Photosynthetic and morphological functional types from different steppe communities in Inner Mongolia, North China

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Abstract

Morphological functional types and photosynthetic pathway types were identified for the forage species from steppe communities in Inner Mongolia, China, using the data of both field survey and published papers. Seven typical steppe communities were selected to investigate the morphological functional type and photosynthetic pathway type compositions and plant functional type (PFT) diversity in steppe communities at regional scale. Morphological functional types, based on plant height and leaf type combined with life span, were optimal for comparing the community differences in the region, while photosynthetic pathway types were fairly coarse for such studies. Of the seven morphological functional types in the steppe communities, perennial forbs (PEF) were the dominant type, and 60 % of species belonged to this type. Each of the high perennial grass (HPG), short perennial grass (SPG), and annual grass (ANG) types represented less than 10 % of the total, even though the grass species were dominant in the seven steppe communities. The differences of PFTs between the steppe communities were remarkable, and the PFT richness and diversity increased from the communities with moist conditions to the ones with dry environments.

Additional key words: C_3, C_4, and CAM plants; morphology; photosynthetic pathway; plant diversity; plant functional types.

Introduction

Plant functional types (hereafter PFTs) refer to groups or types of plant species that share morphological and physiological attributes and play a similar role in ecosystems (Chapin 1993, Paruelo and Lauenroth 1996, Wang 2003). They are derived from plant attributes based on morphology, physiology, regenerative growth, life form, and bioclimatic tolerance according to the aims and scales of the study (Smith *et al*. 1993, Duckworth *et al*. 2000, Wang 2003). PFTs are popular means for studying the logical links between physiological and life-history strategies at plant level and ecological processes at ecosystem and global levels (Chapin 1993, Paruelo and Lauenroth 1996). Most of studies were focused on PFT classification (Waller and Lewis 1979, Smith *et al*. 1993, Paruelo and Lauenroth 1996, Scholes *et al*. 1997, Pillar 1999, Duckworth *et al*. 2000, Wang 2003) and their relations with local and global change (Teeri and Stowe 1976, Collins and Jones 1985, Chapin 1993, Cramer 1997, Collatz *et al*. 1998). Some researchers tested the PFT diversity and abundance in grasslands, shrublands, and woodlands (Paruelo and Lauenroth 1996). These works provide strong evidence that the abundance of PFTs correlates with vegetation differences, land use, and climatic change at local, regional, and global scales. Nevertheless, a comparative study on the differences in PFT composition and diversity at community level in steppe vegetation in China was lacking.

Steppe, distributed at the eastern end of the Eurasian steppe zone, covers large continuous areas in Mongolia plateau, and the main location in China is Inner Mongolia and the western Manchuria plain. The usual growing conditions on the steppe produce herbage superior both in quality and in quantity, so that this type of grassland is one of the best suited in northern China for the rangeland industry (Jiang *et al*. 1985, Li *et al*. 1988). Studies on local flora, grassland ecosystems, plant biomass, and their responses to climatic variables have been conducted (Jiang *et al*. 1985, Li *et al*. 1988, Zhao *et al*. 1988, Liu 1993), but differences in PFT composition and diversity between steppe communities remain unclear. The objective of the present study was to investigate the compositions of morphological functional type and photosynthetic

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pathway type and PFT diversity in steppe communities at regional scale. This study brings new information for better understanding the plant functional types in Inner Mongolian steppe and their relations with ecosystems, climate changes, and land use.

Materials and methods

Study site: The study was conducted in the Xilin river basin (41°35'~46°46' N, 111°09'~119°58' E) in the Mid-Inner Mongolia. The typical steppe in the region, which covers about 40 000 km^2 area, is part of the Mongolian Plateau of average 1 200 m a.s.l., varying from 900 m in the northeast to 1 500 m in the southwest. Most of the region has dark chernozem and chestnut soils. Because of the variability in topography (elevation and landscape), annual precipitation, and annual temperature, the community types and soils vary significantly from upland to lowland or from high southwest to low northeast. There are seven main communities in the region, *e.g.* *Filifolium sibiricum* (FS), *Stipa baicalensis* (SB), *Festuca ovina* (FO), *Leymus chinensis* (LC), *Stipa grandis* (SG), *Stipa krylovii* (SK), and *Artemisia frigida* (AF). Floristic composition varied among the seven community types, 184 species were identified in LC, 121 in FS, 104 in SG, 99 in FO, 96 in SB, 62 in AF, and 40 in SK. These variations resulted in the differences in PFT composition and diversity.

Climate: The main determinants of the climate in the region are the Mongolian anticyclone and moist Pacific air mass. In winter, northeastern China is dominated by an intense Mongolian anticyclone. The steep pressure gradient between this high and the Aleutian low-pressure system produces a strong westerly flow of cold, dry continental air at the surface over north China. As the anticyclone breaks down in spring, the region comes increasingly under the influence of moist Pacific air mass, reaching a climax in the summer monsoon, which lasts two months. The mean annual air temperature ranges from –1.4 °C to +2 °C, varying from –21 °C in January to +21 °C in July. Moisture gradient is very steep, with annual precipitation varying from 250 mm in the northwest to 450 mm in the southeast. Precipitation is not distributed evenly over growing season, of which 70 % falls between June and August in this region.

