GEO-ECOLOGICAL TRANSECT STUDIES IN NORTHEAST TIBET (QINGHAI, CHINA) REVEAL HUMAN-MADE MID-HOLOCENE ENVIRONMENTAL CHANGES IN THE UPPER YELLOW RIVER CATCHMENT CHANGING FOREST TO GRASSLAND

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With 4 figures and 7 photos
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Summary: Geo-ecological transect studies in the pastures of the upper catchment of the Huang He (99°30'–100°00'E/35°30'–35°40'N; 3,000–4,000 m a.s.l., Qinghai province, China) revealed evidence that pastures replace forests. Plot-based vegetation records and fenced grazing exclosure experiments enabled the identification of grazing indicator plants for the first time. The mapping of vegetation patterns of pastures with isolated juniper and spruce forests raise questions as to the origin of the grasslands, which are widely classified as "natural" at present. Soil investigations and charcoal fragments of *Juniperus* (8,155 ± 63 uncal BP) and *Picea* (6,665 ± 59 uncal BP) provide evidence of the wider presence of forests. As temperatures and rainfall records undoubtedly represent a forest climate, it is assumed that the present pastures have replaced forests. Circumstantial evidence arising from investigations into the environmental history of the Holocene effectively substantiates this theory.

Zusammenfassung: Geoökologische Transektuntersuchungen in Hochweiden des oberen Einzugsgebietes des Gelben Flusses (99°30'–100°00'E/35°30'–35°40'N; 3.000–4.000 m NN, Provinz Qinghai, China) geben Hinweise auf ältere, mutmaßlich menschverursachte Umweltveränderungen. Fünfjährige Weideanschlussexperimente und floristisch vollständige Vegetationsaufnahmen erlauben erstmals die Identifizierung von Weidezeigerpflanzen. Vegetationsmosaike von Triftweiden mit isolierten Baumvorkommen in Normalstandorten sind Grundlage der Hypothese, dass Viehhalter die Wälder durch Weiden mittels Feuer ersetzt haben. Temperatur und Niederschlag weisen das Untersuchungsgebiet als Waldklima aus. Bodenuntersuchungen und determinierte Holzkohlen (*Juniperus* 8.155 ± 63 uncal BP, *Picea* 6.665 ± 59 uncal BP) stützen die Hypothese. Der Indizienbeweis wird für den umweltgeschichtlichen Nachweis als hinreichend angesehen.

Keywords: Global change, fire ecology, Tibet, China.

1 Introduction

The Huang He (Yellow River) catchment appears to be one of the most vulnerable discharge systems in the world due to the fact that millions of people are affected by droughts or flooding if severe upstream environmental changes take place (e.g. Wang and Cheng 2000; Zhang et al. 2003; Zeng et al. 2003; He et al. 2004; Zhou et al. 2005). The upper catchment of the Huang He is widely dominated by rangelands of the Tibetan Plateau. Thus investigations on the present vegetation dynamics or new findings about earlier environmental changes (e.g. Geldmacher et al. 2003; Shen et al. 2005; Kaiser et al. 2007) may provide information which could facilitate a better environmental management programme for the Huang He catchment. This contribution can therefore be seen in the context of the Highland-Lowland interaction system (Ives and Messerli 1989). The mapping of vegetation and soils provide an initial inventory of the status quo; repeated monitoring of grazing exclosure plots constitute a second step. The interpretation of recent vegetation patterns combined with paleosol findings open new insights into the human dimension of environmental changes in the grasslands of the Tibetan Plateau.

2 Study area and climatic setting

The area under investigation is located in the Chinese province of Qinghai on the north-eastern Tibetan Plateau, approximately 200 km southwest of Xining in the Xinghai district (99°30'–100°00'E/35°00'–36°00'N) of the Hainan prefecture. Larger parts of the study area are located

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on the grasslands of a loess-covered terrace of the Huang He between 3,300 and 3,400 m a.s.l. (Photo 1), and are embedded in mountain ranges with steep limestone cliffs emerging 800 m above the Huang He terrace. The district comprises an area of 11,621 km² with approximately 50,000 people, of which approximately 10,000 live in the district capital Xinghai (3,320 m; Koch 2003). The most famous site in the district is a mountain massif 19 km west of Xinghai, Drakar Tredzong, which is one of the three most important sacred sites for Buddhist Tibetans of the Amdo region (Baumer and Weber 2002; Gyurme Dorje 2003). A monastery on the south side of the mountain lies at 3,800 m (Fig. 1 "Saizuong"). Due to its being considered a sacred mountain, the forests of *Juniperus przewalskii* (juniper) and *Picea crassifolia* (spruce) have been conserved and large numbers of Blue Sheep (*Pseudois nayaur*) graze in this sacred forest. The forest, although partly destroyed during the Cultural Revolution, is an important site for considerations on the natural vegetation of the area.

