 7, l: 5 (Loc. 1, 5, 12, 36, 38, 39, 48, 49, 57, 60, 62, 70, 72, 76, 86)

***Didymium squamulosum*** (Alb. & Schwein.) Fr. [DDYsqu, C, 8] **III**: 4, **IV**: 4 / b: 1, l: 7 (Loc. 5, 13, 53, 60, 70, 76, 90, 92)

***Diderma chondrioderma*** (de Bary & Rostaf.) G. Lister [R, 1] **III**: 1 / l: 1 (Loc. 42)

Only one (sc 21134) specimen with several, well-matured sporocarps that fits well the description of this species.

***Echinostelium arboreum*** H.W. Keller & T.E. Brooks [EHarb, A, 17] **II**: 9, **III**: 6, **IV**: 2 / b: 5, d: 1, l: 8, w: 3 (Loc. 33, 34, 38, 49, 54-56, 62, 70, 78, 81, 83, 84, 91, 95)

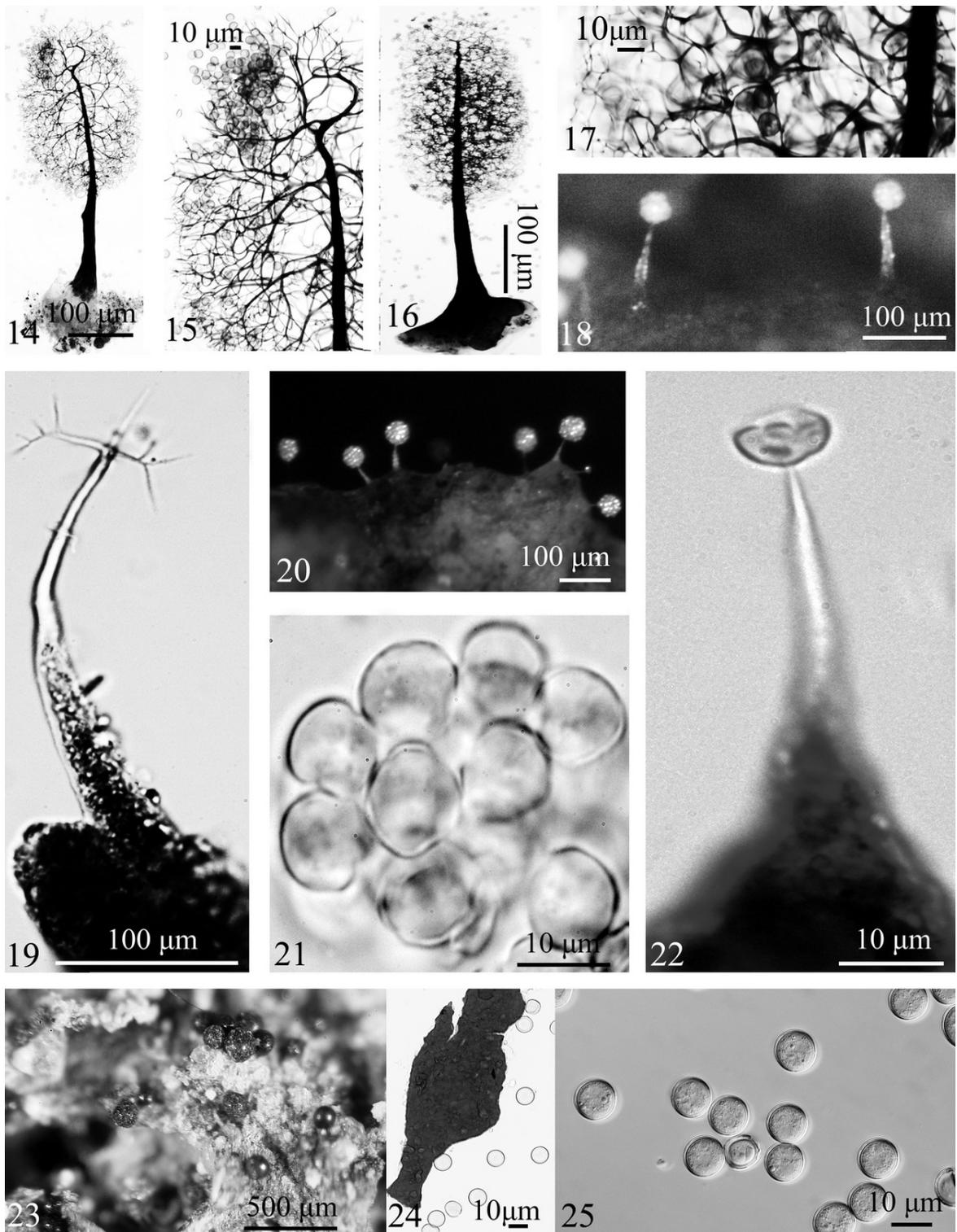
Sporocarps stout, stalked, golden yellow-brown, iridescent under a dissecting microscope (Fig. 18). Capillitium arising from one point at the centre of the sporotheca with a few perpendicular, stiff branches, these mostly dichotomous 1(-2) times more forked, at the tips about 1 µm in diam (Fig. 19). Novozhilov *et al.* (2006) give a detailed description for specimens from the Caspian Lowland which also applies to the Mongolian collections.

***Echinostelium colliculosum*** K.D. Whitney & H.W. Keller [EChcol, A, 35] **II**: 9, **III**: 20, **IV**: 6 / b: 28, w: 7 (Loc. 7, 17, 19, 35, 36, 40, 48, 50, 55-57, 61, 62, 72, 75-78, 81, 83, 91, 93-96, 98)

Large colonies of shining, pinkish or colourless, very small (60-100 µm in height) sporocarps (Fig. 20), spores clustered in groups of 20-50, bearing pads at points of spore-to-spore contact (Fig. 21), always with a spore-like columella (Fig. 22).

***Echinostelium minutum*** de Bary [R, 1] **IV**: 1 / b: 1 (Loc. 92)

***Fuligo cinerea*** (Schwein.) Morgan [R, 1] **III**: 1 / d: 1 (Loc. 53)



**Figs 14-15.** *Comatricha laxa* (sc21028). **14.** Dehisced sporocarp (TL). **15.** Detail of capillitium (TL). **Figs 16-17.** *Comatricha pulchella* (sc21026). **16.** Dehisced sporocarp (TL). **17.** Detail of capillitium (TL). **Figs 18-19.** *Echinostelium arboreum* **18.** Two sporocarps (DM, sc21013). **19.** Sporocarp by TL (sc21021). **Figs 20-21.** *Echinostelium colliculosum* (sc21016). **20.** Sporocarps in moist chamber (DM). **21.** Spore cluster (TL). **22.** Dehisced sporocarp showing a collapsed spore-like columella (TL). **Figs 23-25.** *Licea alexopouli* (sc21124). **23.** Sporocarps in moist chamber under dissection microscope. **24.** Spores and black opaque peridium (TL). **25.** Spores (TL).

