Natural occurrence and backwater infection of C_4 plants in the vegetation of the Yangtze hydropower Three Gorges Project region

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Abstract

Natural occurrence of C_4 species, life form, altitude pattern, and infection by the Three Gorges Project (TGP) were studied in the TGP region. 76 species (about 2.5 % of the total 2 685 vascular plant species in the region), in 6 families and 42 genera, were identified with C_4 photosynthesis. 91 % of these C_4 species belong to *Monocotyledoneae*, *e.g. Cyperaceae* (14 species), *Gramineae* (54 species), and *Commelinaceae* (1 species). Of these C_4 species, *Gramineae* was the leading C_4 family: 54 C_4 grass species (71 % of the total C_4 species), about 36 % of the total grasses, were identified in the TGP region. 98 % C_4 species was found in therophyte (55 %) and hemicryptophyte (43 %). This is consistent with high grass and sedge compositions in the region. Most habitats of more than a half of these C_4 species (65 %) will be submerged permanently, but no species will be endangered or extinct, because 95 % C_4 species can be found from 500 to 800 m above sea level. The abundance of some C_4 species will be dropped due to the reduction of distribution scope. It will take a long-term to explore the effects of the TGP on plants, vegetation, and environment.

Additional key words: altitude pattern; geophytes; hemicryptophytes; life form; therophytes.

Introduction

C_4 plant occurrence, physiology, and geographical distribution have been a popular research field since the work by Downton and Tregunna (1968) and Black (1971), as means of studying relationships between vegetation and environmental changes. Most studies focused on the classification of plant species as to their types of photosynthetic pathway (Williams and Markley 1973, Downton 1975, Raghavendra and Das 1978, Waller and Lewis 1979, Redmann *et al.* 1995, Wang 2002), geographic distributions (Teeri and Stowe 1976, Teeri *et al.* 1980, Takeda and Hakoyama 1985, Ueno and Takeda 1992, Sayed and Mohamed 2000), and relations with climate change (Collins and Jones 1985, Ehleringer *et al.* 1997, Yin and Li 1997, Collatz *et al.* 1998, Keeley 1998, Pyankov *et al.* 2000). Some researches tested the relations between land use and relative abundance of C_4 species in some regions (Wang 2002a,d). But none has yet looked at the effects of large hydropower project on the changes of C_4 species.

The Yangtze Three Gorges Project (hereafter referred as the TGP) is located in Xiling Gorge of the Three Gorges reaches of the Yangtze River mainstream, with the dam at Sandouping in Yichang county in central China's Hubei Province. The TGP covers about 632 km^2 and is about 650 km long (from 106 to 110 E). Water line will rise as high as 240 m above sea level in 2009 when the TGP is finished. The effects of the TGP on ecology and environments have been documented by many researches (Jin *et al.* 1984, Chen 1994, Chen *et al.* 1994). Most of these studies focused on the influences of backwater on local vegetation, biota, rare and endangered flora, and economic flora (Jin *et al.* 1984, Chen 1994, Chen *et al.* 1994), some tested the changes of wildlife, rare and endangered animals, as well as public health (Jin *et al.* 1984, Chen *et al.* 1994). But the natural occurrence of C_4 species and their changes by the TGP remain unclear. The objective of this study was to investigate the natural occurrence of C_4 species and their potential infected by the TGP. The results could be important for the interpretation of the effects of large project constructions in the world.

Received 2 January 2003, *accepted* 30 January 2003.
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Acknowledgments: I am grateful for the funding provided by National Key Basic Research Special Foundation Project (NKBRSF project G2000018607), and in part by Key Project of the Chinese Academy of Sciences (KSCX1-08-03).

