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Caterpillar Fungus (*Ophiocordyceps sinensis*) Production and Sustainability on the Tibetan Plateau and in the Himalayas

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Abstract

Caterpillar fungus (*Ophiocordyceps* = *Cordyceps sinensis*) is an entomophagous fungus endemic to the Tibetan Plateau and the Himalayas. It has become the most important source of cash income in wide areas of the Tibetan Plateau, where it is known as *yartsa gunbu*, 'summer grass winter worm'. The market is driven by Chinese consumers, who refer to it as *dongchong xiacao*. The value of this myco-medicinal has increased by 900% between 1997 and 2008, creating a globally-unique rural fungal economy. However, actual annual production data is still not available for many areas of the Tibetan Plateau in China as well as the Himalayan production areas of India, Nepal and Bhutan. This paper analyses available production data and estimates the total annual production in the range of 85 to 185 tons for all production areas. Current availability of multi-annual production figures is limited and allows only for provisional estimates regarding the sustainability of current harvesting quantities. Centuries of collection indicate that caterpillar fungus is a resilient resource. Still, unprecedented collection intensity, climate change and the recent economic dependence of local economies on caterpillar fungus calls for sustainable resource management. Absence of long-term field studies indicating best management practices—at best in their infancy in some production areas—necessitate a degree of improvisation in designing resource management strategies. The development of easily implementable approaches that can rely on community support will be crucial for successful management. Most promising from a socio-economic, administrative and also mycological perspective is the establishment of an end date of the collection season, which might allow for sufficient spore dispersal to guarantee sustainability.

Keywords

Tibet, *yartsa gunbu (Cordyceps sinensis)*, mycology, rural economy, biodiversity, sustainable development

Introduction

Caterpillar fungus (*Ophiocordyceps sinensis*) known as *yartsa gunbu* (Tibetan*: dbyar rtswa dgun 'bu*), 'summer grass-winter worm' or simply *bu*—'worm'—in Tibetan, alias 冬虫夏草 (*pinyin: dongchong xiacao*) is a fungus endemic to the Tibetan Plateau and surrounding Himalayas that parasitises the larvae of ghost

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moths (*Thitarodes* spp.). Together, the dried club-shaped fruiting body with the larva is traded as a precious medicinal. Thus, the terms caterpillar fungus, *Yartsa gunbu* and *dongchong xiacao* describe an organism more complex than simply the fungus *Ophiocordyceps sinensis*. *Ophiocordyceps sinensis* is an entomophagous flask fungus in the newly recognized family Ophiocordycipitaceae (Pyrenomycetes, Ascomycota).[1] At the same time when establishing the new family, *Cordyceps sinensis* was transferred to the new genus *Ophiocordyceps*, and thus renamed *Ophiocordyceps sinensis*. However, in everyday usage *Cordyceps sinensis* is still accepted and will therefore be used interchangeably with *Ophiocordyceps sinensis* throughout this paper.

Caterpillar fungus occurs in alpine ecosystems on the Tibetan Plateau and surrounding Himalayas. In China, the distribution area spans the Tibet Autonomous Region (TAR), Qinghai, Sichuan, Gansu and Yunnan Provinces. In the Himalayas it is collected in Nepal, Bhutan and India (especially Uttaranchal, Sikkim and Himachal Pradesh). It is distributed in grass- and shrub-lands that receive a minimum of 350 mm average annual precipitation. It is found at an altitude of 3000–5000 meters above sea level rising from the east to the west of the Plateau. Locally it occurs within an altitudinal range of 500 m around the potential tree line. Reliance on livestock herding on the Plateau has increased the habitat of caterpillar fungus substantially through continuous expansion of its pastoral areas at the expense of forest ecosystems.[2] In general caterpillar fungus is a spring fungus, like morels (*Morchella* spp.). The fruiting season starts as early as mid-April on the eastern slopes of the Tibetan Plateau, but in most other locations in May, and lasts locally about six weeks. However, the fruiting is delayed locally with increasing altitude, thus the fungus can be collected for nearly two months at different altitudes in some areas. By mid-June to mid-July the collection season is over, but mature fruit bodies with low value are reported to persist into August.

Yartsa gunbu use and collection probably dates back at least a thousand years in Tibet, but first scriptural reference of *yartsa gunbu* in Tibetan Medicine is found in a fifteenth-century text authored by Nyamnyi Dorje (1439 to 1475), *An Ocean of Aphrodisiacal Qualities—A special work on* Yartsa Gunbu.[3] In Traditional Chinese Medicine (TCM), so far the first known mention is by 汪昂 (Wang Ang) in 1694 in 本草備要 (*Ben Cao Bei Yao*), the *Complete*

[1] Sung et al. 2007.

[2] Winkler 2005.

[3] Winkler 2008a. This text has been translated into English in cooperation with Tibetologist Jakob Winkler and is published in Winkler 2008b and posted on my webpage: www.danielwinkler.com.

