Isolated Mountain Forests in Central Asian Deserts: A Case Study from the Govi Altay, Mongolia

Jan Cermak, Lars Opgenoorth, Georg Miehe

Abstract

The role of isolated mountain forests in Central Asian drylands has been the subject of a number of recent studies. The present paper examines islands of birch and willow forest in the Mongolian Govi Altay Mountains. Using vegetation surveys, dendrochronological studies and charcoal findings, it is attempted to assess the present-day ecological state of the vegetation as well as the environmental history and ecological trends. One of the three forests studied seems to be expanding rapidly due to declining levels of utilization under climatically favourable conditions. The other forests however, situated about 350 km to the south-east of the former, are threatened by consistently high levels of anthropogenic pressure. Based on ecological evidence, the forest islands' role as witnesses of a once coherent forest belt that may have been retreating since the mid-Holocene is discussed.

1 Introduction: Isolated Forests – A Biogeographical Challenge

We consider isolated forests a phenomenon of the forest ecotone and its oscillations under changing climate and human impact. In the case of the forest islands of the southern Govi Altay with the nearest comparable forest patches hundreds of kilometres away this is certainly a far-reaching assumption and only becomes intelligible when one presumes that three quarters of Mongolia were under forest in the past. Forest islands surrounded by vegetation of a non-forest climate have posed a challenge to the environmental sciences for decades and it is worthwhile to consider the Govi Altay forest islands in the light of this global issue of mountain biogeography.

In tropical mountains forest islands in altitudes of 4000 m surrounded by tropical-alpine Páramo grassland several hundred metres above the upper limit of the forest belt were explained as warm niches favoured by high soil temperatures (Troll 1959; Walter and Medina 1969) or forest fragmentation simply as a result of human impact (Ellenberg 1979; Miehe and Miehe 1994; Kessler 2002; Wesche 2002).

In the deserts of western High Asia isolated forest stands have been perceived as relics of former forests and were used for mapping the potential natural forest vegetation of Afghanistan (Freitag 1971). In the deserts of Southern Tibet isolated forest remnants were surveyed up to 600 km west of the present-day western limit of forest growth (Zhang 1988; Miehe et al. 2000). The dry limit of those junipers in Southern Tibet is expected to correlate with 250 mm annual precipitation. From field evidence in the Tibetan Himalaya of Nepal and climatic data it is estimated that *Pinus wallichiana* needs 300-350 mm a^{-1} on northern exposures and *Betula utilis* D. Don. requires 400 mm a^{-1} (Miehe et al. 2003). Since these isolated trees are fruiting and regenerating in locations with no noticeable environmental favor, their continued presence must be attributed to religious protection. They can be seen as part of a forest belt in Southern Tibet that was destroyed over the centuries.

The eastern declivity of High Asia has pastures of alpine Cyperaceae and isolated groves of juniper or spruce as well, thus showing a similar contradiction of mountain forest islands surrounded by alpine vegetation as in the tropical alpine Páramo grassland.

It is still unclear what led to forest fragmentation in Eastern Tibet: Forests may have been cleared in the mid-Holocene (Schlütz 1999). Another theory suggests that Holocene reforestation was constrained by an almost closed turf cover of alpine Cyperaceae (Miehe et al. 1998).

In Central Asia the striking pattern of forest-covered shady slopes and steppe in southern exposure had been widely accepted as natural (Walter 1974) but was blurred by the occurrence of elm-trees or even larch or pine in the middle of meadow-steppe (Hilbig and Knapp 1983). The conclusion is now widely accepted that meadow steppe is replacing forests (Hilbig 1995; Sommer 1998). Vegetation surveys in the Govi Gurvan Sayhan National Park even revealed isolated elm trees surrounded by *Stipa glareosa* - *Anabasis brevifolia* - steppe with annual precipitation of less then 130 mm (Wesche et al. 2003).

The review of the significance of isolated forests surrounded by alpine or steppe vegetation shows that the human dimension of Global Change has been underestimated worldwide. A study of forest islands in mountains of a Central Asian desert is presented here to contribute to the dialogue about the interference of climatic changes and human impact on vegetation dynamics in the Old World's desert belt. Within this framework, the aim of the current study was to assess and appraise the natural history and current potential for persistence of the forest islands in the Govi Altay.

2 Study Area

2.1 Location

The sites chosen for the present study are located in the Govi Altay Mountains of southern Mongolia, roughly between 43° and 45°N, and 101° and 104°E (figure 1). The Govi Altay rises out of the steppe and desert environments of the Govi. Unlike the continuous chain of the Mongolian Altay, the Govi Altay is characterized by its loose sequences of small mountain ranges, most of which run parallel to each other. The depressions are interspersed with lakes and saltpans. The main chain of the Govi Altay extends over more than 500 km from west to east and includes (in this direction) the Bayan Tsagaan, Gurvan Bogd and Gurvan Sayhan Mountains. The latter two are again subdivided into distinct mountain formations: The Ih Bogd is the western part of the Gurvan Bogd; the Dzüün Sayhan lies in the eastern Gurvan Sayhan (Murzaev 1954).

The areas under investigation in the present study lie within the Dzüün Sayhan and Ih Bogd mountains (figure 1). The former rise up to 2815 m a.s.l. while the latter include the highest peak of the Govi Altay at 3957 m a.s.l. (Murzaev 1954; Hilbig et al. 1984).