The area receives summer precipitation from the East Asian monsoon, mostly with torrential rains after thunderstorms in the afternoon. The Xinghai climate station in the centre of the gravel plain has a forty year mean annual rainfall of 353 mm (1961–2001), ranging from 214 mm to 483 mm. Towards the western mountains rainfall increases 1.3 fold between 3,332 m and 3,600 m (Fig. 2). The mean annual precipitation extrapolated to the 1961–2001 period of Xinghai climate station for the pastures around Da Heba ("rain gauge 2", 3,080 m) is 367 mm/a, whereas the *Kobresia-Stellera chamaejasme* pastures of the western terrace receive 378 mm/a ("rain gauge 3", 3,360 m) and 423 mm/a ("rain gauge 4", 3,440 m). The outer lower slopes of the mountains near Saizuong receive 475 mm/a ("rain gauge 5", 3,600 m). Winter snow is irregular and rare, and soon melts on southern exposures, but may last for months on the shaded slope. In Xinghai, mean monthly temperatures are above 5 °C between May and September, and above 10 °C during June and August. Frost however may occur during summer at the higher altitudes. During winter, northeast Tibet is subject to the Siberian High Pressure. Mean monthly temperatures of December and January at Xinghai are below -10 °C. The mean monthly temperature of the coldest month is -20.8 °C, and the absolute minimum is -33.5 °C. In January, subsoil temperatures (-10 cm; Hotdog Data logger, ELPRO; Buchs) at 3,620 m with a southern exposure fluctuate by 5 °C to 10 °C around 0 °C, and reach 20 °C from April on, whereas the shaded slope at the same altitude remains

Photo 1: Da Heba river with irrigated fields of rape and wheat, surrounded by degraded *Achnatherum splendens-Achnatherum inebrians* pastures. The gravel terraces are 360 m thick. Overgrazing and road construction trigger landslides and increase the sediment load of the Huang He.
3300 m; Photo: G. Miehe, July 1999.

