

## Productivity of reed (*Phragmites australis* Trin. ex Steud.) in continental-arid NW China in relation to soil, groundwater, and land-use

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### Summary

Reed (*Phragmites australis* Trin. ex Steud.) is a cosmopolitan plant species which can build up large stands in wetlands, floodplains, and on sites where groundwater is available. *Phragmites australis* provides many ecosystem services, such as the production of raw material (e.g. house construction or organic fuel). In the desert regions of Central Asia, reed occurs along river, e.g. the Tarim, Syr Darya, Amu Darya, and serves as fodder plant and raw material for construction and paper production. In those arid regions, reed occurs on submerged sites as well as non-flooded sites in a wide variety of phenotypes, ranging from so-called „giant reed“ (2-4 m high) to dwarf-like thorny reed not exceeding 40 cm stem length. We investigated the net primary production of the different phenotypes and their distribution with regard to soil and groundwater salt content and regarding grazing. The phenotypes were characterized through stem length, stem diameter, number of leaves per stem length, leaf weight ratio, leaf length, and leaf width. The net primary production reached 6,004 kg/ha·a on a non-grazed site, which is submerged for one month in late summer. The depth of the closed capillary fringe before onset of the flood was 2.2 m. The electric conductivity at the closed capillary fringe (determined from a water saturated soil extract) was 2 mS/cm. Stem length and stem diameter did not decrease with increasing soil and groundwater salt content, as expected. Conversely, stem length and stem diameter decreased and leaf weight ratio increased with increasing grazing intensity. Thus, grazing turned reed into dwarf-like thorny phenotypes. Non-grazed reed stands are the most productive ecosystems of the riparian vegetation at the Tarim and have a high potential to be used as raw material plant. We conclude that biomass harvesting could be an alternative to grazing with regard to sustainable land use.

### Introduction

Reed (*Phragmites australis* Trin. ex Steud.) as a cosmopolitan plant species occurs all over the world and can build up large stands in wetlands, floodplains, and on sites where groundwater is available (BJÖRK, 1967; BJÖRNDAHL, 1983; HANGANU et al., 1999; OSTENDORP, 1993; RODEWALD-RUDESCU, 1974; SCHIEFERSTEIN, 1997). Natural reeds range from mono-specific stands to diverse vegetation types (DIERSCHKE, 1994; ELLENBERG, 1996). Additionally to its role in ecosystem functioning (e.g. self-purification of water, habitat for a broad range of animals; OSTENDORP, 1993), *Phragmites australis* provides many ecosystem services (COSTANZA et al., 1997), such as the production of raw material for different purposes (e.g. organic fuel).

Reed also is a key species in the floodplains of the streams in Central Asia, e.g. the Tarim River (THEVS, 2005; 2006a; 2006b), Syr Darya, and Amu Darya (OGAR, 2003). In these continental-arid regions, where large deserts with sparse or without any vegetation occur, it serves, for example, as fodder plant and is intensively grazed by sheep and goat (THEVS, 2006b), as shown in Fig. 1. Additionally, it is used as

raw material for paper production and mats (MIJIT and THEVS, pers. observation). In the Tarim River floodplain, reed stands naturally occur in a mosaic together with forests mainly built-up by the tree species *Populus euphratica*.



Fig. 1: Reed (*Phragmites australis*) grazed by sheep and goat, site 1. The trees are *Populus euphratica*.

