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Integrative Management of Commercialized Wild Mushroom: A Case Study of *Thelephora ganbajun* in Yunnan, Southwest China

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Abstract The management of wild mushroom is interdisciplinary in nature, whereby the biophysical considerations have to be incorporated into the context of a wide range of social, economic and political concerns. However, to date, little documentation exists illustrating an interdisciplinary approach to management of wild mushrooms. Moreover, the empirical case studies necessary for developing applicable and practical methods are even more rare. This paper adopted an interdisciplinary approach combining participatory methods to improve the habitat management of *Thelephora ganbajun*, an endemic and one of the most economically valuable mushroom species in Southwest China. The paper documents an empirical case of how an interdisciplinary approach facilitated the development of a scientific basis for policy and management practice, and built the local capacity to create, adopt and sustain the new rules and techniques of mushroom management. With this integrative perspective, a sustainable management strategy was developed, which was found not only technically feasible for farmers, but also acceptable to the government from an ecological and policy-related perspective. More importantly, this approach has greatly contributed to raising the income of farmers. The paper highlights how the integration of biophysical and socioeconomic factors and different knowledge systems provided a holistic perspective to problem diagnosis and resolution, which helped to cope with conventional scientific dilemmas. Finally, it concludes that the success of this interdisciplinary approach is significant in the context of policy decentralization and reform for incorporating indigenous knowledge and local participation in forest management.

Keywords Non-timber forest products (NTFPs) · Fungi · Interdisciplinary research · Community-based natural resource management · Indigenous knowledge · Participatory action research

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Introduction

For centuries, people across the world have been using wild mushrooms for food, medicine and cosmetics as well as for other economic and cultural purposes (Boa 2004; Moerman 2008). As one of the most important non-timber forest products (NTFPs), they are a major source of substantial income for millions of farmers and, in particular, indigenous peoples around the world (FAO 1997). On a global scale, more than 3,000 species of wild mushrooms are consumed, while more than 100 species are of great medicinal value for fighting against cancer and other life-threatening diseases (Garibay-Orijel and others 2009). A recent estimate shows wild edible mushrooms have generated about USD 2 billion in global revenues in 2004 (Boa 2004). Moreover, wild mushrooms have important ecological functions as they provide vital nutrition to the native forests and even commercial plantations in which they live symbiotically where their mycorrhizal association greatly supports the growth of tree (Ouzouni and Riganakos 2007).

Recent societal and scientific interest in wild mushrooms (as much as in other NTFPs) emerged to advance their commercialization for forest management in alternative development strategies and reconcile the economic, cultural, and ecological values of the ecosystem (Nepstad and Schwartzman 1992; Fox 1995; Wollenberg and Ingles 1998). However, issues of overharvesting, resource degradation and increasing resource competition have occurred along with the increased commercialization of many NTFPs (Neumann and Hirsch 2000; Belcher and Schreckenberg 2007) including wild mushrooms (Winkler 2008; Yang and others 2009; He 2010). Clearly, the issue of sustainability of wild mushrooms is an interdisciplinary question in nature. It is a challenge for current forest management practices to integrate biophysical considerations into various social and institutional contexts, while attempting to promote economic development through maintaining and even increasing production and simultaneously maintaining or improving ecological conditions (He and others 2007). The discussion of wild mushroom management, therefore, encompasses a wide range of social, economic, political, and ecological questions. However, there is little documentation of the interdisciplinary approach to the integrative management of wild mushrooms. Moreover, empirical case studies for developing applicable and practical methods are even more rare.

This paper presents a pilot project of integrative management for improving the production and sustainable harvest of *Thelephora ganbajun*, an endemic and one of the most economically valuable mushroom species in Southwest China. It aims to document an empirical case of how an interdisciplinary approach facilitated the development of scientific basis for policy and management practice, and built the local capacity to create, adopt and sustain the new rules and techniques of mushrooms management. The research was carried out in Baoshan Prefecture, Yunnan Province of China, situated in one of the twenty-five World Biodiversity Hotspots (Myers and others 2000), and with the largest diversity of edible wild mushrooms in the world (Wu and Lu 2006). The project team consisted of farmers, local foresters, social scientists and ecologists who tried to respond to the pressure of intensive mushroom harvesting at the project site. The team attempted to develop a sustainable mushrooms management strategy that integrated biodiversity conservation into livelihood development, incorporated indigenous knowledge into scientific knowledge, and combined natural sciences with social sciences. This strategy allowed for a wide collaboration among scientists, farmers and government officials (Fortmann 2008).

The central contribution of the paper is to present a case for coping with the dilemmas in mushroom management. In this study, the integration of biophysical and socioeconomic factors and different knowledge systems provide a holistic perspective to problem diagnosis and resolution. The paper illustrates how similar approaches can be created elsewhere by policy-makers and project managers to improve conditions for mushroom production. The paper highlights that the sustainable management strategy should be not only technically feasible for farmers, but also acceptable to the government from an ecological and policy-related perspective. More importantly, this strategy should make a significant contribution to local income generation. Using the results gained from the empirical case study, the paper suggest that the success of the interdisciplinary approach is significant in the context of policy decentralization and reform for integrating indigenous knowledge and extensive local participation in forest management and biodiversity conservation.