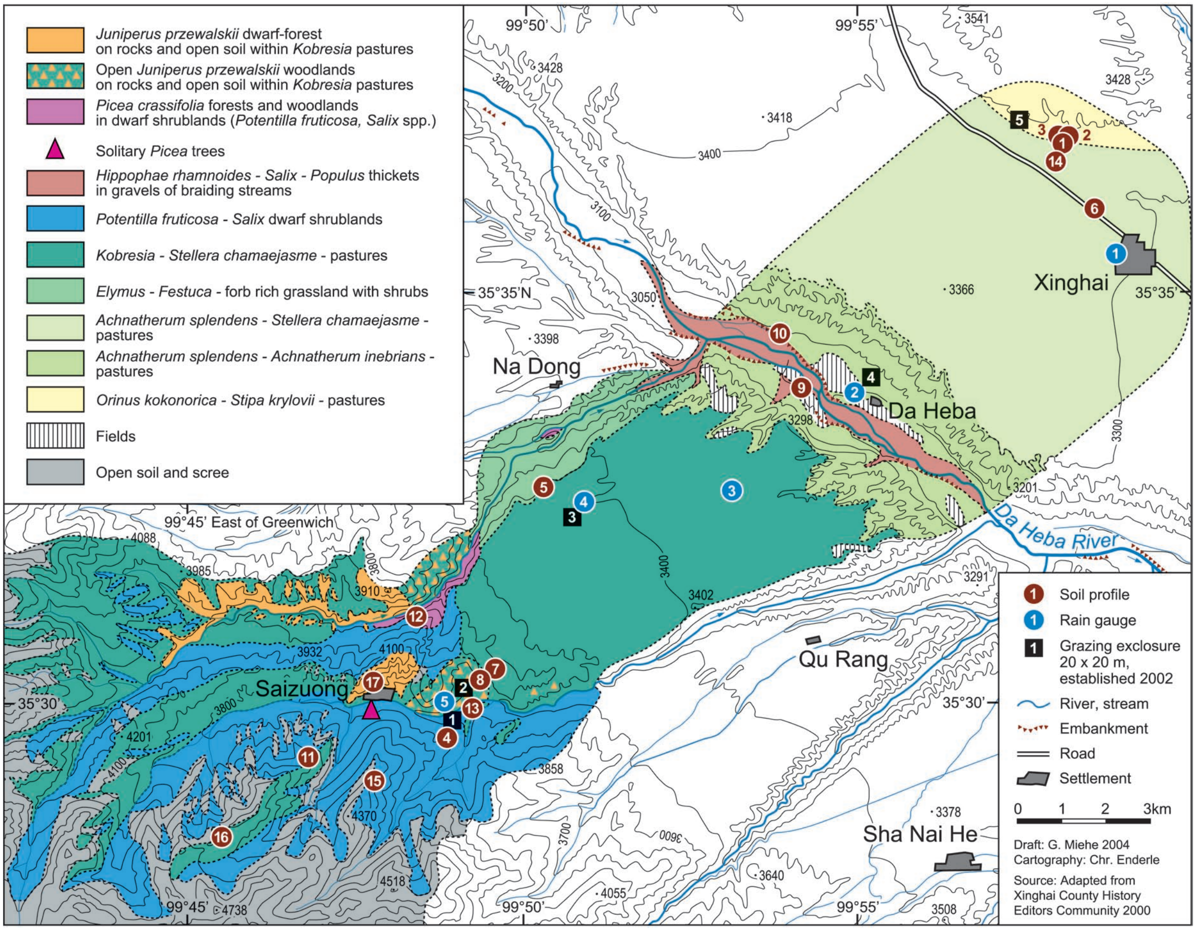

Fig. 1: Vegetation patterns of pastures and forest islands in the upper Huang He catchment

frozen between November and mid-April. The highest subsoil temperatures are reached in June at 15 °C with daily amplitudes of 5 °C.

3 Pedogeomorphological investigations

In 2002, 17 soil sections in the Xinghai area were recorded along a geomorphological transect (Fig. 3). Horizon designations and soil types are given, using WRB (IUSS-ISRIC-FAO 2006). A new designation was created for a widespread Tibetan topsoil phenomenon called "*Kobresia* turf" (Miehe 1988; Kaiser et al. 2008). This horizon consists of a high quantity of felty remains of fine sedge-roots (*Kobresia pygmaea*) as well as amorphous humus and minerogenic matter ('Afe': suffix *fe* from *fe*lty). Several soil analyses were performed, the procedures and results of which are documented in Kaiser (2007). The AMS radiocarbon ages presented (analysed in the Erlangen Laboratory) are uncalibrated.

Aeolian silts are the predominant soil substrates of the transect. However, a high gradient of altitude-dependent precipitation has caused a highly differentiated soil type pattern. Marked gradients of several topsoil parameters from that transect are given in figure 4 and corroborate the dependence of soil on the altitudinal variation of climate (e.g. decrease in EC, Na^+ and pH with increasing altitude; increase in C_{org} and Fe_d with increasing altitude).

"Salic" Kastanozems with distinct enrichments of salts are developed on deep-lying (semiarid) sites on the "High Terrace I" site. Chernozems and Phaeozems were observed on the adjacent western (semi-moist) terrace plains, consisting of 90-cm-thick Ah horizons at a maximum. Repeatedly, buried soils have been found in loess-layers of the foothills. In profile XIN 7, the dating of a buried 33-cm-thick 3Ahkb horizon (= thin Chernozem) by means of humic acids yielded an age of 12,229 ± 119 uncal BP (Erl-8074), pointing to late-Glacial sedimentation of the above-lying aeolian silts. A few pollen grains preserved in this

