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Managing Multi-functional Forests Using Forest Development types (FDTs) - A Perspective from Monoculture Forests in Southern Subtropical China

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ABSTRACT

The Chinese Government wants to develop mixed stands with complex structures, particularly in monoculture forest areas. However, despite the enthusiasm for planting trees, is sufficient thought being given to the development of forestry objectives? A logical alternative would seem to describe the structure of such mixed stands through the use of specific-model management tools. This paper conceptualizes and assesses forest development types (FDTs) of management designs and silvicultural principles across three contemporary forest development types: the restoration, the nature-based, and the commercial paradigms. Forest development type design and silvicultural treatments were conceptualized from a review and case studies. The study was conducted as a case study focusing on the planning and development of long-term management goals for three mixed stands for multiple uses. Using FDTs, visual representations of planting design and stand development were obtained as a basis for the "expert" assessment of five criteria: the forest overview, the objectives, the proportion of tree species, the mix type, and the management operations. The assessment showed that forests vary considerably among planting designs and silvicultural systems. FDTs utilizing succession and variation in species, diversity, growth and tree regeneration offer an extended paradigm of multi-functional management. With regard to the ongoing move from timber-dominated forestry to the multifunctional management of mixed stands, fostering dialogue may be the most effective means for forest development types to contribute to the implementation of new management paradigms.

INTRODUCTION

Forest management practices have recently changed, and there is a trend away from homogeneous, even-aged monoculture forests to close-to-nature systems (Lu 2006). The management of multiple functions, including timber, non-timber forest products (NTFPs), and cultural and environmental value can enhance the ecological, economic, and social functions of tropical forests (Panayotou & Ashton 1992). The adaptation of forest management to its long-term effects of stand dynamics and these dynamics' relevance for flexible forest management remains limited (Pretzsch et al. 2014). These questions still pose significant challenges in China. Although reforestation and afforestation initiatives in China have been profound in quantitative terms, forests only cover approximately 18% of China's landmass, and timber yields and quality are lower than those of many other places (Stone 2009). Close-to-nature forest management is a leading issue in China. It has been practiced in various forms in the central and southern provinces, such as Beijing, Guangxi and Hainan, for more than 20 years (Liu et al. 2009, Meng et al. 2011). However, close-to-nature forestry is a complex management paradigm that is difficult to communicate (Gönner & Seeland 2002). If we look closely at the experiences from past application, insufficient progress has been made toward the following original goals: 1. The establishment of mixed stands, and 2. the promotion of forest models. A progressive forestry vision currently requires forests to satisfy multiple stakeholder demands for multiple products and services (Kant 2004). Forest management was regarded principally as a catalytic agent for social and economic development (Wiersum 1999). Thus, there is a need to negotiate a set of objectives and shared responsibilities. However, it has been demonstrated that ignorance and hesitance toward targeted forest structures have been the cause of the uncertainty that underpins research on the benefits of forest management. The urgent and one-sided pursuit of the ultimate forest form has ignored two prominent problems in forest management:

1. Which forest conditions should we aspire to meet for fulfilling social demands?
2. How should developing such forest conditions translate into benefits and costs?

The key to solving these problems lies in creating proper and effective multi-functional forest management strategies to adjust the standing forest structure, to foster standing forests with high productivity and, simultaneously, to consider the economic and ecological benefits of the targeted forest trees with high productivity.

Forest development types (FDTs) reflect a silvicultural model developed for the targeted forest based on biotope and potential natural forest vegetation as well as its succession process, economic needs, technical possibilities and other factors (Larsen & Nielsen 2007). All theoretical considerations and technical designs of forest management are conducted through specific models and technologies in the specific forest. Therefore, the silvicultural model of the forests, based on forest ecological mechanisms and socio-economic considerations and technical feasibility, is the direct and most effective technical component in the forest management system. China has an interest in increasing the amount of its woodland cover, particularly in monoculture forest areas. However, despite the enthusiasm for planting trees, is sufficient thought being given to the development of plantation forest interiors? Moreover, implementing new management goals and using tools challenge professionals who are educated and trained within the age-class forestry tradition to use their knowledge in creative ways. In this context, forest development types combined with the illustration of these types by means of profile diagrams were developed as a means of organizing and facilitating the communication of long-term goals for close-to-nature stand development (Larsen & Nielsen 2011).

