

C₃ and C₄ photosynthetic pathways and life form types for native species from agro-forestry region, Northeastern China

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Abstract

Of the total 570 species, 194 species in 116 genera and 52 families were found with C₃ photosynthesis, 24 species in 17 genera and 6 families with C₄ photosynthesis, and 2 species in 1 genera and 1 family with CAM photosynthesis. 90 % of the total species can be found in Changbai Mountain flora, more a half (69 %) in North China flora, and about 1/3 in Mongolian flora and Xinan flora, respectively. The occurrence of C₄ species was not as common as that in adjacent grasslands and deserts, but relatively more than in the adjacent forests. Of the total 24 C₄ species, 63 % C₄ species (15 of 24) was found in *Gramineae*. Nine life form types can be found, reflecting the moist climate in the region, especially the occurrence of epiphyte and liana forms. Relatively more geophyte life form plants suggested the winter in the region was much colder than in grasslands. These indicated that both ecological studies and land management decisions must take into account plant photosynthetic pathway and life form patterns, for both of them are closely related to climatic changes and land use.

Additional key words: agro-forestry region; C₃ and C₄ species; CAM plants; Tumen Mountains.

Introduction

C₄ biota account for approximately 18 % of the total global phyto-productivity, but it was estimated that in the world only one half of the 10 000 grass species and a thousand of the 165 000 dicotyledonous plants have C₄ photosynthesis (Hattersley 1987, 1992, Ehleringer *et al.* 1997). Only 30 % of these C₄ species have been identified worldwide (Li 1993) since the works by Downton and Tregunna (1968) and Black (1971). C₃, C₄, and CAM plants are the main plant functional types and the popular means for studying the logical links between physiological and life-history strategies at plant level, as well as ecological process at ecosystem and global levels (Collins and Jones 1985, Collatz *et al.* 1998, Keeley 1998, Pyankov *et al.* 2000, Wang 2003). Some studies proved that vegetation management decisions must take into account photosynthetic types, because they are closely related to climate, land use, and human activities (Williams and Markley 1973, Wang 2004). Many methods, *e.g.* carbon isotope ratio ($\delta^{13}\text{C}$), "Kranz" type leaf anatomy, low CO₂ compensation concentration, and photosynthetic enzyme ratio, have been used for C₃ and C₄ identification, but many studies suggested that the carbon isotope ratio method is more reliable (Redmann *et al.* 1995, Liu *et al.*

2004).

Tumen Mountains, located at latitude 44°6'N, longitude 126°2'E in Jiutai, Jilin province, is a typical agro-forestry region that covers an area of about 2 400 km² in the Northeastern China. The east of this area is Changbai Mountain, a typical forestry region, while the west is the Northeast China Plain with large expansion of agricultural lands and meadows. The transitional climatic conditions of the region make its community composition more complex, with both forest species and grassland species (Qian *et al.* 1957). However, few studies on flora, community classification, and land use had been well conducted in the region (Qian *et al.* 1957, Wang 2004). The patterns of photosynthetic pathway types and plant life forms in the region remain unclear and the information could be important for the interpretation of relationships between the changes of plant flora and land use, climate changes, as well as for deterioration land restorations. Present study investigated C₃, C₄, and CAM composition and life forms in the region. The results may contribute new information for better understanding of photosynthetic pathway types, life forms, and their relations with ecosystems, climate changes, and land use.

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Materials and methods

This study was conducted in Tumen Mountains, a typical agro-forestry region in Northeastern China. The area is on the eastern end of the Northeastern China plain, on average 260 m above sea level, varying from 140 to 542 m. The relief is very complicated and it is primarily a hill landscape mixed with deciduous broadleaf forest, rangeland, cultivated land, valley, and wetland. Most of the region has mountain dark brown forest soils and brown soils, with 5 to 9 % organic matter in the surface layer. The main determinants of the climate in Northeast China are the Mongolian anticyclone and the moist Pacific air mass. In winter, the climate of the area is dominated by the Mongolian anticyclone, which produces a westerly flow of cold, dry air and much snowfall. As the anticyclone breaks down in spring, the region comes increasingly under the influence of moist Pacific air masses, reaching a climax in the summer monsoon, which lasts 4–5 months. The mean annual air temperature is about 5.6 °C, varying from –18 °C in January to 23 °C in July. Average annual precipitation is 850 mm, with

Results

Floristic composition of photosynthetic pathway types: 570 vascular plant species (about 70 % of the total species), in 305 genera and 87 families, were identified in Tumen Mountain region. Only 220 species (39 % of 570 species) were classified into their types of photosynthetic pathway (C_3 , C_4 , and CAM) (Table 1). Of these species, 19 species in 14 genera and 6 families were identified in *Pteridophyta*, 551 species in *Angiospermae*. 431 *Angiospermae* species in 233 genera and 68 families were found in *Dicotyledoneae*, e.g. *Compositae* (78 species), *Rosaceae* (31 species), *Ranunculaceae* (27 species), *Liliaceae* (27 species), *Labiatae* (24 species), *Fabaceae* (24 species), *Polygonaceae* (20 species), *Umbelliferae* (19 species), *Caryophyllaceae* (19 species), and *Chenopodiaceae* (11 species). 120 *Angiospermae* species, in 58 genera and 13 families, were in *Monocotyledoneae*, e.g. *Gramineae* (43 species), *Lemnaceae* (27 species), *Cyperaceae* (25 species), and *Iridaceae* (4 species). Of all species listed in Table 1, 90 % can be found in Changbai Mountain flora, 69 % in North China flora, and 33 and 32 % in Mongolian flora and Xinan flora, respectively.

As for photosynthetic pathway types, 194 species (34 % of the identified species in Table 1) in 116 genera and 52 families were found with C_3 photosynthesis, 24 species in 17 genera and 6 families with C_4 photosynthesis, and only 2 species in 1 genera and 1 family with CAM photosynthesis. Of the identified C_3 species, 163 species in 96 genera and 46 families were classified into *Dicotyledoneae*, e.g. *Compositae* (23 species), *Rosaceae* (16 species), *Fabaceae* (12 species), *Ranunculaceae*

81 % falling between April and September.

Floristic species were obtained from samplings conducted from 1986 to 2004 and from references published from 1957 to 2004 (Qian *et al.* 1957, Wang 2002a, 2004). Photosynthetic pathway types for plant species were determined by stable carbon isotope ratio ($\delta^{13}C$) and from the references published between 1976 and 2004 (e.g. Teeri and Stowe 1976, Raghavendra and Das 1978, Waller and Lewis 1979, Teeri *et al.* 1980, Takeda and Hakoyama 1985, Ueno and Takeda 1992, Li 1993, Redmann *et al.* 1995, Yin and Li 1997, Pyankov *et al.* 2000, Wang 2002b, 2004, Liu *et al.* 2004). Plants with $\delta^{13}C$ values above –19 ‰ were considered to have the C_4 photosynthesis, and those with $\delta^{13}C$ values less than –21 ‰ to have C_3 photosynthesis (Redmann *et al.* 1995). Plants identified in the region were classified into nine life forms: macrophanerophyte (M), nanophanerophyte (N), epiphyte (E), liana (L), chamaephyte (Ch), hemi-cryptophyte (H), geophyte (G), therophyte (Th), and hydrophyte (HH), respectively.