The forests are exemplary forest islands in the sense applied in the introduction. Two of the three forests are located in the eastern Dzüün Sayhan

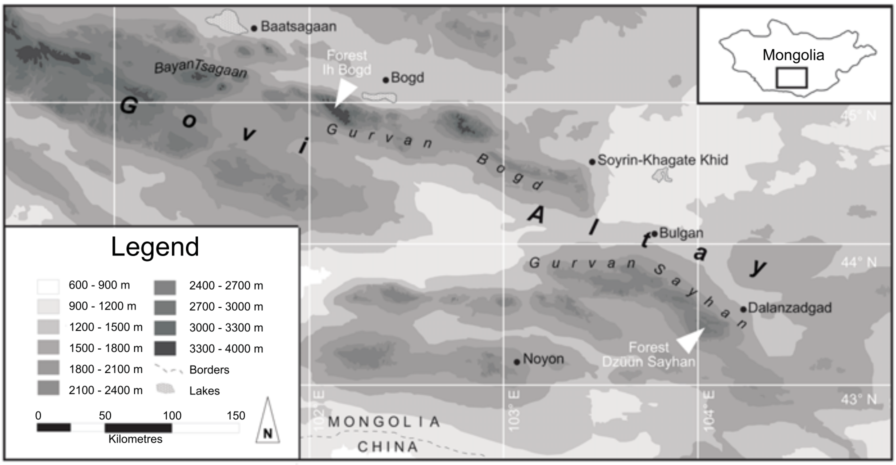

Figure 1 Site Map Govi Altay

range within the Govi Gurvan Sayhan National Park (around 43.5°N, 104°E); the third forest lies about 350 km to the north-west, in the Ih Bogd range near the opposite end of the Govi Altay (around 45°N 101°E).

2.2 Climate

Mongolia is known for its extreme continentality. With the nearest ocean at a distance of about 2000 km to the east, behind the Hinggan Mountains and against the main direction of the frequent west winds, levels of precipitation and water vapour are low. Seasonal and inter-annual variation of temperature and precipitation levels is immense. Although, precipitation in Mongolia decreases on a north-west to south-eastern gradient in general (Weischet and Endlicher 2000), an opposing trend can be found at least from the Dzüün Sayhan to the Nemegd Uul where conditions get progressively drier towards the west (Wesche et al. 2003).

In Dalandzadgad, just to the north-east of the Dzüün Sayhan and roughly 1000 m lower than the forest sites, temperatures drop to -15°C in winter and may reach 40°C in summer (figure 2). Strong winds blow throughout the year, reaching maxima of 25 m s^{-1} in spring. The average annual precipitation is between 125 and 150 mm, 75 % of which fall in June, July and August. Medium temperatures rise above 5°C on 182 days a year, i.e. the thermal conditions of the plant growth period are met (Barthel 1983; Haase 1983; Reading et al. 1999; Weischet and Endlicher 2000). Dalandzadgad displays

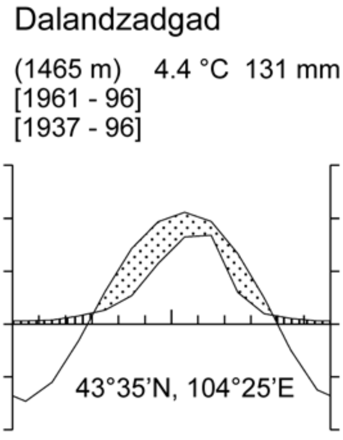

Figure 2 Climate Diagram for Dalandzadgad. Data: Meterological Survey of Mongolia, personal communication

the highest variability in summer precipitation of all places in Mongolia (between 8 and 162 mm in August), with very unreliable timing. About 70 % of rainfall events yield less than 1 mm of water (Weischet and Endlicher 2000).In the mountain ranges of the area conditions are considerably wetter in summer, due to convective precipitation centred around higher altitudes (cf. Retzer 2003).

In the Ih Bogd, rainfall levels are roughly similar to those in the Dalandzadgad region. Like in other regions, summer conditions start and end very abruptly (Hilbig et al. 1984). From its geographical location within the climatic gradients described above, one might assume slightly wetter and cooler conditions than those observed at Dalandzadgad and in the Dzüün Sayhan.

2.3 Vegetation

Desert steppe and dry steppe vegetation surround the Govi Altay Mountains, but vegetation changes noticeably with altitude. On the northern declivity of the Ih Bogd range the following units are observed (bottom up): *Stipa glareosa – Anabasis brevifolia*-dominated semi desert and desert steppe associations (< 2000 m a.s.l.), mountain steppe with *Stipa krylovii*, *Koeleria gracilis* and *Agropyron cristatum* (2000-2700 m a.s.l.), alpine mats of *Kobresia* (2700-3100 m a.s.l.), and high alpine rock cushion vegetation with *Rhodiola quadrifida*, *Saxifraga* spp. and *Arenaria meyeri* (> 3100 m a.s.l.) (Hilbig et al. 1984).

In a similar form the same is encountered in the Dzüün Sayhan. Desert steppe vegetation with *Stipa* and *Allium* spp. reaches up to 1800 to 2000 m a.s.l., mountain steppe covers the upper part of the range (Dasch and Tschimedregsen 1996). In few locations surrounding the forest sites meadow steppe can be encountered, regarded as a replacement community for forest in northern and central Mongolia (Sommer 1998; Sommer and Treter 1999; Wesche et al. 2003). As the Dzüün Sayhan barely reaches 2800 m, the alpine belt is missing almost entirely, only a few mats of *Kobresia myosuroides* are present in the highest locations (Miehe 1996; Wesche et al. 2003).

The striking feature of the Ih Bogd and Dzüün Sayhan are woodlands of *Betula* (birch) and *Salix* (willow) trees and shrubs, found on north-facing slopes. While on south-facing slopes, the grass-dominated vegetation of the mountain steppe is frequently interrupted by large patches of *Juniperus (J. pseudosabina* in the Ih Bogd range, *J. sabina* in the Dzüün Sayhan), woodland of *Betula* and *Salix* trees and shrubs are found in parts of this zone in northern exposure. The latter occur on north-exposed slopes, and in north-facing rills and gullies (Hilbig et al. 1984). They are the subject of the present paper.

3 Methods

In order to achieve the aim of the present study, i.e. to assess the position of the forests in the framework of human impact and climatic changes, a range of methods was applied. Combining vegetation surveys, dendroecological studies, and radiocarbon dating of charcoal findings the authors tried to portray the natural history and the present-day state of the forests, trace possible reasons for their current isolation and identify ecological trends regarding their potential for persistence.

