Structure of *Pinus massoniana* and broadleaf tree mixed forest in the middle and upper reaches of the Changjiang River

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Abstract: The structure of *Pinus massoniana* and broadleaf tree mixed forest was studied with a view to provide a scientific basis for such forest ecological function research and managements in the region of the middle and upper reaches of the Changjiang River in China. The existing distribution of forest in the region is not suitable, due to a large proportion of coniferous forest and a small proportion of broadleaf forest, as well as a large proportion of pure forest, small of the broadleaf tree mixed forest. Such kind of coniferous and pure forest tree structure is the major factor to lead the whole drainage area's ecosystem fragile, non-virtuous crisis. This study collected 95 scientific research sample-plots of eight stand types of *Pinus massoniana* and broadleaf tree mixed forest·in four provinces or municipalities (Hunan, Hubei, Sichuan, and Chongqing). The results showed that the stand structure of P. massoniana and broadleaf tree mixed forest had an obvious advantage, could adapt to a variety of environmental conditions and had great vitality and ecological potential compared to coniferous forest in the function of the water and soil conservation. The research suggested that the *P. massoniana* and broadleaf mixed forest was developing toward the stable, healthy cycle. Therefore, the *P. massoniana* and broadleaf tree mixed forest should be vigorously developed in the middl e and upper reaches of the Changjiang River shelterbelt construction.

Key words: *Pinus massoniana* and broadleaf tree mixed forest; stand structure; middle and upper reaches of the Changjiang River

Introduction

In the process of constructing protection forest system in the middle and upper reaches of the Changjiang River, a prominent problem encountered is that the distribution and structure of forest in the middle and upper reaches of the Changjiang River is unreasonable, reflected in the large proportion of coniferous forest area which holds 67.15% of the forest area [1]. The mixed Coniferous and broadleaf forest has a small proportion, accounting for 32.85%. Pure forest has a large proportion, accounting for 88.4% while the mixed forest has a small proportion, accounting for only 11.6%. Such Conifer problem and pure forest problem are major factors which lead the whole-basin forest ecosystem to a fragile and non-virtuous crisis [1-2].

A large number of domestic and foreign studies show that mixed forest plays an important ecological role in maintaining and preserving forest community diversity, landscape diversity and biological diversity. Mixed forest also provides and creates appropriate basic conditions for the sustainable development of forestry and artificial simulation of natural communities. More importantly, the modern ecology has proved that un-even aged mixed forest has important theoretical and practical significance in genetics, species evolution and maintaining ecological balance [3-4].

This research is one part of the 3 state projects, *i.e.* "the 8th Five-year Plan" research topics "Research on soil and water conservation forests management model and tables of Pinus massoniana and Chinese Weeping Cy-press in the middle and upper reaches of the Yangtze River"; "the 9th Five-year Plan" research topic "Research on the transforming techniques of the low-quality and low-benefit secondary forests in the middle and upper reaches of the Yangtze River" and National Natural Science Foundation of China for topic of "Characteristics of sprouting natural regeneration of a subtropical evergreen broadleaved forest". Based on these studies, we take a typical representative of *Pinus massoniana* and broadleaf tree mixed forest in the middle and upper reaches of the Changjiang River as our research object. We discuss its law of stand structure with vitality and ecological potential, which provides the scientific basis for studying the ecological function and building management and technology system for this stand.

Materials and Methods

1. Selection of sample-plot

Sample-plots should be selected according to three coherences, which are consistency of appearance structure, consistency of the type composition and consistency of habitat characteristics and four similar characteristics, which are conformation structure approximation, seasonal appearance approximation, the ecological characteristics of approximation, forest environment and external conditions approximation [5].

On the basis of surveying the whole forestry, sample-plots should be set in the storey and species which are both complete, mixed stands which are uniformity and stands that are not destructed by people.

Under the species-area curve, we determine that the size of the arbor layer standard is 0.0667hm^2, the minimum size of the shrub layer standard is 0.011hm^2 and the size of herb layer and forest litter is 1m^2.