(12 species), and *Salicaceae* (12 species), while the other 31 species in 20 genera and 6 families in *Monocotyledoneae*, e.g. *Gramineae* (17 species), *Lemnaceae* (4 species), and *Cyperaceae* (4 species). 4 % of identified species in the Table 1, or about 3 % of the species in local flora, was found with C_4 photosynthesis. Five C_4 species in 5 genera and 4 families were identified in *Dicotyledoneae*, e.g. *Chenopodiaceae* (2 species), *Amaranthaceae* (1 species), *Portulacaceae* (1 species), and *Euphorbiaceae* (1 species). 19 species in 12 genera and 2 families were found in *Monocotyledoneae*, e.g. *Gramineae* (15 species), *Cyperaceae* (2 species), and *Commelinaceae* (2 species). This suggested that the occurrence of C_4 species was not as common as that in grassland and desert vegetations in the north China.

The occurrence of C_4 species was remarkably related with habitats in Tumen Mountains. 15 C_4 species were found in disturbed and cultivated land (DB), e.g. *Amaranthus retroflexus* L., *Kochia scoparia* (L.) Schrad., *Salsola collina* Pall., *Commelina communis* L., and *Setaria gigantea* Makino, six species in rangeland (RL), e.g. *Spodiopogon sibiricus* Trin., *Chloris virgata* Sw., *Cleistogenes squarrosa* (Trin.) Keng, *Eragrostis ferruginea* Beauv., and *E. pilosa* (L.) P. B., and 5 species in wet soil (WS), e.g. *Echinochloa candata* Roshev., *Arthraxon hispidus* (Thunb.) Makino., *Arundinella hirta* (Thunb.) Tanaka., *Cyperus amuricus* Maxim., and *C. serotinus* Rott.. This indicated that the occurrence of C_4 species was mainly in the unstable ecosystems or habitats in the region.

Table 1. Photosynthetic pathways (C₃, C₄, and CAM), life forms and habitats for native species in Tumen Mountain, an agro-forestry region, in Northeastern China. Nomenclature follows Kitagawa (1979). Plant life forms: M = macrophanerophyte, N = nanophanerophyte, E = epiphyte, L = liana, Ch = chamaephyte, H = hemicryptophyte, G = geophyte, Th = therophyte, HH = hydrophyte. Habitat types: DB = disturbed and cultivated land, RL = rangeland, SH = south hillside, NH = north hillside, GR = gravel, IF = in forest, WS = wet soil, VA = valley, respectively.

Family	Species	C ₃ /C ₄	Life form	Habitat
<i>Pteridophyta</i>				
<i>Aspidiaceae</i>	<i>Athyrium brevifrons</i> Nakai		G	VA IF
	<i>A. coreanum</i> Christ.		G	VA IF
	<i>A. pycnosotum</i> Christ.		G	VA IF
	<i>Camptosorus sibiricus</i> Rupr.		G	GR IF
	<i>Dryopteris crassirhizoma</i> Nakai		G	IF
	<i>D. gymnophylla</i> Christ.		G	IF
	<i>Matteuccia struthiopteris</i> Todaro		G	IF RL
	<i>Onoclea sensibilis</i> var. <i>interupta</i> Maxim.		G	WS
	<i>Thelypteris palustris</i> var. <i>pubescens</i> Fernald		G	WS
	<i>Woodsia macrochlaena</i> Mett.		G	DR
	<i>W. polystichoides</i> Eaton		G	DR
	<i>Equisetaceae</i>	<i>Equisetum arvense</i> L.		G
<i>Ophioglossaceae</i>	<i>Botrychium robustum</i> Und.		G	VA IF
<i>Polypodiaceae</i>	<i>Pyrrhosia petiolosa</i> Ching		H	VA SH
	<i>Adiantum pedatum</i> L.		G	VA IF
	<i>Cheilanthes argentea</i> Kuntz.		G	GR
	<i>Pteridium aquilinum</i> L. var. <i>japonicum</i> Nakai		G	RL IF
<i>Selaginellaceae</i>	<i>Selaginella involvens</i> f. <i>minor</i> Milde		H	GR
<i>Angiospermae</i>				
<i>Dicotyledonae</i>				
<i>Aceraceae</i>	<i>Acer ginnala</i> Maxim.	C ₃	M	VA
	<i>A. mono</i> Maxim.	C ₃	M	IF
<i>Actinidiaceae</i>	<i>Actinidia polygama</i> Planch.	C ₃	L	VA IF
<i>Adoxaceae</i>	<i>Adoxa moschatellina</i> L.		H	VA IF
<i>Amaranthaceae</i>	<i>Amaranthus retroflexus</i> L.	C ₄	Th	DB
<i>Araliaceae</i>	<i>Acanthopanax sessiliflorus</i> Seem.	C ₃	N	IF
	<i>Aralia elata</i> Seem.	C ₃	N	IF
	<i>Eleutherococcus senticosus</i> Maxim.	C ₃	N	IF
<i>Aristolochiaceae</i>	<i>Asarum heterotropoides</i> Fr. Schmidt.		H	IF VA
<i>Asclepiadaceae</i>	<i>Cynanchum atratum</i> Bge.	C ₃	H	RL
	<i>C. purpureum</i> K. Schum.	C ₃	H	RL
	<i>Metaplexis japonica</i> Makino		Th	DB
	<i>Vincetoxicum amplexicaule</i> S. et. Z.		H	RL
	<i>V. pycnostelma</i> Kitag.		H	RL
	<i>V. sibiricum</i> var. <i>australe</i> Maxim.		H	RL
<i>Balsaminaceae</i>	<i>Impatiens noli-tangere</i> L.		Th	WS VA
	<i>I. textori</i> Miq.		Th	VA IF
<i>Berberidaceae</i>	<i>Berberis poiretii</i> Schneid.	C ₃	N	VA SH NH
	<i>B. amurensis</i> Rupr.	C ₃	N	VA SH NH
	<i>Caulophyllum robustum</i> Maxim.		G	VA IF
<i>Betulaceae</i>	<i>Betula davurica</i> Pall.	C ₃	M	SH IF
	<i>B. fruticosa</i> var. <i>ruprechtiana</i> Kitag.	C ₃	N	VR SH
	<i>Corylus heterophylla</i> Fisch.	C ₃	N	SH NH
	<i>C. mandshurica</i> Maxim.	C ₃	N	IF SH NH

