Development of silvicultural models for multi-functional forest management:
Systematic consideration and application in the tropical forestry experiment center, Southwestern China

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5. Conclusion
1. Objects and the joint study of Multi-functional Forest Management

- MFFM is an important topic with the “ecological civilization” development set by Chinese leadership now and before.

**Objects in Chinese Project**

1. Species and single tree level relationship for MFFM
   - Individual difference, completion relationship etc.

2. Stand level silvicultural models for MFFM

3. Landscape level planning techniques of MFFM

4. Integrated theory and techniques of MF to Carbon sequestration and climate changes
1. Objects of joint study on Multi-functional Forest Management


4. **Analyse der Qualität der Holzbiomasse**: Analyse von neuen Methoden für die Bestimmung der Holzhärte als Schlüsselparameter für die Holzverwendung. Durch wertführendes Analysieren können Rückschlüsse auf Brennverhalten, Biomasseproduktion und Kohlenstoffbindung sowie zu Auswirkungen auf den Nährstoffkreislauf gezogen werden.

Concept and classification of Multi-Function of Forest

Multi-functional forest is the one which more then one function or services are needed in a same time.
This is new charaters of plantation and make some changes in FM.

(1) Production function: timber, food, fuel, fiber, water etc.
(2) Regulating function: adjust air condition, precipitation, etc.
(3) Cultural Service: science and educational, entertainment, etc
(4) Life supporting function: carbon sink, wind resistance, etc

Above are the first layer for MFFM,
The next step is to make sure the main function, and other function of the stand. Then use function zone, species selection, operation intensity, and silvicultural model.
2. Present situation of plantation management in China

- Less species, coniferous species.
- Even-aged, pure forest with single structure.
- Large area with **low productivities**: average standing volume is 84 m³/ha (Germany 320 m³/ha, BMBF 2005), and plantation 45 m³/ha.
- Other problems such as forest health, vitality, and ROI (return on investment) etc. which causing Various contradictions between land utilization, society and environment. (Portucel and Silva 2008; Lu, et al 2009)
Lacking of suitable silvicultural regime

Silvicultural model is the weakest and simplest task in Chinese forest management.

Clear-cutting apply in most region, sometimes with confused technical and executive routine.

Due to lack of practical experience, the concept and technical of silvicultural model system is disordered.

Silvicultural operation classification oriented not by the overall goal but stage target, and composed by four tending operation types (lighting cutting, thinning, increment felling and sanitation felling) and harvest operation types (clear-cutting, shelterwood cutting and selection cutting).
3. Systematic Approaches of silvicultural regime for MFFM

3.1 Systematic consideration:

What is plantation? Integrity, relativity, collectivity, purpose, adaptability etc.

- Definition of objects: a new plantation concept
- Target analysis: goals and principles of multi-functional forest management
- Element and relationship: composition, index, process, action
- Structure: level, space, element, time etc.
- Function quantification: completeness, technical parameters, relational model
- etc...
3.2 Objectives definition: a new concept of plantation

- new plantation concept:

   “Plantation are: all or partly afforested by seeds or seedling, species used can be site suitable introduced or native, single or mixed, stand can be even or uneven aged, and one or multi-layer structured.

- This definition contain a series, from signal structure plantation to complexity structure near natural forest, It the expand under the target of multi-functional forest management(Figure right).
Frame of silvicultural models designing

systems thinking of the framework silvicultural models:
Constrains and pre-conditions are functional zoning, species selection, and FDT, all regulated by MF principles and aimed on managing goal.
3.3 Goal and principle of multi-functional forests

- Identical with the international standard of sustainable development

- The goal of multi-functional forest management could express as “maintain the health and vitality of forest, and developing possibly the functions of supplying, regulating, recreation and supporting.”
Principles:

Dividing the Goal of MFFM into following 7 points:

(1) Pursuing the maximization growth of forest in quantity and quality.

(2) Maintain the stability and productivity of forest.

(3) Take timber production as the dominant function and keep other service function at the same time. Give priority to material production and economic benefit, while take the environmental service as limitations (WWF 2009).

(4) Keep the high conservation value of forest at both stand and landscape level (Portucel and Silva 2009).

(5) Hold the integrity of ecosystem, including the primary community and landscape structure.

(6) Play the function of carbon sink, in order to response to global climate change (Mead 2001).

