

INTRODUCTION, GROWTH PERFORMANCE AND ECOLOGICAL ADAPTABILITY OF HONGMU TREE SPECIES (*PTEROCARPUS* SPP.) IN CHINA

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XU C, ZENG J, CUI T, CHEN Q & MA Y. 2016. Introduction, growth performance and ecological adaptability of Hongmu tree species (*Pterocarpus* spp.) in China. Hongmu is a general term for eight precious timbers in China. *Pterocarpus* is a significant component of Hongmu tree species, but its natural distribution has not been found in China. Species of *Pterocarpus* were introduced and cultivated in China in the 1950s. After more than half a century, *Pterocarpus* grows and develops well in southern subtropical and tropical regions of China. We reviewed the introduction and cultivation history of *Pterocarpus* species in China, their growth performances and ecological adaptabilities, and prospect of future development and cultivation of *Pterocarpus* Hongmu forest resources in China.

Keywords: Precious timber tree species, *Pterocarpus indicus*, *P. macarocarpus*, *P. marsupium*, *P. santalinus*

INTRODUCTION

Hongmu is a conventional name for a specific type of precious timbers in China, which are naturally formed over a long period of time and favoured for their dark stripes and natural texture. Hongmu and their products are considered as unique and scarce wood resources (Zhai et al. 2014) and are always cherished as cultural treasures. Hongmu products, especially furniture, are considered as elements that embody China or Chinese culture.

Hongmu tree species have the highest value among all precious timber trees, and many of them produce precious medicinal materials. However, there are only limited original Hongmu tree species and forest reserves in China. More than 98% of Hongmu timbers are imported. Thus, cultivation of Hongmu forest resources has become a significant forestry development strategy of China (Li 2005). This paper reviews the introduction, growth performances and ecological adaptabilities of Hongmu tree species of *Pterocarpus* in China.

CLASSIFICATION OF HONGMU TREE SPECIES

Hongmu is world-famous and used for making high-end furniture, carvings, musical instruments and artistic handicrafts. However, Hongmu was a confusing name in the Chinese timber market, because many timber products were sold under the name Hongmu. In August 2000, the China State Bureau of Quality and Technical Supervision (now General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China) issued for the first time the *National Hongmu Standards of the People's Republic of China* (GB/T18107-2000) that has played positive role in guiding and regulating the Hongmu market. The scientific basis for the development of this National Hongmu Standards was the research by the Research Institute of Wood Industry, Chinese Academy of Forestry and the National Technical Committee of Timber Standardization on timber characteristics of Hongmu furniture fragments in the Ming and Qing dynasties and modern

Hongmu furniture materials. In the process of developing this National Hongmu Standards, the correctly indentified timber samples and data from home and abroad were fully extracted by the researchers.

According to the National Hongmu Standards, Hongmu falls into eight categories based on commodity science, namely, red sandalwood/red sanders, scented rosewood, padauk, red rosewood, black rosewood, ebony, striped ebony and wenge. Timber sources for the eight categories belong to 33 species of 5 genera (*Pterocarpus*, *Dalbergia*, *Diospyros*, *Millettia* and *Cassia*) from 3 families (Papilionaceae, Caesalpiniaceae and Ebenaceae). Eight of these species are *Pterocarpus*, namely, *P. santalinus* (red sanders/red sandalwood), *P. cambodianus* (Vietnam padauk/thonong), *P. dalbergioides* (Andaman padauk/Andaman redwood/vermillion), *P. erinaceus* (ambia), *P. indicus* (Burmacoast padauk/Manilla padauk/narra), *P. macarocarpus* (Burma padauk), *P. marsupium* (padauk/narra) and *P. pedatus* (maidu). A total of 16 species belong to *Dalbergia*, 6 to *Diospyros*, 2 to *Millettia* and 1 to *Cassia*. The National Hongmu Standards also specify that Hongmu refers to the heartwood of the 33 tree species. Heartwood is the centre of log and without living cells. Its colour is darker than that of sapwood. Therefore, Hongmu is a proper noun and specific term. It does not refer to all red timbers and does not include all high-end furniture timbers. Instead it is a general term for eight timber types. They vary greatly in texture and value but show common characteristics as hard, heavy, fine and red/black timbers. Normative timber names such as red sandalwood, scented rosewood and padauk, as well as the specific species and producing regions should be specified to indicate wood properties of Hongmu.

