Photosynthetic and morphological functional types for native species from mixed prairie in Southern Saskatchewan, Canada

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Abstract

Photosynthetic pathways (*e.g*. C_3, C_4) and morphological functional types (*e.g*. trees, shrubs, high perennial grasses, perennial forbs) were identified for the native species from the Saskatchewan mixed prairie, using the data from references published between 1950 and 2003. Of the total 219 identified species in 145 genera and 45 families, 208 species in 137 genera and 44 families were found with C_3 photosynthesis, and most of these species are dominants (*e.g. Agropyron dasystachyum* Hook. and *Stipa spartea* var. *curtiseta* Hitchc.). 11 species in 10 genera and 3 families were identified with C_4 photosynthesis (*e.g. Atriplex argentea* Nutt., *Andropogon scoparius* Michx., *Boutelou gracilis* Lag., *Calamovilfa longifolia* Hook.). The amount of total identified C_4 species in the region is much less than that from the South Dakota mixed prairie (27 species). *Gramineae* is the leading family with C_4 photosynthesis (8 species), *Chenopodiaceae* ranks the second (2 species). Relatively less forb types [50 % perennial forbs (PEF) and 12 % annual forbs (ANF)] and more graminoid types (25 %) composition suggested that the rangelands in the region are relatively stable. Lacking of the knowledge on the optimal traits for PFTs classification in the region, further studies (*e.g*. C_3 and C_4 plant identification and optimal trait selection) are needed to explore the relationships between PFTs and vegetation variations, as well as land-use and climate changes.

Additional key words: C_3 and C_4 species; habitats.

Introduction

The classification of plant species into functional types has received much attention since the introduction of the concept of plant functional types (PFTs), because PFTs provide a logical links between physiological and life-history strategies at plant level, as well as ecological process at ecosystem and global levels (Paruelo and Lauenroth 1996, Wang 2003). PFTs are referred 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). PFTs are defined based on the relevant traits, *e.g.* plant morphology, physiology, life history, and bio-climatic tolerance, depending on the intentions and studying scales (Wang 2003). The common use of PFTs classifications has been proposed to describe biological attributes of vegetation in relation to climate changes (Teeri and Stowe 1976, Teeri *et al*. 1980, Box 1996, Ehleringer *et al*. 1997, Collatz *et al*. 1998), geographical distribution (Collins and Jones 1985, Takeda and Hakoyama 1985, Keeley 1998, Pyankov *et al*. 2000, Wang 2002), disturbance regime and land use history (Williams and Markley 1973, Hattersley 1992, Liu *et al*. 2004). Some studies clearly document the importance of PFTs (*e.g*. photosynthetic pathways and morphological functional types) in predicting vegetation dynamics in grasslands (Williams and Markley 1973, Wang 2002, 2003). These works provide strong evidence that the abundance of PFTs correlated with vegetation differences, land use, and climatic change in local, regional, and global scales.

The mixed prairie is characterized by Clements as a region, the potential climax vegetation of which includes both mid-grasses and short-grasses. It lies entirely within the Great Plain, with a latitudinal range of about

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2 600 km (29–52°), encompassing 3 Canadian provinces and 8 American states (Coupland 1992). The mixed prairie in the southern Saskatchewan, located at the northern end of the mixed prairie, covers large continuous area. Land use in the region is shared between crop production and rangeland grazing, and the proportion of the area allocated to each activity varies according to aridity of climate and the character of the soil. Studies on the rangelands, *e.g.* community classification, plant biomass, and grazing effects, have been well conducted (Coupland 1961, 1992, Coupland *et al*. 1973), but the patterns of plant functional types and its relation with local climate remain unclear. The information could be important for predicting climate changes, vegetation dynamics, and land use at both local and global scales. We investigated the composition of photosynthetic pathways and morphological functional types in the region and the results may be useful for the interpretation of relationships between the changes of plant functional types and land use and climate changes.