3.1 Vegetation

Vegetation surveys followed the Zürich-Montpellier School of Braun-Blanquet (1932), as described by Müller-Dombois and Ellenberg (1974). Almost all recent studies of the vegetation of Mongolia employ the Braun-Blanquet phytosociological approach, so that comparability of results was ensured by this choice of methodology. In accordance with this approach, floristically complete vegetation surveys were conducted in subjectively selected locations. Sites considered in this investigation were located along forest – steppe gradients, i.e. forest centre, forest fringe inside, forest fringe outside, and open steppe vegetation. Plots of the last type were also surveyed on slopes resembling those with forest cover with respect to slope, altitude and exposure.

Species ground cover was estimated in percent rather than on the Braun-Blanquet scale to ensure compatibility with previous surveys in the area (e.g. Miehe 1996). Plant specimens were collected for reference and exact identification.

Identification of all plant specimens collected in the field was carried out at the herbarium at the University of Halle, Germany and using the Flora recently published in English (Grubov 2001). Plant names and authorities were assigned based on Gubanov (1996).

Statistical analysis of the data was carried out using the packages PC-Ord 3.15 (McCune and Mefford 1999) and SPSS 11.0.0 (SPSS Inc. 2001). Identification of communities was based on Two Way Species Analysis (TWINSPAN) (Hill 1979). In accordance with Braun-Blanquet's plant-sociological approach it was run on a presence / absence-based matrix rather than abundance. Since it is objective in terms of repeatability this approach was given preference over the traditional tabular rearrangement by hand.

3.2 Dendrochronology

For the dendrochronological approach 100 m² plots were chosen on the fringes and in the centres of the forests. On these plots all trees larger than 1 centimetre diameter at breast height were cored (as smaller trees might be fatally damaged by the coring) using standard techniques (Schweingruber 1983; Fritts 2001). One increment core was taken at each tree's bole base for determining its age and two at breast height for further dendroecological analysis. Where the pith was not reached, the missing years were estimated according to the method of Bräker (1981). Though the encountered tree species can grow single-stemmed and do so on the sites, most of the trees grow multi-stemmed – ranging from two stems up to 50 stems per individual in some cases. In multi-stemmed trees only the major stem was cored. On one plot all stems were sampled for reference.

The sampling at breast height excluded reaction wood. Sample processing followed Pilcher (1990). Tree-ring width measurement and crossdating were conducted using the TSAP 3.6 package (Rinn 2000). Statistical tests for crossdating were Gleichläufigkeit values and Student's t-test. The single curves of 10 dominant and codominant willows were combined into tree mean-curves and a site chronology for the Dzüün Sayhan Forest. The low-frequency variability in individual tree ring series attributable to tree ring ageing, forest stand development or differences in the vitality of individual trees was removed by standardising the data using the moving-average trend index that is included in the TSAP package. The annual mean increments of the site-chronology were correlated with monthly mean temperatures and monthly mean precipitation sums of each month, starting with May of the preceding year until September of the year the tree ring was formed. The meteorological data used is from Dalandzadgad, located about 30 km southwest of the Dzüün Sayhan Forests at ca. 1400 m a.s.l.

Additional information such as damage by fraying, ramming and browsing, tree height and diametre at breast height was collected.

3.3 Others

In soil examinations accompanying the vegetation surveys layers of charcoal were found in different soil depths. Genus and ^{14}C-age of the specimens were determined.

In support of the ecological studies a small number of semiformal interviews were conducted with nomads, to reveal further aspects of the distribution and utilization of the forests.

4 Results and Discussion

4.1 The Forests and Their Present-Day State

4.1.1 Vegetation

In the Dzüün Sayhan, a large forest described by Miehe (1996; 1998) ('Dzüün Sayhan A' photo 1) and a small one in a neighbouring valley ('Dzüün Sayhan B') were studied. In the Ih Bogd range a forest in Bitüüt valley was concentrated on ('Ih Bogd' photo 2). Interviews with locals at the mountain ranges between the Dzüün Sayhan and Ih Bogd as well as at the latter two revealed that today there are no other *Betula*-*Salix* forests than the ones studied.

The three forests investigated differ greatly in extent, covering 0.5, 30 and 50 ha, respectively. They are composed of *Betula* and *Salix* spp., growing in more or less dense stands on north- to north-east facing slopes at altitudes roughly between 2400 and 2700 m a.s.l. Position and area figures of all three forests are summarized in table 1. The smallest of the forests, Dzüün Sayhan B, may still be referred to as a forest in accordance with the definition put forward by the FAO Forest Resources Assessment, which assumes an area of at least 0.5 ha with a tree crown cover of at least 10 % (FAO 2001).

Photo 1 *Betula*-*Salix* Forest in the Dsüün Sayhan Mountains

Photo 2 *Betula-Salix* Forest in the Ih Bogd Mountains

The dominant tree species are *Betula microphylla*, *B. platyphylla* and *Salix taraikensis*. On average they are around 5 m high; the highest trees reach 7.5 m.

Two Way Indicator Species Analysis (TWINSPAN) of the entire vegetation dataset from all forests allowed the vegetation to be classified into communities. The first two levels of the two-way ordered TWINSPAN table are followed up in the following remarks.

Table 1 Study sites

	Dzüün Sayhan A	Dzüün Sayhan B	Ih Bogd
Coordinates of centre	43° 29.15’ N 104° 05.59’ E	43° 29.75’ N 104° 04.64’ E	44° 58.51’ N 100° 19.60’ E
Total area (estimate)	30 ha	0.5 ha	50 ha
Altitudinal range (m a.s.l.)	2380-2580	2470-2550	2510-2680
Protected area	Yes	Yes	No
Slope exposure	NNW to NNE	NE	NNE

The Ih Bogd vegetation quadrats are identified as the same association as the four species-richest plots of the Dzüün Sayhan. These lie notably above 2500 m a.s.l. The herbaceous vegetation of these plots and the Ih Bogd plots can be described as alpine *Kobresia* meadow (Hilbig 1995), a community generally found at higher altitudes. The main difference between these Ih Bogd and Dzüün Sayhan locations is the presence of trees and shrubs in the Ih Bogd, making them a different sub-association. Since, according to Hilbig (1987), potential forest sites reveal themselves by a herbaceous vegetation which largely resembles that of forest understoreys, the Dzüün Sayhan meadow steppes may be seen as possible forest sites. Indeed, as Hilbig (1995, p. 127) remarks, ‘most meadow steppes on mountain slopes used to be forest’.