2. Standards investigation

The main contents of surveying the *P. massoniana* and broadleaf tree mixed forest standard: Firstly, surveys of ecological environmental factors: standards of the terrain factor, soil and vegetation factors (including the main vegetation types, quantity and distribution in forest). Secondly, surveys of lamellar factor: it needs to measure the main factor of all individuals and biomass of the various components in the arbor layer; survey species, volume, fractional coverage, height and biomass of the components in shrub layer; survey species, fractional coverage, height and biomass of the components in herbaceous layer and take methods of collection, preservation, classification and weighting for analysis in forest litter. Thirdly, surveys of management factor: it needs to survey circumstances of enclosure land of the hillside for regeneration, management measures and the destruction or interference [6].

3. Information and distribution of samples

Researchers collect 95 scientific research sample-plots of eight stand types of *P. massoniana* and Broadleaf Tree mixed

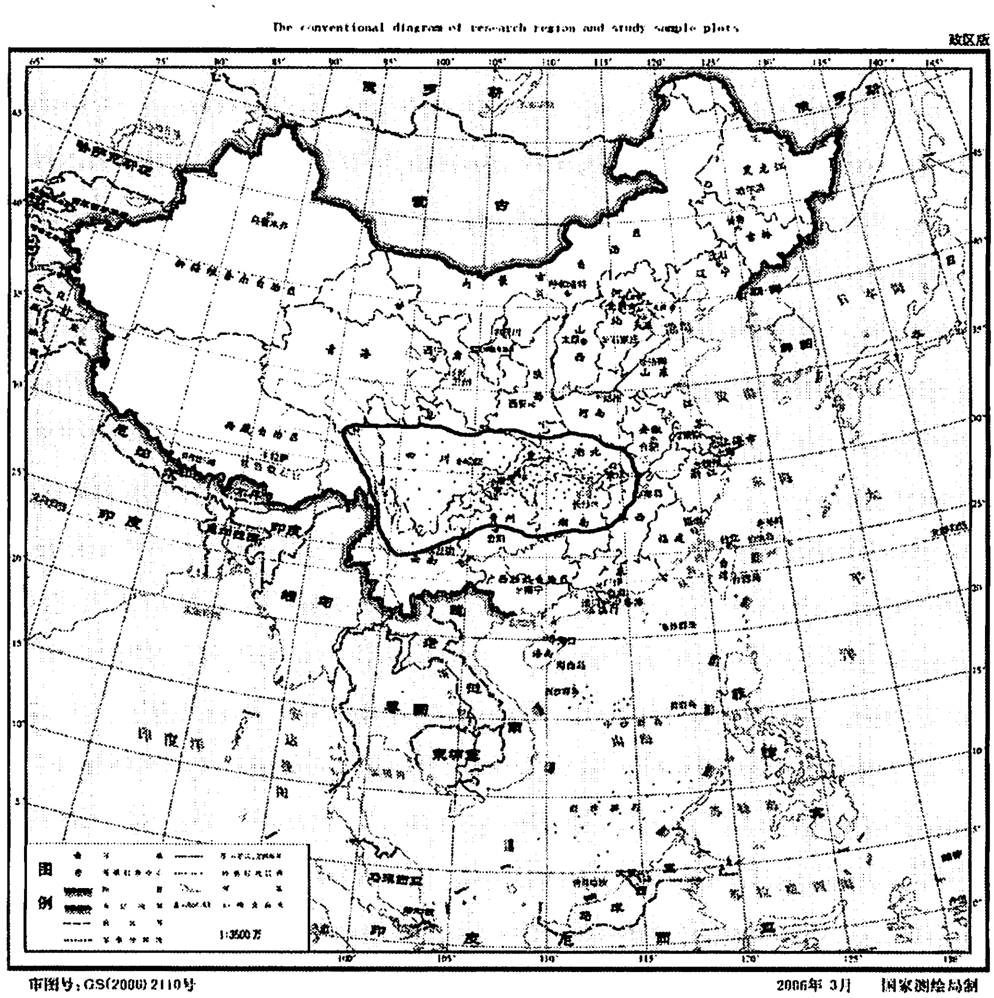

Fig. 1. Map of the research region and study plots in *Pinus massoniana* and broadleaf tree mixed forests in four provinces or municipalities (Hunan, Hubei, Sichuan, Chongqing) in China.

forest in four provinces or municipalities (Hunan, Hubei, Sichuan, Chongqing) as showed in Fig. 1, among which there are 32 detailed measurements sample-plots. The plot information has adequate distribution sequence and broad representation in site conditions, age, height, diameter at breast height, density and community structure.

