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Regeneration and Development of Native Plant Species in Restored Mountain Forests, Hainan Island, China

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Natural regeneration was studied at 7-year-old native species regeneration sites on abandoned lands in central mountain areas of Hainan Island, off China's southern coast. Using linear sampling, 7 belt transects (each 5 m in width, with a cumulative length of 2000 m) were established and then subdivided into 400 plots (5 m × 5 m). Plant regeneration was surveyed on each plot. For each woody species, the life stage, mature height, dispersal mode, and successional status were assessed. The regenerating woody community at the sites was found to be species-rich, with 40 species identified. However, the community was dominated by a subset of secondary forest pioneer species, such as Liquidambar formosana, Aporosa chinensis, *and* Lannea grandis, *whereas a number of prominent primary forest species, such as* Castanopsis hainanensis *and* Machilus chinensis, *were almost completely absent. Clustering analysis divided the 40 species into different functional groups: those with a primarily economic function, a primarily ecological function, or both. A schematic illustration of the distribution of the 40 vegetation species over a larger area was created to show the functions and dominant status of species in the plots. This diagram can provide a clear reference for practical planning of forest rehabilitation. The results indicate that self-restoration has been successful in promoting native forest development to a certain extent, but that there is a need for management interventions in restoring vegetation species diversity and functional complexity, especially where natural successional processes are hampered by artificial or natural disturbances.*

Keywords: *Linear sampling; functional groups; importance value; ecological niche; restoration strategy.*

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Introduction

Tropical forests are increasingly subject to forest conversion and degradation (Chapman and Chapman 1999), with a subsequent loss of species diversity and ecosystem services. At local and regional scales, land-use changes are among the most immediate drivers of loss of species diversity. Intensification of land use, especially the conversion of natural ecosystems into agro-ecosystems, is believed to both change the composition and reduce the diversity of biological communities (Van der Putten et al 2000).

Hainan Island's tropical forests have, in the last 100 years, undergone deforestation, degradation, and recent reforestation (Zhai et al 2013). Through the Sloping Land Conversion Program, approximately 170,000 ha of forest were replanted by the end of 2008, increasing Hainan's forest cover by 5.2%, but much of the replanted land consisted of rubber and pulp plantations, which represent a threat to Hainan's natural tropical forests (Zhai et al 2012; Zhang and Zhu 2012). These transitions have major impacts on biodiversity.

Because preserving natural forests is a possible method for maintaining tropical forest diversity, the conversion of abandoned land into natural secondary forests can greatly contribute to the maintenance of biodiversity (Aide et al 1995). From an ecological perspective, native forest regeneration can be a suitable tool for community succession and development during the restoration process (Aide et al 2000; Camargo et al 2002; Cusack and Montagnini 2004; Chazdon 2008), but natural regeneration of secondary forests on degraded tropical lands is often a slow and uncertain process, impeded by factors such as human and livestock disturbance, unfavorable microclimatic conditions, exhaustion of soil seed banks, and low rates of seed input from nearby forests (Parrotta et al 1997; Holl 1999; Shono et al 2006). A sound understanding of the vegetation dynamics and the factors that control these dynamics is needed to effectively

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manage or restore secondary forest in degraded regions (Jansen 1997).

To grasp the dynamics of the regeneration and development of vegetation during the conversion of abandoned land into secondary forests and then use this information to guide further assisted regeneration in tropical mountain forests in Hainan Province, we documented the changes in species richness, composition, and structural diversity of the plant community. The ecological niche of different tree species was analyzed to describe how members of a population compete for limited resources and how this, in turn, alters conditions on the abandoned land (Lomolino and Brown 1998; Guariguata and Ostertag 2001).

In addition, the study took species functions into account. Long-lived tree species that can self-renew and grow continuously (with both saplings and seedlings present in the restored forest) were regarded as having an *ecological* function, increasing the elasticity of the ecosystem during secondary succession. High-value indigenous tree species were regarded as having an *economic* function, improving the economic value of the forest and generating greater economic interest from local residents (Liu et al 2011). Some tree species have both functions. The results of this study can contribute to the development of a more effective restoration strategy that considers natural ecosystems and forest economics.

