# Mapping the *Ophiocordyceps sinensis* value chain: actors, profits and social institutions in south-west China

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**Abstract** Commercial use of wildlife is booming. However, knowledge of trade, price structure and benefit distribution mechanisms remain limited for many endemic, threatened and economically valuable species, impeding efforts to develop conservation intervention schemes in line with sustainable objectives. We illustrate the nature of commercialization of the caterpillar fungus *Ophiocordyceps sinensis*, collected in a high-altitude Tibetan region. Using the value-chain approach, we document how caterpillar fungus is collected in a remote mountainous region and traded across a wide range of middlemen until it finally reaches high-end markets in urban centres. Mapping the caterpillar fungus value chain helps identify the actors involved and the social institutions (i.e. the rules, norms and arrangements that shape people's behaviours) facilitating access to markets and influencing profit distribution and price structure. We present the complex dynamics of this commercialization process, providing a holistic value-chain analysis that encompasses actors, profits and institutions.

**Keywords** Benefit distribution, caterpillar fungus, ethnobotany, NTFP, *Ophiocordyceps sinensis*, south-west China, value chain

## Introduction

Study of the commercial use of wild flora and fauna is an evolving field of research. Knowledge of the commercialization process can bolster development approaches to address overexploitation and illegal trade (Nuno et al., 2017; Hinsley & 't Sas-Rolfes, 2020). Through market interventions, well-targeted and well-developed strategies can reduce illegal trade and illicit consumption, as has been seen with rhinoceros horn (Truong et al., 2016), pangolins (Wang et al., 2020) and sea turtles (Thomas et al., 2020). Although reducing illegal wildlife trade is a global conservation priority, the growth of the commercial use of wild flora requires deeper understanding (Ticktin et al., 2020). In many cases the global trade of wild-harvested plants, particularly medicinal plants, is legal and plays a critical role in local economies (He, 2010; Cunningham et al., 2018). In this global trade, overexploitation and species endangerment have both been observed (Chen et al., 2019), and there are concerns about benefit-sharing (He et al., 2014). There is a need to deepen our understanding of market processes in the commercialization of wild-harvested plants to improve conservation interventions and social sustainability (Goettsch et al., 2015; Williams et al., 2018).

*Ophiocordyceps sinensis* (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora is commonly known as the caterpillar fungus, and in Tibetan as *yartsa gunbu*, which means 'summer grass and winter worm' (冬虫夏草 in Chinese; Plate 1). It is widely distributed in alpine grasslands across mountainous regions of the Himalayas and Tibetan Plateau (Cannon et al., 2009). It has been used locally in traditional Chinese medicine for centuries, but a booming market has driven a significant increase in the price of the fungus simultaneous with the growing consumer middle class in China, which is now the largest global market for caterpillar fungus (He, 2018). During 2002–2017 the price increased from c. USD 3,000/kg to USD 31,000/kg (Cunningham & Long, 2019), and global trade of caterpillar fungus is estimated to be c. USD 5–11 billion annually (Shrestha, 2012). It is now one of the most expensive traditional Chinese medicines, with a unit price that exceeds that of gold (Yeh & Lama, 2013; Woodhouse et al., 2014; He et al., 2022). Although the commercialization of caterpillar fungus contributes to the livelihoods of collectors (Winkler, 2010; Pouliot et al., 2018), the potential for overharvest in China, Nepal, Bhutan and India has been documented (Shrestha & Bawa, 2013; Wallrapp et al., 2019; Wei et al., 2021) and poses a substantial threat to future livelihoods and ecosystem functioning (Winkler, 2008; Hopping et al., 2018). Considerable international attention has been given to the caterpillar fungus (Li et al., 2021), and it is included in the China Biodiversity Red List and categorized as Vulnerable on the IUCN Red List (Yang, 2020).

The fungus cannot be cultivated (Martel et al., 2017), and harvesting contributes significantly to the livelihoods of poor local communities in the Himalayas and Tibetan Plateau. Commercial caterpillar fungus collection accounts for 53% of household income of those who collect the fungus in Nepal (Shrestha & Bawa, 2014), 40–90% in China

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PLATE 1 (a) Collecting the caterpillar fungus *Ophiocordyceps sinensis* in a high-altitude harvesting area, (b) caterpillar fungus packed for sale in a wholesale market, (c) the parasitic caterpillar fungus (top) growing in the larval body of a moth (bottom), and (d) pieces of dried caterpillar fungus being sold in a local market. Photos: the authors.