Methods: Community floristic composition was obtained from the field survey in the growing seasons of 2000 and 2001, as well as from literature published from 1988 to 2003 (Li *et al.* 1988, Zhao *et al.* 1988, Liu 1993, Wang 2003). In the field survey, plants were sampled from 60–80 randomly located 1×1 m quadrats in each community type. Considering the species-area relationship, 8–10 communities with different area were used as community replicates in each community type. Plant species, morphology (*e.g.* plant height, leaf type, life span), landscape, elevation, and soil type were recorded. The data on photosynthetic pathway types were compiled from references published between 1985 and 2002 (*e.g.* Takeda and Hakoyama 1985, Li *et al.* 1988, Li 1993, Redmann *et al.* 1995, Pyankov *et al.* 2000, Wang 2002a,b, 2003). Plants identified in the region were classified into photosynthetic pathway types (C_4, C_3, and CAM) by physiological attributes and into morphological functional types: shrubs (SHR), high perennial grasses (HPG), short perennial grasses (SPG), annual grasses (ANG), annual forbs (ANF), perennial forbs (PEF), and succulents (SUC) by morphological attributes (Zhao *et al.* 1988, Li *et al.* 1988, Wang 2003) (Table 2).

Mean species number and proportion of PFTs in each community type were statistically analyzed with the *MINITAB 13.1*, and regressions of PFT richness and diversity from community types were performed using *EXCEL for Windows 98*. PFT richness (R) was calculated using Margalef's (1959) index:

$$R = \frac{S-1}{\ln N} \qquad (1)$$

where N is the number of species in the community and S is the number of PFTs.

PFT diversity (H) was calculated using the Shannon-Wiener index (Barbour *et al.* 1987):

$$H = -\sum_{i=1}^{S} Pi \ln Pi \qquad (2)$$

where Pi is the PFT proportion of the total PFT number in each community, and S is the number of PFTs.

Results

PFT: Of the total 257 species, 126 species were identified with C_3 (97 species), C_4 (26 species), and CAM (3 species) photosynthetic pathways (Table 2) which is 77, 21, and 2 %, respectively. The occurrence of C_4 species was common in *Gramineae* (12 species) and *Chenopodiaceae* (6 species). *Gramineae* was the leading C_4 family, followed by *Chenopodiaceae*. The differences in the occurrence and percentage of photosynthetic pathway types among the seven communities were significant in the steppe region (Fig. 1*A,B*). LC and SG communities had the greatest number of species in both C_3 and C_4, followed by AF, FS, and SK. In general, the numbers for both C_3 and C_4 species were reduced significantly from LC to SK communities, the species numbers of C_3 and C_4

for SK community being only about 37 and 29 % of that for LC community, respectively. There were more CAM species among the relatively dry vegetation types (*e.g.* AF, FO, and SG). The percentages of C_3 and C_4 species in LC, SG, AF, and SK were fairly high (Fig. 1*B*). Relatively more plants of the C_4 type in the drier communities (*e.g.* AF and SK) indicated that C_4 plants are generally more tolerant to drought and have greater ability to maintain intense photosynthesis.

Table 1. The community types, topography, soil types, annual precipitation, and annual temperature of the Xilingol steppe in Inner Mongolia, North China.

Community type	Landscape	Elevation [m]	Soil type	Annual precipitation [mm]	temperature [°C]
Filifolium sibiricum	Upland	1300~1500	Dark chernozem	>450	–1.4
Stipa baicalensis	Upland	1270~1500	Dark chernozem	<450	–1.4
Festuca ovina	Upland	1300~1500	Dark chernozem	<450	–1.4
Leymus chinensis	Lowland	900~1300	Chernozem	350~450	–0.3~1
Stipa grandis	Lowland	1100~1300	Chernozem	350~450	–0.3~1
Stipa krylovii	Lowland	900~1100	Light chernozem	250~350	1~2
Artemisia frigida	Lowland	900~1100	Light chernozem	250~350	1~2

