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Phytosociological affinities and habitat preferences of *Juniperus sabina* L. and *Artemisia santolinifolia* TURCZ. ex BESS. in mountain sites of the south-eastern Gobi Altay, Mongolia

With one Map, 6 Figures and 3 Tables

Summary

Plant community composition was analysed for 145 relevés, randomly sampled on steep slopes in the Gobi Gurvan Sayhan National Park, southern Mongolia. Cluster analysis designated seven communities into three main groups, namely mountain steppes, dominance stands of the dwarf shrub *Artemisia santolinifolia*, and scrub composed of *Juniperus sabina*. Multivariate classifications corresponded well to available phytosociological classification schemes. Dense mountain steppes on northern exposures, as well as juniper stands on south- and east-facing scree slopes, had high contents of organic matter and cations in the soil, while stands with disturbance-tolerant species such as *Carex stenophylla*, annuals, or *A. santolinifolia* grew on less favourable soils. Stands of the latter species showed some overlap with *J. sabina* with respect to species composition and site conditions, and specimens of *A. santolinifolia* were present in most relevés of juniper stands. The complete absence of juniper seedlings suggested an apparent potential replacing of ageing specimens of *J. sabina* by *A. santolinifolia.* However, both species were distinct in cluster, ordination and correlation analyses, so this process seems to be still in its infancy.

Zusammenfassung

Vergesellschaftung und Habitatansprüche von *Juniperus sabina* L. and *Artemisia santolinifolia* TURCZ. ex BESS. in Bergsteppen des südlichen Gobi Altai, Mongolei

Der vorliegende Text beschreibt die Pflanzengesellschaften der steilen Gebirgshänge im Gobi Gurvan Sayhan Nationalpark in der südlichen Mongolei. 145 zufällig genommene Vegetationsaufnahmen wurden mittels Cluster-Analyse klassifiziert, die sieben Gesellschaften in drei Gesellschaftsgruppen ergab: Bergsteppen, Dominanzbestände von *Artemisia santolinifolia* und *Juniperus sabina*-Gebüsche. Diese multivariate Klassifikation deckte sich gut mit vorhandener pflanzensoziologischer Literatur. Sowohl dicht-wachsende Bergsteppen auf Nordhängen als auch Wacholder-Gebüsche auf süd- und ost-exponierten Hängen hatten hohe Gehalte von organischer Substanz und leicht austauschbaren Kationen in der Bodenmatrix, während gestörte Bestände mit *Carex stenophylla* und mit *A. santolinifolia* auf weniger günstigen Böden wuchsen. *Artemisia santolinifolia* zeigt zum Teil ähnliche Habitatansprüche wie *J. sabina* und kommt entsprechend auch in den meisten Wacholder-Gebüschen vor. Da sich *J. sabina* zur Zeit nicht generativ verjüngt, *A. santolinifolia* aber sehr wohl, besteht die Möglichkeit, dass der Beifuß den Wacholder mittelfristig ersetzt. Sowohl die Cluster-Analyse, als auch Ordinations- und Korrelationsanalysen zeigen aber, dass beide Arten derzeit noch gut unterscheidbare Gesellschaften bilden, so dass ein eventueller Umbau der Wacholder-Gebüsche noch nicht sehr weit fortgeschritten ist.

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Introduction

Mongolia is well known for its vast grasslands which cover 1.3 Mio. km^2 and offer some of the world's finest examples of extensive central Asian steppes (WHITE et al. 2000). Mongolia is also a mountainous country with most of its territory well above 1000 m a.s.l. (BARTHEL 1990) and much of the landscape is governed by extensive pediments that surround large mountain ranges. These mountains climb up to 4000 m a.s.l. in the Mongolian Altay and many of the lesser summits still reach up to 3000 m. Slopes are often steep and exposed to excessive erosion and debris movement in successive freeze-thaw cycles. Thus, they offer special site conditions which are very different from the surrounding pediments with their relatively stable surfaces, where slow wind deflation and linear erosion along (episodically flooded) river beds are the main erosive processes. Moreover, mountains generally receive more precipitation than the surrounding lowlands (BARTHEL 1990) and this pattern is of special importance in the Gobi Altay in southern Mongolia where mountain ranges are surrounded by dry semi-desert environments. The upper slopes receive considerably more precipitation than the pediment regions (RETZER 2003) and support vegetation types very different from those of the neighbouring desert steppes.

The vegetation of Mongolia is well documented with important contributions provided by the continuous research efforts of joint Russian-Mongolian expeditions (e.g. LAVRENKO et al. 1979; Gunin & Vostokova 1995; English summaries in LAVRENKO & KARAMYSHEVA 1993; KARAMYSHEVA & KHRAMTSOV 1995). In the last three decades, the work of W. Hilbig yielded a wealth of even more detailed studies (overviews e.g. HILBIG 1982; 1988) which culminated in the publication of a comprehensive classification system (HILBIG 1990; 1995; 2000). This classification was based on a phytosociological approach and became the benchmark work on the vegetation of Mongolia.

