Biological Conservation xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Trade, harvest, and conservation of caterpillar fungus (*Ophiocordyceps sinensis*) in the Himalayas

Uttam Babu Shrestha [a,*], Kamaljit S. Bawa [a,b]

[a] Department of Biology, University of Massachusetts, Boston, MA 02125, USA
[b] Ashoka Trust for Research in Ecology and Environment (ATREE), Bangalore, India

ARTICLE INFO

Article history:
Received 2 September 2012
Received in revised form 24 October 2012
Accepted 31 October 2012
Available online xxxx

Keywords:
Medicinal plants
Ophiocordyceps sinensis
Sustainability
Nepal

ABSTRACT

Unsustainable trade in wildlife is regarded as a major driver of biodiversity loss and ecosystem degradation. Unregulated wildlife trade propels over-exploitation of species, resulting in population declines, and often in combination with other factors may ultimately extirpate species from their natural habitats. Concern about the impacts of trade on biodiversity has largely focused on flagship animal species. Here, we report on the impact of trade on natural populations of the world's most expensive biological resource, a unique caterpillar fungus (*Ophiocordyceps sinensis*). Based on interviews with 203 harvesters and 28 traders, and focus group discussions in Dolpa, Nepal, we quantify the amount of harvest and trade. After legalization of trade in Nepal in 2001, trade volume increased persistently, reaching a peak of 2442.4 kg in 2009 and subsequently declining to 1170.8 kg in 2011. The local market price has increased by up to 2300% over the last 10 years. However, mean annual harvest declined from 260.66 ± 212.21 pieces per person in 2006 to 125.82 ± 96.84 pieces per person in 2010. Our analysis of harvesters' perceptions of resource abundance and sustainability shows that virtually all harvesters (95.1%) believe the availability of the caterpillar fungus in the pastures to be declining, and 67% consider current harvesting practices to be unsustainable.

1. Introduction

Unsustainable wildlife trade is regarded as a major driver of biodiversity loss and ecosystem degradation (Broad et al., 2003). Because local harvests are often guided by demand and price in regional and global markets (Weckerle et al., 2010), rising prices can result in over-exploitation of many species leading to population declines in their habitats (Nijman, 2010). Studies on the impact of commercial trade on biodiversity are largely focused on flagship species of mammals (Corlett, 2007), amphibians and reptiles (Schlaepfer et al., 2005), and fishes (Sethi et al., 2010) that have been commercially traded for relatively long periods of time. Here, we report the impact of trade on natural populations of a comparatively new natural commodity on the international stage, the caterpillar fungus complex.

1.1. Species

The caterpillar fungus is celebrated for its extensive medicinal use, extraordinary life history, and high market value. The fungus is believed to strengthen lung and kidneys, increase energy and vitality, stop hemorrhage, and decrease phlegm (Holliday and Cleaver, 2008). A recent study seems to show anti-aging and anti-tumor effects (Wong et al., 2010). However, the caterpillar fungus is widely traded as an aphrodisiac and a powerful tonic (Holliday and Cleaver, 2008; Winkler, 2010a,b), and it has been hyped as a 'Himalayan Viagra' by popular media including The Wall Street Journal, the Economist, and CNN.

In Tibet, the caterpillar fungus is popularly called 'Yartsa gunbu', literally meaning 'summer grass winter worm' (Holliday and Cleaver, 2008); in Nepali it is 'Yarsagumba' and 'Kira' in Dolpa. However, it is neither a grass nor a worm, but a parasitic complex formed by the relationship of the fungus *Ophiocordyceps sinensis* (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora with the larval stage of several species of moth (known as 'ghost moth') belonging to the genus *Thitarodes* (Winkler, 2010a). More than 50 species belonging to the family Hepialidae (Lepidoptera) are reported as the hosts of caterpillar fungus (Wang and Yao, 2011). *Thitarodes* spp. spend much of their life-cycle as winter-dormant larvae. After several years feeding on roots underground, the larvae pupate, reaching adult stage in early summer (Cannon et al., 2009). The fungal propagules are released from the stromata in late summer and infect the host caterpillar residing in the soil. Following the period of host dormancy, the fungus grows and spreads inside the host caterpillar, finally killing it by consuming the essential nutrients (Cannon et al., 2009). The fungus then enters a mycelial growth phase and finally forms one or more stromata that emerge

* Corresponding author. Address: University of Massachusetts, Department of Biology, 100 Morrissey Blvd., Boston, MA 02125, USA. Tel.: +1 857 413 8812.
E-mail address: ubshrestha@yahoo.com (U.B. Shrestha).