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
<i>Boraginaceae</i>	<i>Brachybotrys paridiformis</i> Maxim.		H	IF
	<i>Lappula echinata</i> var. <i>heterocantha</i> O. Kuntze	C ₃	H	RL
	<i>Lithospermum erhyrorhizon</i> S. et Z.	C ₃	G	RL
	<i>Trigonotis nakaii</i> Hara		H	VA IF
	<i>T. peduncularis</i> Benth.		H	DB
<i>Campanulaceae</i>	<i>Adenophora divaricata</i> Fr. et Sav.	C ₃	G	RL
	<i>A. gmelini</i> Fisch.	C ₃	G	VA RL
	<i>A. remotiflora</i> Miq.		G	VA RL
	<i>A. tetraphylla</i> Fisch.		G	VA RL
	<i>Campanula glomerata</i> L.		G	VA RL
	<i>C. punctata</i> Lam.		G	VA RL
	<i>Codonopsis lanceolata</i> Benth et Hook.		G	VA
	<i>Platycodon grandiflorum</i> DC.	C ₃	G	RL
<i>Caprifoliaceae</i>	<i>Lonicera chrysantha</i> Turcz.	C ₃	N	VA IF
	<i>L. praeiflorens</i> Patalin	C ₃	N	VA IF
	<i>Sambucus buergeriana</i> Bl.	C ₃	N	VA IF
	<i>Virburnum sargentii</i> Koehne	C ₃	N	VA IF
<i>Caryophyllaceae</i>	<i>Cerastium fischerianum</i> Ser.		H	RL IF
	<i>C. pauciflorum</i> Steven		H	RL
	<i>Dianthus chinensis</i> L.	C ₃	H	RL
	<i>Gypsophila davurica</i> Turcz.		H	RL
	<i>G. oldhamiana</i> Miq.		H	RL
	<i>G. pacifica</i> Kom.		H	RL
	<i>Lychnis fulgens</i> Fisch.		H	RL
	<i>L. cognata</i> Maxim.		H	RL
	<i>Melandrium firmum</i> Rohrbach		H	RL
	<i>Moehringia lateriflora</i> Fenzel		H	VA RL IF
	<i>Pseudostellaria davidii</i> Fr. Pax.		G	VA RL IF
	<i>P. heterophylla</i> Pax.		G	VA RL IF
	<i>Silene repens</i> Pall.	C ₃	H	VA RL
	<i>Stellaria aquatica</i> Scop		HH	WS
	<i>S. bungeana</i> Fenzel		HH	WS
<i>Celastraceae</i>	<i>Evonymus sacrosancta</i> Koidz.	C ₃	N	IF
<i>Chenopodiaceae</i>	<i>Atriplex littoralis</i> L.		Th	DB
	<i>Axyris amaranthoides</i> L.	C ₃	Th	DB
	<i>Chenopodium album</i> L.		Th	DB
	<i>Ch. bryoniaefolium</i> Bge.		Th	DB
	<i>Ch. centrорubrum</i> Nakai		Th	DB
	<i>Ch. glaucum</i> L.	C ₃	Th	DB
	<i>Ch. hybridum</i> L.	C ₃	Th	DB
	<i>Ch. stenophyllum</i> Koidz.		Th	DB
	<i>Kochia scoparia</i> (L.) Schrad.	C ₄	Th	DB
	<i>Salsola collina</i> Pall.	C ₄	Th	DB
	<i>Teloxys aristata</i> Moquin		Th	DB
<i>Chloranthaceae</i>	<i>Tricercandra japonica</i> Nakai		G	IF
<i>Compositae</i>	<i>Achillea sibirica</i> Ldb.		H	RL
	<i>Achyrophorus ciliatus</i> Schultz.		G	SH RL
	<i>Adenocaulon adhaerescens</i> Maxim.		H	IF DB
	<i>Arctium lappa</i> L.		G	VA RL
	<i>Artemisia annua</i> L.	C ₃	Th	DB
	<i>A. argyi</i> Levl. et Vant.	C ₃	H	SH RL
	<i>A. japonica</i> var. <i>manshurica</i> Kom.		H	SH RL
	<i>A. keiskeana</i> Miq.		Ch	GR IF RL

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
<i>Compositae</i> (cont.)	<i>Artemisia mongolica</i> Fisch.	C ₃	H	SH DB VA
	<i>A. sacrorum</i> subsp. <i>laxiflora</i> Kitag.		Ch	RL
	<i>A. scoparia</i> Waldst. et Kit.	C ₃	Ch	DB
	<i>A. selengensis</i> Turcz.	C ₃	H	VA WS
	<i>A. sibirica</i> Maxim	C ₃	H	RL
	<i>A. sieversiana</i> Willd.	C ₃	H	DB
	<i>A. stolonifera</i> Kom.		H	VA IF
	<i>A. sylvatica</i> Maxim.		H	IF
	<i>Aster ageratoides</i> Turcz.		H	IF
	<i>A. fastigiatus</i> Fisch.		H	WS
	<i>A. hispidus</i> Thunb.	C ₃	H	VA RL
	<i>A. holophylla</i> Hemsl.		H	DB
	<i>A. incisus</i> Fisch.		H	VA RL
	<i>A. lautureanus</i> Fr.		H	RL
	<i>A. scaber</i> Thunb.		H	SH VA RL
	<i>A. tataricus</i> L. f.		H	RL
	<i>Atractylodes japonica</i> Koidz et Kitag.		H	IF RL
	<i>Bidens maximowicziana</i> Oett.		Th	WS
	<i>B. parviflora</i> Willd.		Th	DB
	<i>B. tripartita</i> L.		Th	WS
	<i>Cacalia aconitifolia</i> Bge.		H	SH NH RL
	<i>C. auriculata</i> DC.		H	IF
	<i>C. hastata</i> L.		H	VA IF
	<i>Carduus crispus</i> L.		H	VA DB
	<i>Carpesium cernuum</i> L.		H	RL
	<i>C. triste</i> Maxim.		H	VA IF
	<i>Cirsium pendulum</i> Fisch.		H	RL
	<i>C. segetum</i> Bge.		H	DB
	<i>C. setosum</i> Bieb.		H	DB
	<i>C. vlassovianum</i> Fisch.		H	VA RL
	<i>Erigeron acre</i> L.		H	VA RL
	<i>E. kamschaticum</i> DC.		H	DB
	<i>Eupatorium lindleyanum</i> DC.		H	VA WS
	<i>Gnaphalium uliginosum</i> L.		H	SH RL
	<i>Hieracium umbellatum</i> L.	C ₃	H	VA RL
	<i>Inula japonica</i> Thunb.	C ₃	H	WS
	<i>I. salicina</i> L.		H	RL
	<i>Ixeris chinensis</i> subsp. <i>graminifolia</i> Kitag.	C ₃	H	GR RL
	<i>I. sonchifolia</i> Hance	C ₃	H	GR RL
	<i>Lactuca indica</i> L.	C ₃	G	RL
	<i>L. raddeana</i> Maxim.		G	RL
	<i>L. triangulata</i> Maxim.		Th	RL
	<i>L. sibirica</i> Benth.		G	RL
	<i>Leibnitzia anandria</i> Nakai		H	RL
	<i>Leontopodium leontopodioides</i> Reauv.	C ₃	H	RL
	<i>Picris japonica</i> Thunb.	C ₃	H	RL VA
	<i>Saussurea maximowiczii</i> Rehder.	C ₃	H	DB
	<i>S. odontolepis</i> Sch. – Bip.	C ₃	H	RL
	<i>S. pulchella</i> Fisch.		H	RL
	<i>S. sinuata</i> Kom.		H	VA IF
	<i>S. stenolepis</i> Nakai		H	VA IF
	<i>S. triangulata</i> Trautv.		H	SH IF
	<i>S. ussuriensis</i> Maxim.		H	IF
	<i>Scorzonera albicaulis</i> Bge.	C ₃	G	SH RL
	<i>Senecio argunensis</i> Turcz.		H	SH RL