(Weckerle et al., 2010) and similarly significant proportions in Bhutan (Wu et al., 2016) and India (Negi et al., 2015). Concerns about overharvesting and market unsustainability have emerged (Smith-Hall & Bennike, 2022). Despite its importance to Indigenous mountain communities, there is a lack of knowledge regarding the commercial processes involved in caterpillar fungus collection and trade, particularly regarding its pathways from remote communities to urban markets. To our knowledge, the literature documenting the caterpillar fungus trade is mostly limited to ethnographic approaches. For example, Yeh & Lama (2013) traced this trade and its actors to provide a general overview. Sulek (2019) assessed the local relationships of actors to understand market structure. He et al. (2022) quantified the trade but limited their investigation to the consumption sector. Qualitative and quantitative approaches can be combined to secure a holistic understanding of market dynamics and profit distribution, and thus determine whether conservation intervention could achieve sustainable trade.

Here we examine the commercialization of caterpillar fungus using a value-chain approach involving a combination of qualitative and quantitative methods. Following Ribot (1998) and He (2010), we tracked the flow of products from harvest to the final market in cities, to understand the commercialization process. We mapped the value chain, focusing on the collection of caterpillar fungus in Deqin County, north-western Yunnan Province, China, and we tracked the product as it moved to the end market in Sichuan Province. By mapping this value chain, we identified the actors involved and the social institutions (i.e. the rules, norms and arrangements that shape people's behaviours) that facilitate access to the market and influence profit distribution and price structure (He et al., 2018). This approach allowed us to gain insights into the ways in which actors, profits and institutions form a value chain and how social and economic relationships are embedded within it.

## Methods

Caterpillar fungus has gained a high degree of significance and economic value because of its perceived medicinal value and its harvesting from landscapes distant from human intervention (Liang, 2018; He et al., 2022). This research was carried out in Yunnan Province, one of the five major locations in China for caterpillar fungus harvesting and trading (Fig. 1; Stewart, 2014; Yeh & Coggins, 2014; Wei et al., 2021). To map the value chain, we began with Shusong village in Deqin County, which is one of the most productive regions for caterpillar fungus in Yunnan. Shusong village lies in Baima Snow Mountain Nature Reserve, and caterpillar fungus has been collected there for > 20 years, with collection allowed even after the establishment of the Reserve in 1988. Author JH has been carrying out research in the Baima Snow Mountain region for the last 20 years and Shusong Village is a focus for the research of BF. This long-term engagement has allowed us to build trust and strong personal relations with local people and