Within the forest and forest fringe quadrats of the Dzüün Sayhan, the second association identifiable from the TWINSPAN table, a clear separation is possible between plots encroached by *Juniperus sabina* and those with a rich shrubby understorey including *Rosa acicularis*, *Grossularia acicularis*, *Spiraea media*, *Juniperus sabina*, *Ribes rubrum*, *Cotoneaster* spp. and *Lonicera* spp.

4.1.2 Climatic Constraints

Water availability is the crucial factor limiting the growth of forests in the mountain forest steppe zone of central and northern Mongolia. Although this zone is significantly more humid than the Govi Altay, forests are already very near their dry limits and can only survive due to a very complex system of water conservation where evaporation is kept to a minimum. Forests in the mountain forest steppe zone are strictly confined to north-facing slopes. It would appear that this is due to the reduced radiation in these locations, resulting in lower temperatures and evapotranspiration levels (Treter 1996). High levels of mean sensitivity (table 2) and the good crossdatability of the willow curves of the Dzüün Sayhan forests are distinctive indicators for a strong dependency of annual increment to water availability in contrast to for example nutrient supply or temperature regime.

However, in accordance with observations made further north (Haase 1983), the seasonal timing of moisture availability seems to be of much greater ecological importance than total precipitation sums. Firstly, most rain falls in summer when the evaporation levels are highest. Secondly, forests are not supplied with rain water before the summer rains of July and August. When the snow melts early in the year, temperatures are still too low to support plant growth (Richter et al. 1963; Treter 1996).

Table 2 Descriptive statistics of the willow ring width chronology

	Dzüün Sayhan
Beginning [yr]	1801
End [yr]	2001
No. of years	201
Missing rings [%]	0
Tree ring width	
Mean [1/100 mm]	41
Median [1/100 mm]	43
Standard Deviation	120.33
Mean sensitivity	36

The solution to both problems is ‘home-made’. When rainwater becomes available, it quickly infiltrates into the forest soils, and with the forest canopy in place direct evaporation is kept to a minimum. At the same time, snow cover remains in place for a longer time, its moisture becoming available to forest plants in spring when it is needed most. This was confirmed by an account of a Dzüün Sayhan National Park ranger who reported snow cover as late as May in the Dzüün Sayhan forest area.

These findings are supported by results from the climate-growth correlation between yearly increment and meteorological data from the Dalandzadgad meteorological station shown in figure 3. One can see that even though January precipitation only combines a small portion of the annual precipitation sums it does predict annual increments significantly on a 95 % level.

During summer convective processes lead to pronounced local differences in precipitation levels, especially in mountainous areas. This may explain the low predictive power the climatic data from Dalandzadgad has for the annual increment on the Dzüün Sayhan forests.

The strong summerly convective influence in the mountains was affirmed by meteorological measurements by Retzer (2003) in the nearby Dund Sayhan Mountains.

Tree physiognomy also indicates a significant role of snow. Photo 3 shows a typical sabre-formed stem bases found in areas with high snow pressure due to heavy snowfall or creeping snow (e.g. Timell, after Schweingruber 1996; Holtmeier 2000; 2003). One could mistake bends due to creeping hills but they typically show accumulation of material above the tree and erosion of material on the lower side. Neither is predominant on the researched sites. Although snow constitutes only a small part of total anual precipitation it appears to play an important ecological role. One must assume that snow is

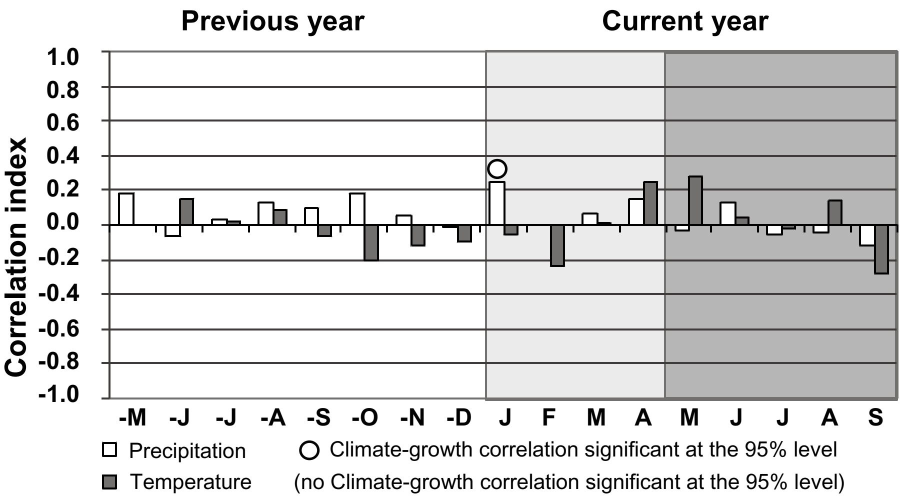

Figure 3 Climate-growth correlation of the willow chronology from the Dsüün Sayhan Forest with monthly mean temperatures of the years 1968-1999 and monthly precipitation sums of the years 1938-1999 from Dalandzadgad meteorological station. The annual increments of each year are being correlated with monthly climate data starting with May of the previous year until September of current tree ring year. The correlation index ranges between -1 and 1

blown to the forests from the adjacent steppe. The protective forest canopy supports snow accumulation.

Another interesting aspect is the presence of a frozen soil layer from as little as 80 centimetres downwards. Given the unusually hot and dry conditions prevalent in southern Mongolia during the summer of 2001 (cf. Retzer 2003), one may assume a more permanent and possibly perennial presence of this frost layer.