INTRODUCTION AND CULTIVATION HISTORY OF HONGMU TREE SPECIES OF *PTEROCARPUS* IN CHINA

Original Hongmu tree species in China included only *Dalbergia odorifera*, *D. fusca* and *Cassia siamea*, while the introduced Hongmu tree species mainly belong to *Pterocarpus*. Eight Hongmu tree species of *Pterocarpus* have been introduced to tropical and subtropical regions of China, including Hainan, Guangdong, Guangxi, Fujian and

Yunnan. The early introduction was scattered, spontaneous and multichannel, and without proper organisation. Gifts from overseas Chinese or foreign friends were two major sources of Hongmu tree seeds, thus, no corresponding introduction record was established. By the end of the 20th century, Hongmu prices in domestic and foreign timber markets soared fast, and it became more difficult to import Hongmu from foreign countries. Fortunately, the early-introduced Hongmu trees of *Pterocarpus* grew well and attracted the attention of experts. In the early 2000s, researchers from the Chinese Academy of Forestry investigated the introduction year of *Pterocarpus* according to planting year or age of adult trees. The earliest introduction of *Pterocarpus* in China started in the early 1950s, and it was also the earliest-introduced species among all Hongmu tree species. The introduction of *Pterocarpus* reached a climax in the 1960s, which basically laid the germplasm foundation for the demonstration and extension of *Pterocarpus*.

The earliest introduction and cultivation of *Pterocarpus* were concentrated at the bases of the Chinese Academy of Tropical Agricultural Sciences/China University of Tropical Agriculture in Danzhou City, Hainan Province, and later in Xishuangbanna Botanic Garden of Chinese Academy of Sciences in Mengla County, Yunnan Province and also in the Tropical Forestry Experiment Station, Chinese Academy of Forestry in Jianfeng Ridge, Hainan Province. Among all introduced species of *Pterocarpus*, four (*P. indicus*, *P. macarocarpus*, *P. santalinus* and *P. marsupium*) were widely planted and showed good growth performances. Cultivation scale of *Pterocarpus* has been constantly expanding in southern subtropical and tropical regions of China. Current introduction researches are mainly carried out by the Chinese Academy of Forestry, focusing on studies of geographical provenance and pedigree selection of *P. macarocarpus* and *P. santalinus*.

GROWTH PERFORMANCE OF INTRODUCED HONGMU TREE SPECIES OF *PTEROCARPUS* IN CHINA

Pterocarpus indicus

Pterocarpus indicus is the most widely-cultivated species of *Pterocarpus* in China. It grows very fast,

especially in crown growth and has become a significant landscaping tree species in tropical regions (Zeng et al. 2000, Chen et al. 2004). *Pterocarpus indicus* in Hekou County, Yunnan Province, initially planted together with rubber trees (*Hevea brasiliensis*) by the China State Farms in 1951, is the oldest species of *Pterocarpus* in China. In Hainan Province, the age of initial fruiting for *Pterocarpus* is 6 to 7 years old, blooming is in middle April till late May and the period from initial blooming to full blooming is only two or three days. Winged pods ripen in mid-August till late September and can remain on the branches for a long time without falling off. Mean height, diameter at breast height (dbh) and clear length of 25- to 48-year-old trees were 22.2 m, 75.0 cm and 4.43 m respectively. Annual mean height and dbh growths were 60.9 cm and 1.83 cm respectively (Table 1).

Pterocarpus macarocarpus

In Xishuangbanna, the initial fruiting age of *P. macarocarpus* is 4 to 5 years old, blooming period is May till June, and its winged pods ripen in December till January. It is a fast-growing tropical tree species with straight bole and excellent wood quality (Wang & Yang 2006). Mean height, dbh and clear length of 18- to 30-year-old trees were 28.8 m, 39.5 cm and 12.3 m respectively. Annual mean height and dbh growths were 123.1 and 1.66 cm respectively (Table 1). Heartwood of *P. macarocarpus* is formed early. The measure of 38 tree stumps of 18-year-old *P. macarocarpus* showed that mean base diameter of the tree was 24.9 cm. Its mean peeled diameter, heartwood diameter, sapwood thickness and heartwood per cent was 23.4 cm, 16.5 cm, 6.9 cm and 70.5% respectively (Table 2). Mean heartwood diameter of stumps of six 30-year-old trees was 34.5 cm (results not shown), accounting for 75% of the tree base cross-sectional area. It takes almost 20 years for *P. indicus* and *P. santalinus* to form heartwood, but heartwood of *P. macarocarpus* forms much faster. It takes 4 to 5 years (7 years at the latest) after forestation for the heartwood to form and is available for harvest 25 years later. The trunk of *P. macarocarpus* is straighter than *P. indicus*, so it is an ideal Hongmu tree species in China. However, because its resistance towards cold is the weakest between the four species of *Pterocarpus*, it should be cultivated in regions