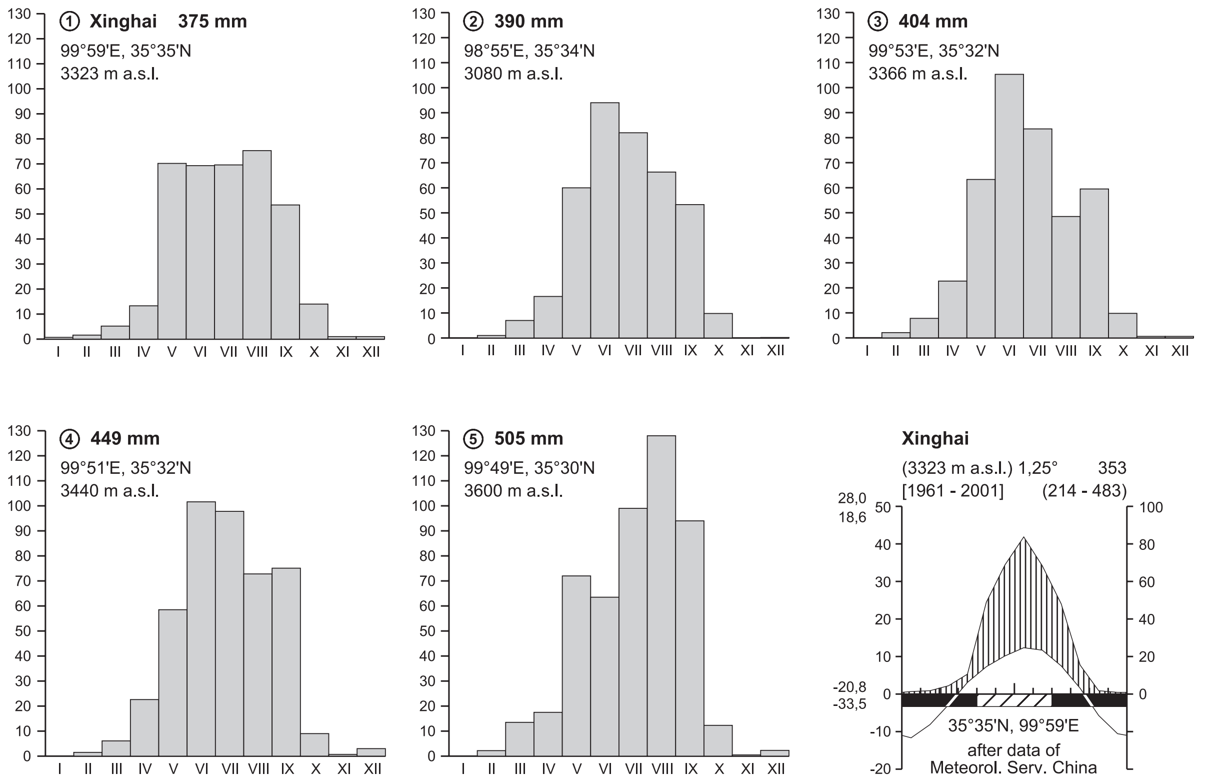

Fig. 2: Climatic diagram of Xinghai (after data of the Meteorological Service of China) and monthly totals of rainfall of Xinghai climatological station and project rain gauges (200 cm²) between 3,080 and 3,600 m between August 2002 and December 2005 (Localization s. Fig. 1)

paleosol belong to herbs. Cambisols developed from debris and slope deposits occur in the highest parts of the transect. Humic Gleysols take up high-lying mountain saddles with diminished drainage. *Kobresia* turfs were observed above approx. 3,500 m a.s.l. capping different soil types. In general, sites higher than 4,000 m a.s.l. are influenced by (partly fossil) periglacial mass movements (solifluction, screes). The environs of profile XIN 16 (Humic Cambisol), which was recorded at 4,385 m a.s.l. in a cirque, showed several glacial and periglacial phenomena (till, erratics, sorted circles and stripes, free and bound solifluction).

Profile XIN 13 represents a more than 350-cm-thick colluvial infill of a stream valley lying in the foothills at 3,550 m a.s.l. The adjacent slopes are composed of *Potentilla fruticosa-Salix* dwarf shrublands (NW-facing) and *Kobresia pygmaea* pastures (SE-facing). The colluvial infill mainly consists of a distinct layering of silt beds alternating between rich and poor levels of organic matter (LOI = 9.5% in maximum). In the lower part, two concentrations of charcoal were dated at 6,665 ± 59 uncal BP (250–270 cm, *Picea*, Erl-6773) and 8,155 ± 63 uncal BP (270–290 cm, *Juniperus*, Erl-6774). A probable buried soil beneath was not reached.

4 Vegetation patterns of a pastoral ecosystem

The vegetation patterns as given in figure 1 reflect a relief-dependent precipitation gradient, and superimposed by accessibility. Despite a homogenous substrate of gravel and loess it is evident that the rainfall gradient of the area, the impact of nomadic husbandry through the centuries, the impact of a drastically increased population and the highest livestock numbers recorded in 50 years (Koch 2003) have all influenced the floristic composition and the carrying capacity of the pastures. Only on very steep limestone cliffs is the vegetation untouched; all other communities are subject to human impact. Even remote scree slopes with sparse vegetation are grazed.

The *Kobresia* pastures continue into the mountains covering the southern slopes with a felty turf of a golf course-like *Kobresia pygmaea* pasture covering between 70 and 80% of the turf. *Stipa* species however are present with nearly 30%. After 5 years of grazing exclosure the golf course-like Cyperaceae-dominated pasture changed into a grassland of 30 to 40 cm in height, overgrowing the smaller Cyperaceae. Cliffs and soil patches of southern exposures interrupting this turf are partly colonized with *Juniperus*