Materials and methods

Floristic species were obtained from 6 references about the flora published from 1961 to 2000 (*e.g.* Jin *et al.* 1984, Delectis Florae Reipublicae Popularis Sinicae Agendae Academiae Sinicae Edita 1987-1991, Chen 1992), and some local flora (Editorial Board of the Flora Sichuanica 1981). The information on photosynthetic pathway types was compiled from 9 references published between 1985 and 2002 (Takeda and Hakoyama 1985, Li 1993, Redmann *et al.* 1995, Yin and Li 1997, Pyankov *et al.* 2000, Wang 2002a,b,c,d). C_4 photosynthetic type was determined from microscopic studies of Kranz anatomy (K), $\delta^{13}C$ fractionation (D), as well as low CO_2 compensation concentration (L) (0-10 μmol mol^{-1}) (Li 1993, Redmann *et al.* 1995, Wang 2002a,b,c,d). Geographical data (*e.g.* elevation, physiogeographical region) were compiled from Chen (1994) and Delectis Florae Reipublicae Popularis Sinicae Agendae Academiae Sinicae Edita (1987-1991).

Results

Floristic composition: 76 species, about 2.5 % of the total 2 685 species in the TGP region, in 42 genera and 6 families, were identified with C_4 photosynthesis (Table 1). Of the total C_4 species, 9 % (7 of 76) was found in *Dicotyledoneae*, *e.g. Amaranthaceae* (5 species), *Portulacaceae* (1 species), and *Euphorbiaceae* (1 species). 91 % was found in *Monocotyledoneae*, *e.g. Cyperaceae* (14 species), *Gramineae* (54 species), and *Commelinaceae* (1 species). In the TGP region 4 % of genera and 3 % of families were found as C_4 species. Of the C_4 species, *Gramineae* was the leading C_4 family with 54 C_4 species (71 % of the total C_4 species), about 36 % of all grasses was identified in the TGP region. They were followed by *Cyperaceae* (18 % of the total C_4 species and 21 % of the total sedges occurring in the region) and *Amaranthaceae* (7 % of the total C_4 species). The C_4 species belonging to other families were only 4 % of the total C_4 species. *Setaria* was the leading C_4 genus with 8 C_4 species, followed by *Eragrostis* (6 C_4 species), *Amaranthus* (5 C_4 species), and *Digitaria* (4 C_4 species). All species in these 4 genera have C_4 photosynthesis. Unlike in north-eastern China grasslands, no species belonging to *Chenopodiaceae* was identified with C_4 photosynthesis and the abundance of *Chenopodiaceae* plants was only 0.3 % in the local flora. No endemic C_4 species was found in the TGP region. This suggested that the C_4 species mainly occurred in very few families in this moist region.

Plant habitats and life form: Most of the present habitats for C_4 species, *e.g.* disturbed and cultivated lands (DB), wet lands (WL), and moist river bank (RB), will be submerged in 2009 when the TGP is finished, except those above 240 m a.s.l. Of the 76 C_4 species, 36 % was found in disturbed and cultivation lands, followed by those in hillsides (32 %), wet lands (30 %), range land (24 %), river banks (RB) (13 %), farm lands (7 %), forests and shrubs (7 %), and on sandy soil (4 %). Most of the *Dicotyledoneae* C_4 species are cultivated plants or those distributed in DB, while most of sedges were found in moist habitats, *e.g.* RB and WL. C_4 grass species were found in all habitats in the TGP region, mainly due to the large presence (71 %) among the total C_4 species. This suggests that the *Dicotyledoneae*, sedges, and some grass C_4 species will be influenced severely by backwater when the TGP is finished in 2009.

Three life forms of C_4 species were identified in the TGP region (Table 1). 55 % (43 of 76) was in therophyte (Th) form, 43 % (33 of 76) was in hemicryptophyte (H) form, and not more than 2 % (1 of 76) were found in geophyte form (G). More C_4 species in Th and H forms indicated that the TGP region is moist and warm.

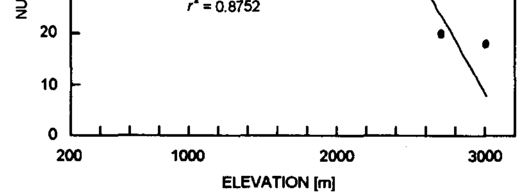

Fig. 1. The altitude pattern of C_4 species in the Yangtze Three Gorges Project region in central China.