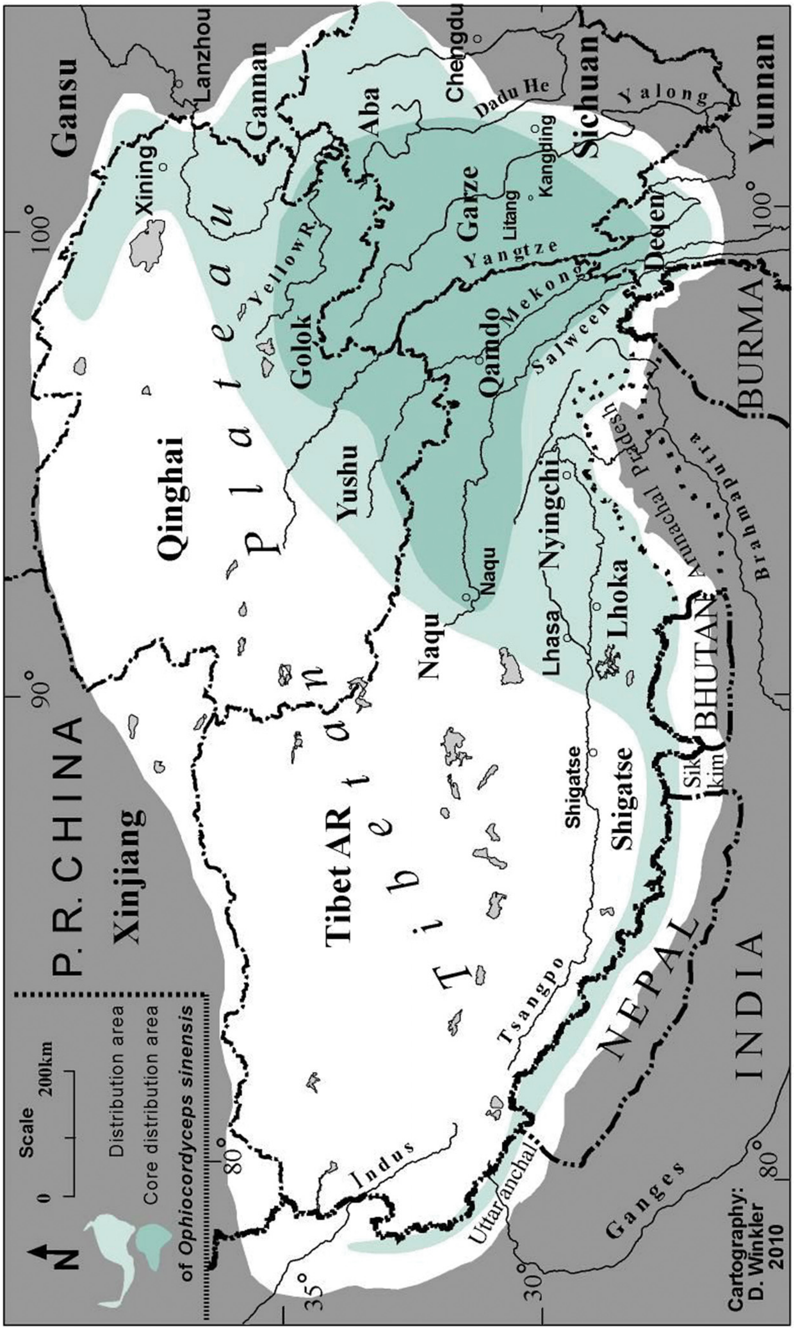

Fig. 1. Distribution area of Yartsa Gunbu (*Ophiocordyceps sinensis*)

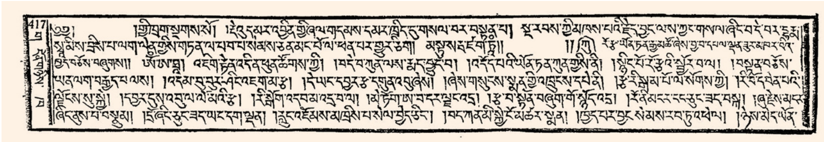

Fig. 2. First folio of the Tibetan text on *Yartsa Gunbu* by Zurkhar Nyamnyi Dorje

Essentials of Materia Medica.[4] The first Western report was published in 1736 by the Jesuit priest Du Halde who was treated by the Emperor's physician at the imperial court with *Cordyceps*. Du Halde reported its Chinese name as *Hia* [sic] *Tsao Tong Tchong.*

In traditional Tibetan and Chinese medicine *Ophiocordyceps sinensis* is recognized as a powerful tonic and aphrodisiac. It is also prescribed for lung, liver and kidney issues. Western medical research on *O. sinensis* suggests anti-tumour, anti-viral, and anti-cancer activities,[5] immuno-modulating effects, anti-oxidation, reduction of cholesterol, and increase of stamina and libido. Each year dozens of new medical research papers on *O. sinensis* are published, especially in East Asia.[6] However, to understand the current phenomena of increasing value one has to realize that this myco-medicinal is mostly consumed by Chinese communities in the PRC and elsewhere in East Asia. Furthermore it has also become a fashionable luxury product, often given as a gift, and a culinary status symbol in China, especially during the Chinese New Year. Caterpillar fungus is also popular in Japan and Korea. However, this expensive natural product has not really reached the western market. Most *Cordyceps sinensis* consumed in the West are pills made from the ground mycelium, the network of fungal strands (hyphae) artificially grown on grains. It is sold for a fraction of the price of the natural product.

The quality of caterpillar fungus is judged mostly on the basis of the size of the larva, which is also expressed in the amount of specimens it takes to yield one pound (500g). One pound of the biggest *yartsa gunbu* consists of 800 to 900 dried and cleaned specimens. Medium quality requires about 1200 to 1500 specimens, the latter already regarded in the TAR as low quality. It requires about 1500 to 2000, sometimes even 2500 specimens of Himalayan *yartsa gunbu* to weigh in at one pound. Another very important quality feature besides larval size is the ratio of the size of the stroma, the fungal fruit body growing out of the head of the larva, versus the size of the insect larva. The

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4 Winkler 2008a.

5 For the latter see Wong et al. 2010.

6 For detailed references see Canney (2006), Holliday & Cleaver (2004), and Zhu, Halpern & Jones (1998); for a timely critical review of a range of medicinal studies see Paterson (2008).

highest value is attributed to a *yartsa gunbu* whose stroma is a bit shorter than the larva or at least not much longer, since in general this ratio indicates the timing of the harvesting; the right point is believed to optimize the medicinal potency.[7] These quality issues are here described in detail since they are also an important consideration in the context of resource management.

This ratio of stroma to larva is mostly dependent on the timing of the collection in the lifecycle of the fungus. The main approach to secure an optimal ratio is to collect caterpillar fungus early in the season. This results in terminating stroma growth by removal from the ground before the stroma has reached its full length and before the spore-producing tissue, the perithecium that contains the ascus cells, is developed or even starts to develop in the top third of the stroma. In short, these specimens are collected before sporulation and thus the fungus has no chance to disperse spores for future larvae infection. Since immature specimens, which Tibetans refer to as *nga bu*,[8] meaning early *yartsa gunbu*, are the most desired of all caterpillar fungi, collectors aim to dig most of their *yartsa gunbu* during this early stage.[9] An undesirable larva-stroma ratio results when the caterpillar fungus is harvested very late in its lifecycle, towards the end of the collection season, 'when nearly all fungi are sporulating and the search is terminated although there are still healthy fruiting bodies in the ground. These are left behind since the larva is so deteriorated that the fungus becomes nearly worthless'.[10] At this point most biomass will have been shifted above ground to facilitate sporulation, as the fungus exhausts its mycelial reserves in the larva; the exoskeleton of the larva turns into a soft and empty shell, which will shrink substantially in the drying process.[11] Tibetans know such late-stage caterpillar fungus as *tshar bu*, meaning 'done' or 'finished' *yartsa gunbu*. It has the lowest economic value, often just a fraction of a specimen harvested in prime condition. To avoid overpaying for late stage caterpillars, buyers usually squeeze not-fully dried larvae to assess

[7] These traditional concepts regarding an optimum in potency have not been scientifically studied yet, to the best of my knowledge.

[8] *Nga* (*snga*) means 'early'. *Bar bu* is the Tibetan name for *yartsa gunbu* in the middle of its growing cycle (like *bar* in bardo, the in-between state, or also meaning 'middle') and *tshar bu* for its final stage (after Lama 2007, p. 72).

[9] For further objectives in early digging by collectors see Steward (2010).

[10] Winkler 2008b.

[11] Some caterpillar fungi have disproportionately long stroma. The fungus grows an elongated stroma when the larva overwintering in the top layer of the mineral soil is covered with a thick duff layer. Thus the stroma has to grow longer than usual to reach above ground to facilitate spore dispersal. Elongated stromata occur on sites with a high accumulation of under-composed biomass, i.e. in subalpine forest environments, where only a small fraction of caterpillar fungi are found. In the case of an elongated stroma, the larva-stroma ratio can be easily corrected by the collector or dealer by clipping the top part of the stroma.