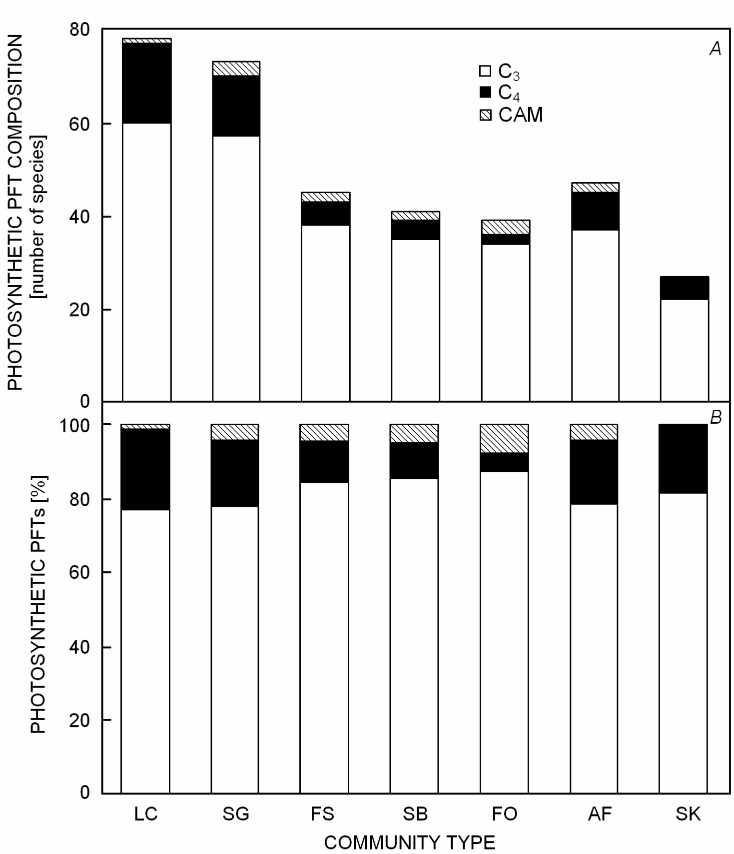

Fig. 1. The photosynthetic pathway types of the present plant species (*A*) and their composition (*B*) in different community types (PFTs) in Inner Mongolia steppe, north China.

Morphological functional types: A detailed description of the floristic composition in each community is presented in Table 2. Of the 257 species identified in the seven communities, 7 functional types, *e.g.* shrubs (SHR), high perennial grasses (HPG), short perennial grasses (SPG), annual grasses (ANG), annual forbs (ANF), perennial forbs (PEF), and succulents (SUC) were grouped by morphological traits, *e.g.* height, leaf morphology, and life span. There were six PFTs in the SB and FO communities, but seven PFTs occurred in the other five communities. Of the total identified species in the region, 60 % was of the PEF type, followed by ANF (15 %),

HPG (10 %), SHR (6 %), SPG (4 %), ANG (4 %), and SUC (2 %). The grass PFTs represented about 18 % of all, even though the species were dominant (*e.g. Stipa grandis* P. Smirn., *S. baicalensis* Roshev., *Leymus chinensis* Trin. Tzvel.), and produced 90 % of herbage in the steppe vegetations. This indicated that the abundance of PFTs was not consistent with the community composition.

The morphological PFT compositions of the communities varied significantly due to the differences in precipitation, soil, mean annual temperature, and elevation (Table 1). Species abundance of PEF, ANF, and HPG dropped significantly from the LC to SK community (Fig. 2*A*). Number of PEF species in the SK community was only 25 % of that in LC community, and the numbers of ANG and HPG species in SK were about 20 and 35 % of those in LC, respectively. Species numbers in the other two grass PFTs also declined from LC to SK. The numbers of SHR and SUC species did not vary considerably, except that they were a little lower in the LC and SK communities. PFT percentages varied remarkably in the seven communities (Fig. 2*B*): PEF percent exhibited relatively little variation among the seven communities, being significantly low in the AF community, while the ANF percent was twice the average value. The SHR percent increased from LC to SK, *i.e.* from moist to drier. Annual grass percentages were rather low in the seven communities, and no annual grasses were identified in both SB and FO communities, indicating that human disturbances of the communities were not common in the region.

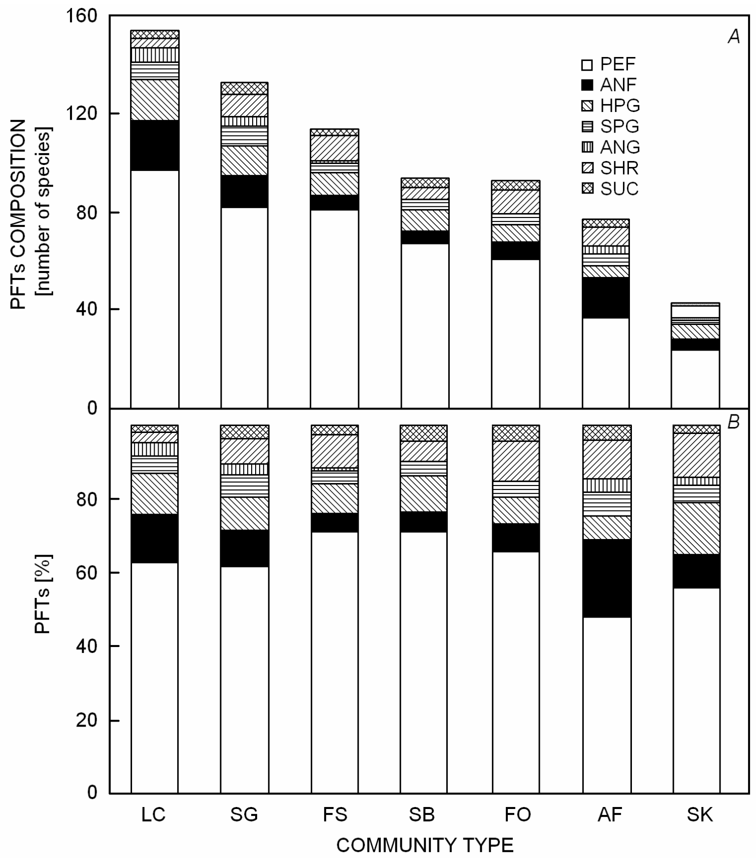

Fig. 2. Species numbers in each plant functional type, PFT (*A*) and their percentages (*B*) in steppe communities in Inner Mongolia, north China.