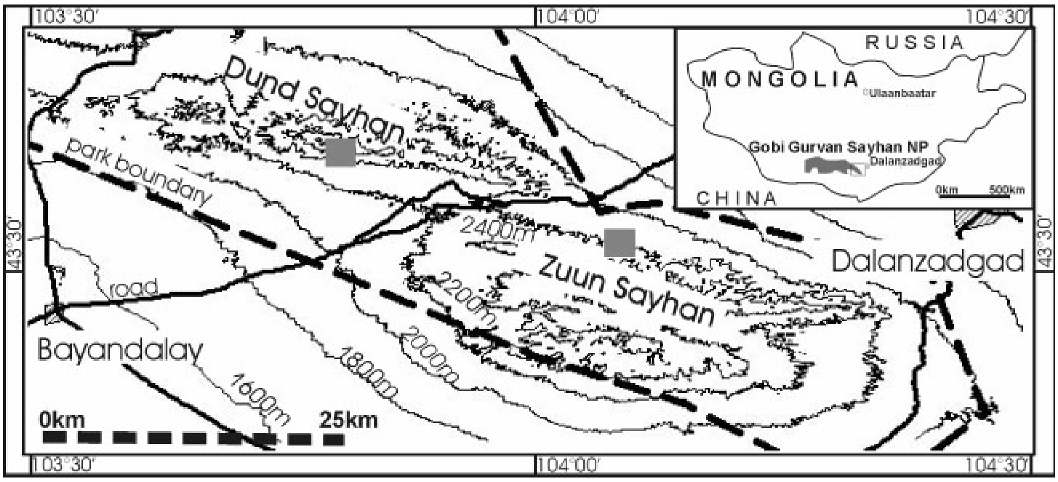
Not all regions of the country have been studied with such intensity. Less well known sites include the easternmost Gobi Altay, large parts of which were designated as a new protected area in the 1990′s. The Gobi Gurvan Sayhan National Park (Mongolian for "Three Beauties of the Gobi") is one of the largest nature reserves in the world. The semi-desert vegetation has been studied before by HELMECKE & SCHAMSRAN (1979 a, b), but detailed studies on the vegetation pattern on the mountain slopes have, as yet, not been conducted.

They are of major interest to nature conservation efforts, since mountains support important populations of endangered animals (Marco Polo Sheep/*Ovis ammon*; Snow Leopard/*Uncia uncia*; READING et al. 1999) and host plant communities that have their main distributional range in the moister parts of Asia. These include dense mountain steppes, but also woody vegetation composed of the prostrate shrub *Juniperus sabina*. This juniper is widespread in mountains ranging from Mediterranean Europe to Central Asia, but stands in the southern Gobi Altay form extreme outposts within the overall range (MEUSEL et al. 1965). They are restricted to steep slopes in the Gobi Altay and are considered especially valuable for nature conservation in the national park (BEDUNAH & SCHMIDT 2000). However, seedlings of *J. sabina* are currently not found (WESCHE et al. submitted), whereas the other widespread shrub, *Artemisia santolinifolia*, propagates well (RONNENBERG et al. submitted) and could potentially invade juniper stands. Thus, the main focus of our study was to assess whether communities made up of these two species have distinct ecological preferences or show some overlap in their small-scale distribution in the south-eastern Gobi Altay.

Presented here is a local study on the vegetation patterns in two relatively moist mountain ranges with certain emphasis on site conditions and habitat preferences. As few numerical classifications have been published on any of the vegetation types common in Mongolia (cf. FERNANDEZ-GIMENEZ & ALLEN-DIAZ 2001), we adopted a statistical approach and compared this to results gained by traditional phytosociological methods.

Study area

The Gobi Gurvan Sayhan National Park (henceforth called GGS NP) is located in southern Mongolia (Map 1). At some 27 000 km^2



Map 1
Map of the eastern Gobi Gurvan Sayhan National Park showing the two main mountain ranges Dund Sayhan and Zuun Sayhan and the two study regions (= grey squares; national park boundary = dotted line; roads = black lines; contour lines at intervals of 200 m)

it is the second largest protected area in the country (BEDUNAH & SCHMIDT 2000) and includes deserts, desert steppes and mountain steppes. The present study was performed in the two easternmost ranges of the Gobi Altay (DUND SAYHAN & ZUUN SAYHAN, Map 1) which are surrounded by desert steppes. Mountains have generally shallow soils and support open vegetation types on their southern slopes and partly dense swards on northern exposures (Fig. 1). The climate in the GGS NP is semi-arid and highly continental with a pronounced seasonality. The nearest governmental weather station, Bayandalay (some 30 km distant from the study sites at 1570 m a.s.l., Fig. 1) reports a mean annual temperature of 4.5 °C (mean temperature in July 20 °C, in January –18 °C; National Meteorological Service of Mongolia). Frosts occur regularly from September to May. Mean annual precipitation in Bayandalay is 110 mm, but is estimated to reach a total of 130 mm at 2300 m a.s.l. (RETZER 2003). Short-term measurements of our group suggest that precipitation might reach well above 200 mm in the summit region (RETZER 2003). The relatively moist conditions allow for growth of several vegetation types which grow zonally in the moister northern parts of Mongolia, but are strongly restricted to montane sites within the GGS NP.

Methods

We adopted a statistical plot-based approach. In 2002, sites for relevés were selected with the help of a GPS using 160 randomly generated UTM-coordinates at an altitudinal range of 2300–2800 m, i.e. above the pediment regions (Map 1). We sampled 145 sites, leaving out only those coordinates that fell on bare rock. Size of relevés was 9 m^2, which was chosen as a compromise between comprehensive community data and a spatial resolution that allows assessment of fine-scale patterns. We recorded all vascular plants and estimated species' cover directly in percent because commonly used cover scales (LONDO 1976) would have been too coarse for the sparse vegetation of the Gobi. Species were tentatively identified in the field with the help of a standard flora (GRUBOV 2001), identifications were later cross-checked in the "Flora of Mongolia" collection from the herbarium in Halle (HAL) and with recent accounts of the flora of Mongolia (GUBANOV 1996; GRUBOV 2000 foll.)