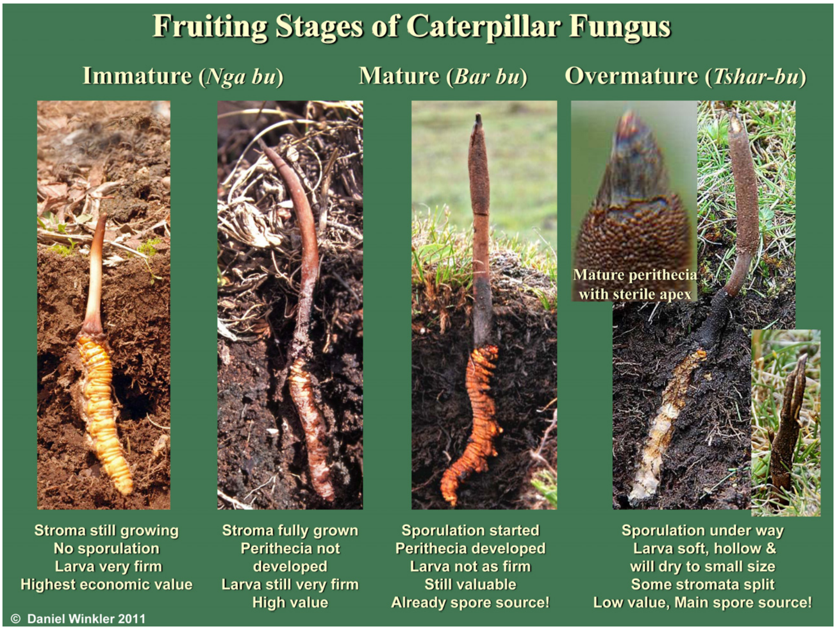

Fig. 3. Fruiting Stages of *Ophiocordyceps sinensis*

their firmness, an important sign of quality. However, at this stage sporulation is taking place and spore dispersal can continue for several weeks, thus the fungus has high ecological value. Many collectors still dig specimens at this stage in full awareness of the reduced economic value. Traders often remove the tiny larva and the stroma is sold alone, traded for only a third of the value of the smallest caterpillar fungus, on a weight basis. Interestingly, Steward points out that the market's focus on the early stage *yartsa gunbu*, which seriously undermines spore distribution, and the consequential lower value attached to sporulating *yartsa gunbu*, could 'rather paradoxically serve as a means to sustain' the population, since it would be less of a sacrifice to leave them in the ground.[12]

The caterpillar fungus collected in Bhutan and other Himalayan areas[13] is traditionally known in Tibet as *go marpo*, meaning 'red head', for the darker red color of the larval head segment. This distinction is based on the host

[12] Steward 2009, p. 20.

[13] The other Himalayan areas besides Bhutan are: the Himalayan regions of Nepal and India as well as the narrow Himalayan region in TAR, which is administrated in the prefectures of Shigatse (pinyin: Rikaze), Tsetang (or Lhoka, pinyin: Shannan) and Nyingchi (pinyin: Linzhi), formerly known as Kongpo.

insect and not the fungus, although Zang and Kinjo (1998) had claimed that the Himalayan *Cordyceps* was a distinct species, *C. nepalensis*. However, this has been disproved by recent DNA studies.[14] As reported above, the Himalayan caterpillar fungus is much smaller than most Tibetan Plateau fungi, since the parasitized Himalayan ghost moth larvae are smaller than most of their Plateau cousins. As size is perceived as a major quality aspect, this reduces the value of *go marpo*. However, even if *go marpo* has the same size as regular *yartsa gunbu* it is still less valued. So far the source of this traditional evaluation is not clear. Apart from differences in size, there is no scientific evidence that supports this traditional bias against the Himalayan *go marpo* that would explain why Bhutanese collectors only receive 30% to 60% of the value of Tibetan *yartsa gunbu* for their caterpillar fungus. Biochemical assays could change such perception if the results were to indicate that the active ingredients such as Cordycepin are comparable in the Himalayan and Tibetan caterpillar fungi.

Economic relevance of caterpillar fungus collection

Caterpillar fungus has been collected for centuries in substantial amounts.[15] In recent years value and collection intensity have immensely increased: its value increased by 900% between 1997 and mid-2008. In mid-2008, average quality sold for ¥30,000 ($4,400) per *jin* (500g), while top quality sold for up to ¥80,000 ($13,200) per *jin* in Lhasa. In Shanghai, the same quality *yartsa gunbu* at that time fetched up to ¥160,000 ($26,400).[16] The enormous value of this commodity has led to ever-increasing collection pressure. For example, Dengqen County officials (Qamdo Prefecture, TAR) reported in an interview that 37,000 of its 60,000 inhabitants participated in caterpillar fungus collection in 2005. The importance of the income from fungus collection and trade for rural Tibetans cannot be overemphasized. In 2004, TAR caterpillar fungus production figured at 50.5 tons. At a market price of ¥18,000 / *jin* this represents a value of ¥1.8 billion, equaling 8.5% of the GDP of the TAR, exceeding the value of the secondary sector of mining and industry (¥1.5 billion in 2004).[17] In prime collection areas of Qamdo and Naqu Prefectures caterpillar fungus collection contributes 70–90% to the household income. In rural areas and in small towns, which are settled by 93% of the TAR population, per capita income from caterpillar fungus collection in 2004 figured at ¥463 based

[14] See Sung et al. 2007.
[15] Winkler 2008a.
[16] Winkler 2008b.
[17] Tibet Statistical Yearbook 2004.

on a conservative value of ¥11,000 per *jin*, representing 25% of rural denizens' per capita income (¥1,861 in 2004). Thus, the contribution to cash income is at least 40% of that earned by the rural population in the TAR.[18] The contribution of *Cordyceps* to household income has further increased since 2004, through early 2008 when value peaked; but during the global financial crisis, caterpillar fungus prices came down 30–40% in China in late 2008 retreating to 2006 levels.[19] A poor harvest in 2009 in the TAR, attributed by some collectors to an unusually dry spring and a belated arrival of the monsoon rains, pushed prices in summer 2009 back to nearly pre-crisis levels, where roughly they also remained in 2010. However, even taking all these fluctuations into account, caterpillar fungus income contribution is crucial for rural communities and its loss in rural areas would have a catastrophic impact.

Impact on rural communities

This stream of cash income to rural communities from collection and trade of *yartsa gunbu* has caused a far-reaching transformation of social and economic conditions in the last fifteen years. *Yartsa gunbu* income provides cash for health care, education, transportation—especially motorcycles—consumer goods and 'spore' money for entrepreneurial activities such as trade as well as community activities. It also opened access to bank loans, which were next to impossible to obtain for rural Tibetans. Thus, the income derived through the collection and trade of this precious myco-medicinal has led to an empowerment of marginal communities, often living in extremely remote locations, who used to secure their survival only through pastoral and agricultural activities. Furthermore, the cash influx has led to a commodification of local production and services. In fungal resource rich areas, formerly non-cash based exchanges of local products, and more intriguingly neighborly work assistance, is now being compensated in cash instead of bartered goods or work exchange. Farming or herding work services are solicited with the newly available cash resources. Thus, the caterpillar fungus boom is facilitating the integration of rural Tibetan households into regional, national and international economic cycles by providing the necessary product and cash in exchange for participation in this commodity trade.

