Ecosystem Management originated from management and utilization of the traditional forest resources (Christensen et al. 1996). This management method has been widely recognized because of growing awareness of environmental degradation and resource depletion. Ecosystem management advocates use of the principles and methods to manage the natural environment and resources with a view of maintaining balance between natural resources and socio-economic systems. However, ecosystem management is not only applicable to the management of natural resources, but has also developed into an integrated resource management system targeting the structure, function and processes of sustainability (ecosystem, social and economic). This approach ensures that ecological services and biological resources have not been irreversibly consumed due to human activities, and achieves long-term sustainability (Zhao et al. 2004; Yang et al. 2004). Ecosystem management has rich scientific content and pressing social needs and potential applications (Yu 2001). Forest ecosystem management has formed a robust theoretical framework in China (Liao and Zhao 1999; Yang and Jiang 2003; Zhou et al. 2007), and has promoted the formulation of relevant national laws, regulations and policies.

The rubber tree is a typical tropical economic crop that produces natural rubber, an important industrial raw material and strategic resource. The natural rubber ecosystem has been degenerated due to a long term focus on economic benefits, and a new method for the management of natural rubber is needed. The ecosystem management provides a new approach for natural rubber industry ecosystem management. This method can guide the production and management of the natural rubber industry, and this will benefit the healthy and sustainable development of the natural rubber industry.

1 Natural rubber industry ecosystem and industry ecosystem management

The natural rubber industry ecosystem is composed of the biotic environment (producers, consumers and decomposers) and the abiotic environment (natural environment, economic and social environment). Relationships between ecosystem elements are complex (Fig. 1). Sustainable survival and development of the system largely depends on its ability to adapt to the change of the ecological environment.

The natural rubber industry ecosystem is a typical compound ecosystem (Jiang and Wang 2004), and its management can not merely focus on the economic benefits but should take into full account the coordination of ecological, economic and social benefits for sustainability, health and industry development.

2 Ecosystem management of natural rubber in Hainan

Hainan is a tropical island and the second largest island in China, the environment is good for growing rubber trees.
After decades of effort, Hainan has become the largest production and supply base of natural rubber in China and rubber forest is one of the largest artificial ecosystems on the island (Jiang and Wang 2004).

2.1 Basic principles of management
2.1.1 The overall optimization principle
To create a natural rubber industry ecosystem with economic efficiency, ecological harmony and social civilization based on harmonization of the natural ecological environment with the overall development objectives of the natural rubber industry.

2.1.2 The regional differentiation principle
The resources distribution and environmental characteristics are differ at different spatial levels of the ecosystem. Therefore, a development strategy of the natural rubber industry should be according to environment characteristic of the industry itself, and based on full study of the functional status, problems and development trends of the regional ecological elements, and overall consideration the requirements of the national strategic development plan.

2.1.3 The pioneering adaptation principle
Any industry development has its particular niche. Resource scarcity leads to improved the capability of organisms in external development and expansion environmental capacity. Successful development of a natural rubber industry needs expansion resource niche and adjustment the needs niche that allows for transformation and adaptation to the environment.

2.1.4 The coordinated symbiosis principle
Coordinated symbiosis is a process of cooperation and coexistence, and mutual benefit of different type subsystems. The natural rubber industry ecosystem consists of multiple elements, media, layers and niches, and its subsystems and ecologic elements are mutually influenced and restricted. The relationship of the subsystems and various elements in each subsystem should be handled correctly to ensure the benefits of all subsystems.

2.1.5 The complementary self-generation principle
When the functions within the system break down, some components of the system expand to become dominant and cause the system to run rampantly or become deformed, and some components are able to compensate or replace the original function in order to stabilize the overall system. Attention should be given to the role of these two responses in the regulation of the natural rubber industry ecosystem. The functions of some components in the system should be compensated more than expanded when the system needs to be stabilized, but expanded further when required.