(7) Keep close cooperation with stakeholder (Portucel and Silva 2008)
3.4 Function Zoning as pre-condition for multi-functional forest management

- **Definition:** Divide the forest into different function types following regulation standards in the management unit.
- **Purpose:** Realize the classification of multi-function forest management and use different intensity operations in corresponding function types.
- **Classification based on geographical, site, biotope, preservation area etc.**

- 4 function types in Experimental center of tropical forestry (ECTF):
  1. **strict protection ecological forest zone:** forests have special function and value, need strict protect, commercial felling is forbidden.
  2. **ecological forest zone with some optimization tending:** low intensity operation activity.
  3. **Commercial forest zone with restricted felling:** low intensity felling for timber production, clear-cutting is forbidden.
  4. **Commercial forest zone:** production oriented with general operation intensity.
Methods and operation steps of Functional Zoning

Graph data

Attribute data

Basis map

Elevation

Gradient

Road

river

national defense

Protection zone

Experiment forest

Restrict condition

function zone

operation intensity map

Sighting points and Tourism area

River buffer zone
3.5 Species consideration for multi-functional forest management

- Tree species (species groups) are the basic elements for multi-functional forest management.
- Species features such as growth environment (altitude, soil type, and mother rock), economic value, growth cycle, nutrient preserving capability, water and soil conservation, drought-enduring, fire resistance, and landscape aesthetics etc. have close relationship with the design of silvicultural models.

5 types of species in ECTF: all species classified into:

1) pioneer tree species (*Eucalyptus* spp., *Mytilaria laeensis*... ... ),
2) long-life pioneer tree species (*Pinus massoniana*, *Cupressus sp. Etc.*),
3) opportunist tree species (*Styrax roseus*, etc.),
4) sub-climax tree species(*Schima superha*, *Erythrophloeumfordii*),
5) climax tree species(*Dalbergia odorifera*, *Castanopsis hystrix*).
<table>
<thead>
<tr>
<th>Code</th>
<th>Latin name</th>
<th>Target function</th>
<th>Environment description</th>
<th>Succession types</th>
<th>Regeneration estimate</th>
<th>Site condition</th>
<th>Mixed species</th>
<th>Suitable FDTs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Eucalyptus</td>
<td>Fast growing</td>
<td>Pup wood</td>
<td>1,2,3,4,5</td>
<td>1, 2, 3</td>
<td>Fertile, Good water permeable, sand soil</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Bambusa grandis</td>
<td>Defend wind</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Phyllostachys pubescens</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Citrus sinensis</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


* indicate the suitable FDTs.
Combination of function regionalization, species classification for forest development type in Experimental center of tropical forestry (ECTF)

<table>
<thead>
<tr>
<th>species</th>
<th>Code</th>
<th>Succession process</th>
<th>Altitude</th>
<th>Forest development type in Function zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucalyptus robusta</td>
<td>EuRo</td>
<td>1</td>
<td>1</td>
<td>FDT 1 EuRo-BeAl</td>
</tr>
<tr>
<td>Teektuna grandis</td>
<td>TeGr</td>
<td>1-2</td>
<td>1</td>
<td>FDT 2 EuRo-DaOd</td>
</tr>
<tr>
<td>Pinus massoniana</td>
<td>PiMa</td>
<td>2</td>
<td>1-2</td>
<td>FDT 3 TeGr</td>
</tr>
<tr>
<td>Cunninghamia lanceolata</td>
<td>CuLa</td>
<td>2-3</td>
<td>2-4</td>
<td>FDT 4 PiMa- MyLa</td>
</tr>
<tr>
<td>Mytilaria laoensis</td>
<td>MyLa</td>
<td>2-3</td>
<td>1-3</td>
<td>FDT 5 PiMa- CaFi-CaHy</td>
</tr>
<tr>
<td>Castanopsis fissa</td>
<td>CaFi</td>
<td>2-3</td>
<td>2-4</td>
<td>FDT 6 PiMa- CaHy</td>
</tr>
<tr>
<td>Betula alnoides</td>
<td>BeAl</td>
<td>1-3</td>
<td>1-2</td>
<td>FDT 7 CuLa- MyLa</td>
</tr>
<tr>
<td>Erythrophloeum fordii</td>
<td>ErFo</td>
<td>1-2</td>
<td>1-2</td>
<td>FDT 8 CuLa-CaFi-CaHy</td>
</tr>
<tr>
<td>Dalbergia odorifera</td>
<td>DaOd</td>
<td>4-5</td>
<td>1-2</td>
<td>FDT 9 CuLa-CaHy</td>
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<tr>
<td>Castanopsis hystrix</td>
<td>CaHy</td>
<td>5</td>
<td>1-3</td>
<td>FDT 10</td>
</tr>
</tbody>
</table>

Note: Succession process and shade-tolerance: 1. pioneer tree species; 2. long-life pioneer tree species; 3. opportunist tree species; 4. sub-climax tree species; 5. climax tree species.

