Differences in Net Primary Productivity Among Contrasting Habitats in *Artemisia ordosica* Rangeland of Northern China

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### Abstract

*Artemisia ordosica* Krasch. is a semishrub native to the Ordos Plateau of Inner Mongolia, northern China, and forms a unique and dominant vegetation type in the sandland of the region. To determine the variation of productivity in *A. ordosica* rangeland, we investigated net primary production (NPP), fine root turnover, soil microbial C (Cmic), and soil organic carbon density (SOCd) on sand dunes differing in mobility (i.e., fixed, semifixed, and shifting sand dunes) in Mu Us sandland. We found that, on an area basis, the NPP, SOCd, Cmic, and fine root turnover rates all increased with increasing vegetation cover. However, the ratios of root NPP to total NPP (RMRN) increased with declining vegetation cover. Total NPP varied markedly among habitats and ranged from 18.3 g·m⁻²·yr⁻¹ for communities on the shifting sand dunes to 293.8 g·m⁻²·yr⁻¹ for communities on the fixed sand dunes; whereas the rates of fine root turnover varied from 0.16 · yr⁻¹ to 0.54 · yr⁻¹. Our study demonstrated that habitat change in sandland has significant impacts on ecosystem productivity by affecting many related aspects of NPP. From the perspective of biomass production, protection of the semifixed dunes from degradation should be taken as a higher priority than trying to convert shifting sand dunes to semifixed sand dunes; whereas conversion of semifixed sand dunes to fixed sand dunes would appear to be a much easier task than restoring shifting sand dunes.

### Resumen

*Artemisia ordosica* Krasch. es una subarbustiva nativa de la Planicie de Ordos del interior de Mongolia, al norte de China, que forma un único y dominante tipo de vegetación en la región de las tierras arenosas. Para determinar la variación en la productividad de los pastizales con hábitat de *A. ordorisca*, investigamos la producción primaria neta (NPP), cambios en raíces finas, C microbial en el suelo (Cmic), y densidad de carbono orgánico en el suelo (SOCd) en las dunas de arena de diferente movilidad (ej., fijas, semifijas, y dunas de arena cambiantes) en las tierras arenosas de Mu Us. Encontramos que, en base a área, la NPP, SOCd, Cmic, y la tasa de cambio de raíz fina se incrementaron al aumentar la cobertura de vegetación. Sin embargo, las tasas de NPP de la raíz a total NPP (RMRN) se incrementaron al disminuir la cobertura vegetal. La NPP total varió notablemente entre hábitats, dentro del rango de 18.3 g·m⁻²·yr para comunidades en las dunas de arena cambiantes, a 293.8 g·m⁻²·yr para las comunidades en las dunas de arena fijas; mientras que las tasas de cambio de raíces finas varian de 0.16 · yr⁻¹ a 0.54 · yr⁻¹. Nuestro estudio demostró que el cambio de hábitat en las tierras arenosas tuvo un impacto significativo en la productividad, afectando muchos aspectos relacionados con la NPP. Desde el punto de vista de producción de biomasa, la protección de las dunas semifijas de la degradación debe considerarse de mayor prioridad que tratar de convertir las dunas cambiantes a semifijas; mientras que la conversión de las dunas semifijas a dunas fijas puede parecer una tarea mucho más fácil que la restauración de las dunas de arena cambiantes.

**Key Words:** *Artemisia ordosica*, net primary production (NPP), Ordos Plateau, soil organic carbon (SOC) density, turnover rate
An important aspect of alterations in ecosystem structure and function is changes in biomass and net primary productivity (NPP) with habitat. A shift of NPP in quantity and allocation is making it very difficult to compute the global carbon budget when the impact of human-induced global climate change is to be assessed (Intergovernmental Panel on Climate Change 2007). Of particular importance is the belowground carbon pool, which is estimated to sequester more than half of the world’s carbon and plays an active role in offset fossil fuel emissions (Lal 2004). In arid or semiarid ecosystems, the percentage of belowground carbon is even higher because root system turnover rate is low (Schlesinger et al. 1990; Gill and Jackson 2000) and more assimilated carbon is allocated to belowground compartments (Rice et al. 1998). Despite dryland ecosystems covering nearly one-third of the earth’s land surface, the fundamental knowledge about the responses of ecosystems covering nearly one-third of the earth’s land surface, the fundamental knowledge about the responses of the carbon cycle to environmental change is still limited and is poorly documented relative to other main biomes. The *Artemisia ordosica* Krasch. community is a unique vegetation type endemic to Ordos Plateau. *A. ordosica* is a semishrub that occurs in habitats ranging from fixed to shifting sand dunes (Zhang 1994). The species is of great importance to the regional socio-economic activities as a source of firewood and fodder plants for livestock, in addition to its role in ecosystem functioning. Research conducted in the region has helped to gain some insight in understanding the succession dynamics (Wang and Liang 1997; Wang et al. 1997) and general productivity (Wang and Li 1994; Liu 1998; Cheng et al. 2001) of *A. ordosica* communities. However, detailed information is lacking on the responses of above- and belowground NPP patterns in *A. ordosica* rangeland to changing habitats caused by natural and anthropogenic disturbances, which is key to understanding the adaptive strategy of the vegetation to long-term environmental perturbations.