Materials and methods

The mixed prairie, widely distributed in southern Saskatchewan, lies near the northern edge of the mixed prairie association of Clements, and the zonal vegetation in the region was classified into five major community types (*e.g*. *Stipa–Agropyron*, *Stippa–Bouteloua*, *Bouteloua–Agropyron*, *Stippa–Bouteloua–Agropyron*, and *Agropyron–Koeleria*) (Coupland 1992). Floristic composition varies throughout the region in response to regional climate, soil texture, and physiographic position, and the rangeland is mainly dominated by xerophytes, *e.g*. *Agropyron dasystachyum* Hook. and *Stipa spartea* Trin. Most of the region has dark brown, brown, and sandy loam soils. Average soil pH for the region is about 8.0, rising from 7.2 to 8.3 (Jong and Stewart 1973, Coupland 1992). The climate of the region is generally dry-sub-humid to semi-arid, with some years ranging from humid to arid. Dry years tend to be grouped and periods of severe drought occur. Mean annual air temperature is about 4 °C, varying from –14 °C in January to 20 °C in July. Annual precipitation is about 400 mm, 70 % of which is falling mainly during the growing season. Winds are strong and frequent, particularly in spring.

Complete species' lists for the mixed prairie were obtained from local floras, published from 1950 to 1996 (Coupland 1950, 1961, 1992, Saskatchewan Agriculture and Food 1996). Photosynthetic pathway types for native species were determined by stable carbon isotope ratio ($\delta^{13}C$) and from the references published between 1985 and 2002 (*e.g.* Downton 1975, Raghavendra and Das 1978, Ode *et al*. 1980, Takeda and Hakoyama 1985, Li 1993, Redmann *et al*. 1995, Pyankov *et al.* 2000, Wang 2002, Rusch *et al.* 2003, Liu *et al*. 2004). Plants identified in the region were classified into both photosynthetic pathway types by physiological attributes ($\delta^{13}C$) and morphological functional types, *i.e.* trees (TRE), shrubs (SHR), high perennial grasses (HPG), short perennial graminaceous plants (grasses and sedge) (SPG), annual grasses (ANG), annual forbs (ANF), and perennial forbs (PEF), by morphological attributes (Table 1).

Table 1. Photosynthetic pathway (C_3 or C_4) and morphological functional types in mixed prairie in Southern Saskatchewan, Canada. Nomenclature follows Kitagawa (1979). Plant functional types: TRE = trees, SHR = shrubs and vines, HPG = high perennial grasses, SPG = short perennial graminaceous plants (grasses and sedge), ANG = annual grasses, ANF = annual forbs, PEF = perennial forbs, HAL = halophytes, HYD = hydrophytes. Habitat types: LT = level terrain, GS = grassy slopes, HW = hillwash, EE = eroding escarpments, CB = coulee bottoms, MC = miscellaneous (*e.g.* saline meadows, sand-gravel, disturbed lands).

	Species	C_3/C_4	PTFs	Habitat
Pteridophyta				
Selaginellaceae	*Selaginella densa* Rydb. var. *densa*	C_3	PEF	GS
Angiospermae				
Pinaceae	*Juniperus communis* L.	C_3	SHR	CB
	J. horizontalis Moench.	C_3	SHR	HW EE
Dicotyledoneae				
Aceraceae	*Acer negundo* var. *interius* (Britt.) Sarg.	C_3	TRE	HW
Anacardiacea	*Rhus aromatica* var. *trilobata* Nutt.	C_3	SHR	HW EE
	R. radicans var. *rydbergia* (Small) Rehder	C_3	SHR	CB MC
Apocynacaea	*Apocynum cannabinum* L.	C_3	PEF	MC
Betulacea	*Betula fontinalis* Sarg.	C_3	TRE	CB
Boraginaceae	*Cryptantha macounii* (Eastw.) Pays	C_3	ANF	HW EE
	Lappula echinata Gilib.	C_3	ANF	MC

Table 1 (continued)

