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Photosynthetic pathway and morphological functional types in the vegetation from North-Beijing agro-pastoral ecotone, China

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Abstract

Photosynthetic pathways (C_3, C_4, and CAM) and morphological functional types were identified for the species from vegetation in agro-pastoral ecotone, North Beijing. 792 vascular plant species (nearly half of the total species in the ecotone), in 66 families and 317 genera, were identified with C_3, C_4, and CAM photosynthesis (Table 1). 710 species (90 % of the identified species in Table 1) in 268 genera and 64 families were found with C_3 photosynthesis, 68 species (9 % of the total identified species) in 40 genera and 7 families with C_4 photosynthesis, and 14 species in 4 genera and 1 family with CAM photosynthesis. *Gramineae* is the leading family with C_4 photosynthesis (43 species), *Cyperaceae* ranks the second (16 species) followed by *Chenopodiaceae* (5 species). The significant increase of C_4 proportion (C_4/total species) with land deterioration suggested the plants of this type are remarkably responsive to land use in the ecotone. 792 species were classified into nine morphological functional types and the changes of most of these types (*e.g.* perennial forbs (PEF), annual grasses (ANG), and annual forbs (ANF)) were consistent with habitats and vegetation dynamics in the agro-pastoral ecotone. Hence the photosynthetic pathways, combined with the morphological functional types, are efficient indications for studying the linkage between species and ecosystems in the ecotone.

Additional key words: C_3, C_4, and CAM species; land use.

Introduction

Plant functional types (PFTs), mainly including photosynthetic pathways (C_3, C_4, and CAM) and morphological functional types, have become popular means for studying the logical links between physiological and life-history strategies at plant level, as well as ecological processes at ecosystem and global level (Chapin 1993, Paruelo and Lauenroth 1996, Wang 2003). PFTs are defined on the basis of plant morphological and physiological traits, life history, and bioclimatic tolerance, relying on the research intentions and studying scales (Wang 2003). Most of studies on PFTs were focused on photosynthetic pathway identification (Williams and Markley 1973, Downton 1975, Raghavendra and Das 1978, Waller and Lewis 1979, Redmann *et al.* 1995, Wang 2002a, Liu *et al.* 2004), morphological functional type classifications (Smith *et al.* 1993, Aguiar *et al.* 1996, Paruelo and Lauenroth 1996, Scholes *et al.* 1997, Diaz *et al.* 1998, Mclntyre *et al.* 1999, Duckworth *et al.* 2000), as well as relationships between PFTs and global changes (Teeri and Stowe 1976, Teeri *et al.* 1980, Collins and Jones 1985, Takeda and Hakoyama 1985, Ueno and Takeda 1992, Box 1996, Cramer 1997, Diaz and Cabido

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Abbreviations: ANF = annual forbs; ANG = annual grasses; ARO = arbor; DC = disturbed and cultivated land; FO = forest; HPG = high perennial grasses; HYD = hydrophytes; PEF = perennial forbs; PFTs = plant functional types; RL = rangeland; SH = shrubs; SHR = shrubs; SL = saline land; SPG = short perennial grasses; SS = sand soil; SUC = succulents; WE = wetland; WO = woodland.
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1997, Ehleringer *et al.* 1997, Leemans 1997, Yin and Li 1997, Collatz *et al.* 1998, Keeley 1998, Pyankov *et al.* 2000, Wang 2003, 2004). These works provide strong evidence that the abundance of PFTs correlates with different vegetation, land use, and climate attributes on local, region, and global scales. Consequently, the photosynthetic and morphological functional types must be taken into account in making land management decisions, *e.g.* seasonal development patterns (warm season *versus* cool season) (Williams and Markley 1973), grazing succession (Wang 2002a), as well as land use.

North-Beijing agro-pastoral ecotone lies approximately in the ecological transitional zone between the eastern farming region and northern pastoral areas in North China. The location of this ecotone makes it a vast natural ecological shelterbelt and water conservation reservoir for the eastern agricultural area but the ecotone is ecologically sensitive due to its transitional position. Increasing demands for agricultural land and need for livestock led to deterioration of land. Land use, especially over-farming and overgrazing, have stepped up the deterioration of fragile ecological environment (Shen 2001). The substantial reduction in canopy cover throughout the region, combined with land desertification, has resulted in considerable changes in vegetation, *e.g.* plant composition, distribution, and PFTs. There was little research about PFTs in this ecotone. The patterns of photosynthetic and morphological functional types in this region remain unclear. We investigated the composition of PFTs and their ecological roles in this ecotone. The results may contribute to better understanding of the relationships among the changes of PFTs, land use, and climate changes.

Materials and methods

We conducted the study in North-Beijing (40°46′~42°61′N, 113°55′~118°31′E), a typical agro-pastoral ecotone in Northern China. This region consists of three parts, south-east Mongolian plateau, northern part of Hua-bei plain, and north-east Yan Mountain, which covers about 60 000 km^2, on average 1 200 m a.s.l., varying from 800 m in the south-east to 1 600 m in the north-west. Most of the region is covered by chestnut, sandy, saline, and gray cinnamon soils. The main determinants of the climate in this region are the Mongolian anticyclone and moist Pacific air mass. In winter, the region is dominated by an intense Mongolian anticyclone. The steep pressure system produces strong westerly flow of cold and dry continental air at the surface. 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 to four months. The mean annual air temperature ranges from 0 to 10 °C, varying from –21 °C in January to 26 °C in July. Moisture gradient is very steep, with annual precipitations varying from 250 mm in the north-west to 500 mm in the south-east. Precipitations are not distributed evenly over the growing season, of which 70 % falls between June and August.

Floristic species were obtained from references published from 1980 to 2003 (Commissione Redactorum Flora Intramongolicae 1980, Beijing Normal University 1984, Commissione Redactorum Flora Hebeiensis 1986, Li *et al.* 1988, Zhang and Liu 1992, Liu 1993, Wang 2002b,c,d, 2003).

Photosynthetic pathway types for the native species were determined by stable carbon isotope ratio ($\delta^{13}C$) and references from 1985 to 2004 (*e.g.* Takeda and Hakoyama 1985, Li 1993, Redmann *et al.* 1995, Yin and Li 1997, Pyankov *et al.* 2000, Wang 2002b,c,d, 2003, Liu *et al.* 2004). Shoot tissue was collected from field-grown plants, dried at 80 °C for 48 h and ground. Stable carbon isotope ratio ($\delta^{13}C$) in the plant tissue was determined by using *Delta^{plus} XP* mass spectrograph. Plants with $\delta^{13}C$ values above –19 ‰ were considered to have C_4 photosynthesis, while $\delta^{13}C$ values lower than –21 ‰ to have C_3 photosynthesis (Redmann *et al.* 1995). Plants identified in the region were classified into both photosynthetic pathway types by the physiological attributes ($\delta^{13}C$) and morphological functional types, *e.g.* arbor (ARO), shrubs (SHR), high perennial grasses (HPG), short perennial grasses (SPG), annual grasses (ANG), annual forbs (ANF), perennial forbs (PEF), hydrophytes (HYD), and succulents (SUC) by the morphological attributes (Table 1). Habitats were classified into forest (FO), woodland (WO), shrubs (SH), wetland (WE), disturbed and cultivated land (DC), rangeland (RL), sand soil (SS), and saline land (SL).

Results

Floristic composition of photosynthetic pathway types: 792 vascular species (nearly half of the total species in the ecotone), in 66 families and 316 genera, were collected (Table 1). Of these 792 species, 5 species were in *Gymnospermae* and 787 species in *Angiospermae*. 68 % (534 of 787) were found in *Dicotyledoneae*, *e.g. Compositae* (96 species), *Leguminosae* (47 species), *Rosaceae* (43 species), *Ranunculaceae*

(37 species), *Polygonaceae* (31 species), *Chenopodiaceae* (27 species), *Labiatae* (23 species), and *Scrophulariaceae* (22 species). 32 % (253 of 787) were found in *Monocotyledoneae*, *e.g. Gramineae* (150 species), *Cyperaceae* (51 species), *Liliaceae* (28 species), and *Iridaceae* (7 species). As regards the composition of photosynthetic pathway types, 710 species (90 % of the identified species in Table 1) in 268 genera and 64 families were found with C_3 photosynthesis, 68 species (9 % of the total) in 40 genera and 7 families with C_4 photosynthesis, and 14 species in 4 genera and 1 family with CAM photosynthesis (Table 1). Few families were found to possess of C_4 species, *e.g. Gramineae* (43 species), *Cyperaceae* (16 species), *Chenopodiaceae* (5 species), and only 1 species in each of *Amaranthaceae*, *Euphorbiaceae*, *Portulacaceae,* and *Zygophyllaceae*.

The occurrence of C_4 species was common in graminaceous plants (grasses and sedges), which make up 74 % of the total C_4 species, followed by *Chenopodiaceae* (20 %). *Gramineae* is the most abundant family in flora (122 species in 64 genera) and 43 species in 29 genera (45 % of the total amount) were identified as having C_4 photosynthesis. These 43 C_4 grasses were found in different habitats, 23 species in RL, 22 species in DC, 11 species in WE, 5 species in SS, 2 species in WO, and 2 species in SL, respectively. 41 *Cyperaceae* species in 10 genera were identified in the region. 16 species in 4 genera had C_4 photosynthesis. The number of sedge C_4 species found in this zone was larger than that in Inner Mongolia steppe (2 species in 1 genera) (Wang 2003) and Northeast China grasslands (12 species in 6 genera) (Yin and Li 1997). Of this 16 sedge C_4 species, 13 species were in WE, 11 species in DC, 4 species in RL, and 1 species in WO. No sedge C_4 species was found in SS, SL, SH, and FO. Of the 7 plant families with C_4 photosynthesis in the region, *Chenopodiaceae* ranks the third in abundance. 5 species in 3 genera were C_4 plants, which was less than those found in *Gramineae* and *Cyperaceae*. For the habitats of 5 C_4 chenopods, 4 species were found in DC, 2 species in each of RL, SL, and SS, 1 species in WE.

The occurrence of C_4 plants and C_4 proportion were significantly related to habitats in the ecotone (Fig. 1). 42 species were found in DC (17 % of the total species), 29 species in RL (6 % of the total), 28 species in WE (13 % of the total), 10 species in SS (9 %), 4 species in SL (20 %), and 3 species in WO (2.6 %). No C_4 species were found in FO and SH. DC boasts the highest number of total C_4 species, while SL ranks first in C_4 proportion.