We conducted a 2-yr study on carbon cycling in *A. ordosica* communities in three types of habitat, i.e., fixed, semifixed, and shifting sand dunes, in the Mu Us sandland. The objectives of this study were to 1) assess NPP variation in *A. ordosica* communities among the three habitat types, and 2) determine the habitat effects on fine-root production, turnover rate, soil organic carbon density, and soil microbial biomass carbon. Findings from this study will be useful to those who manage rangelands in the arid and semiarid areas of northern China and who predict the carbon budget in this region under future environments.

**MATERIALS AND METHODS**

**Study Site**

This study was conducted from July 2004 to September 2005 on sites near the Ordos Sandland Ecological Research Station of the Chinese Academy of Sciences (lat 39°29’N, long 110°11’E, 1295 m above sea level). The climate typically is continental and semiarid (aridity index 0.3). Annual mean precipitation is ~358 mm, of which 60–80% falls between June and August. Annual mean temperature varies from 6.0°C to 8.5°C; the monthly mean temperature fluctuates between 20°C and 24°C in July and is approximately ~10°C in January. Much of the region is covered by loose sands of varying depth.

Cover of other species, which consist of *Hedysarum mongolicum* Turcz., *Chenopodium aristatum* L., and *Agriophyllum squarrosum* (L.) Moq., is 1–5% in all habitats. Fixed, semifixed, and shifting sand dunes are the three typical landscapes on Ordos Plateau. Percentage of vegetation cover is the index often used to determine the type of sandland because the dune activity correlates positively with the vegetation cover.

**Aboveground and Coarse Root Biomass and NPP Measurement**

Three 10 m × 10 m plots were established in each of the fixed, semifixed, and shifting sand dunes near the research station. For a detailed description of the characteristics of the three habitats, please refer to the article by Li and Xiao (2007). The height and the canopy diameter (D) in two perpendicular directions were measured for all *A. ordosica* plants on each plot at a monthly interval from May to September in 2005. The aboveground and coarse root (D > 2 mm) biomass of individual *A. ordosica* plants was determined based on the site-specific allometry (Li and Xiao 2007). The aboveground and coarse root biomass of other plants was directly measured by harvesting and weighing of oven-dried samples (65°C to constant weight) from May to September in 2005. Aboveground and coarse root NPP of *A. ordosica* communities were estimated as the difference between maximum and minimum biomass of the target components, which were measured in May and September, respectively.

**Fine Root Biomass and NPP Measurement**

A soil corer (inner diameter of 8 cm) was used to collect root samples for estimating fine root biomass at six random points on each plot. Cores were collected at monthly intervals from early May to late September 2005. Samples from each location were taken to a depth of 100 cm and separated into 0–5-, 5–15-, 15–30-, 30–45-, 45–60-, 60–75-, 75–90-, and 90–100-cm layers. The fine roots were washed and sorted into classes of 0–1- and 1–2-mm diameters. Live and dead root fragments were separated by visual inspection based on attributes described by Persson (1980) and Vogt and Persson (1991) in which the xylem of dead roots appears darker and deteriorated, the degree of cohesion between the cortex and periderm decreases, and root tips become brittle and less resilient. Dry weights were determined after oven-drying at 65°C to constant weight.

In order to estimate fine root (D = 2 mm) productivity, a simplified ingrowth core method was used (Janssens et al. 2002). Similar to the sampling method described above, soil core samples were collected at six random locations on each plot in August 2004. Samples from each location were taken to a depth of 100 cm and separated into 0–5-, 5–15-, 15–30-, 30–45-, 45–60-, 60–75-, 75–90-, and 90–100-cm layers. After removal of roots, the soils were placed back to the same holes with the same stratification. We tried to retain the original bulk density by filling each stratum with the appropriate mass of soil and covering the surface with the original litter. Those cores were sampled again in August 2005 for newly produced fine roots to calculate belowground net primary productivity.

The rate of fine root turnover was estimated as the ratio of the total fine root biomass produced in 1 yr over the mean
standing biomass of fine roots (Aber et al. 1985; Aerts et al. 1992). The ratio of root NPP to total NPP (RMR\textsubscript{N}, g·g\textsuperscript{-1}) was also calculated.