2.1.6 The diversity and dominance principle
Diversity ensures the stability and vitality of the system, and dominance ensures the development strength of the system. The natural rubber industry ecosystem will maintain strong and rigid development only if it contains predominant components and competitive products. This system should have a multi-element structure and diverse products to enhance flexibility and stability and reduce risks. A reasonable match between dominance and diversity is a prerequisite for sustainable development of the natural rubber industry.

2.1.7 The recycling principle
The dynamic equilibrium of the matter and energy cycle is a basic function of any ecosystem. Natural ecosystems form a stable and efficient circulation system in long-term ecological succession, and guaranteeing healthy development of the system. Sustainable development of the natural rubber industry ecosystem must follow the laws of nature and the theory of ecological balance, and requires planning of the use and reuse of resources.

2.2 Management steps
Ecosystem management of the natural rubber industry applies the principles of ecology, economics, sociology, management and other multi-disciplinary to guarantee the health and stable development of the ecosystem. Specific management steps as shown below (Fig. 2).

2.2.1 Describe the current state of the system
To investigated the current state of the natural rubber industry ecosystem, classified and analysis for the information, and provide a basis for identifying management target and draw up of management program.

2.2.2 Identify management targets
First level target is to achieve sustainable development of the natural rubber industry ecosystem; the second level target is to realize a good ecological environment, rapid economic development and social stability. Specific targets include to maintence biological diversity, increase the rate of return on investment, and improve living standards.
2.2.3 Identify stakeholders and manage objects

Identifying stakeholders is an essential step when implementing ecosystem management of the natural rubber industry. Primary stakeholders are those that very dependent on system resources and may become the most active force, such as producers and consumers. Secondary stakeholders are not usually very dependent on resources but are powerful groups or individuals such as governmental organizations, environmental organizations and vendors.

2.2.4 Draw up management plan and organize implementation

Management plans clarify the content and measures of management, personal responsibility and obligations in ecosystem management, and makes the management work have rules to follow. Ecosystem management plan should consideration to ecological, economic and social benefits, to ensure that health and sustainable develop of the natural rubber industry.

2.2.5 Tracking, monitoring and evaluation

Ecological system is extremely complex and constantly changing, if we want to obtain relatively continuous and comprehensive information that it must to tracking and monitoring the ecosystem. Through evaluation can integrated the independent information to diagnose system problem and find out the main factors of effect industrial development, and to provide scientific basis to adjust the management strategy.

2.2.6 Adjust and optimize management program

Ecosystem management plan is not immutable, and should change at the right times according to ecosystem characteristics, natural conditions and human activity.

2.3 Management approaches

2.3.1 Ecological engineering of rubber plantation

Long-term rubber cultivation practices shows that irrational planting structures cause blockages of ecosystem energy flow, material flow and information flow. We designed methods of ecological engineering for Hainan rubber plantations according to ecological engineering design principles, traditional agro-ecological engineering methods and rubber plantation experience (Fig. 3).

Soil and climate are the main environmental factors affecting the growth and development of rubber trees. Especially low temperatures limit the growth and yield of the rubber tree in Hainan. Therefore, agro-climate analysis and regionalization are most important in selection and evaluation of rubber planting environments. Two main principles should be followed: (i) more than 30 years of meteorological data should be considered, since the rubber tree is a long-term crop; (ii) meteorological indices of selected planting sites should be as similar as possible to the place of origin. Temperature and moisture related to chilling injury are the main indicators for climatic regionalization of the rubber tree when selecting appropriate sites.

Selection and release of desirable rubber clones is one of the main ways for China’s rubber plantation industry to succeed in a relatively short period of time. The specific measures include: local field trial and local extension of the clones; cultivation of multi-clones, planting clones in the line of local conditions; rubber planting recommendation; and implementation of appropriate agricultural technical standards and measures.