Our focus in this paper is on strategically developing an approach to forest management for restoring stands in subtropical plantation station forests, where the importance of economics and ecological value equals or even surpasses classical production goals. As a first step, we design the forest development type of different trees for the given forest development types for the Fubo plantation station forests of Guangxi Province. Second, we review the expected utility of different classes of formalized silvicultural processes for assessing the multi-functionality of an alternative forest management model. Third, we assess different forest development types, i.e., the course of mean diameter, top height, diversity, current stand growth, standing volume, tree number and other stand characteristics, as tentative evaluations of a multi-objective management optimization problem. We provide a clearer picture of these relationships by examining a forest development type as a “multi-function” of governance with the intention of offering insight into improved implementation of forest management initiatives involving small holders.

MATERIALS AND METHODS

Study sites and history: The study sites are located in the Fubo plantation station forests (21°57'-22°19' N, 106°39'-106°59' E), the Experimental Center of Tropical Forestry (ECTF), Chinese Academy of Forestry, Pingxiang City, Guangxi Zhuang Autonomous Region, China, which belongs to the subtropical region. The annual rainfall is 1,200 to 1,500 mm, the temperature varies between 20.5°C and 21.7°C, and the relative humidity is 80%-84%. The plots are located at an altitude of 430m-680m above sea level (a.s.l.) and the topography consists of low mountains. The sandy-textured soil at the study site was formed from granite, classified as red soil according to Chinese soil classification, and the pH value is 4.8-5.5. The vegetation is a coniferous-broadleaf mixed forest dominated by Masson pine (*Pinus massoniana*) and Chinese fir (*Cunninghamia lanceolata*) with a well-developed understory of evergreen shrubs, Castanopsis *hystrix* and *Mytilaria laosensis*, with *Erythrophleum fordii* and *Michelia gioi* as minor components. Masson pine (*Pinus massoniana*) and Chinese fir (*Cunninghamia lanceolata*) have been the widely planted native conifers for plantations and widely used for wood production in the tropics and subtropics throughout the world as well as in China due to their rapid growth. Because of their high commercial value, many native broadleaved and coniferous forests are often being actively converted to plantations of pure Masson pine and Chinese fir. In southern China in particular, forest development of plantation forests with an average age of between 20-40 years is not optimal.

Since 1991, a variety of community-based management systems have been implemented in the ECTF based on socio-economic and biological-ecological studies, including mixed stand, high-value species, agro-forestry, eco-tourism, and forestry. Several cooperatives have been founded within the ECTF that conduct controlled timber extractions. Problems in commercial plantation management are strongly benefit-oriented toward a controlled farming system. Another portion of the ecological forests lies in a protected area and lacks proper management, which has created many problems. Such long-term, simplified forest land use has resulted in a severe reduction of natural biodiversity and has led to further degradation. Moreover, the short-rotation monoculture plantation silvicultural model, particularly for exotic tree species such as *Eucalyptus* and rubber, has caused rapid land degradation, leading to reduced forest productivity and destabilized ecosystems. As a result of degradation, recent forest quality has been poor, with an average standing volume of 85.88 m^3ha^{-1}. This figure has reached 45 m^3ha^{-1} at plantations. The country’s average forest growth of 4.5 $m^3ha^{-1}yr^{-1}$ has occurred with weak ecosystem resiliency and a loss of positive interactions among species, rendering the forest susceptible to pests and disease. Pests and diseases have increased the urgency for land protection and restoration.