**Calculation of Soil Organic Carbon Density**

Soil samples were collected to a depth of 100 cm and separated into eight layers (as described previously) from four random locations on each plot in September 2005 with a soil corer (inner diameter 4 cm). The samples were air-dried after the surface organic materials or root fragments were completely sieved off. Soil organic carbon (SOC) content was determined for each sample by the dichromate oxidation method as described in Bao (2000).

SOC density for a soil profile with a depth of d (cm), SOC\textsubscript{d} (t·C·ha\textsuperscript{-1}), was calculated using the following equation:

$$\text{SOC}_{d} = \sum_{i=1}^{n} \frac{(1-V_{i} \%) \times B_{i} \times C_{i} \times T_{i}}{100}$$

where \( n \) is the number of pedogenic horizons in the soil survey, \( V_{i} \% \) is the volumetric percentage of the soil fraction \( >2 \text{ mm} \) (rock fragment), \( B_{i} \) is the bulk density (g·cm\textsuperscript{-3}), \( T_{i} \) is the thickness (cm) in the layer \( i \), and \( C_{i} \) is the organic C content (%). In this study, the depth of soil profiles for SOC\textsubscript{d} calculations was set to 100 cm. Soil bulk density was determined for each habitat type using three soil profiles.

**Measurement of Soil Microbial Biomass C**

Four soil samples were taken from the top 10 cm on each plot with a soil corer (inner diameter of 4 cm) in September 2005. Samples were stored in a chest cooler and taken to a laboratory for soil microbial biomass C (C\textsubscript{mic}) analysis using the chloroform-fumigation method (Witt et al. 1999).

**Statistical Analysis**

One-way analysis of variance was used to detect the significance of variation of the means of above- and belowground net primary production, root turnover rate, C\textsubscript{mic}, SOC density, and vertical distribution of fine roots on the three types of habitats. Least significant difference (LSD) was used in the multiple comparisons among habitats. Significant differences were determined at \( P < 0.05 \) level unless otherwise stated. All statistical analyses were performed with SPSS 13.0 for Windows.

**RESULTS**

**Habitat Effects on Above- and Belowground Biomass and NPP**

The three types of habitats differed significantly in the seasonal dynamics of biomass. Generally, biomass increased with time within a single growing season at the community level, with the rate of increase declining markedly from the fixed sand dunes to the shifting sand dunes. Biomass increased from 189 to 444 g·m\textsuperscript{-2} on the fixed sand dunes, 88 to 236 g·m\textsuperscript{-2} on the semifixed sand dunes, and 16 to 35 g·m\textsuperscript{-2} on the shifting sand dunes (Fig. 1).

The above- and belowground NPP displayed a declining trend from the fixed sand dunes to the shifting sand dunes (Fig. 2). The aboveground NPP of the fixed sand dunes was 219.5 g·m\textsuperscript{-2}·yr\textsuperscript{-1}, approximately twice that of the semifixed sand dunes (119.1 g·m\textsuperscript{-2}·yr\textsuperscript{-1}) and 10 times that of the shifting dunes (11.5 g·m\textsuperscript{-2}·yr\textsuperscript{-1}). Belowground NPP was 74.3 g·m\textsuperscript{-2}·yr\textsuperscript{-1}, 42.2 g·m\textsuperscript{-2}·yr\textsuperscript{-1}, and 6.8 g·m\textsuperscript{-2}·yr\textsuperscript{-1} for the fixed, semifixed, and shifting sand dune habitats, respectively. However, the ratio of root NPP to total NPP (RMR\textsubscript{N}, g·g\textsuperscript{-1}) was significantly greater on the shifting sand dunes than on the fixed and semifixed sand dunes (Fig. 2).

**Habitat Effects on Fine Root NPP and Its Vertical Distribution**

Fine root NPP of the two diameter classes displayed decreasing patterns in response to the changing habitat types (Fig. 3a). Namely, the 1–2 mm fine root NPP dropped from 4.9 g·m\textsuperscript{-2}·yr\textsuperscript{-1} on the fixed sand dunes to 0.06 g·m\textsuperscript{-2}·yr\textsuperscript{-1} on the shifting sand dunes; the <1 mm fine root NPP dropped from 12.8 g·m\textsuperscript{-2}·yr\textsuperscript{-1} to 0.8 g·m\textsuperscript{-2}·yr\textsuperscript{-1}, respectively. In all
habitats, the NPP of fine roots < 1 mm was greater than that of 1–2 mm. As for the vertical distribution of root NPP, more than 70% of the fine roots < 1 mm and 90% of the fine roots 1–2 mm were located in the upper 30 cm soil layer in all three habitat types. Very little fine root NPP was observed below 60 cm (Fig. 4). The peak fine root NPP occurred at a depth of about 30 cm along the soil profile, but the magnitude of the fine root density differed markedly between different types of habitats.

