The colonization of active sand dunes by rhizomatous plants through vegetative propagation and its role in vegetation restoration

Bo Liu [1], Zhimin Liu [1*], Lixin Wang[2,3]

[1]*State Key Laboratory of Forest and Soil Ecology, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang, 110164, China*

[2]*Water Research Centre, School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW, 2052, Australia*

[3]Department of Earth Sciences, Indiana University-Purdue University, Indianapolis (IUPUI), Indianapolis, Indiana 46202, USA

* *Corresponding author*

Zhimin Liu
Institute of Applied Ecology, Chinese Academy of Sciences
72 Wenhua Road
Shenyang 110016

TEL: 86-24-83970431
E-mail: liuzhimin6555@yahoo.com.cn

This is the author's manuscript of the article published in final edited form as:

Liu, B., Liu, Z., & Wang, L. (2012). The colonization of active sand dunes by rhizomatous plants through vegetative propagation and its role in vegetation restoration. Ecological Engineering, 44, 344-347. http://dx.doi.org/10.1016/j.ecoleng.2012.04.021

ABSTRACT This study aims to elucidate vegetative propagation in *Phragmites communis*, and its role in colonizing active sand dunes. The experiment was conducted in the Horqin Sand Land in Inner Mongolia, northeastern China. Quadrats were established along twenty transects from the dune slack to the windward slope through the ecotone (a transitional zone between the dune slack and the windward slope of active sand dune). Biomass, biomass allocation and relative growth rate (RGR) of *P. communis* were quantified monthly from May to August in 2007. Our results showed that rhizomes extended towards the active sand dune at a rate of 523.5 ± 20.8 cm per year. The RGR of ramets and rhizomes increased along the gradient from the dune slack to the windward slope. The percentage of rhizome biomass in total biomass increased significantly along the same gradient. The results indicate that *P. communis* is able to adjust growth strategy according to the environmental conditions. The results also demonstrate that vegetative propagation of rhizomatous grasses significantly contributes to plant encroachment to active sand dunes and plays an important role in the vegetation restoration of dune fields.

Keywords: Biomass allocation, *Phragmites communis*, ramet development, restoration, rhizome extension, rhizomatous, sand dune, vegetative propagation

1. Introduction

There are 6,000,000 km^2 of sand dunes in the world, of which 85% are located in dry inlands, and 15% are along coasts or river banks in humid regions (Zhu et al., 1998). During the last decades, attentions have been focused on vegetation restoration of active sand dunes (e.g., Jiang et al., 2006; Su et al., 2007; Cao et al., 2011). Vegetation development at different parts of sand dunes (i.e., ecotone and dune slack) is closely associated with the success of vegetation restoration of active sand dunes (Yan et al., 2007).

Vegetation in the dune slacks can expand their population towards the sand dunes through both sexual and vegetative propagation. Vegetative propagation is believed to be advantageous because it enables plant to survive heavy erosion and burial by means of rhizomes (Yu et al., 2008). Population expansion from the dune slacks to the ecotones through sexual propagation has been reported (Yan et al., 2007). However, how plants expand their population from the dune slacks to the ecotones through vegetative propagation, and the ecological significance of such vegetative propagation in sand dune ecosystems are not clear.

The rate of rhizome extension is particularly important for colonizing bare patches, and the rate varies among species. Some species are able to elongate several meters each year but others only a few centimeters (Marbà and Duarte, 1998). Rhizome extension rate reflects the ability of rhizomatous grasses to colonize active sand dunes and hence determines the progress of vegetation restoration of the active sand dunes. However, there were few studies quantifying the rhizome extension rate of rhizomatous grasses in colonizing active sand dunes.