***Licea alexopouli*** M. Blackw. [R, 1] II: 1 / d: 1 (Loc. 34)

Prominent characters of this species are the shiny black globose and sessile sporocarps (Fig. 23) of 0.07-0.15 mm diam., a very thick peridium appearing opaque black in transmitted light (Fig. 24) that is impregnated with refuse material, and pale yellow, smooth spores (9.7-10.0-10.5(-10.9)  $\mu\text{m}$  in diam., with a conspicuous, 0.8-1.2  $\mu\text{m}$  thick wall (Fig. 25). This rare fimicolous species is known from North America (California: Mock and Kowalski 1976; Texas: Blackwell, 1974; West Virginia: Stephenson, pers. comm.), and East Africa (Kenya, Tanzania: Eliasson and Lundqvist, 1979). Most, but not all of our sporocarps, were impregnated with crystalline refuse matter, as observed in culture by Mock and Kowalski (1976).

***Licea belmontiana*** Nann.-Bremek. [R, 1] III: 1 / d: 1 (Loc. 53)

The distinguishing trait of this species is the rose tint in spore colour as seen under transmitted light (Figs 26, 27). Rare, recorded also from the Caspian Lowland (Novozhilov *et al.*, 2006).

***Licea denudescens*** H.W. Keller & T.E. Brooks [LICden, C, 6] II: 3, III: 1, IV: 2 / b: 4, w: 2 (Loc. 39, 70, 75, 91, 93, 94)

When fresh and moist, the sporocarps look like shiny yellowish brown or dark olivaceous balls within a drop of clear gelatine (Fig. 28). The thicker outer layer of the peridium consists of material that is gelatinous when moist (Fig. 29) and finally weathers away by exposure to rain over a period of time. The inner layer of the peridium is densely ornamented with tiny warts and papillae. The spores are glossy brown or dark olivaceous in mass, concolorous by transmitted light, thick-walled with a paler area, smooth if seen by the light microscope.

***Licea kleistobolus*** G.W. Martin [R, 1] II: 1 / b: 1 (Loc. 83)

***Licea tenera*** Jahn [O, 4] II: 2, III: 1, V: 1 / d: 4 (Loc. 37, 58, 59, 64)

This species approaches *Perichaena*

*liceoides* in habit and substrate preferences. Our specimens of *L. tenera* have a peridium with amorphous deposits in which the outer layer lacks the granular deposits characteristic for *P. liceoides*. Spores are minutely roughened (asperulate), requiring oil immersion for visibility (Fig. 31) but appear delicately warted under SEM, with warts of 0.2-0.5  $\mu\text{m}$  width (Fig. 32). The verruculose spore ornamentation of Mongolian specimens differs from the more spinulose ornamentation of specimens found in the Caspian Lowland (Novozhilov *et al.*, 2006). This is another example of a strictly coprophilous myxomycete.

***Perichaena chrysosperma*** (Curr.) Lister [PERchr, C, 5] III: 4, IV: 1 / b: 2, l: 2, w: 1 (Loc. 13, 57, 71, 84, 86)

***Perichaena corticalis*** (Batsch) Rostaf. [R, 1] II: 1 / d: 1 (Loc. 38)

Found to be fairly common throughout the arid regions of Kazakhstan and Russia on bark of various desert shrubs (Schnittler 2001; Novozhilov *et al.*, 2006). Surprisingly, only one specimen (sc21129) was collected on dung of horse in this study (Figs 33-34).

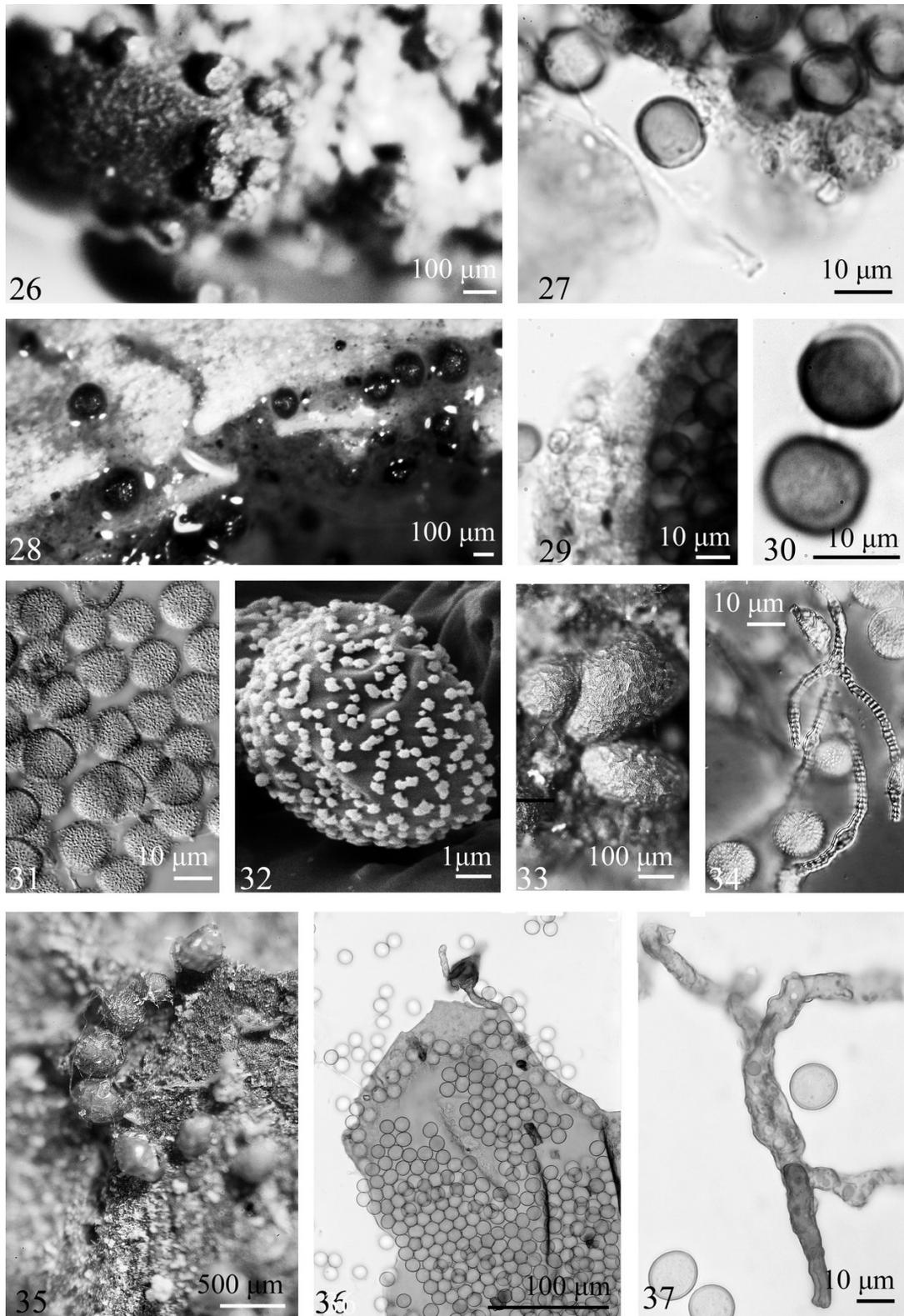
***Perichaena corticalis*** var. *liceoides* (Rostaf.) G. Lister [PERlic, O, 3] II: 1, III: 1, V: 1 / d: 3 (Loc. 33, 53, 67)