Reed has a phenotypic plasticity, as reported by VRETARE et al. (2001) with pot experiments with submerged reed. It is well adapted to highly fluctuating water levels (PAGTER et al., 2005). In continental-arid regions, reed occurs on submerged sites as well as non-flooded sites in a wide variety of phenotypes, ranging from so-called „giant reed“ over „medium-sized reed“ to „small reed“ or „claw reed“, respectively (GAO and XU, 1995; LIU et al., 2005; XU et al., 1995). Giant reed has stem heights of 200-400 cm and 15-30 nodes and is found on submerged or periodically flooded sites. These stands are partly used to harvest reed as raw material as mentioned above. Medium-sized reed has stems 40-200 cm high with 10-20 nodes. It is found on non-flooded sites. Small reed has stems with an average growth height of 10-20 cm, not exceeding 40 cm, and 8-12 nodes and occurs on sites with salt accumulation, i.e. with a salt content of 37.1 g/kg in the upper 30 cm of the soil (GAO and XU, 1995). The latter reed appears sturdy with contracted internodes. Leaves are hard and thorny and thus resemble claws. Consequently, the phenotypes of *Phragmites* reeds seem to correspond with the flood regime and topsoil salinization (GAO and XU, 1995; XU et al., 1995). According to HASLAM (1969; 1970), contracted internodes are due to nutrient deficiency and salt. HELTINGS and GALLAGHER (1992) showed in a pot experiment that reed growth decreases with increasing salt content. Reed has to take up water from the groundwater and the saturated soil horizon above the groundwater, when not flooded. KARUNARATNE et al. (2004) showed that harvest of reed in spring and particularly in summer removes nutrients from the plant and consequently the nutrient content of the rhizomes decreases. However after harvesting reed, leaf production increases while stem height and diameter decrease.

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In our study, we hypothesize that under the continental-arid climate in Southern Xinjiang (1) productivity of *Phragmites australis* is reflected by different phenotypes and corresponds to the salt content in the saturated soil horizon above the groundwater. Therefore, we investigate the variety of different phenotypes in the Tarim River floodplain in relation to the salt content of the saturated soil horizon above the groundwater and the groundwater depth. (2) We consider a relationship between stand biomass and net primary production, respectively, and different phenotypes. The aspect of productivity has to be seen against the background that reed could be used as raw material and thus is a major source of income for the local people. It serves also as building material for house construction, e.g. roof thatching and insulation, and as energy source (WICHTMANN, 1999; WICHTMANN et al., 2000). Low quality reed can be used as packing material (WICHTMANN, 1999). (3) We also hypothesize that grazing affects the phenotype of reed.

## Material and methods

### Study area and investigation sites

Our investigation area is the Tarim Huyanglin Nature Reserve at the middle reaches of the Tarim River in Xinjiang, NW China (Fig. 2). The Tarim River is 1,321 km long and flows along the northern edge of the Tarim Basin. The Tarim Basin is bordered by the mountain ranges of the Tian Shan in the north and northeast, the Pamir in the West, and the Kunlun Mountains and Tibetan Plateau, respectively, in the south and southeast. The surrounding mountain ranges exceed up to more than 7,000 m above sea level and cut off all humid air currents. Consequently, the climate of the study area is extremely continental-arid with a mean annual precipitation of less than 50 mm and a mean annual potential evapotranspiration of more than 2,500 mm. The mean annual air temperature is 10.6 °C. The average air temperature in January is -9 °C and in July 25 °C, thus reflecting the strong continental character of the climate (WEILI XIAN DIFANGZHE BIANZUAN WEIYUANHUI, 1993; XINJIANG WEIWUER ZIZHIQU SHUILI TING and XINJIANG SHUILI XUEHUI, 1999; YUAN and LI, 1998).

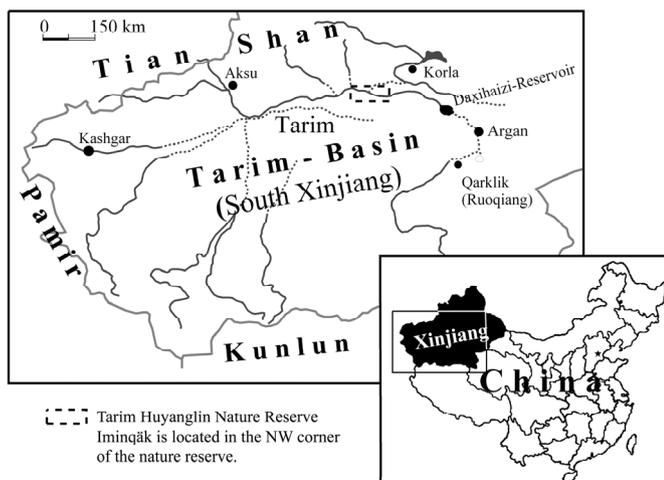


Fig. 2: Location of the study area, the Tarim Huyanglin Nature Reserve.