0006-3207/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biocon.2012.10.032

Please cite this article in press as: Shrestha, U.B., Bawa, K.S. Trade, harvest, and conservation of caterpillar fungus (*Ophiocordyceps sinensis*) in the Himalayas. Biol. Conserv. (2013), http://dx.doi.org/10.1016/j.biocon.2012.10.032

Fig. 1. *Ophiocordyceps sinensis* in the natural habitat.

from the head of the buried caterpillar (Winkler, 2010a). The fungal stromata grow to ∼2–6 cm above the soil surface in early spring, when they are harvested along with the subterranean mummified caterpillar (Fig. 1).

O. sinensis is restricted to high altitudes of the Himalayas and Tibet. It is found in alpine and sub-alpine pastures above tree line, having been recorded at elevations of 3540–5050 m in Nepal (Devkota, 2010), 4200–5200 m in Bhutan (Cannon et al., 2009), 3200–4200 m in India (Singh et al., 2010) and 3000–5000 m in Tibet (Winkler, 2010a).

Although the caterpillar fungus has presumably been used in traditional Tibetan and Chinese medicine as a tonic and aphrodisiac and as relief medicine for lung, liver and kidney problems for centuries, it emerged as a significant market commodity only after economic liberalization in China in the 1980s (Winkler, 2010a). Global trade rapidly expanded after the 1993 World Athletic Championships in Stuttgart, Germany, when Chinese athletes—reportedly training on dietary supplements of *Othiocordyceps* and turtle blood—set multiple records in distance running (Winkler, 2010b). Today, it is the world's highest-priced biological commodity (Stone, 2008), more expensive by weight than gold. Best quality fungus in China fetched up to US $100,000 kg^{-1} (Yuan 650 g^{-1}) in March 2012 (Agile News, 2012), and in Singapore it reached US $130,000 kg^{-1} (Leng, 2012) at a time when the price of gold was about US $68,000 kg^{-1}. On average, however, the retail price of the product ranges from US $45,000 to 90,000 kg^{-1} (NPR, 2011; Agile News, 2012). Annual production in the Himalayas and Tibetan plateau is thought to be ∼85–185 tons (Winkler, 2010a), yielding an astonishing total estimated current global market value of US $5–11 billion (Shrestha, 2012). From 1997 to 2008, the market price climbed by ∼900% in Tibet (Winkler, 2010a), and from 2001 to 2011 by ∼2300% in Nepal. Exploding market demand and the dramatic price increases of the last 10 years may pose a serious threat to the existence of this species in its native habitat. There is widespread concern about the sustainability of the current harvest rates of this species (Cannon et al., 2009), but the quantitative trends in harvest, trade, supply and demand are not well known. Here we: (a) quantify trends in harvest, trade, supply and demand over the last 5 years in Nepal Himalayas, a major supplier of caterpillar fungus in the global markets, and (b) document harvester perceptions of collection patterns, harvesting modes, resource abundance and sustainability, as well as trader perceptions of supply and demand. We show that the amount of caterpillar fungus collected in the field is sharply declining, and discuss the possible reasons for this decline.