Materials and methods

Study site

The study site is located in the village of Shenzhuang in Baisha County, Hainan Province, China (latitude 19°07′N to 19°08′N; longitude 109°22′E to 109°23′E; elevation 300–600 m above sea level). This region has a tropical monsoon climate. The mean annual air temperature varies between 22.5°C and 25.6°C, and the minimum and maximum temperatures are 17°C and 36°C. Annual precipitation ranges from 1500 to 2000 mm, with an average of 1750 mm (Meng et al 2010). The dominant parent rocks of soils in the study area are granite and sandstone, and the soil supporting the forest is primarily a mountain lateritic red earth (Jiang et al 2002; Liu et al 2011).

The study was conducted in an early natural secondary forest with an area of 7 ha. Before the early 1950s, the site was covered with tropical primary monsoon rain forest dominated by species in the families Dipterocarpaceae, Sapindaceae, Annonaceae, and Burseraceae. From 1952 to 2000, the site was clear-cut and replanted as a rubber plantation. After 2000, the rubber trees were cut down because of their decline in production. Then the area was enclosed and conserved under the Natural Forest Protection Project of the Hainan Forestry Bureau (Li et al 2008). Meanwhile, other types of forest (such as watershed protection forest) were also zoned and protected. The study site has been abandoned since the forest closure.

Natural recruitment survey

Natural recruitment in the restored forest was studied with systematically spaced linear sampling (Barnard 1950; Wyatt-Smith 1995). Seven belt transects that were 5 m wide and had a cumulative length of 2000 m were established on 1 ha of abandoned land (Figure 1). The horizontal distance between each belt was 100 m. The belts were subdivided into 400 plots, each 5 m^2 in area (Table 1). All woody plants with height ≥30 cm in these plots were measured and tagged. Regeneration species were grouped based on their Dbh (diameter at breast height). For those in group 1 (Dbh ≥ 5 cm), the species name, Dbh, and height were noted. For species in group 2 (Dbh < 5 cm), only species name and number were noted.

Species with a height <30 cm were not surveyed. For each species, the size at maturity, ecological characteristics, self-renewability, longevity, and timber value were estimated based on a literature survey (Chen 1964, 1965), and these characteristics were used to separate the species into the "economic" and "ecological" functional groups described earlier.

Floristic diversity, species importance value, and ecological niche

Species diversity is an important aggregate indicator that reflects the effect of secondary forest restoration in tropical regions (Connell 1978; Wright 2002). In this study, each regeneration plot per belt was considered to be an individual community. Four diversity indices, with different roles with respect to diversity assessment, were calculated as follows (Zhang 2004):

$$\text{Shannon} - \text{Wiener index:}$$

$$H = -\sum_{i=1}^{S}(P_i \ln P_i), \text{ where } P_i = \frac{N_i}{N}. \quad (1)$$

$$\text{Richness index: } D = \frac{S-1}{\ln N}. \quad (2)$$

$$\text{Evenness index: } E = \frac{H}{\ln S}. \quad (3)$$

$$\text{Dominance index: } \lambda = -\sum_{i=1}^{S}[N_i(N_i-1)/N(N-1)]. \quad (4)$$