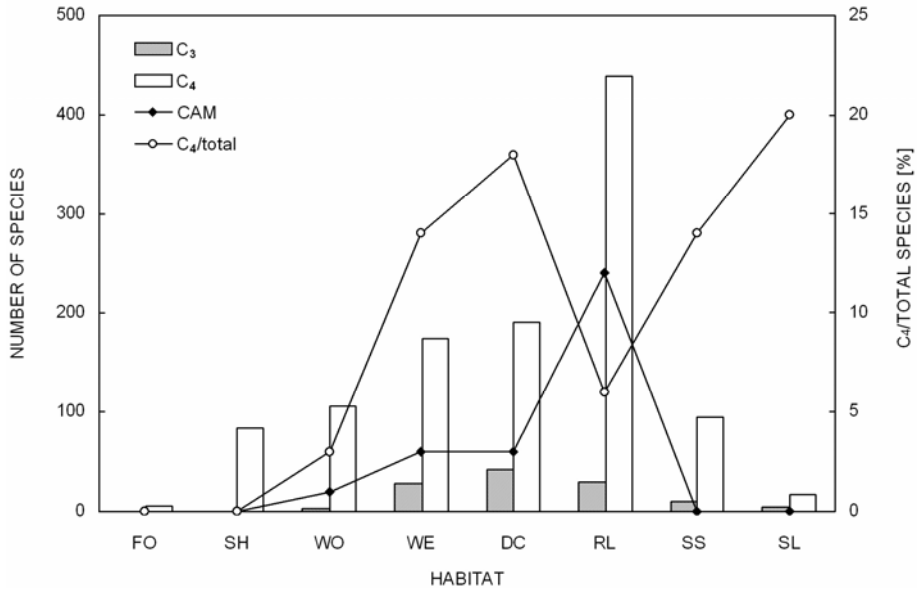

Fig. 1. Numbers of photosynthetic pathway types (C_3, C_4, and CAM) in different habitats in agro-pastoral ecotone, Northern Beijing. Habitats: FO = forest, WO = woodland, SH = shrubs, WE = wetland, DC = disturbed and cultivated land, RL = rangeland, SS = sand soil, SL = saline land.

Morphological functional types: We classified the species in the region into 9 functional types (ARO, SHR, HPG, SPG, ANG, ANF, PEF, HYD, and SUC) after their plant morphological attributes and life-span (Table 1 and Fig. 2). Of the total 792 species in Table 1, 46 % was PEF type, 21 % ANF type, 12 % HPG type, 9 % SHR type, and 5 % ANG type followed by SPG, ARO, SUC, and HYD with 2 % in each of them. The total percentage of grass species, including HPG, SPG, ANG, and some HYD species was about 19 % and these grass types make up about 80 % of forage production in the rangelands in the region. Most grasses are the dominant species, *e.g.*

Leymus chinensis (Trin.) Tzvel., *Stipa krylovii* Roshev., *Cleistogens squarrosa* (Trin.) Keng, and *Calamagrostis epigeios* (L.) Roth., which constitute over 80 % of the biomass. 26 % of the total species were ANF and ANG, *e.g. Salsola collina* Pall., *Corispermum declinatum* Steph. *ex* Stev., *Setaria viridis* (L.) Beauv., and most of these species were also dominant species in sandy soil, old field, and overgrazed grassland.

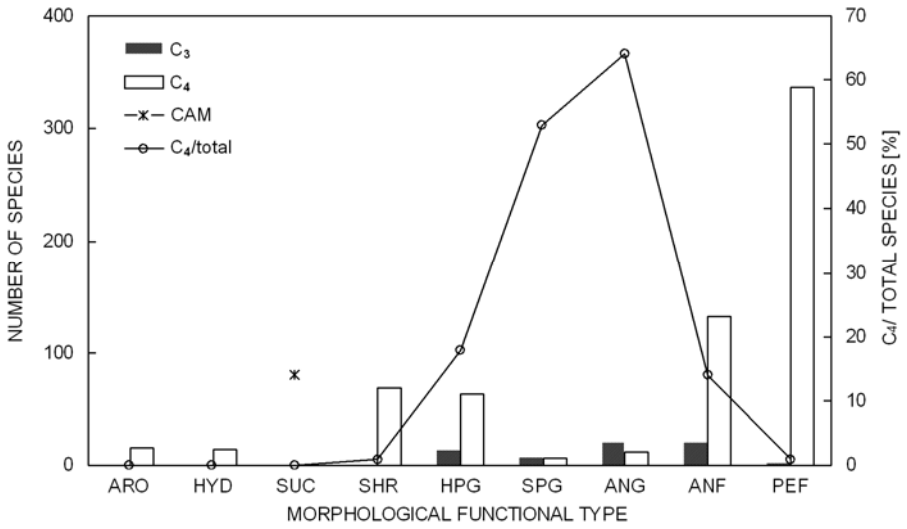

Fig. 2. Photosynthetic pathway compositions in morphological functional types in the agro-pastoral ecotone, Northern Beijing.

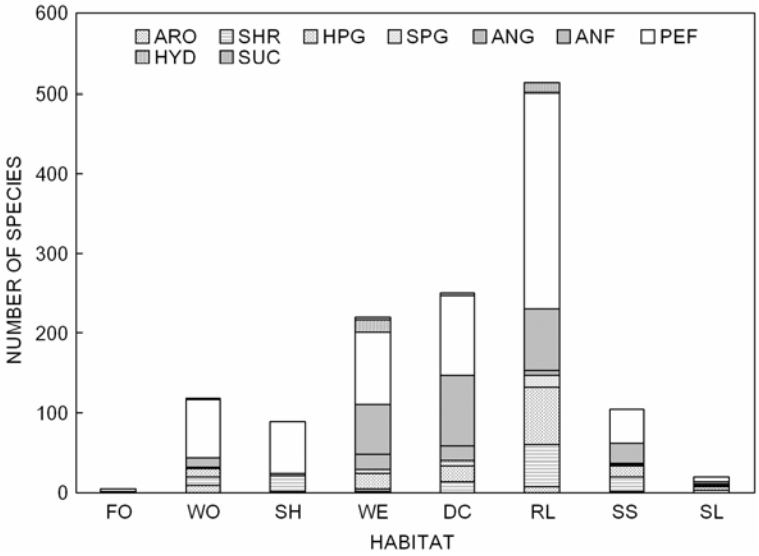

Fig. 3. The morphological functional type compositions in different habitats in the agro-pastoral ecotone, Northern Beijing. Habitats: FO = forest, WO = woodland, SH = shrubs, WE = wetland, DC = disturbed and cultivated land, RL = rangeland, SS = sand soil, SL = saline land.

The responses of morphological functional type composition to land use were remarkable in the region (Fig. 3). Species proportion (species/total species) of PEF and HPG decreased from RL to DC and from RL to SS, while that of ANF and ANG increased considerably. The relative abundance for ANG and ANF in the DC and SS indicated that the environmental stresses were higher in these two habitats.

Photosynthetic pathway compositions varied considerably in these morphological functional types (Fig. 2). C_4 abundances in morphological functional type were relatively higher in the grass functional types, *e.g.* 18 % in HPG, 53 % in SPG, and 64 % in ANG as well as in ANF type (14 %), but much lower in SHR (1 %) and PEF (less than 1 %).

Table 1. Photosynthetic pathways (C_3, C_4, and CAM) and morphological functional types in agro-pastoral ecotone, Northern Beijing. Nomenclature follows Kitagawa (1979). Morphological functional types, *e.g.* arbor (ARO), shrubs (SHR), high perennial grasses (HPG), short perennial grasses (SPG), annual grasses (ANG), annual forbs (ANF), perennial forbs (PEF), hydrophytes (HYD) and succulents (SUC). Habitats: FO = forest, WO = woodland, SH = shrubs, WE = wetland, DC = disturbed and cultivated land, RL = rangeland, SS = sand soil, SL = saline land.

Family	Species	C_3/C_4	PFTs	Habitat
Gymnospermae				
Cupressaceae	*Sabina vulgaris* Ant.	C_3	SHR	SS
Ephedraceae	*Ephedra equisetina* Bunge	C_3	SHR	RL SS
	E. monosperma Gmel. *ex* Mey.	C_3	SHR	RL SS
	E. sinica Stapf	C_3	SHR	RL SS
Pinaceae	*Picea meyeri* Rehd. *et* Wils.	C_3	ARO	SS
Angiospermae				
Dicotyledoneae				
Amaranthaceae	*Achyranthes bidentata* Bl.	C_3	PEF	WE
	Amaranthus retroflexus L.	C_4	ANF	DC
	A. roxburghianus Kung	C_3	ANF	DC
Asclepiadaceae	*Cynanchum bungei* Decne	C_3	PEF	DC RL SH WE
	C. paniculatum (Bge.) Kitag.	C_3	PEF	DC RL
	C. thesioides (Freyn) K. Schum.	C_3	PEF	DC WE
	Metaplexis japonica (Thunb.) Makino	C_3	PEF	DC RL SH WE
Berberidaceae	*Berberis amurensis* Rupr.	C_3	SHR	SH RL
	B. poiretii Schneid.	C_3	SHR	RL DC
	Caulophyllum robustum Maxim.	C_3	PEF	WO WE
Betulaceae	*Betula gmelinii* Bunge	C_3	SHR	SS
	B. platyphylla Suk.	C_3	ARO	RL
Boraginaceae	*Asperugo procumbens* L.	C_3	ANF	RL
	Cynoglossum divaricatum Steph.	C_3	PEF	DC SS
	Lappula consanguinea (Fisch. *et* C.A. Mey.) Gurke	C_3	ANF	SH RL DC
	L. myosotis V. Wolf	C_3	ANF	DC RL
	L. redowskii (Horn.) Green	C_3	ANF	RL
	L. heteracantha (Ledeb.) Gurke	C_3	ANF	RL SS DC
	Lithospermum erythrohizon Sieb. *et* Zucc.	C_3	PEF	DC SH
	L. arvense L.	C_3	ANF	RL DC
	Lycopsis orientalis L.	C_3	ANF	DC WE
	Mertensia davurica (Sims) G. Don.	C_3	PEF	RL
	Messerschmidia rosmarinifolia Willd	C_3	PEF	SS SL
	Trigonotis amblyosepala Nakai *et* Kitag.	C_3	ANF	WE RL
	T. peduncularis (Trev.) Benth	C_3	ANF	DC
Campanulaceae	*Adenophora elata* Nannf.	C_3	PEF	RL SH
	A. gmelinii (Spreng.) Fisch.	C_3	PEF	RL
	A. polyantha Nakai	C_3	PEF	RL SH
	A. stenanthina (Ledeb.) Kitag.	C_3	PEF	RL
	A. teraphylla (Thunb.) Fisch.	C_3	PEF	RL
	Campanula punctata Lamk.	C_3	PEF	RL SH
Caryophyllaceae	*Cerastium arvense* L.	C_3	PEF	RL DC
	C. caespitosum Gilib.	C_3	ANF	RL
	Cucubalus baccifer L.	C_3	PEF	SH RL WE
	Dianthus chinensis L.	C_3	PEF	RL SH
	D. superbus L.	C_3	PEF	RL WO
	Gypsophila acutifolia Fisch.	C_3	PEF	RL
	Lychnis cognate Maxim.	C_3	PEF	WO SH