Results and Analysis

1. Layer structure

Due to the interspecific differences between characteristics of the growth and the shade of drought-tolerant of tree species and the fact that individual space-time make forest plant ecological competition form stratification structure: different levels of forest plants have different positions and roles. This study adopts some important statistics to reflect the different levels of plant communities in the status and role. The results of important value of the tree species of *P. massoniana* and broadleaf tree mixed forest is showed in Table 1.

What to explain is that all the results are the combined results of samples which just reflect general trends. Owing to growing competition and differences between the individual growth patterns in time-space, layered trees can enable the important values of straticulate states to change in different times and different sites. Although the collective woodlands in southern China are very serious in jamming, population structure patterns are often damaged; the general mixed species law and the law of layered trees in particular are very clear. To retain the trees whose important values are over 61%, the protection forest operating system must be emphasized.

2. Population distribution pattern

Population distribution pattern is a quantitative description of the level of population, space allocation and distribution state under the combinative factors including biological characteristics of species, interspecific relations and habitat conditions and so on. We adopt a specific time- investigation method(Leak 1975), which is to investigate the layout distribution of *P. massoniana, Schima superba, Castanopsis sclorophylla* mixed forests on the basis of the theory of replacing the time-varying by the space difference [7]. We mainly calculated T- values of species, the average support index, poly block index and pattern index. Finally, we hold that pattern index is the integrative index reflecting the distribution pattern. The results are shown in Table 2.

From the table, we can see that the four tree species in the first sublayer of the main-story species show an aggregative distribution (lump). In the sublayer, the distribution of *Liquidambar formosana, Symplocos sumuntia* and *Quercus chenii* show an aggregative trend; *Castanopsis fargesii, Elaeocarpus japonicus, Ilex chinensis* show an Poisson distribution, that is called random distribution. Obviously, there are too many *P. massoniana* and fewer broadleaf trees in the main story.

After calculating shrub layer's distribution pattern of various kinds of population, we find that *Loropetalum chinense, Viburnum foetidum var. rectangulatum, Vaccinium bracteatum, Embelia longifolia* are aggregatively distributed, while *Photinia parvifolia, Camellia cuspidate, Gardenia jasminoides, Dalbergia hupeana, Quercus fabric, C. sclorophylla, S. superba, Elaeocarpus sylvestris, Cinnamomum camphora, L. formosana, Syzygium buxifolium* ect. are randomly distributed. So effectively protecting

Table 1. Important Statistics about *Pinus massoniana* and Broadleaf Tree Mixed Forest.

	Species	Relative abundance (%)	Relative frequency (%)	Relative Notable degrees (%)	Important value (%)	Percentage important value
Dominant Species	*Pinus massoniana*	25.99	12.95	83.37	124.31	41.4
	Schima superba	29.53	13.9	5.99	49.42	16.5
	Castanopsis sclorophylla	19.28	13.9	2.8	35.98	12
	Quercus chenii	8.92	5.53	2.22	16.67	5.6
Associated Species	*Cinnamomum camphora*	4.06	8.97	2.11	15.14	5
	Liquidambar formosana	4.6	7.91	1.56	14.07	4.7
	Elaeocarpus japonicus	1.11	6.43	0.09	7.63	2.5
	Castanopsis fargesii	2.43	1.94	1.24	5.61	1.9
	Ilex chinensis, Quercus fabri	0.53	4.49	0.05	5.05	1.7
	Dalbergia hupeana, Symplocos sumuntia	0.77	2.99	0.16	3.91	1.3
	Elaeocarpus sylvestris, Castanopsis carlesii,Diospyros kaka var. silvestris,Adinandra millettii,Vacciniumbracteatum,Toxicodendron verniciflnum,Cyclobalanopsis glauca,Quercus acutissima,Quercus acutissima,Albizia kalkora etc.	0.06～0.30	0.50～2.00	0.00～0.11	0.50～2.00	1

Table 2. Main Population Distribution Patterns of Pinus massoniana and Broadleaf Tree Mixed Forest Arbor Layer.