All examined sporocarps lack a capillitium. Prominent differences between this taxon and *L. tenera* include the structure of the peridium and spore ornamentation (Novozhilov *et al.*, 2006). This species appears to be common in arid regions (Novozhilov *et al.*, 2003; unpubl. observations of M. Schnittler from Big Bend National Park in Texas, unpubl. observations of I. Zemlyanskaya, Yu. Novozhilov, M. Schnittler and G. Adamonite from Kazakhstan).

***Perichaena depressa*** Libert [PERdep, A, 19] II: 1, III: 14, IV: 4 / b: 10, l: 9 (Loc. 12, 17, 36, 42, 53-58, 70, 75, 77, 84-86, 90, 92, 95)

***Perichaena luteola*** (Kowalski) Gilert [R, 1] V: 1 / d: 1 (Loc. 68)

Another strictly coprophilous myxomycete sporadically found in arid regions (Novozhilov *et al.*, 2006). The hallmark of this



**Figs 26-27.** *Licea belmontiana* (sc21066). **26.** Fresh sporocarps in culture (DM). **27.** Spores (TL). **Figs 28-30.** *Licea denudescens* (sc21114). **28.** Sporocarps in culture (DM). **29.** Surface of peridium covered by a gelatinous hyaline layer (TL). **30.** Spore (TL). **Figs 31-32.** *Licea tenera* (sc21036). **31.** Spores (TL). **32.** Spore (SEM). **Figs 33-34.** *Perichaena corticalis* (sc21129). **33.** Sporocarps (DM). **34.** Spores and capillitium (TL). **Figs 35-37.** *Perichaena luteola* (sc21159). **35.** Sporocarps in moist chamber (DM). **36.** Peridium and spores (TL). **37.** Capillitium and spores (TL).

species is the bright shiny, olive-yellow globose sporocarps having a transparent thin peridium with a smooth inner surface (Figs 35-36). Spore mass and capillitium yellow, the latter composed of a network of branched and anastomosed tubules 1-4  $\mu\text{m}$  diam. (Fig. 37), with a few free ends that are weakly attached to the peridium (Fig. 36).

*Perichaena quadrata* T. Macbr. [PERqua, A, 16] **III**: 16 / b: 3, d: 4, l: 6, w: 3 (Loc. 12, 40, 50, 54, 55, 57, 59, 80, 90)

*Perichaena vermicularis* (Schwein.) Rostaf. [PERver, A, 25] **I**: 1, **III**: 19, **IV**: 5 / b: 6, d: 2, l: 14, w: 3 (Loc. 17, 22, 25, 36, 42, 50, 53-57, 60-62, 75-78, 85, 92)

*Perichaena* sp. [**O**, 3] **III**: 3 / l: 3 (Loc. 25, 40, 54)

Small colonies of scattered stalked sporocarps resembling *Hemitrichia pedata*, stalk stout, dull brown to black, usually one half, rarely as long as the sporotheca, rarely absent (Figs 38-39). *Sporotheca* 0.11-0.14 mm in diam., globose, translucent yellowish, spore mass visible through the peridium. *Peridium* under transmitted light smooth and pale yellow, densely covered with yellow-brown granulae 2.5-3.5  $\mu\text{m}$  in size, but these not forming a regular crust, no ornamentation visible, opening irregularly. *Capillitium* absent. *Spores* in mass pale brown to yellowish brown, under transmitted light very pale yellow, (12.6-13.3-14.7(-16.6)  $\mu\text{m}$  in diam., globose to slightly subglobose, with an irregular network of low, meandering ridges 0.6-0.8  $\mu\text{m}$  tall, forming meshes of irregular shape and size (Figs 40-41).

Recently, this myxomycete was also recorded in western Kazakhstan (unpubl. Observations of I.V. Zemlyanskaya). Apparently, this is another taxon in the transitional species complex between *Licea* and *Perichaena*. The absence of any traces of a capillitium in all our specimens links it to the stalked Liceales, but the colour of the spore mass lets it appear as a *Perichaena*. The very distinctive spore ornamentation sets this taxon apart from *Perichaena pedata* and *P. tessellata*, both possessing warted spores. *P. reticulospora* has coarsely and prominently banded-reticulate spores with a reticulum consisting of

ridges 1  $\mu\text{m}$  high and (6-)8-11(-13) meshes per hemisphere (Keller and Reynolds, 1971).

*Physarum cinereum* (Batsch) Pers. [**O**, 2] **III**: 1, **IV**: 1 / b: 2 (Loc. 71, 86)

*Physarum compressum* Alb. & Schwein. [**R**, 1] **III**: 1 / l: 1 (Loc. 90)

*Physarum decipiens* M.A. Curtis [PHYdec, A, 13] **III**: 9, **IV**: 4 / b: 7, l: 2, w: 4 (Loc. 1, 5, 50, 53, 54, 57, 72, 75, 76)