After 1998, the shortcomings of the two-class commercial-ecological management police were recognized, and a search for ecologically and environmentally friendly policies and silvicultural models commenced. The current management plan of the ECTF follows the traditional operation schedule approach of agriculture (short rotation, clear cutting, pure forest, etc.), which restricts the close-to-nature transformation on a larger scale. This type of forest management maintains a multi-aged stand through timber cutting at intervals (felling cycle) by establishing a diameter cutting limit. Thus far, the mixed afforestation has been conducted as an experiment, although its effect on multi-functional forestry has been demonstrated. Fig. 1 shows the percentages of total timber volume and the forest area of different forest types in the ECTF. The characteristics of the three plantation stands are summarized in Table 1.

Forest development type design: The study was designed as a case study focusing on the forest development types of long-term management goals for monoculture plantation stands and was expected to illustrate many of the possibilities and challenges related to the management of mixed stands for multiple uses. Forest development type describes the development of target forest dynamics with respect to ecological-protective, economical-productive, and social functions. Species compositions and desired stand structures and dynamics are outlined and related to site conditions using the FDTs. The desire for structural and species variation is reflected in the principles of nature-based afforestation, which combines natural succession and more traditional planting design models in planting designs that catalyse and guide succession toward the anticipated FDT (Larsen & Nielsen 2011). Species features, such as growth environment (altitude, soil type, rock), economic value, growth cycle, nutrient-preserving capability, water and soil conservation, drought endurance, fire resistance, and landscape aesthetics are closely related to the design of silvicultural models.

Our study area was afforested with the two types of pure forest (*Pinus massoniana* and *Cunninghamia lanceolata*) in 1991. The initial density of afforestation was 2,500 stems per hectare (100 per plot). With time, the number of trees in each plot was changed due to factors such as self-thinning, competition, herbivory and snow storms. However, the canopy is still dominated by the species *Pinus massoniana*, *Cunninghamia lanceolata* and some minor shrubs, including *Evodia lepta*, *Maesa japonica*, *Clerodendrum cyrtophyllum* and *Psychotria rubra*. In 2011, we designed three different tree paradigms for the given forest development types: the restoration, nature-based, and commercial paradigms (Table 2).

1. *FDT1-restoration paradigm*: Restoration has emerged and established itself concomitantly with the adoption of nature-based forest management. The restoration paradigm focuses on the consequences of design and management in terms of ecological value. The models work with species mixtures, planting distances and succession in various ways. Nitrogen-fixing, pioneer-tolerant and poor-site-tolerant species, such as *Pinus massoniana*, can be used to improve soil fertility. Diversity and the ages of trees, their density (particularly in the understory) and vegetation structures indicate a high rate of diversity experience.

2. *FDT2-nature-based forestry paradigm*: Regarding forest restoration function goals, tree species should be selected for artificial promotion in the circumstance that the stand has high diversity with tree species; for example, native tree

Table 1: Main tree species characteristics of study site observed at three FDTs.

Species	Individuals	DBH range (cm)	Basal area ($m^2 \cdot ha^{-1}$)	Tree height range (m)	Important value
Pinus massoniana	476	1.1-50	17.55	1.7-31.6	51.08
Cunninghamia lanceolata	398	5-35.1	15.22	2-22.6	14.70
Mytilaria laosensis	186	5-33.2	13.21	4.4-24.5	4.26
Eucalyptus robusta	179	5-17.2	11.22	6.5-21.8	2.46
Castanopsis hystrix	109	1.1-28	9.14	1.5-17.6	3.75
Castanopsis fissa	91	7.4-21.6	8.23	7.1-17.9	1.4

Table 2: Summary of the different trees for the given forest development types.