The Tarim River is fed by melting water and precipitation in the surrounding mountain ranges. About 75 % of the annual run-off of the Tarim River is concentrated in the months July, August, and September (Fig. 3) resulting in annual summer flood periods (SONG et al., 2000; GIESE et al., 2005). During the annual floods, the water level rises 3-4 m above base flow.

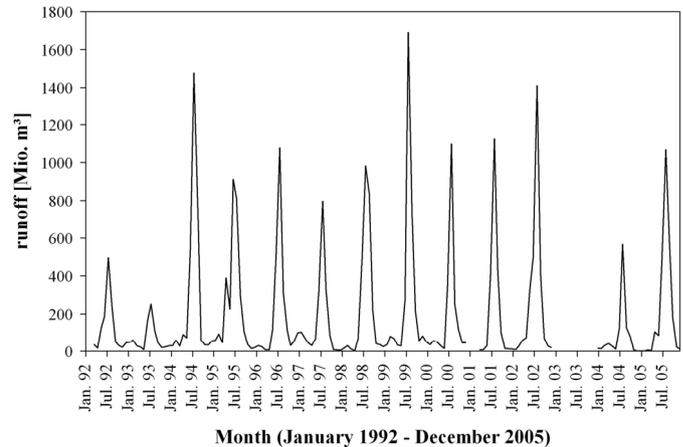


Fig. 3: Monthly runoff of the Tarim River at Yengi Bazar, western boundary of the Tarim Huyanglin Nature Reserve.

In contrast to the lower reaches of the Tarim river which has been strongly degraded due to excessive use of the water resources in the past decades, the Tarim Huyanglin Nature Reserve still has a natural to near-natural floodplain character (HAI et al, 2006; Hou et al., 2007; 2007a; SONG et al., 2000). However, most of the reed stands are more or less heavily grazed by goat and sheep. The grazing system is transhumant. The herds are kept at the families' homes during the winter. In spring, they are brought to pastures close to the river and graze there until the summer. In summer, just before the onset of the summer flood, the herds are moved to pastures at the edge of the floodplain out of the reach of the flood. In autumn, the herds are brought back to the herders' homes (THEVS, 2006b).

In the Tarim Huyanglin Nature Reserve, four investigation sites were established near the settlement of Iminqäk (Fig. 2) where different phenotypes from so-called „small reed“ to „giant reed“ were observed. Site 1 is grazed for 3-4 months per year with 32 sheep and 128 goat in 2002 and 37 sheep and 300 goats in 2003 on an area of 93 ha (data gathered by THEVS and MIJIT, 2003). The herd was brought to site 1 every day during the grazing period. Site 2 is only occasionally grazed, because it does not belong to any of the herders in the vicinity of Iminqäk. Site 3 and 4 is not grazed.

### Determination of groundwater depth and soil sampling

On the four investigation sites, soil profiles were drilled with a machine driven soil borer into the closed capillary fringe above the groundwater layer. The depth of the closed capillary fringe served as proxy for groundwater depth. The profiles were drilled in July 2004, i.e. during base flow and before onset of the flood season, in order to record the deepest water level that the plants have to endure.

In the field, the depth of the closed capillary fringe was recorded according to AG BODEN (1994) as proxy for the groundwater level. The depth of the closed capillary fringe is determined by knocking onto the soil borer. If water comes out of the soil sample, the closed capillary fringe is hit. Furthermore, the depth of oxidized (iron mottles) and reduced horizons was recorded. From each investigated plot, soil samples were taken from the closed capillary fringe and from the top 100 cm of the soil profile in order to determine salinization. The electric conductivity of the saturation extract was measured after SCHLICHTING et al. (1995) and served as a proxy for salt content of the groundwater.

## Reed sampling

The net primary production (NPP) was determined on the basis of the stand biomass at the end of the vegetation season (Sept. 2004 and Oct. 2006, respectively) using a correction of 10 % added to the stand biomass. This correction applies for non-grazed reed and takes losses due to herbivores and dead plant parts into account (KVĚT, 1971; WESTLAKE, 1965). As the summer flood was very low in 2004 and site 1 therefore was grazed till autumn, we there analysed the stand biomass in 2006, when grazing was stopped due to the summer flood.

