Characteristics of *Tithonia diversifolia*: an alien invasive plant in Yunnan, south-west China

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Tithonia diversifolia, an alien ornamental plant introduced from Central America, has being naturalized in tropical, southern and central sub-tropical regions in the Yunnan Province of China (Wang *et al.* 2004). In order to evaluate this ominous alien species, our team has carried out a comprehensive study on its current geographical distribution, natural communities, vegetative proliferation and karyomorphology in Yunnan Province since 2001.

The current distribution of *T. diversifolia* in Yunnan

Road-networks and rivers may play an important role in expanding species populations in different regions, especially for invasive species (Mühlenbach 1979; Xie *et al.* 2001; Imaizumi *et al*. 2006). Based on what Wang and Sun (2004) described as its distribution in Yunnan Province (Fig.1:A), its distribution region has been further explored, with special attention to the populations along road-networks (Fig.1:B).

Tithonia diversifolia probably first escaped to become naturalized in the 1930s (Wang & Sun, 2004), and it is currently distributed in at least 64 counties in Yunnan Province. The whole extent of its geographic distribution in Yunnan is ca. 234,673 km^2 (about 60 % of Yunnan's total territory). Ominously, the populations have expanded northward to a latitude of 25º45´N in Yunnan (Fig. 1), where they are now commonly established at altitudes of 76–2000 m.

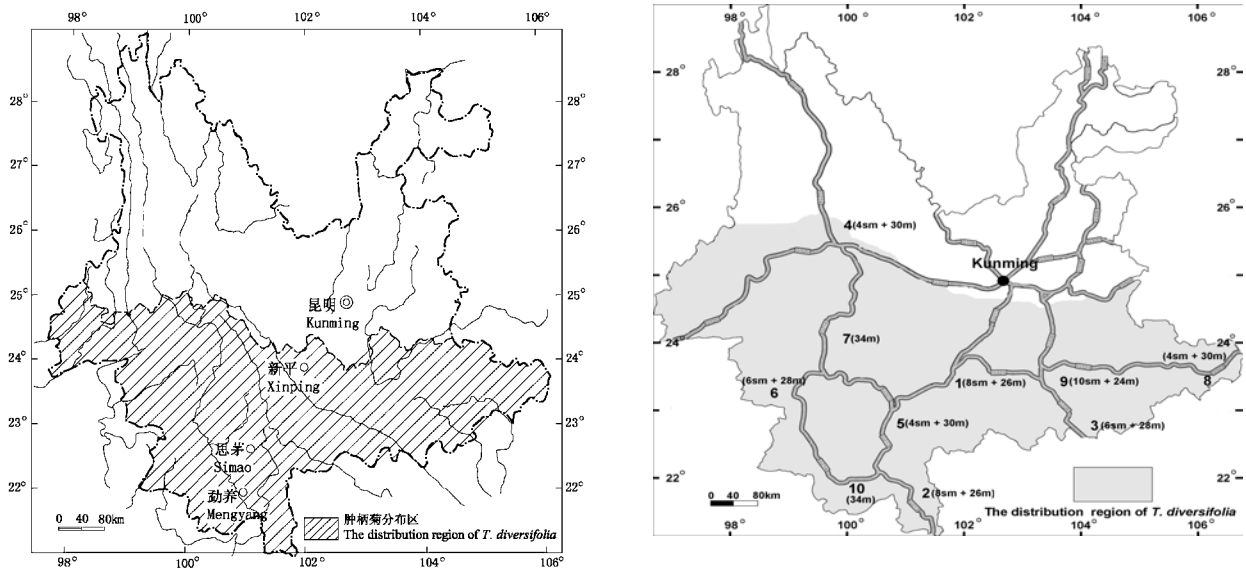

Fig.1 *Current distribution of* Tithonia diversifolia *in Yunnan, China.* ***A*** *Cited from Wang&Sun, 2004;* ***B:*** *Refreshed current distribution based on further investigations*

Naturalized communities of *T. diversifolia* in Yunnan

The naturalized populations of *T. diversifolia* in Yunnan are fasciculate shrubs or semi-shrubs, most of which flower between October and February and fruit from late December. Mature plants can produce a large number of fertile seeds, fruit amount is around 80,000–160,000 achenes/m^2, and the 1000-seed weight is about 4.6–6.5g. The light-winged seeds with pubes and pappus can be readily dispersed to new regions by air, water, vehicles, human activity or on livestock.