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
<i>Compositae</i> (cont.)	<i>Senecio integrifolius</i> Claville.	C ₃	H	SH RL
	<i>S. nemorensis</i> L.		H	RL
	<i>S. palustre</i> Hook.		H	WS
	<i>S. pierotii</i> Miq.		H	SH RL
	<i>Serratula coronata</i> L.	C ₃	H	VA IF
	<i>Siegesbeckia pubescens</i> Makino		Th	DB
	<i>Solidago virgaurea</i> subsp. <i>coreana</i> Kitag.		H	IF RL
	<i>Sonchus brachyotus</i> DC.		G	DB
	<i>Synurus deltoides</i> Nakai		H	SH RL
	<i>Tagetes patula</i> L.		Th	DB
	<i>Taraxacum brassicaefolium</i> Kitag.		H	DB
	<i>T. heterolepis</i> Nakai et Koidz.		H	DB VA RL
	<i>T. ohwianum</i> Kitam.	C ₃	H	DB
	<i>T. pseudo-albidum</i> Kitag.		H	SH VA RL
	<i>Xanthium japonicum</i> Widd.	C ₃	H	DB
<i>Convolvulaceae</i>	<i>Calystegia japonica</i> Choisy	C ₃	G	DB
	<i>Cuscuta chinensis</i> Lam.		Th	DB
	<i>C. japonica</i> Choisy		Th	DB
<i>Crassulaceae</i>	<i>Penthorum chinense</i> Pursh.		H	WS
	<i>Sedum aizoon</i> L.	CAM	H	WS
	<i>S. telephium</i> L.	CAM	H	WS RL
<i>Cruciferae</i>	<i>Arabis pendula</i> L.		Th	DB
	<i>Barbarea orthoceras</i> Ldb.		H	DB
	<i>Capsella bursa-pastoris</i> Medicus		H	DB
	<i>Cardamine amaraeformis</i> Nakai		H	VA WS
	<i>Dentaria leucantha</i> Tausch.		H	WS IF
	<i>Dontostemon dentatus</i> Ldb.	C ₃	H	DB WS
	<i>Draba nemerosa</i> L.		H	DB
	<i>Lepidium apetalum</i> Willd.	C ₃	H	DB
	<i>Roripa globosa</i> Thell.		H	DB WS
	<i>R. palustris</i> Besser		H	DB
<i>Thlaspi arvense</i> L.		H	DB	
<i>Cucurbitaceae</i>	<i>Schizopepon bryoniaefolius</i> Maxim.		Th	WS
<i>Dipsacaceae</i>	<i>Scabiosa mansenensis</i> Nakai	C ₃	H	RL
<i>Euphorbiaceae</i>	<i>Acalypha australis</i> var. <i>lanceolata</i> Hayata		Th	DB
	<i>Euphorbia fischeriana</i> Steud.	C ₃	G	RL
	<i>E. humifusa</i> Willd.	C ₄	Th	DB
	<i>E. manshurica</i> Maxim.		G	RL
	<i>Securinega suffruticosa</i> Rehder		N	RL
<i>Fabaceae</i>	<i>Amblyotropis pauciflora</i> Kitag.		H	RL
	<i>Astragalus melilotoides</i> Pall.	C ₃	H	RL
	<i>Glycine soja</i> Seib. et Zucc.		Th	DB WS
	<i>Kummerowia striata</i> Makino	C ₃	Th	DB
	<i>Lathyrus davidii</i> Hance	C ₃	H.	RL
	<i>L. palustris</i> L.		H	RL
	<i>Lespedeza bicolor</i> Turcz.	C ₃	N	SH RL
	<i>L. cyrtobotrya</i> Miq.	C ₃	N	IF
	<i>L. davurica</i> Schindler	C ₃	Ch	RL
	<i>L. hedysaroides</i> Kitag.		Ch	RL
	<i>L. tomentosa</i> Sieb.		Ch	RL
	<i>Maackia amurensis</i> Rupr.		M	IF SH
	<i>Medicago ruthenica</i> Ldb.	C ₃	H	DB RL
	<i>M. sativa</i> L.	C ₃	H	DB RL

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
<i>Fabaceae</i> (cont.)	<i>Melilotus suaveolens</i> Ledeb.	C ₃	H	DB RL
	<i>Trifolium lupinaster</i> L.	C ₃	H	VA RL
	<i>T. repens</i> L.	C ₃	H	WS
	<i>Vicia amoena</i> Fisch.		H	IF RL
	<i>V. cracca</i> var. <i>canescens</i> Maxim.		H	IF RL WS
	<i>V. pseudo-orobus</i> Fisch. et Mey		H	IF RL
	<i>V. tanakae</i> Fr. et Sev.		H	SH IF RL
	<i>V. unijuga</i> Al. Br.	C ₃	H	IF
<i>Fagaceae</i>	<i>Quercus dentata</i> Thunb.	C ₃	M	IF
	<i>Q. mongolica</i> Fisch.	C ₃	M	IF
	<i>Q. liaotungensis</i> Koidz.	C ₃	M	IF
<i>Gentianaceae</i>	<i>Crawfordia volubilis</i> Makino		H	NH IF
	<i>Gentiana scabra</i> Bge.		H	RL
	<i>G. squarrosa</i> Ldb.		Ch	SH RL
	<i>G. uchiyamai</i> Nakai		H	WS
	<i>G. zollingerii</i> Fawcett.		Ch	WS
	<i>Swertia diluta</i> Benth. et Hook.		Th	RL WS
<i>Geraniaceae</i>	<i>Geranium davuricum</i> DC.		H	WS
	<i>G. eriostemon</i> Fisch.		H	WS
	<i>G. japonicum</i> Fr. et Sav.		H	VA WS
	<i>G. sibiricum</i> L.	C ₃	H	DB
	<i>G. wilfordii</i> Maxim.		H	WS IF
<i>Haloragaceae</i>	<i>Myriophyllum spicatum</i> L.		HH	WS
<i>Hypericaceae</i>	<i>Hypericum ascyron</i> L.		H	WS
	<i>H. attenuatum</i> Choisy		H	RL
<i>Juglandaceae</i>	<i>Juglans mandshurica</i> Maxim.	C ₃	M	IF
<i>Labiatae</i>	<i>Agastache rugosa</i> O. Kuntze		H	WS
	<i>Ajuga multiflora</i> Bge.		H	WS
	<i>Amethystantus inflexus</i> Nakai		H	VA IF
	<i>Amethystea caerulea</i> L.		Th	DB
	<i>Clinopodium chinensis</i> O. Kuntze		H	VA WS
	<i>Drachocephalum argunense</i> Fisch.		H	SH RL
	<i>Elscholtzia manshurica</i> Kitag.	C ₃	H	SH RL
	<i>E. patrini</i> Garcke		Th	DB
	<i>Glechoma hederacea</i> var. <i>longituba</i> Nakai		H	VA RL
	<i>Lamiun barbatum</i> S. et Z.		H	VA RL
	<i>Leonurus macranthus</i> Maxim.		H	VA RL
	<i>L. sibiricus</i> L.		H	DB
	<i>Lycopus coreanus</i> Lev.		H	RL
	<i>L. lucidus</i> Turcz.		H	WS
	<i>Marrubium incisum</i> Benth.		H	DB
	<i>Meehania urticifolia</i> Makino		H	VA IF
	<i>Mentha davurica</i> Fisch.		H	WS
	<i>Perilla nankinensis</i> Decne		Th	DB
	<i>Scutellaria baicalensis</i> Georgi	C ₃	G	SH VA
	<i>S. dependens</i> Maxim.		H	WS
<i>S. regeliana</i> Makino		H	WS	
<i>S. transitra</i> Makino		H	IF	
<i>Stachys riederi</i> var. <i>hispida</i> Hara		H	WS	
<i>Linaceae</i>	<i>Linum stelleroides</i> Planchon	C ₃	Th	RL
<i>Loranthaceae</i>	<i>Viscum coloratum</i> Nakai		E	IF
<i>Lythraceae</i>	<i>Lythrum salicaria</i> L.	C ₃	H	WS