Many years of rubber planting have shown that shelter-forest can reduce natural disasters and protect rubber plantations, and it is essential to construct wind belt network in rubber plantations areas. The protective effect of the shelter-forest belt depends on the structural configuration and the direction, width and distance between the shelter-forest. The environment in natural rubber planting areas are complex, and the climatic conditions vary greatly. Therefore, shelter-forest planning must be done in accordance with local conditions. The wind belt direction needs to be based on the major wind direction.

Intercropping in rubber plantations can establish a stable
artificial multi-layer ecological community to allow the rubber plantation to form a healthy circulatory system and improve the ecological environment for growth of the main crop and intercrop. Intercropping of cover crops in rubber plantations has numerous advantages, such as conserving soil and water, increasing soil nutrient content, improving soil physical properties, maintaining and improving biodiversity of the rubber plantation ecosystem, promoting the growth of the rubber tree and increasing yield. Common cover crops include cereal, oil crops, potatoes, economic crops and green manure crops. The common cropping system includes a one-year, two-year or three-year rotation system.

Annual rainfall is high and concentrated in Hainan’s rubber plantations, and hard to be absorbed completely by the soil in a short time, causing soil erosion. We must focus on water and soil conservation engineering when the rubber tree planted. The main technical measures for soil and water conservation engineering in rubber plantation include: contoured planting on slopes, building benches and terraces on gentle slopes; terraces should be constructed in the area with smaller rainfall intensity, very strong water permeability in soil, or hill slope of less than fifteen degrees; contoured terraces should be built in the area with higher rainfall intensity, poor water permeability in soil, or steep slope, but without radiant cooling in winter.

Fertilization management significantly affects tree and bark growth of high yield clone rubber trees. Available nutrients will be reduced with the growth of the rubber tree, particularly in the peak period of stem thickening and height growth, and the rubber tree needs supplementary fertilizer through nutrient diagnosis. Tapping will inhibit growth of the rubber tree, the greater intensity of tapping the more obvious inhibition of the growth of the rubber tree. Especially since stimulated tapping has been practiced, it is very important to good tend and enhance fertilizer for the rubber trees.

2.3.2 Natural rubber industry ecosystem regulation

The basic principle of ecosystem regulation is to regulate ecological structure and relationships across different time and spatial scales, and to ensure sustainability, health and stability of ecosystem function. Specific regulation of natural rubber industry ecosystem in Hainan are divided into natural regulation and artificial regulation according to the relationship of the rubber industry ecosystem and regional ecological system. Natural regulation includes regulation advantages and disadvantages of nature force, and regulation of temperature, moisture and biological competition. Human behavior affects various aspects of the compound ecosystem, such as resource utilization and economic development and social development trends. Artificial regulation includes technical regulation and institutional regulation.

Structural regulation of the natural rubber industry ecosystem includes: regulate spatial structures of the rubber planting; acceleration replanting of the old rubber plantation to adjust time structure of rubber plantation; adjust variety structure of the rubber planting; make full use of existing factories, and adjust processing layout of the natural rubber.

Institutional regulation of the nature rubber industry ecosystem includes: break the barriers between departments and sectors, establish basic idea, approaches and methods; establish scientific and rational structural framework of industrial business entities on the basis of reforming existing systems; emphasis on building the institutional network, establish and improve the management, market circulation, finance and social service institutions involved in industry, and develop the market of futures transaction and e-commerce transaction; build the prototype of targeted institutional system model, adjust targets and measures in the next phase, improve the institutional system of the natural rubber industry.

Functional regulation includes eco-physiological regulation and biological regulation strategies. After a new tapping system was adopted, physiological processes and material flow processes changed significantly, and material circulation was significantly faster, accelerating nutrient depletion of the rubber plantation ecosystem. This forces us to seek a new functional regulation strategy, and to improve the fertilizer formula and fertilizing mode. In addition, biological regulation should also adopted, and strengthen research in ecological adaptability and service function of the inter-crops, and other areas of the biological regulation should also to research.