Supplementary data included parameters easily assessed in the field (e.g. exposure, presence of small mammal burrows, or water surplus); soil chemical characteristics were obtained from mixed top soil samples (– 5 cm) taken on the plots. Soil samples were kept dry until an analysis of the fine soil fraction (< 2 mm) was conducted in the laboratory of the Institute of Geobotany in Halle. Soil pH and conductivity were analysed in a water extract (20 g soil, 50 ml water) with standard probes (PH537 & COND315I by WTW, Germany). Carbo-

Fig. 1
Overview of vegetation patterns in the Gobi Gurvan Sayhan mountains. Slopes in northern exposures are covered by dense swards with *Festuca valesiaca* and *Arenaria meyeri*; patches of *Juniperus sabina* grow on southern exposures among boulders and moving rock screes (photo facing eastwards, taken in August 2001)

nate content was tested with 10% HCl; as no reaction was detected we refrained from taking detailed subsequent measurements with a Scheibler device. Total carbon and nitrogen content was analysed using a CN Analyser (VARIO EL, ELEMENTAR, Germany). Exchangeable cations were extracted with NH_4Cl and measured using Atomic Absorption Spectrometry (Ca^{2+}, Mg^{2+}), and flame photometry (Na^+, K^+) respectively. Measurements were carried out in an acetylene flame using the VARIO AAS by ANALYTIK JENA (Germany). Contents of all elements were adjusted to refer to oven dried soil (105 °C).

Statistical analysis started with a multivariate classification of the relevé data. We excluded all species which occurred in less than two relevés from the analysis. Cover values were transformed according to $y = \log(x + 1)$. Aspect was transformed into “northness”, i.e. the cosinus of the exposure in degrees, and “eastness”, the sinus of the exposure, to allow for standard statistical analysis. As an initial DCA suggested a moderate heterogeneity among the data (length of gradient 4 s.d., cf. McCune et al. 2002), we used Euclidean distance as a distance measure. Samples were clustered using Ward's method (minimum variance clustering). Clearly distinct groups were used to structure the original table, information was then condensed in a summary table which indicates the community groups and the frequency of species in the given group. In a second step, a Canonical Correspondence Analysis (CCA) was performed in order to assess species-environment relations. Rare species were downweighted to account for the undue influence they have in Correspondence Analysis. We used forward selection to include only those environmental variables that had significant impact on the ordination ($p < 0.05$, Monte Carlo test with 999 runs; CANOCO 4.5, Ter Braak & Smilauer 2002). Stability of the final ordination was assessed with two Monte Carlo tests, one for the first axis and one for all axes together (9999 runs). For those soil parameters important in the CCA, differences among communities were tested with a Kruskal-Wallis ANOVA because data were not normally distributed (Kolmogorov-Smirnov Test). Correlations among species cover and environmental variables were analysed using Pearsons r. Univariate statistics were derived with SPSS 12.0 (SPSSINC. 2003), multivariate with PCORD 3.15 (MCCUNE & MEFFORD 1997) and CANOCO 4.5 (TER BRAAK & SMILAUER 2002).

Results

Ward's algorithm tends to form rather clear-cut clusters so "pruning" of the diagram (not shown) into seven principal communities was straightforward (Table 1). The main division occurred between those relevés dominated by *Juniperus sabina* (communities 6 and 7) and all other stands, namely mountain steppes and dominance stands of *Artemisia santolinifolia*. Communities 1–3 are characterised by the presence of widespread grassland species (e.g. *Agropyron cristatum*, *Heteropappus altaicus*) and share a set of species typical for mountain steppes (*Stipa krylovii*, *Arenaria meyeri*, *Bupleurum pusillum*, *Artemisia frigida*). Relatively moist mountain steppes on north-facing slopes have a number of characteristic species such as *Festuca valesiaca* and its companions (community no. 1, Table 1). These are the most diverse stands in the area, with a median species richness of 17. The vegetation is relatively dense (Fig. 2) with *F. valesiaca* reaching a median cover of 6%, followed by *Allium eduardii*, *Arenaria meyeri* and *Agropyron cristatum.* Near summits, or at extremely steep sites (community 2, Table 1), soil movement becomes more extreme and swards open up (median total cover of 10% vs. 29% for community 1). At 2%, only *Arenaria meyeri* and *Agropyron cristatum* reach median cover values above 1%. *Stipa gobica* and *Saussurea pricei* indicate the affinities to vegetation of the pediments, where both are common. Disturbance on the sites is indicated by a set of annual species (see *Chenopodium vulvaria* group in Table 1) and by the perennial *Carex stenophylla* (including *C. duriuscula* and *C. stenophylloides*, cf. DICKORÉ 1995). This sedge benefits from grazing and is shared with community no. 3, which occupies weakly inclined sites in various exposures. The species set is rather heterogeneous comprising the characteristic species of mountain steppes (*Stipa krylovii* group in Table 1) as well as the aforementioned ruderals and *C. stenophylla. Artemisia santolinifolia* is present in almost all samples and reaches a median cover of 5%.

Artemisia santolinifolia benefits from soil disturbance in community 3, as it does in group no. 5 (Table 1). This comprises only two samples which are characterised by the dominance of the large bunch grass *Achnatherum inebrians* (median cover 25%). With the exception of *A. santolinifolia* (cover 4%), annuals are mainly abundant here (cover *Chenopodium vulvaria* 10%, *Axyris prostrata* 5%). Dominance stands of *A. santolinifolia* (Fig. 3) were assigned a special group in the cluster analysis (group 4) where the shrub covers a median of 25% of the surface. *Nepeta sibirica* and *Rheum undulatum* reach median cover values of 3%, while *Lophanthus chinensis* and *Androsace maxima* are less dominant, though relatively frequent. The presence of such species points to a high level of soil disturbance, as do annual species of the *Chenopodium vulvaria* group in Table 1.

Juniper has median cover values of 58% and 73% in communities 6 and 7 respectively. No other species attains such high cover values, but ever present companions include *Thalictrum foetidum*, *Artemisia rutifolia,* and notably, *A. santolinifolia*. The two juniper communities are differentiated by the presence of the large shrub *Lonicera microphylla*, which is restricted to the interior of juniper patches (median cover 3% in community 6). Young plants of *L. microphylla* appear to benefit from the safe-sites provided by the junipers, but we found no recruitment of *J. sabina*.