Pattern of altitude distribution: Table 1 and Fig. 1 summarise the botanical-altitude pattern for the C_4 species in the TGP region and the C_4 species abundance with altitude gradient. Most of these C_4 species (95 %) can be found from 500 to 800 m a.s.l., *e.g.* the large area of hillsides and range lands. More than half of these species (65 %) is distributed in habitats below the water line (240 m a.s.l.), indicating that some distribution area for most of these C_4 species will be submerged by backwater in 2009. Numbers of C_4 species drop significantly with the increase in altitude (from 800 to 3 000 m a.s.l.), while only 18 species (24 %) can be found on top of mountains (above 3 000 m a.s.l.). Moisture is sufficient in the region, but low temperature in the high altitude of mountains is the critical factor for the C_4 species distribution in the TGP region. Altitude distribution pattern also indicates that some C_4 species will be influenced severely by the TGP in 2009.

Table 1. Occurrence, ecological distribution, and life form of C_4 species in the Three Gorges Project region in China. Nomenclature follows Kitagawa (1979) and Yin and Wang (1997). Habitat types: CL = cultivated, FO = frost, DB = disturbed and cultivated land, SS = sandy soil, WL = wet land, HS = hillside, RL = rangeland, RB = river bank. Life forms: H = hemicryptophyte, G = geophyte, Th = therophyte, respectively.

	Species	Sites	Life form	Elevation [m]
Dicotyledoneae				
Amaranthaceae	*Amaranthus caudatus* L.	CL	Th	200 – 1 000
	A. lividus L.	DB	Th	180 – 1 500
	A. paniculatus L.	CL	Th	< 2 150
	A. retroflexus L.	DB	Th	< 1 700
	A. tricolor L.	CL	Th	500 – 1 000
Portulacaceae	*Portulaca oleracea* L.	DB	Th	< 1 300
Euphorbiaceae	*Euphorbia humifusa* Willd.	HS WL	Th	< 1 400
Monocotyledoneae				
Cyperaceae	*Bulbostylis barbata* (Rottb.) Kunth	RB SS	Th	127 – 1 000
	B. densa (Wall.) Hand.-Mazz	RB SS	Th	100 – 3 200
	Cyperus iria L.	DB	Th	520 – 2 300
	C. micoiria Steud.	HS WL	H	50 – 1 500
	C. orthostachyus Franch et Savat	RB	Th	200 – 1 500
	C. pilosus Vahl.	WL	H	500 – 1 300
	C. rotundus L.	HS WL	H	20 – 1 800
	Fimbristylis bisumbellata (Forsk.) Bubani	SS WL	Th	100 – 1 530
	F. dichotoma (L.) Vahl.	RB WL	H	120 – 1 500
	F. miliacea (L.) Vahl.	WL	Th	500 – 1 600
	Kyllinga brevifolia Rottb.	HS DB	H	170 – 2 000
	Mariscus sumatrensis (Retz.) T. Koyama	HS FO	H	200 – 3 200
	Pycreus globosus (All.) Reicht.	RB WL	Th	300 – 2 400
	P. sanguinolentus (Vahl.) Nees	WL	H	250 – 3 000
Gramineae	*Arthraxon hispidus* (Thunb.) Makino	HS WL RL	Th	> 150
	Arundinella bengalensis (Spreng.) Druce	HS WL	H	700 – 18 500
	A.hirta (Thunb.) Tanaka	FO RL	H	70 – 1 500
	A. setosa Trin.	RL FO	H	130 – 3 200
	Bothriochloa ischaemum (L.) Keng	HS RL	H	500 – 3 000
	Brachiaria villosa (Lam.) A. Camus	RL	Th	400 – 2 200
	Capillipedium parviflorum (R. Br.) Stapf.	DB RL	H	40 – 3 000
	Coix lacryma-jobi L.	DB	Th	50 – 2 000
	Cynodon dactylon (L.) Pers.	DB	H	100 – 2 500
	Digitaria ciliaris (Rotz.) Koel.	RL DB	Th	400 – 2 400
	D. cruciata (Nees *ex* Steud.) A. Camus	RL	Th	300 – 3 100
	D. ischaemum (Schreb.) Schreb. *ex* Muhl.	DB RB	Th	560 – 3 680
	D. violascens Link	RL RB	Th	400 – 2 150
	Eccoilopus cotulifer (Thunb.) Hack.	HS DB	Th	75 – 2 500
	Echinochloa colonum (L.) Link.	WL DB	Th	20 – 1 800
	E. crus-galli (L.) Beauv.	WL DB	Th	40 – 1 700
	Eleusine indica (L.) *Gaertn.*	DB	Th	300 – 3 100
	Eragrostis cilianensis (All.) Link.	RL HS	Th	400 – 2 500
	E. ferruginea Beauv.	DB HS	H	550 – 2 100
	E. mairei Hack.	HS	H	1 500 – 3 700
	E. nigra Nees.	HS RL	H	300 – 4 000
	E. pilosa (L.) Beauv.	DB	Th	290 – 1 900
	E. poaeoides Beauv.	DB RL	Th	400 – 1 800
	Eremochloa ophiuroides (Munro) Hack.	HS RL	H	200 – 1 300
	Eriochloa villosa Thunb.	DB	Th	230 – 1 700