Both rhizome extension and ramet development are important in colonizing bare patches and expanding the population for rhizomatous grasses. Rhizome extension is a means of species invasion, and new population cannot develop without ramet development. On the other hand, ramet development is a means of population maintenance, and the population size will not expand without rhizomes extension. Thus it is of great importance to invest the limited resources efficiently between rhizomes and ramets to guarantee the maintenance and expansion of a population. Biomass allocations between rhizome extension and ramet development, and the allocation variations among seasons therefore reflect plant species' ability to effectively invest resources between invading a bare patch and maintaining the population size in the occupied patch. In the active sand dunes, environmental conditions change dramatically from the dune slacks to the windward slopes. Along this gradient, aeolian activities (e.g., aeolian erosion and sand burial) become stronger, vegetation becomes sparser, and there is less soil compaction (Yan et al., 2007). These environmental condition changes may affect the relationship between rhizome extension and ramet development. Plants could adapt to these changes and maximize the resource allocation between new habitat colonization and maintenance of the current population. The field evidence of such adaptation, however, is lacking.

Phragmites communis is a widespread rhizomatous species (Chen and Jia, 2002). It can propagate sexually and vegetatively. There are numerous studies involving sexual reproduction of *P. communis* (e.g., Mckee and Richards, 1996; Saltonstall and Stevenson, 2007). However, vegetative propagation of *P. communis* and its role in the vegetation restoration of the active sand dunes are not reported.

The Horqin Sand Land, a typical degraded temperate grassland in the agro-pastoral zone of

Inner Mongolia, northern China (118°35′-123°30′E, 42°41′-45°15′N), has suffered from severe desertification (Liu et al., 1996). In recent years, measures such as tree and shrub plantings have been applied to control shifting sand (Zhao et al., 2007). The role of sexual and vegetative propagation is equally important in natural restoration. The function of sexual reproduction in vegetation restoration at the active dune fields has been extensively studied in the Horqin Sand Land (Yan et al., 2007). However, there is little information on the function of rhizomatous grasses in stabilizing the active sand dunes. Since *P*. *communis* can expand its population from the dune slack to the windward slope through the ecotone by means of vegetative propagation, it could be a promising sand binder and has a potential to be used as nurse plant in vegetation restoration of the active dunes.

The objectives of this study are to 1) investigate how fast *P. communis* colonizes the active sand dunes, 2) examine how *P. communis* adjusts the biomass allocation between ramets and rhizomes at various locations (i.e., dune slack, ecotone and windward slope), 3) evaluate the application potential of vegetative propagations of *P. communis* in vegetation restoration of the active sand dunes.

2. Materials and methods

2.1. Study site

The study area was located at Wulanaodu Village (119°39’E, 43°00’N, 480 m a.s.l.) in the western part of the Horqin Sand Land, Inner Mongolia, China. Mean annual temperature is 6.3°C, with maximum temperature of 23.0°C in July and minimum temperature of -14.0°C in January. Mean annual precipitation is 340 mm, with 70-80% of the precipitation occurring between May and September. Soil of the active sand dunes and the dune slacks were aeolian sandy soil and meadow soil, respectively (Cao et al., 2000).

2.2. Measuring rhizome extension

Ten horizontal rhizomes of *P. communis* near the ecotone were randomly selected, and the position of the growing apex was labeled on April 1, 2007. The length of the rhizome extension was measured at a 10-day interval from April 1 to August 21, 2007. The labeled rhizomes were excavated on August 21, 2007 for biomass estimation. The aboveground (ramet) and belowground (rhizome) biomass were measured by drying the corresponding plant tissues at 80°C for 48 h and weighing them using an electronic balance.

2.3. Monitoring the biomass allocation

The measurements were conducted on the transitional zone between the dune slack and the windward slope of an active sand dune. On April 16, 2007, twenty transects were set up from the dune slack to the windward slope through the ecotone on an active sand dune. Six 1 m × 1 m quadrats were established at an interval of 4 m along each transect. Quadrats 1 and 2 were located at the dune slack; quadrats 3 and 4 were at the ecotone; and quadrats 5 and 6, were at the lower windward slope (Fig. 1). Quadrats 1 through 4 were occupied by *P. communis*, and quadrats 5 and 6 were bare. Five transects were randomly selected and harvested on May 18, June 16, July 16 and August 18, 2007, respectively. The aboveground ramets were cut off before harvesting rhizomes in each quadrat. The belowground rhizomes were then carefully excavated to a depth of 100 cm and completely collected within quadrats. Dry weights of aboveground and belowground tissues were measured as described above.