Materials and Methods

Study Species

The *Thelephora ganbajun*, locally known as “Gang-Ba-Jun” is an ectomycorrhizal fungi that grows in symbiosis with pine forests (Mao 1998). Recent ecological study documents that *T. ganbajun* are usually found in pure Yunnan Pine (*Pinus yunnanensis*) and Khasya Pine (*P. kesiya*) forest, or mixed forest of conifer and broad leaved forest with Yunnan pine at an altitude of 800 to 2,200 m.a.s.l. (Gui and others 2005). Sometimes it also grows in Evelynia Keteleeria (*Keteleeria evelyniana*) and Chinese Fir (*Cunninghamia lanceolata*) forests (Gui and others 2005). The symbiotic relationship with its forest ecosystem not only provides essential nutrition and the natural conditions for its growth, but also makes the *T. ganbajun* an endemic and non-cultivatable mushroom.

In taxonomy, however, there has been confusion over the commercial *T. ganbajun* for a long time resulting in a lack of documentation worldwide (Fu and Guai 1997). While 51 species of *Thelephora* occur in wide distribution across the world, 11 of the 16 species occurring in China can be found in Yunnan (Gui and others 2005). Six species are commercially valuable and commonly traded in the market, including *T. Vialis, T. ganbajun, T. aurantiotincta, T. fuscella, T. japonica* and *T. palmate* (Gui, and others 2005; Wang and Liu 2002). This study focuses on the *Thelephora ganbajun* that is widely distributed in Yunnan and has high commercial value.

T. ganbajun is commercially harvested as it is one of the favorite edible mushrooms for people in Yunnan due to its unique and popular flavor. Nevertheless, inadequate annual production to meet the market demand makes *T. ganbajun*

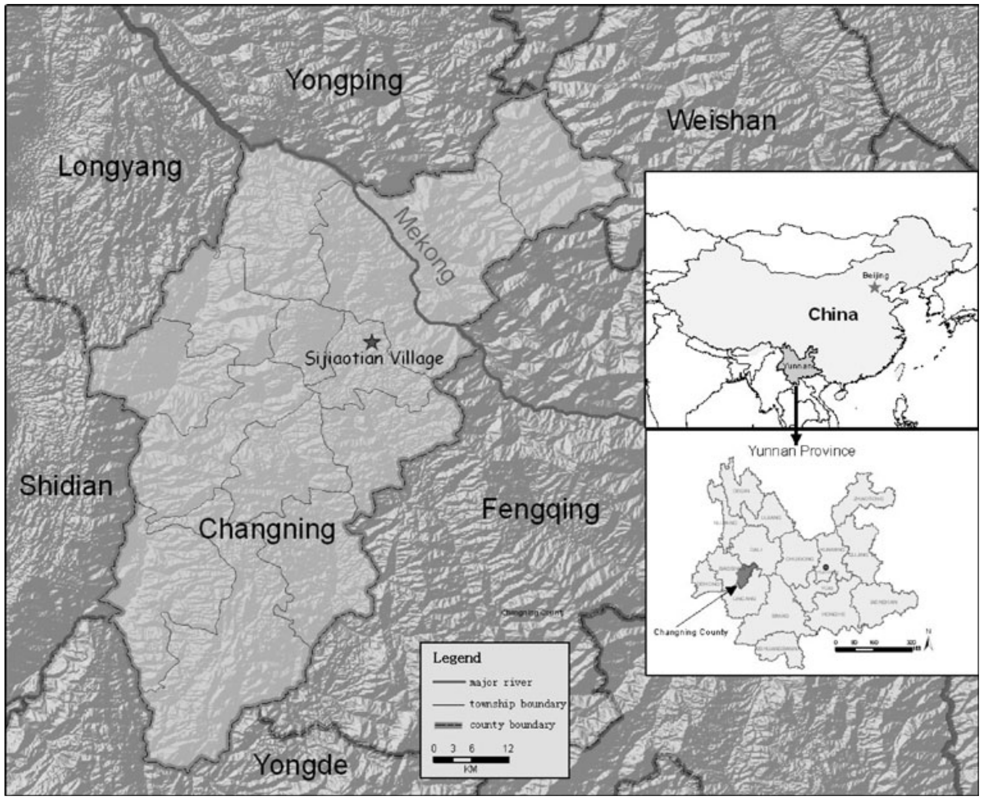


Fig. 1 The location of Sijiaotian village

consumption a luxury and its price has been dramatically increasing every year. In 2002, annual production across the province was only about 10,000 tonnes and the price was USD 20-50 per kilogram (Zhao and others 2009). This high economic value has been driving forest-dependent communities to exclusively devote their resources to meeting the increasing market demand. Throughout the mushroom season from May to October, millions of farmers, mostly ethnic peoples in remote areas, are engaged in harvesting *T. ganbajun* for sale.