FDT code	Dominant species	Associated species	Forest target	paradigm	Area (ha)
FDT1	CuLa	MyLa	CuLa-MyLa broadleaf cultivate	Restoration	646.4
FDT2	CuLa	CaFi	CuLa-CaFi mixed stand	Nature-based	207.5
FDT3	CuLa	CaHy	CuLa-CaHy high-value timber	Commercial	174.2

PiMa-*Pinus massoniana*, CuLa-*Cunninghamia lanceolata*, EuRo-*Eucalyptus robusta*, MyLa-*Mytilaria laosensis*, CaFi-*Castanopsis fissa,* CaHy-*Castanopsis hystrix* species can increase biodiversity. The desired structural (horizontal and vertical) and age variations are expedited through selective-harvest-creating gaps for natural regeneration. The anticipated long-term FDT is *Cunninghamia lanceolata* (40-60%) in a group mixture with *Pinus massoniana* and *Castanopsis fissa* (30-50%), and we planted seedlings of five native species (*Castanopsis fissa, Magnoliaceae glance, Schima superba*) at 3-m spacing across the entire treatment unit of other broadleaved trees, which led to regeneration in the canopy gaps.

3. *FDT3-Commercial forestry paradigm*: According to the features of the species (e.g., shade tolerance, growth speed), the strong focus on timber production resulted in simple planting designs with geometrically defined monoculture stands (often established with a temporary nurse crop), replanting of high-value tree species (i.e., *Castanopsis hystrix, Erythrophleum fordii* Oliv.) and fast-growing and poor-site-tolerant species (*Eucalyptus robusta*) planted in straight rows. Tree species providing food for animals can improve biodiversity and the spread of tree seeds. The management aim of maintaining uniformity by lifting the canopy in one layer resulted in the regeneration of clear-cutting and planting.

The specific design of the development type included, in recent years, five aspects of logical conceptual requirements: the forest overview, the forest development objectives, the proportion of tree species, the mix type, and the management measures. As an important tool for close-to-nature forest management, forest development type is a target-forest model with a design falling between a plantation forest and a natural forest with regard to the biotope, the characteristics of the target trees (species), and the forest development process under the consideration of their own interests (Larsen & Nielsen 2011). The main idea is to optimally combine natural possibility and human need.

Silvicultural operations of stands: It is not surprising that different forest development types have different formalized silvicultural processes. Long-term silvicultural planning, in which the consequences of potential management programs can be studied, provides the basis for subsequent planning activities. However, one drawback of today's silvicultural model system is the emphasis on timber production and the limited ability to address other forest values, such as ecological and social values. The silvicultural operations can be grouped as follows: (1) clear cutting; (2) mosaic clear cutting; (3) strip intermediate cutting; (4) shelter cutting; (5) group selection cutting; (6) single-tree selection cutting, and (7) enclosure protection. In recent decades, the rapid extension of plantations has increased the need for a better understanding of the relationship between silvicultural planning and sustainable production in intensively managed plantation systems (Table 3).

Data analysis: For our August 2010 study in the ECTF, we used 60 circular plots of 400 m^2 covering the entire study area, traced out systematically. Within each plot, all of the trees with a diameter at breast height (DBH) > 5 cm were mapped. Detailed inventories for each forest were carried out from 2012, inside which all the trees with a DBH > 5 cm were individually marked, geo-referenced, and botanically identified. Plant species, number, height, and coverage were recorded from the quadrants. DBH measured 1.30 m above the ground, and tree height was measured using a Suunto PM 5/1520 PC device.

The total number of species, the number of species represented by a single individual and the diversity in each forest were calculated. We quantified the diversity of different management intensities, which was characterized based on species richness (S), the Simpson index (D), the Shannon-Wiener index (H'), and Pielou's index (J) (Magurran 1988), calculating the number of species among the observed individuals.

The mean height and diameter increments were calculated by dividing height and diameter by tree age. Age was taken from records. Cumulative volume growth was calculated for each year by the basal area multiplied by the corresponding tree height and a common form factor of 0.6: $V_t = \pi \times (\frac{DBH_t}{2})^2 \times h_t \times f$, where V_t is the volume at age

Table 3: Different silvicultural models for Chinese fir development types.