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Caryophyllaceae (cont.)	*Lychnis fulgens* Fisch.	C_3	PEF	WO SH
	Moehringia lateriflora (L.) Fenzl	C_3	PEF	WO WE
	Sagina japonica (Sw.) Ohwi	C_3	ANF	WE
	Silene conoidea L.	C_3	ANF	RL DC
	S. firma Sieb. *et* Zucc.	C_3	ANF	RL
	S. jenisseensis Willd.	C_3	PEF	RL
	S. repens Patr.	C_3	PEF	SS RL WE SH
	Stellaria bungeana Fenzl	C_3	PEF	RL SH
	S. gypsophiloides Fenzl	C_3	PEF	SS
	S. infracta Maxim.	C_3	PEF	RL
Celastraceae	*Euonymus alatus* (Thunb.) Sieb.	C_3	SHR	RL SH
	E. bungeanus Maxim.	C_3	SHR	RL DC
Chenopodiaceae	*Agriophyllum squarrosum* (L.) Moq.	C_3	ANF	WE SS
	Atriplex patens (Litv.) Iljin	C_3	ANF	WE
	A. sibirica L.	C_4	ANF	WE RL DC
	Axyris amaranthoides L.	C_3	ANF	WE RL DC
	Bassia dasyphylla (Fisch. *et* Mey.) O. Kuntze	C_3	ANF	SS
	Chenopodium acuminatum Willd.	C_3	ANF	DC WE
	C. album L.	C_3	ANF	DC
	C. aristatum L.	C_3	ANF	RL DC
	C. foetidum Schrad.	C_3	ANF	RL DC WE
	C. glaucum L.	C_3	ANF	SL WE DC
	C. hybridum L.	C_3	ANF	RL DC
	C. serotinum L.	C_3	ANF	DC WE
	Corispermum candelabrum Iljin	C_3	ANF	WE SS
	C. chinganicum Iljin	C_3	ANF	SS
	C. declinatum Steph. *ex* Stev.	C_3	ANF	SS RL
	C. puberulum Iljin.	C_3	ANF	SS SL
	C. stauntonii Moq.	C_3	ANF	SL SS
	Kochia prostrata (L.) Schrad.	C_4	SHR	RL SS
	K. scoparia (L.) Schrad.	C_4	ANF	DC
	K. scoparia (L.) Schrad. var. *sieversiana* (Pall.) Ulbr. *ex* Aschers. *et* Gradbn.	C_4	ANF	SL DC
	Salsola collina Pall.	C_4	ANF	DC SS SL
	S. komarovii Iljin	C_3	ANF	WE SS
	S. ruthenica Iljin	C_3	ANF	SS
	Suaeda corniculata (C. A. Mey.) Bge.	C_3	ANF	SL
	S. glauca Bge.	C_3	ANF	DC WE SL
	S. liaotungensis Kitag.	C_3	ANF	SL
	S. salsa (L.) Pall.	C_3	ANF	SL
Chloranthaceae	*Chloranthus japonicus* Sieb.	C_3	PEF	RL WO
Compositae	*Achillea alpina* L.	C_3	PEF	RL DC
	A. asiatica Serg.	C_3	PEF	RL WE
	A. ptarmicoides Maxim.	C_3	PEF	RL SH
	Anaphalis hancokii Maxim.	C_3	PEF	RL WO
	Artemisia anethoides Mattf.	C_3	ANF	SL
	A. annua L.	C_3	ANF	DC RL
	A. apiacea Hance	C_3	ANF	RL DC
	A. argyi Lévl. *et* Vant.	C_3	PEF	WO SH RL DC
	A. brachyloba Franch.	C_3	SHR	RL
	A. capillaris Thunb.	C_3	PEF	DC RL
	A. commutata Bess	C_3	PEF	RL SS
	A. desertorum Spreng	C_3	PEF	RL
	A. dracunculus L.	C_4	PEF	DC RL

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Compositae (cont.)	*Artemisia eriopoda* Bge.	C_3	PEF	RL WO SH
	A. giraldii Pamp.	C_3	PEF	RL
	A. halodendron Turcz.	C_3	SHR	SS
	A. igniaria Maxim.	C_3	PEF	RL SH
	A. integrifolia L.	C_3	PEF	RL DC
	A. japonica Thunb.	C_3	PEF	RL WO SH
	A. klementze Krasch.	C_3	SHR	SS
	A. laciniata Willd.	C_3	PEF	RL SH
	A. latifolia Ledeb.	C_3	PEF	RL WO SH
	A. lavandulaefolia DC.	C_3	PEF	RL SH DC
	A. mongolica Fisch.	C_3	PEF	RL SS
	A. scoparia Wald. *et* Kit.	C_3	ANF	SS WE RL
	A. selengensis Turcz.	C_3	PEF	WO DC WE
	A. subdigitata Mattf.	C_3	PEF	RL WE
	A. subulata Nakai	C_3	PEF	RL DC
	A. tanacetifolia L.	C_3	PEF	RL
	Aster ageratoides Turcz.	C_3	PEF	RL
	A. alpinus L.	C_3	PEF	RL SH
	A. tataricus L. f.	C_3	PEF	RL SH
	Bidens bipinnata L.	C_3	ANF	DC RL
	B. cernua L.	C_3	ANF	DC
	B. pilosa L.	C_3	ANF	DC
	Callistephus chinensis (L.) Ness	C_3	ANF	RL SH
	Carduus crispus L.	C_3	ANF	DC RL
	Centipeda minima (L.) A. Br. *et* Ascher.	C_3	ANF	WE
	Cirsium pendulum Fisch.	C_3	ANF	RL
	Dendranthema chanetii (Lévl.) Shih	C_3	PEF	RL WE SH
	D. naktongense (Nakai) Tzvel.	C_3	PEF	RL SH
	Erigeron kamtschaticus DC.	C_3	ANF	SS
	E. acer L.	C_3	ANF	WE RL
	Echinops dissechtus Kitag.	C_3	PEF	SS RL
	E. gmelini Turcz.	C_3	PEF	RL
	E. pseudosetifer Kitag.	C_3	PEF	RL DC
	Filifolium sibiricum (L.) Kitam.	C_3	PEF	RL
	Gnaphalium baicalense Kirp.	C_3	ANF	WE
	Hemistepta lyrata Bge.	C_3	ANF	RL DC
	Heteropappus altaicus (Willd.) Novopokr.	C_3	PEF	RL DC
	Hieracium umbellatum L.	C_3	PEF	RL WO
	Inula britanica L.	C_3	PEF	WE DC
	I. japonica Thunb.	C_3	PEF	DC WE RL
	I. linearifolia Turcz.	C_3	PEF	RL DC WE
	Ixeris chinensis (Thunb.) Nakai	C_3	PEF	DC RL
	I. sonchifolia Hance	C_3	PEF	RL DC
	Kalimeris incise (Fisch.) DC.	C_3	PEF	WE RL SH
	K. integrifolia Turcz.	C_3	PEF	DC RL
	K. mongolica (Franch.) Kitam.	C_3	PEF	WE DC
	Leontopodium leontopodiodes (Willd.) Beauv.	C_3	PEF	RL SS
	L. longifolium Ling	C_3	PEF	RL WE SH
	L. smithianum Hand.-Mazz.	C_3	PEF	RL
	Ligularia fischeri (Ledeb.) Turcz.	C_3	PEF	RL WE SH
	L. mongolica DC.	C_3	PEF	RL
	L. sibirica (L.) Cass.	C_3	PEF	WE SH
	Neopallasia pectinata (Pall.) Poljak.	C_3	ANF	RL SS
	Olgaea leucophylla (Turcz.) Iljin	C_3	PEF	SS RL
	O. tangutica Iljin	C_3	PEF	DC RL SS