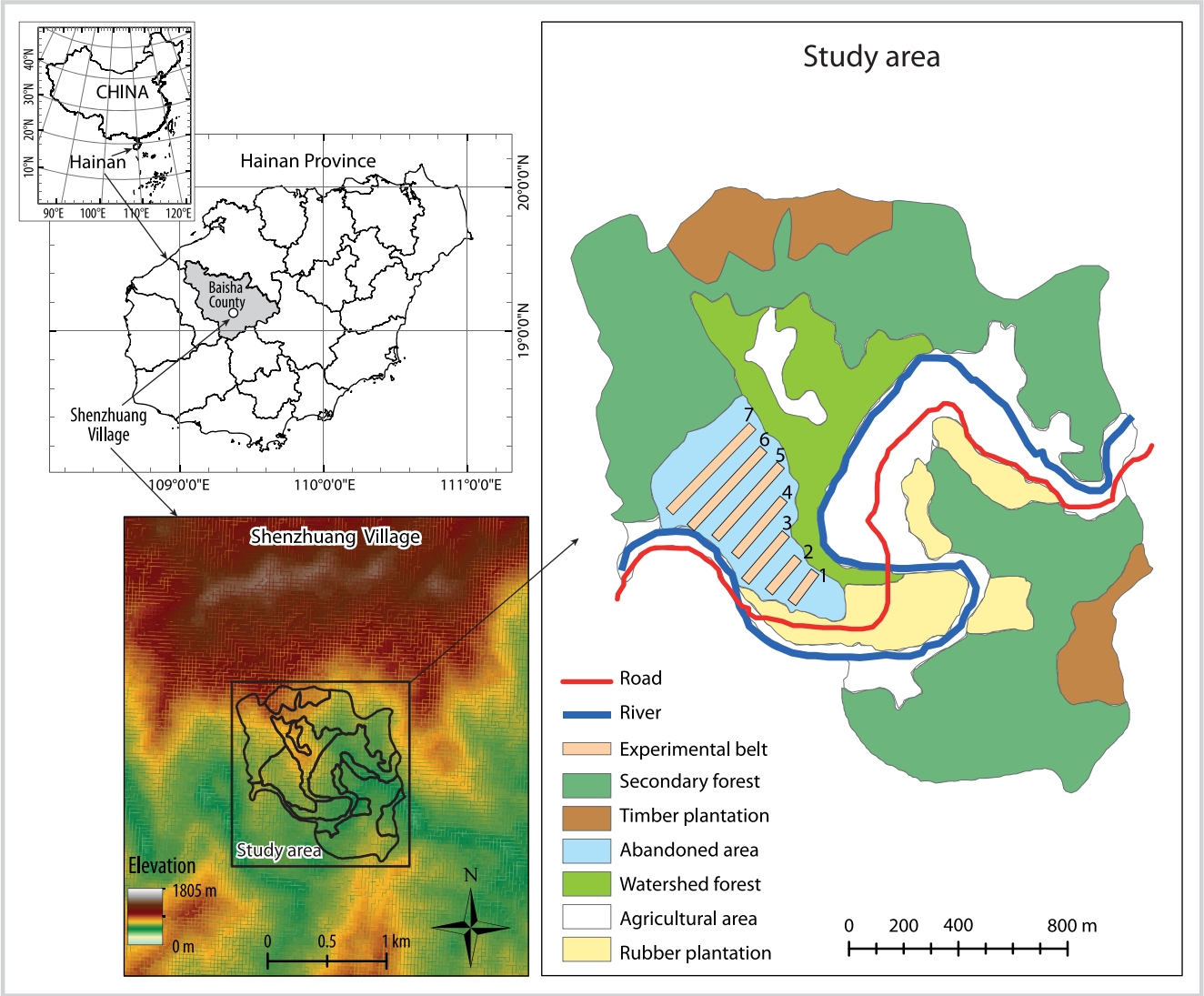
In Equations 1 and 4, N_i is the number of individuals of species i; N is the total number of individuals of all species; and S is the number of species. In Equation 1, P_i is the relative abundance of species i. In Equation 3, H is the result of Equation 1.

The importance value index (IVI) was calculated as follows to rank species contribution to the forest community composition (Magurran 2004):

$$\text{IVI} = RD_i + RF_i + RA_i. \quad (5)$$

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FIGURE 1 Land cover map and location of the area for the study of the regeneration of native plant species on abandoned land in Hainan. (Map by Xianzhao Liu)



In Equation 5, RD_i is relative dominance, RF_i is relative frequency, and RA_i is relative abundance.