2. Materials and methods

2.1. Study area

Field surveys to collect information on caterpillar fungus harvesting for this study were carried out in the remote alpine pastures of Majphal Village Development Committee (VDC) in Dolpa, western Nepal (Fig. 2), in the summer of 2011. Dolpa district is regarded as a major warehouse of caterpillar fungus, contributing ∼40% of the total Nepalese supply in 2011. The caterpillar fungus of Dolpa is unusually large, has an attractive golden color, and, therefore, commands a higher price from traders (*personal observation*). The fungus is collected from 24 pastures in Dolpa district (DFO-Dolpa, 2010), among them five (*Saikumari*, *Pokepani*, *Ruppatan*, *Chinarangsi*, *Batule*) located in the Majphal VDC. This study addressed harvesters foraging caterpillar fungus in *Saikumari*, *Chinarangsi*, *Ruppatan* and *Batule*. Harvesters coming from different parts of Dolpa and adjoining districts set up camp for 2 months in three locations: *Tarpare* (28°53′15.7128″N, 82°46′56.8806″E, 4016masl), *Opa* (28°51′20.7102″N, 82°35′8.664″E, 3841masl) and *Baghdanda* (28°51′52.416″N, 82°47′2.313″E, 3743masl). Camp locations are permanently fixed and assigned by a local institution, *Toridwari Jadibuti Sankalan Tatha Byabasthapan Sameetee* (Toridwari Herbs Collection and Management Committee). A representative sample of harvesters from four districts, 18 VDCs and 50 villages were surveyed in these three camps. There were about 2600 collectors in three camps combined (A caravan of harvesters is shown in Fig. 3).

2.2. Data collection

Qualitative data were collected through key informant interviews, focus group discussions, informal communications, and personal field observations. The study proposal was approved prior to field research by the Institutional Review Board (IRB) of University of Massachusetts, Boston. Written consent was secured from all respondents before interviews and discussions by explaining the study objectives. Altogether we interviewed 203 harvesters (∼10% of total and ∼35% of the population of the three camps meeting the selection criteria—see below) with sets of structured and semi-structured questionnaires in harvester's camp sites during May–June 2011.

We limited surveys to harvesters having at least 5 years experience of caterpillar fungus harvesting. We first collected and listed names of all harvesters in our pool with at least 5 years harvesting experience. Name slips were placed in a box and interviewees were randomly chosen through the lottery method and without replacement. A substitute was chosen if the randomly drawn respondent was unavailable or did not want to be interviewed. We asked about quantities harvested, number of days spent (effort) and sale price. We also documented harvesters' perceptions of collection patterns, harvesting modes, resource abundance, and trends in success rate per unit effort. Furthermore, we conducted nine focus group discussions and several informal meetings with four local institution leaders, four school teachers, and five government officials. In the focus group discussions, we validated the information gathered from individuals. We also gathered trade information by interviewing 28 village and district level traders at the camps and in Dunai, the district headquarter of Dolpa and documented trader's perception on trends of supply and demand. The data were analyzed using PASW 18. We used linear regression to observe harvest trends per capita.

3. Results

3.1. Trade in caterpillar fungus

Although trade in caterpillar fungus in Nepal started in 1987–1988 and may have started in Dolpa (*unpublished data*), it was only legalized in 2001, with the provision of revenue of 20,000 Nepalese rupees kg^{-1} to the government. In 2006 the revenue amount was reduced to 10,000 Nepalese rupees kg^{-1}. Notable amounts of caterpillar fungus are traded without paying revenue, but revenue

Please cite this article in press as: Shrestha, U.B., Bawa, K.S. Trade, harvest, and conservation of caterpillar fungus (*Ophiocordyceps sinensis*) in the Himalayas. Biol. Conserv. (2013), http://dx.doi.org/10.1016/j.biocon.2012.10.032