However, despite its high ecological and economic significance, and while increased pressure and threats to its production are clearly observed, little research has been done towards better understanding and improving the sustainable use and conservation of this species. While there are a few scientific studies concentrating on its bio-chemical characteristics (e.g., Hu and others 2001; Yang and others. 2004), to our knowledge, this paper is the first application of an interdisciplinary approach to integrate biophysical factors and socio-economic factors in the study of *T. ganbajun*.

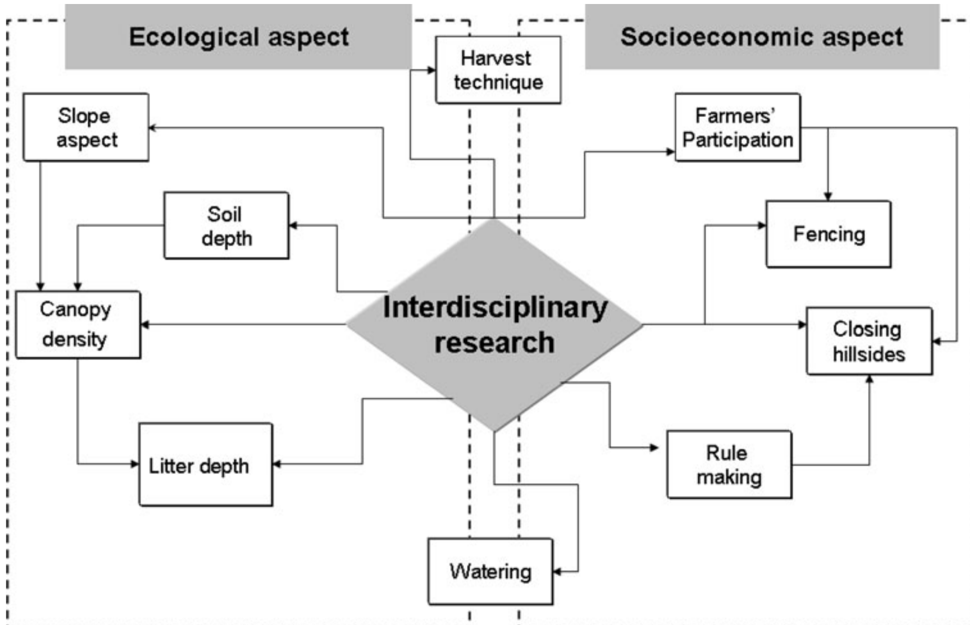
Study Site

Changning County in Baoshan Prefecture of Yunnan Province is situated in the middle of the upper tributary watersheds of the Salween and Mekong rivers. It is an area of rich biodiversity with a forest cover of 45.2% dominated by two major species, *Pinus yunnanensis* and *Pinus kesiya*. These forests provide a favorable habitat for important non-timber forest products. The pilot study was carried out from late 2006 to 2009 in one administrative village, Sijiaotian (99°40′53″E, 24°50′50″N) (see Fig. 1), which includes 16 natural villages with a total population of 2,539. The inhabitants of these villages are of the Han-Chinese and Yi ethnic group. The per capita annual income in 2005 was 1,150 RMB (USD144), according to the Changning County Government Record.

The village is situated in a subtropical climate, where mean annual temperature is 13°C with annual rainfall from 1,400 to 1,700 mm. It is located between 1,750 to 1,980 m.a.s.l., with the mountain ranges providing opportunities for a variety of agroecosystem management practices. Farmers cultivate paddy rice and rape seed in the valleys and corn in the uplands. Agroforestry practices, such as cultivation of walnut (*Juglans regia*) and chestnut (*Castanea mollissima Bl.*) with annual crops, and tea combined with alder (*Alnus nepalensis D. Don*), are common agroforestry land use patterns that provide substantial cash income. With the dominant species of pine forest (*Pinus yunnanensis* and *P. kesiya*) as natural vegetation within the 1983.7 hectares of forested land, forest cover accounts for 47% of land in the village.

The forest ecosystem provides an abundance of NTFPs for the villagers' livelihood. More than 20 species of edible

Fig. 2 Interdisciplinary research framework



wild mushrooms can be found in the village forest and of which *Thelephora ganbajun, Termitomyces eurrhizus R. Heim, Russula Virescens* (*Schaeff. Ex Zant.*) *Fr., Cantharellus cinnabarinus Schwein* and *Lactarius deliciosus* have great economic value and have been widely collected for commercial purposes. Village documentation shows that mushroom collection plays a significant role in local livelihoods providing approximately 37% of local cash income every year. During the mushroom season from June to October, 50% of the villagers mainly women and children are involved in mushroom picking. However, intensive harvesting of wild mushrooms has been increasing pressure on the resource use and leading to an overall decline in economic benefits.