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
Magnoliaceae	<i>Schizandra chinensis</i> Baillon	C ₃	N	VA IF
Malvaceae	<i>Abutilon avicennae</i> Gaetrn.		Th	DB
	<i>Malva verticillata</i> L.		Th	DB
Menispermaceae	<i>Menispermum davuricum</i> DC.		G	DB
Moraceae	<i>Cannabis sativa</i> L.		Th	DB
	<i>Humulus japonicus</i> S. et Z.		Th	DB
Oenotheraceae	<i>Chamaenerion angustifolium</i> Scop.		H	RL
	<i>Circaea quadrisulcata</i> Fr. et Sav.		H	RL
	<i>Epilobium cephalostigma</i> Haussk.		H	RL
	<i>E. palustre</i> L.		H	RL
Oleaceae	<i>Fraxinus mandshurica</i> Rupr.	C ₃	M	VA IF
	<i>F. rhynchophylla</i> Hance	C ₃	M	VA IF
	<i>Syringa amurensis</i> Rupr.	C ₃	M	VA IF
Orobanchaceae	<i>Orobanche caerulea</i> Steph.	C ₃	Th	RL
	<i>O. pycnostachya</i> Hanca		Th	RL
Papaveraceae	<i>Chelidonium majus</i> L.		H	DB
	<i>Corydalis ambigua</i> Cham. et Schl.		G	VA RL
	<i>C. speciosa</i> Kitag.		H	VA RL
	<i>Hylomecon vernalis</i> Maxim.		G	VA IF
Pedaliaceae	<i>Sesamum indicum</i> L.		Th	DB
Phrymaceae	<i>Phryma leptostachya</i> L.		H	IF VA
Plantaginaceae	<i>Plantago asiatica</i> L.	C ₃	H	DB
	<i>P. depressa</i> Willd.	C ₃	H	DB
Polygalaceae	<i>Polygala japonica</i> Houth	C ₃	H	RL
	<i>P. tenuifolia</i> Willd.	C ₃	H	RL
Polygonaceae	<i>Fagopyrum vulgare</i> Hill.		Th	DB
	<i>Persicaria bungeana</i> Nakai		Th	DB RL
	<i>P. cochinchinensis</i> Kitag.		Th	DB
	<i>P. hydropiper</i> Spach.		Th	WS
	<i>P. koreensis</i> Nakai		Th	DB
	<i>P. lapathifolia</i> S. F. Gray	C ₃	Th	DB
	<i>P. longiseta</i> Kitag.		Th	DB
	<i>P. maackiana</i> Nakai		Th	WS
	<i>P. nodosa</i> Opiz.		Th	DB WS
	<i>P. perfoliata</i> H. Gross		Th	WS
	<i>P. sieboldii</i> Oliv.		Th	WS
	<i>P. thunbergii</i> H. Gross		Th	DB WS
	<i>P. viscosa</i> H. Gross		Th	DB
	<i>P. yokusaiana</i> var. <i>laxiflora</i> Hara		Th	IF
	<i>Pleuropterus cilinervis</i> Nakai		Th	WS
	<i>Pleuropterygium divaricatum</i> Nakai		H	RL
	<i>Polygonum aviculare</i> L.	C ₃	Th	DB
	<i>P. humifusum</i> Pall.		Th	DB
	<i>Rumex acetosa</i> L.	C ₃	H	VA RL
	<i>R. callosus</i> Rech. F.	C ₃	H	DB
Portulacaceae	<i>Portulaca oleracea</i> L.	C ₄	Th	DB
Primulaceae	<i>Androsace filiformis</i> var. <i>glandulosa</i> Krylow		H	WS
	<i>A. umbellata</i> Merrill		H	WS
	<i>Lysimachia barystachys</i> Bge.		G	VA RL
	<i>L. davurica</i> Ldb.		H	RL

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
<i>Primulaceae</i> (cont.)	<i>Primula sieboldii</i> E. Morr.		G	WS
<i>Ranunculaceae</i>	<i>Aconitum coreanum</i> R. Raym.		G	RL
	<i>A. kusnezowii</i> Reich.		G	VA RL
	<i>A. sczukini</i> Turcz.		G	IF RL
	<i>Actaea acuminata</i> Wallich		G	IF RL
	<i>Adonis amurensis</i> Rgl.		G	VA IF
	<i>Anemone raddeana</i> Rgl.		G	VA IF
	<i>Aquilegia oxysepala</i> Trautv. et Mey		H	RL
	<i>Caltha membranacea</i> N. Schip.		HH	WS
	<i>Cimicifuga davurica</i> Maxim.	C ₃	H	WS IF
	<i>C. simplex</i> Warm.		H	RL
	<i>Clematis fusca</i> Turcz.		N	RL
	<i>C. hexapetala</i> Pall.	C ₃	H	RL
	<i>C. mandshurica</i> Ruor.	C ₃	H	RL
	<i>Paeonia albiflora</i> Pll.	C ₃	G	RL IF
	<i>P. obovata</i> Maxim.	C ₃	G	RL IF
	<i>Pulsatilla chinensis</i> Rgl.	C ₃	G	RL
	<i>P. koreana</i> Nakai	C ₃	G	RL
	<i>Ranunculus chinensis</i> Rgl.		H	WS
	<i>R. cymbalaria</i> var. <i>mandshuricus</i> Hara		H	WS
	<i>R. grandis</i> Honda.		H	WS
	<i>R. japonicus</i> Thumb.	C ₃	H	WS
	<i>R. repens</i> L.		H	WS
	<i>R. sccleratus</i> L.		H	WS
	<i>R. ternatus</i> Thunb.		H.	WS
	<i>Thalictrum aquilegifolium</i> L.	C ₃	H	IF
	<i>Th. thunbergii</i> DC.	C ₃	H	SH RL
	<i>Trollius macropetalus</i> Fr. Schm.		H	WS
<i>Rhamnaceae</i>	<i>Rhamnus davuricus</i> Pall.	C ₃	N	IF
	<i>R. parviflorus</i> Bge.	C ₃	N	IF
<i>Rosaceae</i>	<i>Agrimonia coreana</i> Nakai		H	DB
	<i>A. pilosa</i> var. <i>japonica</i> Nakai		H	DB
	<i>Crataegus pinnatifida</i> Bge.		H	IF
	<i>Filipendula koreana</i> L.		H	WS
	<i>F. palmata</i> Maxim.		H	WS
	<i>Fragaria orientalis</i> Losina-Los.		H	RL WS
	<i>Geum aleppicum</i> Jacq.	C ₃	H	DB
	<i>Malus baccata</i> Borkh.		M	IF VA
	<i>Micromeles alnifolia</i> var. <i>lobulata</i> Koidz.		M	IF
	<i>Potentilla anserina</i> L.	C ₃	H	WS DB
	<i>P. bifurca</i> var. <i>glabrata</i> Lehm.	C ₃	Ch	SH DB
	<i>P. centigrana</i> Maxim.		H	RL IF
	<i>P. chinensis</i> Seringe	C ₃	H	RL
	<i>P. cryptotaeniae</i> Maxim.		H	WS IF
	<i>P. flagellaris</i> Willd	C ₃	H	DB
	<i>P. fragarioides</i> L.	C ₃	H	RL
	<i>P. freyniana</i> Bornm.	C ₃	H	DB
	<i>P. kleiniana</i> Wight et Arnott.	C ₃	H	DB
	<i>P. paradoxa</i> Nutt.	C ₃	H	DB
	<i>P. rugolosa</i> Kitag.	C ₃	Ch	GR RL
	<i>Prunus ansu</i> Kom.	C ₃	M	IF
	<i>P. mandshurica</i> Koeh.		M	IF
	<i>P. padus</i> var. <i>pubescens</i> Rgl.		M	IF
	<i>Pyrus ussuriensis</i> Maxim.		M	VA