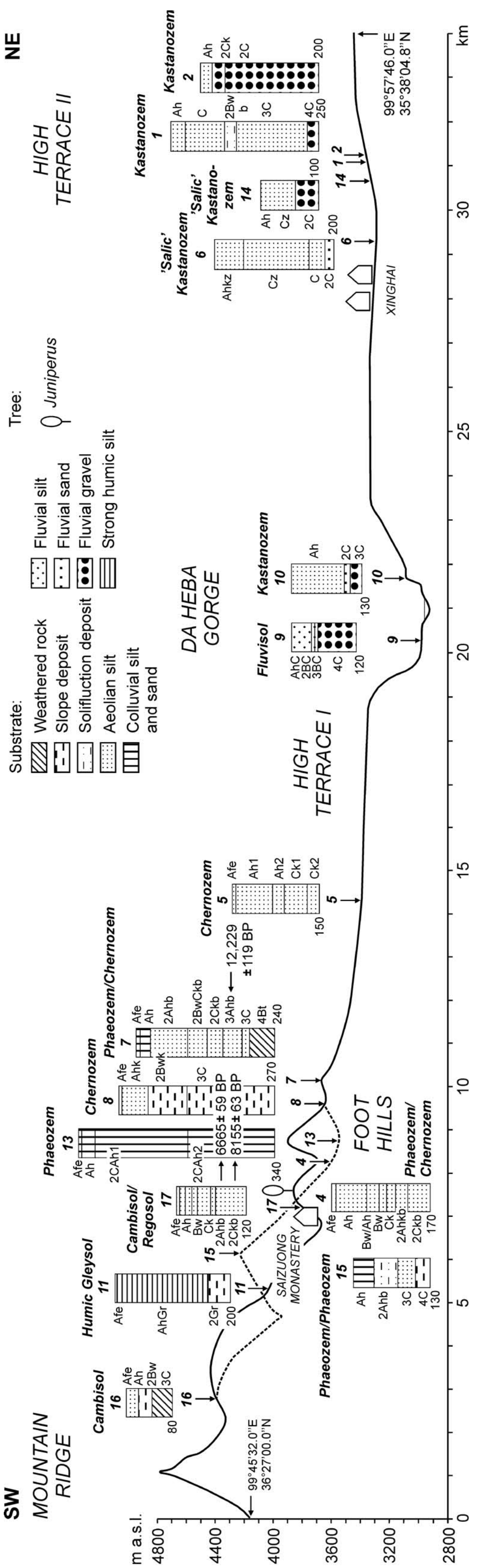

Fig. 3: Pedogeomorphological Xinghai transect

przewalskii (Photo 2, 3). The highest trees in the area are found at 4,100 m a.s.l. (*Juniperus przewalskii*) on inaccessible cliffs above the monastery. The northern exposures of the mountains have dwarf shrublands of *Salix* spp., *Spiraea* spp. and *Potentilla fruticosa*. Some of the slopes still show depleted stands of *Picea crassifolia* (Photo 4). Opposite Saizuong there are two isolated spruce trees, suggesting a forest potential for that slope. Open soil patches are widespread and demonstrate the devastating effects of overgrazing. The slate and limestone screes are sparsely colonized by plants adapted to solifluction.

It therefore raises the question of how the different impacts have specifically influenced the carrying capacity of the three grassland types in the area; the *Orinus kokonorica-Stipa krylovii* pastures, the *Achnatherum splendens* pastures and the *Kobresia humilis-Stellera chamaejasme* pastures. The grasslands of the eastern terrace (*Orinus* and *Achnatherum* pastures) are grazed year round by goats and sheep, and the *Kobresia* pastures of the western terrace are used as winter grazing grounds for yak and sheep for 6 to 7 months. All test sites where pastoral data were sampled were fenced-off in 1995 (Koch 2003). As rangeland classifications had until then not been based on quantified data on the intensity of grazing impact, it was necessary to develop reliable indicators to estimate the extent of desertification. In order to identify such grazing indicator species in all three grassland types transect investigations were undertaken in summer 2002 (Koch 2003).

Orinus kokonorica-Stipa krylovii pastures prevail on the eastern terrace north of Xinghai (Photo 5). Cover degrees of flowering plants range around 30%, mosses and lichens are lacking. Apart from the dominant grasses, the forbs recorded here are weeds well known in all degraded rangelands of Tibet (*Artemisia demissa, Chenopodium album, Dracocephalum heterophyllum, Heteropappus gouldii, Iris* spp., *Potentilla bifurca* and *Sibbaldianthe adpressa)*. After 5 years of grazing exclosure the cover degree doubled, mainly due to increased cover percent age of the grasses.