In northern Mongolia the presence of a permanent frost layer has been described as a function of forest cover: Canopy and organic soil layers protect the soil from solar radiation in summer. While air temperatures show no marked differences between steppe and forest areas, soil temperatures do (Treter 1996). Where the forest is cleared, the permafrost layer soon disappears; snow thaws early and the conditions for forest growth are no longer given. Considering discussion about the mentioned permafrost layers in the forests of northern Mongolia this presumed permafrost layer has important ecological functions in terms of water preservation and cooling (Haase 1983; Brzezniak and Pacyna 1989). In the north the permafrost is usually found at a depth between a few decimetres and 150 cm in summer. In winter the frost stratum extends to include the upper soil layers. The forest topsoil freezes later than the topsoil of ‘open’ vegetation, leaving more time

Photo 3 Typical Sabre-Shaped Stem Bases, Dzüün Sayhan

for the absorption of water from early snow (Bernatzky 1978). In the process of freezing the subsoil dries out and the moisture is concentrated in the topsoil. When temperatures begin rising in spring, the ‘active layer’ of the ground frost thaws and releases its moisture to the vegetation (Succow and Kloss 1978; Haase 1983). Correspondingly, the lowest water deficit in the forest steppe zone occurs in May, at the beginning of the growing period (Glazik 1999).

The discovery of the frozen layer in the particular situation outlined above may be interpreted as an indication of similar processes being in place in the Govi Altay. However, longer term observations would be needed to ascertain this.

Another adaptation to dealing with water stress can be concluded from the above-mentioned trend to build colonies: All of the birch and willow species encountered can grow as single-stemmed trees and sometimes do so on the researched sites. Nevertheless most of the specimens encountered were multi-stemmed. This phenomenon has been observed in many forests at the alpine timberline and has been interpreted as an adaptation to different ecological constraints (Holtmeier 2000; 2003).

Figure 4 shows the annual increment of three stems of the same tree. As can be seen, stem 1 is the oldest of the stems and has had the predominant annual increment until 1990. From that time on the stems’ growth rate declines

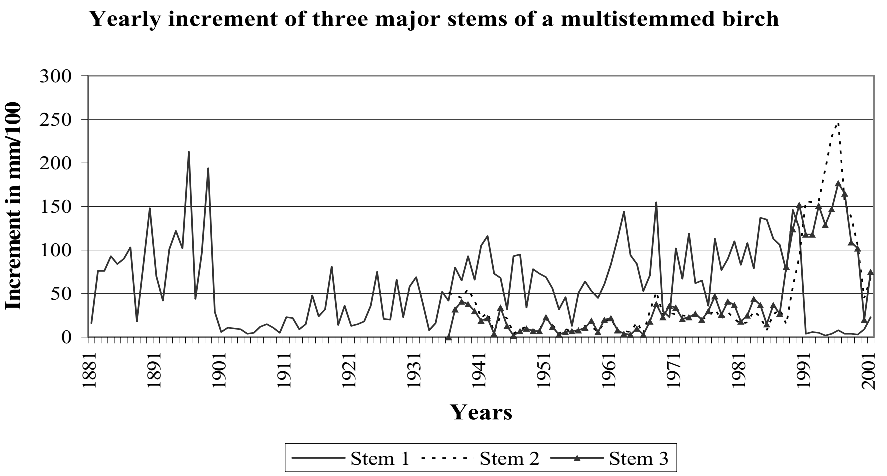

Figure 4 Yearly increment of three major stems of a multi-stemmed birch. Declining growth of the major stem in 1990 is accompagnied by increasing growth of the two minor stems

rapidly and it is to be expected that the specimen is going to die in the near future. At the same time the other two stems 'take over' – the tree survives. The important factor is that the already established root system is still in place – crucial water access is thus granted and a decisive advantage in competing with other individuals or even other species is given. This strategy would also explain why no clearings and in turn no seedlings were found within the forest whereas seedlings are present at the forest fringes.

4.1.3 Human and Livestock Impact

Livestock droppings, trampling and traces of grazing and browsing were encountered in most vegetation plots. Some timber was found near the Ih Bogd forest. In 1957, a major earthquake occurred in the Govi Altay. With its epicentre in the Ih Bogd and Baga Bogd ranges, it resulted in ruptures over a length of 260 km ('Bogd rupture') and extensive rockfalls, landslides and tension cracks in the mountain ranges (Kurushin et al. 1997).

A vast landslide occurred in the upper reaches of the Ih Bogd, in the vicinity of today's forest. A block of rock of about 140 x 10^6 m^3 broke off and slid down to the valley ground. The material now covers the valley along a stretch of more than 3 km with a maximum width of about 1.2 km. According to local herders the valley used to be inhabited seasonally before the landslide. Since then however the main entrance route has been blocked for horse-back and cattle access, thus today only a few hunters come to the upper reches of the valley.

This ‘remoteness’ leads to one of the major differences between the forests in the Dzüün Sayhan and Ih Bogd mountains. While in the Ih Bogd almost no signs of browsing, ramming or fraying could be found – only 6 % of the trees showed such signs – evidence of strong disturbance at the forest fringes is omnipresent in the Dzüün Sayhan. In these plots up to 93 % of the sampled trees were partly heavily damaged by large herbivores. Without doubt the yak population is capable of contributing to forest decline in this area. But as with the microclimate the forest seems to protect itself by being so dense that large herbivores cannot access its centre easily so that only few signs of animal damage - on 4 % of the trees - can be observed there.

4.2 Environmental History

4.2.1 Short Term Environmental History

The age structure of the three Ih Bogd plots (figure 5) clearly indicates a young and expanding forest with an age gradient from the forest centre plot to the outer plots. Outposts of the emerging forest too small for coring could be observed on adjacent north-facing slopes as well. Overgrown tree stumps as well as solitary ‘older’ trees (115 years in the outer plot, 85 and 82 years in the forest centre) witness that there were trees even before this new expansion process.