Given the different means of resource utilization, only populations that made up more than 1% of the total community were selected for ecological niche analysis. For the analysis, the quadrant was taken as the resource state and the basal area as the quantity index of different populations (Petraits 1979):

$$B_i = \frac{\lg \sum N_{ij} - \left(\frac{1}{\sum N_{ij}}\right)\left(\sum N_{ij} \lg N_{ij}\right)}{\lg r}. \quad (6)$$

In Equation 6, B_i is the niche breadth of species i; N_{ij} is the rank value of species i in terms of resource utilization (basal area in this text); and r is the resource rank number, which is the number of plots. The range of B_i is from 0 to 1; 0 indicates species i uses no resources, and 1 indicates species i uses all the resources in the plant community.

Functional grouping and schematic illustration of the distribution of regeneration

Species functions were taken into account at the beginning of our study, and 4 indices were selected to evaluate the regeneration species. Timber class and size at maturity were selected as economic indicators. Self-renewal ability and longevity were chosen as ecological indicators. Then, each species was evaluated with the Delphi Experts Grading Method (Linstone and Turoff 1975) using the 4 indices (*Supplemental material*, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00110.S1). Each species was assigned to one of three functional

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TABLE 1 Floristic composition and diversity of regeneration species in group 1.

Belt	Number of		Diversity				Adjacent land-use type
	Plots	Plants	Shannon-Wiener index	Richness	Evenness	Dominance	
1	42	42	1.33	2.14	0.60	0.15	Road and rubber plantation
2	43	53	1.45	2.27	0.63	0.16	Road and rubber plantation
3	53	76	1.37	1.85	0.62	0.18	Road and rubber plantation
4	42	79	1.54	2.29	0.64	0.20	None
5	61	166	1.90	2.74	0.70	0.23	None
6	63	170	2.19	3.89	0.72	0.19	None
7	96	206	2.40	4.69	0.74	0.19	Secondary forest
Total	400	792	2.61	5.84	0.71	0.12	

groups: economic, ecological, or both economic and ecological. Species within each functional group were then divided into 4 grades based on cluster analysis implemented in SPSS 11.0 (Norusis 2002).

Based on the grouping results, a 4 step analytical procedure was conducted to assess the restored forest in view of defining management recommendations:

1. Identify the main (number of dominant) species in each plot.
2. Judge the functional attributes of each identified species, including economic importance, ecological importance, combined ecological and economic importance, and species with little use.
3. Use 4 colors (yellow, green, red, and brown) to describe the 4 functions.
4. Describe the attributes of each plot in an Excel spreadsheet, and fill each cell of the spreadsheet with the color corresponding to the functional attribute. For plots with no woody species, fill the cell with gray.

Following these 4 steps, a schematic illustration of regeneration species showing the functional groups in each area was compiled (Figure 2), and a future management strategy aiming for economic and/or ecological restoration was developed based on the data in this schematic illustration.