However, this transformation is also causing challenges. In the past, community disputes mostly occurred over grazing rights. Nowadays, they are now

[18] All figures from Winkler 2008a and 2008b.
[19] Winkler 2008b.

mostly fought over access to caterpillar fungus resources, and some of these turn violent, resulting in a few deaths each year. The availability of cash allows for outsourcing of services, which by itself is not negative. However, outsiders are often hired for construction and other jobs even as locals are not taking up such trades to satisfy community needs for such services. Training locals in such trades would strengthen local economies and generate income year round. However, the immense income that can be made from *yartsa gunbu* collection undermines engagement in long-term economic activities which offer much smaller economic returns.

In recent years, an array of research papers has shed light on the *yartsa gunbu* phenomenon from many perspectives, such as anthropology, geography and economics, documenting the impact especially on rural Tibetan communities.[20] Research on the Caterpillar fungus phenomenon and its impact on Himalayan communities were published by Sharma (2004), Shiva (2006), Negi et al. (2006), and Cannon et al. (2009), among others. All these papers clearly demonstrate how intricately the income generated from *yartsa gunbu* collection and trade is now interwoven with local socio-economic processes and how dependent these communities have become on the income generated by this medicinal fungus.

Most observers, just glancing at this phenomenon, quickly pose a key question. Is this production boom sustainable? Unfortunately, we do not have an answer to this crucial question that is based on sound scientific methodology. This is very perplexing considering how important *Cordyceps* income is for households all over the Tibetan Plateau and the Himalayas. Based on field data I collected with Luorong Zhandui in 2005, I have calculated that *Cordyceps* provided on average 40% of rural cash income and 8.5% of the GDP of the Tibet Autonomous Region (TAR). Furthermore, in prime collection areas in TAR, such as the Sok, Baqen and Biru in the South of Naqu Prefecture as well as Dengchen and Riwoqe counties in the North of Qamdo Prefecture *yartsa gunbu* provides more than 50% to the overall local household income, and probably 80–90% to the cash income. Similar, astonishingly high financial contributions are also observed in the prime collection areas of South Qinghai.[21] For Yushu Prefecture, Gruschke (2008) calculated that the value of the *Cordyceps* harvest is three times as high as the total budget of the Prefecture! Costello (2003) and Sulek (2009) described how far reaching the impact of the *Cordyceps* economy is on households in Golok Prefecture. Though the percent of income derived from *yartsa gunbu* is probably not as

[20] Cf. Boesi 2003; Costello 2003; Winkler 2003, 2005, 2008a, 2008b; Luorong 2005; Lama 2007; Gruschke 2008; Boesi and Cardi 2009; Steward 2009; Sulek 2009.

[21] Winkler 2008a.

high in the Tibetan Autonomous Prefectures of western Sichuan,[22] northwest Yunnan,[23] and southwest Gansu and eastern Qinghai,[24] it is still unmatched by any other product's contribution to local incomes.

Annual Production

Thus far, research that collates all the caterpillar fungus production data available to present a reliable estimate on the overall annual production of *yartsa gunbu* is lacking. I had previously published an estimate of the overall annual caterpillar fungus production as 100 to 200 tons.[25] In the current paper, I will try to fine-tune that estimate. However, this figure is still provisional and the quality of the data used to calculate the estimate differs widely. My overall intention is to make the case that more reliable data are needed to move from an estimate to a reliable figure. Having reliable data is of great importance to understand the industry, its importance for the whole region and also to assess its sustainability in light of the lack of sound, long-term *in-situ* studies on the impact of intense annual collection.

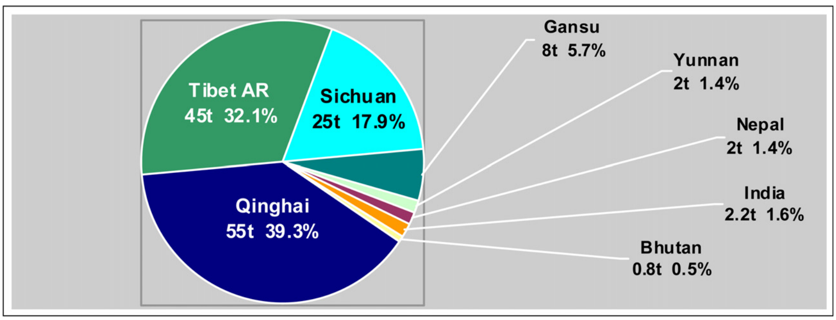

Fig. 4. Estimated Caterpillar Fungus Production by Production Region

[22] Winkler 2003, 2005. In the certain areas of the prefectures of Garze, Aba, Qamdo, Nyingchi and Deqen, pine mushroom or matsutake (*Tricholoma matsutake*) is also of great relevance in regard of rural cash income generation (Winkler 2008b).

[23] Steward 2009.

[24] For eastern Qinghai Province's Huangnan (Malho), Hainan (Tsolho), and Haibei (Tsojang) Autonomous Prefectures, I am not aware of any *yartsa gunbu* production numbers.

[25] Winkler 2008a. All weight units used are based on the metric system.

Generating any estimate on the current state of fungal production is a challenging exercise. Anybody familiar with fungi is aware of the enormous fluctuations in yearly production of fruiting bodies, generally perceived as the result of fluctuations in weather. And of course there is the secrecy about collecting mushrooms, a phenomenon common to mushroom collectors across many cultures in order to protect one's 'own' hunting grounds from other collectors. Furthermore, the data available has been generated using a wide range of methods, from informed estimates to detailed collection of harvest amounts on household level (reported to township, county and prefecture level by government agencies in the TAR, for example). And there are recent sales figures recorded at government prescribed auctions in Bhutan. Still, even in the latter two scenarios there is space for uncertainty.[26] Incongruities in data collected at the household level can appear when collectors do not want to disclose how much they are actually collecting or if people exaggerate their collection success.[27] Furthermore, since the product is so valuable there is also reason to believe that some agencies have incentive to underreport the harvest quotas, a trend observed in the case of reports on the collection totals from county to prefecture level.[28] In the case of Bhutan's government, an auction system was established to optimize rural income, but not all fungi are necessarily going through these official channels.[29] Still, both approaches are generating very useful data on harvesting amounts that could indicate major production patterns over time, which could be analyzed to infer mechanisms for decreases in *yartsa gunbu*, whether for climatic reasons or the impacts of continuous intensive harvesting, the paramount concern when arguing for the necessity of resource management. The availability of data in India and Nepal has improved substantially with localized studies in the main production areas by Negi C. et al. (2006) and Negi P. et al. (2009) for Uttaranchal, India and Devkota (2006, 2009) for Dolpa, but reliable data for other caterpillar fungus producing areas in the Nepal and India Himalaya is still lacking. On the Tibetan Plateau somewhat reliable data is still missing for harvest amounts in

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[26] For Bhutan, Nigel Hywel-Jones reports: 'We have good evidence that locals are sending some of their harvest over the border into Tibet. And one year, when Tibetans realised there was a higher price in Bhutan they were sending their Tibetan *Cordyceps* to be sold by Bhutanese at the auctions. So, even the auction records from Bhutan don't give an accurate picture of what is being collected and traded in Bhutan!' (personal communication via email 5-2-2010).