Dendrochronology promises to supply exact dates for changes in forest dynamics. Looking at the forest centre plot where the process of expansion most likely started out one can observe that most trees are between 40 and 60 years of age – in other words: their germination took place between 1940 and 1960. At a first glimpse this would contradict the hypothesis that forest expansion is a direct result of the 1957 earthquake as mentioned above. But one has to keep in mind that tree growth is extremely slow under present conditions – taking 20 years to reach 1 cm diameter in breast height. Thus assuming that the use of timber was one of the major threats to forest growth before the earthquake, it seems plausible that an array of trees with an age of about 20 years would have been there when the 1957 earthquake happened and in the consequence the forest was left to itself. At the forest fringe all the trees germinated after the earthquake and no old stumps were encountered. This is a clear hint that the area had been cleared of forests before and that the abrupt decline of grazing after the earthquake made the succession possible.

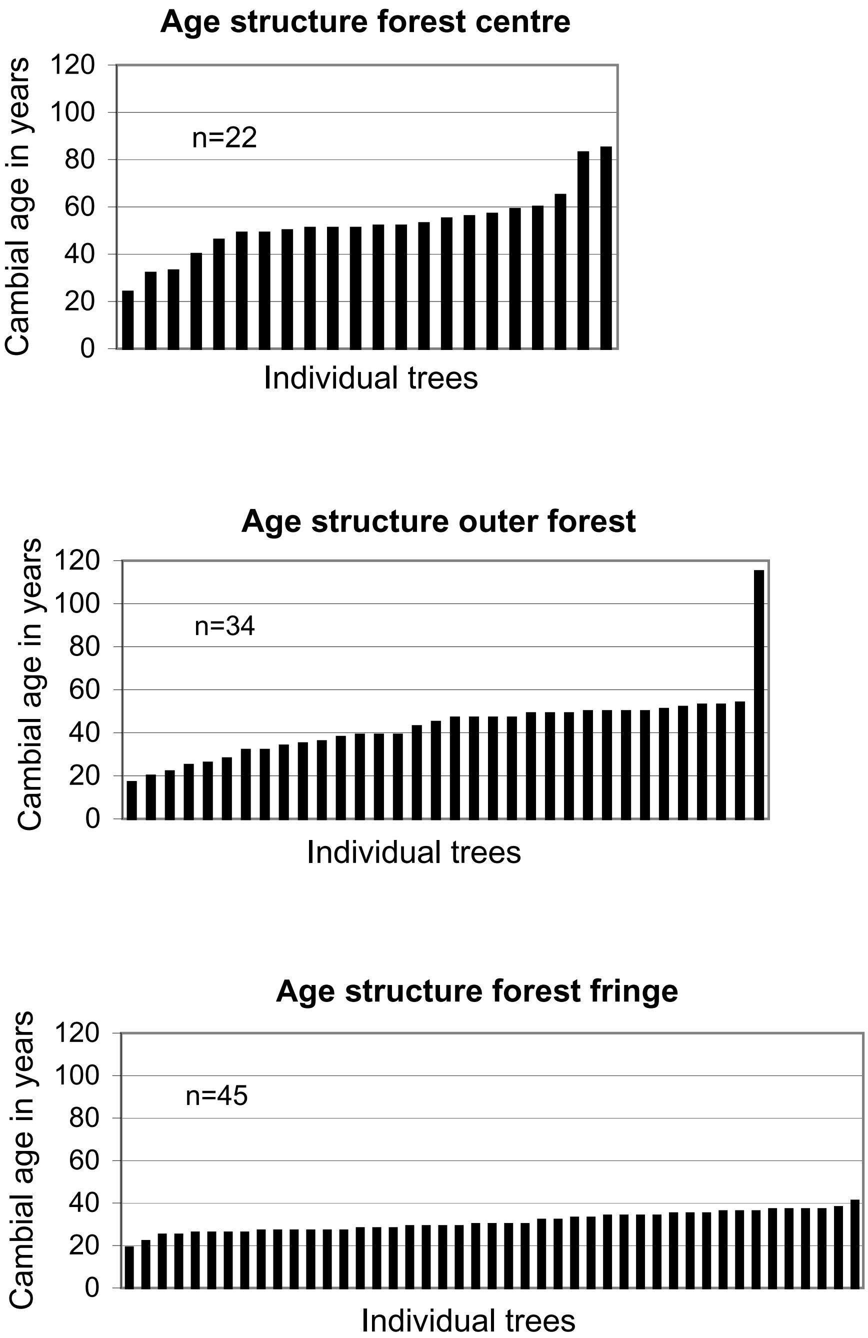

Figure 5 Tree age structure on three plots from centre to forest fringe. Tree ages are represented by cambial ages

Tree ages in the Dzüün Sayhan forests witness a totally different situation. All the plots sampled show a much more diversified age structure – which means that no directed expansion as in the Ih Bogd can be observed here. On the contrary, it seems that this little forest patch at least within today's fringes must have been stable for at least 150 to 220 years, as the oldest cored trees are that age and large decaying trunks of deadwood are found throughout the forest.

4.2.2 Long Term Environmental History

In several locations under forest and under adjacent steppe charcoal was found at different soil depths. These have been identified as *Betula*, *Salix*, and *Juniperus* and in one case *Picea* or *Larix* (no further discrimination possible from charcoal, Schoch 2002, pers. comm.). The *Picea/Larix* has been ^{14}C dated to 3743 ± 51 years (2296 BC – 2014 cal. BC, Erl-5517). The presumably oldest *Betula*-specimen has been ^{14}C dated to 4335 ± 53 years (3098 BC – 2878 cal. BC, Erl. 5518). These findings correspond well with dated macrofossil findings of *Larix*, *Picea* and *Abies* at Bayan Sayr, the Tsakhir Khalgyn Mountains and Uert valley (Dinesman et al. 1989, cited in Dorofeyuk 2000). This underlines the likeliness of a closed forest belt at some time in the Holocene with forest cover in locations that are forest-free at the moment. This belt may have appeared during a more humid phase between 5000 and 2000 years BP, which has been suggested for the north before (Klimek 1980). This conjecture is further corroborated by floristic features encountered in and around the forests, such as *Viola* spp. and *Paeonia*. Not being anemochores, these species are known to be slow migrators (Jäger 2002; pers. comm.).