Sublayer	Specific name	X	V	Distribution pattern	T- value	I_δ	Average support index	poly block index
I	*Pinus massoniana*	44.633	62.308	Clump	10.242**	1.396	45.029	1.009
I	*Schima superba*	54.321	73.196	Clump	9.580**	1.348	54.669	1.006
I	*Castanopsis sclorophylla*	36.778	56.627	Clump	12.020**	1.54	37.318	1.015
I	*Cinnamomum camphora*	10.45	17.644	Clump	7.021**	1.688	11.138	1.086
II	*Liquidambar formosana*	13.167	26.559	Clump	11.049**	2.017	24.184	1.077
II	*Symplocos sumuntia*	7	22.167	Clump	10.615**	3.167	6.167	1.31
II	*Quercus chenii*	25.556	40.344	Clump	8.767**	1.579	26.134	1.023
II	*Castanopsis fargesii*	25	30.726	poisson	1.803	1.229	10.229	1.009
II	*Elaeocarpus japonicus*	5.7	7.286	poisson	1.472	1.278	9.978	1.049
II	*Ilex chinensis*	2	1.2	poisson	-0.633	0.6	1.6	0.8

the shrub layers of target species, and getting rid of non-target trees in and around the weeds, improving light conditions, and allowing full growth of various kinds of shrub layer are an important principle of forest management.

3. Diameter and the age structure

We have studied this issue over ten years, and in the past we only studied on the distribution of stand diameter according to the numbers of trees, which seems to have little practical significance. Later, we summarized domestic and foreign experience, adopted the method of splitting the sizes of the structure to replace the age structure, especially took regression analysis for diameter and age of the species, established reckoning models, thus determined the age of the trees through the diameter we measured which was difficult to get, then provided practical information for mixed forest operators. Its reckoning models are as follows:

P. massoniana $D_{1.3}=0.3125+0.5005A$ r=0.88

S. superba $D_{1.3}=1.6383+0.4077A$ r=0.86

C. sclorophylla $D_{1.3}=1.3917+0.4157A$ r=0.94

Many foreign scholars adopted the method of partitioning tree classes (Knouls & Grant (98) Loumer 1980. leak 1964) on the arbor layer population age structure and its dynamic change. According to this, we combine the standard materials, and divide mixed tree into five classes:

Grade one seedling:h<0.33m; two-grade seedling:h >0.33m and root<2.5m; grade three young tree: 2.5<h < 7.5m; four-grade s tanding tree:7.5<dbh<22.5cm; grade five dominate tree:dbh >22.5cm.

We analyzed the structure of *P. massoniana* trees and Broadleaf Tree mixed forest according to the standard, the results were as follows:

Grade one seedling *S. sumuntia, E. japonicus, L. chinense*

Grade two seedling *Q. chenii, Cyclobalanopsis glauca*

Grade three young tree *C. sclorophylla, S. superba, Q. chenii, E. japonicus, S. sumuntia*

Grade four standing tree *S. superba, P. massoniana, Q. chenii, C. sclorophylla, C. camphora*

Grade five dominate tree *P. massoniana*

It can be seen from the age growth distribution of trees that *P. massoniana* belong to upper level, and a large number of broadleaf trees which grow stably will replace the positive conifer species to form evergreen broadleaf forest, which is what we hope that forest ecosystem is developing in the state of stable and virtuous circle. To the transformation of the secondary forest, we must first adopted the mixed coniferous and broadleaf forest as the transitional business model, and then protect formation and development of broadleaf forest with the upper level *P. massoniana*, therefore, the protection of the upper level *P. massoniana* and undergrowth broadleaf trees is the basic strategy in the transformation of secondary forest.

4. Species diversity and interspecific correlation

Species diversity refers to the number of species in a community, the number of individual of all the species and its uniformity. It is a reflection of species richness and changes, the stability and dynamics of communities and the relationship with environment in a certain habitat. It has important significance to discuss the optimal community structure and subrogation developments in theory, and in practice it also has important significance on the protection, management, development and utilization of the biological resources. We compared different methods in the determination of species diversity of *P. massoniana* and broadleaf tree mixed forest. The results showed that the Shnnon-hecner index is relatively better. The results of index calculation of the 32 *P. massoniana* and broadleaf tree mixed forest sample-plots were that the average value of arbor was 0.5952 ± 0.173 and the average value of shrubs was 0.6422 ± 0.1454. The average index value is shown like this: *P. massoniana* and broadleaf tree mixed forest < Mid-Subtropical evergreen broadleaf forest < South subtropical evergreen broadleaf forest. The uniformity of *P. massoniana* and Broadleaf Tree mixed forest arbor tree was 53.4573 ± 16.5698 and the shrubs was 53.13 ± 16.01, and it was lower than the average broadleaf forests. In the *P. massoniana* and broadleaf tree mixed forest, there were more young trees of *S. superba, C. sclorophylla, Q. chenii and C. camphora* and less young trees of *Massion Pine.* This shows that the stand is developing to become evergreen broadleaf forest and in the direction of stable and beneficial cycle, but we must end the human destruction in the management. The materials in Table 3 show that interspecific of *P. massoniana* and Broadleaf Tree mixed forest existed mosaic structure and complementarity in the interspecific relationship.