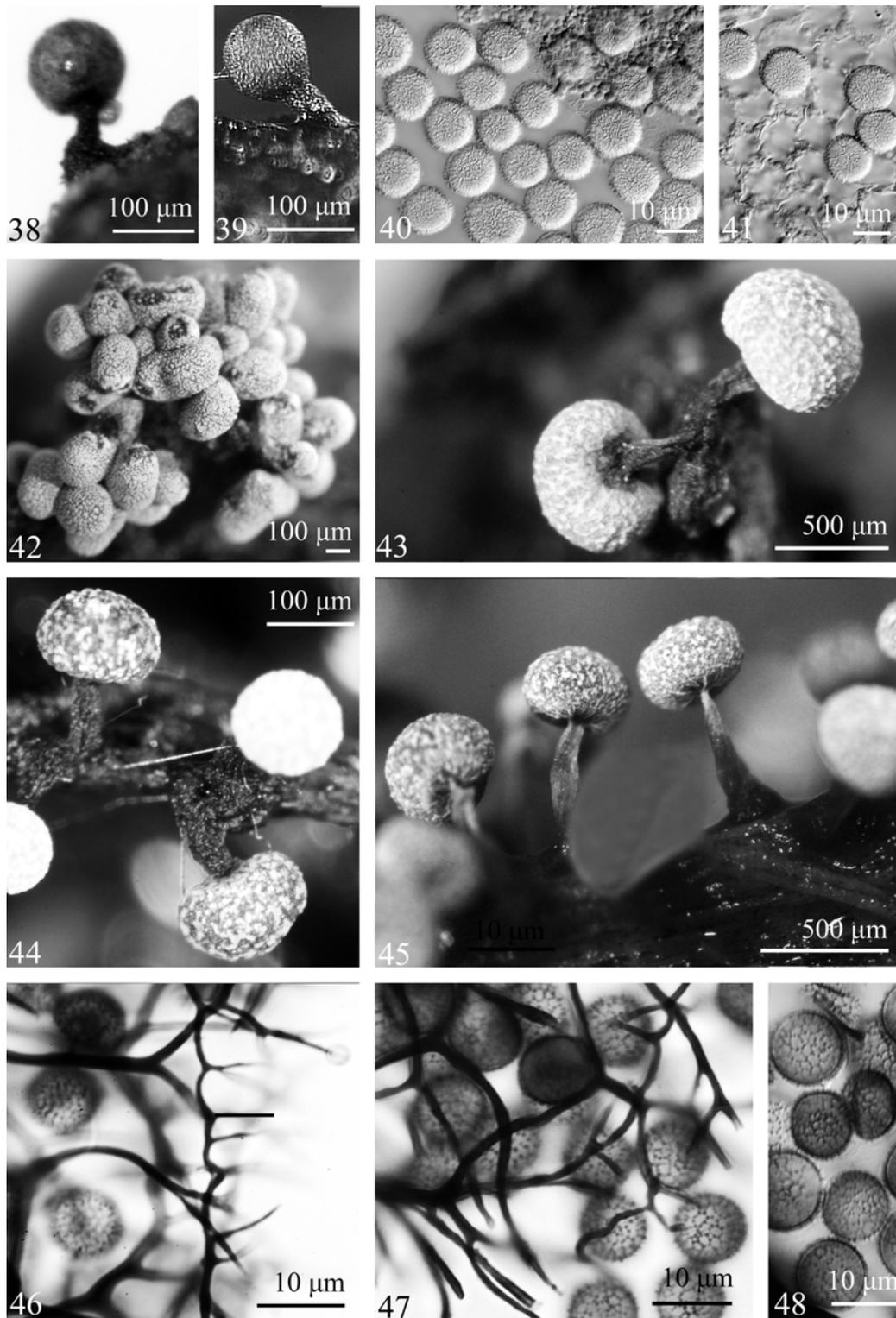
*Physarum didermoides* (Pers.) Rostaf. [PHYdio, C, 6] **II**: 1, **III**: 2, **IV**: 1, **V**: 2 / b: 1, d: 3, l: 1, w: 1 (Loc. 2, 11, 15, 67, 94)

All specimens have sporocarps with a double peridium consisting of a calcareous outer layer and a fragile, fugaceous, inner membranous layer (Fig. 42). Fairly common in arid areas of Eurasia (Schnittler, 2001; Novozhilov *et al.*, 2006).

*Physarum gyrosom* Rostaf. [**R**, 1] **III**: 1 / w: 1 (Loc. 11)

*Physarum* cf. *notabile* T. Macbr. [PHYnot, A, 72] **I**: 4, **II**: 13, **III**: 48, **IV**: 4, **V**: 1 / b: 19, d: 14, l: 19, w: 18 (Loc. 1, 7, 11-13, 17, 19, 22, 25, 28-30, 33-43, 48, 50, 53, 54, 57-63, 68, 75-78, 80, 81, 83-85, 93-95)

According to the literature (Martin and Alexopoulos, 1969), *P. notabile* is reported mostly on wood in temperate and boreal deciduous and coniferous forests. The specimens from Mongolia display considerable variation in habit, peridial lime distribution, shape and the proportions of stalk and sporotheca and do not agree perfectly with the description of this species from temperate and boreal regions. Three forms can be distinguished from this survey. **Form 1** (sc21072) has large sporangia with thin stalks of 0.8-1.5 mm height, 200-250  $\mu\text{m}$  in diam. at the apex and 100-150  $\mu\text{m}$  in diam. at the base, reddish-brown at the apex, black in other parts. Sporothecae are globose-depressed to umbilicate, 0.5-1.5 mm wide, white-greyish and densely incrustated by lime granules, reddish-brown at the base under the dissecting microscope. (Fig. 43). **Form 2** (sc21004) has small sporangia with short and more or less evenly thick stalks of 0.3-0.5 mm



**Figs 38-41.** *Perichaena* sp. (sc21100). **38.** Fresh sporocarp in moist chamber (DM). **39.** Dried sporocarp (DM). **40.** Spores (TL). **41.** Spores and inner surface of peridium (TL). **Fig. 42.** *Physarum didermoides* (sc21075). Habit (DM). **Figs 43-45.** *Physarum* cf. *notabile*. **43.** Sporocarps with thick stalk and large subglobose sporotheca (sc21072, from 1). **44.** Sporocarps with short thick stalk and a small subglobose sporotheca (sc21004, form 2). **45.** Sporocarps with long stalk and small subglobose sporotheca (sc21070, form 2a, all DM). **Figs 46-48.** *Stemonitopsis amoena*. **46.** Surface of capillitium with short free ends, pointing outwards and spores (both TL), ornamented with a reticulum (sc21088). **47-48.** Detail of capillitium and spores (TL) (sc21079).

height, 150-200 µm in diam. at the base, evenly black or dark brown without reddish tints. Here, sporothecae are subglobose, 150-200 µm wide, white-greyish, evenly incrustated with white lime on all surface, dull grey at the bottom without reddish tints (Fig. 44). **Form 2a** (sc21070) is very similar but has a long stalk tapering towards the apex, 0.5-1.0 in mm height, 200-300 µm in diam. at the base, 50-150 µm wide at the apex, black or dark brown in the lower half and yellowish at the apex, without reddish tints. *Sporothecae* are subglobose, 0.2-0.4 mm wide at the bottom, white-greyish, evenly incrustated with white lime over the entire surface, dull grey at the bottom and without reddish tints (Fig. 45). All forms have a physaroid capillitium with white nodes, variable in size and shape (20-80 µm in extent), connected by hyaline threads, a columella is absent. Spores are uniform violet brown in TL, ornamentation verruculose, 10-11.5 µm diam.

These forms agree well with morphotypes recently described from western Kazakhstan (Schnittler and Novozhilov, 2000) and the Caspian Lowland (Novozhilov *et al.*, 2006). Form 3, known from western Kazakhstan, with clearly compressed to weakly reniform sporothecae is absent in our collections from Mongolia. Apparently, this taxon is the most abundant myxomycete in winter-cold arid areas (Novozhilov and Golubeva, 1986; Schnittler 2001; Novozhilov *et al.*, 2006; unpublished data from deserts and steppes of Kazakhstan, Orenburg region of Russia). We assume that all forms mentioned above represent different asexual strains of one morphospecies that is widely distributed within Eurasia.