The ordination summarises the environmental relationships between these seven communities. Juniper stands form a fairly closed group in the lower left corner of the CCA-diagram (Fig. 4). Environmental vectors indicate that soils have relatively high pH values, stands accumulate more litter than other communities and prefer eastern aspects on relatively steep slopes. The two communities differentiated by the presence of *Lonicera microphylla* show considerable overlap in the ecological space, although stands without this shrub are less restricted to eastern exposures.

The other clearly differentiated group is formed by communities 1 and 2 (lower right corner of Fig. 4). They have a relatively strict preference for northern exposures at high alti-

Table 1
Frequency table of the seven main communities according to a cluster analysis (Ward's method, Euclidean distance). Vertical lines indicate main divisions in the cluster diagram, numbers give percent frequency in relevés of the given group (species with <3 occurrences in table not shown, abbreviations in [ ] used in Fig. 1)

Community no.	1	2	3	4	5	6	7
Median species richness	17	12	10	8	7	9	8
Median total cover	29	10	25	26	56	67	78
No. of relevés	18	19	30	17	2	12	47
Plant species typical of							
– the *Festuca valesiaca* rock steppes							
Festuca valesiaca [FESVAL]	89	11	3	0	0	8	0
Amblynotus rupestris	67	11	10	0	0	0	0
Astragalus multicaulis	50	5	13	0	0	8	4
Pedicularis abrotanifolius	39	5	13	6	0	0	0
Smelovskia alba	33	0	0	0	0	0	0
Silene jenisseensis	22	11	0	0	0	8	0
Poa attenuata	17	11	3	6	0	0	6
– the *Hedysaro pumili-Stipetum krylovii*							
Stipa krylovii [STIKRY]	28	58	40	6	0	17	26
Oxytropis pumila	44	42	17	0	0	0	0
Potentilla sericea	44	37	7	0	0	8	13
Arnebia fimbriata	22	0	17	12	0	8	13
– the *Stellaria petraea/Dichotoma*-subassociation							
Arenaria meyeri [AREMEY]	94	89	23	6	0	8	9
Artemisia pycnorhiza [ARTPYC]	72	42	20	0	0	0	11
Artemisia frigida [ARTFRI]	67	58	20	6	0	17	6
Bupleurum pusillum	78	47	13	0	0	0	2
Peucedanum hystrix	50	26	7	0	0	17	4
Allium eduardii [ALLEDU]	89	32	0	0	0	17	9
Orostachys spinosa	61	21	0	0	0	8	9
Scorzonera ikonnikovii	17	21	0	0	0	8	2
Saussurea pricei	6	26	0	0	0	8	4
Stipa gobica	0	21	0	12	0	0	0
– the *Agropretea christati*							
Agropyron cristatum [AGRCRI]	100	95	90	65	0	50	66
Allium prostratum	78	68	33	6	0	0	19
Heteropappus altaicus	6	37	33	12	0	0	23
Koeleria altaica	56	16	20	0	0	25	13
Limonium flexuosum	44	0	23	0	0	0	0
Potentilla bifurca	0	26	7	0	0	0	2
– the *Carex stenophylla*-subass. of the *Hedysaro*-stipetum							
Carex stenophylla [CARSTE]	22	58	63	0	0	8	11
– the *Artemisia santolinifolia*-community							
Artemisia santolinifolia [ARTSAN]	17	26	90	100	100	100	85
Lophanthus chinensis [LOPCHI]	6	5	30	41	0	17	13
Androsace maxima	0	0	23	29	0	0	0
– the *Sisymbrietea/Scrophularietea*							
Chenopodium vulvaria [CHEVUL]	6	26	70	41	100	0	19
Salsola pestifera s.l. [SALPES]	0	42	63	35	50	0	6
Chenopodium album	0	5	20	35	50	8	6

Chenopodium hybridum	0	5	10	24	50	17	19
Axyris prostrata	0	5	33	0	50	8	4
Stellaria dichotoma	6	0	20	29	0	8	11
Nepeta sibirica	0	0	3	18	0	0	0
Rheum undulatum	6	0	10	6	0	0	0
– the *Achnatherum inebrians*-community							
Achnatherum inebrians	0	0	7	12	100	0	6
Allium vodopjanoveae	0	0	3	6	50	0	4
Elymus paboanus	0	0	0	6	50	8	0
Elymus secalinus	0	0	0	6	50	0	0
Thermopsis lanceolota s.l.	0	0	0	6	50	0	0
– the *Artemisia rutifolia*-community							
Lonicera microphylla [LONMIC]	6	0	0	6	0	75	13
Artemisia rutifolia [ARTRUT]	11	16	7	29	0	50	32
Vicia costata	6	0	0	18	0	17	11
Silene repens	0	0	7	35	0	8	11
– the *Juniperus sabina*-community							
Juniperus sabina [JUNSAB]	6	0	3	0	0	100	100
Thalictrum foetidum [THAFOE]	72	11	23	35	0	100	64
Poa stenophylla s.l.	11	16	13	29	0	83	47
Ptilotrichum canescens	22	21	17	12	0	25	21
Companions							
Aster alpinus	22	5	7	6	0	0	4
Ephedra sinica	17	0	0	0	0	0	9
Thymus gobicus	11	11	0	6	0	17	6
Oxytropis tragacanthoides	11	16	3	0	0	8	4
Astragalus mongholicus	6	0	13	6	0	0	11
Youngia tenuifolia	6	0	3	0	0	0	4
Iris potaninii	6	5	10	0	0	0	11
Youngia tenuicaulis	6	5	0	0	0	0	4
Potentilla conferta	6	11	7	0	0	0	0
Astragalus brevifolius	0	11	7	0	0	0	0
Polygonum alpinum	0	5	10	0	0	0	2
Galium verum	0	5	10	6	0	8	13
Allium senescens	0	5	7	6	0	17	2
Artemisia dracunculus	0	0	10	6	0	0	0
Isatis costata	0	0	10	12	0	0	2
Elymus chinensis	0	0	7	0	0	0	6
Pedicularis flava	0	0	7	6	0	0	2
Dracocephalum fruticulosum	0	0	3	0	0	8	6
Lappula intermedia	0	0	3	6	0	0	4
Potentilla desertorum	0	0	3	6	0	8	2
Papaver croceum	11	0	0	0	0	0	2
Rhodiola rosea	11	0	0	0	0	0	2
Crepis crocea	6	0	7	0	0	0	0
Isatis tinctoria	6	0	3	0	0	0	2
Bupleurum bicaule	0	0	3	0	0	0	4
Crepis spec.	28	26	7	0	0	0	6
Allium altaicum	0	0	7	0	0	0	0
Carex pediformis	0	0	0	0	0	0	4
Chamaerhodos erecta	0	5	0	0	0	0	2
Clematis tangutica	0	0	0	12	0	0	0
Festuca lenensis	0	0	3	0	0	0	2