2.4. Calculation and Statistical analyses

The relative growth rate (RGR) of aboveground ramet and belowground rhizome was calculated using the following equation (Hoffmann and Poorter 2002):

$$\mathrm{RGR} = \frac{\overline{\ln(W_2)} - \overline{\ln(W_1)}}{t_2 - t_1},$$

where W_1 and W_2 are the dry weight of ramet or rhizome at time t_1 and t_2. $\overline{\ln(W_t)}$ is the mean of natural log-transformed plant weight at time *t*.

Two-way ANOVA with location (e.g., the dune slack, the ecotone) and sampling time as two main factors were used to test differences in biomass, biomass allocation and RGR (SPSS software, 14^{th} edition). Mean separations were achieved by LSD *post hoc* test at $\alpha = 0.05$.

3. Results

Rhizomes extended towards the active sand dune at a rate of 523.5 ± 20.8 cm $year^{-1}$. The rhizome extension rate increased from April to June and then decreased. The maximal extension rate was 7.6 cm d^{-1} (Fig. 2).

The RGR of ramet and rhizome decreased from May to August at all three locations (e.g., dune slack, ecotone and windward slope, Table 1). The RGR of ramet and rhizome increased along the gradient from the dune slack to the windward slope (Table 1). The percentage of rhizome biomass in total biomass (rhizome + ramet) increased significantly along the same gradient (Fig. 3).

4. Discussion

Since rhizomes of *P. communis* were able to extend more than 5 m towards the active sand dune each year (Fig. 1), and the active sand dune migrated at a rate ranging from 1.8 m to 3.8 m per year in the study site (unpublished data). Vegetative propagation of *P. communis* therefore could play an important role in the natural vegetation restoration of the dune fields.

Increases in the RGR of both ramets and rhizomes at the windward slope indicate that population of *P. communis* was spreading rapidly from the dune slack to the windward slope. Adjusting the biomass allocation between ramets and rhizomes of *P. communis* during the colonization process may be an effective strategy to maintain and expand the population. At the dune slack with dense vegetation, *P. communis* tends to produce more ramets, but at the windward slope of the active sand dune with sparse vegetation it tends to produce more rhizomes. The results indicate that *P. communis* strengthens its dominance in the dune slack and expands its population at the windward slope.

The vegetative propagation of *P. communis* may significantly contribute to the restoration of active sand dunes. Multilayered underground rhizome network of *P. communis* stabilizes sand. Ramets connected by rhizomes reduce wind power and erosion. In addition, *P. communis* population developed on active dunes can trap seeds of other species and facilitate their seedling emergence and establishment. Therefore, *P. communis* can function as a pioneering plant species near the ecotone area between the dune slack and the dune body. The multiple sand-stabilizing functions provided by *P. communis*, however, have not been realized by most of the people who are working on the sand-fixing practice. Therefore, we suggest that 1) protection measures be taken to prohibit grazing in order to protect *P. communis* in the dune slack to accelerate vegetation restoration, 2) rhizomatous plants can be used as nurse plants to facilitate the encroachments of non-psammophyte species on active dunes, and 3) planting rhizomatous grasses with fast rhizome extension rate near the ecotone and interdune lowland may be an effective way to control the movement of the active sand dunes.

5. Conclusions

Based on field observations from a typical degraded temperate grassland in northern China, we found that population of *P. communis* expanded from the dune slack to the windward slope at a rate of 523.5 ± 20.8 cm per year during the colonizing process. *P. communis* adjusted the biomass allocation between ramets and rhizomes during the colonizing process, which was an effective strategy for population expansion. The results suggest that vegetative propagation of rhizomatous grasses significantly contributes to plant encroachment in the active sand dunes and hence plays an important role in the vegetation restoration of dune fields.