Results

Floristic diversity

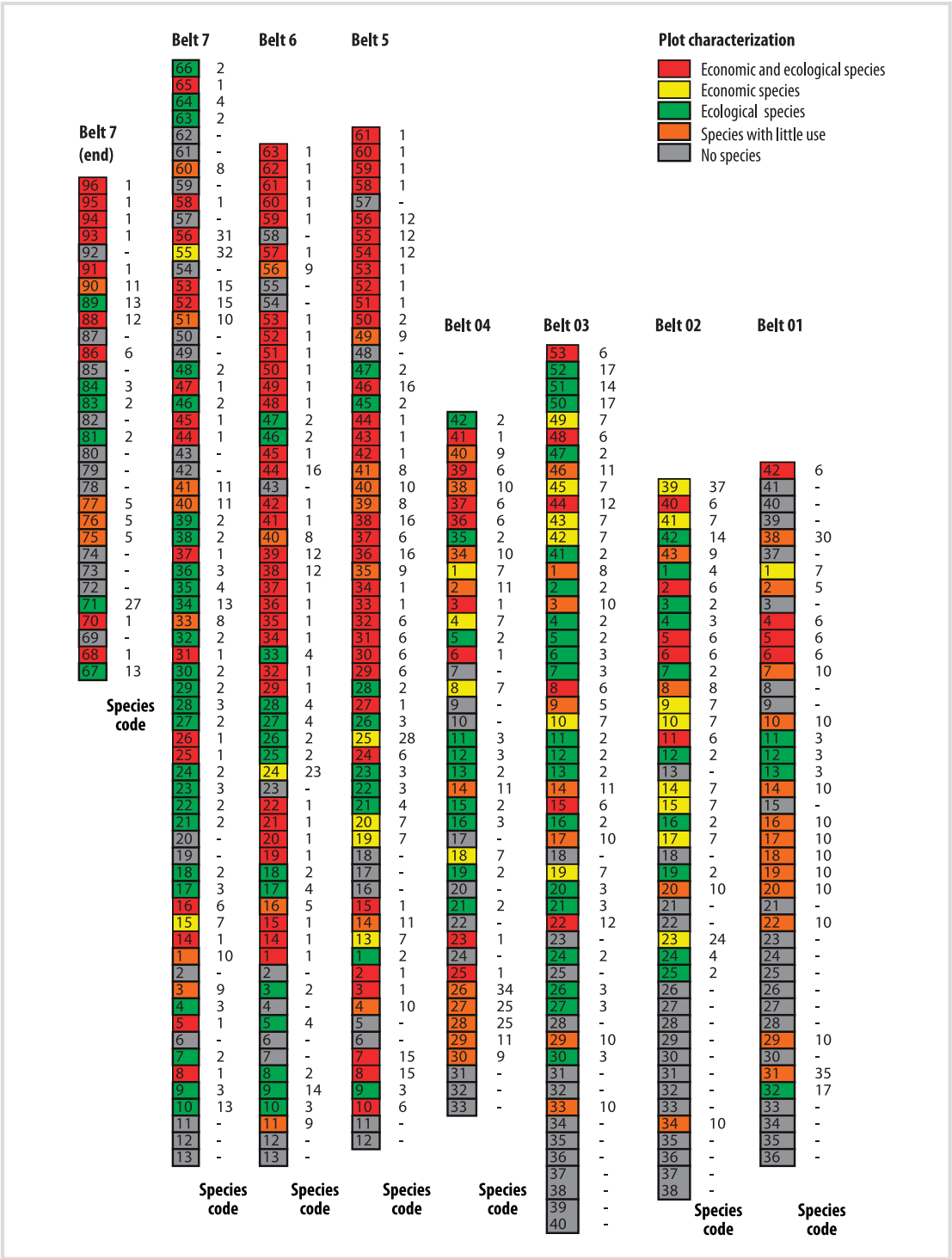
After a 7 year self-restoration period, group 1 (Dbh ≥ 5 cm) contained 792 plants belonging to 40 species. Both the species and number of plants in the 7 belts of plots were different (Table 1). Belt 7 had the greatest number of species and types of regeneration, but the average number of regenerating species per plot in belt 7 was 2.15; this was lower than the result for belt 5 (2.72) and belt 6 (2.70). Belts 1 and 4 had the same number of plots, whereas the numbers of plants and species of regeneration were lower in belt 1 (42 plants, 9 species) than in belt 4 (79 plants, 11 species).

Diversity (based on all 4 indices) was greater in belt 7 than in the other 6 belts; this may be due to the fact that belt 7 had the highest number of plots (96). The difference in diversity between belts 1 and 4 may be because of the belts' positions (belt 1 was more accessible by road than belt 4 and thus had more human disturbance). Both the Shannon-Wiener (2.61) and richness (5.84) indices displayed maximum values when calculated for the total sampling population, and the value of these 2 indices in the 7 belts increased with a higher number of plots, except for belts 3 and 4. Because of possible human influence, the restoration effect, as indicated by the Shannon-Wiener (1.37) and richness (1.85) indices, was poorer in belt 3 than in the other belts. Evenness varied only slightly (0.60–0.74) among the 7 belts and the total (Table 1), and the 7 belts had a minimal dominance value (0.12).