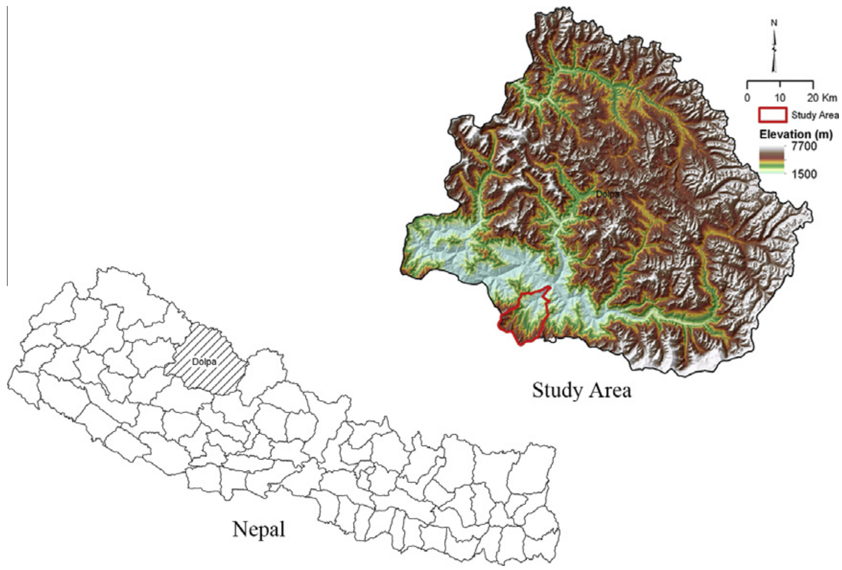

Fig. 2. Map of the study area.

Fig. 3. A caravan of harvesters in Dolpa, Nepal.

data are the only official source of information to quantify total amount of trade. According to revenue figures from the Government of Nepal, only 3.1 kg of caterpillar fungus was officially traded in 2002 from all of Nepal; trade volume reached a peak at 2442.4 kg in 2009 and then declined to 1170.8 kg in 2011 (Fig. 4A). From Dolpa district, 3.1 kg was marketed in 2002 (this was the only district of Nepal officially marketing the fungus in that year). Dolpa trade volume peaked at 872.4 kg in 2009 and then declined continuously to 473.8 kg in 2011. In that year, revenue on fungus trade was collected from five districts (Darchula, Dolpa, Jumla, Kathmandu and Myagdi), showing that trade has expanded spatially, despite falling total volumes characterizing the last few years.

3.2. Market price of caterpillar fungus

Along with the surging trade volume, the price of caterpillar fungus has also increased dramatically. Virtually no monetary value existed in 1987–1988; caterpillar fungus was traded for cigarettes, noodles, and other goods not easily available in the village (*unpublished data*). By 2001, Dolpa harvesters sold fungus for NRs 20–25 per piece, but they received NRs 200–600 per piece in 2011, representing an increase of $\sim$900–2300% (Fig. 4B). Similarly, local traders sold one kg to wholesalers/exporters for NRs 80,000–130,000 in 2001, but received NRs 1,100,000–1,600,000/kg in 2011—an increase of $\sim$1275–1131% (Fig. 4C). However, local market prices are erratic and large fluctuation is common, influenced by market demand, timing and location of trading.

3.3. Caterpillar fungus harvest

Caterpillar fungus is traditionally harvested by the poorest of the poor living in the high mountain regions of the Himalayas during May–July. The annual harvest per person ranged between 48 and 427 pieces (mean 260.66 ± 212.21, $n = 167$) in 2006; in 2010 it sank to between 28 and 123 pieces (mean 125.82 ± 96.84, $n = 197$). The average decline was thus 32.58 (SE = 3.70, $P < 0.0001$) pieces per harvester per year during the last 5 years (Table 1). Similarly, the average daily collection per person decreased by 3.14 (SE = 0.32, $P < 0.0001$) pieces per year during

Please cite this article in press as: Shrestha, U.B., Bawa, K.S. Trade, harvest, and conservation of caterpillar fungus (*Ophiocordyceps sinensis*) in the Himalayas. Biol. Conserv. (2013), http://dx.doi.org/10.1016/j.biocon.2012.10.032