*Physarum pusillum* (Berk. & M.A. Curtis) G. Lister [R, 1] II: 1 / b: 1 (Loc. 95)

*Stemonitis flavogenita* E. Jahn [O, 2] III: 2 / d: 2 (Loc. 56, 62)

*Stemonitopsis amoena* (Nann.-Bremek.) Nann.-Bremek. [O, 2] IV: 2 / d: 2 (Loc. 74, 76)

Applying the currently used generic delimitation of *Stemonitis* and *Stemonitopsis*

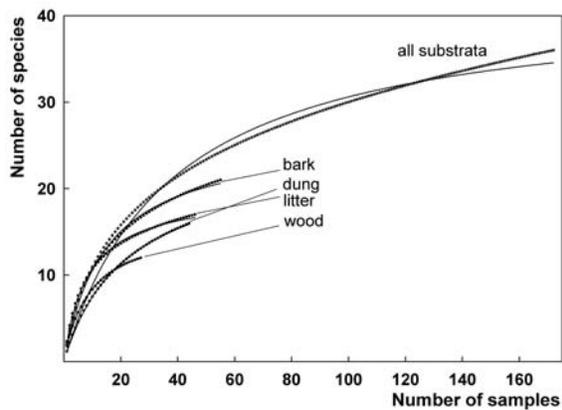
(Nannenga-Bremekamp, 1967; Lado, 2001), the Mongolian specimens have to be accommodated in the genus *Stemonitopsis* due to the very incomplete capillitium net in the upper part of the sporotheca. The capillitium is dark red-brown; with an internal net branching from the whole length of the columella, and forms about 5-7 meshes over hemisphere of the sporotheca. Capillitial threads are thin with few expansions and have numerous free ends at the surface (Figs 46-47); the surface net is best developed at the sporotheca base but is very incomplete above, with irregularly shaped meshes 5-15 µm in diam. Spores are pale lilac-grey under transmitted light; (8.4-)9.6-10.8(-11.0) µm in diam.; delicately verrucose-reticulate with 5-7 meshes on the diam. (Fig. 48). Our specimens have larger spores, (9.3-)9.6-10.8(-11.0) µm in diam., than that given in the original description of the species (Nannenga-Bremekamp, 1968), otherwise our sporocarps match in habit and capillitial structure with specimens pictured by Neubert, Nowotny and Baumann (2000: 301).

Three scanty collections apparently belonging to *Perichaena* were immature and, together with 40 records of non-fruiting plasmodia, are omitted in the annotated species list.

### *Myxomycete diversity*

Since no myxomycete fructifications were observed in the field, all data of this survey originate from moist chamber cultures. The 333 records were obtained from 283 moist chamber cultures (excluding 40 records of non-fruiting plasmodia), representing 36 species from 13 genera and 7 families. However, one third of the 36 taxa were classified as rare for the whole area.

Fitting the species accumulation curve by a hyperbolic function, an estimate of 42 expected species was obtained (Fig. 48). Applying a simple hyperbolic function to fit species accumulation curves computed separately for each of the sampled groups of substrates, the survey was to 80% complete for bark-inhabiting, 85% for litter-inhabiting, 66% for dung-inhabiting and 75% for wood-inhabiting species, respectively.

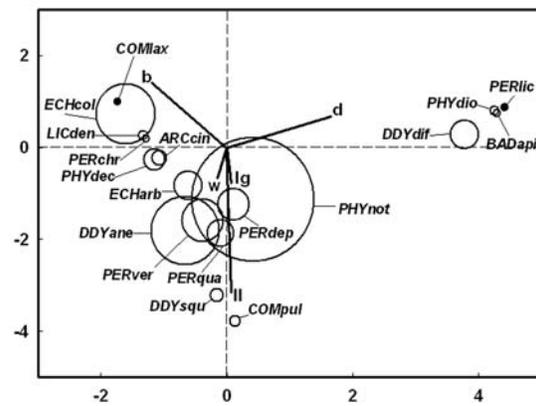


**Fig. 48.** Species accumulation curves of samples (172 moist chamber cultures being positive for myxomycetes) versus cumulated species numbers (dots). Solid lines show the results of regression analysis using a saturation function  $y = Ax/(B + x)$ , where  $A$  is the maximum number of species to be expected and  $B$  is the number of samples needed to reach half of the number of species to be expected.

### Substrate-species relationships

Both species richness and diversity vary considerably within groups of substrates and decrease from bark of living plants (21 species,  $H' = 2.52$ ), over litter (17 species,  $H' = 2.45$ ), dung of herbivorous animals (16 species,  $H' = 2.38$ ), to woody debris (12 species,  $H' = 2.10$ ). The mean value for the number of species per culture shows the same trend (Table 1).

Up to six species per single moist chamber were observed on the bark and litter, but only up to four species on dung and wood. Remarkable is the high abundance of a few dominant species: the nine species classified as abundant ( $> 3\%$  of the 333 records) provide three quarters of all records in the survey. Similar trends can be observed for the productivity of moist chamber cultures (given in terms of average number of species per culture: bark 1.85, litter 1.72, dung 0.61, wood 1.50). Looking for substrate-specific taxa, the picture almost reverses, with eight species found exclusively on dung, six on bark, four on litter, and only one on woody debris. Coprophilous and corticolous species seem to be more specialized than other ecological groups. The results of a canonical correspondence analysis (CCA, Fig. 49) support this statement. The most abundant corticolous species are *Echinostelium colliculosum* (28



**Fig. 49.** Biplot of a canonical correspondence analysis (CCA) computed for occurrences of the 18 common species of myxomycetes on different substrates. The size of each circle is proportional to the abundance of the respective species. Abbreviations for species are indicated in the annotated species list, those for substratum groups are **b** – bark, **d** – dung, **w** – wood debris, **Ig** – litter of grasses, **II** – leaf litter.

records of 35 registered on bark) and *Licea denudescens* (4/6); dominant litter-inhabiting forms are species of *Perichaena* (34/73), and *Didymium anellus* (20/40). Typical coprophilous species are *Licea tenera* (4/4), *Badhamia apiculospora* (4/5), and *Didymium difforme* (7/17). Surprisingly, *Fuligo cinerea*, one of the most common coprophilous species in the Mangyshlak peninsula (MP, Schnittler 2001), Caspian Lowland (CL, Novozhilov *et al.*, 2003), and the American Colorado Plateau (CP, Novozhilov *et al.*, 2006), is rare in western Mongolia (one record only).

### Myxomycete diversity in different vegetation types

When considering species observed in moist chamber cultures (Table 2), species richness and diversity increase from vegetation type I (extrazonal grasslands, 5 species,  $H' = 1.42$ ) to III (dry steppe/shrub community, 27 species,  $H' = 2.60$ ) and IV (montane steppe/tall shrub, 17 species,  $H' = 2.65$ ) to decrease again (V, alpine steppe, 6 species,  $H' = 1.73$ ). A similar picture is obtained when looking at the myxomycete species apparently limited to a vegetation zone: I (1 species), II (4), III (8), IV (3) and V (1); with the zones I and V only being represented by only one rare coprophilous species.