2.3.3 Ecosystem health evaluation and sustainable management

Natural rubber industry ecosystem health mainly reflects the planting structure, energy flows, and ecological services. Biodiversity plays an important role in maintaining integrity and stability of the ecosystem. Biodiversity is lower in the rubber plantations in Hainan State Farms than in natural ecosystems. Biodiversity is different in rubber plantations due to differences in rainfall, soil fertility, plantation age and human activity. The general trend was higher rainfall and more abundant biodiversity in rubber plantations, biodiversity declines with the age of the rubber forest, and diversity index shows a significant positive correlation with soil fertility (Liu 2003).

Accounting and analysis of ecological footprint to evaluate regional sustainable development has become central in ecological economics. The results of accounting and analysis of the natural rubber industry ecosystem shows that the Hainan State Farms had a per capita ecological footprint of 0.44038 ha and per capita ecological capacity of 9.11196 ha, available per capita ecological footprint of 8.01852 ha and per capita ecological capacity of 7.57814 ha. Hainan state farms had a per capita ecological footprint surplus of 5.71852 ha as compared with the per capita ecological footprint of the world and a per capita ecological footprint surplus of 6.69352 ha, against the per capita...
ecological footprint of the whole country. This indicates that
the natural rubber industry ecosystem in Hainan state farms
is healthy and sustainable in economic development terms.

The artificial forest ecosystem replaced of the natural
forest ecosystem conforms to the law of value transfer in
ecosystem service functions. Ecosystem service functional
value in economic and social systems will be amplified
several times or even scores of times through input of
human labor, material and energy. The total value of
ecosystem service function in rubber plantations in Hainan
State Farms are lower than those of montane rainforest,
the lower part of which can be regarded as natural input
and bring about powerful economic and social service
function value (Table 1). The ratio of the sum of economic
service functional value and social service functional value
to natural input is 21:1 for rubber plantations managed in
Hainan State Farms.

Ecological audits reflect relationships between the
economic growth of natural rubber industry with the
resource environment and social progress. Ecological
audits of the natural rubber industry in Hainan State Farms
shows that natural rubber plantations have strong ecological
service functions in soil conservation, water saving, fixing
of carbon dioxide and the release of oxygen (Table 1).
The natural rubber industry in Hainan State Farms mainly
relies on energy input and affected by the environment at
lower levels, and the ratio of the energy input to currency is
lower than in other areas of the country. This is to say that
the natural rubber industry has relatively good economic
benefits.

3 Prospects

Ecosystem management research has mainly focused on the
theoretical study in ecological economics and policy. Little
practical study into the specific technical and management
measures has been done. Ecosystem management of natural
rubber plantations is a huge systematic project involving
ecological, economic and social factors. Long-term
monitoring and basic experiments will aid the effective
management of natural rubber industry ecosystems.

3.1 Research on regional environmental evolution after
large-scale rubber planting

From the 1970s to 80 there was an academic debate about
the rubber planting impact on the ecological environment
in China (Luo et al. 1983; Huang and Zhang 1983). By the
end of 1980s, UNDP experts investigated rubber plantations
in Hainan, and held that large-scale planting of natural
rubber in Hainan was a successful example of industrial
restructuring in tropical regions. Driven by the lifting
of agricultural and rubber taxes, strong market demands
for natural rubber, and subsidies for improved varieties,
some rubber farmers disregard cultivation techniques of
the rubber tree by planting rubber at an extremely high
elevation, latitude and slope. Arguments about the impact
of planting rubber on ecosystem services have now arisen

(\(Du et al. 2008\)). Similar debates have taken place in other
natural rubber producing countries. However, research
conducted by Li et al. (2009) and Chen and Peng (2010)
show that large-scale planting of rubber does not negatively
impact the regional environment as long as appropriate
cultivation measures are implemented. Long-term and
large-scale substitution of natural vegetation with rubber
plantations will give some impact on the structure, function
and ecological process of the regional ecosystem and the
regional ecological environment will also evolve, but this
evolution, either positive or negative, also attracts wide
attention. With continued evolution of the ecological
environment we still need to strengthen research the
impact of large-scale planting of rubber on the regional
ecosystem, and explore appropriate methods for ecosystem
management.