After the 7 year self-restoration period, group 2 (Dbh < 5 cm) had 2729 plants belonging to 26 species, of which 24 species were also in group 1. The main species were *Liquidambar formosana*, *Aporosa chinensis*, and *Cratoxylon ligustrinum*, which accounted for 56.4% of the total in this group (*Supplemental material*, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00110.S1).

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FIGURE 2 Species and functional group distribution on 7 ha of abandoned land. Plot size was 5 × 5 m. Plot numbers are given inside the colored cells, and species codes are given to the right. **Note:** Plot size was 5 × 5 m. Plot numbers are given inside the colored cells, and species codes are given to the right of these cells. For key to species codes, see Supplemental Material, Tables S1, http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00110.S1.



Importance value and niche breadth

The IVI and niche breadth were only analyzed for group 1. Among the 40 regeneration species, the IVI of *L. formosana* was the highest (62.7), followed by *A. chinensis* (43.9) and *Lannea grandis* (31.1). These 3 dominant species account for 45.9% IVI in the whole regeneration community, which indicates that their self-renewal and growth abilities were excellent. Over 20 species had fewer than 5 stems per

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TABLE 2 The 10 tree species with the highest importance value and niche breadth.[a)]

Species	Relative abundance	Relative dominance	Relative frequency	Importance value	Niche breadth
Liquidambar formosana	23.1	27.5	12.1	62.7	0.68
Aporosa chinensis	18.8	10.1	15.1	43.9	0.61
Lannea grandis	10.4	10.1	10.6	31.1	0.55
Eriobotrya deflexa	6.4	9.1	6.8	22.3	0.52
Engelhardtia colebrookiana	8.1	4.4	7.0	19.5	0.48
Syzygium cumini	4.2	8.6	4.4	17.2	0.38
Cratoxylon ligustrinum	5.3	2.4	4.6	12.3	0.56
C. hainanensis	0.7	6.3	0.8	7.9	0.42
Glochidion puberum	2.7	2.1	2.5	7.3	0.48
Phyllanthus emblica	2.7	1.6	2.8	7.1	0.46

[a)]Subtotal of 10 species with the highest importance value and niche breadth is 231.3; value for other species is 68.7.

hectare, and the IVI of these species was also low in the regeneration community (*Supplemental material*, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00110.S1). The top 10 regeneration species in terms of IVI values (Table 2) account for 77.1% of the total IVI and form the core of the early secondary community.

L. formosana had the greatest niche breadth (0.68) among the top 10 IVI species, which indicates it had the best adaptability in terms of environmental resources in the current community. The second greatest niche breadth was for *A. chinensis* (0.61), followed by *L. grandis* (0.55). *Syzygium cumini* had the least niche breadth (0.38), but its IVI was not the lowest.

Functional grouping and schematic illustration of regeneration distribution

Within each functional group, species were graded based on their value. The grades were divided by the equivalent of a quartile of 4 indices (*Supplemental material*, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00110.S1) and then adjusted according to species IVI and dispersal agent. The values of the different functional groups in grade 4 were highest among the 4 grades (Table 3). *L. formosana*, *C. ligustrinum*, *Trema orientalis*, and *Castanopsis hainanensis* had the highest economic and ecological value when taking all factors into account. More than half of the 40 regeneration species had good economic value (species listed in grades 3 and 4 in the economic group in Table 3), whereas only 25% had a correspondingly good ecological value.

Figure 2 shows the entire regeneration area in a schematic way. Although 40 species were surveyed in the 400 plots, only 27 were recorded as the main species. Each functional group had only 1 or 2 main species (Table 4). Species with economic functions were found in 26 plots and were mainly distributed in belts 2 and 3. *S. cumini* was the major species and took up 80.8% (21 plots) in this functional group. Species with ecological functions were

TABLE 3 Value of regeneration species in the 3 functional groups.[a)]