**Table 1.** Statistical data for all investigated substrates.

Substrate (plant name)	Sub <sup>a</sup>	pH <sup>b</sup>	Wr <sup>c</sup>	Mc <sup>d</sup>	R <sup>e</sup>	R/Mc <sup>f</sup>	S/Mc <sup>g</sup>
<i>Amygdalus pedunculata</i>	b2	6.70 ± 0.51	7.94 ± 1.71	5	7	1.40	1.20
<i>Caragana bungei</i>	b2	6.27 ± 0.15	7.44 ± 0.47	4	5	1.25	1.25
<i>Caragana leucophloea</i>	b2	6.84 ± 0.54	8.93 ± 0.34	24	40	1.71	1.46
<i>Caragana spinosa</i>	b2	5.60 ± 0.05	12.89	1	1	1.00	1.00
<i>Salix</i> sp.	b2	6.90	5.54	1	0	0.00	0.00
Total bark (type b2)	b2	6.76 ± 0.05	8.64 ± 0.3	34	53	1.06	0.98
<i>Atraphaxis bracteata</i>	b3	7.38 ± 0.13	15.43 ± 2.97	4	16	4.00	3.75
<i>Atraphaxis frutescens</i>	b3	6.98 ± 0.33	17.23 ± 0.37	5	9	1.80	2.60
<i>Lonicera microphylla</i>	b3	6.61 ± 0.41	16.82 ± 5.55	4	4	1.00	0.75
<i>Nitraria sibirica</i>	b3	7.60 ± 0.05	15.58	1	0	0.00	0.00
Total bark (type b3)	b3	7.03 ± 0.07	18.76 ± 1.85	14	29	1.70	1.53
<i>Artemisia xerophytica</i>	b5	7.57 ± 0.78	5.69 ± 1.17	2	4	2.00	2.00
<i>Artemisia santolinifolia</i>	b5	6.9 ± 0.19	16.96 ± 1.22	3	10	3.33	3.00
<i>Artemisia sphaerocephala</i>	b5	7.05 ± 0.13	20.02 ± 1.30	4	7	1.75	1.75
<i>Artemisia dolosa</i>	b5	7.03 ± 0.35	14.86 ± 2.57	3	6	2.00	1.33
<i>Oxytropis aciphylla</i>	b5	7.31	24.86	1	0	0.00	0.00
Total bark (type b5)	b5	7.04 ± 0.08	18.22 ± 1.09	13	23	1.82	1.62
<i>Chenopodium frutescens</i>	bw	6.10	6.60	1	0	0.00	0.00
<i>Krascheninnikovia ceratoides</i>	bw	7.00 ± 0.46	5.76 ± 0.89	8	22	2.75	2.75
Total bark (type bw)	bw	6.90 ± 0.09	5.85 ± 0.79	9	22	1.38	1.38
<b>Total bark</b>		<b>6.87 ± 0.13</b>	<b>11.38 ± 0.72</b>	<b>71</b>	<b>132</b>	<b>1.85</b>	<b>1.68</b>
<i>Achnatherum splendens</i>	lg	7.27 ± 0.48	18.56 ± 2.51	5	4	0.80	0.60
<i>Elymus</i> sp.	lg	6.90	22.01	1	1	1.00	1.00
<i>Stellaria pulvinata</i>	lg	7.27 ± 0.30	13.81 ± 2.08	4	3	0.75	0.50
<i>Stipa glareosa</i>	lg	7.72 ± 0.30	10.70 ± 2.04	7	5	0.71	0.71
<i>Stipa gobica</i>	lg	7.56 ± 0.39	12.06 ± 3.74	14	8	0.57	0.57
Total grass litter (lg)	lg	7.48 ± 0.04	13.35 ± 0.75	31	21	0.77	0.68
<i>Amygdalus pedunculata</i>	ll	7.37 ± 0.46	10.58 ± 3.41	5	14	2.80	2.20
<i>Atraphaxis frutescens</i>	ll	7.10	26.05	1	0	0.00	0.00
<i>Caragana bungei</i>	ll	7.05	22.76 ± 0.44	2	3	1.50	1.50
<i>Caragana leucophloea</i>	ll	7.19 ± 0.43	15.56 ± 5.27	24	63	2.63	2.38
<i>Ephedra przewalskii</i>	ll	7.38	6.20	1	2	2.00	2.00
<i>Eurotia ceratoides</i>	ll	7.60 ± 0.25	12.13 ± 0.96	3	11	3.67	3.33
<i>Ribes acicularis</i>	ll	6.93 ± 0.28	21.18 ± 0.46	3	6	2.00	1.67
Mixed litter	ll	7.50	32.22	1	2	2.00	2.00
Total leaf litter (ll)	ll	7.21 ± 0.03	16.0 ± 0.90	40	101	2.07	1.88
<b>Total litter</b>		<b>7.33 ± 0.03</b>	<b>14.84 ± 0.62</b>	<b>71</b>	<b>122</b>	<b>1.72</b>	<b>1.54</b>
<i>Anabasis brevifolia</i>	w3	7.82 ± 0.65	4.57 ± 0.76	10	15	1.50	1.40
<i>Artemisia</i> sp.	w3	8.34	8.20	1	2	2.00	1.00
<i>Artemisia xerophytica</i>	w3	7.40 ± 0.14	7.93 ± 0.47	4	4	1.00	1.00
<i>Caragana leucophloea</i>	w3	7.14 ± 0.29	4.37 ± 0.79	8	23	2.88	2.50
Total wood (type w3)		7.54 ± 0.07	5.24 ± 0.34	23	44	1.84	1.48
<i>Anabasis brevifolia</i>	w4	7.71 ± 0.32	4.73 ± 0.73	8	7	0.88	0.63
<i>Artemisia</i> sp.	w4	6.37	6.73	1	1	1.00	1.00
<i>Artemisia xerophytica</i>	w4	7.40 ± 0.37	5.15 ± 0.32	4	4	1.00	1.00
<i>Atraphaxis frutescens</i>	w4	7.40	20.52	1	0	0.00	0.00
<i>Ephedra przewalskii</i>	w4	7.40	6.18	1	1	1.00	1.00
<i>Eurotia ceratoides</i>	w4	7.85	4.80	1	2	2.00	2.00
<i>Oxytropis aciphylla</i>	w4	7.10	9.60	1	1	1.00	0.00
Total wood (type w4)	w4	7.49 ± 0.06	5.53 ± 0.36	17	16	0.98	0.80
<b>Total decayed wood</b>		<b>7.52 ± 0.04</b>	<b>5.36 ± 0.24</b>	<b>40</b>	<b>60</b>	<b>1.50</b>	<b>1.30</b>
Camel	d	7.88 ± 0.56	8.35 ± 1.74	25	13	0.52	0.48
Cow	d	8.48 ± 0.12	8.66 ± 2.33	7	6	0.86	0.86
Horse	d	7.52 ± 0.57	12.05 ± 2.66	18	5	0.28	0.28
Pika	d	7.15	20.16	1	0	0.00	0.00
Sheep	d	7.64 ± 0.36	9.21 ± 1.67	50	38	0.76	0.64
<b>Total dung</b>		<b>7.70 ± 0.02</b>	<b>9.57 ± 0.25</b>	<b>101</b>	<b>62</b>	<b>0.61</b>	<b>0.54</b>

<sup>a</sup>Substrate type: bark texture groups (b2 = smooth but rupturing with age, b3 = peeling, b5 = fibrous), litter (lg = grass remnants, ll = leaf litter), wood (w3 = moderately, w4 = strongly decayed) and herbivore dung (d).