Interdisciplinary Research Methods

Overall Research Framework

This pilot study adopted an interdisciplinary approach combined with participatory methods to assess the biophysical and socioeconomic factors that influence the production and sustainable use of *T. ganbajun*. In response to increasing pressure on the mushroom resource in Sijiaotian, the Baoshan Forestry Bureau approached the World Agroforestry Centre (ICRAF) to initiate this action research in 2006. Thus, the concept of interdisciplinary approach (Tress and others 2005) and participatory research (Chambers 1997) was introduced to the forest officials. The active aim of the research was to experiment with the potential methods for improving the habitat management resulting from the analysis of different ecological and socioeconomic variables with the focus on the "Farmer First" principle throughout the project (Chambers and others 1989). Different variables identified by interdisciplinary assessment helped to generate an overall research framework (see Fig. 2), and the following subsections detail how this framework was formulated.

Assessing the Socioeconomic Context

The research team of local foresters and researchers conducted the socioeconomic assessment by using a participatory rural appraisal toolkit (PRA) (Chambers 1994) for problem diagnosis. Interviews were undertaken with a random selection of 35 mushroom-harvest households using semi-structured interviews. The interview questionnaire covered the following topics: (1) basic information about the village and household; (2) who is involved in mushroom harvesting and what are the mushroom management practices; (3) who has knowledge about mushroom harvesting and management in the village; (4) what are the problems and challenges for *T. ganbajun* management and in what ways can it be improved; (5) what kinds of regulations will be effective and easy to enforce in the village.

The household survey provided a basic understanding of the local context, which also helps to identify the local mushroom specialists/village experts (Davis and Wagner 2003). Then, four focus groups were organized with differentiation of gender, social and knowledge status (men, women, villager leaders and village experts), while PRA tools such as problem tree, institutional mapping and land use mapping were used within the group discussions. Based on the participatory problem diagnosis (Doorman 1990), the institutional arrangement for good management was identified as a priority for improving recent harvest practices that included the strategy of formulation of village regulations, fencing, and closing of the hillside (for detailed discussion, see the results section). The ideas for improving institutional arrangements emerged from local people experiences from other regions as well as information from existing literature (e.g., Yang and others 2009). Meanwhile, in the group discussions, farmers suggested the establishment of a mushroom association for monitoring and evaluation of harvesting practices. The association aims to build up the social capital and institutional arrangement to ensure that ecologically sound techniques and management practices can be applied. The social dimension therefore focuses on the process of local institution building.

Experimental Plot Selection and Monitoring

From the ecological side, as informed by Cunningham (2001), an ethnobotanical inventory was adopted for the investigation of indigenous knowledge which included vegetation, habitat of *T. ganbajun* as well as the impacts of harvest practices. The research team of local foresters and researchers worked with the village specialists and identified slope aspect, soil depth, litter depth and canopy density as key ecological variables that affect the mushroom growth, while harvest and watering techniques were suggested as the management methods having a major influence on mushroom growth. These variables were tested through the use of representative plots where the dominant vegetation was pine forest (*Pinus yunnanensis and P. kesiya*). Based on randomized blocks design and assistance from the forest bureau (see Table 1), a total of fifty-four 20 m × 20 m experimentation blocks were set up in the village for different treatments: slope aspect (12 blocks), soil depth (9 blocks), litter depth (15 blocks), and canopy density (9 blocks). These blocks aimed to understand the ecological factors that affect the quality and quantity of mushrooms. In addition, with the combination of ecological and social perspectives, another nine 20 m × 20 m experimentation blocks were set up to compare the methods of watering mushroom pots and harvest techniques as cross-cutting schemes. The distribution of those experimental plots was in five households that actively participated in the experimentation, monitoring and data recording.

Data Analysis

The research generated a considerable amount of data for analysis. The quantitative data presented in this paper is raw data including ecological techniques of habitat management, harvest and economic value and so forth. Data were examined by One-way ANOVA using canopy density, litter depth, soil depth, slope aspect, and management technique as treatment factors and variations as block structures. Means of mushroom production were compared using Fisher's LSD test when the *F*-test from ANOVA was significant at $P < 0.05$. The qualitative data include farmers' knowledge, and interaction of stakeholders also collected by researchers. The interdisciplinary approach of combining qualitative and quantitative data analysis strategies was used with the aim of strengthening research findings.