We can see from Table 3 that the biomass of 15 year-old *P. massoniana* and *Q. chenii* mixed forest arbor layer was 73.07 t/h㎡, which was 1.55 times as much as that of pure oak forest and 1.61 times as much as that of pure pine forest; the biomass of 35-year-old mixed forest was 53.37 t/h㎡, which was 20.9% higher than pure pine forest; the biomass of *P. massoniana* and *Quercus variabilis* mixed forest arbor layer was 104.4% higher than pure pine forest and 40.0% higher than pure *Q. variabilis* forest. We could see from the proportion of the components, the dry matter proportion of stem, branches, leaves, roots of pine trees in the *P. massoniana* and *Q. acutissima* mixed forest was 46.9 ~ 65.3: 15.4 ~ 11.3:16.2 ~ 6.4 : 21.6 ~ 17.1; the proportion of pure pine forest was 47.2 ~ 62.7: 29.1 ~12.5 :16.4~8.3:12.9~16.5. *Q. acutissima* mixed forest was similar to pure forest. The economic factor was higher in *P. massoniana* and *Q. variabilis* mixed forest because that the proportion of stem was big and stick relatively had a small proportion of *P. massoniana* and *Q. variabilis.* It had little difference in leaf biomass ratio among different types of stands. But the proportion of the pine root in mixed forest was higher in pure forest, and it would help to raise the tree resistance to environmental factors (drought, storm) and the utilization of soil fertilities.

The change of topography will lead to the change of ecological factors and soil factors. Therefore, different site spaces will be different to the growth of interspecific trees. The information shows that the growth of *P. massoniana* and *Q. variabilis* mixed forest is better in the hillocky area and poorer in the hilly area. The growth of *P. massoniana* and *Q. variabilis* mixed forest in the lower stands of timber volume is 3.1 times as much as that of the upper stands, followed by central stands.

To the biomass of components, the overground and underground parts of pine and cork mixed forest's structure are harmonious. The parts of the overground form the same layer of inlaid crow of forest and the underground root presents sandwich inlaid distribution, which has not only improved the unit area biomass and accumulation, better used space and eased up all kinds of interspecific conflicts, but also confirmed the stability

Table 3. The Influence of the Components' Biomass of *Pinus massoniana* and Broadleaf Tree Mixed Forest Arbor Layer and the Impaction of Different Stands on Growth.