<sup>b</sup>Average and standard error of pH values for all moist chambers prepared with material from this plant.

<sup>c</sup>Average and standard error of water retention [ml water per g dry mass] for the respective substrate.

<sup>d</sup>Number of moist chamber cultures prepared with this substrate.

<sup>e</sup>Total number of records (including plasmodia).

<sup>f</sup>Average number of records per moist chamber (including non-fruiting plasmodia) from all cultures prepared with the respective substrate.

<sup>g</sup>Average number records determined to species per moist chamber  $\pm$  standard error (excluding non-fruiting plasmodia).

## Discussion

Except for the paper of Novozhilov and Golubeva (1986), no other records of myxomycetes are known for Mongolia; this study presents the first comprehensive survey for the country. The total of 333 records belong to 36 species; including previous data, 47 myxomycete taxa have now been recorded for Mongolia. Certainly, this represents only a minor fraction of the total myxomycete diversity of the country, since the taiga belt has not been studied so far. All following statements and discussions are therefore meant to be valid only for the arid, treeless southern and southwestern part of Mongolia.

As a whole, the results of this survey fit well into the pattern recorded for similar surveys from other arid zones of Eurasia, like Kazakhstan (Schnittler, 2001), or the Caspian Lowland (Novozhilov *et al.*, 2006). In all these regions, including this survey, myxomycete fructifications in the field are at best exceptionally rare, thus the following conclusions are solely based on results from moist chamber cultures. The productivity of moist chambers is relatively high (Mongolia: average value of 1.94 species per culture), but especially for the number of sporocarps that a species produces in a culture (average for the 72 records of *Physarum cf. notabile*: 87 sporocarps). The most abundant species (> 3% of all records, scale value A, 9 species) accounted for 254 records (76% of all 333 records), and these figures drop sharply towards rare species (C: 7 species, 46 records, 14%; O: 8 species, 21 records, 6%; R: 12 species; 12 records, 4%). *Physarum cf. notabile* as the most common species was recorded alone 72 times (22% of all records). As a whole, the species diversity (Shannon-index  $H' = 2.8$ ) of the Depression of Great Lakes is comparable with figures from

other arid areas, and the Simpson's dominance index is rather high ( $D = 0.09$ ).

Since all records originate from substrate cultures, we obtained an unbiased data set for species' abundances, allowing us to estimate the degree of completeness of the survey. However, cultures allow only to detect myxomycetes that can be reactivated from microcysts, sclerotia and/or spores. Thus, the rather high degree of completeness shown by our data holds true only for taxa responding well to the culture technique applied. Among substrates, dung might be a notable exception, since (i) its species accumulation curve is much steeper than that of those for the other substratum types, and (ii) a rather large proportion of the species occurring on dung are rare but also specific for that substrate.

Interesting are the differences in species richness and specificity for the three main groups of substrates: Bark had the most diverse myxomycete assemblage (21 species, 10 species preferring this substrate, 6 exclusively occurring on bark, altogether 119 records). Second in specificity was dung (16 species, 11 preferring, 8 exclusive, 52 records). Ground litter (17 species, 7 preferring, 4 exclusive, 109 records) has a less specialized species assemblage, but many ubiquitous species; wood was species-poor and virtually non-specific (12 species, one but rare species exclusively occurring there, 52 records). As a conclusion, herbivore dung can be seen as understudied for the region; its guild of apparently rare but specialized species is not yet fully explored. The surprising diversity of coprophilous myxomycetes may be a result of the long presence of large herbivores in Central Asian arid zones, and it seems that most if not all of the species survived well the transition from wild to domestic herbivores taking place with human

**Table 2.** Statistical data for myxomycete assemblages from different vegetation types of the Great Lake Basin of western Mongolia.

Parameter	Total	Vegetation types <sup>a</sup>				
		I	II	III	IV	V
Mean elevation (m)	1463	1167	1217	1300	2038	3097
Sampled localities	82	5	27	33	13	4
Total number of samples	283	13	70	158	31	11
Bark	72	-	12	41	19	-
Litter	71	7	9	44	7	4
Dung	100	6	30	52	5	7
Wood	40	-	19	21	-	-
Proportion of positive cultures (%)	64.3	53.8	52.9	69.0	67.7	72.7
Records <sup>b</sup>	333	10	62	205	48	8
Species per culture	2.07	1.67	1.77	1.98	2.28	1.14
Standard Error	1.22	0.33	0.19	0.11	0.25	0.14
Species	36	5	18	27	17	6
Genera	13	5	8	11	8	5
Ratio species/genera	2.8	1.0	2.3	2.5	2.1	1.2
Shannon H'	2.81	1.42	2.37	2.60	2.65	1.73
Simpson D	0.09	0.28	0.13	0.11	0.08	0.19

<sup>a</sup> Vegetation types: I = extrazonal grasslands, II = desert steppe/dwarf shrub communities of the plains, III = dry steppe/shrub communities of the foothills, IV = mountain steppe/tall shrub communities, V = alpine steppe.

<sup>b</sup> Excluding non-fruiting plasmodia.

history of nomadism. This pattern contrasts with surveys from temperate and boreal forests (Stephenson, 1988; Schnittler *et al.*, 2006; Novozhilov and Lebedev 2006), where decaying wood seems to possess the most specialized but also most common species assemblage. There is another important difference: woody debris of temperate and boreal zones usually has many common and specialized species, whereas all species specialized for dung are apparently rare. However, sampling methods for these two substrata are usually not comparable (field observations vs moist chamber culture technique); only a larger set of data from moist chamber cultures of decayed wood from temperate zones would allow a direct comparison.