PFT richness and diversity: Variations in numbers of species, the simplest measure of PFT diversity in the seven communities, were described above. But the richness index of Margalef (Eq. 1) and diversity index of Shannon-Wiener (Eq. 2) can comprehensively reflect the PFT differences among the communities. PFT richness index (R) incorporating both the number of PFTs and the number of species in PFT was the highest in SK, even if the total number of species in this community was considerable lower. In general, the R index increased from the moist community to the drought one (Fig. 3). This suggested that the PFT richness was not consistent with the community species abundance in the steppe vegetation.

The Shannon-Wiener diversity index H (Eq. 2) includes not only richness, but also evenness of the PFT distribution. The latter is the ratio of diversity to maximum possible diversity for the given numbers of species and PFT. This index also increased significantly

Table 2. Photosynthetic pathways (C_3, C_4, and CAM) and plant functional types from different communities in Inner Mongolian steppe, North China. Nomenclature follows Kitagawa (1979) and Yin and Wang (1997). Communities: FS = *Filifolium sibiricum* community, SB = *Stipa baicalensis* community, FO = *Festuca ovina* community, LC = *Leymus chinensis* community, SG = *Stipa grandis* community, SK = *Stipa krylovii* community, AF = *Artemisia frigida* community. Plant functional types (PFTs): SHR = shrubs, HPG = high perennial grasses, SPG = short perennial graminaceous plants (grasses and sedge), ANG = annual grasses, ANF = annual forbs, PEF = perennial forbs, SUC = succulents.

	Species	C_3/C_4	Community	PFTs
Gymnospermae				
Ephedraceae	*Ephedra sinica* Stapf.		FS SG SK AF	SHR
	E. monosperma Gmel. *ex* Mey.		FO	SHR
Angiospermae				
Dicotyledoneae				
Polygonaceae	*Polygonum angustifolium* Pall.		FS FO LC	PEF
	P. aviculare L.	C_3	LC AF	ANF
	P. divaricatum L.		FS SB FO LC SG	PEF
	P. sibiricum Laxm.	C_3	FS LC	PEF
Chenopodiaceae	*Agriophyllum pungens* (Vahl) Link A. Dietr.	C_4	SG	ANF
	Atriplex sibirica L.	C_4	LC	ANF
	Axyris amaranthoides L.	C_3	AF	ANF
	Bassia dasyphylla O. Kuntze	C_4	SG	ANF
	Chenopodium acuminatum Willd.	C_3	LC	ANF
	Ch. glaucum L.	C_3	LC	ANF
	Kochia prostrata Schrad.	C_4	FS FO LC SG SK AF	SHR
	K. sieversiana (Pall.) C.A. Mey.	C_4	LC	SUC
	Salsola collina Pall.	C_4	SB SG SK AF	SUC
Amaranthaceae	*Amaranthus retroflexus* L.	C_4	AF	ANF
Portulacaceae	*Portulaca oleracea* L.	C_4	AF	ANF
Caryophyllaceae	*Arenaria capillaris* Poir.		FS FO	PEF
	Dianthus superbus L.		FO	PEF
	D. versicolor Fisch. *ex* Link		FS SB FO SG AF	PEF
	Gypsophila davurica Turcz. *ex* Fenzl		FS LC SG	PEF
	Melandrium apricum (Turcz.) Rhrb.		FS SB FO LC SG	ANF
	Silene jenissensis Willd.		FS SB FO LC SG SK	PEF
	S. repens Patr.		LC	PEF
	Stellaria cherleriae Willd.		FS	PEF
Ranunculaceae	*Clematis hexapetala* Pall.	C_3	FS FO LC	PEF
	Delphinium grandiflorum L.		SB LC	PEF
	Pulsatilla ambigua Turcz. *ex* Pritz.		FS SB FO LC SG	PEF
	P. turczaniovii Kryl. *ex* Sery.		LC	PEF
	Ranunculus japonicus Thumb.	C_3	SG	PEF
	Thalictrum petaloedeum L. var. *supr.* (Nakai) Kitag.	C_3	SG SB	PEF
	Th. simplex L.	C_3	SB FO SG SK	PEF
	Th. squarrosum Steph.	C_3	FS SB FO LC SG AF	PEF
Papaveraceae	*Papaver nudicaule* L.		LC	PEF
Cruciferae	*Dontostemon integrifolium* (L.) Ledeb.		FO LC SG SK AF	ANF
	D. micranthus C.A. Mey.		FS	ANF
	Draba nemoroda var. *leiocarpa* Linded.		FS SB FO LC SG	ANF
	Lepidium apetalum Willd.	C_3	AF	ANF
	Ptilotrichum elongatum C.A. Mey.		FS SB FO SG AF	SHR
	Thlaspi cochleariforme D.C.		SB FO LC	PEF
Crassulaceae	*Orostachys fimbriatus* (Turcz.) Berger	CAM	FS SB FO SG AF	SUC
	O. malacophyllus (Pall.) Fisch.	CAM	SB FO SG AF	SUC
	Sedum aizoon L.	CAM	FS FO LC SG	SUC
Rosaceae	*Chamaerhodos canescens* J. Krause		FS	PEF
	Ch. erecta (L.) Bunge		FO SG SK AF	ANF
	Geum aleppicum Jacq.	C_3	LC	PEF

Table 2 (continued)