Table 1 *The biological indexes of* T. diversifolia *and its companion species (Wang & Sun, 2004)*

Species	Indexes	Meng-Yang		Si-Mao		Xin-Ping		ANOVA
		Riverside	Hillside	Riverside	Hillside	Riverside	Hillside	
Tithonia diversifolia	Cover grade①	5	5	5	5	5	5	—
	Above-ground biomass (kg/m^2)	31.59±2.43	25.66±2.27	28.32±2.42	25.21±2.12	25.34±2.28	22.43±2.08	NS
	Density ($stems/m^2$)	33±1.85	28±1.74	31±2.13	27±2.01	28±2.39	26±1.70	NS
	Height (m)	2.97±0.07	2.90±0.13	2.78±0.08	2.93±0.12	2.76±0.10	2.61±0.07	NS
	Stem diameter (cm)	2.88±0.12	2.85±0.06	2.78±0.13	2.90±0.09	2.77±0.08	2.62±0.08	NS
Companion species	Cover grade①	5	3	4	4	4	3	—
	Above-ground biomass (kg/m^2)	1.87±0.30	0.86±0.20	1.26±0.26	1.73±0.23	1.09±0.26	0.79±0.23	*

Adopting Braun-Blauquet system; Data of table: Average value ±standard error; Significant level: NS P 0.05, *P 0.05, **P 0.01

Table 2 The main companion plant species and their abundance (Wang&Sun, 2004)

Sites	The companion species and their abundance
Meng-Yang	Ac^F; Bp^O; Ca^F; Cm^R; Dc^F; Dv^F; Eo^F; Mc^F; Mp^F; Pn^O; Sg^O; Sn^F;Sp^O; Ul^R
Si-Mao	Ac^F; Bp^O; Dc^F; Ds^F; Ar^F; Eo^F; Sp^O; Ul^O
Xin-Ping	Ac^F; Bp^F; Dc^F; Ds^F; Ar^F; Eo^R; Ul^O

Superscript is Clements abundance. F= Frequence; O=Occasional; R=Rare; Ac: Ageratum conyzoides; Ar: Ageratum coelesticum; Bp: Bidens pilos; Ca: Chrysopogon aciculatus; Cm: Crotalaria mucronata; Dc: Digitaria ciliaris; Ds: D. sanguinalis; Dv: D. violanscens; Eo: Eupatorium odoratum; Mc: Microstegium ciliatum; Mp: Mimosa pudica; Pn: Panicum notatum; Sg: Setaria glauca; Sn: Synedrella nodiflora; SP: Spilanthes paniculata; Ul: Urena lobata

The community physiognomy of *T. diversifolia* is presented as the three main types, which are: patch-shaped community, belt distribution community and large-scale distribution community. Its green biomass was 22.4–31.49kg/m^2; however the green biomass of its companions, most of which were annual, biennial and perennial weeds, was 0.79~1.87kg/m^2 and taken over 3.2~6.4% of the total in the communities (Tables 1 & 2).

In our research, six fruit characters were analyzed (infructescence size, fruit number per infructescence, seed set, 1000-seed weight, seed length and width) in five populations of Meng-Yang, Pu-Wen, Si-Miao, Yuan-Jiang and Xin-Ping). The results revealed that all the fruit characters presented the significant difference respectively among populations. The characters' value was less in areas sited in lower latitudes and altitudes, where the temperature is relatively higher than that of the areas in the higher latitudes and altitudes.

Clonal proliferation of *T. diversifolia*

The branch-cluster, plant phalanxes and proliferation characters from the basal and the prostrate branches of the selected *T. diversifolia* populations were observed in certain planned periods. The distance between clonal ramets and the maternal individuals were measured. The clonal proliferation process in the *T. diversifolia* populations was plotted and recorded.