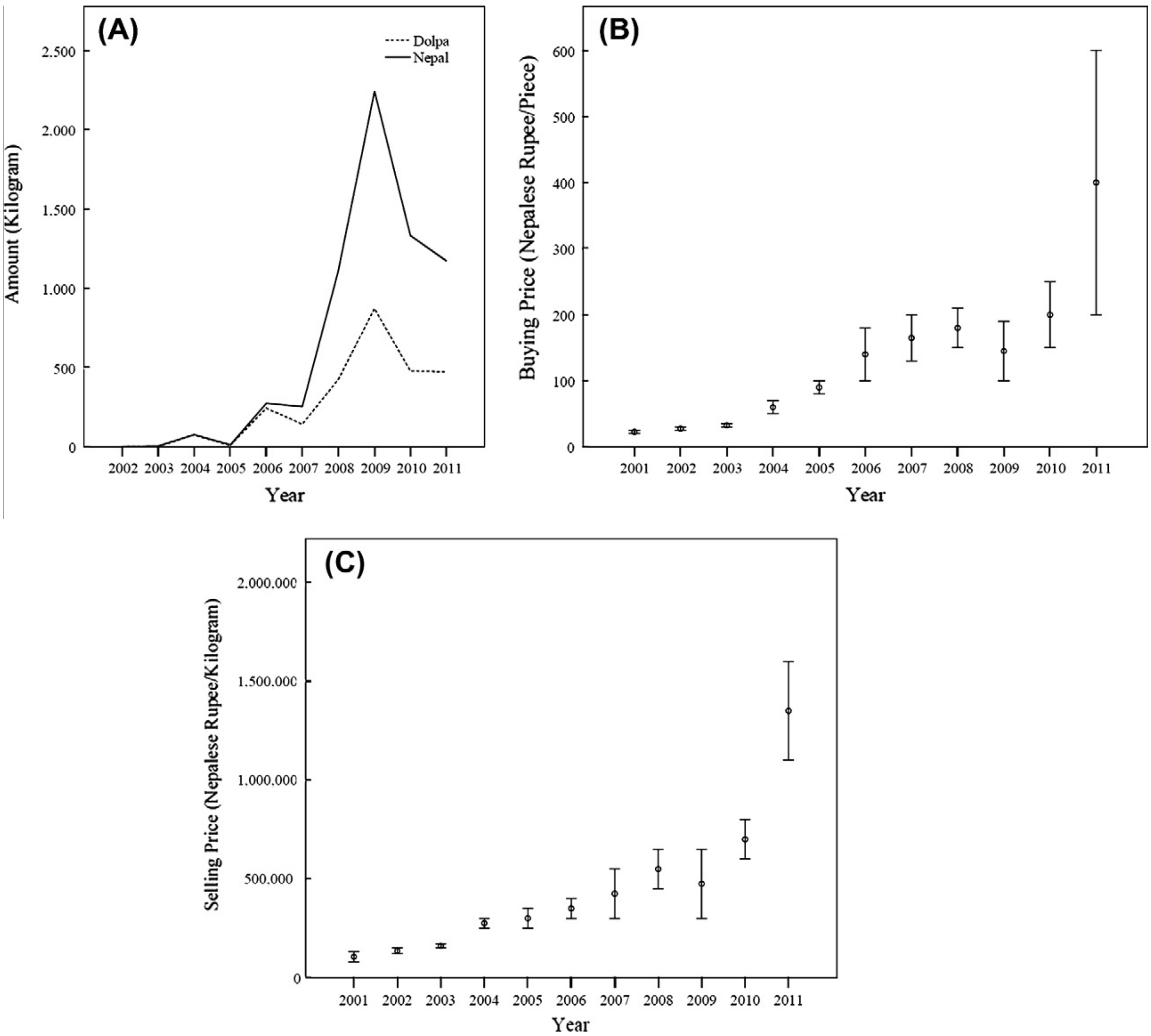

Fig. 4. (A) Total amount of trade in caterpillar fungus based on revenue data. (B) Trends of buying price by the traders in Dolpa. (C) Trends of selling price by the traders in Dolpa.

the same period. By contrast, the average number of collection days increased from 16.87 ± 10.89 (n = 167) in 2006 to 20.76 ± 10.34 (n = 197) in 2010 or a day (0.97) per person per year (SE = 0.25, P < 0.0001) (Table 1).