The *Achnatherum splendens* pastures belong to a rangeland type of greatest distribution in Central Asia. The species is nearly grazing resistant and slightly salt tolerant, as is indicated by the presence of Central Asian Chenopodiaceae (*Bassia, Kochia, Suaeda*). The bunches of *Achnatherum* are nearly 1 m tall and have a diameter of 0.5 m. Their mean cover degree is 30% which reduces the carrying capacity substantially because the remaining forbs are also not preferably grazed. *Chenopodium album* and *Sibbaldianthe adpressa* display the highest cover degrees here, which

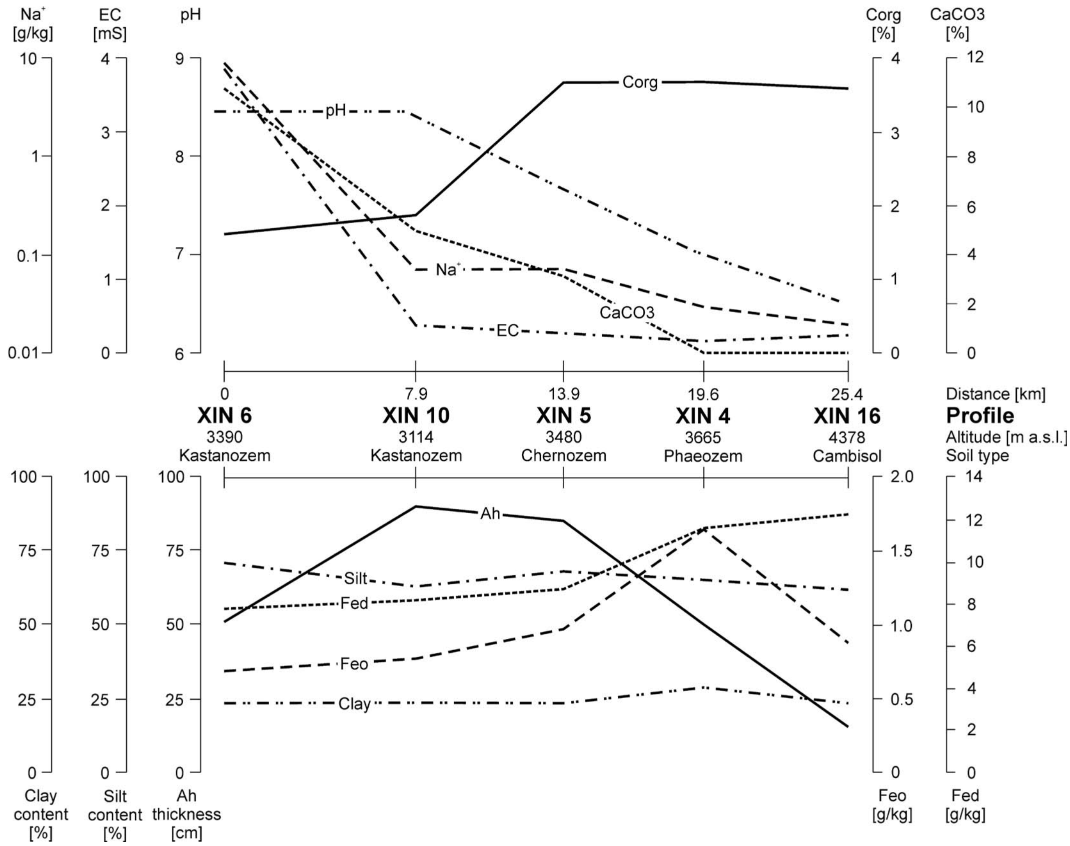

Fig. 4: Soil parameters of selected profiles along the Xinghai transect

clearly shows the trampling impact. After grazing exclosure, from 2002 to 2007, *Achnatherum* increased in cover from 13% to 30%, *Orinus* increased from 3% to 18%, yet grazing weeds like *Convolvulus arvensis* or *Sibbaldianthe adpressa* increased as well.

The *Kobresia-Stellera chamaejasme* community (Photo 6, 7) dominates the pastures of the western terrace and represents a pasture type which largely dominates montane altitudes of moist eastern Tibet (Kürschner et al. 2005). Rainfall is 1.2 fold higher (see Fig. 2) than on the eastern terrace (Xinghai climatological station). Degree of cover reaches 90% and is three times higher than the grassland types on the eastern terrace. Species numbers are three to four times higher. In contrast, stocking rates are two times higher than in the *Orinus* or *Achnatherum* grasslands (Koch 2003), although the plant cover is nearly closed. This can be attributed to the presence of *Kobresia humilis* and *K. pygmaea,* both of which have established a largely trampling-resistant felty turf cover. A high presence of species avoided by livestock even during winter (*Achnatherum inebrians, Ligularia tangutica, Stellera chamaejasme, Cryptothladia kokonorica, Thermopsis* spp., Tsanjo, pers. comm. 30. Aug. 2007) shows that this grassland type is ecologically stable and has clearly been under the influence of selective grazing habits of livestock for a considerable while. However, the best known grazing weed of moist pastures of Central Asia, *Stellera chamaejasme*, covers approx. 20% of the pasture. After only three years of grazing exclosure, *Stellera* became overgrown by graminoids and decreases in cover from 20% to 15% in the course of 5 years (Photo 7).