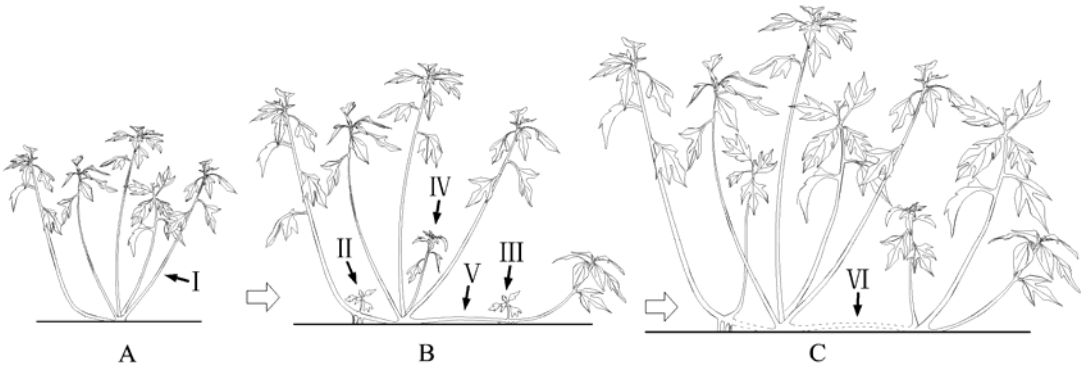

Fig. 2 *Clonal growth and branching of* T. diversifolia *(Wang & Sun, 2004)* ***A:*** *branch-cluster;* ***B:*** *proliferation from the basal branches and the prostrate branches;* ***C:*** *plant phalanxes I basal branch, II clonal ramets produced by inclined branches, III distant ramets produced by the prostrate branches & IV branches produced from the cluster base, V pacers; VI senescent spacers.*

Fig.2 shows the clonal proliferating process of *T. diversifolia*. Field observations indicated that the species has a great capacity to grow clonally. The clonal growth was especially common during rainy reason when adventitious roots and young shoots rapidly emerge from nodes on lower or the prostrate branches and clonal growth contributing to extensive horizontal expansion of patches, which could easily construct dense community with clonal growth. It could be inferred that *T. diversifolia* might firstly developed from the limited seeds or young branches in the new ranges, and then the small population could gradually established from the small quantity of individuals if the habitat was adaptable. After several growth cycles of the population expanded through both strong clonal proliferation and seedling regeneration, the large scale of mono-dominant community was formed. Eventually, the large-scale mono-dominant community could be ready as the diffusible source for occupation of new regions. Therefore the species' ability to proliferate strongly both vegetatively and sexually (from seeds) may greatly contribute to the invasiveness of *T. diversifolia*.

Karyomorphology of *T. diversifolia*

Cytological data are essential in studies of the systematic and evolutionary implications of *the* Asteraceae, because karyological characters are often stable (Stebbins 1971; Hong 1990; Nazarova 1994; Nazarova & Estella 1997; Liu *et al.* 2001; Garnatje *et al.* 2004; Inceer & Beyazoglu 2004; Garcia *et al.* 2004). For *T. diversifolia*, ten populations, ranging from tropical to north subtropical areas at altitudes of 76–2000 m in Yunnan (Fig.3), were sampled for the cytological studies. The results revealed that chromosome numbers in all the 10 populations were $2n = 34$ at metaphase, and the basic chromosome number was $x = 17$ except for some chimera cell types where $2n = 32$ or 68 (less than 5%). And also, the karyotype variation at the diploid level of all the sampled populations presented some distinguishable cytological characters (Fig. 4 & 5).