Table 1 (continued)

	Species	Sites	Life form	Elevation [m]
Gramineae (cont.)	*Eulalia quadrinervis* (Hack.) Ktze	HS	H	600 – 3 600
	E. speciosa (Debeaux) Ktze	HS	H	40 – 3 000
	Eulaliopsis binata (Retz.) C.E. Hubbard	HS	Th	250 – 2 400
	Imperata cylindrica (L.) Beauv. var. *major*	HS RL	G	100 – 2 800
	Ischaemum aristatum L.	HS RL	H	< 750
	Microstegium vimineum (Trin.) A. Camus	WL	Th	660 – 1 600
	Miscanthus sacchariflorus (Maxim.) Hack.	RL RB	H	850 – 2 200
	M. sinensis Anders	HS DB	H	120 – 1 800
	Muehlenbergia hugelii Trin	WL	H	1 000 – 3 400
	M. japonica Steud.	WL	H	650 – 3 000
	Panicum bisulcatum Thunb.	DB WL	Th	140 – 1 400
	Paspalum thunbergii Kunth *ex* Steud.	DB WL	H	220 – 1 600
	Pennisetum alopecuroides (L.) Spreng	DB HS	H	350 – 1 600
	Phaenosperma globosa Munro	FO	H	240 – 3 000
	Pogonatherum crinitum (Thunb.) Kunth	RB HS	H	350 – 1 950
	P. paniceum Hack.	HS RB	H	500 – 2 700
	Saccharum sinense Roxb.	CL	H	50 – 1 800
	Sacciolepis indica (L.) Chase	WL	Th	50 – 2 000
	Setaria chondrachne (Steud.) Horda	FO WL	Th	75 – 685
	S. faberii Herrm.	HS DB	Th	150 – 1 250
	S. forbesiana (Nees) Hook. F.	DB	Th	250 – 2 600
	S. glauca (L.) Beauv.	DB	Th	172 – 4 100
	S. italica (L.) Beauv.	CL	Th	644 – 1 800
	S. palmifolia (Koen) Stepf.	WL	Th	500 – 2 100
	S. plicata (Lam.) T. Cooke	WL FO	Th	970 – 2 300
	S. viridis (L.) Beauv.	DB	Th	70 – 3 700
	Spodiopogon sibiricus Trin.	HS FO	H	160 – 1 900
	Sporobolus fertilis (Steud.) W.D. Clayton	DB RL	H	80 – 1 900
	Themeda japonica (Willd.) Tanaka	RL	H	100 – 2 600
Commelinaceae	*Commelina communis* L.	WL	Th	120 – 1 800