where the lowest air temperature is relatively higher in spring. Tropical regions of China are located in the northern margin of the world tropics and are vulnerable to cold.

Pterocarpus marsupium

All large *P. marsupium* trees in mainland China were planted in the 1960s and 1970s. The earliest planting sites were the Chinese Academy of Tropical Agricultural Sciences/China University of Tropical Agriculture. Cultivation was later extended to Xishuangbanna Botanical Garden and the Tropical Forestry Experiment Station of Chinese Academy of Forestry. This is also a Hongmu tree species full of vigour. Five- to six-year-old trees can blossom and bear fruit, blooming period is early December till late January the following year and winged pods ripen in mid-June till late July. Mean height, dbh and clear length of 26- to 36-year-old trees were 23.3 m, 56.4 cm and 6.5 m respectively, and the annual mean height and dbh growths were 73.1 cm and 1.78 cm respectively (Table 1).

Pterocarpus santalinus

Pterocarpus santalinus has the most straight and beautiful trunk shape compared with the rest of the species of *Pterocarpus*. It was firstly cultivated in at the Chinese Academy of Tropical Agricultural Sciences/China University of Tropical Agriculture in 1962. In Danzhou Tropical Botanical Garden, Xishuangbanna Botanical Garden and Tropical Forestry Experiment Station of the Chinese Academy of Forestry, the tree grows very well. Mean height, dbh and clear length of 22- to 36-year-old courtyard trees were 16.7 m, 35.7 cm and 6.8 m respectively. Annual mean height and dbh growths were 61.2 and 1.25 cm respectively (Table 1). In Danzhou city, the age of first flowering/fruiting is about 10 years old, later than the other three species. Flowering period is mid-October till mid-November, and the winged pods ripen in late April till mid-May. Sown within 12 months after seed (pod) collection, germination rate in nursery is 30 to 38%, which is significantly lower than that of *P. indicus* (83 to 90%) but is much higher than *P. macarocarpus* (15 to 20%) and *P. marsupium* (8 to 12%).

Table 1 Growth performance of Hongmu tree species of *Pterocarpus* in courtyard and/or botanical garden

Tree species	Cultivation area	Age (year)	Plant growth performance		
			Height (m)	Dbh (cm)	Clear length (m)
<i>P. indicus</i>	County town of Hekou, Yunnan Province	48	25.0	112.0	3.8
	Chinese Academy of Tropical Agricultural Sciences/China University of Tropical Agriculture (Danzhou city, Hainan Province)	36	23.5	78.0	6.0
	Xishuangbanna Botanical Garden, CAS (Mengla, Yunnan Province)	25	18.0	35.0	3.5
<i>P. macarocarpus</i>	Xishuangbanna Botanical Garden, CAS (Mengla, Yunnan Province)	30	33.0	46.0	14.5
	Tropical Forestry Experiment Station of CAF (Jianfeng Ridge, Hainan Province)	18	24.5	32.9	10.0
<i>P. marsupium</i>	Chinese Academy of Tropical Agricultural Sciences/China University of Tropical Agriculture (Danzhou city, Hainan Province)	36	30.0	52.3	6.5
	Xishuangbanna Botanic Garden, CAS (Mengla, Yunnan Province)	33	22.0	75.8	5.9
	Tropical Forestry Experiment Station of CAF (Jianfeng Ridge, Hainan Province)	26	18.0	41.1	7.0
<i>P. santalinus</i>	Chinese Academy of Tropical Agricultural Sciences/China University of Tropical Agriculture (Danzhou city, Hainan Province)	36	21.0	57.3	7.8
	Tropical Forestry Experiment Station of CAF (Jianfeng Ridge, Hainan Province)	24	17.0	23.5	6.0
	Xishuangbanna Botanical Garden, CAS (Mengla, Yunnan Province)	22	12.0	26.3	6.5