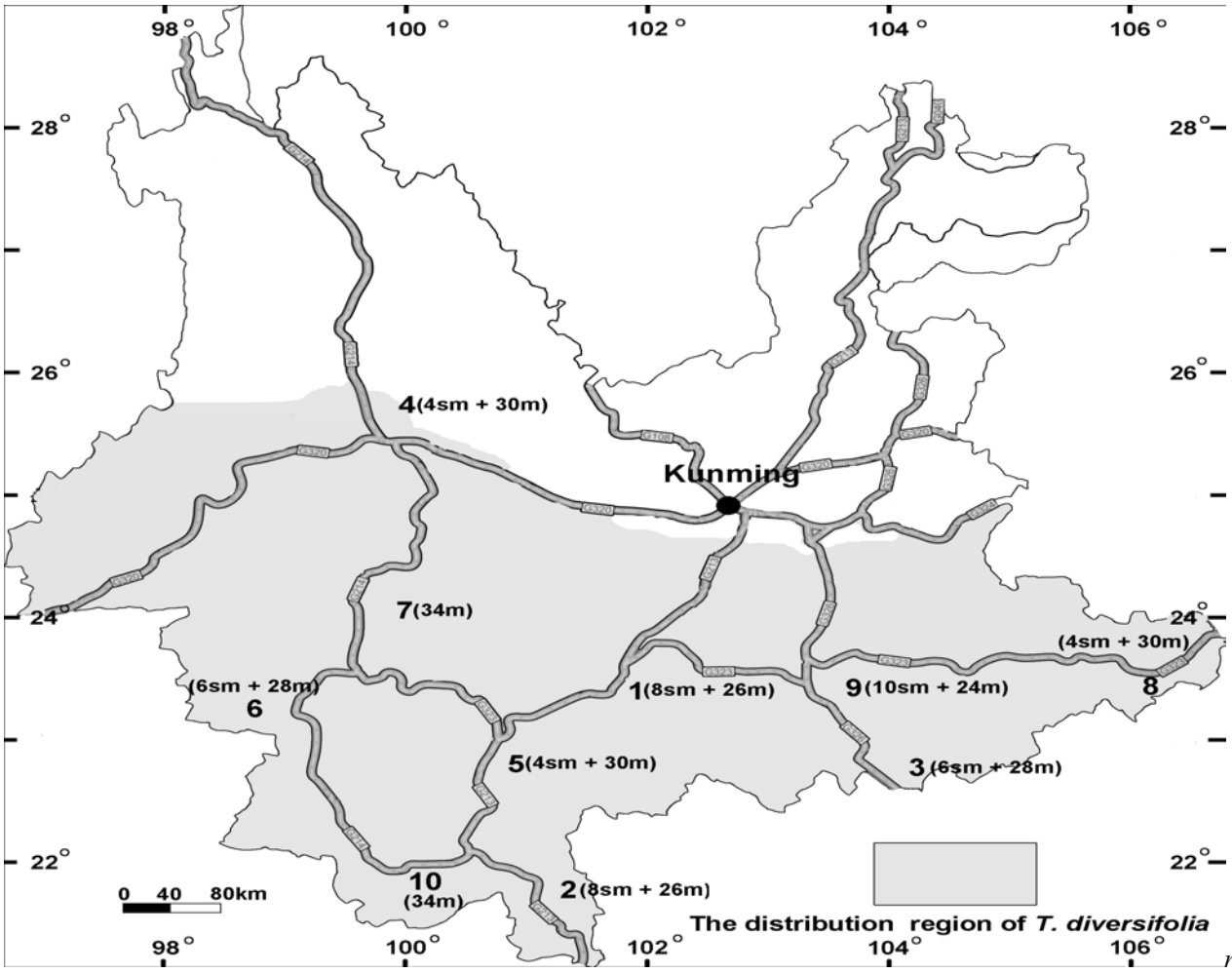

Fig.3 Locations of T. diversifolia *populations sampled for cytology study. Bold lines represent main transportation road-network in Yunnan province, and inside the Brackets are the Karyotype formulas.* ***1*** *Yuan-Jiang;* ***2*** *Meng-La;* ***3*** *He-Kou;* ***4*** *Bin-Chuan ;* ***5*** *Si-Mao;* ***6*** *Nan-Gun-He ;* ***7*** *Lin-Cang;* ***8*** *Fu-Ning;* ***9*** *Meng-Zi ;* ***10*** *Jing-Hong*