3.4. Local perceptions about trade and sustainability

Most traders believe that the demand for the caterpillar fungus has been increasing but the supply decreasing. Analysis showed that 64.3% of traders believe demand is increasing while 25.0% believe demand is decreasing (Fig. 5A). Regarding supply, 92.9% of traders believe supply is decreasing whereas 7.1% think there has been no change (Fig. 5B). This is reinforced by declines of ~28% in trade volume per trader during the last 5 years. The average amount of caterpillar fungus traded by a trader was 6.16 ± 5.45 kg (n = 28) in 2006, and 4.46 ± 3.84 kg (n = 28) in 2010. Furthermore, most of the harvesters (95.1%) believe that the availability of the caterpillar fungus in the pastures has decreased; only 1.0% believe that the amount of fungus has increased and 2.5% find no change (Fig. 5C). Therefore, most harvesters (70.9%) think that it has become more difficult to find the fungus while only 3.9% think it has become easier (Fig. 5D). We asked harvesters if they expect to continue finding the fungus in future, assuming that current rate and mode of harvest continue. We

Table 1
Trends of harvest and days of spending during harvest of Caterpillar fungus in 5 years (2006–2010).

Year	Average total number of harvest per person (pieces)	Mean days of spending	Average per person per day harvest (pieces)
2006	260.66 (±212.21)	16.87 (±10.89)	19.63 (±17.98)
2007	221.12 (±189.86)	17.45 (±10.97)	16.73 (±17.51)
2008	186.60 (±153.23)	17.89 (±10.30)	13.31 (±14.69)
2009	164.04 (±124.26)	19.28 (±10.11)	10.12 (±8.54)
2010	125.82 (±96.84)	20.76 (±10.34)	7.25 (±6.63)

Please cite this article in press as: Shrestha, U.B., Bawa, K.S. Trade, harvest, and conservation of caterpillar fungus (*Ophiocordyceps sinensis*) in the Himalayas. Biol. Conserv. (2013), http://dx.doi.org/10.1016/j.biocon.2012.10.032

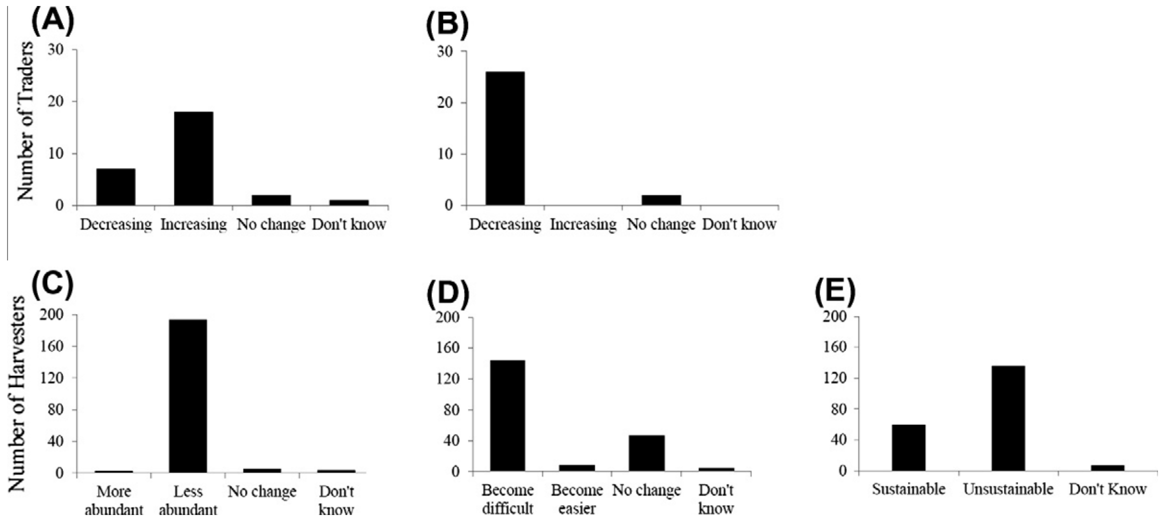

Fig. 5. (A) Traders' perceptions on demand of caterpillar fungus. (B) Traders' perceptions on supply of caterpillar fungus. (C) Harvesters' perceptions on abundance. (D) Harvesters' perceptions on ease of harvesting. (E) Harvesters' perceptions on sustainability of the harvest.