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Compositae (cont.)	*Picris japonica* Thunb.	C_3	ANF	DC WO RL
	Rhaponticum uniflorum (L.) DC.	C_3	PEF	RL
	Saussurea amara (L.) DC.	C_3	PEF	DC
	S. chinnampoensis Lévl. *et* Vant	C_3	ANF	WE RL
	S. iodostegia Hance	C_3	PEF	RL
	S. japonica (Thunb.) DC.	C_3	ANF	RL DC
	S. mongolica Franch.	C_3	PEF	WO RL
	S. runcinata DC.	C_3	PEF	SL
	S. ussuriensis Maxim.	C_3	PEF	WO SH
	Scorzonera albicaulis Bge.	C_3	PEF	DC RL
	S. austriaca Willd.	C_3	PEF	RL
	S. divaricata Turcz.	C_3	PEF	RL
	Senecio flammeus Turcz. *ex* DC.	C_3	PEF	RL SH
	S. nemorensis L.	C_3	PEF	WO RL
	Serratula centauroides L.	C_3	PEF	DC RL
	S. coronata L.	C_3	PEF	RL WE
	Synurus deltoides (Ait.) Nakai	C_3	PEF	DC
	Taraxacum asiaticum Dahlst.	C_3	PEF	RL
	T. erythropodium Kitag.	C_3	PEF	RL SL
	T. mongolicum Hand.-Mazz.	C_3	PEF	DC
	T. sinicum Kitag.	C_3	PEF	SL
	Tephroseris kirilowii Turcz.	C_3	PEF	RL DC
	T. subdentata (Bge.) Holub	C_3	PEF	WE RL
	Xanthium sibiricum Patrin *ex* Willd.	C_3	ANF	DC
	Youngia japonica (L.) DC.	C_3	ANF	RL DC
	Y. stenoma (Turcz.) Ledeb.	C_3	PEF	SL RL
	Y. tenuifolia (Willd.) Babc. *et* Stebb.	C_3	PEF	RL SH
Convolvulaceae	*Convolvulus ammannii* Desr.	C_3	PEF	RL DC
	C. arvensis L.	C_3	PEF	DC
	C. tragacanthoides Turcz.	C_3	SHR	RL SL
	Cuscuta chinensis Lam.	C_3	PEF	RL DC SH SS
	Pharbitis hederacea (L.) Choisy	C_3	ANF	DC
	P. nil (L.) Choisy	C_3	ANF	RL DC
Crassulaceae	*Orostachys fimbriatus* (Turcz.) Berger	CAM	SUC	RL DC
	O. malacophyllus (Pall.) Fisch.	CAM	SUC	RL
	O. minutus (Kom.) Berg.	CAM	SUC	DC
	Tillaea mongolica (Franch.) S. H. Fu	CAM	SUC	RL
	Rhodiola dumulosa (Franch.) S. H. Fu	CAM	SUC	RL
	R. kirilowii (Regel) Regel	CAM	SUC	RL
	R. rosea L.	CAM	SUC	WO RL WE
	Sedum aizoon L.	CAM	SUC	WE RL
	S. pallescenes Freyn.	CAM	SUC	RL
	S. sarmentosum Bge.	CAM	SUC	WE
	S. spectabile Boreau.	CAM	SUC	RL
	S. stellariifolium Franch.	CAM	SUC	RL WE
	S. tatarinowii Maxim.	CAM	SUC	RL
	S. verticillatum L.	CAM	SUC	RL DC
Cruciferae	*Berteroella maximowiczii* (Palib.) O. E. Schulz	C_3	ANF	RL WE
	Descurainia sophia (L.) Webb. *ex* Prantl	C_3	ANF	DC
	Dontostemon dentatus (Bge.) Ledeb.	C_3	ANF	RL DC
	D. eglandulosus (DC.) Ledeb.	C_3	PEF	RL
	D. micranthus C. A. Mey.	C_3	ANF	RL DC
	Eruca sativa Gars.	C_3	ANF	DC
	Hesperis oreophila Kitag.	C_3	PEF	RL

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Cruciferae (cont.)	*Hesperis trichosepala* Turcz.	C_3	ANF	RL
	Lepidium apetalum Willd.	C_3	ANF	RL DC
	L. latifolium var. *affine* C. A. Mey.	C_3	PEF	SS SL DC WE
	Orychophragmus violaceus (L.) O. E. Schulz	C_3	ANF	DC
	Ptilotrichum tenuifolium (Stech.) C. A. Mey.	C_3	PEF	RL
Dipsacaceae	*Scabiosa comosa* Fisch. *et* Schult	C_3	PEF	RL SS
	S. tschiliensis Grün	C_3	PEF	RL
Euphorbiaceae	*Euphorbia esula* L.	C_3	PEF	RL SS
	E. humifusa Willd.	C_4	ANF	DC WE SS
Fagaceae	*Quercus acutissima* Carr.	C_3	ARO	WO
	Q. dentata Thunb.	C_3	ARO	WO
	Q. mongolica Fisch.	C_3	ARO	WO
	Q. variabilis Bl.	C_3	ARO	WO
Gentianaceae	*Centaurium meyeri* (Bge.) Druce	C_3	ANF	WE DC
	Gentiana dahurica Fisch.	C_3	PEF	RL
	G. triflora Pall.	C_3	PEF	RL SH
	Halenia sibirica Borkh.	C_3	ANF	RL
	Lomatogonium carinthiaca A. Br.	C_3	ANF	RL
Geraniaceae	*Erodium stephanianum* Willd.	C_3	ANF	DC RL
	Geranium dahuricum DC.	C_3	PEF	RL SH
	G. maximowiczii Regel *et* Maack.	C_3	PEF	RL WO
	G. pretense L.	C_3	PEF	WE RL
	G. wilfordii Maxim.	C_3	PEF	RL WO
Labiatae	*Ajuga iliata* Bge.	C_3	PEF	RL WO DC
	A. multiflora Bge.	C_3	PEF	RL WE
	Amethystea caerulea L.	C_3	ANF	DC WE SS
	Clinopodium chinensis (Benth.) O. Ktze.	C_3	PEF	RL DC
	Lenourus japonicus Houtt.	C_3	ANF	RL DC
	L. macranthus Maxim.	C_3	PEF	SH WO RL
	L. sibiricus L.	C_3	ANF	RL WO SS
	Mentha haplocalyx Briq.	C_3	PEF	WE
	Phlomis detosa Franch.	C_3	PEF	RL WO
	P. mongolica Turcz.	C_3	PEF	RL
	P. tuberosa L.	C_3	PEF	RL
	P. umbrosa Turcz.	C_3	PEF	WO RL
	Salvia miltiorrhiza Bge.	C_3	PEF	RL DC WO
	S. umbratica Hance	C_3	PEF	RL DC
	Schizonepeta multifida (L.) Briq.	C_3	PEF	RL
	S. tenuifolia (Benth.) Briq.	C_3	ANF	RL DC
	Scutellaria baicalensis Georgi	C_3	PEF	RL DC
	S. dependens Maxim.	C_3	ANF	WE WO
	S. macrodonta Hand.-Mazz.	C_3	PEF	RL WE
	S. regeliana Nakai.	C_3	PEF	WE
	S. scordifolia Fisch. *ex* Schrank	C_3	PEF	RL WE
	Thymus mongolicus Ronn.	C_3	SHR	RL DC
	T. quinquecostatus Celak.	C_3	SHR	RL DC
Leguminosae	*Aeschynomne indica* L.	C_3	ANF	WE RL DC
	Astragalus capillipes Fisch.	C_3	PEF	SS RL
	A. dahuricus (Pall.) DC.	C_3	ANF	RL DC SS
	A. galactites Pall.	C_3	PEF	RL DC
	A. melilotoides Pall.	C_3	PEF	RL DC SH
	Astragalus membranaceus (Fisch.) Bge.	C_3	PEF	RL DC
	Caragana arborescens (Amm.) Lam.	C_3	SHR	SH

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Leguminosae (cont.)	*Caragana intermedia* Kuang *et* H.C. Fu	C_3	SHR	SS
	C. jubata (Pall.) Poir.	C_3	SHR	RL SH
	C. leveillei Kom.	C_3	SHR	RL DC SH
	C. microphylla Lam.	C_3	SHR	RL DC SH
	C. pekinensis Kom.	C_3	SHR	RL DC SH
	C. pygmaea (L.) DC.	C_3	SHR	RL SS
	C. rosea Turcz.	C_3	SHR	RL DC SH
	C. sinica (Buhoz) Rehd.	C_3	SHR	SH
	C. stenophylla Pojark.	C_3	SHR	RL SS
	Gueldenstaedtia multiflora Bge.	C_3	PEF	DC RL
	G. stenophylla Bge.	C_3	PEF	WE RL DC
	G. verna (Georgi) Boriss.	C_3	PEF	RL
	Hedysarum alpinum L.	C_3	PEF	RL
	H. gmelinii Ledeb.	C_3	PEF	RL
	H. mongolicum Turcz.	C_3	SHR	SS RL
	Lespedeza bicolor Turcz.	C_3	SHR	RL SH
	L. cytobotrya Miq.	C_3	SHR	RL SH WO
	L. davurica (Laxm.) Schindl.	C_3	SHR	RL DC
	L. floribunda Bge.	C_3	SHR	RL WO DC
	Melilotus albus Desr.	C_3	ANF	DC RL
	M. dentatus (Wald. *et* Kit.) Pers.	C_3	ANF	RL DC
	M. suaveolens Ledeb.	C_3	ANF	RL DC WE
	Melissitus ruthenica (L.) C. W. Chang	C_3	PEF	RL SS DC
	Oxytropis bicolor Bge.	C_3	PEF	RL SS DC
	O. hailarensis Kitag.	C_3	PEF	SS RL
	O. hirta Bge.	C_3	PEF	RL DC
	O. leptophylla (Pall.) DC.	C_3	PEF	RL
	O. microphylla (Pall.) DC.	C_3	PEF	WE SS
	O. ochrantha Turcz.	C_3	PEF	SS RL WO
	O. psammocharis Hance	C_3	PEF	RL DC
	Sophora flavescens Ait.	C_3	SHR	WE DC SS
	Swainsonia salsula (Pall.) Taub.	C_3	PEF	WE SL DC RL
	Thermopsis alpine Ledeb.	C_3	PEF	RL WO
	T. lanceolata R. Br.	C_3	PEF	RL WE SS DC
	Trifolium luponaster L.	C_3	PEF	RL WE
	Vicia amoena Fisch.	C_3	PEF	RL SH
	V. cracca L.	C_3	PEF	RL SH
	V. gigantea Bge.	C_3	PEF	RL SH
	V. ramuliflora (Maxim.) Ohwi.	C_3	PEF	RL WO
	V. unijuga A. Br.	C_3	PEF	RL WE
Linaceae	*Linum perenne* L.	C_3	PEF	RL WO DC
	L. stelleroides Planch.	C_3	ANF	RL DC
Lythraceae	*Ammannia baccifera* L.	C_3	ANF	WE
	Lythrum salicaria L.	C_3	PEF	WE
Menispermaceae	*Menispermum dauricum* DC.	C_3	PEF	RL DC
Moraceae	*Cannabis sativa* L. f. *rudralis* (Janisch.) Chu	C_3	ANF	RL SS
	Fatoua villosa Thunb.	C_3	ANF	DC
	Humulus scandens (Lour.) Merr.	C_3	ANF	DC
	Morus mongolica (Bur.) Schneid.	C_3	SHR	RL
Orobanchaceae	*Orobanche cernua* Loefling	C_3	ANF	RL
	O. coerulescens Steph. *et* Willd.	C_3	ANF	RL SS
	O. pycnostachya Hance	C_3	ANF	RL SS
Oxalidaceae	*Oxalis corniculata* L.	C_3	PEF	DC WE WO