CAF = Chinese Academy of Forestry, CAS = Chinese Academy of Sciences, dbh = diameter at breast height

Table 2 Peeled diameter, heartwood diameter, sapwood thickness and heartwood per cent of stumps of 18-year-old *Pterocarpus macarocarpus* in Hainan

Diameter (cm)	Number of stumps	Peeled diameter (cm)	Heartwood diameter (cm)	Sapwood thickness (cm)	% heartwood
18–20	3	18.4	13.1	5.3	71.2
20–22	12	20.4	14.5	6.0	71.1
22–24	3	22.8	14.6	8.2	64.0
24–26	11	24.3	16.9	7.4	69.5
26–28	5	26.7	18.9	7.8	70.8
28–30	2	29.0	21.5	7.5	74.1
30–32	2	31.3	24.0	7.4	76.7
Mean		23.4	16.5	6.9	70.5

The upper limit exclusion method was adopted to get the diameter grade; total number of stumps = 38; heartwood is diameter and sapwood is thickness; heartwood per cent = heartwood diameter/heartwood peeled diameter × 100

Forestation trial

Based on performance of *Pterocarpus* in Danzhou City in the early 1960s, the Tropical Forestry Experiment Station of Chinese Academy of Forestry established trial stands of *Pterocarpus* at the Jianfeng Ridge in mid-1970s. The spacing in and between rows of trees of sloping land and flat land were 3 m × 4.5 m and 3.5 m × 5 m respectively. Our surveys on the 32-year-old *P. indicus* pure stand, 25-year-old *P. indicus* and *P. marsupium* mixed stand and the 15-year-old *P. santalinus* pure stand showed that they all had very good growth performances (Table 3).

Since the 21st century, application of precious timber tree species in forestation has gained increasing attention, especially Hongmu tree species in southern subtropical and tropical regions of China, and new forestation trials have been successively carried out in these regions. Young stands of *P. indicus* in mine areas of Maoming, Guangdong Province and in hilly areas of Pure, Yunnan Province grow well, but they are much less profitable than local eucalypts (*Eucalyptus urophylla* × *E. grandis*) (Gu et al. 2007, Shi et al. 2010). The forestation trial in the hot dry valley area of Panzhihua, Sichuan Province show that *Pterocarpus* grow well and much better than *Tectona grandis* (Liu et al. 2011).

Landscape application

Hongmu tree species in China were initially introduced to botanical garden and arboreta and gradually expanded to courtyard, park and urban landscaping. Site conditions and management strengths of the chosen areas are much better than barren mountains for cultivating landscape trees. Landscape Hongmu tree species display beautiful magnificent crowns and have various health-care functions and promote public understanding of these tree species in China. Hongmu has now become an important landscape tree species (Chen et al. 2004). As an outstanding landscape species in tropical regions and coastal cities in south subtropics, *P. indicus* has been widely used in Hainan and Leizhou Peninsula as well as in landscaping of streets, courtyards and parks in Guangzhou and Fuzhou (Table 3).

ASSESSMENT OF ECOLOGICAL ADAPTABILITY

Soil adaptability

Pterocarpus species show strong adaptability to soil conditions, and they are tolerant to saline-alkali soil and waterlogging. The introduced species of *Pterocarpus* grow well in red soil of Guangdong, latosol in Xishuangbanna and Hekou of Yunnan as well as latosol, seafont sandy soil and alluvial soil in Hainan, and even grow normally on land with saline water nearby the salt field. In Guangzhou, seedlings are tolerant to short-term waterlogging (Chen et al. 2004). *Pterocarpus indicus* has strong adaptability to soil conditions, including urban soil environment. Favourable cultivation conditions enhance the fast growth characteristics of these trees.