In order to determine the biomass, 8 sub-plots were randomly placed on each site in July 2004, September 2004, and October 2006, respectively. Each sub-plot had an area of 1 m x 0.5 m. All living and dead stems were counted. On the basis of the living stems, the stem density was calculated. In each sub-plot, the 10 stems closest to the centre line were cut and leaves were separated from the stem. Leaves and stems were oven-dried (24 h at 105 °C) and weighted to determine the total plant and leaf weight (BJÖRNDAL, 1983). Derived from the average total plant weight of the 10 sampled plants and the stem density, the above ground stand biomass was calculated and values given for the area of one hectare.

Furthermore from each harvested plant, the stem length and basal stem diameter were measured and number of leaves was counted as morphological data (BJÖRK, 1967; BJÖRNDAL, 1983; DYKYJOVA et al., 1973). These data were also retrieved from 30 plants of site 1 in July 2004. From randomly chosen plants from each site, the length and width of leaves were measured.

## Data analysis

From the data obtained by the above described procedure, the following indices were calculated: leaf weight ratio, leaves per stem length, and leaf area quotient (BJÖRNDAL, 1983).

Leaf weight ratio = leaf weight [g] / total plant weight [g]  
 Leaves per stem length [m<sup>-1</sup>] = Number of leaves / stem length [m]  
 Leaf area quotient = leaf length [cm] / leaf width [cm]

The data of each of the four sites were compared with each other regarding significant differences with a one-way analysis of variance (ANOVA) with the Duncan post-hoc test. The data of the two sampling dates of each site were tested for significant differences using the t-test. The statistical analysis was done with the SPSS program.

## Results

### Groundwater depth and salinization

The characterization of sites and soils are given in Tab. 1. Site 1 on average is flooded for two months per year, which is the longest flood period of all sites. This site also shows the highest capillary fringe (1.3 m) and the lowest electric conductivity at the closed capillary fringe (1.8 mS/cm) as well as in the top 100 cm of the soil profile (2.0 mS/cm). In contrast, site 2, which is not flooded at all, shows by far the highest electric conductivity in the top 100 cm (52.6 mS/cm) compared to all other sites. However, the electric conductivity at the closed capillary fringe of site 2 (2.9 mS/cm) does not exceed that of site 3 (3.3 mS/cm). While the electric conductivity in the top 100 cm differs between the sites, the electric conductivity at the closed capillary fringes of the four sites does not differ very much. The soil profiles of sites 1, 2, and 4 have a greyish, reduced horizon within 3 m below surface, indicating that the closed capillary fringe does not sink below 3 m for longer time periods.

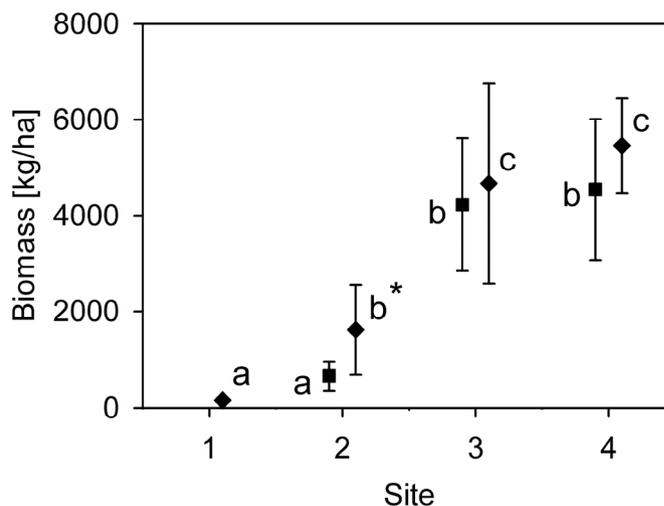
**Tab. 1:** Flood duration, soil characterization, and grazing intensity of the four reed stands investigated in Iminqäk at the Tarim River.