Acknowledgements

We thank Zhengning Wang, Xiumei Wang, Hongmei Wang, Yongming Luo, Ming Li and Le Zhang for field and laboratory assistance. The study was financially supported by National Natural Science Foundation of China (30870468) and National Key Technologies Research and Development Program (2006BAC01A12). We thank two anonymous reviewers for the constructive comments.

References

Cao, C.Y., Kou, Z.W., Jiang, D.M., Luo, Y.M., Ding, X.P., 2000. Interdune succession in the Kerqin Sandy region. Acta Phytoecologica Sinica. 24, 262–267 (in Chinese with English abstract).

Cao, C, Y., Jiang, S. Y., Zhang, Y., Zhang, F.X., Han, X. S., 2011. Spatial variability of soil nutrients and microbiological properties after the establishment of leguminous shrub *Caragana micophylla* Lam, plantation on sand dune in the Horqin Sand Land of Northeast China. Ecol. Eng. 37: 1467-1475.

Chen, M.J., Jia, S.X., 2002. Forage Floras of China. Agriculture press, Beijing (in Chinese).

Hoffmann, W.A., Pooter, H., 2002. Avoiding bias calculations of relative growth rate. Ann. Bot. 80, 37–42.

Jiang, G.M., Han, X.G., Wu, J.G., 2006. Restoration and management of the Inner Mongolia grassland require a sustainable strategy. AMBIO: A Journal of the Human Environment. 35, 269-270,

Liu, X., Zhao, H., Zhao, A., 1996. Wind-sandy Environment and Vegetation in the Horqin Sandy Land, China. Science Press, Beijing (in Chinese).

Marbà, N., Duarte, C.M., 1998. Rhizome elongation and seagrass clonal growth. Mar. Ecol. Prog. Ser. 174, 269–280.

Mckee, J., Richards, A.J., 1996. Variation in seed production and germinability in common reed (*Phragmites australis*) in Britain and France with respect to climate. New Phytol. 133, 233–243.

Saltonstall, K., Stevenson, J.C., 2007. The effect of nutrients on seedling growth of native and introduced *Phragmites australis*. Aquat. Bot. 86, 331–336.

Su, Y.Z., Zhao, W.Z., Su, P.X., Zhang, Z.H., Wang, T., Ram, R., 2007. Ecological effects of desertification control and desertified and land reclamation in an oasis-desert ecotone in an arid region: a case study in Hexi Corridor, northwest China. Ecol. Eng. 29, 117-124.

Yan, Q.L., Liu, Z.M., Ma, J.L., Jiang, D.M., 2007. The role of reproductive phenology, seedling emergence and establishment of perennial *Salix gordejevii* in active sand dune fields. Ann. Bot. 99, 19–28.

Yu, F.H., Wang, N., He, W.M., Chu, Y., Dong, M., 2008. Adaptation of rhizome connections in drylands: increasing tolerance of clones to wind erosion. Ann. Bot. 102, 571–577.

Zhao, H.L., Zhou, R.L., Su, Y.Z., Zhang, H., Zhao, L.Y., Drake, S., 2007. Shrub facilitation of desert land restoration in the Horqin Sand Land of Inner Mongolia. Ecol. Eng. 3, 1–8.

Zhu, Z.D., Zhao, X.L., Ling, Y.Q., Hu, Y.D., Wang, T., 1998. Sandy land rehabilitation engineering. China Environmental Press, Beijing (in Chinese).