Table 1 (continued)

Community no.	1	2	3	4	5	6	7
Median species richness	17	12	10	8	7	9	8
Median total cover	29	10	25	26	56	67	78
No. of relevés	18	19	30	17	2	12	47
Leontopodium ochroleucum	11	0	0	0	0	0	0
Potentilla multifida	0	0	0	0	0	0	4
Sedum aizoon	0	0	0	0	0	0	4
Allium polyrrhizum	0	5	0	0	0	0	0
Arabidopsis mollissima	0	0	0	0	0	8	0
Caragana leucophloea	0	5	0	0	0	0	0
Convolvulus ammanii	0	5	0	0	0	0	0
Dontostemon integrifolius	0	5	0	0	0	0	0
Euphorbia mongolica	0	0	3	0	0	0	0
Haplophyllum dauricum	0	0	0	0	0	8	0
Koeleria macrantha	0	0	0	0	0	0	2
Lepidium densiflorum	0	0	3	0	0	0	0
Sibbaldianthe adpressa	0	5	0	0	0	0	0
Stellaria petraea	6	0	0	0	0	0	0

Fig. 2
Relatively dense rock steppes with *Festuca valesiaca* on northern exposures. Swards are heavily grazed, mostly by Yaks (central Dund Sayhan, July 2002)

Table 2
Pearson correlations among cover values of the two main woody species in the study area and principal environmental variables (Pearson r-values)

	Juniperus sabina	*Artemisia santolinifolia*
northness	−0.18*	−0.18*
eastness	0.19*	0.06
altitude	0.04	−0.03
inclination	0.11	−0.2
pH	0.36**	−0.01
conductivity	0.28**	−0.06
Ca	0.10	−0.28**
K	0.24**	0.00
Mg	−0.40**	−0.18*
carbon	0.46**	−0.06
N	0.11	−0.06
litter	0.87**	−0.19*
stones <2 cm	−0.41**	0.07
stones >2 cm	−0.21*	0.21*
bare soil	−0.45**	−0.15

* $p < 0.05$, ** $p < 0.01$)

tudes (see also Fig. 1), and show a tendency towards high contents of magnesium and calcium in the soil. There is again some overlap among the two communities, but stands with *F. valesiaca* are strongly restricted to the described conditions while those relevés with *Stipa gobica* are more scattered in the diagram and overlap with *Artemisia santolinifolia*-communities on more disturbed sites. Communities 3 and 4 are placed in the centre and the upper part of Figure 4, indicating that they avoid steep slopes and higher altitudes. They occur on soils with a rather coarse matrix and many stones on the surface, moreover many relevés were taken on small mammal burrows. *Achnatherum inebrians* stands are grouped separately in the ordination diagram indicating their distinct position in the ecological space.

The position of the species in Figure 5 indicates a similarity between *Salsola pestifera* and *Chenopodium vulvaria*, and *Lophanthus chinensis* and *Carex stenophylla*. These benefit from disturbance as indicated by vectors for loose stones on the surface and by the presence of small mammal burrows. *Artemisia santolinifolia* is intermediate between the four species and both *Juniperus sabina* and *Lonicera microphylla*. Communities formed by the latter three species indeed show some overlap. A last, clearly distinct group is constituted by species of moist mountain steppes (e.g. *Festuca valesiaca*), which are found in the left part of the diagram.

Soil conditions differ significantly among communities (Fig. 5). Communities with *Festuca valesiaca* or *Stipa gobica* have high values of magnesium and calcium, and community 1 has a high content of carbon. Stands with *Achnatherum inebrians* (only two relevés – box plots therefore to be treated with caution) show high soil conductivity, a high potassium content and a low soil pH-value. Soils under juniper stands are characterised by high values of pH and conductivity and have high contents of carbon, calcium and potassium. Stands with *Artemisia santolinifolia* are intermediate with respect to their soil conditions, the only notably exception is the potassium content under community 3.

In a final step, we analysed site preferences for the two focal species *Juniperus sabina* and *Artemisia santolinifolia* with correlation analysis. This suggested distinct environmental preferences of the two species (Table 2). Both have a tendency to avoid north-facing slopes and show no preferences with respect to altitude and inclination. Levels of magnesium in the soil tend to increase with decreasing cover of both species, but all other correlations differ between the two. *Juniperus sabina* is more abundant on east-facing slopes, is positively associated with increasing soil pH and conductivity values, and with high contents of potassium and carbon. It avoids stony sites with lots of bare substrates. *Artemisia santolinifolia* has a negative association with calcium and magnesium, but has no further relation other than preferring stony sites. Thus, both species are different with respect to the main site conditions, and this was also supported by a direct comparison of their cover values. Figure 6 indicates that sites usually have a high cover of *J. sabina* or *A. santolinifolia*, and that there is a weak, albeit significant, negative correlation between the two species ($r = -0.21$, $p < 0.05$). However, while *J. sabina* is usually accompanied by at least some *A. santolinifolia*, there are many sites with the latter that completely lack juniper. This suggests that *A. santolinifolia* is capable of growth in most juniper stands, but