	Species	C_3/C_4	Community	PFTs
Rosaceae (cont.)	*Potentilla acaulis* L.	C_3	SB FO LC SG SK AF	PEF
	P. anserina L.	C_3	FS	PEF
	P. bifurca L.	C_3	FS SB FO LC SG SK AF	PEF
	P. flagellaris Willd.	C_3	LC	PEF
	P. fragaricides L.	C_3	SG SK	PEF
	P. longifolia Willd. *ex* Schlech.		SB	PEF
	P. multifida L. var. *nubigena* Wolf.		AF	PEF
	P. sericea L.		FS SG AF	PEF
	P. tanacetifolia Willd. *ex* Schlech.		FS SB FO LC SG SK AF	PEF
	P. verticillaris Steph. *ex* Willd.		FS SB FO LC SG SK AF	PEF
	P. viscose Willd. *ex* Schlech.		SB FO LC SG	PEF
	Sanguisorba officinalis L.	C_3	FS SB FO LC SG	PEF
	Sibbardia adpressa Bunge		FS	PEF
	S. bijugs Bunge		FS SG	PEF
	Spiraea aquilegifolia Pall.		FS FO	SHR
Fabaceae	*Astragalus adsurgens* Pall.		FS SB FO LC SG	PEF
	A. dahuricus (Pall.) D.C.		AF	ANF
	A. galactites Pall.		FS FO LC SG SK AF	PEF
	A. melilotoides var. *tenuis* Turcz.		FS SB FO LC SG	PEF
	A. mongholicus Bunge.		LC	PEF
	A. scaberrimus Bunge.		FO SG	PEF
	Caragana microphylla Lam.	C_3	FS SB FO LC SG SK AF	SHR
	C. stenophylla Pojark.	C_3	SG SK AF	SHR
	Glycirrhiza uralensis Fisch.		LC SG	PEF
	Gueldensfaedtia stenophylla Bunge.	C_3	SB FO SG SK AF	PEF
	G. verna (Georgi) A. Bor.		LC	PEF
	Hedysarum gmelini Ldb.		FS SB FO LC SG AF	PEF
	H. lignosum Ldb.		FO	SHR
	Lathyrum palustris L.		LC	PEF
	L. quinquenervius Miq.		SB	PEF
	Lespedeza davurica Schindler	C_3	FS SG	SHR
	L. hedysaroides Kitag.		FS	SHR
	Medicago falcata L.		LC	PEF
	M. lupulina L.		LC	ANF
	Melilotoides ruthenica (L.) Sojak	C_3	LC FS	PEF
	Melissitus ruthenica (L.) Peschkova		FS SB LC SG AF	PEF
	Oxytropis hirta Bunge	C_3	LC SG	PEF
	O. filiformis D.C.	C_3	FS SK AF	PEF
	O. grandiflorus Pall.		FS	PEF
	O. leptophylla (Pall.) D.C.		FS SB SG AF	PEF
	O. myriophylla D.C.	C_3	FS SB FO LC SG AF	PEF
	O. ochrantha Turcz.		FS LC	PEF
	Swainsona salsula Pall.		LC	PEF
	Thermopsis lanceolata R.Br.	C_4	FS SB LC SG	PEF
	Trifolium lupinaster L.		FS SB FO LC SK	PEF
	Vicia ampena Fisch. var. *oblongifolia* Reg.		FS SB LC	PEF
	V. cracca L.		SB LC	PEF
	V. unijuga R.Br.		FS LC	PEF
Geraniaceae	*Erodium stephanianum* Willd.	C_3	AF	ANF
Linaceae	*Linum baicalense* Juz.		LC	ANF
	L. perenne L.		FS SB	PEF
Zygophyllaceae	*Tribulus terrestris* L.	C_4	LC	ANF
Rutaceae	*Haplophyllum dauricum* Juss.	C_3	FS SB FO LC SG AF	PEF
Polygalaceae	*Polygala tenuifolia* Willd.	C_3	FS SB FO LC SG	PEF
Euphorbiaceae	*Euphorbia esula* L.	C_3	FS SB FO LC SG	PEF
	E. hirtella Maxim.		LC	ANF

Table 2 (continued)