Table 1 Summary of randomized blocks design for different treatment and variations

Treatments	Variations	Number blocks
Slope aspects	N-facing	Three replicates
	S-facing	Three replicates
	SE and SW facing	Three replicates
	NE and NW facing	Three replicates
Soil depth	≤50	Three replicates
	50–100 cm	Three replicates
	≥100 cm	Three replicates
Canopy density	0.5	Three replicates
	0.6	Three replicates
	0.7	Three replicates
Litter depth	1–2 cm	Three replicates
	2–3 cm	Three replicates
	3–4 cm	Three replicates
	4–5 cm	Three replicates
	5–6 cm	Three replicates
Harvest technique	Traditional	Three replicates
	Cutting without watering	Three replicates
	Cutting with watering	Three replicates

Results

Building Local Institutions for Mushroom Management

The forest tenure system in China maintains a distinction between state forests (*guoyoulin*), collective forests (*jintilin*), and increasingly household forests after the forest reforms of decollectivization in the early 1980s. Villages have both use and ownership rights over collective forest, while various levels of government own the state forests (Miao and White 2004; Liu 2001). While this forest tenure system has clarified the right to trees, mushrooms and other types of NTFPs remain in a legal vacuum. It is suggested that the forest titling regulation caused unclear property rights in the context of NTFPs resources (He 2002). As a result, the tenure system for NTFPs is *de facto* open access so that people go wherever they want and harvest as much as they can. However, this environment also enables a great opportunity for the initiating of community-based resource management that can be complementary to state policy efforts.

Given that a decrease in production has been observed in the Sijiaotian village, participatory problem diagnosis was conducted with extensive participation from farmer representatives, forest extension officials as well as ICRAF facilitators in late 2006. The unclear tenure system was one of the first problems identified by farmers. The other more specific problems included: (1) unclear rights to access, harvesting and control over NTFPs; (2) unclear rules for management and poor enforcement of access; (3) weak collaboration within the village; (4) lack of collective action and organization for management. The subsequent discussion concentrated on the strategy of problem solving and action for implementing a potential management strategy. A village meeting was held afterwards with the participation of almost all villagers to approve and institutionalize the sustainable mushroom management strategy in the village.

The strategy for sustainable mushroom management includes:

- *Clearly defining boundaries*: Neighboring communities and households negotiate with each other to define the boundaries of the areas where mushroom collection can take place. Mushroom collection boundaries associated with forest boundaries demarcates the usufruct of individuals more clearly.
- *Fencing the forestland*: Simple wooded fences were established according to defined boundaries that reinforce the use rights of individual households and effectively exclude outsiders from access to the resource.
- *Rules for management:* Simple and easily understood rules for mushroom collection were framed. Those included, for example, (1) closing hillsides for every 10 days which enables the mushroom re-growth; (2) no gathering of immature or over-mature mushrooms. If the rules are broken, the person will be subject to a fine; the amount is defined at the village meeting.
- *Mushroom association:* A mushroom association was formed based on the local elections. The association takes the responsibility for the enforcement of rules, convening village meetings for review and amendment of the local rules as well as facilitating participatory action research.

With the participatory approach, these management institutions are locally devised through collective choices that make the strategy easily enforceable. Simple and understandable rules with low transaction costs as well as setting up the accountability mechanism for monitoring helped build the social foundation and system for further technology development and dissemination. Those ultimately contribute to sustainable mushroom management and positive economic and ecological benefit for the communities.

Mushroom Habitat Management

Beyond the institutional setting, an understanding of mushroom habitat is critical to improve management, and ensure good quality and sustainable production. Within the fifty-four experimentation blocks, the treatments including litter depth, canopy density, soil depth and slope aspects that may affect mushroom production were observed. The voluntary participation of farmers by applying their local knowledge and understanding of mushroom habitat factors contributed not only to enrich research design, but also assisted monitoring work throughout the research process.

Based on the survey conducted in 2007, it was observed that *T. ganbajun* production was highly affected by different microhabitats. Table 2 summarizes the analysis of variations and shows the significant differences respectively among different litter depths ($F = 46.741$, d.f. = 4, $P < 0.001$), different canopy densities ($F = 5.577$, d.f. = 2, $P < 0.05$), different soil depth ($F = 82.4$, d.f. = 2, $P < 0.001$), and different slope aspects ($F = 115.581$, d.f. = 3, $P < 0.001$). LSD-testing was applied as multiple comparisons to examining the means of production within the groups of treatments (see Fig. 3). For litter depth, 2-3 cm and 2-4 cm are the most productive levels that have significant difference

Table 2 Summary of ANOVA for different treatments

Source of variation	d.f.	Mean square	F	P
Litter depth				
Between groups	4	9.909	46.741	<0.001
Within groups	10	0.212		
Total	14			
Canopy density				
Between groups	2	1.214	5.577	<0.05
Within groups	6	0.218		
Total	8			
Soil depth				
Between groups	2	49.440	82.400	<0.001
Within groups	6	0.600		
Total	8			
Slope aspects				
Between groups	3	30.148	115.581	<0.001
Within groups	8	0.261		
Total	11			