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Oxalidaceae (cont.)	*Oxalis stricta* L.	C_3	PEF	WO DC WE RL
Papaveraceae	*Corydalis bungeana* Turcz.	C_3	PEF	DC RL
	C. edulis Maxim.	C_3	ANF	WO DC RL
	C. remota Fisch. *ex* Maxim.	C_3	PEF	WO SH
Plantaginaceae	*Plantago aritime* L. var. *salsa* (Pall.) Pilger.	C_3	PEF	SL
	P. asiatica L.	C_3	PEF	RL DC
	P. depressa Willd.	C_3	ANF	DC
	P. hostifolia Nakai *et* Kitag.	C_3	PEF	RL
Polygonaceae	*Atraphaxis bracteata* A. Los.	C_3	SHR	SS
	A. manshurica Kitag.	C_3	SHR	SS
	Fagopyrum tataricum (L.) Gaertn.	C_3	ANF	DC
	Polygonum alpinum All.	C_3	PEF	RL
	P. amphibium L.	C_3	PEF	WE
	P. angustifolium Pall.	C_3	PEF	RL
	P. aviculare L.	C_3	ANF	WE DC
	P. bistorta L.	C_3	PEF	RL WO
	P. caespitosum Bl.	C_3	ANF	WE
	P. convolvulus L.	C_3	ANF	RL DC
	P. dissitiflorum Heml.	C_3	ANF	WE
	P. divaricatum L.	C_3	PEF	RL
	P. excurrense Steward	C_3	ANF	WE
	P. lapathifolium L.	C_3	ANF	WE DC
	P. longisetum De Bruyn	C_3	ANF	WE
	P. maackianum Regel	C_3	ANF	WE DC
	P. nepalense Meisn.	C_3	ANF	RL WE
	P. orientale L.	C_3	ANF	DC WE
	P. perfoliatum L.	C_3	ANF	WE
	P. plebeium R. Br.	C_3	ANF	DC WE
	P. sibiricum Laxm.	C_3	PEF	SL
	P. sieboldii Meisn.	C_3	ANF	WE
	P. suffultum Maxim.	C_3	PEF	WE WO RL
	P. viviparum L.	C_3	PEF	RL WO
	Rheum franzenbachii Munt.	C_3	PEF	WO RL
	Rumex acetosa L.	C_3	PEF	RL WE
	R. acetosella L.	C_3	PEF	RL
	R. hadrocarpus Rech.	C_3	PEF	DC
	R. maritimus L.	C_3	ANF	WE
	R. marschallianus Rchb.	C_3	ANF	SL WE
	R. patientia L.	C_3	PEF	WE DC
Plumbaginaceae	*Limonium bicolor* (Bge.) O. Kuntze	C_3	PEF	SL
	L. aureum (L.) Hill.	C_3	PEF	SL
Polygalaceae	*Polygala sibirica* L.	C_3	PEF	RL SH
	P. tatarinowii Regel.	C_3	ANF	RL WO
	P. tenuifolia Willd.	C_3	PEF	DC RL SH
Portulacaceae	*Portulaca oleracea* L.	C_4	ANF	DC WE
Ranunculaceae	*Aconitum alboviolaceum* Kom.	C_3	PEF	SH WO
	A. kusnezoffii Reichb.	C_3	PEF	RL WO
	A. paniculigerum Nakai var. *wulingense* (Nakai) W. T. Wang	C_3	PEF	RL WO
	A. sinomontanum Nakai	C_3	PEF	WO SH
	Actaea asiatica Hara	C_3	PEF	FO
	Anemone silvestris L.	C_3	PEF	WO RL
	A. cathayensis Kitag.	C_3	PEF	RL WO
	Aquilegia viridiflora Pall.	C_3	PEF	RL WE

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Ranunculaceae (cont.)	*Batrachium bungei* (Steud.) L. Liou	C_3	HYD	WE
	B. pekinense L. Liou	C_3	HYD	RL WE
	Caltha natans Pall.	C_3	HYD	WE
	C. palustris L.	C_3	PEF	WE WO
	Cimicifuga dahurica (Turcz.) Maxim.	C_3	PEF	SH WO RL
	C. simplex Wormsk.	C_3	PEF	RL SH
	Clematis acerifolia Maxim.	C_3	SHR	RL
	C. heracleifolia DC.	C_3	SHR	WE RL
	C. hexapetala Pall.	C_3	SHR	RL
	C. pinnata Maxim.	C_3	PEF	RL
	Delphinium grandiflorum L.	C_3	PEF	RL SS
	D. siwanense Franch.	C_3	PEF	RL
	Halerpestes cymbalaria (Pursh) Greene.	C_3	PEF	SL WE
	H. ruthenica (Jacq.) Ovcz.	C_3	PEF	WE SL
	Leptopyrum fumarioides (L.) Reichb.	C_3	ANF	DC
	Pulsatilla chinensis (Bge.) Regel	C_3	PEF	RL
	P. turczaninovii Kryl. *ex* Serg.	C_3	PEF	RL SH
	P. ambigua Turcz. *ex* Pritz.	C_3	PEF	RL SH SS
	R. japonicus Thunb.	C_3	PEF	WE RL
	R. monophyllus Ovcz.	C_3	PEF	RL WE
	R. sceleratus L.	C_3	ANF	WE
	Thalictrum baicalense Turcz.	C_3	PEF	WO RL
	T. foeniculaceum Bge.	C_3	PEF	RL SS
	T. foetidum L.	C_3	PEF	RL
	T. macrorhynchum Franch.	C_3	PEF	RL DC WO
	T. petaloideum L.	C_3	PEF	RL
	T. przewalskii Maxim.	C_3	PEF	RL SH
	T. simplex var. *brevipes* Hara	C_3	PEF	RL DC
	T. squarrosum Steph. *ex* Willd.	C_3	PEF	RL
Rhamnaceae	*Rhamnus davurica* Pall.	C_3	SHR	RL WO
	R. globosa Bge.	C_3	SHR	WO SH
	R. schneideri var. *mandshurica* Nakai	C_3	SHR	WO
	R. ussuriensis J. Vass.	C_3	SHR	SH WO
Rosaceae	*Agrimonia pilosa* Ledeb.	C_3	PEF	RL WE DC
	Chamaerhodos canescens J. Krau.	C_3	PEF	RL
	C. erecta (L.) Bge.	C_3	ANF	RL SS
	Cotoneaster acutifolius Turcz.	C_3	SHR	RL
	C. melanocarpus Lold.	C_3	SHR	WO RL
	C. mongolicus Pojark.	C_3	SHR	RL SS
	Filipendula palmata (Pall.) Maxim.	C_3	PEF	RL DC WE
	Malus baccata (L.) Borkh.	C_3	ARO	WO SH
	M. mandshurica Kom.	C_3	ARO	WO
	Physocarpus amurensis (Maxim.) Maxim.	C_3	SHR	RL FO
	Potentilla acaulis L.	C_3	PEF	RL
	P. bifurea L.	C_3	PEF	RL DC
	P. chinensis Ser.	C_3	PEF	RL DC
	P. conferta Bge.	C_3	PEF	RL
	P. discolor Bge.	C_3	PEF	RL DC
	P. flagellaris Willd. *ex* Schlecht.	C_3	PEF	WE DC
	P. fragarioides L.	C_3	PEF	DC RL WE
	P. freyniana Bronm.	C_3	PEF	RL WE
	P. multifida L.	C_3	PEF	RL DC
	P. strigosa Pall. *ex* Pursh	C_3	PEF	RL
	P. supine L.	C_3	ANF	DC

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Rosaceae (cont.)	*Potentilla tanacetifolia* Willd.	C_3	PEF	RL
	P. verticillaris Steph.	C_3	PEF	RL DC
	Prunus ansu Kom.	C_3	SHR	RL
	P. davidiana Franch.	C_3	ARO	RL
	P. humilis Bge.	C_3	SHR	RL SH
	P. padus L.	C_3	ARO	WO
	P. sibirica L.	C_3	SHR	RL
	P. tomentosa Thunb.	C_3	SHR	RL
	Rose acicularis Lindl.	C_3	SHR	RL WO SH
	R. dahurica Pall.	C_3	SHR	RL SH WO
	Rubus crataegifolius Bge.	C_3	SHR	RL DC
	R. idaeus L. var. *borealisinensis* Yü *et* Lu	C_3	SHR	RL SH
	R. saxatilis L.	C_3	PEF	WO RL SH
	Sanguisorba appalanata Yu *et* Li	C_3	PEF	RL WE
	S. officinalis L.	C_3	PEF	RL
	Sibbaldia adpressa Bge.	C_3	PEF	SS
	Spiraea aquilegifolia Pall.	C_3	SHR	RL
	S. blumei G. Don.	C_3	SHR	RL
	S. fritschiana Schneid.	C_3	SHR	WO RL
	S. mongolica Maxim.	C_3	SHR	RL
	S. pubescens Turcz.	C_3	SHR	RL WO
	S. salicifolia L.	C_3	SHR	RL
Rubiaceae	*Galium aparine* L.	C_3	ANF	DC RL
	G. verum L.	C_3	PEF	WO RL
	Rubia chinensis Regel	C_3	PEF	WO WE
	R. cordifolia L.	C_3	PEF	DC SH
Rutaceae	*Haplophyllum dahuricum* (L.) A. Juss.	C_3	PEF	SS RL
	Phellodendron amurense Rupr.	C_3	ARO	WO
Salicaceae	*Populus davidiana* Dode	C_3	ARO	RL SS WO
	Salix cheilophila Schneid.	C_3	SHR	RL SH
	S. gordejevii Y. L. Chang *et* Skv.	C_3	SHR	SS
	S. matsudana Koidz.	C_3	ARO	WE
Santalaceae	*Thesium chinensis* Turcz.	C_3	PEF	RL
	T. longifolium Turcz.	C_3	PEF	SS RL WO
	T. refractum C. A. Mey.	C_3	PEF	RLWO
Saxifragaceae	*Parnassia oreophila* Hance	C_3	PEF	RL
	P. palustris L.	C_3	PEF	RL WE
	Penthorum chinense Pursh	C_3	PEF	WE
	Ribes diacanthum Pall.	C_3	SHR	SS RL
	R. mandshuricum (Maxim.) Kom.	C_3	SHR	WO RL
	Saxifraga cernua L.	C_3	PEF	RL
	S. sibirica L.	C_3	PEF	RL WE
Scrophulariaceae	*Cymbaria dahurica* L.	C_3	PEF	RL DC
	C. mongolica Maxim.	C_3	PEF	RL DC
	Euphrasia pectinata Ten.	C_3	ANF	RL SH
	Linaria vulgaris Mill.	C_3	PEF	RL WE DC
	Lindernia procumbens (Krock.) Philcox	C_3	ANF	WE
	Melampyrum roseum Maxim.	C_3	ANF	WO RL
	Omphalothrix longipes Maxim.	C_3	ANF	WE
	Pedicularis artselaeri Maxim.	C_3	ANF	RL WO
	P. chinensis Maxim.	C_3	ANF	RL
	P. flava Pall.	C_3	PEF	RL
	P. spicata Pall.	C_3	ANF	RL