[27] During our 2005 fieldwork in a range of counties in the TAR, Luorong Zhandui and I asked collectors if they had been questioned about their collection amounts by local officials. Many interviewees confirmed that they had. When asked if they were reporting actual numbers, some replied, 'Why should I? It is none of their business!', while some assured us, 'Of course, I would tell nothing but the truth'.

[28] Winkler 2008b.

[29] Cannon et al. 2009.

northwest Yunnan and western Sichuan. Hopefully this data will become available soon.

This table outlines the annual production of *O. sinensis* based on the Chinese political units used on the Tibetan plateau; when available multi-annual and multi-source averages are used.

Province		**Tibet AR**	**Qinghai**	**Sichuan**	**Gansu**	**Yunnan**	**Total**
Annual production in kg	**Estimate**						
	low	30,000	35,000	10,000	4,000	1000	80,000 kg
	medium	**45,000**	**55,000**	**25,000**	**8,000**	**2,000**	**135,000 kg**
	high	60,000	70,000	32,000	10,000	3,000	175,000 kg
Source		TAR Gov. data[30]	Qiu Jianjun & Li et al. (2010)[31]	Dai 1994 & Estimate[32]	Zhao et al. 2010 Estimate[33]	Estimate[34]	

Fig. 5. Annual Caterpillar fungus Production on the Tibetan Plateau in China in Kilogram

[30] Caterpillar fungus production numbers were obtained from TAR Ministry of Agriculture with assistance of Luorong Zhandui, China Tibet Research Center, Beijing. Figures from 1999 through 2004 have been published in Winkler 2008a.

[31] Li et al. (2010) report for Golok TAP alone 23t and Qiu Jianjun 40t in 2008 (Presentation at Xining International *Ophiocordyceps sinensis* Conference June 2010).

[32] Estimate based on Dai 1994 reporting an annual production of 10–20 tons for Garze / Ganzi TAP alone. However Aba is also a major production area and some *Cordyceps* is collected in Muli Tibetan Autonomous County and elsewhere in Liangshan Yi Autonomous Prefecture. A brochure from a major *Cordyceps* dealer at Chengdu's Hehuazi market reports an average annual harvest of 32t in western Sichuan.

[33] Before June 2010 there were no *Cordyceps* production data for Gansu available, but an estimate based on the following extrapolation was made; using the grassland area of Qamdo Prefecture (5,600,000 ha according to 'Land Use in Tibet' 1992) and the average annual harvest of 15.1 t (Winkler 2008a) between 1999–2004, I calculated roughly eight specimens per hectare at 3000 specimens per kg. Multiplying the pasture area of Gannan of 2,510,000 ha by eight spec. / ha I arrive at 20.08 million specimens that would weigh in at 6693 kg at 3000 specimens per kg. [Note, caterpillar fungus concentration in its prime habitat is much higher, i.e. Cannon *et al.* (2009) report from transects of two test plots in Namna, Bhutan 156, resp. 256 specimens per ha. Negi (2009) reported 350–1100 spec. per ha in caterpillar 'hot spots' in Johar, Uttaranchal, India]. However, at the Xining International *Ophiocordyceps sinensis* Conference June 2010 production figures for Gansu were reported by Zhao et al. (2010) at 8.1t average annual harvest, the figure used in the table.

[34] This estimate is based on information provided by Li Jiyue (communication by email April 2010) that the government of Dechen TAP reports an annual production of 300 kg. Yang (2008) reported for the 1980s an annual *Cordyceps* production in northwest Yunnan's main production areas of close to 900 kg. Overall, it seems to be a low estimate.

To arrive at an estimate for the global production of caterpillar fungus, the three Himalayan countries of Nepal, India (including Sikkim), and Bhutan need to be added to the production calculations of the Tibetan Plateau; all of these areas contain *Cordyceps* habitat and should therefore be included in any estimates.

Country		**India**		**Nepal**		**Bhutan**[37]	**Total**
Annual production in kg	**Estimate**	Uttarakhand	Other areas[35]	Dolpo[36]	Other areas		
	low	1,250	450	500	500	500	3,200 kg
	medium	**1,500**	**750**	**1,000**	**1,000**	**750**	**5,000 kg**
	high	1,800	1000	1,700	1,500	1,500	7,500 kg
Source		Negi 2009[38]	Estimate	Devkota 2009	estimate[39]	Cannon *et al.* 2009	

Fig. 6. Annual Caterpillar Fungus Production in Himalayan Countries[40] in Kilograms

[35] This includes the production in Himachal Pradesh, Sikkim and western Arunachal Pradesh.

[36] These are rounded amounts. Shiva Devkota kindly pointed out to me in an email that the District Forest Office in Dolpo collected revenue from *Cordyceps* for the following amounts, in 2006 (148 kg), 2007 (241 kg), 2008 (773 kg) and 2009 (872 kg). Overall production in Dolpo is almost 1000 kg per year. On my *Cordyceps* blog [www.Ophiocordyceps.com] Raju Chhetri, who stated that he is involved in a sustainability study in Nepal, posted 'Local people collect more than 1500 kg every year' in Dolpo.

[37] My high estimate is higher than the officially auctioned amounts of caterpillar fungus (see below), since not all fungi are necessarily going through official channels (Cannon et al. 2009). Government auctions are the prescribed marketing channel for caterpillar fungus in Bhutan. In 2009, 595 kg were sold at an average of about US$2800 per kg at auctions. In 2008, 685 kg were auctioned at about $3000 per kg according to Ministry of Agriculture figures (after Dahal 2009). Cannon et al. (2008) report 673 kg for 2008, 140 kg for 2007, 507 kg for 2006, 35 kg for 2005 and 176 kg for 2004. Five year total is 1531 kg, at an average of 306 kg. Adding the 2009 harvest the total is 2126 at an average of 354 kg between 2004 and 2009.

[38] Negi et al. (2009) reported these harvest amounts for India's Uttaranchal [now Uttarakhand] as the annual harvests from 2003 to 2008 at the 5th International Medicinal Mushroom Conference in Nantong.

[39] According to Chaudhary (2004 quoted from Regmi 2007) the annual collection of *Cordyceps* was 500 kg in Dolpa, 300 kg in Jumla, 200 kg in Humla and 200 kg in Kalikot. These figures were taken into account for estimating Nepal's other production areas.

[40] The Himalayan valleys administrated by the TAR in Xigaze, Shannan and Nyingchi Prefectures are not included here; they are contained in the Tibetan Plateau table. Also, it is appropriate to point out that the mountain areas of northwest Yunnan and western Sichuan are not part of the Himalayas, as some recent publications falsely claim.