Altitude (m): 1. <350, 2. 350-750, 3. 750-1050, 4. > 1050;
# 4. Developing silvicultural models for FDTs

**Silv. Model** is a prescription of all operation with technical parameters from forest establishment to the end-harvest. *A Life-circle management plan of forest.*

## Different silvicultural models for the given forest development types

<table>
<thead>
<tr>
<th>Forest development type</th>
<th>Dominant species</th>
<th>Associated species</th>
<th>Silvicultural models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>FDT 1</td>
<td>EuRo</td>
<td>BeAl</td>
<td>*</td>
</tr>
<tr>
<td>FDT 2</td>
<td>EuRo</td>
<td>DaOd</td>
<td></td>
</tr>
<tr>
<td>FDT 3</td>
<td>TeGr</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>FDT 4</td>
<td>PiMa</td>
<td>MyLa</td>
<td>*</td>
</tr>
<tr>
<td>FDT 5</td>
<td>PiMa</td>
<td>CaFi</td>
<td>*</td>
</tr>
<tr>
<td>FDT 6</td>
<td>PiMa</td>
<td>CaHy</td>
<td></td>
</tr>
<tr>
<td>FDT 7</td>
<td>CuLa</td>
<td>MyLa</td>
<td>*</td>
</tr>
<tr>
<td>FDT 8</td>
<td>CuLa</td>
<td>CaFi</td>
<td>*</td>
</tr>
<tr>
<td>FDT 9</td>
<td>CuLa</td>
<td>CaHy</td>
<td></td>
</tr>
<tr>
<td>FDT 10</td>
<td>MyLa, CaFi, BeAl</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>FDT 11</td>
<td>ErFo</td>
<td>BL species</td>
<td>*</td>
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<tr>
<td>FDT 12</td>
<td>ErFo</td>
<td>CaFi, CaHy</td>
<td></td>
</tr>
</tbody>
</table>


* indicate the suitable FDTs.
FDT Euca-DaOd 3: *Eucalyptus robusta - Dalbergia odorifera* succession management type

FDT Euca-DaOd 3: *Eucalyptus robusta - Dalbergia odorifera* succession management type, main storey is *Eucalyptus* and *Dalbergia odorifera* is planted under them.
4.1 Model of clear cutting (the highest managing intensity)

Operating requirement in ECTF

- the operation is restrained by some terrain condition:
  1) flat terrain with gradient $\leq 5^\circ$, the largest area of clear-cutting < 30 hectares.
  2) low mountain or hill with gradient between $6^\circ$ and $15^\circ$, the area < 20 hectares;
  3) gradient between $15^\circ$ and $25^\circ$, the area < 5 hectares.
  4) Moreover, clear cutting with continuous band felling blocks is applied where the gradient is larger than $25^\circ$, dividing the cutting area into 3-5 banding (200 meter width), cut these blocks in order (Figure below).

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**Figure:** Diagram showing banding felling blocks with felling direction, point of uploading, and log transportation.
4.2 Mosaic clear cutting

Concept:

Mosaic clear cutting, and the cutting area is less than 5 hectares. The largest width and length of cutting banding are 100 and 500 meters when the gradient is more than 15°. Reforestation in the cutting blocks should be finished in two years after the felling.

- The cut area is strict less than 5 hectares.
- The cutting blocks should be arranged like mosaic grids, and the regeneration (artificial or natural) in the cutting blocks can be protected by the adjacent stands (Figure).
- The width of retained banding is more than the average stand height; the boundary of cutting block should be selected where stands have better wind resistance.

Tree species consideration and Function regionalization: suitable for the III and IV function zones.
4.3 Strip intermediate cutting

**Concept:**
Harvest the mature woods in banding, and use the gap effect to promote the natural regeneration. Different from mosaic clear-cutting, the banding width of this operation is designed as 1.5-2 times average tree height. Strip cuts are used to harvest a stand over a period of three to seven years by removing several strips rather than harvesting the entire stand at once. Strip cutting was developed to take advantage of natural seeding from the leave-strips.

**Tree species consideration:** native broad-leaved tree species with fast or medium-fast growing feature.

**Function regionalization:** this model is suitable for the II and III function zones.

**Operating requirement:**
- Felling a banding (width=1.5-2 times average tree height) in stand, and use artificial assistant regeneration or natural regeneration the restore the cutting-blank.
- It can be seemed as a silvicultural model for high-quality woods.
- According to characters of natural regeneration, the target of harvest should change together with the promotion and expansion of regeneration.
4.4 Shelter cutting

**Concept:**

Also known as the 'Shelter wood system', is a silvicultural model in which over story trees are removed in a series of cuts designed to achieve a new, even-aged stand under the shelter of remaining trees (DeLong 1995).