Table 1 The relative growth rates of ramets and rhizomes of *P. communis* at six quadrats and three periods

	Quadrat location											
	Dune slack		Ecotone		Windward slope		Dune slack		Ecotone		Windward slope	
	1	2	3	4	5	6	1	2	3	4	5	6
Three periods	RGR of ratem (mg mg^{-1} day^{-1})						RGR of rhizome (mg mg^{-1} day^{-1})					
May 18-Jun 16	30.7a	34.2 a	28.9 a	28.5 a	33.5 b	-	3.5a	4.0a	8.8ab	13.9b	81.4c	-
Jun 16-Jul 16	5.8a	4.7a	8.6ab	15.6b	28.8c	26.4c	2.20a	1.8a	7.8b	7.5b	29.9c	83.8c
Jul 16-Aug 18	2.1a	1.4a	4.39b	4.2b	25.3c	22.6c	0.9a	1.0a	3.5b	4.5b	15.3c	16.1c

Note: (1) "-" means no *P. communis* in quadrat; (2) Numbers with the same letter within each row are not significantly different at $\alpha = 0.05$.

Figure legends:

Fig. 1. Expansion of *P. communis* near the ecotone between the windward slope and the dune slack and an illustration of transects and quadrats used in this study.

Fig. 2. Rhizome extension rate of *P. communis* during colonization in 2007. The error bars represent standard errors.

Fig. 3. Biomass allocation (%) between rhizomes and ramets of *P. communis* along the transect from the dune slack to the windward slope through the ecotone on May 18 (A), June 16 (B), July 16 (C) and August 18 (D), 2007.

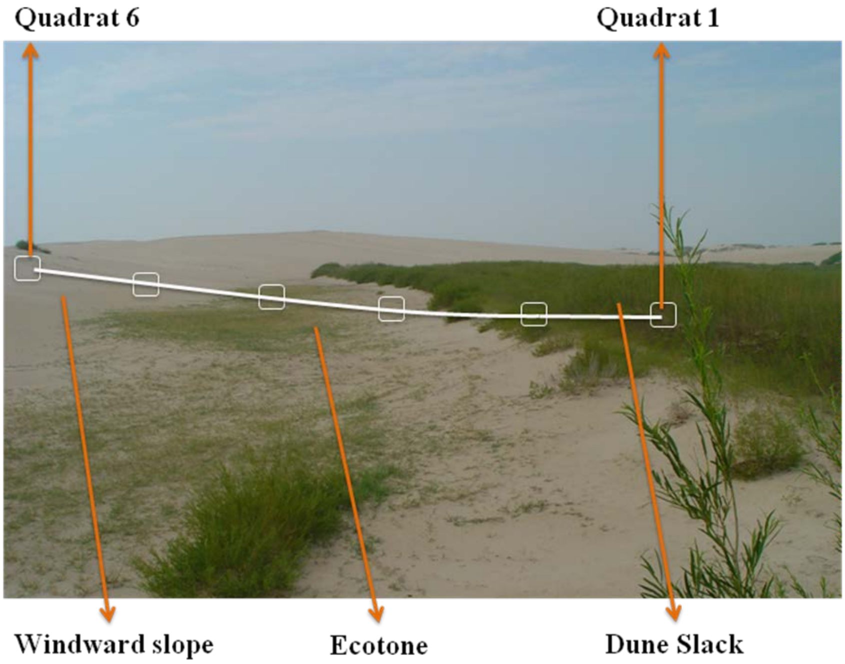
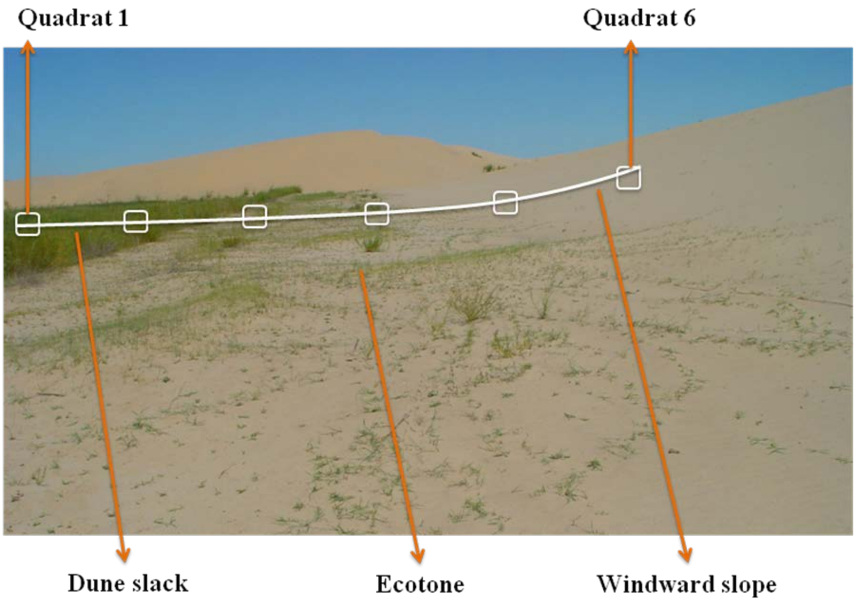