Site parameter	Site			
	1	2	3	4
Flood duration per year [month]	2	0	1	1
Depth of closed capillary fringe [m]	1.3	2.5	2.9	2.2
Depth of iron mottles [m]	0	1.0	.	0
Depth of greyish reduced soil horizon [m]	.	2.7	2.9	2.2
Electric conductivity at closed capillary fringe [mS/cm]	1.8	2.9	3.3	2.0
Electric conductivity in the top 1 m of the soil profile [mS/cm]	2.0	52.6	8.5	2.7
Grazing intensity*	2	1	0	0

\* Grazing intensities: 2 - intensively grazed, 1 - occasionally grazed, and 0 - not grazed.

### Reed biomass, production, and morphology

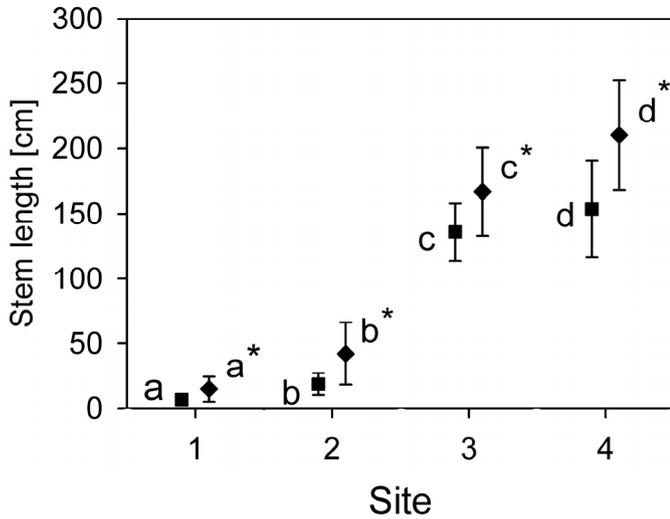
Sites 3 and 4 both harbour the reed stands with the highest biomass (Fig. 4) as well as the tallest reed plants (Fig. 5) with the highest diameter (Fig. 6). The reed stands sampled in summer on site 1 and 2 are more or less sturdy with contracted internodes, i.e. the number of leaves per stem length is relatively high (Fig. 7). As indicated by the comparatively high leaf weight ratio of the reed of the sites 1 and 2 (Fig. 8), in those two reed stands more biomass of the plants is concentrated in the leaf than in the reed stands of sites 3 and 4.



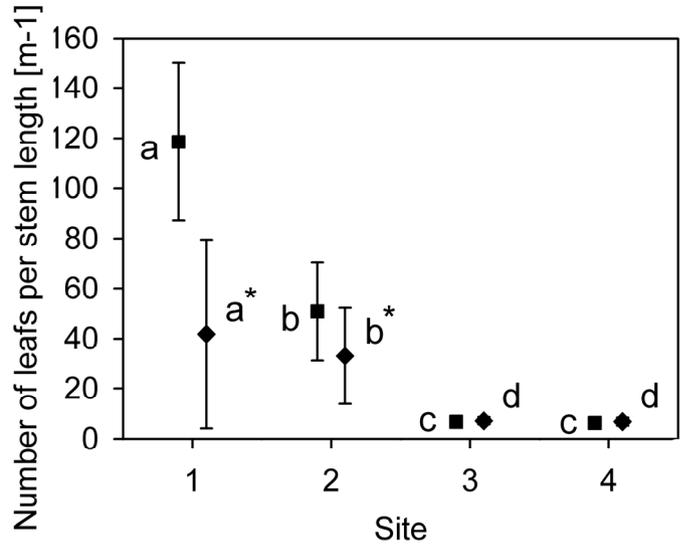
**Fig. 4:** Biomass in summer (left square shaped dots and bars of each pair) and autumn (right diamond shaped dots and bars of each pair). Dots represent means, bars represent standard deviation. \* indicates significant differences at  $\alpha < 0.05$  between summer and autumn for one site. Letters indicate significant differences at  $\alpha < 0.05$  after the Duncan post-hoc test between sites.

The NPP of sites 3 and 4, both not grazed, is 5,129 kg/ha·a and 6,004 kg/ha·a, respectively. The biomass at the end of the vegetation season on sites 3 and 4 is 4,663 kg/ha and 5,458 kg/ha, respectively. In contrast, on site 1, which is the most intensively grazed site, a biomass at the end of the vegetation season of only 159 kg/ha was recorded (Fig. 4).