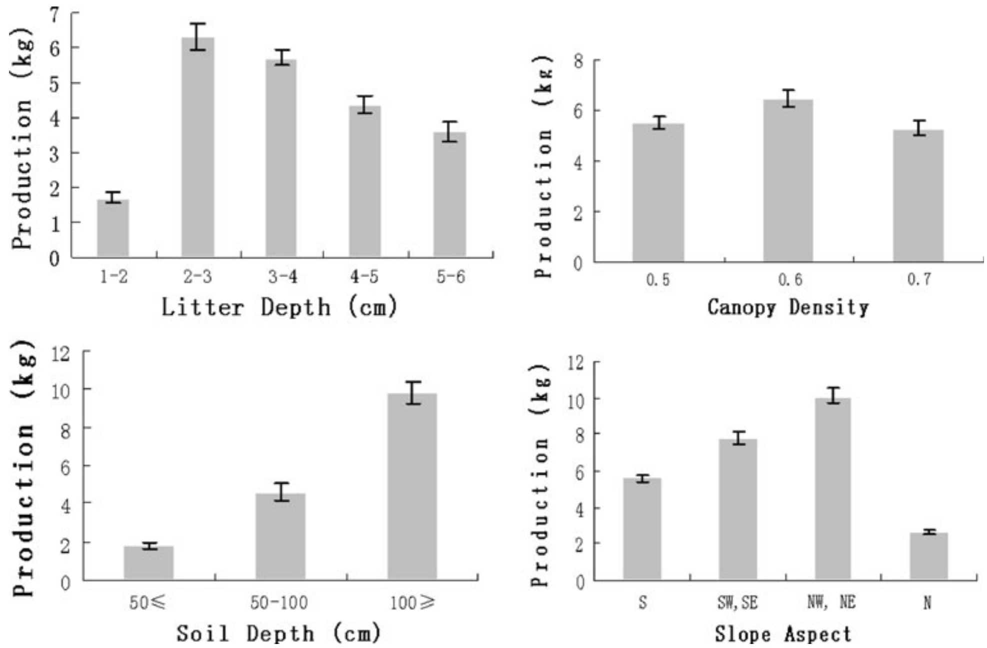


Fig. 3 *Error bar*, Mean production ± SE of different treatments

against others ($P < 0.001$), but no-significance between them ($P = 0.142$). Regarding canopy density, the highest production of mushroom occurs under 0.6 which presents a significant difference from 0.5 and 0.7 ($P < 0.05$). The significant difference in productivity occurs in all variations of soil depth ($P < 0.01$) and slope aspects, ($P \leq 0.001$), while mushroom productivity reaches its highest when soil depth is ≥ 100 cm and slope is on the NW and NE facing side.

It is clear that mushroom production has a close correlation with the microenvironment. The evidence from the ecological study showed that light and micro-humidity are predominant factors affecting mushroom quantity and quality. Too much light and/or less humidity caused a drying of the mushroom body and slow growth. In contrast, too little light and/or high humidity leads to slower growth and mould. In practice, both light and humidity can be adjusted through the modification of litter depth and canopy density to improve mushroom productivity.

The results of this analysis were presented to the local mushroom association at the end of 2007. Villagers used the data to formulate the best mushroom management practices in order to obtain the best production. Tilling and debranching have been conducted to reduce canopy density to 0.6. The litter depth has been managed through adding or removing the litter to reach 2-4 cm. Although slope aspects and soil depth cannot be artificially modified, farmers take that information as critical criteria for targeting the areas where intensive management should be applied. In those targeted areas, most of the households invested in installing a field guardhouse to stay overnight during the mushroom season to monitor the mushrooms.

Improved Harvesting Technique

Sustainable mushroom management has also focused on the harvesting techniques and pre-harvesting management. The farmer innovators collaborated with forest extension officials and ICRAF facilitators to experiment with different harvesting techniques that affect mushroom production. There are three different harvesting techniques: (1) the traditional way is to harvest the mushroom body by hand, (2) using a knife to cut the mushroom body, (3) keeping about 50 cm as an area for the mushroom, watering the mushroom 15 days then using a knife to cut the body.

Table 3 summarizes the analysis of variations and shows the significant differences in harvesting techniques ($F = 47.553$, d.f. $= 2$, $P < 0.001$). LSD-testing was applied as multiple comparisons to examine the means of production within the groups of treatments (see Fig. 4). Among the harvesting techniques i.e. "traditional", "cutting without watering" and "cutting with watering", mushroom productivity shows significant difference ($P < 0.001$), while the management practice of cutting with watering results in the highest productivity.