	Species	C_3/C_4	PTF type	Habitat
Boraginaceae (cont.)	*Lithospermum incisum* Lehm.	C_3	PEF	MC
	Plagiobothrys scopulorum I. M. Johnston	C_3	PEF	MC
Cactaceae	*Opuntia polyacantha* Haw.	C_3	PEF	HW EE
	O. fragilis (Nutt.) Haw.	C_3	PEF	MC
Campanulaceae	*Campanula rotundifolia* L.	C_3	PEF	GS MC
Caprifoliaceae	*Lonicera dioica* var. *glaucescens* (Rydb.) Butters	C_3	SHR	CB
	Symphoricarpos occidentalis Hook.	C_3	SHR	GS CB MC
Caryophyllaceae	*Arenaria lateriflora* L.	C_3	PEF	MC
	Cerastium arvense L.	C_3	PEF	LT GS HW
	Paronychia sessiliflora Nutt.	C_3	PEF	HW
Chenopodiaceae	*Atriplex argentea* Nutt.	C_4	ANF	HW
	A. nuttallii S. Wats.	C_3	SHR	LT GS MC
	Chenopodium berlandier Moq.	C_3	ANF	MC
	Ch. fremontii S. Wats.	C_3	ANF	MC
	Ch. leptophylum Nutt.	C_3	ANF	MC
	Endolepis suckleyi Torr.	C_3	ANF	MC
	Eurotia lanata (Pursh) Moq.	C_3	SHR	LT GS HW
	Salsola kali var. *tenuifolia* Tausch.	C_4	ANF	MC
	Suaeda maritime var. *americana* (Pers.) Boivin	C_3	ANF	MC
Compositae	*Achillea millefolium* var. *occidentalis* DC.	C_3	PEF	LT GS CB MC
	Agoseris glauca (Pursh) Raf.	C_3	PEF	CB MC
	Antenaria parvifolia Nutt.	C_3	PEF	LT GS
	Artemisia biennis Willd.	C_3	ANF	MC
	A. caudata var. *calvens* Lunell Cronq.	C_3	PEF SHR	MC
	A. drancunculus L.	C_3	PEF	HW EE
	A. frigida Willd.	C_3	SHR	LT GS HW CB
	A. longifolia Nutt.	C_3	PEF	EE
	A. ludoviciana var. *pabularis* (Nels.) Fern.	C_3	SHR	MC
	Aster falcatus Lindi.	C_3	PEF	LT GS MC
	A. laevis L.	C_3	PEF	GS MC
	Cirsium flodmanii (Rydb.) Arthur	C_3	PEF	MC
	Crepis intermedia Gray	C_3	PEF	MC
	Erigeron caespitosus Nutt.	C_3	PEF	GS HW MC
	E. glabellus var. *pubescens* Hook.	C_3	PEF	MC
	Gaillardia aristata Pursh	C_3	PEF	GS MC
	Grindelia squarrosa (Pursh) Dunal	C_3	ANF	GS MC
	Gutierrezia sarothrae Britt. *et* Rusby	C_3	ANF	LT GS HW
	Haplopappus armeriodes Nutt.	C_3	ANF	HW MC
	H. nuttallii T. *et* G.	C_3	PEF	MC
	H. spinulousus (Pursh) DC.	C_3	PEF	HW MC
	Helianthus annuus L.	C_3	ANF	HW MC
	Heterotheca villosa (Pursh) Shinners	C_3	PEF	HW
	Hieracium umbellatum L.	C_3	PEF	CB
	Hymenoxys richardsonii Cocherell	C_3	PEF	GS HW
	Iva axillaris Pursh	C_3	PEF	HW MC
	Lactuca pulchela (Pursh) DC.	C_3	PEF	HW MC
	Liatris punctata Hook.	C_3	PEF	MC
	Ratibida columnifera Wooton *et* Standl.	C_3	PEF	LT GS HW
	Senecio canus Hook.	C_3	PEF	GS HW MC
	Solidago canadensis var. *gilvocanescens* Rydb.	C_3	PEF	MC
	S. missouriensis Nutt.	C_3	PEF	GS HW MC
	S. rigida L.	C_3	PEF	GS MC
	S. spathulata var. *neomexicana* Cronq.	C_3	PEF	MC
	Stephanomeria runcinata Nutt.	C_3	PEF	HW MC
	Taraxacum officinale Weber	C_3	PEF	MC
	Townsendia exscapa (Rich.) Porter	C_3	PEF	HW MC

Table 1 (continued)