Grade	Functional group		
	Economic species (codes)	Ecological species (codes)	Economic and ecological species (codes)
1	3, 4, 5, 8, 9, 10, 11, 13, 22, 25, 30, 33, 34, 38	5, 7, 8, 9, 10, 11, 13, 16, 21, 23, 24, 25, 28, 30, 33, 34, 35, 36, 40	5, 8, 9, 10, 11, 13, 21, 25, 30, 33, 34
2	2, 14, 17, 21, 27, 35, 36	17, 18, 19, 20, 26, 29, 31, 32, 37, 39	7, 16, 17, 18, 19, 20, 23, 24, 26, 28, 29, 31, 32, 35, 36, 37, 39, 40
3	1, 7, 19, 20, 23, 24, 26, 29, 32, 37, 39, 40	3, 4, 14, 15, 22	2, 3, 4, 14, 22, 27, 38
4	6, 12, 15, 16, 18, 28, 31	1, 2, 6, 12, 27, 38	1, 6, 12, 15

[a)]For key to species codes, see *Supplemental material*, Table S1, http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00110.S1.

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TABLE 4 Main species in each functional group.[a)]

Functional group	Species		Number of plots	Percent of study area	Average Dbh (cm)	Average height (m)
	Number	Code of main species				
Economic species	6	7	26	6.50	8.52	5.70
Ecological species	7	2, 3	98	24.50	7.63	5.10
Economic and ecological species	6	1, 6	111	27.75	9.40	6.60
Species with little use	8	10	55	13.75	4.25	4.90
No species	–	–	110	27.50	–	–
Total	27	–	400	–	–	–

[a)]For key to species codes, see *Supplemental material*, Table S1, http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00110.S1. The codes of species are consistent with those in Table 3.

found in 98 plots and were distributed relatively uniformly throughout the 7 belts. *A. chinensis* and *L. grandis* were the main species with ecological value in this restored forest. Although species with both economic and ecological functions were found in 111 plots (27.75%), the distribution was not uniform, and these species were mainly concentrated in the top sections of belts 5 and 6. *L. formosana* was the most prevalent of the 6 multifunction species and made up 63.1% of this functional group. Regeneration species with little economic and ecological value were found in 55 plots, and there were 110 plots with no species. Both of these types of plots should receive more attention in future restoration management.

Discussion

Diversity and succession in the regenerated area

A plant community is a product of many factors, such as human activities, dispersal abilities of different species, interactions within a community, and ecological and spatial scales of variation (Tonteri 1994). After a 7 year enclosed self-restoration, native regeneration displayed good progress in the abandoned region. The Shannon-Wiener and richness indices of the restored secondary forest were at satisfactory levels relative to other studies (Brunig 1973; Byer and Weaver 1977; Squiers and Wistendahl 1977). The regeneration diversity displayed a disequilibrium distribution in the 7 survey belts. Community diversity (as measured by the 4 indices) in the locations next to the road and rubber plantation (belts 1, 2, and 3) was lower than other areas, which indicates that human activity and dispersal ability of different species might be the main factors influencing the diversity restoration of early tropical secondary forests (Holl 1999; Shono et al 2006). Species evenness was also affected by the above factors and displayed inhomogeneity across the restored region (Table 1).

Importance value and ecological niche breadth are 2 indices that reflect the ecological importance of different woody species and provide helpful information for species selection (Marcano-Vega et al 2002). Although the 2 indices are based on different concepts and have no direct relation, woody species (such as *L. formosana* and *A. chinensis*) with greater niche breadth demonstrate better use of multi-environmental resources, resulting in a higher rate of regeneration and growth and a higher IVI (Table 2; *Supplemental material*, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00110.S1). Combined with their economic and ecological value, woody species with a high niche breadth and IVI should receive more attention in future restoration management.

Dominant pioneer species are unrivaled in their ability to colonize open low-nutrient sites because of their diverse growth forms, various seed propagation methods, and photophilous nature. These species play a key role in habitat restoration and facilitate the recruitment of other, neutral or shade-tolerant species; all of these types of species together can drive secondary succession to a high level (Smith and Knapp 2003). *L. formosana* is the most important dominant pioneer species in this study in terms of its IVI value, followed by *A. chinensis* and *L. grandis* (Table 2). These species occupy a wide ecological niche and can adapt to and use the available surroundings very well, which give them a remarkable sprouting and growth ability on recently abandoned land (Wang and Zhang 2002).