5 Conclusions

All evidence collected about the three *Betula* - *Salix* forest islands of the Govi Altay supports the hypothesis that today's isolated forests are the last remnants of a former forest belt spanning the entire Govi Altay. Charcoal findings and floristic evidence link the present-day forest islands to periods past.

The reasons underlying the retreat of a former forest belt to today's few forest islands can only be guessed upon. Today's islands suggest that even though the climate developed unfavourably after the establishment of a forest belt in the Altay the climatic conditions would support an already established forest ecosystem. Charcoal findings in different soil layers – or in other words:

forest fires at different times, the strong pressure of livestock, and well documented current timber utilization can surely account for a large portion of the forests' decline. As the situation in the Dzüün Sayhan forests suggests - once the forest cover was broken up it was at least very difficult for forests to once again penetrate the steppe.

The picture presented today differs for the two investigated areas. While all evidence in the Ih Bogd mountains points to an expanding forest on the north-facing slopes as a consequence of people and their livestock leaving the area after the 1957 earthquake, the Dzüün Sayhan forests seem to be under strong pressure from livestock. This seems especially challenging since these forests must be regarded as 'true' remnants: Since the forests ensure their own survival today, their eradication under today's climatic circumstances would most certainly be final.

Acknowledgements

We would like to thank Werner Schoch of the Laboratory for Quaternary woods, who determined the charcoal specimens. Andreas Rigling from the Swiss Federal Institute for Forest, Snow and Landscape Research who assisted with the dendrochronological analysis. Thomas Hennig of the University of Marburg, who assisted us in the field-campaign and Christiane Enderle for preparing some of the graphs.

The Bundesministerium für Wirtschaftliche Zusammenarbeit (BMZ) and the German Research Council (DFG) supported the research with financial grants.

References

Barthel H (1983) Die regionale und jahreszeitliche Differenzierung des Klimas in der Mongolischen Volksrepublik. Studia Geographica 34: 1-91

Bernatzky A (1978) Tree Ecology and Preservation. Elsevier, Amsterdam

Bräker OU (1981) Der Alterstrend bei Jahrringdichten und Jahrringbreiten von Nadelhölzern und sein Ausgleich. Mitt. Forstl. Bundes-Vers.anst. Wien 142: 75-102

Braun-Blanquet J (1932) Plant Sociology: The Study of Plant Communities. Facsimile 1965, 1. edn, Hafner, New York

Brzezniak E, Pacyna A (1989) Types of the Vertical Plant Zonality in the Mountains of Mongolia Against a Background of the Climate. Prace Botaniczne 18: 7-19

Dasch D, Tschimedregsen L (1996) Forschungsbericht der Pflanzengeographischen Untersuchungen im komplexen Schutzgebiet Gobi-Gurvan-Saichan. Akademie der Wissenschaften der Mongolei, Ulaanbaatar

Dorofeyuk NI, Tarasov PE (2000) Rastitel 'Nost' Sapadnoy i Yuzhnoy Mongolii v Poesdnem Pleystozene i Golozene. Botanicheskiy Zhurnal 85, 2: 1 – 17

Ellenberg H (1979) Man's influence on Tropical Mountain Ecosystems in South America. Journal of Ecology 67: 401-416

Food and Agricultural Organization of the United Nations (FAO) (2001) Global Forest Resources Assessment 2000 - Main Report. FAO Forestry Paper 140. FAO, Rome

Freitag H (1971) Die natürliche Vegetation Afghanistans. Vegetatio 22: 285-344

Fritts HC (2001) Tree Rings and Climate. The Blackburn Press, Caldwell, New Jersey

Glazik R (1999) Struktura Bilansu Wodnego na Obszarze Mongolii. Acta Universitatis Nicolai Copernici 103: 257-268

Grubov VI (2001) Key to the Vascular Plants of Mongolia (With an Atlas). Science Publishers, Enfield

Gubanov IA (1996) Konspekt flory vneshnei Mongolii: sosudistye rasteniia. Valang, Moscow

Haase G (1983) Beiträge zur Bodengeographie der Mongolischen Volksrepublik. Studia Geographica 34: 231-367

Hilbig W (1987) Zur Problematik der ursprünglichen Waldverbreitung in der Mongolischen Volksrepublik. Flora 179: 1-15

Hilbig W (1995) The Vegetation of Mongolia. Amsterdam

Hilbig W, Knapp HD (1983) Vegetationsmosaike und Florenelemente an der Wald-Steppen-Grenze im Chentej-Gebirge (Mongolei). Flora 174: 1-89

Hilbig W, Stubbe N, Dawaa N, Schamsran Z, Dorn M, Helmecke K, Bumzaa D, Ulykpan K (1984) Vergleichend biologisch-ökologische Untersuchungen in Hochgebirgen der Nordwest- und Südmongolei. Erforschung biologischer Ressourcen der Mongolischen Volksrepublik 4: 5-49

Hill MO (1979) TWINSPAN – a FORTRAN Program for Arranging Multivariate Data in an Ordered Two Way Table by Classification of the Individuals and the Attributes. Cornell, Department of Ecology and Systematics, Ithaca, NY

Holtmeier F-K (2000) Die Höhengrenze der Gebirgswälder. Arbeiten Institut für Landschaftsökologie, Westfälische Wilhelms-Universität 8

Holtmeier F-K (2003) Mountain Timberlines – Ecology, patchiness, and dynamics. Advances in Global Change Research, 14. Kluwer Academic, Dordrecht

Kessler M (2002) The „Polylepis Problem": Where do we stand? Ecotropica 8: 97-110