Forest development type	Dominant species	Associated species species	Silvicultural models 1	2	3	4	5	6	7
FDT1	CuLa	MyLa	√	√					
FDT2	CuLa	CaFi	√	√					
FDT3	CuLa	CaHy					√	√	√

MyLa-*Mytilaria laosensis*; CaFi-*Castanopsis fissa*; CuLa-*Cunninghamia lanceolata*; CaHy-*Castanopsis hystrix*.
1: Clear cutting, 2: Mosaic clear cutting in small area (< 5 ha), 3: Strip intermediate cuttings, 4: Shelter cutting, 5: Group selection cutting, 6: Single-tree (target-tree) selection cutting, 7: Enclosure.

Table 4: Diversity indexes of tree species under different forest development types.

FDT	Shannon-Wiener index	Simpson index	Pielou's index
FDT1	1.77	0.65	0.71
FDT2	2.37	0.81	0.54
FDT3	2.17	0.71	0.61

t, DBH_t is the diameter at age t; h_t is the tree height at age t, and f is the form factor (the ratio of tree volume to the volume of a cylinder with the same basal diameter and height). For each growth form (advanced regeneration and adult tree), the stem density and basal area data were calculated and subjected to one-way ANOVAs to examine significant differences in these variables among forests. All the analyses were performed using R software 2.15.3. The stand density of trees, DBH, height, basal area and volume were compared between the three forest development types using one-way ANOVAs.

RESULTS

Tree species richness and diversity: The total species richness in the studied plots was 21 tree species, consisting of 1,187 individuals belonging to 25 plant families. This corresponds to an average of 21 woody trees per ha. *Pinus massoniana* was the most species-rich group recorded out of all the species in the studied area, with an Importance Value Index (IVI) of 51.08, followed by the species *Cunninghamia lanceolata*, *Mytilaria laosensis*, *Eucalyptus robusta*, *Castanopsis hystrix* and *Castanopsis fissa*. The study site is dominated by two species (*Pinus massoniana* and *Cunninghamia lanceolata*) (50% of all trees). Such dominance by a few species is an indication of a less diverse forest site in terms of tree species. It is known that diversity usually decreases with the increasing dominance of a few species. The highest richness occurred in the FDT2 and the lowest in FDT1 (Table 4). In terms of numbers of genera, FDT2 was the most diverse forest, followed by the FDT1 and the FDT3. The mean values of the Shannon indices were 1.77, 2.37 and 2.17, respectively. The mean values of the Shannon and Simpson indices reflect a less diverse forest site.

Diameters and regeneration: The highest individual DBH value in FDT2 was 17.8 cm, compared to 16.7 cm in FDT1 and 15.4 cm in FDT2 (Table 5). More than 50% of the stems belonged to the DBH class < 30 cm. The corresponding mean basal area was estimated at approximately 1 m^2 per ha, and the mean volume was 13 m^3 per ha. Both basal areas were calculated based on trees>5 cm. Based on basal area cover, the first three dominant species were *Pinus massoniana, Cunninghamia lanceolata* and *Mytilaria laosensis*. The height values were 15.7 m, 16.8 m and 14.1 m, respectively. The greatest tree height was recorded in FDT2 (16.8±2.1 m), followed by FDT3(15.7±1.1 m), and the least was recorded for FDT1 (14.1±1.1 m). The mean density of the natural regeneration was approximately 214 ha^{-1} juvenile density in FDT1, 179 in FDT2 and 312 in FDT3, whereas in the FDTs, only 4% of the regeneration exceeded 1.3 m. In the three FDTs, the main species in the natural regeneration was *Cunninghamia lanceolata*, at 98%, 88% and 89%, respectively. The mean stocking density of living trees>5 cm DBH was similar across the three FDTs (893 ha^{-1}, 755 ha^{-1} and 585 ha^{-1}, respectively).