5 Considerations about forests

The grasslands of northeast Tibet are classified as natural "altifrigetic meadow" (Peng et al. 1997), or most recently as "*Leontopodio souliei-Kobresietum humilis* Associations" (Kürschner et al. 2005; based on 14 relevés), but are different from the pastures of the Tibetan Plateau further to the south (Chen et al. 1994). However, the "Atlas of Tibet Plateau" (1990) as well as the "Vegetation Map of Qinghai" (Zhou 1990) display a more complex feature of several "alpine" grassland types interspersed with forest islands of *Picea crassifolia* and *Juniperus przewalskii*. The forests

Photo 2 and 3: Sunny slopes with *Kobresia pygmaea* pastures and *Juniperus przewalskii* woodlands on open soil or rocks, surrounded by the felty turfs of *Kobresia*. The mosaic of golf course-like *Kobresia* pastures and fragmented juniper groves of *Juniperus przewalskii* is typical for northeastern Tibet. Yak chafing sites (black arrows) or marmot's burrows provide open sites where *Juniperus* can establish. Determined charcoal shows the probability that juniper forests had been burnt and replaced by pastures.
3,950 m; Photo: G. Miehe, August 2002.

Photo 4: North-exposed depleted and grazed *Picea crassifolia* forest. Clearings are widely occupied by *Bistorta vivipara* (white flowers). *Juniperus* woodlands of the sunny slope in the background.
3,600 m; Photo: G. Miehe, August 2002.

Photo 5: *Orinus kokonorica-Stipa krylovii* pastures of the eastern terrace. The highly degraded pastures have a plant cover only 30%. After two years of grazing exclosure the plant cover regenerates to 60%.
3,340 m; Photo: G. Miehe, July 2005.

Photo 6: *Kobresia-Stellera chamaejasme* pastures of the western terrace. The winter pastures have been changed to private land ownership and fenced since 1995. The houses have been built in the course of ongoing sedentarism programs.
3,600 m; Photo: G. Miehe, August 2002.

Photo 7: *Kobresia humilis-Stellera chamaejasme* pastures. The near-by rain gauge records 448 mm/a. The pastures represent the less degraded montane yak-winter pastures of northeast Tibet.
***Stellera chamaejasme* (white flowers), the widespread grazing weed of humid eastern Central Asia covers 20% and decreases after two years grazing exclosure due to unimpeded growth of the graminoids.**
3,420 m; Photo: G. Miehe, July 2004.