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Scrophulariaceae (cont.)	*Pedicularis striata* Pall.	C_3	PEF	RL WO
	P. tatarinowii Maxim.	C_3	ANF	RL
	Rehmannia glutinosa (Gaertn.) Libosch. *ex* Fisch. *et* Mey.	C_3	PEF	DC
	Scrophularia buergeriana Miq.	C_3	PEF	RL WE
	S. modesta Kitag.	C_3	PEF	RL WO
	S. moellendorffii Maxim.	C_3	PEF	RL
	Siphonostegis chinensis Benth.	C_3	ANF	RL
	Veronica dahurica Stev.	C_3	PEF	RL SS WO
	V. didyma Tenore	C_3	ANF	WE
	V. incana L.	C_3	PEF	RL SS
	V. linariifolia Pall. *ex* Link	C_3	PEF	RL SH
Solanaceae	*Datura stramonium* L.	C_3	ANF	DC RL
	Hyoscyamus niger L.	C_3	ANF	RL DC WE SS
	Physalis alkekengi L. var. *francheti* (Mast.) Makino	C_3	PEF	DC WE
	P. angulata L.	C_3	ANF	DC RL
	P. minima L.	C_3	ANF	RL DC
	Physochlaina physaloides (L.) G. Don	C_3	PEF	RL
	Solanum japonense Nakai	C_3	PEF	WO SH WE DC
	S. nigrum L.	C_3	ANF	DC
Thymelaeaceae	*Diarthron linifolium* Turcz.	C_3	ANF	RL
	Stellera chamaejasme L.	C_3	PEF	RL
Tiliaceae	*Corchoropsis tomentosa* Mak.	C_3	ANF	RL
Ulmaceae	*Hemiptelea davidii* (Hance) Planch.	C_3	SHR	DC
	Ulmus laciniata (Trautv.) Mayr.	C_3	ARO	RL WE
	U. lamellose T. Wang *et* S. L. Chang	C_3	ARO	RL
	U. macrocarpa Hance	C_3	SHR	RL
	U. pumila L.	C_3	ARO	RL
Umbelliferae	*Angelica dahurica* (Fisch.) Benth.	C_3	PEF	RL SH
	A. polymorpha Maxim.	C_3	PEF	RL SH
	Bupleurum bicaule Helm.	C_3	PEF	RL
	B. chinensis DC.	C_3	PEF	RL WE
	B. sibiricum Vest. var. *jeholense* (Nakai) Chu	C_3	PEF	RL
	B. smithii Wolff	C_3	PEF	RL
	Carum buriaticum Turcz.	C_3	ANF	RL DC
	C. carvi L.	C_3	ANF	RL
	Cicuta virosa L.	C_3	PEF	RL WE
	Czernaevia laevigata Turcz.	C_3	ANF	WE SH RL
	Ferula bungeana Kitag.	C_3	PEF	SS
	Heracleum moellendorffii Hance	C_3	PEF	WO RL
	Peucedanum terebinthaceum (Fisch.) Fisch. *ex* Turcz.	C_3	PEF	RL
	P. praeruptorum ssp. *hirsutiusculum* Y. C. Ma	C_3	PEF	WE RL
	P. trinioides Wolff	C_3	PEF	RL
	Saposhnikovia divaricata (Turcz.) Schischk.	C_3	PEF	RL
	Sphallerocarus gracilis (Bess.) K.-Pol.	C_3	ANF	DC RL
Urticaceae	*Girardinia cuspidata* Wedd. in D.C.	C_3	ANF	DC RL
	Laportea macrostachya (Maxim.) Ohwi.	C_3	PEF	WO DC
	Parietaria micrantha Ledeb.	C_3	ANF	WE DC
	Pilea hamaoi Makino	C_3	ANF	WO WE
	P. mongolica Wedd.	C_3	ANF	WE
	Urtica angustifolia Fisch. *ex* Hornem.	C_3	PEF	RL DC
	U. cannabina L.	C_3	PEF	RL DC
	U. laetevirens Maxim.	C_3	PEF	DC WO RL
Valerianaceae	*Patrinia rupestris* Juss.	C_3	PEF	RL

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Valerianaceae (cont.)	*Patrinia scabra* Bge.	C_3	PEF	RL DC
	Valeriana officinalis L.	C_3	PEF	RL SH
	V. rupestris (Pall.) Jass. subsp. *scabra* (Bunge) H. T. Wang	C_3	PEF	RL
Verbenaceae	*Caryopteris mongholica* Bge.	C_3	SHR	RL SL
	Vitex negundo L.	C_3	SHR	SH
Violaceae	*Viola acuminate* Ledeb.	C_3	PEF	WO RL WE
	V. colina Bess.	C_3	PEF	WO FO RL
	V. dissecta Ledeb.	C_3	PEF	RL WO WE
	V. mongolia Franch.	C_3	PEF	WO RL
	V. yedoensis Makino	C_3	PEF	DC RL
	V. yezoensis Maxim.	C_3	PEF	WO SH RL
Zygophyllaceae	*Nitraria schoberi* L.	C_3	SHR	SL SS
	N. sibirica Pall.	C_3	SHR	SL RL
	Peganum harnala L.	C_3	PEF	SL RL
	P. nigellastrum Bge.	C_3	PEF	RL
	Tribulus terrestris L.	C_4	ANF	DC SS
Monocotyledoneae				
Alismataceae	*Alisma plantago-aquatica* L.	C_3	HYD	WE
	Sagittaria trifolia L.	C_3	PEF	WE
Araceae	*Arisaema amurense* Maxim.	C_3	PEF	WO WE
	A. hetetrophyllum Bl.	C_3	PEF	WO SH RL
	P. ternata (Thunb.) Breit.	C_3	PEF	WE
	Pinellia pedatisecta Schott	C_3	PEF	WO RL
Butomaceae	*Butomus umbellatus* L.	C_3	HYD	WE
Commelinaceae	*Commelina benghalensis* L.	C_3	PEF	WO WE
	C. communis L.	C_3	ANF	RL DC WO
	Streptolirion volubile Edgew.	C_3	ANF	RL SS
Cyperaceae	*Blysmus rufus* (Huds.) Link	C_3	HYD	WE
	B. sinocompressus Tang *et* Wang	C_3	PEF	WE
	Bulbostylis barbata (Rottb.) C. B. Clarke	C_4	ANF	RL DC WE
	B. densa (Wall.) Hand.-Mazz.	C_4	ANF	WE DC WO
	Carex arnellii Christ	C_3	PEF	FO RL
	C. capillaris L.	C_3	PEF	RL
	C. duriuscula C. A. Mey.	C_3	PEF	RL SS DC
	C. hancockiana Maxim.	C_3	PEF	WE SH
	C. heterostachya Bge.	C_3	PEF	RL DC
	C. jaluensis Kom.	C_3	PEF	WE FO
	C. korshinskyi Kom.	C_3	PEF	RL SS
	C. lithophila Turcz.	C_3	PEF	RL WE SS
	C. longerostrata C. A. Mey.	C_3	PEF	FO SH
	C. neurocarpa Maxim.	C_3	PEF	WE
	C. onoei Franch. *et* Sav.	C_3	PEF	RL WE DC
	C. orthostachys C. A. Mey.	C_3	PEF	WE
	C. pediformis C. A. Mey.	C_3	PEF	RL SS
	C. peiktusani Kom.	C_3	PEF	RL WO WE
	C. planiculmis Kom.	C_3	PEF	WE
	C. raddei Kük.	C_3	PEF	WE DC RL
	C. stenophylloides V. Krecz.	C_3	PEF	RL SS
	C. tangiana Ohwi	C_3	PEF	RL
	C. ussuriensis Kom.	C_3	PEF	WO RL
	C. vesicaria L.	C_3	PEF	WE
	C. amuricus Maxim.	C_3	ANF	DC

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Cyperaceae (cont.)	*Cyperus compressus* L.	C_4	ANF	DC
	C. fuscus L.	C_3	ANF	DC
	C. glomeratus L.	C_4	ANF	WE
	C. imbricatus Rezt	C_4	ANF	WE
	C. iria L.	C_4	ANF	RL WE DC
	C. michelianus (L.) Link	C_4	ANF	WE
	C. microiria Steud.	C_4	ANF	WE DC
	C. nipponicus Franch.	C_4	ANF	WE DC
	C. orthostachyus Franch.	C_4	ANF	WE
	C. rotundus L.	C_4	PEF	DC WE
	Eriophorum polystachion L.	C_3	PEF	WE
	Fimbristylis bisumbellata Bubani	C_4	ANF	WE
	F. dichotoma L.	C_4	ANF	RL DC WE
	F. stauntoni Deb. *et* Fr.	C_4	ANF	DC
	F. subbispicata Nees *et* Mey.	C_3	ANF	RL WE
	Juncellus pannonicus (Jacq.) C. B. Clarke	C_3	PEF	WE DC SL
	J. serotinus (Rottb.) C. B. Clarke	C_3	PEF	WE SS
	Kobresia bellardii (All.) Degl.	C_3	PEF	DC
	K. capillifolia (Decne.) C. B. Clarke	C_3	PEF	WE
	Pycreus globosus (All.) Reichb.	C_4	PEF	DC WE
	P. sanguinolentus (Vahl) Nees	C_4	PEF	RL DC WE
	Scirpus pumilus Vahl	C_3	PEF	WE
	S. sylvaticus var. *maximowczii* Regel	C_3	PEF	WE
	S. tabernaemontani Gmel.	C_3	HYD	WE
	S. triqueter L.	C_3	PEF	WE
	S. yagara Ohwi	C_3	PEF	WE
Gramineae	*Achnatherum extremiorientale* Keng	C_3	HPG	RL
	A. pekinense (Hance) Ohwi	C_3	HPG	RL.
	A. purpurascens (Hitchc.) Keng	C_3	HPG	RL
	A. sibiricum (L.) Keng	C_3	HPG	RL
	A. splendens (Trin.) Nevski	C_4	HPG	SL
	Aeluropus littoralis var. *sinensis* Debeaux	C_3	SPG	SS
	Agropyron cristatum (L.) Gaertn.	C_3	HPG	RL SS
	A. desertorum (Fisch.) Schult.	C_3	HPG	SS
	A. michnoi Roshev.	C_3	HPG	SS
	A. mongolicum Keng	C_3	HPG	SS
	Agrostis capillaris L.	C_3	ANG	WE
	A. clavata Trin.	C_3	HPG	WE RL
	A. gigantea Roth	C_3	HPG	WE
	A. macranthera Chang *et* Skv.	C_3	HPG	RL
	A. mongolica Roshev.	C_3	ANG	WE RL
	A. palustis Huds.	C_3	ANG	WE
	A. sibirica V. Pter.	C_3	ANG	SH WE
	Alopecurus aequalis Scobol.	C_3	ANG	WE
	A. arundinaceus Poir.	C_3	ANG	WE RL
	A. brachystachyus March.	C_3	HPG	WE
	Aristida adscenionis L.	C_4	ANG	RL SS
	Arthraxon hispidus (Thunb.) Makino	C_4	ANG	WE RL DC
	A. prionodes (Steud.) Dandy	C_3	HPG	WE
	Arundinella hirta (Thunb.) Tanaka	C_4	HPG	RL WO
	Avena fatua L.	C_3	ANG	DC
	Beckmannia syzigachne (Steud.) Franald	C_3	ANG	WE
	Bothriochloa ischaemum (L.) Keng	C_4	HPG	RL
	Bromus inermis Leyss.	C_3	HPG	WE RL SS
	B. japonicus Thunb.	C_3	ANG	DC