Table 3 Summary of ANOVA for harvesting technique

Source of variation	d.f.	Mean square	*F*	*P*
Between groups	2	71.804	47.553	<0.001
Within groups	6	1.510		
Total	8			

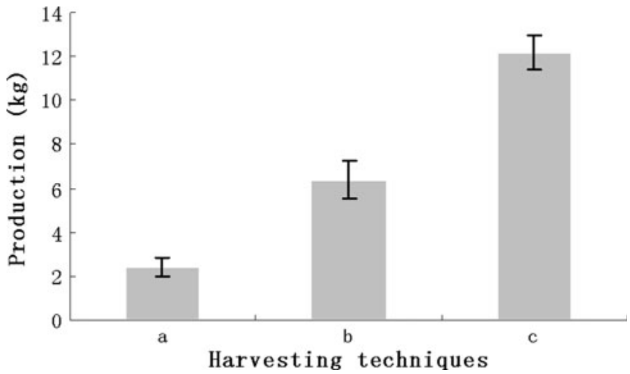


Fig. 4 *Error bar*, Mean production ± SE of harvesting technique. *Note a*, *b* and *c* stand for traditional, cutting without watering and cutting with watering respectively

The farmer innovators also found out the mushroom can only be harvested three times a year from the same spot when using the traditional harvest technique, whereas "cutting without watering" allows harvesting up to five times and the technique of "cutting with watering" allows harvesting up to six times. Because the farmers' own knowledge and innovations helped with obtaining these results, the information about the best practice has been disseminated and adopted widely. The improved harvesting technique has enabled the better quality and higher quantity of mushroom collection.

Economic and Ecological Benefits of Integrative Management

Integrated sustainable management of *T. ganbajun* leads not only to ecological benefits, but the dramatic increase in production boosts cash income from the sale of mushrooms. Table 4 presents the changes in production and economic benefits from the last four years of *T. ganbajun* management. Since 2007, the villagers started to set up institutions and regulations as well as fencing for mushroom management. This initiative resulted in significant benefits in terms of production with income reaching an average of 32.9 kg and USD 523.14 per household respectively. In comparison to 2006 when no special management practices were adopted at all, this showed an increase of 46% in production and 83% in household cash income. In the second round of on-farm demonstration, the average production increased to 43.7 kg and USD 971.71 of cash income per household, with 33% and 86% increases respectively, compared to 2007. This increase was a result of the more comprehensive strategy adopted by the farmers using the on-farm research of integrated methods, which included adjusting canopy density and litter depth, application of improved harvest techniques and watering. In comparison to 2008, a follow-up observation was conducted in 2009 that clearly shows more stable mushroom production as evidence of the effectiveness of the application of the integrative management techniques.

The better economic returns in turn provided significant incentives for the villagers to expand the application of these techniques. More members enrolled in the mushroom association from within the village and from surrounding villages. Simultaneously, the integrative techniques for *T. ganbajun* management have been disseminated and adopted rapidly not only within the association, but more widely through farmer to farmer extension and farmers' voluntary visits to the demonstration sites during the experimentation period. More recently, the county government recorded that the integrative methods have been applied in more than 4,460 hectares of forestland where *T. ganbajun* production increased 113.7 metric tons and generated revenue of about USD 2 million. The promise of economic and ecological benefits have also motivated the provincial government to scale up the adoption of this technology and catalyzed their willingness to further invest in participatory action research.

Table 4 Changes of *T. ganbajun* production and income from 2006 to 2009

Households	Area (ha)	2006		2007				2008				2009			
		Production	Cash income	Production		Cash income		Production		Cash income		Production		Cash income	
		kg	USD	kg	%	USD	%	kg	%	USD	%	kg	%	USD	%
Household A	0.40	20.0	285.71	30.4	52	431.43	51	43.2	42	987.14	129	44.4	0.027	1268.57	0.28
Household B	0.33	12.0	171.43	16.6	38	285.71	67	21.6	30	442.86	55	23.5	0.317	671.43	0.52
Household C	1.00	10.0	128.57	29.6	64	511.43	99	46.1	56	980.00	92	50.2	0.089	1434.29	0.46
Household D	1.00	37.5	428.57	47.9	28	815.71	90	51.2	7	1085.71	33	51.1	−0.002	1460.00	0.34
Household E	1.00	25.0	285.71	40.0	60	571.43	100	56.4	41	1362.86	139	51.4	−0.833	6302.86	0.08
Average	0.75	20.9	260.00	32.9	46	523.14	83	43.7	33	971.71	86	44.12	0.009	1260.57	0.30

% indicates the increasing rate of production and net income against previous year. To be comparable, it used an average exchange rate from 2006 to 2009 (1 USD = 7 CNY)

Discussion and Conclusion

Recent studies on commercial wild mushrooms as well as other forms of NTFPs have been predominantly focused on their economic importance (Kusters and Belcher 2004) and ecological function for forest (tree) conservation (Garibay-Orijel and others 2009). While other studies have examined the existing and potential negative impact on biodiversity conservation (Ticktin 2004) and equity of benefit distribution (He 2010), few studies document an interdisciplinary research effort with integrative and holistic approaches to improve mushroom management for supporting both livelihoods and biodiversity conservation. The main challenge for the researchers and policy-makers to develop a sustainable management plan of commercial NTFPs is how to build up a good social system of secure tenure and working institutions with a sufficient understanding of the species biology and ecology (Belcher and Schreckenberg 2007). The central contribution of this paper is to present a solution using the community-based mushroom management which integrates natural sciences with social science, scientific knowledge with local knowledge, and applies the interdisciplinary approach with participatory methods.