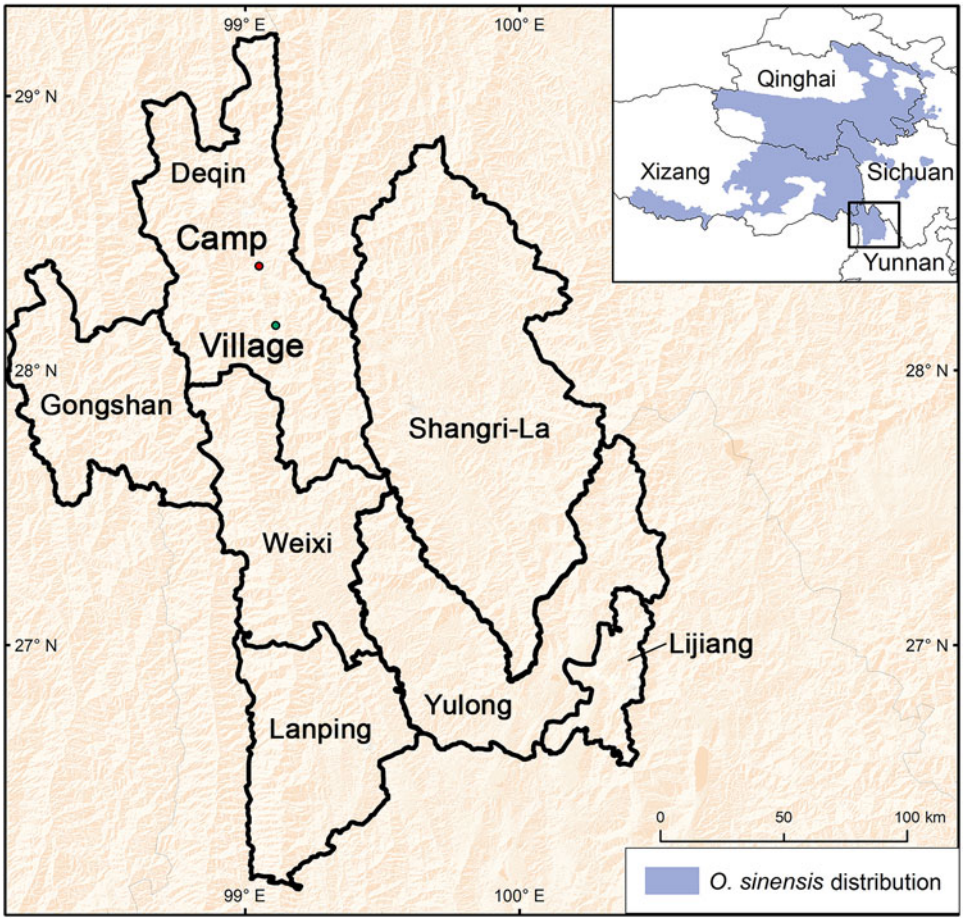


FIG. 1 The location of Shusong village in Deqin County, Yunnan Province, south-west China, and of the temporary camp in which collectors of the caterpillar fungus *Ophiocordyceps sinensis* and village-based traders reside for c. 50 days during the summer.

traders. Shusong village has 216 households and a population of 1,464. Tibetans comprise 99.8% of the population, with an annual per-capita income of USD 2,061 (CNY 13,726 at an exchange rate of USD 1 = CNY 6.66). Collecting non-timber forest products (NTFPs) is one of the primary sources of income for the residents, with revenue from caterpillar fungus and matsutake mushrooms accounting for up to 80% of their total annual income; collectors earn a mean of USD 2,372 (CNY 15,800) annually from collecting caterpillar fungus (Xie, 2017).

We employed the definition of a value chain as a network of actors 'clustered around one commodity … [and] situationally specific, socially constructed, and locally integrated, underscoring the social embeddedness of economic organization' (Gereffi & Korzeniewicz, 1994, p. 2). Accordingly, we considered the economic activities of actors along the value chain that are regulated by economic rationality and are both constrained and enabled by an array of social relations and cultures (Ribot, 1998; He, 2010). We attempted to understand the day-to-day practices of actors, which could indicate their responses to the market across the value chain. It is the interaction between non price-based mechanisms (e.g. social, cultural and political factors) and price-based mechanisms (e.g. market or economic factors) that enables exploration of the ways in which actors behave and make economic decisions. We used the value-chain approach to identify the various actors along the value chain, the profit distribution amongst the actors and the social institutions that shape market access and profit distribution along the value chain. To identify the actors in the value chain in the context of China, we incorporated Olsen & Bhattarai (2005) with He (2010) to form the typology of actors, which principally comprised collectors, village-based traders, local traders and wholesalers.

We carried out semi-structured interviews and participant observation over 6 months of fieldwork during May–June 2018, July–August 2018 and May–July 2019. As informed by Bryman (2001) regarding value-chain studies, we applied a snowball sampling strategy in the surveys of the actors involved in the trade and to obtain an overview of product flow. We conducted semi-structured interviews with all 33 people who participated in the collection of caterpillar fungus in the village in 2019, two village-based traders, 10 local traders and three wholesalers. We also interviewed two local religious leaders and five government officials at different levels in the county-level city of Shangri-La. As the value chain began in a single village,

we identified relatively few actors through the snowball sampling strategy as we only conducted in-depth interviews with the actors who had handled the products from this village. However, participatory observation of collection, transaction, and market activities at different levels of the value chain allowed us to understand market dynamics and cross-check the information obtained from in-depth interviews. We conducted the interviews mainly in Chinese, as local Tibetan and other ethnic groups speak Mandarin well because of their long-term engagement with outside traders and interactions with other ethnic groups in the area. A Tibetan counterpart helped with translation when required. We observed participants throughout the entire value chain, from collection, selling in local markets and transporting to wholesalers and consumers. This allowed us to gain a broad perspective on the value chain and to understand this trade in detail. At the final node, the consumer market, we also observed and interviewed customers and traders to examine sales patterns and identify consumer groups. We did not investigate caterpillar fungus consumption as this was beyond the scope of our study.

## Results

### Caterpillar fungus value chain

The Yunnan caterpillar fungus value chain comprises multi-ethnic actors, with the principal participants being collectors, village-based traders, local traders and wholesalers. The value chain begins with Tibetan collectors who harvest caterpillar fungus in May on Baima Snow Mountain. The c. 5 cm-long fruiting body grows on insects living on grass. Their size and colouring renders them difficult to find but once located the caterpillar fungus is dug out of the surrounding soil intact. The collectors categorize their daily collection based on size and sell them fresh directly to traders, who are generally Tibetan and Hui individuals. The specific value chain for the caterpillar fungus depends on the ethnicity of the trader, the scale of trade and the location of purchase (Fig. 2). Collectors mainly sell caterpillar fungus to village-based traders, although occasionally local traders travel to the mountains to make purchases. Because village-based traders have a limited customer base, the majority of caterpillar fungi are sold to local traders or wholesalers at the local market in Deqin. After purchase, local traders and wholesalers clean and dry the caterpillar fungi before further subdividing them into more grades and selling them to consumers across China.