Discussion

The natural occurrence of C_4 species and the relations with climate, geography, and land use have been well documented in many vegetation types (Teeri and Stowe 1976, Teeri *et al.* 1980, Collins and Jones 1985, Takeda and Hakoyama 1985, Ueno and Takeda 1992, Ehleringer *et al.* 1997, Yin and Li 1997, Collatz *et al.* 1998, Keeley 1998, Pyankov *et al.* 2000, Wang 2002a,b,c,d). These studies provide strong evidence that the relative abundance of C_4 species correlates with climate attributes and land use. But the effects of large projects of industry, agriculture, and hydropower on natural occurrence of C_4 species remain unclear. The total area of the TGP region (including reservoir cover and the vicinity) is only 0.6 % of the total China, but the flora includes more than 10 % of that in the total China (Chen *et al.* 1994). This suggests that the abundance of plants is great in the region. More than 550 vascular species in 358 genera and 120 families will be impacted by backwater in 2009 when the TGP is finished. The most species affected by the TGP were found in *Gramineae*, *Compositae*, and *Euphorbiaceae*. The genus and family of *Distylium* in *Hamamelidaceae*, *Adina* in *Rubiaceae*, *Buddleia* in *Logamaceae*, *Hibiscus* in *Malvaceae*, *Neyraudia* and *Saccharum* in *Gramineae* will be impacted seriously. But no species will be extinct by the TGP when it is finished in 2009 (Chen 1994, Chen *et al.* 1994).

In the TGP region, 3 % of vascular families (6 of 190), *e.g.* *Amaranthaceae*, *Portulacaceae*, *Euphorbiaceae*, *Cyperaceae*, *Gramineae*, and *Commelinaceae*, were found with C_4 species occurrence, which was less than found in north-eastern China grasslands (12 %). This indicated that the families with C_4 species occurrence in the TGP region were not as common as in the dry regions (Pyankov *et al.* 2000, Wang 2002b,c). The total number of families in the TGP region was 190, while in grasslands of north-eastern China it was only 89. The composition of C_4 species in the region (2.5 %) was also less than that in north-eastern China grasslands (7 %), even if the total species number was about 4 times as high as in the latter (Chen 1994, Wang 2002c,d). Geo-relief in the TGP region is complex, but the moisture is sufficient (more than 1 000 mm per year). Sufficient moisture resulted in high percentage of grass and sedge C_4 species, which were about 89 % of the total C_4 species identified in the region (Table 1). But sufficient moisture may limit the occurrence of xerophyte C_4 species, *e.g.* *Cleistogenes squarrosa* (Trin.) Keng, *Tribulus terrestris* L., and some *Chenopodiaceae* C_4 species (*Agriophyllum pungens* Link A. Dietr, *Atriplex sibirica* L., and *Kochia prostrata* Schrad.). This may explain the fact that no *Chenopodiaceae* species with C_4 photosynthesis was found in the region. The existence of C_4 *Chenopodiaceae* species is strongly related with aridity (Pyankov *et al.* 2000, Wang 2000b,c,d). Similar to the other regions in China, no endemic C_4 species was found in the TGP region, which suggests that the endemic species do not have great tolerance to environmental stresses and are limited to special habitats. But C_4 species with high photosynthetic rate and great tolerance to environmental stresses were very common in grasslands, deserts, and forests.

The effects of land use (*e.g.* grassland grazing and cultivation) on C_4 species are well documented in some regions (Williams and Markley 1973, Wang 2002a,b,c), but none has yet looked at the influences of large hydropower project on the changes in composition of C_4 species. The water line of the TGP will rise as high as 240 m a.s.l. in 2009, lands below this level, *e.g.* wetlands, river banks, most farm lands, will be submerged, and the vegetation on these lands will also disappear (Chen 1994, Chen *et al.* 1994). Because the C_4 species are broadly expanded in the TGP region, no species will be endangered or be extinct, even though most habitats of more than a half of these species (65 %) will be submerged permanently. But the abundance of some C_4 species will drop because of the reduction of distribution scope. Most grass and sedge C_4 species are mesic plants, and they may find new habitats by dispersal, especially for the Th form C_4 species. Relative large presence of Th form (55 %) for C_4 species in the vegetation in the TGP region is an advantage as plants diffuse far way, because this type of plants has a high capacity for seed production and dispersal (Wang 2002a,b). H form C_4 species, which are commonly perennial grass and sedge plants with strong clonal reproduction, will be impacted severely by submergence in a relative long period (10-15 years). With the rise of water line from 2003 to 2009, the distributions of most of these C_4 species will change gradually and it is expected to take 7-10 years for the recovery of these species after the TGP is finished. Because of the confounding changes of climate, soil types, altitudes, plant composition, and plant competitions, further studies and surveys on the plants, vegetation, and environments are needed to explore the short-term and long-term effects of the TGP on plants and vegetation.

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