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Gramineae (cont.)	*Calamagrostis angustifolia* Kom.	C_3	HPG	WE
	C. arundinacea (L.) Roth	C_3	HPG	RL WE
	C. epigejos (L.) Roth	C_3	HPG	WE RL DC SS
	C. macrolepis Litv.	C_3	HPG	RL
	C. neglecta (Ehrh.) Gaertn.	C_3	HPG	WE
	C. pseudophragmites (Hall. f.) Koel.	C_3	HPG	WE DC SS
	C. purpurea (Trin.) Trin.	C_3	HPG	RL WE
	Capillipedium parviflorum (R. Br.) Stapf.	C_4	HPG	RL
	Chloris virgata Swartz	C_4	ANG	DC
	Cleistogenes caespitosa Keng	C_3	SPG	RL
	C. chinensis (Maxim.) Keng	C_4	SPG	RL DC
	C. foliosa Keng	C_3	SPG	RL SH
	C. hackeli var. *nakai* (Keng) Ohwi	C_4	HPG	RL
	C. hancei Keng	C_3	HPG	RL DC
	C. polyphylla Keng	C_3	SPG	RL
	C. songorica (Roshev.) Ohwi	C_4	SPG	SS RL
	C. squarrosa (Trin.) Keng	C_4	SPG	RL
	Crypsis aculeata (L.) Ait.	C_4	ANG	DC WE SL
	Diarrhena manshurica Maxim.	C_3	HPG	RL WO
	Digitaria ciliaris (Retz.) Koel.	C_4	ANG	DC
	D. ischaemum (Schreb.) Muhlenb.	C_4	ANG	WE
	D. sanguinalis (L.) Scop.	C_4	ANG	DC
	Diplachne fusca (L.) Beauv.	C_4	ANG	DC WE
	Echinochloa colonum (L.) Link.	C_4	ANG	DC
	E. crus galli (L.) Beauv.	C_4	ANG	DC
	Eleusine indica (L.) Gaertn.	C_4	ANG	DC
	Elymus cylindricus (Franch.) Honda	C_3	HPG	RL DC
	E. dahuricus (Turcz.) Nevski	C_3	HPG	RL DC
	E. excelsus Turcz.	C_3	HPG	RL DC
	E. purpuraristatus C. P. Wang *et* H. L. Yang	C_3	HPG	RL
	E. sibiricus L.	C_3	HPG	RL DC
	E. tangutorum (Nevshi) Hand.-Mazz.	C_3	HPG	RL WE
	Enneapogon borealis (Griseb.) Honda		SPG	RL
	Eragrostis cilianeniss (All.) Link *ex* Vign.-Lut.	C_4	ANG	DC
	E. ferruginea (Thunb.) Beauv.	C_4	HPG	RL DC
	E. pilosa (L.) Beauv.	C_4	ANG	DC
	E. poaeoides Beauv.	C_4	ANG	DC
	Eriochloa villosa (Thunb.) Kunth	C_4	ANG	RL WE
	Festuca litvinovii (Tzvel.) E. Alexeev	C_3	HPG	RL
	F. rubra L.	C_3	HPG	RL
	F. subulata Trin. ssp. *japonica* (Hack.) T. Koyama *et* Kowano	C_3	HPG	WO RL
	Helictotrichon schellianum (Hack.) Kitag. Lineam.	C_3	HPG	WO RL
	Hemarthria altissima (Poir.) Stapf	C_4	HPG	WE
	Hierochloë glabra Trin	C_4	SPG	RL WE
	Hordeum brevisubulatum (Trin.) Link.	C_3	HPG	SL RL
	H. violaceum Boiss. *et* Hohen.	C_3	HPG	WE RL
	Imperata cylindrica (L.) Beauv.	C_4	HPG	RL SS DC
	Koeleria cristata (L.) Pers.	C_3	SPG	RL DC
	Leucopoa albida (Turcz.) Krecz.	C_3	HPG	RL
	Leymus chinensis (Trin.) Tzvel.	C_3	HPG	SL
	L. mollis (Trin.) Hara.	C_3	HPG	SS
	L. secalinum (Georgi) Tzvel.	C_3	HPG	SS
	Melica onoei Franch *et* Sav.	C_3	HPG	WO RL
	M. radula Franch.	C_3	HPG	RL
	M. scabrosa Trin.	C_3	HPG	DC RL

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Gramineae (cont.)	*Melica turczaninoviana* Ohwi	C_3	HPG	WO RL
	M. virgata Turcz.	C_3	HPG	RL
	Microstegium vimineum (Trin.) Camus	C_4	ANG	WE
	Milium effusum L.	C_3	HPG	WO WE
	Miscanthus sacchariflorus (Maxim.) Benth	C_4	HPG	WE RL
	M. sinensis Anderss.	C_4	HPG	DC WO
	Muhlenbergia hugelii Trin.	C_4	SPG	RL WE
	M. japonica Steud.	C_4	SPG	WE
	Oplismenus undulatifolius (Ard.) Roem. *et* Schult.	C_3	ANG	WO WE
	Orthoraphium grandifolium (Keng) Keng	C_3	HPG	RL WO
	Pennisetum alopecuroides (L.) Spreng.	C_4	HPG	RL DC
	P. flaccidum Griseb.	C_4	HPG	RL SS DC
	Perotis indica (L.) Kuntze	C_4	ANG	SS
	Phragmites australis (Cav.) Trin. *ex* Steud.	C_3	HYD	WE
	P. jeholensis Honda	C_3	HPG	WE
	Poa acroleuca Steud.	C_3	ANG	DC WE
	P. annua L.	C_3	ANG	RL DC WE
	P. argunensis Roshev.	C_3	HPG	RL SS
	P. botryoides (Trin.) Trin. *ex* Roshev.	C_3	SPG	RL
	P. hengshanica Keng	C_3	HPG	RL
	P. ianthian Keng	C_3	HPG	RL
	P. lepta Keng	C_3	HPG	RL
	P. longilumis Keng	C_3	HPG	RL
	P. mongolica (Rendle) Keng	C_3	HPG	RL
	P. nemoralis L.	C_3	HPG	WO DC
	P. paucifolia Keng	C_3	HPG	RL
	P. plurifolia Keng	C_3	SPG	RL
	P. pratensis L.	C_3	HPG	RL DC
	P. schoenites Keng	C_3	HPG	RL DC
	P. sibirica Roshev.	C_3	HPG	RL
	P. sphondylodes Trin.	C_3	HPG	RL DC
	P. subfastigiata Trin.	C_3	HPG	WE RL
	P. viridula Palibin	C_3	HPG	WE
	Polypogon monspeliensis (L.) Desf.	C_3	ANG	WE
	Psammochloa villosa (Trin.) Bor.	C_3	HPG	SS
	Puccinellia distans (L.) Parl.	C_3	SPG	SL
	P. hauptiana (Krecz.) Krecz.	C_3	SPG	WE DC
	P. macranthera Krecz.	C_3	HPG	SL
	P. micrandra (Keng) Keng	C_3	SPG	DC SL
	P. tenuiflora (Turcz.) Scribn. *et* Merr.	C_3	HPG	SL
	Roegneria barbicalla Ohwi	C_3	HPG	DC
	R. ciliaris (Trin.) Nevski	C_3	HPG	DC RL
	R. hondai Kitag.	C_3	HPG	RL
	R. japonensis (Honda.) Keng	C_3	HPG	DC
	R. kamoji Ohwi	C_3	HPG	RL WE
	R. pendulina Nevski	C_3	HPG	WO
	R. turczaninovii (Drob.) Nevski	C_3	HPG	RL
	Schizachyrium brevifolium (Swartz) Ness *ex* Buse	C_3	ANG	RL WE
	Setaria glauca (L.) Beauv.	C_4	ANG	DC RL
	S. lutescens (Weigel) F. T. Hubb.	C_4	ANG	RL DC SS
	S. viridis (L.) Beauv.	C_4	ANG	DC RL
	Spodiopogon sibiricus Trin.	C_4	HPG	RL
	Stipa baicalensis Roshev.	C_3	HPG	RL
	S. breviflora Griseb.	C_3	HPG	RL
	S. bungeana Trin.	C_3	HPG	RL DC

Table 1 (continued)