Collectors do not need to pay for a collection certificate, as they do in Tibet and Qinghai. Traders do not incur any additional transaction fees or taxes, only transportation costs. However, as they are also doing business in other medicinal materials, there are no expenses specifically allocated for caterpillar fungus. During interviews, both Hui wholesalers and Tibetan traders indicated that costs were negligible (mainly expenses such as food and travel). The similarity and negligible daily expenditures of each group do not affect the analysis of their sales patterns and profitability, and we did not find other consumption patterns or expenditures that would have affected the analysis of this study.

### Actors along the value chain

*Collectors* Caterpillar fungus on Baima Snow Mountain grows at an altitude of c. 4,500 m and is known for its high quality. The sale of caterpillar fungus is one of the main sources of income for Tibetan collectors, accounting for 61% of their collective annual income. The collection site is in a mountainous area that is collectively owned by Shusong village; 21 of the collectors are men and 12 are women. Unlike Qinghai and Tibet, where production is abundant and old people and children also collect the caterpillar fungus, production is low in Shusong village and therefore old people and children are not involved in collection. Collectors search for caterpillar fungi for up to 10 h per day. Quality determines price, and a broken specimen will command $\leq$ 50% of the price of an intact specimen. Collectors sell all collected caterpillar fungi to village-based and local traders when they return to the temporary collection camp, but mostly to village-based traders living in the camp. These transactions are in cash, and so there are no late payments. Collectors do not maintain a daily record of the number of caterpillar fungi they collect, but most noted that the amount of caterpillar fungi they can collect annually is decreasing. Unexpectedly, price is also decreasing. According to the interviewees, the total annual income from caterpillar fungus is c. USD 1,500–3,000 (CNY 10,000–20,000) per collector for 4–8 pieces of fungus per person per day.

Baima Snow Mountain is a national nature reserve, where national law usually prohibits collection of NTFPs. However, the local people have a long history of collecting NTFPs in this area, and this is an important contribution to their limited livelihood options. Accordingly, the authorities have established regulations for such local collection, to ensure sustainable resource use. The annual collection period begins in May when the temperature increases and caterpillar fungi begin to emerge. This is when villagers ascend the mountain and establish a temporary camp in the area delineated for this purpose by local officials. There is no fixed time limit for collection but the collectors reside in the camp for c. 50 days, and, according to village regulations, the collection period ends on the summer solstice (c. 20 June) of the traditional Chinese lunar calendar. The collection period concludes at this time because the