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
Rosaceae (cont.)	<i>Rosa davurica</i> Pall.	C ₃	N	SH IF RL
	<i>Rubus crataegifolius</i> Bge.		N	SH IF
	<i>Sanguisorba officinalis</i> L.	C ₃	H	RL WS
	<i>S. tenuifolia</i> Fisch.	C ₃	H.	WS
	<i>Spiraea pubescens</i> Thunb.	C ₃	N	GR
	<i>S. salicifolia</i> L.	C ₃	N	VA WS
Rubiaceae	<i>Galium davuricum</i> var. <i>lasiocarpum</i> Nakai	C ₃	H	WS
	<i>G. mandshuricum</i> Kitag.		H	IF
	<i>G. oliganthum</i> Nakai et Kitag.		H	IF
	<i>G. paradoxum</i> Maxim.		H.	IF
	<i>G. verum</i> L.	C ₃	H	RL
	<i>Rubia cordifolia</i> var. <i>pratensis</i> Maxim.		H	IF RL VA
Rutaceae	<i>Phellodendron amurense</i> Rupr.	C ₃	M	IF
Salicaceae	<i>Populus davidiana</i> Dode	C ₃	M	SH
	<i>P. maximowiczii</i> A. Henry	C ₃	M	VA
	<i>P. pseudo-simonii</i> Carr.	C ₃	M	SH IF
	<i>P. simonii</i> Carr.	C ₃	M	IF
	<i>Salix integra</i> Thunb.	C ₃	N	WS VA
	<i>S. koreensis</i> Ander	C ₃	M	WS
	<i>S. matsudana</i> Koidz.	C ₃	M	WS
	<i>S. mongolica</i> Siuzev.	C ₃	M	WS
	<i>S. nipponica</i> Fr. et Sav.	C ₃	M	WS
	<i>S. purpurea</i> var. <i>smithiana</i> Trautv.	C ₃	N	WS
	<i>S. viminalis</i> L.	C ₃	N	VA IF
	<i>S. xerophylla</i> Floderus	C ₃	N	SH IF
	Santalaceae	<i>Thesium chinense</i> Turcz.	C ₃	H
Saxifragaceae	<i>Astilbe chinensis</i> Maxim.		H	WS
	<i>Chrysosplenium amabile</i> Kitag.		Ch	VA IF
	<i>C. pilosum</i> Maxim.		Ch	VA IF
	<i>C. trachyspermum</i> Maxim.		Ch	VA WS
	<i>Deutzia parviflora</i> Bge.	C ₃	N	IF
	<i>D. glabrata</i> Kom.	C ₃	N	IF
	<i>Philadelphus tenuifolius</i> Rupe. et Maxim.	C ₃	N	VA IF
	<i>Ribes mandshuricum</i> var. <i>subglabrum</i> Kom.	C ₃	N	IF
Scrophulariaceae	<i>Melampyrum nakaianum</i> Tuyama		Th	VA RL
	<i>Pedicularis resupinata</i> L.	C ₃	H	VA RL
	<i>Phtheirospermum japonicum</i> Kanitz		H	RL
	<i>Siphonostegia chinensis</i> Benth.		H	RL
	<i>Veronica linearifolia</i> Pall.	C ₃	H	SH RL
	<i>V. longifolia</i> L.		H	SH RL
	<i>V. sibirica</i> L.		H.	SH RL
Solanaceae	<i>Nicotiana tabacum</i> L.		Th	DB
	<i>Physalis angulata</i> L.		H	SH DB
	<i>P. franchetii</i> var. <i>bunyardii</i> Makino		H	SH DB
	<i>Solanum nigrum</i> L.	C ₃	Th	DB
Tiliaceae	<i>Tilia amurensis</i> Rupr.	C ₃	M	IF
	<i>T. mandshurica</i> Rupr. et Maxim.	C ₃	M	IF
Trapaceae	<i>Trapa bispinosa</i> Roxb.		HH	WS
Ulmaceae	<i>Ulmus dentata</i> Thunb.	C ₃	M	IF
	<i>U. macrocarpa</i> Hance	C ₃	M	IF
	<i>U. propinqua</i> var. <i>laevigata</i> Nakai	C ₃	M	IF
	<i>U. pumila</i> L.	C ₃	M	IF

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
<i>Umbelliferae</i>	<i>Angelica czernaevia</i> Kitag.		G	WS RL
	<i>A. maximowiczii</i> Benth		G	WS RL
	<i>A. nemorosa</i> Sqr.		H	WS
	<i>Bupleurum chinensis</i> DC.	C ₃	H	RL
	<i>B. scorzonerifolium</i> Willd	C ₃	H	RL
	<i>Cicuta virosa</i> L.		HH	WS
	<i>Cnidium monnieri</i> Cusson		H	DB
	<i>Daucus carota</i> var. <i>sativa</i> DC.		H	DB
	<i>Heracleum barbatum</i> Ldb		G	WS
	<i>Oenanthe javanica</i> DC.		H	WS
	<i>Ostericum grosseserratum</i> Kitag		G	IF WS
	<i>O. viridiflorum</i> Kitag.		H	WS
	<i>Peucedanum terebintaceum</i> Fisch.	C ₃	G	RL
	<i>Sanicula chinensis</i> Bge.		H	IF
	<i>S. rubriflora</i> Fr. Schm.		H	IF
	<i>Siler divaricatum</i> Benth. et Hook	C ₃	G	RL
	<i>Sium cicutifolium</i> var. <i>angustifolium</i> Kom.		HH	WS
	<i>Torilis japonica</i> DC.		Th	IF DB
<i>Urticaceae</i>	<i>Pilea mongolica</i> Wedd.		H	IF
	<i>Urtica angustifolia</i> Fisch.	C ₃	H	RL
<i>Valerianaceae</i>	<i>Patrinia rupestris</i> Juss	C ₃	H	RL
	<i>P. scabiosaefolia</i> Fisch.		H	VA RL
	<i>Valeriana nipponica</i> var. <i>dasycarpa</i> Hara		H	VA RL
<i>Violaceae</i>	<i>Viola acuminata</i> Ldb.	C ₃	H	IF
	<i>V. collina</i> Besser		H	WS RL
	<i>V. dissecta</i> var. <i>pubescens</i> Kitag.	C ₃	H	RL
	<i>V. fissifolia</i> Kitag.		H	RL
	<i>V. mandshurica</i> W. Becker		H	VA IF
	<i>V. mandshurica</i> f. <i>macrantha</i> Nakai		H	VA IF
	<i>V. mirabilis</i> L.		H	IF
	<i>V. mirabilis</i> var. <i>caulescens</i> DC.		H	IF
	<i>V. mongolica</i> Franch.		H	IF
	<i>V. phalacrocarpa</i> Maxim.		H	RL
	<i>V. prionantha</i> Bge.		H	SH RL
	<i>V. variegata</i> var. <i>viridis</i> Kitag		H	WS RL
	<i>V. verecunda</i> A. Gray		H	IF
	<i>V. yezoensis</i> Maxim.		H	GR
<i>Vitaceae</i>	<i>Vitis amurensis</i> Rupr.		L	VA IF
<i>Monocotyledonae</i>				
<i>Alismataceae</i>	<i>Alisma orientale</i> Juz.		HH	WS
<i>Araceae</i>	<i>Acorus calamus</i> L.		HH	WS
	<i>Arisaema amurense</i> Maxim.	C ₃	G	IF
	<i>A. peninsulae</i> Nakai		G	IF
<i>Commelinaceae</i>	<i>Commelina communis</i> L.	C ₄	Th	DB
	<i>C. communis</i> var. <i>angustifolia</i> Nakai	C ₄	Th	DB
<i>Cyperaceae</i>	<i>Carex albata</i> Boott.		H	RL
	<i>C. angustinowiczii</i> Mein.	C ₃	H	IF
	<i>C. bostrichostigma</i> Maxim.		H	WS
	<i>C. ciliato-marginata</i> Nakai		H	IF
	<i>C. diplasiocarpa</i> V. Krecz.		H	IF
	<i>C. enervis</i> C. A. Mey.		H	GR RL
	<i>C. heterolepis</i> Bge.		H	WS