Tree volume growth: The individual mean volumes of the three FDTs were 0.332 m^3, 0.279 m^3 and 0.403 m^3, respectively. Tree volume varied during development of the different forests types. FDT3 exhibited the greatest stand volume (201.3 m^3 ha^{-1}), whereas FDT1 exhibited the lowest volume (169.6 m^3 ha^{-1}). The overall current stand volume conditions found within the forest development types differed significantly based on the different FDTs. The silvicultural operation treatments affected the timber volume of FDT3 (commercial paradigm) differently (Fig. 2). The change in results pre and post-operation clearly indicated that management influences the harvest volume, which has implications regarding the potential effects of silvicultural models on how different management goals and strategies are reflected among individual trees in response to forest development.

DISCUSSION

In this study, we designed three forest models associated with silvicultural operations that affect tree species composition and diversity in subtropical China. A major effort must be made to describe general patterns of FDTs, the management practices that create them and their ecological significance. We integrated an ensemble of polypore species into three FDTs to evaluate the implications for multi-function forest management. The importance of forest structure in driving ecosystem processes and biodiversity has been well documented, but few studies have designed forest development models that have been recommended for managing complex structures (Spies et al. 1994, Nelson & Halpern 2005). One of the greatest barriers in finding a solution is the increasing discrepancy between economic and ecological interests. We are confronted with both an economic crisis in timber production and an ecological one.

Large woods in the forest are the main targets of forest management goals. From the beginning of the process of forest establishment, only 20% of dominant trees can reach

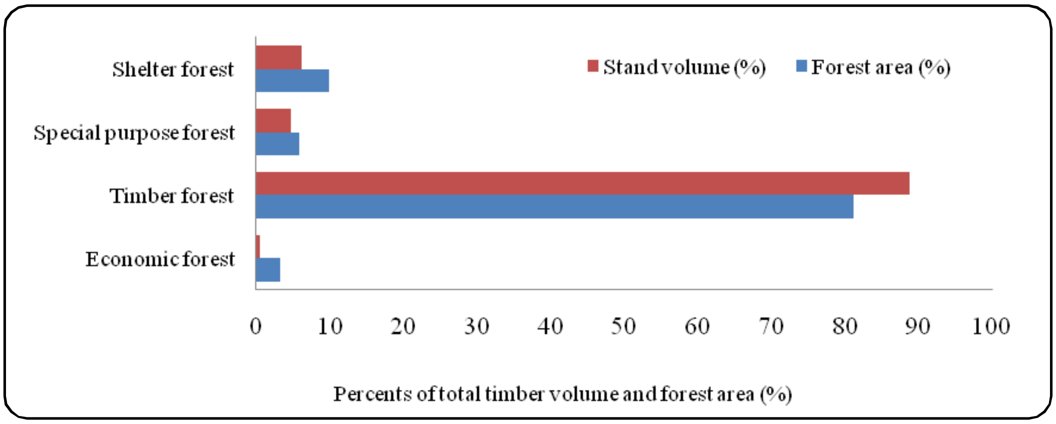

Fig. 1. Percentages of the total timber volumes and forest areas for the different forest types in the ECTF. Source: Experimental Center of Tropical Forestry, Guangxi Province, 2012.