Family	Species	C_3/C_4	PFTs	Habitat
Gramineae (cont.)	*Stipa glareosa* P. Smirn.	C_3	HPG	RL
	S. gobica Roshev.	C_3	HPG	RL
	S. grandis P. Smirn.	C_3	HPG	RL
	S. krylovii Roshev.	C_3	HPG	RL
	S. przewalskyi Roshev.	C_3	HPG	RL
	Themeda japonica (Willd.) C. Tanaka	C_4	HPG	RL
	Tragus berteronianus Schult.	C_4	ANG	DC
	T. mongolorum Ohwi	C_3	ANG	DC
	Tripogon chinensis (Franch.) Hack.	C_4	SPG	RL DC
	Trisetum sibiricum Rupr.	C_3	HPG	RL
	Zoysia japonica Steud.	C_4	SPG	RL
Iridaceae	*Belamcanda chinensis* (L.) DC.	C_3	PEF	RL DC
	Iris dichotoma Pall.	C_3	PEF	RL
	I. lacteal Pall. var. *chinensis* Koidz.	C_3	PEF	RL DC SS
	I. ruthenica Ker-Gawl. var. *nana* Maxim.	C_3	PEF	RL
	I. tenuifolia Pall.	C_3	PEF	RL SS
	I. tigridia Bge.	C_3	PEF	RLSS
	I. ventricosa Pall.	C_3	PEF	RL
Juncaginaceae	*Triglochin palustre* L.	C_3	HYD	WE
Liliaceae	*Allium anisopodium* Ledeb.	C_3	PEF	RL SS
	A. chiwui Wang *et* Tang	C_3	PEF	RL
	A. condensatum Turcz.	C_3	PEF	RL
	A. eduardii Stearn	C_3	PEF	
	A. ledebourianum Roem. *et* Schult.	C_3	PEF	RL SS
	A. longistylum Baker	C_3	PEF	RL
	A. neriniflorum (Herb.) Baker	C_3	PEF	RL
	A. polyrhizum Turcz.	C_3	PEF	RL
	A. senescens L.	C_3	PEF	RL SS
	A. tenuissimum L.	C_3	PEF	RL SS
	A. thunbergii G. Don	C_3	PEF	RL
	A. tubiflorum Rendle	C_3	PEF	RL SH
	A. victorialis L.	C_3	PEF	WO DC RL
	Anemarrhena asphodeloides Bge.	C_3	PEF	RL DC
	Asparagus brachyphyllus Turcz.	C_3	PEF	WO RL
	A. dauricus Fisch. *ex* Link	C_3	PEF	RL DC
	A. longiflorus Franch.	C_3	PEF	RL DC SH
	A. trichophyllus Bge.	C_3	PEF	RL DC
	Hemerocallis citrine Baroni	C_3	PEF	RL DC
	H. lilioasphodelus L.	C_3	PEF	RL WE SH
	H. minor Mill.	C_3	PEF	RL WO
	Lilium dauricum Ker-Gawl.	C_3	PEF	RL WO DC
	L. pumilum DC.	C_3	PEF	RL WO DC
	Lloydia serotina (L.) Rchb.	C_3	PEF	RL SH
	Maianthemum bifolium (L.) F. W. Schmidt	C_3	PEF	WO
	Polygonatum cuminatifolium Kom.	C_3	PEF	RL
	P. sibiricum Delar. *ex* Red.	C_3	PEF	SH WO RL
	Veratrum nigrum L.	C_3	PEF	RL WO
Sparganiaceae	*Sparganium stenophyllum* Meinsh.	C_3	HYD	WE
	S. stoloniferum Hamit.	C_3	HYD	WE
Typhaceae	*Typha angustifolia* L.	C_3	HYD	WE
	T. davidinana Hand.-Mazz.	C_3	HYD	WE
	T. minima Funk.	C_3	HYD	WE
	T. orientalis Presl.	C_3	HYD	WE

Discussion

PFTs, including photosynthetic pathways and morphological functional types, provide more information for studying the logical linkage between species and ecosystems at both species and global levels (Collins and Jones 1985, Chapin 1993, Cramer 1997, Leemans 1997, Duckworth 2000, Wang 2004). Both large-scale climate variations and habitat heterogeneity affect the occurrence of C_4 species. Compared with grassland types in Northern China, the occurrence of C_4 species in the ecotone was relatively higher, mainly due to the complex geo-relief, landscape, and soils (Wang 2002a). 43 C_4 grasses and 16 C_4 sedges were identified in the region. This mainly results from the high graminaceous plant composition, which made up 42 % of the total forage species and 64 % C_4 species in the North China grasslands (Zhang and Liu 1992, Wang 2002c). Relatively more precipitation in the south-east (500 mm) may in part explain the high presence of C_4 grasses and sedges. *Gramineae* (43 C_4 grass species) is the leading family with C_4 photosynthesis. This result differs greatly from the conclusions of Pyankov *et al*. (2000) who found that *Chenopodiaceae* was the leading C_4 family and the *Gramineae* ranks the second in desert and steppe in Mongolia. The south-east part of the ecotone is relatively moist compared with steppe in Mongolia and has relatively higher abundance of C_4 graminaceous plants: 39 C_4 grasses and 16 C_4 sedges which made up of 81 % of the total C_4 species. Only 2 chenopod species were identified as C_4 plants in the south-east part of the ecotone, while 5 C_4 chenopods (all of them) were found in the arid north-west part. 15 C_4 sedge species were found in the south-east part, but no C_4 sedges in the north-west part. This result agrees with the findings of Pyankov *et al*. (2000) that the chenopods were closely correlated with aridity, and also it proved that the abundance of sedge C_4 species was strongly related to precipitation (Yin and Li 1997). These findings suggest that C_4 chenopods may have greater tolerance to drought stress than grasses.

Habitats and land use, *e.g.* salinity, deterioration, and grazing intensities in the region influence the occurrence of C_4 species. This is supported by the observations that the number of C_4 species and C_4 proportion increased significantly with the deterioration from RL to DC (Fig. 1). Number of total species dropped, but C_4 proportion increased significantly from RL to SS and SL. This may correlate with degeneration of natural grassland by overgrazing and desertification of old fields or some infield because of over-farming. The highest abundance of C_4 species occurred in DC, but SL had the highest C_4 proportion due to the low C_3 species composition in SL. Hence the photosynthetic pathway type compositions were not only related to climate changes in the region scale, but also responded to habitats in the small scale.

In studying and predicting consequences of environment changes upon vegetation and ecosystem processes, it has become essential to take into account morphological functional types as well as photosynthetic pathways. Morphological functional types serve as a good indication for studying spatial and temporal changes in the ecotone in the local and region scales (Fig. 2). Species proportion of PEF and HPG decreased with the deterioration from RL to DC or from RL to SS, while species proportion and the number of species for ANG increased dramatically from RL to DC (Fig. 3). The increases of ANF and ANG proportions were consistent with land deterioration and desertification (Wang 2002c,d). We suggest the responses of ANG and PEF types could help predict consequences of vegetation dynamics and land deterioration in the local scale. Relatively more C_4 species in ANF, HPG, ANG, and SPG types indicate that these functional types fit better for agro-pastoral ecotone in the region.

The number of C_4 species in ANF and ANG, making up 60 % of the total C_4 species (42 of 68) in the ecotone, is higher than that of Inner Mongolia steppe (44 %). We suggest that deterioration of land in the region is more severe. Since this region is the main sandy source for the nearby cities (Beijing) and may threaten the eco-safety of North China, we should pay more attention to these connections. In this and previous studies (Wang 2002a, 2004) we pointed out the importance of PFTs in predicting vegetation dynamics. The occurrence of C_4 species provides us an efficient tool for both diagnosis of land conditions and making management decisions.

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It is not necessary to stress to the readers of this journal the importance of photosynthesis for the life on our planet. But perhaps due to our everyday human experience and perspective we often tend to identify photosynthesis only with the higher plants that surround us. We then forget that oceans cover almost 70 % of the surface of our planet. It is the aquatic photosynthesis that provides about half of the global primary production. The aquatic phytoplankton, microscopic photosynthetic algae and bacteria, are the major players that have fundamental and often decisive role in the global ecology of the oceans and whole Earth. However, on the other hand, photosynthesis is only one of the many fascinating processes occurring in the vast, deep, and often still unexplored oceans. Much of the ocean interior has never been seen by human eye and remains a source of new discoveries. For example, only recently a brand new environment around the deep sea vents was discovered and its ecology described. At the same time, large part of mankind depends on the marine environments as a source of food, materials, and living. The human influence on many marine ecosystems has in many areas reached limits of reversibility. Shores are polluted, stocks of commercial fish are decreasing, and intensive coastal aquacultures often cause negative environmental effects. The anthropogenic emissions of greenhouse gases are slowly changing temperature and pH of oceans and this influences not only the vulnerable coral reefs, but might disturb the whole system of oceanic circulation and thus multiply the changes in global climate. These are only few of the reasons why understanding of marine ecology should be one of our priorities.

The reviewed book is a textbook that covers in one volume the complex ecology of all marine environments. The textbook is aimed for advanced undergraduate courses in marine biology or marine ecology. It offers a balanced survey of marine ecology and introduces the major processes and systems that form the marine environment and examines the issues and challenges which surround its future conservation.

The book is divided into 15 individual chapters that are grouped into three major parts. Following the general introduction, the first part deals with the major processes of marine ecology and marine carbon cycle, *i.e.* with the primary and microbial production and the decomposition of organic matter. The primary photosynthetic production is described on fifty pages. The mechanism of photosynthesis is described only very briefly, but attention is given to processes of aquatic photosynthesis that have specific ecological importance – different photosynthetic pigments and their relation to the light field in water, the role of photoacclimation, the dependence of photosynthesis on light and inorganic nutrients, factors limiting photosynthetic growth, and methods how to measure primary production. The chapter on microbial production deals with the dynamics of microbial network, the role of respiration in the decomposition of organic matter, and the release of nutrients.

The second and most extensive part describes individual marine ecosystems: estuaries, rocky and sandy shores, the pelagic environment, continental shelf seabed, the deep sea, mangroves and seagrass meadows, coral reefs, and polar seas. Each of these chapters provides not only general description of environmental features of the ecosystem and their typical inhabitants and diversity, but also specific details on each of these major ecosystems.

The final part then deals with the impacts of human activity on marine ecosystems and discusses the most pressing environmental issues. Individual chapters are on fisheries, aquaculture, pollution, climate change, and marine conservation.

The textbook is clear and instructive, but still detailed enough to provide more than superficial insight into the subjects. Each chapter starts with the summary, the text is accompanied by glossary and number of instructional figures and tables. Supplementary text is added in the margins of the text and specific points are explained in detail in separate boxes. The textbook is well designed and structured, key points and terms are highlighted and cross-referenced so that they are explained in different chapters from different perspectives. I appreciate that the authors refer to the most recent literature and active websites. Full citations of these can be found at the end of the book so the reader can use them for further reading. However, the authors could give more attention to the proper compilation of information from these original sources. I found misleading values for the bacterial and phytoplankton growth rates in the table on p. 128. The errors were probably caused by wrong recalculation of the original data. But this does not diminish the attractiveness and quality of the textbook. A companion website offers freely downloadable images from the text that the teachers can use for preparation of lectures and a web link library of all web sites cited in the text for ease of access by students.

Marine Ecology: Processes, Systems, and Impacts will be of interest to all whose research involves any aspect of aquatic photosynthesis and will be invaluable for advanced undergraduates and postgraduates entering this area.

O. PRÁŠIL (*Třeboň*)