Species such as *Engelhardtia colebrookiana*, *C. ligustrinum*, *Eriobotrya deflexa*, and *S. cumini* comprise a second important part of the restored forest, and some of them belong to the early forest successional process transitional group. Although the roles of these species are smaller than those of dominant pioneer species, their facilitation of the growth of dominant species, as well as secondary succession, is irreplaceable. Furthermore, some of these species play important roles in the economic and ecological development of this forest (*Supplemental Material*, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00110.S1).

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The appearance of rare species is mainly caused by random events such as dispersal by animals, wind, and fire (Leopold and Salazar 2008). The recently restored habitat is unsuitable for the proliferation of these species, but they greatly increase floristic diversity and provide more possibilities for species exploitation in future restoration management.

Two dominant tree species

Considering the obvious leading role of the dominant tree species in the restoration of early secondary forest, a brief discussion of these species is necessary for future management.

L. formosana is a medium to large evergreen tree that can attain a height of 20–35 m and a Dbh of 40–100 cm. The timber is light in color and durable indoors. It can be used for budget furniture, construction, crates, and plywood. Its resin is also of use to the chemical industry (Bonner 1967; Weng et al 2007). With a wide range of seed dispersal options, natural regeneration potential, and environmental suitability, it has become the most common species, with a high importance value and niche breadth in the degraded monsoon forests of the mountainous region of South China. All of these characteristics make *L. formosana* an important species, both economically and ecologically, in the restored forest.

A. chinensis is a small evergreen species that can reach a height of 9 m and a Dbh of 20 cm. The wood is dense and durable and can be used for simple implements and firewood. It is also a pioneer species that regenerates profusely in degraded monsoon forests in the mountainous region of South China. Although the growth rate of *A. chinensi*s is lower than that of *L. formosana*, its recruitment and environmental suitability make it an ecologically important species in the restored forest.

Implications for management

Regeneration species always present a cluster distribution phenomenon regarding the differences of provenance, seed dispersal, and growth, which limits the feasibility of using population sample results to describe the condition of whole secondary forests. In this study, the schematic illustration of the distribution of regeneration indicates a clear distribution of different functional species on the 7 ha of abandoned land (Figure 2).

After 7 years of enclosure, the natural regeneration of useful woody species has achieved a satisfactory standard. These restored species provide indispensable contributions to the subsistence of humans in the form of fuelwood and timber, as well as contributing to ecological restoration.

Although there are 40 woody species on the abandoned land, only a few dominant species or species with high renewability are found in different functional groups (Table 4). Plots near the secondary forest and water conservation forest display a better restoration effect than those in the edge zone, which is adjacent to a rubber plantation and a road (Figure 1).

The results of this study have the following management implications:

1. As a dominant species with higher multifunctional value, *L. formosana* should be utilized in many ways, especially for economic purposes; this could resolve the conflict between the needs of local residents and the need for forest protection.
2. Decisions about species selection and protection should pay more attention to accompanying species with multifunctional value.
3. Adaptability experiments should be performed on valuable rare species such as *Machilus chinensis*, *T. orientalis*, and *C. hainanensis*, and these species could become better established in later stages of secondary succession.
4. Enclosure strength should be increased in the edge zone, where artificial and natural disturbance is intensive.
5. Artificial replanting using multifunctional species such as *L. formosana*, *C. ligustrinum*, and *T. orientalis* should be undertaken in the edge zone and the areas where little natural regeneration has occurred.

Conclusions

This study analyzed and evaluated the regeneration status of native plant species in a restored forest based on data such as species, number, Dbh, and height, which were quickly and easily obtained from linear sampling. Using a method based on the classification of functional groups, an overall schematic illustration of the restored species could be generated for a larger area, and these data provide a clear reference for the planning of forest rehabilitation, land use, and related operational techniques, all of which aim to develop forestry in a sustainable manner.

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SUPPLEMENTAL MATERIAL

TABLE S1 Species number, importance value, and functional characteristics.

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