According to this data, an annual global production of 83.2 to 182.5 tons could be assumed. This is a bit lower than my previous estimate of 100 to 200 tons, but both intersect widely and data inaccuracy is inherent. Ma reported that 'the average annual harvests of China in recent years was about 100 tons'.[41] Zhang et al. reported based on data collected by local governments, 'The annual production of *Cordyceps* in China was around 140 tons in the past years'; they also pointed out 'it is hard to estimate the collected and marketed amount in each year, there is no precise data for China's annual production'.[42] Overall, the production figures and estimates provided in the above tables might be lower than actual harvested amounts due to the informal aspect of the harvest and trade, and thus could even add up to exceed 150t. Since the climatic conditions vary widely over the vast expanse of the Tibetan Plateau and the Himalayas, it would take a series of very extreme weather events that would cause a poor harvest over the whole area. The production data for TAR between 1999 and 2009 demonstrates that annual harvest amounts in Naqu and Qamdo Prefecture fluctuate widely, but often in a non-synchronous way (see figure below); for example, in 2002 Naqu had an excellent harvest at 23 tons (11 year average 17 tons), while Qamdo had a low harvest with 12 tons (11 year average 16 tons). In 2007, Qamdo's harvest was above average at 17.5 tons, while Naqu had a very low yield at 12.5 tons. The low overall harvest in the TAR for 2009 can probably be correlated to the drought, which was reported the worst in 30 years.[43]

Using dendro-chronological methods, Bräuning (2000) showed that the forest region of the Tibetan Plateau—much of which is congruent with caterpillar fungus habitat—has five distinct climate zones. Furthermore, caterpillar fungus starts fruiting three to five weeks earlier in the eastern Tibetan Plateau (i.e. west Sichuan and northwest Yunnan) than in central Tibet (i.e. Naqu and Nyingchi prefectures). In some years in central Tibet, caterpillar fungus fruiting seems to depend on the arrival of the rains of the summer monsoon in June, especially in years after very dry winters. Under the more humid conditions of the eastern Plateau region, fungal fruiting occurs in spring, since soils seem to contain enough moisture in spring to allow for fruiting. However, one should not overstate the correlation between weather events and harvest amounts as we still lack understanding and data to describe this relationship.

41 Ma 2010, p. 9.

42 Zhang et al. 2009, p. 2.

43 Xinhua News Online 2009-06-20 'Drought in Tibet now worst in 30 years'. Accessed online in June 2010 at news.xinhuanet.com/english/2009-06/20/content_11572722.htm June 2010.

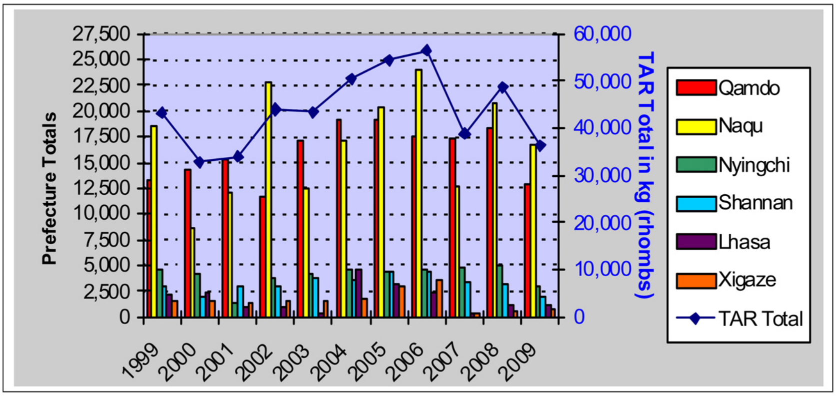

Fig. 7. Annual Caterpillar Fungus Production by Prefecture in the TAR

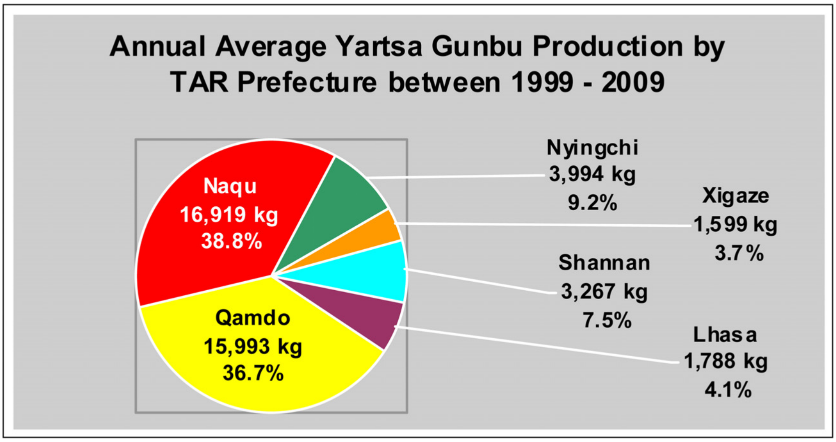

Fig. 8. Average Annual Caterpillar Fungus Production in TAR Prefectures[44] 1999 to 2009

Annual *overall* production might be more regular than one would assume due to the fact that these amounts are influenced by so many factors that vary in so many ways over such a vast area; in the end, the multitude of factors might equalize overall production.

[44] Arid Ngari Prefecture (Ali diqu) is not included in the table, since there is practically no *yartsa gunbu* harvest, but its population of 77,747 people is figured in all the TAR income averages presented.

Sustainability of Collection

Having provided some speculative figures on overall production, it is appropriate to discuss the issue of sustainability, since the lack of scientific data here is even more striking. For the time being we have to work with what is available: collectors will not wait for science to catch up. Any resource of such immense value, and key relevance to rural livelihoods as *the* main cash source, runs the risk of being over-exploited. The current (and apparently increasing) harvest pressure on caterpillar fungus is unprecedented. With increasing numbers of Tibetans collecting, the absence of traditional sustainable collection techniques and, in some cases local governments optimizing collection, the issue of sustainability looms large.[45] A recent publication on the genetic diversity of *Ophiocordyceps sinensis* reports that the greatest diversity is found in Nyingchi (pinyin: Linzhi) Prefecture, the most biodiverse and 'Himalayan' region of the TAR.[46] Genetic diversity is strongly reduced in more northern or western locations, suggesting that the fungal post-glacial advance (or return) onto the Plateau originated in Kongpo, as Nyingchi has been known for centuries. Furthermore, this phylogenetic study mentions a serious decline of *O. sinensis* production, quoting Yang Darong's Chinese-language paper from 1999. In a 2008 unpublished report Yang suggested that the *Cordyceps* production has collapsed and current output is down to 3–10% from 20 years ago.[47] Yang's claim is extraordinary, but is not backed up by baseline data derived from field plots or government agency production figures (as reported above). Also, Yang reports a former annual production of 700–1,200 tons, whereas current production is closer to 80–175 tons on the Tibetan Plateau. His past production figure is nearly 10 times higher than other estimates. A publication from Lhasa's Plateau Biology Research Institute (PBRI 1989) reported an average annual official harvest in TAR of 15 tons[48] between 1957–1983, which currently produces about 30% to 50% of the Plateau production, indicating that current harvest levels are probably higher than previous ones. Annual harvest in the TAR between 1999 to 2009 was 35 to 55 tons. To approach this estimate of around 1,000 tons from a different angle, Yang suggests that around three billion specimens were collected. At an overall population of about 5.4 million Tibetans on the Plateau, Yang is suggesting that, on average, every Tibetan was collecting 555 specimens, and the average family

[45] Hywel-Jones 2003; Boesi 2003; Winkler 2005, 2008a; Yang 2008.