Several of the more common myxomycete taxa seem to represent one widely distributed morphospecies with several separate strains that may represent biospecies, as indicated by the fact that specimens could be grouped to morphotypes according to minor trait differences. Good examples are *Badhamia apiculospora* and *Physarum cf. notabile*, where several forms could be segregated. This would comply with results of mating type analyses for *Didymium iridis* (Clark 2000) and

several other studies, mostly from the Neotropics, (Clark *et al.*, 2002, *Arcyria cinerea*; Clark and Stephenson, 2000; *Physarum melleum*; Clark and Stephenson, 2003; *Didymium squamulosum* and other species), where heterothallic and non-heterothallic (presumptive apomictic) strains or biospecies coexist. More research would be needed to resolve such speciation patterns.

Since desert steppe and dry steppe are the most widely distributed vegetation types in the plains, most (68%) of all samples originate from these two vegetation types, and this bias does not allow a statistical analysis of species diversity within vegetation types. Nevertheless, there seems to be a humpback curve for both species richness and diversity within the elevational gradient spanned by the five major vegetation types (Table 2). An obvious explanation is the absence of shrubs in both extrazonal and alpine grasslands at the ends of the gradient, cutting out the two substrata types bark and wood. On the other hand, more than three quarters of the total species number was already found at lower altitudes (zones I-III). Some ubiquitous species, such as *Physarum notabile*, *Arcyria cinerea* and several obligate coprophilic species are able to inhabit the whole range of elevations. A

**Table 3.** Species richness and diversity of myxomycetes in treeless arid regions of the world as obtained by the moist chamber culture technique.

Parameter	Study regions <sup>a</sup>				
	CL	MP	DGL	CP	CH
Samples cultured	295	146	283	58	85
Proportion of positive cultures	86.7%	82.0%	63.2%	91.2%	n.d.
Records	678	328	333	162	30
Mean species per sample	2.65	2.20	1.94	2.80 <sup>b</sup>	n.d.
Standard Error	0.10	1.15	0.09	0.15	n.d.
Species	44	27	36	19	12
Genera	18	11	13	9	7
Ratio species / genera	2.4	2.5	2.8	2.1	1.7
Shannon H'	3.0	2.5	2.8	2.6	n.d.

<sup>a</sup> Study regions are abbreviated as CL = Caspian Lowland, treeless zonal dry steppe and desert communities (Novozhilov *et al.*, 2006); MP = Mangyshlak peninsula, treeless desert zonal communities (Schnittler and Novozhilov, 2000); DGL = Depression of the Great Lakes (this study); CP = Colorado Plateau, sagebrush communities with *Artemisia tridentata* (Novozhilov *et al.*, 2003); CH = arid areas of Chile (Lado *et al.*, 2006), excluding field records, n.d. = not determined.

**Table 4.** Pairwise comparisons of myxomycete biotas among five treeless, arid study regions. The total of all specimens observed in the field as well as in moist chamber cultures was used for calculation of the adjusted incidence-based Chao-Sørensen similarity indices. Both similarity index (upper right) and numbers of species shared (lower left) are given. Abbreviations for study areas are the same as those used in Table 3.

	CL	MP	DGL	CP	CH
CL	***	0.350	0.683	0.350	0.166
MP	14	***	0.793	0.522	0.164
DGL	11	11	***	0.526	0.350
CP	7	6	11	***	0.320
CH	6	6	7	6	***

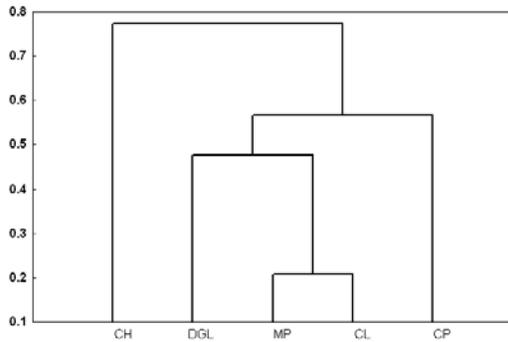
notable exception was *Perichaena luteola* (2 records on dung), recorded in the alpine zone only. The Simpson dominance index (D) reaches a maximum in extrazonal grasslands (D = 0.28) and alpine steppe (0.19). This follows the pattern that species dominance of communities with extreme conditions is higher than in more diverse communities.

As listed in Table 3, our data from western Mongolia fit well into patterns obtained from studies for other arid but winter-cold regions, using the moist chamber culture technique (Mangyshlak peninsula, western Kazakhstan, Schnittler, 2001; Caspian Lowland, southern Russia, Novozhilov *et al.*, 2006).

A comparison based on the adjusted incidence-based Chao-Sørensen similarity

index Cs (Table 4) shows that the myxomycete biota of the Depression of Great Lakes has the highest similarity with myxomycete biota of the Mangyshlak peninsula in Kazakhstan (Cs = 0.79).

One difference is the occurrence of the two acidophilic species *Comatrixia laxa* and *C. pulchella*, which are common in the two other studied regions of Eurasia on acidic bark of *Tamarix*. This major desert shrub genus developing acidic bark is common in Kazakhstan and the Caspian Lowland but is rather rare in western Mongolia. With this exception, all patterns displayed above correspond closely with those obtained from data sets of other winter-cold arid areas, as indicated by an average value of 0.61 for similarity between the three investigated arid winter-cold regions in Eurasia. On the other hand, the average value of 0.42 for similarity between all investigated regions including temperate and warm deserts of western North America (Novozhilov *et al.*, 2003) and South America (Lado *et al.*, 2006) reflects the high level of dissimilarity myxomycete biotas of arid regions of Eurasia and New World (Fig. 50). As to be expected, a hierarchical cluster analysis based on Cs values shows that the myxomycete biotas of arid winter-cold Eurasian regions are most similar to each other, forming a homogenous cluster with biotas from North and South America placed separately (Fig. 50).



**Fig. 50.** Dendrogram of dissimilarity, based on the Chao-Sørensen similarity index (Table 4), of the relative occurrence of the 59 species found in moist chamber cultures in arid study regions (abbreviations as explained in Table 3).

Together with the obvious morphological variability within very common species, these data support the moderate endemism model of microbial and protist distribution (Chernov, 1993; Zavarzin, 1994; Foissner, 1997). Taking into account that this study provided evidence that many morphospecies consist of several separate biospecies, this model seems even more likely to hold true for myxomycetes as well.

### Acknowledgements

We gratefully acknowledge the logistical support during field work provided by Dr. O. Damdinsurenjin, State University Khovd, technical support by L.A. Kartzeva, St. Petersburg as well as advice for the classification of vegetation by A. Zemmrich, Greifswald. Thanks are also due to D.W. Mitchell revising our English text and for discussing and proof-reading the manuscript. Travel was supported in part from the Planetary Biodiversity Inventory project (Global Biodiversity of Eumycetozoans, grant DEB-0316284 from the U.S. National Science Foundation, for the first author) and the German Volkswagen Foundation (grant I/77 426 for the second author). Additional funding for lab work came from the Russian Found for Basic Research (grant 07-04-00353-a) and “Bioraznoobrazie” from the Russian Academy of Science.

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