in figure 1 have, however, not been considered there. In the context of the discourse on the human impact on environments, which have so far been thought of as "natural", the vegetation patterns of the study area provide illustrative arguments against the point. The contradiction of "alpine grasslands" interspersed with forests has so far not been given much attention, which is astonishing enough because "alpine" is by definition treeless and above the upper limit of the montane forest belt (Körner 1999). If "alpine" vegetation and "montane" vegetation occupies the same altitudes at least one of the both should be attached to extrazonal habitat factors if the mosaic is natural. The two tree species found in zonal habitats of the study area (poplars, willows and buckthorn are restricted to water surplus gravel sites, mostly along rivers; see Fig. 1) are *Picea crassifolia* and *Juniperus przewalskii,* which are bound to the northern exposures and found on sunny slopes, respectively. The as yet known abiotic habitat factors (microclimate as a function of the meso-relief, water, soils) provide no evidence of any divergent habitat condition: two isolated *Picea crassifolia* trees marked in the map (Fig. 1) grow on an open north-facing slope without any particular habitat factor; exposure, slope inclination, substrate and soils and the surrounding shrubby pastures (indicating the moisture supply) are identical on the neighbouring slope where trees are absent. The same refers to the southern exposures: *Juniperus przewalskii* trees grow solitarily on limestone outcrops and on open soil surrounded by *Kobresia*-dominated pastures (Photo 2, 3). The juniper trees do not grow right in the felty *Kobresia*-covered soil, but are notably restricted to rocks, screes and open sandy soils. The most simple conclusion to explain why trees have a limited occurrence is that humans have cleared the slopes over the millennia. Fire is certainly the most effective "clearing" tool and charcoal remains provide evidence of its occurrence. Timber extraction played a role as did the collection of fire wood. At present, grazing of livestock has the most severe impact because trampling and browsing destroys seedlings and thus impedes regeneration. It is not a far-fetched conclusion to assume that the slopes around Drakar Tredzong would be forested if there had not been any human interference. The question, however, is whether forests could recover on the slope where only isolated trees are found today. This is easy to answer for the slopes nearest the current tree stands, because the age structure of the trees (by means of diameter and height, not checked through dendrochronological sampling!) shows all age classes, including seedlings and young trees. The nearest forest sites where dendroclimatological analyses were performed lie 170 km to the northwest near Dulan (Sheppard et al. 2004). If it can be ascertained that the climatic modelling is adjustable for the area under consideration it is as very well likely that the sites had been forested in the past and would be forested in future were the human impact to be reduced. The same reference site can be quoted for the pastures of the Huang He catchment on both sides of the Da Heba river: the mean annual precipitation of 353 mm nearly doubles the amount of rainfall of Dulan (179 mm/a, Miehe et al. 2001), and even the minimum annual rainfall between 1961 and 2001 (204 mm/a) is well above the amount of Dulan. As the hills of Dulan have the same tree species as found around Xinghai, it seems plausible to assume that the whole area below the upper treeline in Xinghai county was once forested. Temperatures are certainly appropriate for tree growth because the highest rocks support juniper trees at 4,100 m. However, the Huang He terrace of the area is treeless at present and charcoal has not yet been found. But, as temperatures are suitable for forests and the rainfall is twice as high as in Dulan, there remains little evidence that the present grasslands are natural. In general, early Neolithic sedentary settlements were found in the upper Yellow River catchment dating approx. 5,900-4,100 cal BP (Rhode et al. 2007). The archaeo-zoological record of the Zongri culture at the bank of the Huang He, ca 20 km further east, contains mainly forest animals (*Moschus moshiferus, Capreolus capreolus, Cervus elaphus*) yet grassland animals as well (*Marmota* sp., *Procapra gutturosa*, Flad et al. 2007). Thus it is probably that there was not a complete forest cover in the whole area. Our findings of charcoal provide evidence for the occurrence of forest fires in 8,155 ± 63 uncal BP, which affected the juniper forests of southern exposure, and forest fires 6,665 ± 59 uncal BP years ago affected the shady slopes with spruce above the sampling sites. There is, however, no clear evidence as to whether the forest fires were natural or ignited by humans. As it is a given that forest fires improve grazing conditions and humans were known to use this tool to gain pastures, they can be suspected to have changed the environment according to their needs.

6 Conclusions

Highland pastures of northeast Tibet are widely classified as "alpine" despite the presence of isolated trees or forests in normal habitats.

This pattern of isolated trees and forest islands far above the upper treeline amidst treeless grasslands is well known for all tropical mountains where humans have access. It had previously been described as natural (Troll 1948, 1959), but more in-depth ecological investigations (Ellenberg 1979; Laegaard 1992; Miehe a. Miehe 1994; Kessler 1995; Wesche 2002) revealed that high altitude grasslands replace forests after fire. Thus, the "Polylepis problem" of the tropical Andes and similarly fire-altered tropical mountains in Africa is an issue which largely resembles the situations found in the pastures of northeast Tibet. However, it is still a matter of debate as to whether humans changed forests into grassland, because forest fires verified by the presence of charcoal remains could be natural as well. It has to be admitted that next to nothing is known about the fire ecology of forests in Tibet (Winkler 2000). As the postglacial remigration of forests (Zhang et al. 2005; Herzschuh et al. 2006; Meng et al. 2007) took place under the presence of humans (Madsen et al. 2006; Rhode et al. 2007) it will be difficult to attribute charcoal to either naturally induced forest fire or to human activity. Questions of causes of environmental changes of the Holocene can certainly not be answered by "smoking gun" evidence but only by the probability of circumstantial evidence. Environmental investigations into the causes of fire-induced patterns clearly point to humans if we ask *"cui bono"*: at least livestock-rearing humans profit from forests being converted into pastures and even early hunters used fire (Blyakharchuk et al. 2004).

Thus it is concluded that the presently degraded pastures of northeast Tibet largely originate from forests having being converted into grasslands since at least 8000 years ago. The *Potentilla fruticosa-Salix* dwarf shrublands replace *Picea crassifolia*-forests with certainty. South-facing *Kobresia*-pastures replace *Juniperus przewalskii*-forests. The former forest species composition of the actual pastures of the level Huang He terrace is yet unknown. Vegetation records near Dulan suggest mixed juniper-spruce forests. Furthermore, the human dimension of environmental changes has been underestimated in Tibet.

Acknowledgements

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