The issues of wild mushroom management are interdisciplinary in nature, whereby the biophysical considerations have to be incorporated in the context of a wide range of social, economic and political concerns (Blackstock and others 2007; Belcher and Schreckenberg 2007). Rather than focus on discipline-oriented scientific questions, this case study takes empirical questions from the field as the entry point to bring together expertise from not only scientists and other experts, but also local farmers and forestry officials. In this collaboration, different stakeholders work together to identify the causes of decline in mushroom growth and production and look for possible social organization solutions for mushroom conservation as well as to develop practical techniques for farmers. The paper shows that improved habitat management with the implementation of a sustainable harvest strategy has resulted in dramatically increased production and brought about positive ecological and economic outcomes. Central to this success is the fact that scientific knowledge can be integrated with indigenous knowledge, farmers can collaborate with scientists and government officials, and interdisciplinary integration can be achieved that leads to more locally contextual and adaptive management solutions (He and others 2009). This is a durable and equitable knowledge exchange process that promotes farmer's participation in agricultural research and extension based on the realization that farmers and researchers have different knowledge and skills which may be complementary and provide success if they work together can achieve more (Tress and others 2005; Tucker and others 2007; Fortmann 2008; He and others 2009). Thus, the participatory interdisciplinary research creates a platform for knowledge exchange and mutual learning (Vernooy and others 2006), as well as supports a process of knowledge co-generation (Percy 2005).

In addition, the participatory interdisciplinary research also significantly strengthens farmers' sense of ownership over the research process and eventually contributes to better project implementation and monitoring. Rather than treating famers as the subject of research where "traditional" experts from "hard" science take control, the paper shows that the social dimension of the research could successfully promote the active involvement of farmers in all the stages from problem identification, research design, experimentation, monitoring and evaluation to increased understanding of complex socio-ecological systems. Most importantly, the research enables the farmers to control and make decisions over the on-farm research process (see also Vernooy and others 2006). This farm-led research also significantly strengthens social capital and collective capacity. As the paper shows, the farmers established the wild mushroom association and built collective consensual decision-making mechanisms to respond to rapid environmental, economic and policy changes in the mountainous region of Southwest China.

A well-implemented interdisciplinary research approach can also serve to significantly enhance technology access and dissemination in developing countries. Farmers residing in the remote mountainous regions of Southwest China have comparatively little access to "new" technologies, which has resulted from poor infrastructure, geographic constraints, ethnic and linguistic limitations as well as ineffective extension services and systems. The conventional top-down knowledge transfer approaches have failed to address the issues of pro-poor technology access and adoption as well as efficiency and effectiveness of technology dissemination. But the participatory interdisciplinary research enables the poor farmers to obtain access to the entire process of technology development, adoption and dissemination through the farmer-centred principle and through approaches such as farmers' involvement in technology innovation and farmer-to-farmer extension (Gonsalves and others 2005).

In terms of biodiversity conservation and sustainable forestry management, there are two main policy implications drawn from this pilot project. First, it is a fact the national policy and regulations have extensively ignored the commercial NTFPs. To promote NTFPs for poverty reduction and environmental protection, it is of vital importance that the policy and legal environment improve recognition of indigenous rights over the use of NTFPs and to support the innovation necessary to develop and benefit from the NTFPs based on traditional knowledge systems

(Belcher and Schreckenberg 2007). Forest decentralization reforms could be a significant step in improving the forestry policy and legal environment (Xu and Ribot 2004). The decentralization of forest management could be achieved by strengthening community organizations and community-based NTFPs management as well as by securing forest tenure and improving governance structures.

Second, biodiversity conservation at the species level outside protected areas continues to pose a major challenge in Southwest China. As this case study shows, community conservation and site-specific or species-specific conservation is necessary to complement the state protection programs. Community conservation efforts ultimately also provide a wide range of benefits for local livelihoods. This human inclusive strategy in conservation requires not only a supportive policy and legal environment to ensure local participation and involvement of indigenous knowledge, but also external financial and technical support (Xu and Melick 2006). While participatory interdisciplinary research serves as a powerful and effective tool, more investment in raising government awareness and building capacity at all levels of stakeholders is required.

In conclusion, commercial wild mushroom harvesting could bring major economic benefits and positive conservation outcome for forest conservation in the mountainous regions of China. While the government promotes the edible mushroom industry as a win-win strategy for forest management in Yunnan Province, a broader consideration of social, ecological and policy aspects is necessary. The integration of knowledge and resources with an interdisciplinary perspective creates opportunities for farmers' participation and the incorporation of indigenous knowledge systems and local innovation. This study demonstrated the potential for technological and institutional development for the sustainable management of commercial wild mushrooms to provide livelihood benefits. The methodological and policy implications of this study can help to provide a stronger platform in the future for the application of an interdisciplinary approach that integrates the biophysical dimension into the socioeconomic aspects and incorporate farmers' knowledge and institutional innovations.

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