Fig. 3
Detail of the *Artemisia santolinifolia*-community growing on a slope covered by rock scree. The dominant species is the dwarf shrub *A. santolinifolia*, herbaceous species are negligible in terms of cover (central Dund Sayhan, July 2002)

also occupies some sites which are apparently not available to *J. sabina.*

Discussion

Table 3 summarises the seven units of the present study and their approximate equivalents in the general classification framework provided by HILBIG (1995, 2000). Mountain steppes are the dominant plant community on a variety of sites in the Gobi Altay, so HILBIG (1990) adopts a rather wide concept of the Hedysaro pumili-Stipetum krylovii with several subunits. Steep slopes are colonised by the *Stellaria petraea*-subassociation. The aforementioned species is rare in the Gobi Gurvan Sayhan and is widely replaced by *S. dichotoma*; however a set of petrophilous species such as *Arenaria meyeri*, *Bupleurum pusillum/bicaule* and *Orostachys spinosa* indicates the affinities. In the GGS NP, strictly north-facing slopes are colonised by a particularly luxurious variant of mountain steppe, which is characterised by the presence of *Festuca valesiaca*. Similar stands occur in the mountains surrounding the Uvs-Nuur basin and have been termed “rock steppes” (HILBIG 2003). Several accompanying species are shared with meadow steppes (Helictotrichion schelliani, HILBIG 2000) such as *Aster alpinus* and *Poa attenuata*. Meadow steppes with *Helictotrichon schellianum* are, however, very rare in the GGS NP. Drier slopes in southerly exposures or on other sites with more intense scree movement are covered by the typical, rather open mountain steppes, which lack the closed swards of the previous unit. The species set is less diverse, but several species from the pediments can be found. These include *Saussurea pricei* and the desert

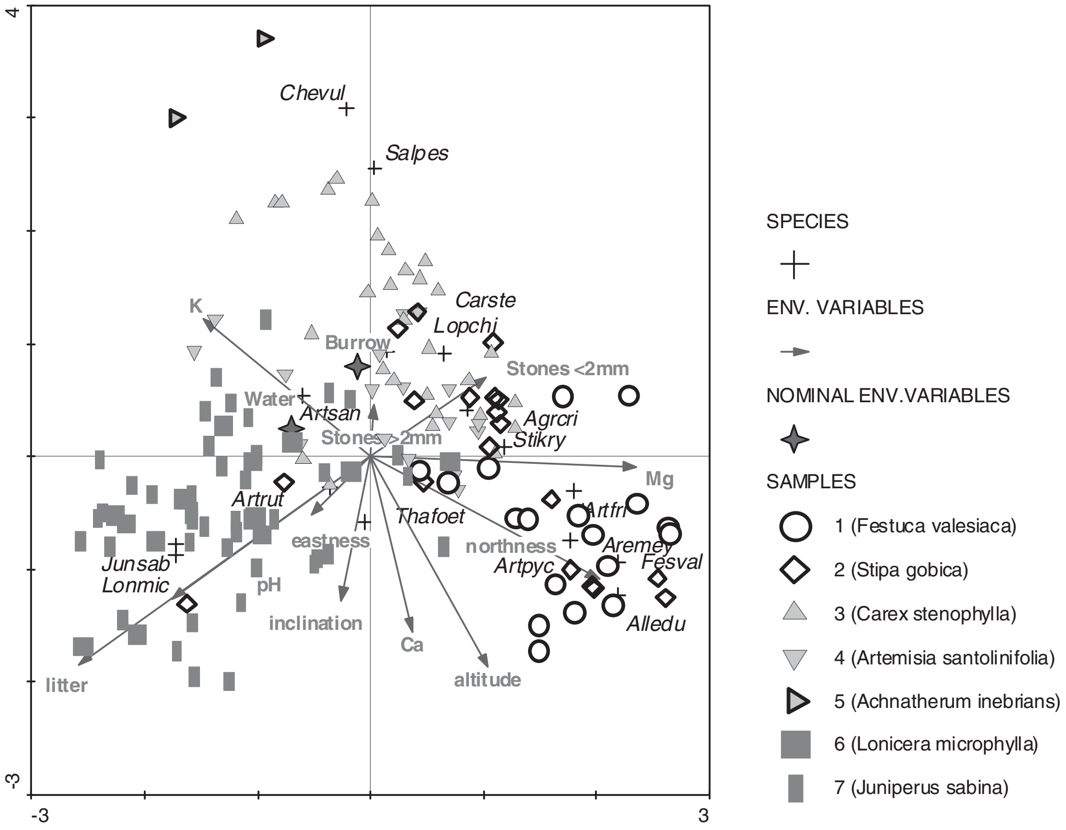


Fig. 4
CCA of relevé data and environmental data. Species cover values were log-transformed; only species with a weight >6 are displayed, abbreviations follow Table 1 (axis 1: Eigenvalue 0.59/species environment correlation explained is 41.4%; axis 2: EV 0.38/ 26.7%; axis 3: EV 0.10/8.7%, significance of axis 1 $p < 0.001$; of all axes $p < 0.001$)

steppe species *Stipa gobica*, which also covers the uppermost pediments in the GGS NP. Most of the petrophilous elements are still present, but annuals hint at the disturbed and partly ruderal character of some relevés. Grazing is more intense on weakly inclined sites in valley bottoms or on plateaus, where the sedge *Carex duriuscula/C. stenophylla* builds a special subassociation under conditions of intense grazing.