	Species	C_3/C_4	PTF type	Habitat
Compositae (cont.)	*Tragopogon dubius* Scop.	C_3	ANF	LT GS CB MC
Cornaceae	*Cornus stolonifera* Michx.	C_3	SHR	MC
Convolvulaceae	*Convolvulus sepium* L.	C_3	PEF	MC
Cruciferae	*Arabis hirsuta* Scop.	C_3	ANF	LT GS
	A. holboellii var. *retrofracta* (Graham) Rydb.	C_3	PEF	HW
	Descurainia pinnata var. *brachycarpa* Fern.	C_3	ANF	LT MC
	D. sophia (L.) Webb.	C_3	ANF	MC
	Erysimum cheiranthoides L.	C_3	ANF	CB
	E. inconspicuum (S. Wats.) Macm.	C_3	PEF	CB
	Lepidium densiflorum Schrad.	C_3	ANF	HW EE
	Lesquerella arenosa (Richards.) Rydb.	C_3	ANF	HW MC
	Rorippa sinuata (Nutt.) Hitchc.	C_3	PEF	MC
Elaeagnaceae	*Elaeagnus commutata* Bernh.	C_3	SHR	MC
	Shepherdia argentia Nutt.	C_3	SHR	CB
Euphorbiaceae	*Euphorbia serpyllifolia* Pers.	C_4	ANF	MC
Fabaceae	*Astragalus bisulcatus* (Hook.) A. Gray	C_3	PEF	CB MC
	A. danicus Retz.	C_3	PEF	LT GS MC
	A. gilviflorus Sheldon	C_3	PEF	HW MC
	A. lotiflorus Hook.	C_3	PEF	MC
	A. missouriensis Nutt.	C_3	PEF	HW
	A. striatus Nutt.	C_3	PEF	HW MC
	A. tenellus Pursh	C_3	PEF	HW MC
	Glycyrrhiza lepidota (Nutt.) Pursh	C_3	PEF	HW
	Hedysarum boreale var. *cinerascens* Rollins	C_3	PEF	HW MC
	Oxytropis sericea var. *spicata* (Hook.) Barneby	C_3	PEF	LT GS HW
	Petalostemon candidum (Willd.) Michx.	C_3	PEF	HW
	P. purpureum (Vent.) Rydb.	C_3	PEF	HW MC
	Psoralea argophylla Pursh	C_3	PEF	MC
	P. esculenta Pursh	C_3	PEF	HW MC
	Thermopsis rhombifolia (Nutt.) Richards	C_3	PEF	HW
	Vicia americana Muhl.	C_3	PEF	LT GS
Haloragidaceae	*Myriophyllum exalbescens* Fern.	C_3	PEF	MC
Labiatae	*Moldavica parviflora* (Nutt.) Britt.	C_3	PEF	CB
	Monarda fistulosa var. *menthaefolia* (Grah.) Fern.	C_3	PEF	MC
Linaceae	*Linum perenne* var. *lewisii* (Pursh) Eat *et* Wright	C_3	PEF	LT GS
	L. rigidum Pursh	C_3	ANF/ PEF	HW
Malvaceae	*Sphaeralcea coccinea* (Pursh) Rydb.	C_3	SHR	HW
Onagracaea	*Gaura coccineaa* Pursh	C_3	PEF	HW EE
	Oenothera caespitosa Nutt.	C_3	SHR	MC
Plantaginaceae	*Plantago major* L.	C_3	PEF	CB MC
Polemoniaceae	*Collomia linearis* Nutt.	C_3	ANF	CB
	Phlox hoodii Richards	C_3	PEF	HW EE
Polygonaceae	*Eriogonum flavum* Nutt.	C_3	PEF	HW EE
	Rumex salicifolius var. *mexicanus* C.L. Hitchc.	C_3	PEF	MC
Primulaceae	*Androsace occidentalis* Pursh	C_3	ANF	CB
	A. septentrionalis var. *puberulenta* (Rydb.) Knuth.	C_3	ANF	LT GS
	Glaux maritime L.	C_3	ANF	MC
	Sterionema ciliatum (L.) Raf.	C_3	PEF	MC
Ranunculaceae	*Anemone canadensis* L.	C_3	PEF	CB
	A. patens var. *wolfgangiana* (Bess.) Koch	C_3	PEF	GS HW
	Clematis ligusticifolia Nutt.	C_3	PEF	CB
	Ranunculus abortivus L.	C_3	PEF	CB
	R. aquatilis var. *capillaceus* (Thuill.) D.C.	C_3	PEF	MC

Table 1 (continued)