Quadrat 6
Quadrat 1
Windward slope
Ecotone
Dune Slack

Fig. 1.


Quadrat 1
Quadrat 6
Dune slack
Ecotone
Windward slope

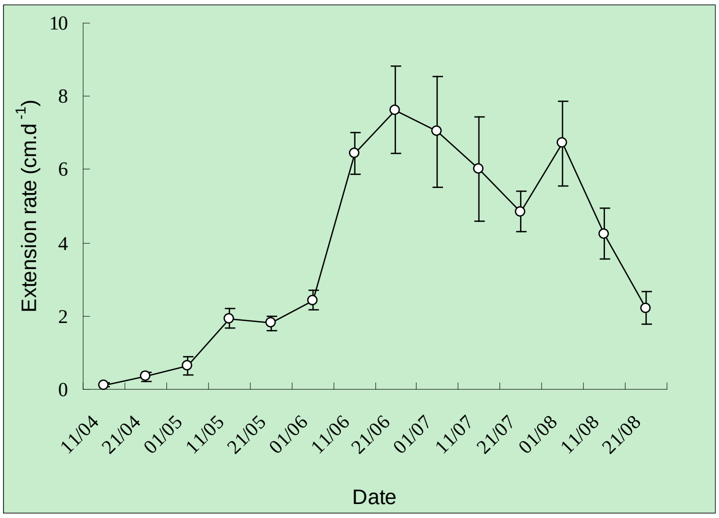

10
8
6
4
2
0
Extension rate (cm.d -1)
11/04
21/04
01/05
11/05
21/05
01/06
11/06
21/06
01/07
11/07
21/07
01/08
11/08
21/08
Date

Fig. 2.

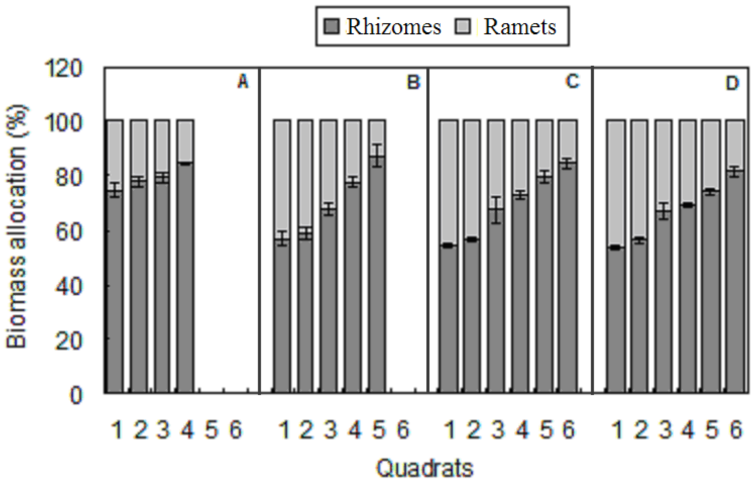

Rhizomes
Ramets
120
100
80
60
40
20
0
Biomass allocation (%)
A
B
C
D
1 2 3 4 5 6
1 2 3 4 5 6
1 2 3 4 5 6
1 2 3 4 5 6
Quadrats

Fig. 3.