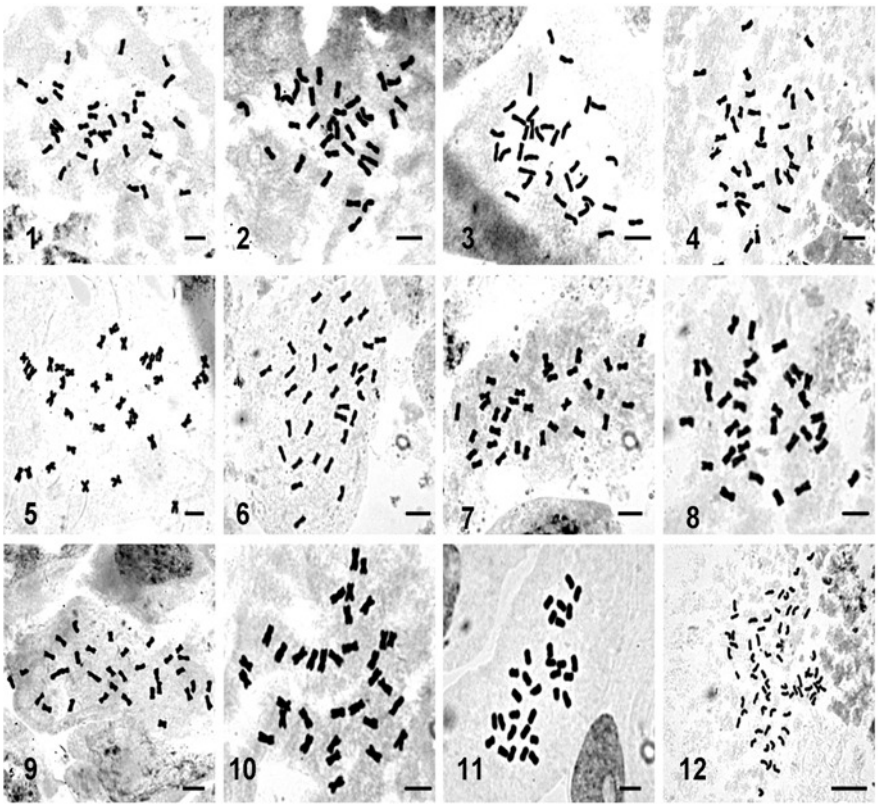

Fig. 4 *Mitotic metaphase chromosomes of the 10* T. diversifolia *populations in Yunnan, SW China.*

Note*: Population 1-10, 2*n *is 34; Population 11, 2*n *= 32; and population 12, 2*n *= 68 ; Scale bars = 10μm.* ***1*** *Yuan-Jiang;* ***2*** *Meng-La ;* ***3*** *He-Kou;* ***4*** *Bin-Chuan;* ***5*** *Si-Mao ;* ***6*** *Nan-Gun-He;* ***7*** *Lin-Cang;* ***8*** *Fu-Ning;* ***9*** *Meng-Zi;* ***10*** *Jing-Hong ;* ***11*** *Hekou, 2*n *= 32; and* ***12*** *Hekou , 2*n *= 68.*