Artemisia santolinifolia is widespread on disturbed soils in the mountain regions of central Asia (e.g. MIEHE et al. 2002) and colonises a wide range of disturbed sites in the study area. It reaches high cover values in the *C. duriuscula* mountain steppes, but also forms dominance stands. They share several species with the related mountain steppes, but are nonetheless usually regarded as a separate albeit rankless unit (*A. santolinifolia*-community, HILBIG 1990; 1995), which is widespread in the Gobi Altay. Our cluster analysis supports the distinct character of this scrub, since stands were clearly differentiated from the mountain steppes and showed the closest relation to the *Achnatherum inebrians*-community. *Artemisia santolinifolia* scrub is common on scree slopes and community 4 often occurs on small mammal burrows where plants benefit from the absence of a dense grass sward. There, water percolates to deeper soil horizons where it is available to shrubs (LAVRENKO & KARAMYSHEVA 1993). *Achnatherum inebrians* is similarly common on

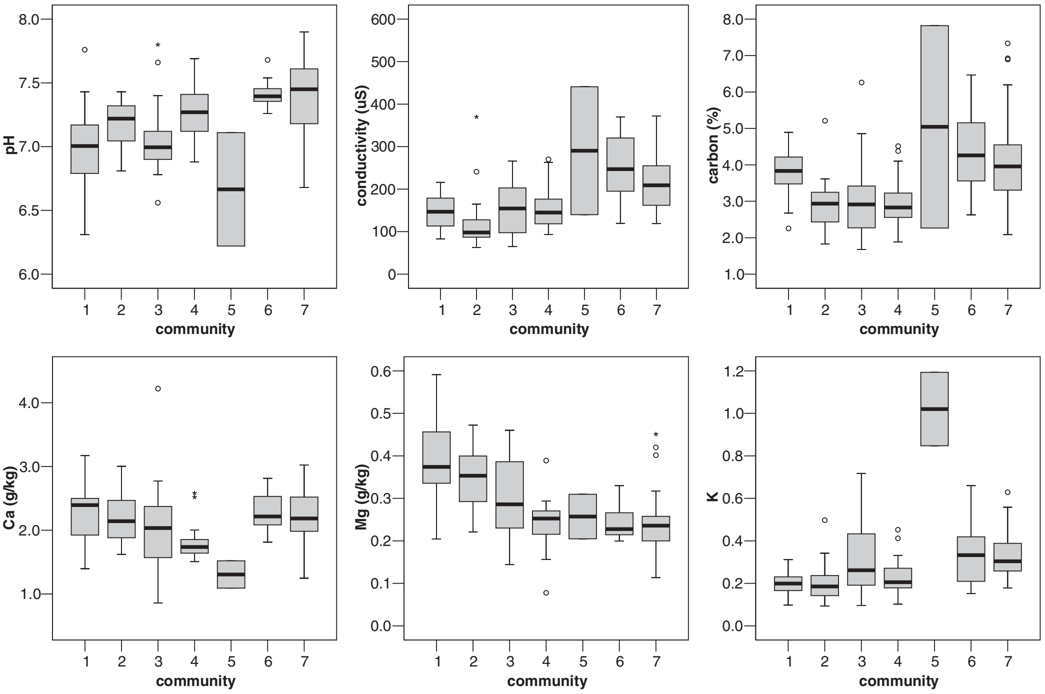


Fig. 5
Box and Whisker Plots for soil variables (Kruskal-Wallis Test in all cases $p < 0.01$), communities are labelled as in Table 1

disturbed sites, but this community is also not easily placed in a phytosociological framework. Stands with the closely related *A. splendens* often form distinct communities on saline soils (Achnatherion splendentis, HILBIG 2000), but they also grow on non-saline steppe sites (Caragano microphyllae-Achnatheretum splendentis). Such sites can, however, also be regarded as true steppe communities with some *A. splendens* (HILBIG 2000). Relevés with *A. inebrians* have not been classified in the literature yet; given that there are even uncertainties concerning the status of the much more widespread *A. splendens,* we regard them as a separate albeit rankless unit.

Equally distinct, yet also not definitely placed in an hierarchical classification system, are stands with *Juniperus sabina* (locally also *J. pseudosabina*). They form clearly defined communities and, much like stands with *A. santolinifolia*, share several species with the adjacent mountain steppes. HILBIG (2000)

Table 3
Phytosociological equivalents of the plant communities described in the text (cf. HILBIG 1995, 2000)

No.		
1	Hedysaro-Stipetum krylovii – *Stellaria petraea*-subass.	*Festuca valesiaca* rock steppes
2	Hedysaro-Stipetum krylovii – *Stellaria petraea*-subass.	typical variant
3	Hedysaro-Stipetum krylovii – *Carex duriuscula*-subass.	
4	*Artemisia santolinifolia*-community	
5	*Achnatherum inebrians*-community	
6	*Juniperus sabina*-community (aff. *Artemisia rutifolia*-community	*Lonicera microphylla* variant
7	*Juniperus sabina*-community	typical variant

designates a Juniperetum pseudosabinae within the Juniperion pseudosabinae, and additionally lists a *J. sabina*-community. If more material becomes available, it might be possible to describe a separate association, but this would require analysis of the phytosociological affinities over the species' wide distributional range (MEUSEL et al. 1965). The typical juniper scrub contains few larger shrubs. *Lonicera microphylla* is found in dry scrub communities together with *Spiraea* species in the north-west of the country (HILBIG et al. 1999) but characterises a moister variant of the juniper scrub in the Gobi Altay. This is supported by statistical analysis of *L. microphylla*'s ecological preferences, which resemble those of *J. sabina* in our study area (Fig. 4).

Figure 4 designates several ecologically different groups of communities. Typical juniper scrub has a preference for steep slopes facing eastern exposures, where they are protected from the predominantly dry westerly winds (RETZER 2003). The community with *L. microphylla* is more restricted and apparently more sensitive to desiccating winds. Juniper scrub occurs also on south-facing slopes but avoids strictly northern exposures, apparently because competition by mountain steppe species is too high. The *F. valesiaca* rock steppes have as equally narrow ecological preferences as the *Juniperus-Lonicera* scrub in the CCA diagram. The main habitat factors are altitude and screening from sun here, i.e. *F. valesiaca* occupies the moistest sites within the mountains. Mountain steppes of community 2 are again less restricted and are found on various exposures. The ordination demonstrates that they have a preference for west-facing slopes with a high cover of small stones. The remaining communities are negatively correlated with inclination and positively with the presence of burrows and large stones. Thus, they benefit from disturbances, and *A. santolinifolia* is indeed also widespread on the pediment regions lower down where it occurs on small mammal burrows, along erosion gullies and on old vehicle tracks (own observations). As expected, some overlap between the *Artemisia santolinifolia* scrub and the *Juniperus sabina* scrub suggests that site preferences are not widely different.