	Species	C_3/C_4	PTF type	Habitat
Ranunculaceae (cont.)	*R. cymbalaria* Pursh	C_3	PEF	MC
	Thalictrum venulosum Trel.	C_3	PEF	CB
Rosaceae	*Amelanchier alnifolia* Nutt.	C_3	SHR	HW CB
	Crataegus rotundifolia Moench	C_3	TRE	CB MC
	Fragaria vesca var. *americana* Porter	C_3	PEF	GS
	Geum perincisum Rydb	C_3	PEF	CB
	G. triflorum Pursh.	C_3	PEF	LT GS
	Potentilla anserina L.	C_3	PEF	MC
	P. argentea L.	C_3	PEF	MC
	P. concinna Rich.	C_3	PEF	HW
	P. gracilis Dougl.	C_3	PEF	CB
	P. pensylvanica L.	C_3	PEF	LT GS
	Prunus pensylvanica L.	C_3	SHR	HW CB
	P. virginiana L.	C_3	SHR	HW CB
	Rosa alcea Greene	C_3	SHR	HW MC
	R. arkansana Porter	C_3	SHR	MC
Rubiaceae	*Galium boreale* L.	C_3	SHR	GS CB
Salicaceae	*Populus deltoids* Marsh. var. *occidentalis* Rybd.	C_3	TRE	CB
	P. tremuloides Michx.	C_3	TRE	CB
	Salix bebbiana Sarg	C_3	TRE/SHR	CB
	S. interior Rowiee	C_3	SHR	CB
	S. lutea Nutt.	C_3	TRE/SHR	CB
Saxifragaceae	*Heuchera richardsonii* R. Br.	C_3	PEF	GS MC
	Ribes oxyacanthoides L.	C_3	PEF	CB
Scrophulariaceae	*Orthocarpus lutens* Nutt.	C_3	ANF	HW MC
	Penstemon albidus Nutt.	C_3	PEF	HW EE
	P. nitidus Dougl.	C_3	PEF	HW EE
Umbelliferae	*Cymopterus acaulis* (Pursh) Raf.	C_3	PEF	HW EE
	Heracleum lanatum Michx.	C_3	PEF	CB MC
	Lomatium foeniculaceum Nutt.	C_3	PEF	LT GS CB MC
	Musineon divaricatum Nutt.	C_3	PEF	HW EE
	Zizia aptera Fern.	C_3	PEF	MC
Urticaceae	*Urtica dioica* var. *procera* (Muhl.) Wedd.	C_3	PEF	CB
Violaceae	*Viola adunca* J.E. Smith	C_3	PEF	CB
	V. nuttallii Pursh	C_3	PEF	HW MC
	V. rugulosa Greene	C_3	PEF	CB
Monocotyledoneae				
Alismaceae	*Alisma triviale* Pursh	C_3	PEF	MC
	Sagittaria cuneata Sheldon	C_3	PEF	MC
Cyperaceae	*Carex atherodes* Spreng.	C_3	SPG	MC
	C. brevior (Dewey) Mack.	C_3	SPG	HW
	C. eleocharis Bailey	C_3	SPG	HW EE
	C. filifolia Nutt.	C_3	SPG	MC
	C. praegracilis W. Boott	C_3	SPG	MC
	C. rossii Boott	C_3	SPG	HW
	Eleocharis palustris (L.) R. *et* S.	C_3	SPG	MC
	Scirpus americanus Pers.	C_3	HPG	MC
Gramineae	*Agropyron albicans* Scribn. *et* Smith	C_3	HPG	LT GS
	A. albicans var. *griffithsii* Scribn. *et* Smith	C_3	HPG	LT GS
	A. dasystachyum Hook.	C_3	HPG	LT GS HW
	A. dasystachyum var. *riparium* Bowden	C_3	HPG	LT GS HW
	A. smithii Rydb.	C_3	HPG	LT GS HW CB
	A. trachycaulum Link	C_3	HPG	CB MC
	Alopecurus aequalis Sobol.	C_3	HPG	MC
	Andropogon scoparius Michx.	C_4	HPG	MC

Table 1 (continued)