Stand types	Tree species types	Age (a)	Arbor layer biomass ($kg/666.7m^2$)										
			Stem		Branch		Leaf		Root		Sum		Ratio
			Dry weigh	(%)	Dry weigh	(%)	Dry weigh	(%)	Dry weigh	(%)			
Mixed forest /pure forest	*Pinus massoniana*	15(17)	1408.1	46.9	461.3	15.37	486.6	16.2	648	21.57	3004		
			-1274.5	-47.22	-867	-29.07	-489.9	-16.43	-35.81	-12.93	-2982.1	4871.3	163.4
	Quercus acutissima	12(15)	1163.3	62.49	239.7	12.7	1217.6	66.5	337.36	18.25	1867.3	-6110.6	-104.9
			-7914.7	-62.16	-458.8	-14.66	-187.3	-59.9	-537.67	-17.19	-3218.5		
Mixed forest /pure forest	*Pinus massoniana*	35(35)	16967	65.31	2932.8	11.3	1673.2	6.4	441.8	17.09	25991	3558.3	
			-18487.5	-62.7	-3675	-12.5	-2450	-8.3	-4812.5	-16.5	-2942.5	-2942.5	120.9
	Quercus acutissima	25	4037.5	67.3	937.5	15.6	322.5	5.4	697.5	11.6	9592		-100
Mixed forest /pure forest	*Pinus massoniana*	32(32)	2694.5	54	641.2	12.7	169.9	3.4	1504.2	30	5010.3		
			-2995.2	-49.7	-707.2	-11.7	-114.4	-1.8	-2204.5	-36.6	-6021.3	-12309.9	204.4
	Quercus variabilis	32(48)	3808.2	52.2	1133	15.6	129.8	2	2228.6	30.5	7229.6	-15135.1	-151.4
			-2995.4	-49.3	-1350.1	-14.8	-110.4	-1.2	-2657.9	-29.1	-9113.8		
Terrain (slope position)	Mixed tree species	amount of trees(n/hm^2)	Height		Diameter at breast height		Individual volume		Cumulation (m^3/hm^2)				
			m	ratio	cm	ratio	m^3	ratio					
Low mountian(top)	*Pinus massoniana*	360	10.2	100	17.4	100	0.1151	100	51.3615				
		-20	-9.8	-100	-17.4	-100	-0.1108	-100	-64.3111				
	Quercus variabilis	345	7.6	100	9.7	100	0.0288	100					
		-27	-9.3	-100	-14.6	-100	-0.0767	-100					
High hillock (middle)	*Pinus massoniana*	300	10.4	102	21.6	124	0.1751	152	67.5872				
		-28	-11.6	-118	-18.7	-108	-0.1489	-134	-104.0085				
	Quercus variabilis	405	8	105	10.8	111	0.0372	129					
		-29	-10.2	-110	-15.6	-107	-0.0954	-124					
Low hillock (undersurface)	*Pinus massoniana*	300	16.3	160	22.3	128	0.2856	248	126.0482				
		-33	-12.2	-131	-21.6	-124	-0.2014	-184	-196.6305				
	Quercus variabilis	435	10.7	140	15	115	0.0928	322					
		-44	-12.6	-136	-17.4	-119	-0.1449	-189					

and rationality of pine and cork mixed forest [8].

Conclusion

The existing distribution of forest in the middle and upper reaches of the Changjiang River is not suitable: the proportion of coniferous forest area is large; the proportion of broadleaf forest and coniferous forest area is small, while pure forest area proportion is large and mixed forest area is small. Such kind of conifers and pure forest tree structure is the major factor to lead the whole drainage area's ecosystem fragile, non-virtuous crisis. Such harmful forest structure in the middle and upper reaches of the Changjiang River shelterbelt system must be adjusted. The layered nature, population distributing pattern, diameter and age structure, species diversity and species-related laws of the *P. massoniana* and broadleaf tree mixed forest in the middle and upper reaches of the Changjiang River are quite obvious. The *P. massoniana* and broadleaf tree mixed forest is developing toward the stable, healthy cycle. The stand structure laws this study discusses can provide the scientific reference for the water and soil conservation ecological function and operating system technology research of *P. massoniana* and broadleaf tree mixed forest. The stand structure of P. massoniana and broadleaf tree mixed forest has an obvious advantage. It can adapt to a variety of environmental conditions and has great vitality and ecological potential and is superior to coniferous forest in the function of the water and soil conservation. So the *P. massoniana* and broadleaf tree mixed forest should be vigorously developed in the middle and upper reaches of the Changjiang River shelterbelt construction [9].

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長江の上中流域における馬尾松広葉樹混合林の林分構成

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要　旨

中国、長江の上中流域の保安林を構築する過程において、林分構造に深刻な森林問題がみられる。そのため、研究グループでは「国家'八・五'攻関課題－長江上中流域における馬尾松、コノテガシワの水保全林の経営モデルと経営数表の研究」、「国家'九・五'攻関課題－長江上中流域における低質の低効率の次生林の改造技術の研究」と「国家自然科学基金－亜熱帯常緑広葉樹林における萌芽更新の特性」等の研究を継続している。それらの研究成果は、中国の長江上中流域に森林の生態的効果の向上と経営管理技術体系の確立に関する科学的根拠を提供するのである。本論文では中国の湖南省、湖北省、四川省、重慶市に設定した95個科学研究標準地から8 種類の馬尾松広葉樹混合林の林分構造が調査され、林分類型と樹種構成が検討された。その結果、馬尾松広葉樹混合林は、針葉樹林に比較して大きな生態的潜在能力があり水土保全機能が高く、いろいろな立地環境への順応および持続的な循環型森林育成の可能性が示唆された。馬尾松広葉樹混合林は、中国の長江上中流域における保護林帯の構築に活用、推進することが望まれた。

キーワード：馬尾松及び広葉樹混合林、林分構造、長江上中部流域