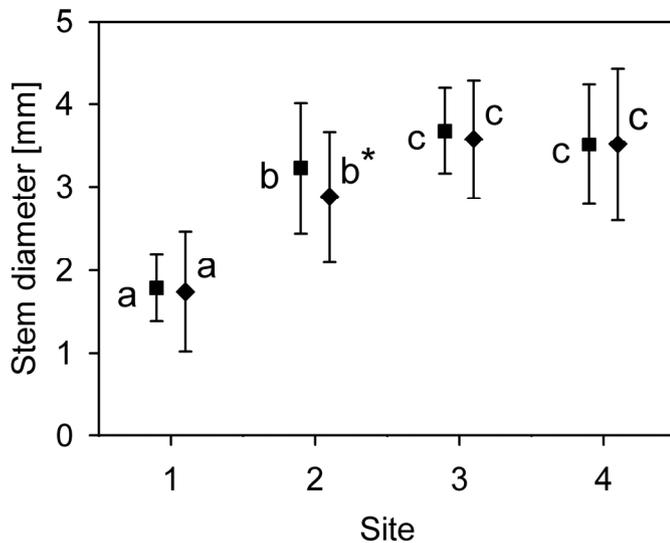
The number of leaves per stem length and the leaf weight ratio of the reed of site 1 drops from 119 leaves per meter and 0.59, respectively, in summer to 42 leaves per meter and 0.24, respectively, in autumn (Fig. 7



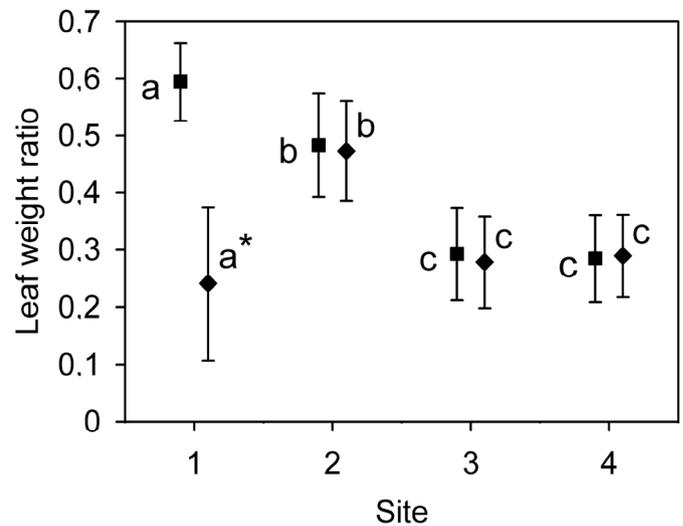
**Fig. 5:** Stem length in summer (left square shaped dots and bars of each pair) and autumn (right diamond shaped dots and bars of each pair). Dots represent means, bars represent standard deviation. \* indicates significant differences at  $\alpha < 0.05$  between summer and autumn for one site. Letters indicate significant differences at  $\alpha < 0.05$  after the Duncan post-hoc test between sites.



**Fig. 7:** Number of leaves per stem length in summer (left square shaped dots and bars of each pair) and autumn (right diamond shaped dots and bars of each pair). Dots represent means, bars represent standard deviation. \* indicates significant differences at  $\alpha < 0.05$  between summer and autumn for one site. Letters indicate significant differences at  $\alpha < 0.05$  after the Duncan post-hoc test between sites.



**Fig. 6:** Diameter in summer (left square shaped dots and bars of each pair) and autumn (right diamond shaped dots and bars of each pair). Dots represent means, bars represent standard deviation. \* indicates significant differences at  $\alpha < 0.05$  between summer and autumn for one site. Letters indicate significant differences at  $\alpha < 0.05$  after the Duncan post-hoc test between sites.