	Species	C_3/C_4	PTF type	Habitat
Gramineae (cont.)	*Bechmannia syzigachne* Fern.	C_3	ANG	MC
	Bouteloua gracilis Lag.	C_4	SPG	GS
	Bromus anoma Rupr.	C_3	HPG	CB
	Calamagrostis canadensis (Michx.) Beauv.	C_3	HPG	MC
	C. inexpansa A. Gray	C_3	HPG	GS
	C. montanensis Scribn.	C_3	HPG	GS
	Calamovilfa longifolia (Hook.) Scribn.	C_4	HPG	GS
	Danthonia intermedia Vasey	C_3	SPG	MC
	Deschampsia caespitosa (L.) Beauv.	C_3	HPG	MC
	Distichlis stricta (Torr.) Rydb.	C_4	SPG	MC
	Elymus canadensis L.	C_3	HPG	CB
	E. glaucus Buckl.	C_3	HPG	MC
	E. glaucus var. *glaucus* Buckl	C_3	HPG	CB
	Festuca altaica Trin.	C_3	HPG	GS MC
	Helictotrichon hookerii (Scribn.) Henr.	C_3	HPG	CB
	Hierochloe odorata (L.) Beauv.	C_3	HPG	CB
	Hordeum jubatum L.	C_3	HPG	MC
	H. jubatum var. *caespitosum* A.S. Hitchc.	C_3	HPG	CB MC
	Koeleria cristata Pers.	C_3	HPG	LT GS HW
	Muhlenbergia cuspidata (Torr.) Rydb.	C_4	HPG	HW EE
	M. richardsonis (Trin.) Rydb.	C_4	HPG	MC
	Oryzopsis hymenoides (Roem *et* Schult.) Ricker	C_3	HPG	MC
	Poa canbyi (Scribn.) Piper	C_3	SPG	MC
	P. compressa L.	C_3	SPG	MC
	P. cusickii Vasey	C_3	SPG	LT GS
	P. glaucifolia Scribn. *et* Williams	C_3	SPG	MC
	P. interior Rydb.	C_3	SPG	MC
	P. juncifolia Scribn.	C_3	SPG	MC
	P. palustris L.	C_3	SPG	HW CB
	P. pratensis L.	C_3	SPG	CB MC
	P. sandbergii Vasey	C_3	SPG	LT GS HW
	P. secunda Pressl.	C_3	SPG	LT GS HW
	Puccinellia nuttalliana (Schult.) Hitch.	C_3	HPG	MC
	Schizachyrium scoparium (Michx.) Nash	C_4	SPG	MC
	Spartina gracilis Trin.	C_3	HPG	MC
	Sporobolus cryptandrus A. Gray	C_4	HPG	MC
	Stipa comata Trin. *et* Rupr.	C	HPG	GS HW
	S. spartea var. *curtiseta* Hitchc.	C_3	HPG	GS HW MC
	S. viridula Trin.	C_3	HPG	LT GS HW
Iridaceae	*Sisyrinchium montanum* Greene	C_3	PEF	LT
Juncaceae	*Juncus balticus* Will.	C_3	PEF	MC
Juncaginaceae	*Triglochin maritima* L.	C_3	PEF	MC
Liliaceae	*Allium textile* Nels. *et* Macbr.	C_3	PEF	HW
	Disporum trachycarpum (Wats.) B. *et* H.	C_3	PEF	CB MC
	Smilacina stellata (L.) Desf.	C_3	PEF	CB MC
Potamogetonaceae	*Potamogeton richardsonii* (Benn.) Rydb.	C_3	PEF	MC

Results

Floristic composition of photosynthetic pathway types: 219 vascular plant species, in 45 families and 145 genera, were identified with C_3 and C_4 photosynthesis (Table 1). Of these species, 1 species was in *Pteridophyta* and 218 species in *Angiospermae*. About 71 % (154 of 219) was found in *Dicotyledoneae*, *e.g*. *Compositae* (38 species), *Chenopodiaceae* (9 species), *Cruciferae* (9 species), *Fabaceae* (16 species), *Rosaceae* (14 species), and *Ranunculaceae* (7 species). 29 % were in *Monocotyledoneae*, *e.g. Gramineae* (47 species), *Liliaceae* (3 species), *Cyperaceae* (8 species), and *Iridaceae* (1 species). As for photosynthetic pathway types, 208 species (95 % of the identified species in Table 1) in 137 genera and 44 families were found with C_3 photosynthesis, 11 species in 10 genera and 3 families with C_4 photosynthesis. 5 % (11 of 219) of the identified species in Table 1 was found with C_4 photosynthesis, *e.g.* *Gramineae* (8 species), *Chenopodiaceae* (2 species), and *Euphorbiaceae* (1 species). The occurrence of C_4 species was not common in *Gramineae* (17 %) and *Chenopodiaceae* (22 %). Number of C_4 species in the Saskatchewan mixed prairie was much less than those from the mixed prairie of South Dakota (27 species) and Mongolian steppe (25 species).