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
Cyperaceae (cont.)	<i>Carex lanceolata</i> Boott.	C ₃	H	IF
	<i>C. leiorhyncha</i> C. A. Mey.		H	WS
	<i>C. leucochloa</i> Bge.		H	IF
	<i>C. longerostrata</i> C. A. Mey.		H	RL
	<i>C. pallida</i> C. A. Mey.	C ₃	H	WS
	<i>C. quadriflora</i> Ohwi		H	IF
	<i>C. raddei</i> Kuken.		H	WS
	<i>C. onoei</i> Fr. et Sav.		H	WS
	<i>C. rhynchophysa</i> C. A. Mey.		H	WS
	<i>C. rubra</i> Lev. et Von.		H.	WS
	<i>C. siderosticta</i> Hance		H	IF
	<i>Cyperus amuricus</i> Maxim.	C ₄	Th	WS
	<i>C. eragrostis</i> Valh.		Th	WS
	<i>C. glomerata</i> L.		Th	WS
	<i>C. orthostachyus</i> Fr. et Sav.		Th	WS
	<i>C. serotinus</i> Rott.	C ₄	H	WS
	<i>Eleocharis palustris</i> R. Br.		H	WS
	<i>Scirpus triquetus</i> L.	C ₃	H	WS
	Dioscoreaceae	<i>Dioscorea nipponica</i> Miq.		G
Gramineae	<i>Agrostis hiemalis</i> Britt.		Th	DB
	<i>Alopecurus amurensis</i> Kom.	C ₃	Th	DB WS
	<i>Arthraxon hispidus</i> (Thunb.) Makino	C ₄	H	WS
	<i>Arundinella hirta</i> (Thunb.) Tanaka	C ₄	H	WS
	<i>Beckmannia syzigachne</i> Feenald	C ₃	Th	WS
	<i>Calamagrostis arundinacea</i> Roth.	C ₃	H	RL
	<i>C. epigeios</i> (L.) Roth	C ₃	H	RL
	<i>C. langsdorffii</i> Trin.		H	WS
	<i>C. pseudo-phragmites</i> Koel.	C ₃	H	RL
	<i>Chloris virgata</i> Sw.	C ₄	Th	DB RL
	<i>Cleistogenes squarrosa</i> (Trin.) Keng	C ₄	H	RL
	<i>Diarrhena mandshurica</i> Maxim.		H	IF
	<i>Digitaria ischaemum</i> Muhl.	C ₄	Th	DB
	<i>D. sanguinalis</i> Scop.	C ₄	Th	DB
	<i>Elymus dahuricus</i> Turcz.	C ₃	H	RL
	<i>E. sibiricus</i> L.	C ₃	H	RL
	<i>Echinochloa caudata</i> Roshev.	C ₄	Th	WS
	<i>Eragrostis ferruginea</i> Beauv.	C ₄	Th	RL
	<i>E. pilosa</i> (L.) P. B.	C ₄	Th	RL DB
	<i>Festuca extremorientalis</i> Ohwi	C ₃	H	IF
	<i>Hierochloa bungeana</i> Trin.	C ₃	H	DB
	<i>Hystrix coreana</i> Ohwi		H	RL
	<i>Koeleria gracilis</i> Pers.	C ₃	H	DB
	<i>Leymus chinensis</i> (Trin.) Tzvel.	C ₃	H	RL
	<i>Milium effusum</i> L.		H	RL
	<i>Miscanthus purpurascens</i> Anderss.		H	RL
	<i>M. sinensis</i> Anderss.	C ₄	H	RL
	<i>Muhlenbergia japonica</i> Steud.		H	IF
	<i>Phragmites communis</i> Trin.	C ₃	HH	WS
	<i>Poa nemoralis</i> L.		H	DB
	<i>P. pratensis</i> L.	C ₃	H	SH RL
	<i>P. sphondylodes</i> Trin.		H	RL
	<i>P. strictula</i> Steudel.		H	DB
	<i>P. viridula</i> Palib.		H	DB
	<i>Roegneria ciliaris</i> Nevski	C ₃	H	DB

Table 1 (continued)