Climatic adaptability

All Hongmu tree species of *Pterocarpus* originate from tropical regions and are sensitive to temperature and heat. Low temperature is a key ecological factor for successful introduction and cultivation. Abundant rain water and heat are favourable for plant growth, which is clearly reflected by seed germination rate and seedling height 60 days after transplanting of plants cultivated during the same period in Guangzhou and Hainan (Table 4). Tropical regions of China are located in northern fringe of the global tropical zone. Therefore, the overall heat conditions are insufficient except in Hainan Island and Xishuangbanna. However, some biological characters of the Hongmu tree species of *Pterocarpus* are favourable for their adaptation to low temperature. Species of *Pterocarpus* begin to sprout and grow until early April in the southern tropical regions, e.g. Guangzhou and Zhaoqing. More than half of the leaves fall off in mid-December—an obvious adaptation to the cold. In Guangzhou, the extreme cold temperature of 0 °C do not cause damage to adult trees of *P. indicus*, but seedlings and young trees are severely affected. Therefore, favourable places for cultivation of Hongmu tree species of *Pterocarpus* are southern tropical regions and tropical regions with extreme minimum air temperature above 0 °C.

Table 3 Growth performance of Hongmu tree species of *Pterocarpus* in forestation trial and/or landscape greening

Tree species	Forestation area	Stand type	Stand age (year)	Average tree		Largest tree	
				Height (m)	Dbh (cm)	Height (m)	Dbh (cm)
<i>P. santalinus</i>	Danzhou	Flat land—pure woodland	36	18.5	27.5	22.6	42.8
<i>P. santalinus</i>	Jianfeng ridge	Sloping land—pure woodland	15	14.9	17.6	16.0	27.4
<i>P. macarocarpus</i>	Jianfeng ridge	Sloping land—pure woodland	18	20.5	23.8	24.5	32.9
<i>P. marsupium</i>	Jianfeng ridge	Sloping land— <i>P. indicus</i> and <i>P. marsupium</i> mixed woodland	25	22.5	31.0	27.2	38.7
<i>P. indicus</i>	Jianfeng ridge	Sloping land— <i>P. indicus</i> and <i>P. marsupium</i> mixed woodland	25	14.4	22.5	16.9	30.6
<i>P. indicus</i>	Jianfeng ridge	Sloping land—pure woodland	32	13.9	25.1	16.0	41.6
<i>P. indicus</i>	Maoming	Mining wasteland—pure woodland	5	3.1	3.3	4.8	5.6
<i>P. indicus</i>	Jianfeng ridge	Urban block—street tree	32	19.4	40.7	21.0	47.4
<i>P. indicus</i>	Jianfeng ridge	Urban block—street tree	6	7.7	25.0	16.0	45.6
<i>P. indicus</i>	Sanya	Urban block—street tree	6	11.0	25.4	12.0	32.5

The spacing in and between rows of trees of sloping land, flat land and urban block were 3 m × 4.5 m, 3.5 m × 5 m and 4.5 m × 12 m respectively. Number of trees measured was 100–125.

Table 4 Seedling growth of four Hongmu tree species of *Pterocarpus* in Guangzhou and Hainan

Tree species	Location	Air temperature of seedling stage (°C)	Seed germination (%)	Seedling height 60 days after transplanting (cm)
<i>P. santalinus</i>	Guangzhou	20–30	40.7	15–25
	Hainan	30–35	48.2	25–30
<i>P. indicus</i>	Guangzhou	20–30	71.3	35–40
	Hainan	30–35	98.2	40–45
<i>P. marsupium</i>	Guangzhou	20–30	10.5	15–20
	Hainan	30–35	13.2	40–45
<i>P. macarocarpus</i>	Guangzhou	20–30	21.0	15–20
	Hainan	30–35	27.0	40–45

Resistance against extremely cold weather

From January till February 2008, south China experienced constant low temperature, rain and snow, as well as freezing that were rare in the past century. As a result, large number of forest plants

were freeze-damaged or dead. *Pterocarpus* could not endure constant low temperature or cold rain below 2.5 °C for more than 1 week. Therefore, large-scale promotion of these species should be limited to the south of 21.5° N or some coastal areas (Xu et al. 2008). Young stands of *Pterocarpus*

(1 or 2 years old) have lower resistance against cold compared with *Dalbergia* and *Santalum*. Lower temperature limit for *Santalum* is $-1\text{ }^{\circ}\text{C}$ and for *D. odorifera*, $-3\text{ }^{\circ}\text{C}$ (Yang et al. 2008). However, the four *Pterocarpus* Hongmu species vary greatly in cold resistance, and the survey of nursery lands in Guangzhou in the same period shows that the most precious *P. santalinus* has the strongest resistance, *P. indicus* the second strongest, while *P. marsupium* and *P. macarocarpus* have poorer cold resistance, but the latter has higher requirements for heat at the planting site (Table 5).