The occurrence of C_4 species was related with habitats in the mixed prairie in the region (Table 1). 7 species can be found in the miscellaneous habitats (*e.g.* saline meadows, sand-gravel, disturbed lands), 2 in grassy slopes, 2 in hillwash, and 1 in eroding. *Bouteloua gracilis* Lag. and *Calamovilfa longifolia* Scribn. can be dominant species in the driest part of the Saskatchewan mixed prairie, in which underling shale deposits have imposed a solonetzic character to the soils.

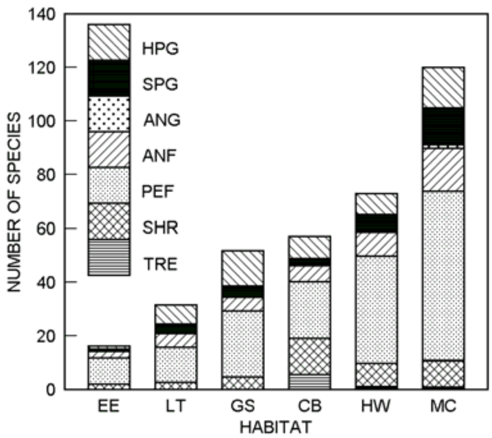

Fig. 1. Plant functional type compositions in habitats in the Saskatchewan mixed prairie.

Morphological functional types: According to plant morphological attributes, growth form, and life-span, the identified plant species were classified into 7 functional types, *e.g.* TRE, SHR, ANF, PEF, HPG, SPG, and ANG (Table 1). Of the total 219 species, 50 % was PEF functional type and 12 % species was ANF, while these two types make up only 1–12 % of the total forage production in the region. 11 and 3 % of these total species were in SHR and TRE types, respectively. Graminoids (grasses and sedge) formed about 25 %, *e.g.* HPG (15 %), ANG (0.5 %), and SPG (10 %), and graminoid types about 83–98 % of forage production in the region. Many grasses are the dominant species, *e.g.* *Agropyron dasystachyum* Hook., *A. smithii* Rydb., *Stipa spartea* var. *curtiseta* Hitchc., *Bouteloua gracilis* Lag., and *Calamovilfa longifolia* Scribn. This indicated that HPG and SPG functional types are the dominant PFTs, even though their species abundances were less than fords (ANF and PEF).

The responses of morphological functional type compositions to habitats were remarkable in the Saskatchewan mixed prairie (Fig. 1). Five PFTs were found in EE, LT, and GS, and the species numbers were 16, 31, and 51, respectively. Six PEFs and relative more species (56 and 72) were identified in HW and CB. All the 7 PFTs (119 species) were in MC, and 52 % of these species was in PEF type. This indicated that complex habitat comprises lead to relative high PFTs abundances.

Like that in the South Dakota mixed prairie, dicotyledonous C_4 species were mainly annual forbs, *e.g.* *Atriplex argentea* Nutt., *Salsola kali* var. *tenuifolia* Tausch., and *Euphorbia serpyllifolia* Pers., while most of the C_4 species were HPG and SPG grasses, *e.g.* *Andropogon scoparius* Michx., *Bouteloua gracilis* Lag., *Calamovilfa longifolia* (Hook.) Scribn., *Muhlenbergia cuspidata* (Torr.) Rydb., and *M. richardsonis* (Trin.) Rydb. This suggests that C_4 species occurred mainly in few PFTs in the region.