Family	Species	C ₃ /C ₄	Life form	Habitat
Gramineae (cont.)	<i>Roegneria semicostata</i> Kitag.	C ₃	H	DB
	<i>Setaria gigantea</i> Makino	C ₄	Th	DB
	<i>S. lutescens</i> (Weigel) F. T. Hubb.	C ₄	Th	DB
	<i>S. viridis</i> (L.) Beauv.	C ₄	Th	DB
	<i>S. viridis</i> var. <i>purpurascens</i> Maxim.	C ₄	Th	DB
	<i>Spodiopogon sibiricus</i> Trin.	C ₄	H	RL
	<i>Stipa sibirica</i> Trin.	C ₃	H	RL
	<i>S. effusa</i> Nakai	C ₃	H	RL
Iridaceae	<i>Iris dichotoma</i> Pall.	C ₃	H	RL
	<i>I. koreana</i> Nakai		H	RL
	<i>I. pallasii</i> Fisch.	C ₃	H	DB RL
	<i>I. tenuifolia</i> Pall.	C ₃	H	RL
Juncaceae	<i>Juncus bufonius</i> L.		HH	WS
	<i>J. decipiens</i> Nakai		HH	WS
	<i>J. gramillimus</i> V. Krecz. et Gont.		HH	WS
	<i>J. krameri</i> Fr. et Sav.		HH	WS
Lemnaceae	<i>Lemna minor</i> L.		HH	WS
	<i>Spirodela polyrhiza</i> Schleid.		HH	WS
Liliaceae	<i>Allium komarovianum</i> Vved.		G	RL
	<i>A. macrostemon</i> Bunge	C ₃	G	RL
	<i>A. monanthum</i> Maxim.		G	IF
	<i>A. schoenoprasum</i> L.	C ₃	G	RL
	<i>Asparagus gibbus</i> Bge.		G	RL
	<i>A. oligoclonus</i> Maxim.		G	RL
	<i>A. schoberioides</i> Kuntz		G	VA RL
	<i>Convallaria keiskei</i> Miq.		G	IF
	<i>Disporum viridescens</i> Nakai		G	IF
	<i>Gagea nakaiana</i> Kitag.		G	VA IF
	<i>Hemerocallis middendorffii</i> Traut. et Mey.		G	RL
	<i>H. minor</i> Miller	C ₃	G	SH RL
	<i>Lilium callosum</i> S. et Z.		G	SH RL
	<i>L. concolor</i> var. <i>buschianum</i> Baker		G	RL
	<i>L. dahuricum</i> Ker-Gawl.		G	WS
	<i>L. disticum</i> Nakai		G	VA IF
	<i>Maianthemum dilatatum</i> Nels. et Macb.		G	VA IF
	<i>Paris verticillata</i> Bieb.		G	IF
	<i>Polygonatum humile</i> Fisch.		G	IF
	<i>P. inflatum</i> Kom.		G	IF VA
	<i>P. involucratum</i> Maxim.		G	SH IF
	<i>P. japonicum</i> Morr. et Dec.		G	VA IF
	<i>P. stenophyllum</i> Maxim.		G	SH
	<i>Smilacina japonica</i> A. Gray		G	VA IF
	<i>Smilax nipponica</i> Miq.		G	IF
	<i>Veratrum davuricum</i> Loes.	C ₃	G	VA RL
	<i>V. maackii</i> Rgl.		G	RL
Orchidaceae	<i>Liparis japonica</i> Maxim.		H	VA IF
	<i>Platanthera mandarinorum</i> Reich.		G	WS IF
	<i>Spiranthes amoena</i> Sprengel		G	VA RL
Potamogetonaceae	<i>Potamogeton malaianus</i> Miq.		HH	WS
	<i>P. pectinatus</i> L.		HH	WS
	<i>P. vaseyi</i> Robb.		HH	WS
Typhaceae	<i>Typha davidiana</i> Hand. – Mzt.	C ₃	HH	WS
	<i>T. latifolia</i> L.	C ₃	HH	WS

Life form and habitats: There are nine life form types for the vascular plants from Tumen Mountains. 51 % of the total species in Table 1 were hemicryptophytes (H), and only 2 % H form species was found with C₄ photosynthesis, which was much less than those from grasslands and deserts. 17 % of these species (94 of 570) were geophytes (G), and this proportion was somewhat higher than that from grasslands and deserts (Wang 2002b). Therophytes (Th) were only about 15 % of the total species, but 21 % of Th form species were C₄ plants, which was about 75 % of the total C₄ species in the region. Th form proportion in the region was also much less than those from grasslands and deserts, but macrophanerophyte (M), nanophanerophyte (N), and hydrophyte (HH) form plants were relatively more abundant, the proportions of these types were about 6, 6, and 4 %,

Discussion

Tumen Mountains is one of the important typical agro-forestry regions in Northeastern China, due to its transitional conditions for both climate and vegetation (Qian *et al.* 1957, Wang 2004). However, the scientific studies on the plants, communities, and vegetations in the region were much less than those on the adjacent grasslands and forests, and the lack of knowledge lead to debate on making land management decisions. The identification of photosynthetic pathway and plant life form types may contribute new information for better understanding the local ecosystems and bring more details for studying the logical linkage between species and ecosystems at both species and regional levels. Transitional climate and vegetation combined with complex relief in the region result in relatively large species and life form abundance, 570 vascular plant species in 305 genera and 87 families were identified in the region. Species abundance in Tumen Mountains region was much higher than those on the adjacent grasslands and forests (Qian *et al.* 1957, Wang 2003, 2004). In grasslands and deserts, high species abundance may result in relatively large abundance of C₄ species, but in this region the total C₄ species number was much less than those in the relatively drier Songnen grassland (43 species) and Hulunbeier grassland (38 species) (Wang 2002b, 2004), while a little more than that in the moist Changbai Mountain (Wang 2004). This may support the hypothesis that abundance of C₄ species is related to longitude and precipitation (Teeri and Stowe 1976, Teeri *et al.* 1980, Wang 2004). Lower C₄ species abundance was likely due to the moist climate in the region, for most *Chenopodiaceae* C₄ species were mainly distributed in drier steppe and desert (Pyankov *et al.* 2000, Wang 2002b). Only two *Chenopodiaceae* C₄ species were identified in the region and *Gramineae* is the leading family with C₄ photosynthesis (15 species). Higher C₃ species abundance was consistent with moist climate in the region (850 mm rainfall), for C₃ species tend to be

respectively. More M and N forms and the occurrence of epiphyte (E) and liana (L) life forms indicated that the region is of relatively moist climate, and its floristic composition is part of the Changbai Mountain flora.

Of the 220 species, classified into C₃, C₄, and CAM, 41 % was found in rangelands (RL) and about 7 % were rangeland species with C₄ photosynthesis. 25 % of these species (54 of 220) can be found in forests (IF), and all these species were with C₃ photosynthesis. 13 % of the species were from disturbed and cultivated lands (DB) and wet soil (WS), respectively, and 29 and 24 % species in these two habitats were found with C₄ photosynthesis. 12 % species was from hillside, including SH and NH, and few species were from gravel (GR). C₄ species were mainly found in disturbed and cultivated land, rangelands, and wet soil in the region.

distributed in moist and low temperature conditions (Ehleringer *et al.* 1997).

Life form types were consistent to regional climate, floristic composition, and geo-relief (Wang 2002b, 2004). The 570 plant species in Table 1 can be classified into nine life form types, which was much more than those from grasslands and deserts (Wang 2002a,b, 2004). The increase of M and N forms, especially the occurrence of epiphyte (E) and liana (L) forms, reflects the moist climate feature of the region, *e.g.* relatively much rainfall. Average annual precipitation in Tumen Mountains region was about 70–80 % greater than in adjacent Songnen grassland. There are only 6–7 tree species and 11 shrubs in the grassland. More M, N, E, and L life form types also suggest that the climate in the region is much similar to that in eastern forests, and its floristic composition may be a part of Changbai Mountain flora. The increase of G life form and the reduction of H life form suggest that the winter in the region is much colder than in the grasslands, for the G life form plants can survive extreme cold environments (Qian *et al.* 1957, Wang 2002b).

Plants of different photosynthetic pathways and life forms have different physiological and ecological responses to climate, geography, land use, and human activities (Williams and Markley 1973, Redmann *et al.* 1995, Wang 2002a). Relatively larger abundance of Th life form C₄ species in the region may be mainly due to tree fell and agricultural cultivation, because this type of plants can become the pioneer species in the restoration succession and have greater capacity to tolerate environment stresses (drought and poor soil) (Wang 2002b). This and other previous studies (Qian *et al.* 1957, Wang 2004) suggested that both ecological studies and land management decisions in the region must take into account plant photosynthetic pathway and life form patterns, both of which are closely related to climatic changes and land use conditions.

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