	Species	C_3/C_4	Community	PFTs
Euphorbiaceae (cont.)	*Euphorbia humifusa* Willd.	C_4	AF	ANF
Violaceae	*Viola dissecta* Ledeb.	C_3	LC SG	PEF
Thymelaeaceae	*Diarthron linifolium* Turcz.	C_3	SG	ANF
	Stellera chamaijasme L.	C_3	FS SB FO LC SG AF	SUC
Umbelliferae	*Bupleurum scorzonerifolium* Willd.	C_3	FS SB FO LC SG AF	PEF
	Saposhnikovia divaricatum (Turcz.) Schischk.	C_3	FS SB FO LC SG SK AF	PEF
Primulaceae	*Androsace longifolia* Turcz.		FS SB FO LC SG SK AF	PEF
	A. septentrionalis L.		FO LC	ANF
	Glaux maritima L.	C_3	LC	ANF
	Primula sibirica Jacq.		LC	PEF
Plumbaginaceae	*Limonium bicolor* O. Kuntze	C_3	FS LC SG AF	PEF
Gentianaceae	*Gentiana dahurica* Fisch.		FS FO LC	PEF
	G. squarrosa Ldb.		FS SB LC SG AF	ANF
	Gentianopsis barbata (Froel.) Ma		FS SB	ANF
Convolvulaceae	*Convolvulus ammannii* Desr.		AF	ANF
Asclepiadaceae	*Cynanchum amplexicaule* Hemsl.	C_3	SG	PEF
Boraginaceae	*Cynoglossum divaricatum* Steph.	C_3	AF SG	ANF
	Eritrichium mandshuricum M. Pop.		FS	PEF
	E. rupestre (Pall.) Bunge		SB FO	PEF
	Lappula myosotis Moench.		FO LC SG SK	ANF
Labiatae	*Phlomis mongolica* Turcz.		LC	PEF
	Ph. tuberosa L.		FS SB SG AF	PEF
	Schizonepeta multifida (L.) Briq.		FS SB FO LC AF	PEF
	Scutellaria baicalensis Georgi	C_3	FS SB FO LC SG	PEF
	S. ikonnikovii Juz.	C_3	LC	PEF
	S. scordiifolia Fisch. *ex* Schrank		SB FO LC SG	PEF
	S. viscidula Bunge		FS	PEF
	Thymus serphyllum L.	C_3	FS FO	SHR
	Th. mongolicum Ronn.		SG AF	SHR
Plantaginaceae	*Plantago asiatica* L.	C_3	LC AF	PEF
	P. depressa Willd.	C_3	LC AF	PEF
Scrophulariaceae	*Cymbaria dahurica* L.		FS SB FO LC SG SK AF	PEF
	Linaria vulgaris Mill.		LC	PEF
	Pedicularis striata Pall.		FS SB FO LC SG	PEF
	Veronica incana L.		FS FO LC	PEF
	V. linarifolia Pall. *ex* Link		SB LC	PEF
	V. sibirica L.		LC SG	PEF
	V. tubiflora L.		LC	PEF
Rubiaceae	*Galium verum* L.	C_3	FS SB FO LC SG	PEF
Valerianaceae	*Patrinia rupestris* Juss.		FS	PEF
Dipsacaceae	*Scabiosa comosa* Fisch. *ex* Roem		FS SB FO LC	PEF
Campanulaceae	*Adenophora coronopifolia* Fisch.		FS SG	PEF
	A. paniculata Nannfeldt		SB SG	PEF
	A. stenanthina (Ldb.) Kitag.		LC	PEF
Compositae	*Arctogeron gramineum* L.		FS	PEF
	Artemisia anethifolia Weber	C_3	LC	ANF
	A. annua L.	C_3	SG LC	ANF
	A. argyi Levl. *et* Vant.	C_3	AF	PEF
	A. commutata Bess.		LC SG SK	PEF
	A. desertorum Spreng.	C_3	AF SG	PEF
	A. dracunculus L.	C_3	FO LC	PEF
	A. eriopoa Bunge		FS SB FO LC SG	PEF

Table 2 (continued)

	Species	C_3/C_4	Community	PFTs
Compositae (cont.)	*Artemisia frigida* Willd.	C_3	FS SB FO LC SG SK AF	SHR
	A. gmelinii Web. *ex* Stechm.		FS SB FO LC SG	SHR
	A. irtramongolica H.C. Fu		SB FO AF	SHR
	A. laciniata Willd.		FS SB FO LC	PEF
	A. japonica Thunb. var. *manshurica* Kom.	C_3	LC	ANF
	A. mongolica Fisch. *ex* Bess.		LC	PEF
	A. pectinata Pall. (*Neopallasia pectinata*) Polsak.	C_3	SG	ANP
	A. scoparia Waldst. *et* Kit.	C_3	FS SB FO LC SK AF	ANF
	A. selengensis Turcz. *ex* Bess.	C_3	LC	PEF
	A. sieversiana Willd.	C_3	AF	ANF
	Aster alpinus L.	C_3	FS SB FO LC SG	PEF
	Crepis crocea (Lamk.) Back.		FS FO	PEF
	Echinops latifolius Tausch		FS SG	PEF
	Filifolium sibiricum Kitam.	C_3	FS SB FO LC SG SK	PEF
	Heteropappus altaicus (Willd.) Novopokr.	C_3	FS SB FO LC SG SK AF	PEF
	Hypochaeris grandiflora Ledeb.	C_4	LC	PEF
	Inula britanica L. var. *sublanata* Kom.	C_3	LC	PEF
	I. japonica Thunb.	C_3	LC	PEF
	Ixeris chinensis Nakai subsp. *graminifolia* Kitag.	C_3	SG	PEF
	I. sonchifolia Bunge	C_3	AF SG	PEF
	Leontopodium leontopodioides Reauv.	C_3	FS SB LC SG	PEF
	Ligularia mongolica (Turcz.) D.C.		SB	PEF
	Olgaea leucophylla Iljin		FS SB LC SG	PEF
	Picris japonica Thunb.	C_3	LC SG SK	ANF
	Rhaponticum uniflorum (L.) D.C.		FS FO LC SG	PEF
	Saussurea japonica (Thunb.) D.C.	C_3	SB SG	PEF
	S. runcinata D.C.	C_3	SB SG	PEF
	Scorzonera austriaca Willd.	C_3	LC SG	PEF
	S. sinensis Lipsch.		SG	PEF
	S. sinensis Lipsch. *et* Krasch.		FS FO	PEF
	Senecio integrifolius Glairv.		FS SB LC SG	PEF
	Serratula centauroides L.		FS SB FO LC SG AF	PEF
	Sonchus brachyotus D.C.		LC	PEF
	Taraxacum mongolicum Hand.	C_3	FO	PEF
	T. ohwianum Kitam.	C_3	LC SG SK FS FO	PEF
	Xanthium strumarium L.	C_3	AF	ANF
	Youngia stenoma (Turcz.) Ledeb.		FO	PEF
	Y. tenuifolia (Willd.) Babcret *et* Stebb.		FS	PEF
Monocotyledoneae				
Cyperaceae	*Carex dahurica* Kukenth.	C_3	LC SG SK FS FO AF	SPG
	C. duriuscula C.A.M.	C_3	SG AF	SPG
	C. enervis C.A.M.	C_4	LC	SPG
	C. korshinskyi Kom.		FS SB FO LC SG AF	SPG
	C. lanceolata Boott		SB LC	SPG
	C. pediformis C.A.M.	C_4	LC SG	SPG
Gramineae	*Achnatherum sibiricum* (L.) Keng		FS SB FO SG SK	HPG
	A. splendens (Trin.) Nevski	C_4	LC	HPG
	Agropyron cristatum (L.) Gaertner	C_3	FS SB FO LC SG SK AF	HPG
	Aneurolepidium secalinum (Georgi) Kitag.		LC	HPG
	Avena fatua L.	C_3	AF	ANG
	Beckmannia syzigachne (Steud.) Fernald	C_3	LC	ANG
	Bromus inermis Leyss.	C_3	FS SB LC	HPG
	Calamagrostis epigeios (L.) Roth	C_3	LC	HPG
	C. purpurea (Trin.) Trin.		LC SG	HPG
	Chloris virgata Sw.	C_4	LC AF	ANG
	Cleistogenes squarrosa (Trin.) Keng	C_4	FS SB FO LC SG SK AF	SPG
	Digitaria ischaemum (Schreb.) Schreb. *ex* Muhl.	C_4	LC SG	ANG
	Echinochloa crus galli (L.) Beauv.	C_4	LC	ANG