Klimek K (1980) Relief and Paleogeography of the Southern Khangai Mountains. Prace Geograficzne 136: 19-27

Kurushin RA, Bayasgalan A, Ölziybat, M, Enhtuvshin B, Molnar P, Bayarsayhan C, Hudnut KW, Lin J (1997) The Surface Rupture of the 1957 Gobi-Altay, Mongolia, Earthquake. The Geological Society of America, Boulder

McCune B, Mefford MJ (1999) PCOrd: Multivariate Analysis of Ecological Data. MjM Software Design, Gleneden Beach

Meteorological Survey of Mongolia (1996) Meteorological Data Dalandzadgad. Personal Communication

Miehe S (1996) Vegetationskundlich-ökologische Untersuchungen, Auswahl und Einrichtung von Dauerprobeflächen für Vegetationsmonitoring im Nationalpark Gobi-Gurvan-Saikhan. GTZ, Ulaan Baatar, Technical Report

Miehe S (1998) Ansätze zu einer Gliederung der Vegetation im Nationalpark Gobi-Gurvan Saikhan. GTZ, Technical Report, Ulaan Baatar

Miehe G, Miehe S (1994) Zur oberen Waldgrenze in tropischen Gebirgen. Phytocoenologia 24: 53-110

Miehe G, Miehe S, Huang Jian, Otsu Tsewang (1998) Forschungsdefizite und -perspektiven zur Frage der potentiellen natürlichen Bewaldung in Tibet. Petermanns Geographische Mitteilungen 142: 155-164

Miehe S, Miehe G, Huang Jian, Otsu Tsewang, Tuntsu Tseren, Tu Yanli (2000) Sacred Forests of South-Central Xizang and their Importance for the Restauration of Forest Ressources. In: Marburger Geographische Schriften 135: 228-249

Miehe G, Miehe S, Schlütz F, Schmidt J, Schawaller W (2002) Sind Igelheiden die zonale natürliche Vegetation altweltlicher Hochgebirgshalbwüsten? Vegetationskundliche Zoogeographische und palynologische Befunde aus dem tibetischen Nepal - Himalaya. Erdkunde 56: 268-285

Müller-Dombois D, Ellenberg H (1974) Aims and Methods of Vegetation Ecology. Wiley & Sons, New York

Murzaev EM (1954) Die Mongolische Volksrepublik: Physisch-geographische Beschreibung. VEB geographisch-kartographische Anstalt, Gotha

Pilcher JR (1990) Sample Preparation, Cross-Dating and Measurement. In: Cook ER and Kairiukstis LA (eds) Methods of Dendrochronology. Applications in the Environmental Sciences. Kluwer Academic, Dordrecht, pp 40-51

Reading RP, Amgalanbaatar S, Lhagvasuren L (1999) Biological Assessment of Three Beauties of the Gobi National Conservation Park, Mongolia. Biodiversity and Conservation 8: 1115-1137

Retzer V (2003) Grazing Ecology of the Gobi Gurvan Sayhan, South Gobi, Mongolia: Carrying Capacity and Forage Competition Between Livestock and a Small Mammal (*Ochotona pallasii*) in a Non-Equilibrium Ecosystem. University of Marburg, unpublished PhD thesis

Richter H, Haase G, Barthel H (1963) Besonderheiten des Periglazials unter kontinentalen Klimaverhältnissen Zentralasiens. Wissenschaftliche Zeitschrift der Technischen Universität Dresden 12: 1153-1158

Rinn F (2000) TSAP 3.6. Heidelberg, Rinntech

Schlütz F (1999) Palynologische Untersuchungen über die holozäne Vegetations-, Klima- und Siedlungsgeschichte in Hochasien (Nanga Parbat, Karakorum Nyanbaoyeze, Lhasa) und das Pleistozän in China (Qinling Gebirge, Gaxun Nur). Dissertationes Botanicae 315

Schweingruber FH (1983) Der Jahrring: Standort, Methodik, Zeit und Klima in der Dendrochronologie. Paul Haupt, Bern

Schweingruber FH (1996) Tree Rings and Environment. Dendroecology. Paul Haupt, Bern
Sommer M (1998) Die Bärentrauben-Lärchenwälder im Charchiraa-Gebirge (Mongolei). Feddes Repertorium 109: 129-138
Sommer M, Treter U (1999) Die Lärchenwälder der Gebirgswaldsteppe in den Randgebirgen des Uvs Nuur Beckens. Die Erde 130: 173-188
SPSS Inc. (2001) SPSS for Windows, Release 11.0.0
Succow M, Kloss K (1978) Standortverhältnisse der nordmongolischen Waldsteppenzone im Vorland des westlichen Chentej. Archiv für Acker- und Pflanzenbau und Bodenkunde 22: 529-542
Treter U (1996) Gebirgs-Waldsteppe in der Mongolei: Exposition als Standortfaktor. Geographische Rundschau 48: 655-661
Troll C (1959) Die tropischen Gebirge. Bonner Geographische Abhandlungen 25
Walter, H (1974) Die Vegetation Osteuropas, Nord- und Zentralasiens. Stuttgart
Walter H, Medina E (1969) Die Bodentemperatur als ausschlaggebender Faktor für die Gliederung der subalpinen und alpinen Stufe in den Anden Venezuelas (vorläufige Mitteilung). Berichte Deutsche Botanische Gesellschaft 82: 275-281
Weischet W, Endlicher W (2000) Regionale Klimatologie – Teil 2: Die Alte Welt. Teubner, Stuttgart, Leipzig
Wesche K (2002) The High-Altitude Environment of Mt. Elgon (Uganda/Kenya): Climate, Vegetation, and the Impact of Fire. Ecotropical Monographs 2
Wesche K, Miehe S, Miehe G (submitted): Desert and Semi-Desert Vegetation in Southern Mongolia: the Plant Communities of the Gobi Gurvan Saikhan National Park (South Gobi Aimag, Mongolia). Phytocoenologia
Zhang Jinwei (ed) (1988) The Vegetation of Xizang. Beijing. In Chinese.