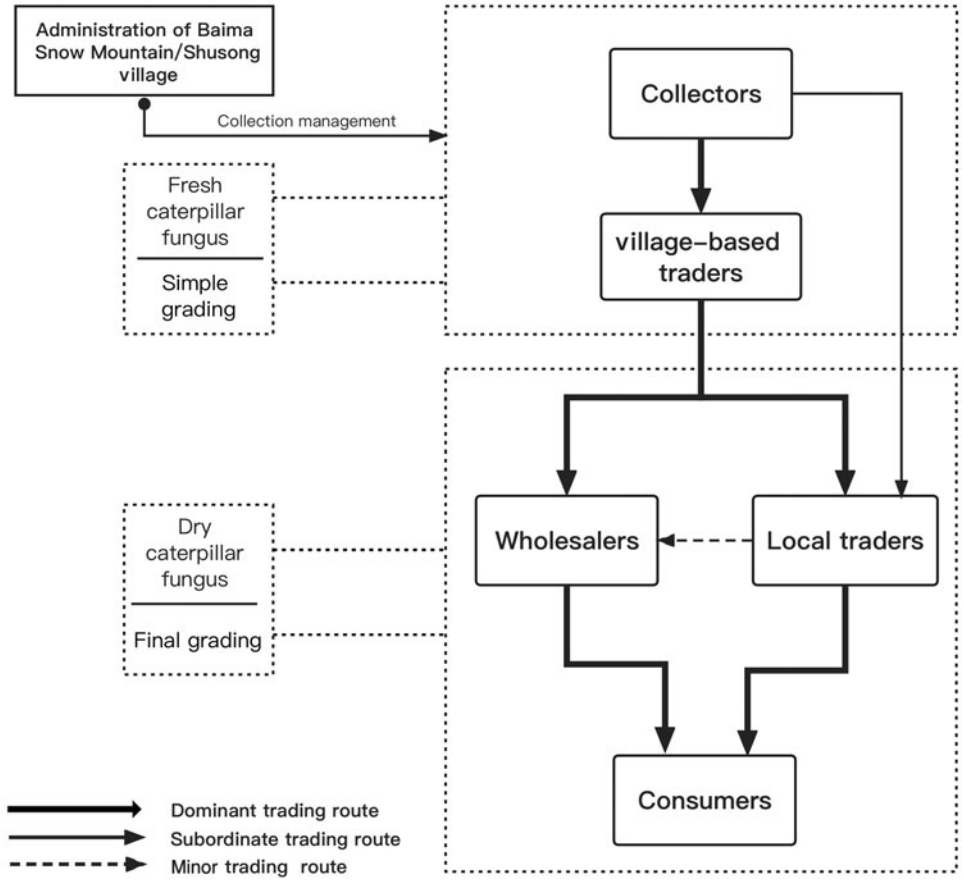


FIG. 2 The caterpillar fungus value chain, showing the main actors involved and the flows of caterpillar fungus, from Shusong village in Deqin County, Yunnan Province, south-west China (Fig. 1), to consumers.

rising temperature induces caterpillar fungus spore maturation and hollowing out, reducing the economic value of specimens and because further collection leads to the spread of bacteria and limits the number of caterpillar fungi that will be available in the following year.

*Village-based traders* The village-based traders are also Tibetans and from the same village as the collectors. They are the elite of the village, with access to some capital, and they are also typically relatives of village leaders and government officials. Village-based traders invest USD 7,500–10,500 (CNY 50,000–70,000) per year in the caterpillar fungus trade, for purchases, and secure a net annual profit of USD 3,000–6,800 (CNY 20,000–45,000) on 1–2 kg. They usually have some business experience and a good command of Mandarin, whereas many local people are only fluent in Tibetan, presenting a challenge in communicating with potential outside buyers. Some village-based traders also run small shops in the temporary camp, supplying collectors with food and drink, thus helping maintain good relationships with collectors and also generating extra income. Village-based traders brush the fresh caterpillar fungi clean of soil and divide them into two grades for sale: large and unassorted. The main customers are those who buy fresh caterpillar fungus in the nearby towns and villages. Caterpillar fungus remains fresh for only 3 days before drying and hollowing out, and therefore village-based traders need to find customers as soon as possible or sell directly to tourists. Because of the limited availability of customers, when they have a large supply of caterpillar fungi, they sell to local traders or wholesalers.

*Local traders* Local traders comprise Tibetans from several villages near Deqin County; they usually trade in groups of 4–5, to strengthen their market competitiveness. These traders invest USD 60,000–90,000 (CNY 400,000–600,000) per year in the caterpillar fungus trade, for purchases, and secure a net annual profit of USD 22,600–37,700 (CNY 150,000–250,000) on 4–7 kg. They also trade in other seasonal products such as matsutake mushrooms and shellfish. These local traders co-finance and share the risk of purchasing caterpillar fungus. They open stalls around the Deqin Bridge in the morning to sell caterpillar fungus, and travel to high-elevation villages in the afternoon to purchase caterpillar fungus. They buy directly from both collectors and village-based traders, the latter at a higher cost, clean and grade the caterpillar fungi and dry them in the sun prior to sale. Their customers mainly come from cities on the eastern seaboard.

*Wholesalers* Hui businessmen acting as wholesalers play an important role in the commercialization and trade of caterpillar fungus throughout China, including in Deqin. Most Hui wholesalers in Deqin County are from Weishan County, Dali, and they do business on a family basis. Most have been doing business in Deqin County for > 20 years and, similar to the Tibetan local traders, they also sell other herbal medicines, although their main focus is selling caterpillar fungus. Caterpillar fungus is also the product in which they invest the most and from which they most benefit. Hui wholesalers do not buy caterpillar fungus directly from Tibetan collectors but by building up a purchasing network of village-based traders. They purchase large quantities, and have relatively predictable sales. Their customers tend to be higher-income customers, such as real-estate owners, with whom they have forged long-term relationships, and these customers will buy large quantities each year. The annual investment of Hui wholesalers is USD 300,000–377,000 (CNY 2.0–2.5 million) for c. 50 kg and net income is c. USD 75,000–90,000 (CNY 500,000–600,000).