Table 2 (continued)

	Species	C_3/C_4	Community	PFTs
Gramineae	*Elymus dahuricus* Turcz.	C_3	LC SG	HPG
	Enneapogon borealis (Griseb.) Honda	C_4	SG SK	ANG
	Eragrostis minor Host.	C_4	LC SG	ANG
	Festuca ovina L.	C_3	FS SB FO	HPG
	F. dahurica L.	C_3	SG	HPG
	Helictotrichon schellianum (Hack.) Kitag.		FS SB LC	HPG
	Hierochloe glabra Trin.	C_4	FS SB LC SG	HPG
	Hordeum brevisubulatum (Trin.) Link	C_3	LC	HPG
	Koeleria cristata (L.) Pers.	C_3	FS SB FO LC SG AF	HPG
	Leymus chinensis (Trin.) Tzvel.	C_3	FS SB FO LC SG SK AF	HPG
	Pennisetum centrasiaticum Tzvel.	C_4	LC SG SK	HPG
	Phragmites communis Trin.	C_3	LC	HPG
	Poa attenuata Trin.		FS SB FO LC SG AF	SPG
	P. pratensis L.	C_3	SG	SPG
	P. sphondylodes Trin. *ex* Bunge		SG	SPG
	Psammochloa villosa Trin.		FO	HPG
	Puccinellia tenuiflora (Turcz.) Scrib. *et* Merr.	C_3	LC	HPG
	Roegneria gmelini Kitag.		LC	HPG
	R. turczaninovii (Drob.) Nevski.	C_3	LC SG	HPG
	Setaria arenaria Kitag.	C_4	LC	ANG
	S. glauca (L.) Beauv.	C_4	FS	ANG
	S. viridis (L.) Beauv.	C_4	AF SG	ANG
	Stipa baicalensis Roshev.	C_3	FS SB	HPG
	S. gobica Roshev.	C_3	SG SK	HPG
	S. grandis P. Smirn.	C_3	FO SG AF	HPG
	S. krylovii Roshev.	C_3	SK AF	HPG
Liliaceae	*Allium anisopodium* Ldb.		FS SB FO LC SG AF	PEF
	A. bidentatum Fisch. *ex* Prokh.		SG	PEF
	A. condensatum Turcz.		FS SB LC SG	PEF
	A. neriniflorum (Herbert.) Baker		SG SK	PEF
	A. polyrrhizum Turcz.	C_3	SB FO LC SG AF	PEF
	A. ramosum L.		FS FO SG	PEF
	A. senescens L.	C_3	FS SB FO LC SG SK AF	PEF
	A. tenuissimum L.	C_3	FS SB FO SG SK AF	PEF
	A. unisopodium L.		SK	PEF
	Anemarrhena asphodeloides Bunge		FS FO SG SK	PEF
	Asparagus davuricus Fisch. *ex* Link.		SG SK	PEF
	A. gibbus Ivan. *ex* Grub.		FO SG AF	PEF
	Hemerocallis minor Mill.		FS SB LC	PEF
	Lilium concolor Salisbury		LC SG	PEF
	L. tenuifolium Fisch.		FS	PEF
Iridaceae	*Iris dichotoma* Pall.	C_3	FS SB LC	PEF
	I. ensata Pall.		SB SG AF	PEF
	I. ruthenica Ker-Gawl.	C_3	LC SG	PEF
	I. tenuifolia Pall.		FS LC SG SK AF	PEF
	I. ventricosa Pall.		SB	PEF

from the moist community to the drier community or from FS to AF, peaked in AF, and was much lower in SB (Fig. 3). The H value of AF was 43 and 45 % greater than those of FS and SB, respectively. The strong linear regression of PFT diversity with community types (from FS to AF) suggested a tight relationship between PFT diversity, community changes, and precipitation.