PROSPECT OF FUTURE DEVELOPMENT AND CULTIVATION OF *PTEROCARPUS* HONGMU IN CHINA

Precious timber species have excellent quality to meet high-end needs of people for wooden products. Therefore, Hongmu forests have become significant national resources. The future competition of the world timber market will focus on precious timber resources among which Hongmu tree species are most outstanding. Hongmu tree species as rare resources have won increasing attention from many countries and international organisations. Currently, the control on harvesting Hongmu tree species has been broadened and strengthened. As with tropical timber species, export of Hongmu resources will eventually be restrained or prohibited in the future (Anonymous 2013).

Declining resources of Hongmu as well as restrictions on logging and banning the export of wood are primary issues to be settled in

international Hongmu market. Cultivation of Hongmu forests should be an important objective in forestry development strategies. *Pterocarpus* is an important component of Hongmu tree species and has adapted well in southern subtropical and tropical regions of China since its introduction more than half century ago. With excellent growth performance, outstanding economic attributes and ornamental properties, Hongmu does not have any serious diseases or pests.

With increasing pressure on Hongmu natural resources and increasing demand for its products, it is pertinent for the world to implement protection policies for these species. It is necessary to cultivate Hongmu forests actively. Hongmu tree species are popular in southern subtropical and tropical regions of China, and these regions are expected to be the largest Hongmu cultivation areas in the world. However, Hongmu timbers have been obtained by cutting natural forests for a long time. Compared with traditional afforestation species, Hongmu plantation forests have a short history of cultivation and less accumulation of related science and technology. From the perspective of sustainable development of Hongmu industry, future cultivation of *Pterocarpus* should focus on the following aspects:

- (1) Enhance collection of germplasm resources, genetic breeding and basic biological research of *Pterocarpus*. China has sparse original Hongmu germplasm resources. Since the early 1950s, and especially in the 1960s, several *Pterocarpus* Hongmu tree species have been introduced to China via folk communication. However, the

Table 5 Resistance of four Hongmu tree species of *Pterocarpus* at seedling stage against low temperature ($0\text{ }^{\circ}\text{C}$)

Tree species	Seedling height (cm)	Number of plants	Undamaged plants (%)	Damaged plants (%)		
				Leaf falling	Dead or top withering	Total damaged
<i>P. santalinus</i>	30–60	60	83	15	2	17
	< 30	60	39	56	5	61
<i>P. indicus</i>	30–60	300	38	52	10	62
	< 30	100	20	21	59	80
<i>P. marsupium</i>	30–60	100	9	76	15	91
	< 30	200	0	0	100	100
<i>P. macarocarpus</i>	30–60	100	0	100	0	100
	< 30	200	0	0	100	100

introduced tree species and provenance were limited, which is unfavourable for genetic improvement and breeding of new varieties. Hongmu arboretum or national germplasm nursery should be established in suitable places to collect Hongmu tree species and provenances to facilitate basic biological and genetic breeding researches.

- (2) Enhance researches on cultivation physiology and regulation technology of Hongmu tree species of *Pterocarpus*. In northern fringe of global tropical zones, low-temperature stress is a key factor restraining the introduction and cultivation of Hongmu tree species. Improvement in cold resistance of Hongmu tree species has not been reported. Researches should be concentrated on understanding the cold-resistance mechanism and regulation technology of these species, especially the relationship between forest nutrition management, improvement of cold resistance and Hongmu timber development and quality.
- (3) In view of the long production cycle of heartwood and slow economic returns, it is necessary to explore and promote multiple investment modes, diversified planting channels and high-efficiency agroforestry management model. Hongmu afforestation increases the reserve of national resources. Thus, central and local governments should give greater financial support and other preferential policies. Application of efforts should also be given to plant *Pterocarpus* by the roadside and in courtyards and for garden landscaping. Finally, research on the utilisation of non-wood forest products of *Pterocarpus* should be explored actively.

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