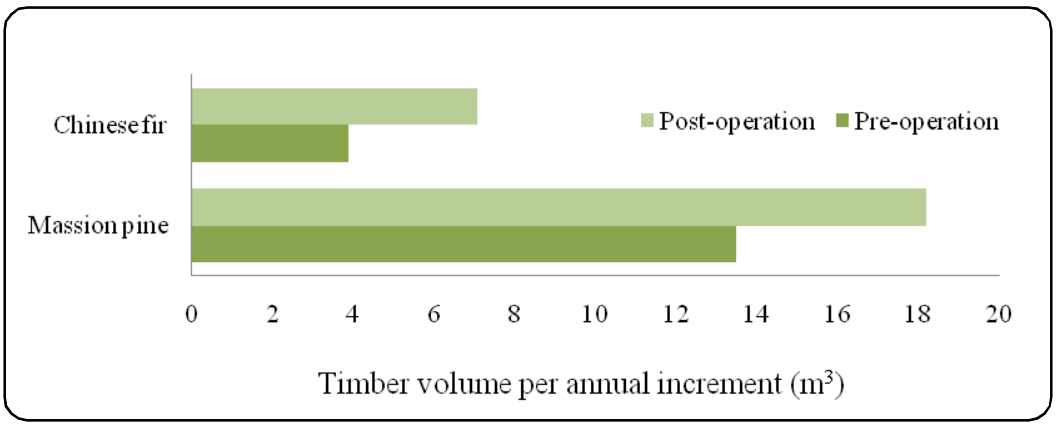

Fig. 2: Timber volume per annual increment of pre-operation and post-operation forest management (m^3).

their maximum growth height to become part of a mature stand. In this context, forest development types were developed as a concept for organizing long-term goals for close-to-nature stand development, which included the following criteria: (1) an overview of the target forest; (2) a target of forest development; (3) the proportion of tree species; (4) the types of mixtures, and (5) impending management requirements. Further cards describing the FDTs and illustrating their distribution at the forest level were successfully used to support communication between the public and professionals at hearings and public arrangements. The characteristics of FDT3 in this study are summarized in Appendix 1.

Our work highlights the importance of forest development processes, such as composition, diversity and dynamics, in influencing structural differences, a finding also reported in studies of Chinese fir plantation systems. Identifying, defining and explaining various multi-functional models and their application to common forest cover types can reveal insights for understanding the forest management processes that have generated important patterns, and each of the preceding essential elements of multi-functional forest practices can be expanded (Wollenberg 2000). Furthermore, additional data on technical aspects and production is maximized for either timber or non-timber across different forest types (Klimas et al. 2012) in terms of the defined objectives that are necessary and that should be included in the model because technology improves over time. To maximize the achievement of the defined objectives, managers and practitioners who work on multiple forest use in the tropics must consider spatial aspects in detail and, thus, inevitably influence how forests are regarded and used by these societies. From a strictly spatial standpoint, trade-offs can be optimized by segregating management objectives (Guariguata et al. 2012). In this process, inter-planted *Castanopsis hystrix* and *Mytilaria laosensis* turned out to be the young tree species with the highest importance value, and they grew better in FDT2. This would help local families increase their earnings-a practical socio-economic benefit of forest modelling. Because needs change continuously,

Table 5: Structural characteristics of the tree species of each forest development type (mean±SE).

Management type	Species	*DBH* (cm)	Height (m)	Basal area ($m^2 \cdot ha^{-1}$)	Density (ha^{-1})	Juvenile density (ha^{-1})
FDT 1	14	16.7±0.19b	15.7±1.1b	12.33	893	214
FDT 2	18	17.8±1.1ns	16.8±2.1a	15.44	755	179
FDT 3	21	15.4±0.7ns	14.1±1.1a	16.17	585	312

Different letters indicate significant differences between forest development types at the P<0.05 level based on Tukey's test. Significantly different values; ns = non-significant (P < 0.05; Student's t-test).

the principle of adaptation (i.e., considering the possible changes of the forest's original functions and ensuring the adaptability of forests that we establish) must be given a high priority (Schütz 1999).

Furthermore, this paper provides an incentive for interactive decision-making processes in designing a forest management model. Although the constraints impeding the implementation of the multiple use of forests differ little from the constraints in plans that only include timber, the required trade-offs in the former are expected to be more problematic (Nasi et al 2011). This paper did not answer the questions of stakeholder interests (Radachowsky et al. 2012) or of norms and regulations (Cronkleton et al. 2012), for example, how to design forest management models for situations of limited available resources and how the uncertainty of available resources affects optimal management planning at the landscape level (Nasi et al. 2012). Further experimental evidence on these topics would be welcome, particularly if it were to concern unexplored regions and rare forest habitats. However, some topics that may be relevant for improving conservation-oriented management have barely been explored. This is the case, for example, for (a) coppice forests, (b) the evaluation of the landscape context and forest history, (c) high-value species communities and the role of different types of forest conservation, and (d) the use of indicator species to assess the conservation importance of forests, for which further investigation should be encouraged.