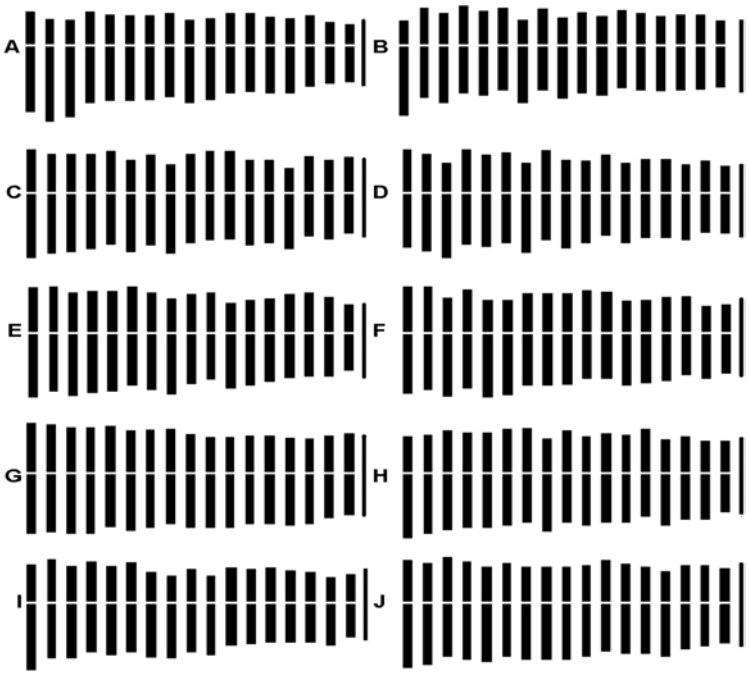

Fig.5 *The haploid ideograms of the 10* T. diversifolia *populations.* ***A*** *Yuan-Jiang;* ***B*** *Meng-La ;* ***C*** *He-Kou;* ***D*** *Bin-Chuan;* ***E*** *Si-Mao;* ***F*** *Nan-Gun-He;* ***G*** *Lin-Cang;* ***H*** *Fu-Ning;* ***I*** *Meng-Zi; and* ***J*** *Jing-Hong. Scale bars = 5μm.*

Based on our understanding of the field observations, we hypothesized that the current populations of *T. diversifolia* in Yunnan may originate from the single source, and thus the karyotype of the different populations might be same. However, beside the base chromosome number of all the 10 populations is $x = 17$ ($2n = 34$), some chimera cell types $2n = 32$ or 68 (less than 5%) were found form the individuals in the He-Kou population. In addition several other distinguishable cytological characters in the 10 populations were also found (Fig.3). The karyomorphological variation of the 10 *T. diversifolia* populations might be explained as:

- All the populations were originated from a single *T. diversifolia* source. However, cytological variation might be happened along with the rapid spreading, to adapt with the different ecological conditions.

- The current *T. diversifolia* populations might be formed from the different introductions or diffusing sources (from different countries or other regions in China), and the subsequent spreading occurred in Yunnan Province. Thus, current different populations of the species might be from multiple independent introductions or different immigrations. The multiple introductions or immigrations could create genetically diverse invasive populations than the single source of introduction or immigration.

T. diversifolia are most likely originated from different sources and the mass regeneration from seeds and cloning have contributed to its quick population establishment. Human introduction for green manure, field pales, ornamentals and the intensive transportations are all play an important role in the species spreading. To confirm this conclusion, further work on its genetic structure using molecular markers to reveal the frequency and size of introductions is necessary.

Ayeni *et al.* (1997) surveyed the occurrence and growth habit of *T. diversifolia* in south-western Nigeria, and it was considered that the populations were established from seeds. Our researches in Yunnan indicated that the clonal growth is certainly essential in the population establishment and formation of the mono-dominant community of the species. Roads are particularly prone to the invasion of non-indigenous plants and the reticulate distribution facilitates the modelling of seed dispersal. Human-mediated dispersal exceeds most other dispersal mechanisms in distance or size (Li & Xie 2002). A case study on a newly constructed highway revealed that *T. diversifolia* has already formed a great numbers of big patches (around 10–15m wide and several kilometres long) along both the highway sides within the past 6 years (Wang & Sun, 2004). And most of the *T. diversifolia* along the main roads and the nearby fields and forests shows large-scale mono-dominant communities. Thus, it can be inferred that the current distribution pattern of *T. diversifolia* in Yunnan may largely be caused by transportation networks, and at least their intensity might be one of the most important pathways for its spreading.

In fact, *T. diversifolia* has already damaged the rich biodiversity in Yunnan, the "Plant Kingdom of China", and it is also a weedy alien species widely occurred in agricultural fields (Sun & Wang, 2004). Therefore, the practical measures, based on the scientific researches, to control its further spread are urgently needed.

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