## Price structure along the value chain

The largest caterpillar fungi on the Deqin market (of which there are c. 2,000 pieces/kg), the collectors sell to village-based traders at USD 7.50 per piece. These actors then sell to local traders or wholesalers for USD 9.00, and these then sell to consumers for USD 14.25 (Table 1). Because Deqin does not regulate collection or impose trading license fees, there are no additional transaction costs for any group. Therefore, with this price structure, the collectors make a profit of USD 7.50 (53% of the total profit), village-based traders USD 1.50 (10%) and local traders and wholesalers USD 5.25 (37%).

The smallest caterpillar fungi, collectors sell for USD 5.25 per piece, and village-based traders make USD 0.38 profit per piece. Local traders and wholesalers have purchasing habits similar to those of village-based traders, purchasing large caterpillar fungi per piece and buying the rest unassorted. In the subsequent grading of caterpillar fungi there will be losses on small caterpillar fungi but gains on large sizes. Profit on one caterpillar fungus piece therefore ranges from USD −1.28 to 6.75. Tibetan local traders and Hui wholesalers indicated that the number of small caterpillar fungi is low, and what is lost on the small sizes is usually compensated by the profit on the large sizes. Along the value chain, the collectors benefit most from the caterpillar fungus harvest.

TABLE 1 Sale price, expenses and profit in the caterpillar fungus *Ophiocordyceps sinensis* trade in south-west China (Fig. 1) in 2018–2019, by the four groups of actors in the value chain and for the two principal grades of caterpillar fungus (large: 1 kg comprises c. 2,000 pieces; small: 1 kg comprises c. 4,000 pieces).

| Caterpillar fungus grade | Large | Small |
|---|---|---|
| **Sale price (USD/piece)** | | |
| Collectors | 7.50 | 5.25 |
| Village-based traders | 9.00 | 5.63 |
| Local traders | 14.25 | 4.35 |
| Wholesalers | 14.25 | 4.35 |
| **Expenses[1] (USD/piece)** | | |
| Collectors | 0.00 | 0.00 |
| Village-based traders | 7.50 | 5.25 |
| Local traders | 7.50–9.00 | 5.25–5.63 |
| Wholesalers | 9.00 | 5.63 |
| **Profit (USD/piece)** | | |
| Collectors | 7.50 | 5.25 |
| Village-based traders | 1.50 | 0.38 |
| Local traders | 5.25–6.75 | −1.28 – −0.90 |
| Wholesalers | 5.25 | −1.28 |

[1]Expenses do not include daily spending on food, or fuel for cars. Interviewees stated they would have incurred those costs for food and fuel anyway as they were also involved in other businesses in the area.

## Social institutions along the value chain

The collectors, village-based traders, local traders and wholesalers maintain and control their profit through various social institutions. Table 2 summarizes the social institutions that capture these benefits across the participant groups.

For collectors, control of access to the mountain is the basis for collecting caterpillar fungus. Only residents of Shusong are allowed to collect in the area that is collectively owned by the village. However, women who have married into other villages and people who have married into the village are also allowed to collect, and collectors supervise outsiders during collection. As Baima Snow Mountain is

TABLE 2 Social institutions (i.e. the rules, norms and arrangements that shape people's behaviours) that allow the actors in the caterpillar fungus value chain to maintain and control their profit.

| Actors | Social institution |
|---|---|
| Collectors | Access control |
| | Cross-border collection |
| | Experience & knowledge of collection |
| | Maintaining good relations with traders |
| Village-based traders | Tibetan ethnic identity |
| | Access to capital |
| Local traders | Tibetan ethnic identity |
| | Access to capital |
| | Experience & knowledge of trading |
| | Customer contacts |
| Wholesalers | Access to capital |
| | Experience & knowledge of trading |
| | Customer contacts |
| | Power in determination of grading & price |

at the junction of Tibet, Yunnan and Sichuan, where the quality and price of caterpillar fungus are known to be good, people from other provinces come to gather caterpillar fungus. Whenever local collectors find people who are not allowed to collect in the area owned by the village, they confiscate their caterpillar fungus and tools and drive them off the mountain.

Cross-border collection makes an important contribution to the income of collectors. Despite clear land ownership demarcation, the interconnectedness of the mountains and uneven distribution of resources between villages together with the absence of restrictive boundaries and lack of strong supervision have led to a situation in which collectors at their village sites will resist outside collectors, but in practice most collectors often collect across boundaries both knowingly and unknowingly. Although collecting across boundaries is not customarily supported, it is typically justified as the continuation of historical practice. Despite cross-border collection conflicts arising every year, cross-border collection provides collectors with an important supplementary source of caterpillar fungus.