[46] Zhang et al. 2009.

[47] Yang 2008; Stone 2008.

[48] The overall harvest could have been higher when informally traded amounts are included, but still would not get anywhere near Yang's claims.

over 3000 specimens—very difficult to imagine! Furthermore, 20 years ago fewer people were collecting, thus increasing these astronomical proportions even further. In short, published and unpublished figures do not indicate a population crash thus far, but do not preclude a slightly reduced harvest either.

Research on the actual consequences of the impact of intensive harvest of caterpillar fungus is noticeably lacking in China. Interestingly, Bhutan, whose annual *Cordyceps* production figures are less than 1% of the overall production, has so far the most advanced field study regarding caterpillar fungus growth and harvest impacts,[49] but it is too early to draw any conclusions regarding the impact of harvesting on annual production. Any field study on sustainable harvesting schemes needs to be long-term, since the lifecycle of the insect host is two-six years.[50] To the best of my knowledge, no such field research has yet commenced on the Tibetan Plateau.

Most statistics still seem to report stable production, but this result from two factors: more people searching more intensely and also new areas being searched that were not previously accessed for fungal extraction. Furthermore, some areas might have lost their production capacity. However, in my experience, having visited a production area, be it in Garze Prefecture (Sichuan), Deqen (Yunnan), Naqu, Qamdo or Nyingchi (TAR) almost annually since 1998, this seems not to be the case: most interviewed collectors did not report reduced output, but complained about reduced harvesting rates per individual due to steadily increasing competition. Similarly, most dealers and brokers did not lament reduced output rates, but report increased competition as well. This is just my personal experience but there are other sources that report collectors complaining about reduced harvests.[51] Overall, there might well be cases where there are reduced harvests, but none reflecting the catastrophic production crash claimed by Yang and spread worldwide by *Science* in an article that strangely relied on a single source for such an outrageous claim.[52]

Recently, climate change as a possible threat to caterpillar fungus production has been repeatedly raised by researchers.[53] Yang (2008) attributes it as a main cause, besides continued over-exploitation, for his claim of a caterpillar fungus production crash. Recent warming, according to Yang, has pushed up the altitudinal limits of the prime caterpillar fungus habitat by around 200–500m from between 3900 to 4400 m, where it supposedly was two decades

[49] Hywel-Jones 2003, Cannon et al. 2009.
[50] Maczey et al. 2010.
[51] For example, Steward 2009.
[52] Stone 2008.
[53] Yang 2008; Stone 2008; Cannon et al. 2009; Winkler 2010.

ago, to now 4400 to 4600 m. Although Yang does not elaborate on this, a 'climb up the mountain' of the habitat would mean a decrease in available surface area just by the nature of the shape of a mountain, since lower altitude areas are always larger than high altitude areas. However, even if the specific shape of the area would compensate for the hypothetical loss of surface area, i.e. a high plateau instead of a peak area, increased altitudinal habitat limits would imply reduction in soil development and soil fertility, reducing suitable habitat for ghost moth populations. Soil development is a very slow process that can take centuries if not millennia, especially in marginal alpine sites. Thus, the upward movement of the climatic conditions suitable to caterpillar fungus growth would seriously undermine overall habitat availability. However, there is no baseline research that would allow a comparison of past habitat to suggested current habitat, and climate change as a cause for Yang's unproven production crash remains a hypothesis and not a fact.

Harris, critically reviewing the evidence for Tibetan Plateau rangeland degradation, or rather the lack of conclusive evidence, analyses in detail available studies on 'climate change' on the Plateau, since climate change is frequently invoked as a contributing cause. He concludes, 'There currently is no persuasive evidence that recent global climate change has led to reduced precipitation generally on the Tibetan Plateau', as is often invoked to demonstrate rangeland degradation.[54] To the contrary, there is evidence of increased precipitation; recent data from the China Meteorological Administration collected between 1961 and 2008 on the Tibetan Plateau indicates a precipitation increase of 10.9 mm per decade in the last 48 years.[55] Zheng also reported a temperature increase of 0.32°C per decade. An increase of precipitation should in general spur production of caterpillar fungus, especially in more marginal sites on the inner, drier Plateau, where caterpillar fungus distribution typically does not cross into areas below the 350mm/a isohyet.[56] Furthermore, Himalayan habitat conditions demonstrate that caterpillar fungus can thrive in much moister conditions than found on the Plateau. However, an increase in temperature could be a more serious challenge for a high altitude specialist, whose mycelium has demonstrated reduced growth rates with increasing temperatures in cultivation trials.[57] Still, host insect and fungal organisms could react to an increase in temperature not only in a spatial manner by moving up as suggested by Yang, but also in a temporal manner, in the case of *Ophiocordyceps*

[54] Harris 2009, p. 4.
[55] Zheng 2009.
[56] Winkler 2005.
[57] Yao 2010.

by initiating fruiting earlier in the year[58] and thus adapting to temperature change theoretically without extensive habitat loss.

In this context, it should be mentioned that Miehe (1996) suggested that wide areas of high altitude *Kobresia* mats in Southern Tibet are relicts of the 'Climate Optimum', a warmer and wetter palaeoclimate in post-glacial times. Miehe's hypothesis was derived from field observations in a multitude of Plateau locations, since over the past 40 years, *Kobresia* sedges were not able to reclaim sites lost to disturbances such as animal trampling or other erosion events. In short, we are dealing with very complex systems that have been exposed through time to a wide amplitude of environmental conditions and the impact of the currently reported increase in temperature and precipitation can not be predicted in a linear way, but will require years of detailed field studies.

Steps toward sustainable management

The dependency of the rural communities on, and the long-term availability of, such a precious resource clearly argue for continued harvest of caterpillar fungus. The fact that *yartsa gunbu* has been collected for centuries, for example in Litang (Garze TAP, Sichuan), which Rockhill (1892) mentions as a sourcing area,[59] and still is being collected in the same area definitely documents its resilience[60] and indicates that no overhasty measures are required, a point Cannon et al. (2009) make for Bhutan's '*Yartsa Guenbub*'. Rapid Vulnerability Assessments by Namgyel (2003) and Winkler (2008a) have indicated a moderate degree of vulnerability. Namgyel states, 'if the traditional rights of the collectors are recognized and a community-based natural resources management system is put in place', this would reduce caterpillar fungus vulnerability even further.[61] Bhutan has been working on such an approach for nearly a decade. Cannon et al. report from Bhutan, 'In the long term, sustainability of

[58] I have interviewed Tibetan collectors regarding the onset of the *yartsa gunbu* fruiting season. In northern Nyingchi Prefecture I was told, 'it starts during the middle of the third month'. In the Tibetan lunar calendar, which is not always synchronous with the Chinese lunar calendar, the middle of the third month is usually early May, but due to its annual shifting in relation to the western solar calendar, the middle of the third month can fall any time between early to mid April and late May.