The number and size of trees removed in this system is based on the amount of light reaching the forest floor required to regenerate a cohort of intolerant and/or mid-tolerant species, while leaving sufficient basal area and trees per area to mitigate harmful environmental conditions on the forest floor.

**Tree species consideration:** Medium fast-growing species such as *Mytilaria laoensis, Castanopsis fissa* and *Betula alnoides*.

**Function regionalization:** this model is suitable for the II and III function zones.

- Preparatory cutting: Number and accumulation are 20% and 25%～30% of the whole stand respectively. The canopy density is 0.6-0.7 after this operation.
- Seed cutting: Number and accumulation are 30% and 10%～25% respectively. The canopy density is 0.4-0.6 after this operation.
- Accretions cutting: Number is less than 40%, and accumulation is 10%～25%. The canopy density is 0.24-0.4.
- Cleaning cutting: Remove all residual canopy trees once the secondary generation grow up.
4.5 Group selection cutting

Concept:

Continuous cut the inferior individuals or mature individuals in group. Under this system, a number of 'groups', or small openings created by the removal of several adjacent trees, are created in complement to the harvest of scattered individual trees. If the groups created are large enough, and if seed-bed conditions are favorable, this can allow species which are intolerant of shade to regenerate (Anderson et al 1990; Wedeles et al 1995; Nyland 1996).

Group selection is designed to mimic larger, multi-tree mortality events, which in some environments may represent natural disturbance regimes.

Tree species consideration: shade tolerant tree species such as Erythrophloe umfordii, Dalbergia odorifera, and Castanopsis hystrix.

Function regionalization: this model is suitable for the II and III function zones.
4.6 Single tree selection cutting

Concept:
Cut the individual trees of mature and/or unhealthy. Leaves most of the trees and a variety of age classes to grow and regenerate an uneven aged forest. Single tree selection results in a stand that is composed almost entirely of species with moderate to high shade tolerance. Single-tree selection is commonly used where visual quality is a strong concern or recreational values are high (Klinka et al. 1990; Navratil 1995).

Tree species consideration: shade tolerant tree species such as *Erythrophloe umfordii*, *Dalbergia odorifera*, and *Castanopsis hystrix*.

Function regionalization: this model is suitable for I and II function zones (gradient between 25°~35°), and could also use in the place where fragile ecological environment and serious soil and water loss for the aim of ecological restoration. It can transform the forest to near-natural forest.
4.7 Enclosure protection

(1) Concept:
Leave the forest with no felling activity; only make some tending operation on target trees (select and mark target tree, cut rattan etc.)

(2) Operating requirement:
This model main use in the places where the terrain is steep (gradient>45°) and complexity. In these regions, forest is difficult to recovery after it is destroyed which causing a series of ecological problems such as soil erosion, vegetation deterioration.

(3) Additional remarks:
Tree species consideration: usually shade tolerant tree species
Function regionalization: this model is suitable for I (gradient >45°), and could also use in the place where fragile ecological environment and serious soil and water loss for the aim of ecological restoration.
An Example for Silvicultural models application

1) Subcompartment analysis
   Forest type: *Pinus massoniana* immature timber
   Average DBH: 19.7 cm
   Average tree height: 14.2 m
   Accumulation: 83.3 m³
   Density: 600 N/hm²
   Elevation: 401 meter
   Gradient: 30°
   Soil thickness: 150 cm
   Mother rock and soil: magmatic rock, latosolic red soil.

2) Function regionalization
   Type III: Commercial forest zone with restricted felling, low intensity felling for timber production, clear-cutting is forbidden.

3) Target analysis
   “timber production—landscape—ecological consideration”

4) Species configuration and FDT
   FDT 5 PiMa- CaFi-CaHy

5) Silvicultural model
   *Group selection cutting*
FDT 5 : PiMa- CaFi-CaHy

Content
1. Forest scene
2. Development goal
3. Timber production
4. Nature conversation
5. Species mixing ratio
6. Mixing type
7. Silvicultural model: Group selection cutting
8. Recent operation methods
5. Conclusion

1. Under the new concept of plantation, a series of forest types from Simple Structured fast-growing plantation to complex structured forest are involved in MFFM.

2. In a systematic consideration of MFFM and based on the control of operation intensity, 7 key silvicultural models are defined to meet the need of rich form of plantation management.
Further study on parameters of silv. Model
Thank you for your attention!