Habitat Effects on Fine Root Turnover

The turnover rate of fine roots < 1 mm was on average 3-fold greater than that for total fine roots (≤ 2 mm diameter), displaying a declining trend from the fixed sand dunes to the shifting sand dunes (Fig. 3b). The difference in the turnover rates was significant among habitat types and was markedly greater between the semifixed and shifting sand dunes than between the fixed and semifixed sand dunes.

Habitat Effects on SOC and Cmic

SOCd differed significantly among the three habitat types, with a declining trend along the habitat gradients from the fixed sand dunes to the shifting sand dunes (Fig. 5). The differences in SOCd were much greater between the fixed and semifixed sand dunes than between the semifixed and shifting sand dunes.

DISCUSSION

Habitat change caused by desertification could influence NPP patterns because productivity is very sensitive to environmental perturbations (Huenneke et al. 2002). Our study in the semiarid Mu Us sandland detected significant differences in aboveground and belowground NPP in A. ordosica communities along habitat gradients representative of different levels of land degradation; the declining NPP from the fixed sand dunes to the shifting sand dunes reflected the deteriorating abiotic and biotic conditions. The fixed sand dunes developed relatively fertile soil containing higher soil organic nitrogen and SOC in the succession process, whereas the activated sand dunes suffered severe nutrient loss. Such difference in soil fertility can account for variable productivity among different habitats (Schlesinger et al. 1990; Busso 1997; Sharifi et al. 1999).

We found that NPP differed more between the semifixed and shifting sand dunes than between the fixed and semifixed sand dunes. This suggests that habitat change between semifixed and shifting sand dunes would result in greater impacts than between fixed and semifixed sand dunes on carbon accumulation in A. ordosica communities. Transformation from semifixed to shifting sand dunes would not only markedly reduce community biomass and productivity, but also make the restoration more difficult because biomass accumulation during the growing season was shown to be far less on the shifting sand dunes. Therefore, protecting the semifixed sand dunes from degradation should be taken as a higher priority than trying to convert shifting sand dunes to semifixed sand dunes; conversion of semifixed sand dunes to fixed sand dunes would appear to be a much easier task than restoring shifting sand dunes.

Fine root NPP showed the same declining trend as aboveground NPP at the community level, indicating that the infertile soil condition on shifting sand dunes also limited the fine root growth. However, for individual plants, the proportion of fine root NPP over total NPP increased when habitat type changed from the fixed and semifixed sand dunes to the shifting sand dunes as shown by the results of RMRc. Differences in habitat conditions are known to affect production allocation in many plants, which likely is a necessary adaptive strategy for providing sufficient nutrients and water to plant growth and survival under poor resource conditions (Nadelhoffer et al. 1985; Steele et al. 1997; Martı´nez et al. 1998; Snyman 2005). Root turnover is a central component of ecosystem carbon and nutrient cycling and is sensitive to many of the factors considered in global change analysis (Aber et al. 1985; Bloomfield et al. 1996). The turnover rate of A. ordosica roots was found to increase with decreasing root diameter and was greater on the fixed and semifixed sand dunes than on the shifting sand dunes. Our estimate of the fine root turnover rate for A. ordosica could be conservative due to potentially underestimated NPP by not accounting for microbial decomposition during the measurement period. Nonetheless, the
values were in the general range found in many other studies for shrubs in temperate zone (e.g., Caldwell et al. 1977; Saterson and Vitousek 1984; Berendse et al. 1987; Martinez et al. 1998; Gill and Jackson 2000; Lauenroth and Gill 2003), and consistent with the result of C mic. The patterns of C mic closely matched SOCd in relation to habitat types.

**MANAGEMENT IMPLICATIONS**

Our study demonstrated that habitat change in sandland has significant impacts on ecosystem productivity by affecting many related aspects of NPP. Thus, the level of productivity provides direct guidance for land-use of different habitats. Fixed sand dunes could be moderately used as rangeland because they have higher productivity and the exploitation of semifixed sand dunes should be cautious because of its fragile vegetation. Protection and overuse might trigger two opposite successional pathways on semifixed sand dunes. From the perspective of biomass production, protecting the semifixed sand dunes from degradation should be taken as a higher priority than trying to convert shifting sand dunes to semifixed sand dunes; conversion of semifixed sand dunes to fixed sand dunes would appear to be a much easier task than restoring shifting sand dunes.

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**LITERATURE CITED**