Discussion

The use of PFT is a popular means for studying the logical links between physiological and life-history strategies at plant level and community structure at population level, for predicting the consequences of global change on vegetation and ecosystem processes at both ecosystem and global levels (Chapin 1993, Paruelo and Lauenroth

1996, Wang 2003). Williams and Markley (1973) and Wang (2002c, 2003) tested the relationships between PFT and land management, because PFT can reflect the tendency of vegetation dynamics. One of the crucial questions is how to define the optimal and comparable PFTs for the regional vegetation types (Pillar 1999, Wang 2003). To define PFT, relevant traits must be selected and an appropriate method must be used to classify plants into types. Morphological and photosynthetic pathway types are the common means for PFT classification at different levels, but these two different traits were misused in many studies (Wang 2003). Morphological functional types brought more details for studying the linkage between species, communities, and ecosystems at local scale, while classification for PFTs by photosynthetic traits (C_3, C_4, and CAM) was coarse and not fit for both the studies (*e.g.* community classification and community structure analysis) and land management (*e.g.* grazing and mowing) at plant community, landscape, and local levels in the steppe region (Wang 2003). This is supported by the observations of this study (Table 2, Figs. 1 and 2).

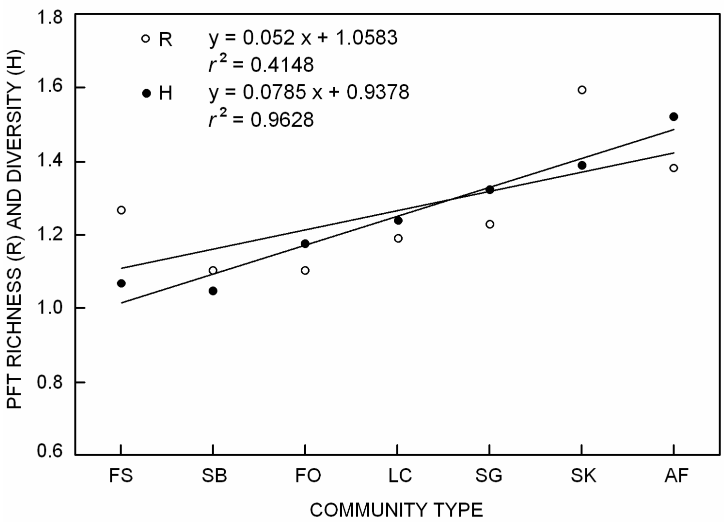

Fig. 3. Plant functional type (PFT) richness (R) index and diversity (D) index in different community types of Inner Mongolia steppe, north China.

Morphological functional types were not only more appropriate for studying the linkage between species, communities, and ecosystems (Smith *et al.* 1993, Wang 2003), but also for steppe management decisions (Wang 2003). Relatively complex geo-relief and landscape in the Xilingol steppe result in vegetation complexities of communities of *Leymus chinensis*, *Filifolium sibiricum*, *Stipa baicalensis*, and *Artemisia frigida* (Li *et al.* 1988, Zhao *et al.* 1988). Morphological functional types are well fit for depicting the differences between these community types (Li *et al.* 1988, Zhao *et al.* 1988) and reflect their seasonal dynamics in the steppe. These may be supported by the observations that species numbers of both PEF and HPG dropped significantly from LC to SK community and from moist to dry seasons, while the species numbers of SPG and SHR types increased remarkably (Fig. 2). Species of ANF, SHR, and SUC types were the main plants composing the dry steppe communities, and probably due to these types the PFTs can use the limited water resource in rainy seasons and survive the dry seasons in the form of dormant seeds (Li *et al.* 1988, Wang 2002a,b,c, 2003). PFT differences among the communities can also be supported by the variables of the R and H indexes observed in this study (Fig. 3). The increase of PFT diversity index from the moist communities to the drier ones was mainly due to the increasing evenness index of the drier communities that indicates that the drier communities are capable to adapt to the drought. This suggests that morphological functional types in the steppe region can indicate both spatial and temporal changes in scales of steppe ecosystem communities.

Photosynthetic pathway type is a too coarse trait for defining PFTs at both the community level and local scale, because of the high C_3 presence and only few families in which C_4 species occur (Wang 2003). This is supported by the observations of this study (Fig. 1) and of the previous research (Wang 2002a,b,c, 2003), but photosynthetic pathway types may be more fit for detecting the PFTs changes at global scale (Wang 2004). This study and the previous ones (McIntyre *et al.* 1999, Pillar 1999) suggest that the identification of optimal PFTs depends on the plant attribute selection and the study scales.

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