CONCLUSIONS

Multi-function forest management using FDTs represents a new forest management model. The development of the multi-functional forest model analysis addresses a relevant topic of forest management that is expected by many scientists to become highly important to policy makers and experts in China. In such a context, this paper has conceptualized and compared different FDTs across contemporary monoculture forests in subtropical forest development types. The FDT provides the opportunity to integrate new perspectives and ideas that are not restricted by disciplines or style, ideas that would appear to enable a wholesome and extremely diverse use of planting design and silviculture as tools to support the creation of appealing forest management. Thus, design for FDTs, as for all forestry objectives, should be flexible to address changes in management funds. This is the most realistic expectation because the promotion of forest management in China is growing, and new, advanced silvicultural technologies are increasingly supported by the Chinese government. To be confident in its performance, however, FDT must be tested by all levels of stakeholders, including professionals, officials, foresters and farmers from different stakeholders. Nevertheless, a better understanding of multiple-use management can be achieved by evaluating more management units. Additionally, forestry training institutes must provide opportunities for farmers to spend substantial time in rural communities, where multifunctionality is not an academic concept but a reality.

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APPENDIX 1

FDT3-Large-Wood and High-Value-Oriented, Mixed, Uneven-Aged Stands of *Cunninghamia lanceolata*

1. Overview of the target forest

Group Chinese fir (*Cunninghamia lanceolata*.) dominates the main forest structure, where a few *Pinus massoniana* and other rapidly growing native species also reside. The sub-structure of the forest consists mainly of *Mytilaria laosensis* and *Castanopsis fissa*. A few *Dalbergia odorifera* and other precious broad-leaved trees are also present. The lower structures in the forest are natural *Mytilaria laosensis* and other native species, with planted precious shade-tolerant trees (*Erythrophleum fordii*, *Castanopsis fissa*) as regenerated structure. Native species are forming the main structure in the forest. The viability and regeneration of native tree species are improved constantly. The forests will ultimately become mixed, uneven-aged forests.

2. Target of forest development

For a region with flat terrain and good soil conditions, the integrated management model for timber production, considering the landscape and ecological services, should be planned and conducted. Target trees will be cultivated, and the large wood of the *Cunninghamia lanceolata* will be harvested. Through the introduction of precious native tree species (e.g., *Castanopsis fissa*) and the reasonable transfer to mixed, uneven-aged broadleaf stands, a combination of high efficiency, high productivity and high value will be realized.

2.1 Timber production

Stem log of Cunninghamia lanceolata: DBH > 30 cm, the age of the first forest generation: 24a-30a, based on the marked needs of the production types. Stem log of native rapidly growing tree species (e.g., *Mytilaria laosensis*), DBH > 60 cm, forest age ca. 36a (approximately one-half of an acacia rotation). Stem log of precious native species (*Castanopsis fissa*), DBH > 60 cm, forest age ca. 48a-72a.

2.2 Nature conservation

Priority is given to protecting natural regeneration and replanting precious broadleaf native species. Protecting naturally regenerated *Castanopsis fissa* and other usual cultivated tree species and protecting other natural resources-e.g., fungi under the forests and decayed timber are also emphasized.

3 Proportion of tree species

Target of the forest-dominant structure: *Cunninghamia lanceolata*, 60%-70%; *Mytilaria laosensis* and *Castanopsis fissa*, 20%-30%; other native tree species, 10%.

4 Types of mixtures

The group mixture is the main structure-namely, Chinese fir having a structure for selective cutting and groups with uneven-aged *Castanopsis fissa*.

5 Impending management requirements

After the target trees are defined, thinning should be achieved using surrounding competitive trees and a portion of normal trees to improve the growth conditions of the dominant treeswhen small wood is harvested. During forest operations, the naturally regenerated young trees must be protected. After such activities, *Dalbergia odorifera* can be planted in group form in the forest.