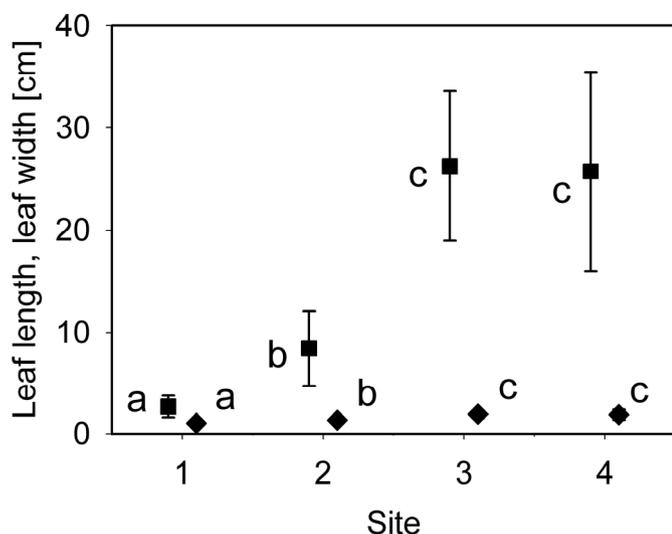
**Fig. 8:** Leaf weight ratio in summer (left square shaped dots and bars of each pair) and autumn (right diamond shaped dots and bars of each pair). Dots represent means, bars represent standard deviation. \* indicates significant differences at  $\alpha < 0.05$  between summer and autumn for one site. Letters indicate significant differences at  $\alpha < 0.05$  after the Duncan post-hoc test between sites.

and 8). The reed of site 1, sampled in summer, has the highest leaf weight ratio, while sampled in autumn, it has the lowest leaf weight ratio of all reed stands investigated (Fig. 8).

The leaf width ranges from 1.0 cm (site 1) to 1.9 cm (site 3), as shown in Fig. 9. The means of the leaf area quotients on sites 1, 2, 3, and 4 are 2.6, 6.2, 13.7, and 13.6, respectively, with sites 1, 2, and 3 and 4 being significantly different from each other (Duncan post-hoc test,  $\alpha < 0.05$ ).

## Discussion

The reed plants sampled in this investigation are similar to those reed plants sampled by GAO and XU (1995) and XU et al. (1995) in Northern Xinjiang with regard to stem length, number of leaves per stem length, leaf length, and leaf width. The reed of sites 3 and 4 correspond to the so-called „giant reed“, of site 2 to „middle reed“, and the reed of site 1 is equivalent to „small reed“ (GAO and XU, 1995; LIU et al., 2005; XU et al., 1995). The reed plants of site 3 and 4 appear in the same phenotype as it is prevalent on sites in Scandinavia (BJÖRK, 1967).



**Fig. 9:** Leaf length (left square shaped dots and bars of each pair) and leaf width (right diamond shaped dots and bars of each pair), both in cm. Dots represent means, bars represent standard deviation. Letters indicate significant differences at  $\alpha < 0.05$  after the Duncan post-hoc test between sites.

We attribute the differences in the phenotypes of reed plants and reed stands, respectively, mostly to grazing. Consequently, this is in accordance with findings of HASLAM (1969). The four sites all have a closed capillary fringe not deeper than 3 m. The presence of a greyish reduced horizon not deeper than 3 m in the soil profiles of sites 1, 2, and 4 indicates that the closed capillary fringe does not fall below 3 m for prolonged time periods. Thus, groundwater supply for reed within 3 m soil depth is ensured on all four sites.

Considering the results with regard to electric conductivity at the closed capillary fringe, the four sites are rather similar with respect to water supply and salt concentration of the groundwater. Furthermore, electric conductivity is well below the limiting value for reed of 12 mS/cm, stated by SERAG (1996). The salt contents in soils under different reed phenotypes shown by GAO and XU (1995) differ widely in the topsoil (0-30 cm), but become more and more similar towards the sub-soil. This corresponds to our results. The salt contents in the topsoil differ between sites, while the salt contents in the closed capillary fringe hardly differ between sites.

Furthermore, we found reed stems in summer sheltered from grazing within groups of trees and shrubs on site 1 (Fig. 1, left side), which were as high as the reed stems on sites 3 and 4. Therefore we conclude that the soil and water conditions on site 1 would fit tall non-sturdy reed stands, but grazing turned the reed into the short and sturdy reed which we sampled for our analysis.