Collecting experience and knowledge allow collectors to locate and dig out the caterpillar fungus. Although there is no standardized technique for this, experienced collectors can find caterpillar fungi more quickly than novice collectors. For example, it is generally easier to find caterpillar fungus in places where it has appeared before, and larvae usually appear in groups. According to one collector, inexperienced collectors 'can spend a whole day on the mountain without finding a single one'. Digging out caterpillar fungus requires digging 20 cm beneath the specimen, to reduce the chance of breakage, and excavated soil must be returned to the hole.

Maintaining good relations with traders also affects the profits of collectors. Collectors prefer traders who are flexible in their purchasing standards, so that if caterpillar fungi are broken they are still graded higher and secure the best price. Late in the season collectors are more likely to find soft or hollow caterpillar fungi. Good relationships with traders will ensure they receive consistent prices and are not undercut. Therefore, although local traders travel to the mountain to buy caterpillar fungus, few collectors sell to them because they do not come daily and lack strong relationships with the collectors.

Village-based traders purchase more caterpillar fungus than other traders on the mountain because their Tibetan ethnic identity and common language facilitate trust, and because they normally live at the temporary camp and have the opportunity to trade immediately when collectors descend each day. Tibetan local traders have the advantage of their ethnic identity when purchasing caterpillar fungus. The Tibetan language is a barrier to trade between Hui wholesalers and collectors, and therefore the wholesalers have established a network of village-based traders in Deqin by guaranteeing these traders a reasonable price and commissions on sales. These village-based traders purchase caterpillar fungus not only during the collecting season but also from collectors who have not yet sold all their caterpillar fungus by the time the collection season has closed, thus enabling the sale of caterpillar fungus to Hui wholesalers throughout the year.

For businesspeople in the caterpillar fungus value chain the amount of capital investment directly determines their ability to benefit and take risks. Some collectors want to be traders because they can earn more than by collecting the caterpillar fungus. However, the minimum annual capital investment of USD 7,500–10,500 required by most village-based traders is unattainable for most collectors. Compared with village-based traders, local traders have c. 8–10 times greater capital investment per year, and wholesalers have 40 times greater capital investment per year. Whenever the price of caterpillar fungus is low, businesspeople will reserve their supplies temporarily until the price increases, but doing so requires greater capital investment, so capital forms the basis for traders to benefit from the caterpillar fungus trade.

Experience and knowledge of trading are key for benefitting from the caterpillar fungus. Some traders are sufficiently experienced to be able to determine the dryness and grade of caterpillar fungi, and hence potential profitability, by handling specimens. Local traders and wholesalers sell dried caterpillar fungus that can be stored, and thus sold, for a longer period. After drying in the sun, caterpillar fungi are graded, and most traders believed that grading usually increases profit margins. However, village-based traders with limited experience and knowledge will only classify caterpillar fungus into two grades (large and unassorted), whereas local traders and wholesalers can grade caterpillar fungus according to common market standards into at least five grades, thus enabling them to satisfy customers with different needs and different levels of purchasing power.

Customer connections are key to businesspeople accruing benefits. The customers of village-based traders are mainly tourists and local people. Previously, highway 214 from Yunnan into Tibet passed through the temporary collecting camp of Shusong village, bringing tourists to village-based traders. However, after the new highway 214 was constructed, bypassing the camp, the number of tourists decreased. Without access to tourist customers the village-based traders were restricted to selling to other traders. In addition, the primary customer base for Tibetan local traders comprises members of the middle class from cities on the eastern seaboard such as Guangzhou and Shenzhen, but they only have a small number of long-term customers. The customers of Hui wholesalers are distributed widely, mainly comprising real-estate owners and other higher-income customers who maintain long-term

contact and have the financial strength to pre-order caterpillar fungus before the annual collecting season begins.

The Hui wholesalers determine grading and pricing in the local caterpillar fungus market, dominating the flow of information in Deqin. Collectors on the mountain indicated that prices are mostly determined by the Deqin market, and most of the information on the state of the market originates from Hui wholesalers, with the Tibetan local traders adjusting their prices according to the prices offered by these wholesalers. Hui Muslims have a reputation for business acumen; their religion encourages men to do business for their families, and weekly prayer rituals facilitate exchange of information for developing business networks. Each year, before the start of the caterpillar fungus collecting season, local Hui people in Deqin obtain information by contacting Hui businesspeople in other large Chinese caterpillar fungus trading markets such as Lhasa and Xining through informal networks within their community. The price will be set for the current year according to purchase prices in these other cross-border Hui Muslim community hubs, prices in the previous year and estimates of production for the current year. Caterpillar fungi are excavated in several regions, and once the annual supply has stabilized, the initial price point will be adjusted in accordance with a variety of factors. Village-based traders believe that, as for other NTFPs, fresh caterpillar fungus is of the highest quality, whereas Hui people believe that fresh caterpillar fungus makes the consumer more prone to illness if eaten directly, and they prefer the dried caterpillar fungus. Neither of these views is rooted in evidence, but they are manifested in the form of caterpillar fungus that each group sells. Because of the capital and sales capacities of Hui traders, consumers have a high degree of confidence in Hui claims about the fungus.