Several soil parameters had a significant impact on the ordination, and for them differences between communities were indeed always significant (Fig. 5). Soil conditions are most beneficial under the *F. valesiaca* rock steppes where soils have high contents of organic matter, a decent cation availability, and a low conductivity indicating sufficient moisture and limited accumulation of salts near the surface. Soils under *J. sabina* range second in our comparison; they have an even higher content of carbon plus high values of calcium and potassium. This is a consequence of litter accumulation, since vegetation cover is dense and stands are not browsed because of their content of toxic substances (e.g. sabinol, HEGI 1965).

Stands with *Achnatherum inebrians* also have a high carbon content and a high conductivity. This indicates some salinity, and indeed one stand was sampled near a small spring. Soils also have a high potassium content, which was also described from stands of *A. splendens* in the northern parts of the Mongolian Gobi (FERNANDEZ-GIMENEZ & ALLEN-DIAZ 1999). Near wells livestock densities are high and animals contribute to translocation and accumulation of potassium via their faeces (STUMPP et al. submitted). However, *A. inebrians* itself is hardly grazed and builds rather dense stands. This explains the similarities between soils under *J. sabina* and under this bunch grass. Open substrates, which are covered by communities 3–5, offer less beneficial conditions and are, most notably, depleted of carbon. This is probably a consequence of the openness of the vegetation and suggests that preservation of the dense *F. valesiaca* rock steppes and the juniper scrub is desirable from a soil-conservation point of view.

The importance of *J. sabina* for soil conditions was also supported by correlations between juniper's cover and certain soil parameters (Table 2). In correlation analysis, dependent and independent variable are not defined. With respect to inclination and aspect, cover of *J. sabina* certainly is the dependent variable, but with respect to the presence of stones and bare soil, relations are less defined. Shrubs generally prefer loose substrates, but the negative correlations found in the GGS NP are a consequence of the high cover the juniper achieves in dense stands. For litter and, as we

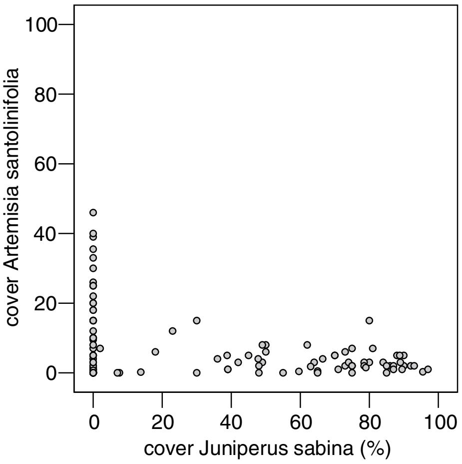


Fig. 6
Mutual exclusion of *J. sabina* and *A. santolinifolia* in the area (correlation between cover values on all sites; Pearson $r = -0.21$, $p < 0.05$)

believe, soil chemical composition, cover of juniper is the independent variable; more juniper induces better soil conditions rather than the presence of better soils being a condition for *J. sabina*. Increasing cover of juniper leads to increased values of pH, soil conductivity, potassium and carbon. Levels of soil carbon have been reported to be higher under juniper in various dry regions of the world (MOORE et al. 2000; CHAMBERS 2001). Higher values of soil pH and conductivity are in line with other reports of high soil pH values under junipers (WALL et al. 2001). Juniper litter is known to have a high content of calcium (MONTES et al. 2002) and might contribute to buffering of the soil. In our case, calcium levels are higher than in other communities, but do not vary with juniper abundance. High conductivity might also indicate intense transpiration, which seems plausible with respect to the high cover junipers reach on the plots. In contrast, *Artemisia santolinifolia* appears to have a very limited influence on soil conditions. Like juniper, it avoids northern slopes but has no positive interaction with any soil chemical parameter. Instead, it is negatively associated with litter and positively associated with large stones, confirming its preference for open, disturbed sites.

The biology of *Juniperus* species has received some attention in the last years (GARCIA et al. 1999; GARCIA 2001; VERDÚ et al. 2004) and many authors have reported poor germination. This corresponds to the lack of seedlings or saplings we found during our study, so there is cause for concern about the long-term survival of the species in the area. The present analysis suggests that *A. santolinifolia* is the principal candidate to replace *J. sabina* in the GGS NP, which is supported by its effective germination under a wide variety of conditions (RONNENBERG et al. submitted), and by the presence of *A. santolinifolia* seedlings in the field. It is relatively unspecific with respect to habitat conditions providing that some soil disturbance lowers competition by the otherwise densely growing hemicryptophytes, which have their roots concentrated in the uppermost soil layers in our region (BORISOVA & POPOVA 1985). Since most of the slopes covered by *J. sabina* have moving scree, sites would generally be suitable for both species. At present, the overlap between communities is limited as indicated by the cluster analysis (Table 1), the CCA (Fig. 4) and the (weakly) negative correlation between the two species. However, Figure 6 indicates that *A. santolinifolia* is usually found in stands of the juniper, whereas the latter is absent from many stands of the *A. santolinifolia*-community. Thus, there is a potential for replacement of juniper patches by *A. santolinifolia*, especially since juniper recruitment is apparently limited (WESCHE et al. submitted). However, this process appears to be in its infancy and will require continued monitoring over the coming decades with junipers ageing and possibly dying.

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