3.2 Research on impact of global climate change on the
rubber plantations

For nearly 100 years, global average temperature has
experienced fluctuations but in general shows an upward
trend. Global warming will cause redistribution of global
rainfall, glacier and frozen soil melt, sea level rise, and so
on, harming the balance natural ecosystems. The IPCC have
predicted that the global average temperature will rise about
1.4–5.8°C by the year 2100. According to this prediction
the global temperature will change tremendously compared
to the past 10 000 years, and impact the global environment.
Extreme weather events will occur more frequently under
global climate change, the regional environment for rubber
planting areas will change and the ecosystem management
of the rubber plantations will faced more challenges and
technical problems.

3.3 Research on utilization of the rubber plantation
ecosystem niche

Rubber plantations have an immaturity of seven years,
and their canopy is not closed in the first three years, so

<table>
<thead>
<tr>
<th>Values</th>
<th>Service functional value index</th>
<th>Total value (CNY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecological value</td>
<td>Water conservation</td>
<td>7.70×10^8</td>
</tr>
<tr>
<td></td>
<td>Soil conservation</td>
<td>0.70×10^8</td>
</tr>
<tr>
<td></td>
<td>Environmental purification</td>
<td>1.03×10^8</td>
</tr>
<tr>
<td></td>
<td>Sand sedimentation and fixation</td>
<td>1.11×10^8</td>
</tr>
<tr>
<td></td>
<td>Produce organic matter</td>
<td>2.50×10^8</td>
</tr>
<tr>
<td></td>
<td>Biological diversity maintenance</td>
<td>1.18×10^8</td>
</tr>
<tr>
<td>Economic value</td>
<td>Latex</td>
<td>2.48×10^8</td>
</tr>
<tr>
<td></td>
<td>Timber</td>
<td>3.03×10^8</td>
</tr>
<tr>
<td>Social value</td>
<td>Increase employment opportunities</td>
<td>3.40×10^8</td>
</tr>
<tr>
<td></td>
<td>and promoting scientific and technological progress</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>121.43×10^8</td>
</tr>
</tbody>
</table>
intercropping can be practiced using the time and space niche of rubber plantations. However, the space of the rubber plantations is basically unused and the potential resource has not been explored after rubber plantations closed their canopy or opened for tapping at the age of eight years. It is necessary to take full advantage of this ecological niche to build a multilayer compound ecological system in rubber plantations and strengthen research on ecosystem management of the natural rubber industry.

3.4 Research on carbon sequestration and carbon trading of natural rubber

The carbon cycle is an important factor in the impact of climate change. A market mechanism of carbon trading should be established to adjust total emissions of greenhouse gases in the world. Major natural rubber producing countries such as Malaysia, Indonesia, Thailand and India have been conducting research on carbon sequestration and carbon trading of natural rubber (Thomas et al. 2002; Rodel 2002). China has also carried out basic research on carbon sequestration of natural rubber (Jiang and Wang 2002; Song and Zhang 2010; Wang et al. 2011). For carbon trading of natural rubber in China, we need to find out the basis of carbon sequestration of the natural rubber, and data reporting and monitoring systems need to be established.

References


天然橡胶产业生态系统管理

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摘 要：天然橡胶产业生态系统管理是实现天然橡胶产业可持续发展的生态途径。本文在系统分析天然橡胶产业生态系统结构和功能的基础上，以海南为例，提出了天然橡胶产业生态系统管理的基本模式，其中重点探讨了天然橡胶产业生态系统管理的基本原则、管理步骤及管理途径，旨在为天然橡胶产业生态系统健康和可持续发展提供理论依据和实践指导。

关键词：生态系统管理；天然橡胶产业；胶园生态工程；可持续管理