Discussion

The PFTs framework constitutes a useful tool for studying the logical links between physiological and life-history strategies at plant level and ecological process at ecosystem and global level, as well as for predicting the vegetation and biodiversity changes as consequences of environmental and disturbance changes and land use shifts at regional and global level (Chapin 1993, Paruelo and Lauenroth 1996, Wang 2003). But one of the crucial problems is how to define the optimal and comparable PFTs for the regional vegetation types (Pillar 1999, Wang 2003). This requires the screening and synthesis of traits from a large number of species across broad environmental and disturbance gradients (Rusch *et al.* 2003, Wang 2004). The studies on coarse traits (photosynthetic pathways) of PFTs in American mixed prairie have been conducted (Teeri and Stowe 1976, Teeri *et al.* 1980, Rusch *et al.* 2003), but PFTs compositions of Canadian mixed prairie remain unclear. The floristic composition of the Saskatchewan mixed prairie is similar in terms of C_3 and C_4 representatives to that predicted by the coarse floristic analysis of Teeri and Stowe (1976). They found that the distribution of C_4 grasses in North America was significantly correlated with mean July consequence minimum temperatures. Their regression model predicts that Saskatchewan mixed prairie should have a grass flora composed 12 % C_4 grass species. Eight of 47 grass species examined in this study, or 17 %, are in fact C_4 species. This is relatively more than in coarse model prediction. The dicotyledonous C_4 species were about 2 % (or 3 of 154), and this supported Teeri and Stowe's model which predicts that about 2 % of native dicotyledonous flora should be C_4 species. The total number of C_4 species (11 species) in the Saskatchewan mixed prairie was less than a half of those from the South Dakota mixed prairie (27 species) and Mongolian steppe (25 species). This consists with conclusion of Ehleringer *et al.* (1997) that the C_4 species favoured the higher temperature and lower CO_2 concentration regions. A cold semi-desert climate dominates the Saskatchewan mixed prairie, leading relatively less C_4 species occurrence, even though some C_4 plants can be dominants species in the driest part of the mixed prairie (*Boutelou gracilis* Lag. and *Calamovilfa longifolia* Scribn.). Relative stability of the Saskatchewan mixed prairie may also lead to less C_4 species occurrence, for stable ecosystems may reduce the introduction of weeds and forbs [*e.g. Portulaca oleracea* L., *Salsola iberica* Senner *ex* Pau, *Echinochloa crus galli* L., and *Setaria glauca* (L.) Beauv. in the South Dakota mixed prairie]. Within the Saskatchewan mixed prairie, the distribution of C_4 species appears to fall within two categories: miscellaneous habitats (*e.g*. saline meadows, sand-gravel, disturbed lands) and the driest lands (grassy slopes and hillwash); this suggests that C_4 plants are more tolerant to environmental stresses (*e.g*. salinity, dryness, and high temperature).

Plant photosynthetic pathways or photosynthetic functional types are relative coarse in describing the PFTs in regional and local scales, while morphological functional types may more fit for depicting the PFTs differences among the habitats, land-use, and community types (Wang 2004), and for reflecting their seasonal dynamics. Only about 50 and 12 % of the identified species fall within two categories PEF and ANF types, respectively, while those for Mongolian steppe are about 60 and 15 %. Graminoid types (*e.g*. HPG, SPG and ANG) in the region form about 25 % of the total species in local flora, but that in Mongolian steppe is 18 %. Relatively more graminoid types and less forb functional types suggest that most of the Saskatchewan mixed prairie is in a relatively fair condition.

Morphological functional types reflect vegetation spatial changes in rangeland ecosystems (Fig. 1). In general, species numbers of PEF, ANF, SHR, and graminoid types increased from EE to MC, indicating that PFTs abundances varied significantly with the habitat changes. There were less PFTs in the early succession stages (*e.g.* eroding escarpments and sand-gravel), while complex habitat lead to relative high PFTs abundances in MC. Most of the stable communities in the habitats (*e.g.* LT, GS, HW, and CB) have relatively less PFTs composition in the Saskatchewan mixed prairie. This is also supported by previous observations (Wang 2003, 2004). This and early study (Teeri and Stowe 1976, Ode *et al.* 1980) document the importance of plant function types (*e.g.* photosynthetic pathways and morphological functional types) in predicting vegetation and habitat changes, land-use, and climate changes in the mixed prairie. To select optimal traits for PFTs classification in the region by the present knowledge, further studies (*e.g*. C_3 and C_4 plant identification, optimal traits' selection) are needed exploring the relationships between PFTs and vegetation variations, as well as land-use and climate changes.

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