[59] 'This mountain [in the valley called Lit'ang Golo] is famous as producing that curious worm-plant known as the *Shar-tsa gong-bu* (*tung-chung hsia-ts'ao* in Chinese), called by botanists *Cordyceps sinensis*' (Rockhill 1894: 361).

[60] Winkler 2005 and 2008a.

[61] Namgyel 2003, p. 12.

wild *Yartsa Guenbub* harvest is through locally focused natural resource management, with the villagers making their own informed decisions about collection policy'.[62] The main conservation initiatives in Bhutan according to Cannon et al. are a limit on the duration of the harvest season during which households are allowed to collect and restrictions on how many members per household can collect; the collection season was limited just to the month of June, so spore dispersal in July is facilitated; only families that have grazing rights are entitled to collect. In 2004, members per household limitations started out with one member, but in 2008 some of the decision-making was handed over to the communities and some agreed to remove the limit. Furthermore, the communities opted for an extended collection season with no regulation when collection could start, but kept the closure date of 30 June.[63] In 2009 these communities went back to limiting each household to send no more than three members to collect.[64] From Nepal, the Asia Network for Sustainable Agriculture and Bioresources (ANSAB 2010) reports on their website, 'Where the District Forest Office, with all its government mechanisms, had failed to regulate *Yarshagumba* collection and to collect royalties [from outsiders], the Forest User Groups have managed to bring about effective regulation of harvesting' and thus secured enormous benefits for the locals. Similarly Steward (2009), in her study on *Cordyceps* collection in northwest Yunnan, suggests that community-based natural resource management (CBNRM) would be the most promising strategy to protect the resource, and for northwest Yunnan this might be an option, being the most open of the Tibetan autonomous areas in China. So far, no collection license system has been introduced in the three *yartsa gunbu* counties of Deqen TAP, though they were already introduced over wide areas of the Tibetan Plateau, especially in the TAR.[65] The licensing system can be an important step for resource management, if used appropriately. Some counties or townships use a licensing system to generate an extra source of revenue by charging very high fees, thus taxing collectors,[66] especially non-locals. Still, the issuing of the licenses facili-

[62] Cannon et al. 2009, p. 2279.

[63] Cannon et al. 2009.

[64] Dahal 2009.

[65] Luorong 2005; see also Winkler 2008b.

[66] A sales tax levied on brokers would make more sense for several reasons. First, it is easier to collect, since there are far fewer brokers than collectors. Second, the collected amounts could be much more substantial and, third, an increase of rural income generation is a central government objective and should not be undermined with taxation. Taxation of the fungal industry could provide substantial funds for rural development, especially for needed investments in education, health programs and fungal resource management.

tates an opportunity for communication between local collectors and 'resource managers', which in the case of the *yartsa gunbu* area on the Plateau usually means low-level local government officials.

The idea of local community or user groups self-managing the *yartsa gunbu* harvest on the Tibetan Plateau should be the ultimate goal to achieve successful resource management and such an approach could be feasible at some point soon in Deqen TAP in northwest Yunnan. However, based on the author's experience working on natural resource management issues with local administrations and Tibetan communities in Sichuan, the TAR, and Qinghai, it seems much more likely that a top-down approach will emerge at this point. Radical management decisions, comparable to the centrally formulated 1998 logging ban that stopped all commercial logging from one day to the next in the Yangtze and Yellow river catchments in the Tibetan areas,[67] are unlikely to be taken, since local communities are too dependent on the fungal income and would likely defy such a collection ban. Centrally, provincially or, in the case of the TAR, regionally formulated regulations[68] addressing issues of sustainable harvesting schemes could be successfully applied, if they are implemented skillfully with a good amount of flexibility that allows for adjustments to local realities. By local realities, I refer to simple facts such as timing of collection. There might be locally delayed seasons due to the fact that *yartsa gunbu* fruiting takes place at different times at different altitudes. A rigid closing date implemented all over the Plateau, as practiced initially[69] in Bhutan, for example, would not be appropriate due to the geo-ecological diversity of the vast Plateau region. Also, flexibility might be necessary due to annual changes, e.g., an early onset or a delay in the emergence of the fungus. The length of the collection season could be uniform, anywhere between three to five weeks; however four weeks seem to be adequate.[70] The main objective in

[67] Winkler 1999.

[68] In April 2006, the first region-wide regulations on collection and protection of *yartsa gunbu* were published based on a policy advisory written by Luorong Zhandui (Winkler 2008a). In brief, the regulations include stipulations for surveying of the resource and development of a protection program, minimizing resource conflict, ensuring environmental protection and clean-up, and an initiative to standardize the licensing system.

[69] Nigel Hywel-Jones reports the following recent developments: 'In Bhutan we are aiming to set up two new monitoring sites in the central and eastern regions. In terms of deciding the "stop date" it is important to learn when the *Cordyceps* starts to mature and produce spores. This is when it is at its least economically valuable level but at its most biologically valuable. Also, research into the flight patterns of the host will help in deciding the stop date in different regions' (personal communication via email 5-2-2010).

[70] Also, for collectors and local economies a clear time frame might be helpful, since much other work—none generating income like *yartsa gunbu*—comes to an abrupt halt during the

limiting the collection season is to guarantee that enough sporulating caterpillar fungi live out their lives undisturbed in the ground. And since these late season specimens are financially less valuable, such a management plan could find local support. Furthermore, it is much easier to find support for such a plan than alternatives such as closing off certain areas, or allowing only the collection of caterpillar fungi that have already started to sporulate.

Government issued regulations only have a reasonable chance of successful implementation if the local communities are integrated in decision making and implementation. The local collectors can be the best stewards of their resources, if they are well informed and understand what is at stake. Under such circumstances they could accept certain regulations—crucially the stopping of collection once sporulation begins late in the season—as part of sustainable resource management. There is not much that can be done in opposition to the local population in a 'harmonious' way, to use official PRC terminology, in such a vast and remote area.

Conclusions

With the steadily increasing value of *yartsa gunbu*, the dependency of rural households on the Tibetan Plateau and in the Himalayas on the caterpillar fungus industry is becoming more pronounced. The lack of clear production data in many areas and the fact that so far only Bhutan is conducting long-term *in situ* studies on harvest impact is striking for a commodity of such value and importance. Any resource of such immense value and of key relevance to rural livelihoods as *the* main cash source runs the risk of being over-exploited. The current harvest pressure on caterpillar fungus is unprecedented. However, its long history of exploitation suggests that the resource is resilient, and there is no evidence for a population crash. It is of paramount importance to develop science-based resource management plans that can be implemented in a simple way taking into account the remoteness of the production areas. It is long overdue for Chinese research institutes to launch their own field trials. With respect to resource management, taking into account the limited scientific evidence available, the most pragmatic approach for caterpillar fungus producing regions in China would be to announce at county or prefecture level limited collection seasons. Each year, dates could be set to limit the

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collection season; schools close and government projects can not find any labor (Winkler 2005). Lama (2007) touches on this subject in the context of 'crowded mountains, empty towns' and Steward (2009) analyses it as 'opportunity costs'.

collection seasons to four weeks after commencement in order to secure sufficient caterpillar fungus spore disposal so that future generations can continue to benefit from *yartsa gunbu*.

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