## Discussion

We have applied a value-chain approach to examine the commercialization of caterpillar fungus, with a particular focus on the actors involved, the profit distribution and the social institutions along the value chain. We highlight three implications of this research for sustainable livelihoods centred on caterpillar fungus and the importance of integrated social-economic analysis across the value chain for future research on NTFPs.

Firstly, our research revealed that middlemen play an important role as a bridge between collectors and consumers. Any perturbation of their role could affect the value chain and harm local livelihoods, as has been observed for other NTFPs (Abtew et al., 2012; He, 2018; Pouliot et al., 2018; Yadav et al., 2019; Shrestha et al., 2019). Our analysis of price structure indicates local middlemen do not extract unreasonable profits, and thus are not exploiters of the market. Rather, local middlemen facilitate the flow of the caterpillar fungus trade, making its commercialization possible and contributing to local livelihood development. Despite the increasing presence of online shops and e-commerce that could potentially link collectors directly to consumers, for collectors from Shusong village language barriers, high transaction costs and lack of familiarity with this new market prevent them from trading caterpillar fungus directly with consumers. In this case the benefits provided by middlemen in terms of language, experience and capital are indispensable, allowing them to facilitate the flow of the caterpillar fungus trade.

Secondly, we found that social institutions shape access to markets and profit distribution, as has also been observed previously (He, 2010; He et al., 2018). Tibetan ethnic identity plays an important role in collection and trade. Tibetan local traders have direct access to the market in the mountains as they live with the collectors in the temporary collection camp, and the trust that stems from their shared Tibetan identity helps maintain strong working relationships with the collectors, which persist over the long term. Even if traders from elsewhere offer higher prices, collectors prefer to trade with other Tibetans because of their long-term stable commercial relationships. Ethnic identity and language also prevent Hui wholesalers from entering the temporary collection camp to purchase caterpillar fungus directly, safeguarding the position of Tibetan traders in the value chain. Hui traders have a network of local purchasers, and their contact with local Tibetans traders ensure their access to resources. Thus, although it is important to understand how caterpillar fungus commercialization is changing rural life (Sulek, 2019), our research highlights how pre-existing social institutions play a key role in shaping market access and profit distribution.

Thirdly, in light of the broad literature on the conservation science of trade (Shrestha & Bawa, 2013; He et al., 2018; Smith-Hall & Bennike, 2022), the sustainable use of caterpillar fungus requires conservation intervention across all levels of the value chain alongside a robust understanding of its economic, social and cultural factors. To foster market sustainability, eliminating middlemen is not a panacea, as has been argued (He, 2010). This is because these village-based and local traders play a crucial role in connecting remote communities to an integrated market structure, and significantly contribute to local livelihood strategies and economic development. What needs further understanding are the motives governing the behaviours of stakeholders and how to develop market infrastructure and improve transparency and information flow. In the local trade, the sales model for collectors could be improved. The price of caterpillar fungus is largely controlled by outside traders, the Hui people. Centralization of sales on a village basis would help collectors control prices, and could increase the role of the village and facilitate more effective

management of caterpillar fungus collection, thus facilitating sustainable development and promoting the equitable distribution of benefits throughout the value chain. Our research also suggests that culture is embedded in the value chain, shaping the ways in which people access and benefit from this trade. In particular, ethnicity plays a role in the formation of the value chain, as has also been found for the mushroom trade (He et al., 2018). This indicates that improving the sustainability of NTFP trade requires an understanding of both the natural and social aspects of the extraction and trade.

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**Conflicts of interest** None.

**Ethical standards** The photographs were obtained non-invasively and the survey and implementation protocol were approved by the ethics committee at the School of Ethnology and Sociology, Yunnan University (YNU-2019-12017000372), and this research otherwise abided by the *Oryx* guidelines on ethical standards.

**Data availability** The data that support the findings of this study are available from the corresponding author upon reasonable request.

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