**Tab. 2:** Net primary production (NPP, dry matter) of reed stands in different regions of the world, sorted from highest to lowest production.

Site	NPP [kg/ha*a]	Reference
Lake Manzala, Nile Delta, Egypt (submerged reed)	46,800	KHEDR (1989), quoted from SERAG (1996)
Hutubi, Zhonggar Basin, Xinjiang, China (submerged reed)	46,200	GAO and XU (1995)
Nile Delta, Egypt (submerged reed)	44,000	SERAG (1996)
Tingitan Peninsula, NW-Marokko	22,960	ENNABILI et al. (1998)
Krankesjön, Sweden (submerged reed)	23,810	BJÖRK (1967)
Ringsjön, Sweden (groundwater level 0-30 cm)	22,100	BJÖRK (1967)
Akigase Park in Saitama Prefecture, Japan	19,800	KARUNARATNE et al. (2003)
Nile Delta, Egypt (saltmarsh)	17,000	SERAG (1991), quoted from SERAG (1996)
Danube Delta, Rumania (fresh water)	9,810-16,320	HANGANU et al. (1999)
Danube Delta, Rumania (salt water)	6,190-10,740	HANGANU et al. (1999)
Sweden	9,900	GRANELI (1984)
Japan, Arakawa flood plain	6,900	ASAEDA et al. (2006)
Tarim, Xinjiang, China (non-grazed reed, 1-2 month flooded per year)	5,129-6,004	THEVS et al. (this study)
Seddinsee (near Berlin), Germany	1,520-4,200	ROLLETSCHEK et al. (1999)
Tarim, Xinjiang, China (occasionally grazed reed, salinized topsoil)	1,773	THEVS et al. (this study)
Hutubi, Zhonggar Basin, Xinjiang, China (non-salinized topsoil, not flooded)	1,372 <sup>1</sup>	GAO and XU (1995)
Tarim, Xinjiang, China (groundwater level 1.6-2 m)	930-1,590	ZHANG et al. (2002)
Tarim, Xinjiang, China (groundwater level 2.3 m)	510	ZHANG et al. (2002)
Hutubi, Zhonggar Basin, Xinjiang, China (salinized topsoil)	277 <sup>1</sup>	GAO and XU (1995)
Fiolen, Sweden (submerged reed)	230	BJÖRK (1967)
Tarim, Xinjiang, China (grazed reed)	159 <sup>1</sup>	THEVS et al. (this study)

<sup>1</sup> stand biomass was determined

Grazing, particularly in spring, poses stress to the reed plants. The young shoots are browsed by the animals and nutrients are removed from the reed (AUSDEN et al., 2005; ESSELINK et al., 2000). According to KARUNARATNE et al. (2004), the nutrient resources of the rhizome are reduced by harvest in spring and summer compared to non-harvested reed. Reed plants harvested, increase leaf growth and decrease stem growth, as found on site 1. Consequently, through grazing the nutrient balance is strongly negatively affected. On site 1, after the herd was removed before autumn 2006, the reed increased in growth height again and became less sturdy, as it was not grazed.

As shown in Tab. 2, the reed stands investigated at the Tarim River have a lower productivity compared to submerged reed. Compared to other non-submerged sites in Xinjiang, the sites 3 and 4 have a high productivity. The lower productivity of the other sites from Xinjiang, shown in Tab. 2, might be due to grazing.

The annual increment of wood of *Populus euphratica*, the main forest building tree and natural wood source at the Tarim River, ranges from 1,795 to 3,459 kg/ha·a (XINJIANG LINKEYUAN ZAOLIN ZHISHA YANJIUSUO, 1989) and 736 to 1,472 kg/ha·a (WANG et al., 1996) on sites in the Tarim Huyanglin Nature Reserve. Thus, with regard to the dominating vegetation and land-use types, non-grazed reed stands are the most productive ecosystems of the riparian vegetation at the Tarim and have a high potential to be used as raw material plant. Stands with sturdy reed yielding low year-end biomass can be turned into reed which yields much higher biomass. We conclude that biomass harvesting could be an alternative to grazing with regard to sustainable land use.

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