found that many harvesters are concerned about conservation and sustainability of the resource: 67% consider current harvesting practices unsustainable while 29.6% believe it is sustainable (Fig. 5E).

4. Discussion and conclusion

Recently, Olsen and Larsen (2003) quantified trade in 11 species of medicinal plants in the Nepal Himalayas but excluded *O. sinensis*, perhaps because trade in this species was relatively insignificant at that time. This study documents trade volumes and provides the first quantitative analysis of trends in harvest for the caterpillar fungus in the Nepal Himalayas. Global production of caterpillar fungus is about 83.2 tons per year. China is the largest producer (80–175 tons), followed by Nepal (1.0–3.2 tons), India (1.7–2.8 tons) and Bhutan (0.5–1.5 tons) (Winkler, 2010a). However, the trade in caterpillar fungus is shrouded in secrecy. Thus uncertainly and margin of error associated with these figures might be high. Although Nepal's share in the international trade of caterpillar fungus is nominal (up to 2%), Nepal is the second largest supplier of caterpillar fungus to the global market after Tibet, China. Therefore, the evidence provided here has significant implications for the overall scenario of trade, harvest and supply of caterpillar fungus. Our results showing recent explosive increases in caterpillar fungus trade and prices in Nepal are consistent with documented price increases in Tibet, the world's major producer/supplier of caterpillar fungus (Winkler, 2010a).

Despite increases in price and demand, our results show that harvests at the local level are decreasing. Moreover, harvesters are experiencing declines in resource abundance. During our interviews with harvesters, Laxmi Karki (52) who has 20 years' experience of collection and trading of caterpillar fungus recalled his old days as "15–20 years ago, people of Majpal VDC used to bring it in 'Doko' (a basket made locally by Bamboo) and wash it in 'Dhara' (tap water) and sell it in 'Dharmi' (local measurement unit, 1 Dharmi = 2.5 kg). Now, individuals are finding less than 100 pieces (30–40 g). Our pastures run out of 'Kira' (caterpillar fungus) in coming 10 years if current practices of harvesting continues."

"A few people, who had connection with handful of traders, were involved in collection of caterpillar fungus 20–22 years ago. Now, you can see thousands of harvesters. The number of harvesters has increased a lot but amount of harvest has decreased in recent years," said Bal Bahadur Lama (49), who claimed himself as a pioneer of caterpillar fungus trade in Dolpa. Our quantitative data also support the experiences of the veterans. The per capita harvest of caterpillar fungus has decreased significantly in the last 5 years (2006–2011). This trend could be attributed to increasing numbers of harvesters in recent years. Records of Toridwari Herbs Collection and Management Committee (the local institution managing pastures of the study area) based on the tax collected from individuals showed that the number of harvesters increased by at least 24% (~2100 harvesters in 2006 vs. ~2600 in 2010). But an overall decrease in total trade volumes, based on revenue data at the district and national levels, points to a sharp decline in the resource. Quoting local harvesters, the popular press has also reported a decline of the fungus in recent years (Taggart, 2012). District forest office of Dolpa estimates that about 50,000 people were involved in harvesting of caterpillar fungus during the 2010 season in Dolpa (DFO-Dolpa, 2010). Therefore, the intensity of the harvest and pressure on the resource due to this large number of collectors can be easily anticipated. Although it is not possible to attribute this decline to a single cause, over-harvesting and premature harvesting are likely to be important factors. We sampled 1257 individual caterpillars collected by 157 harvesters and observed by magnifying glass (20×) that 94.4% of the caterpillar fungi were reproductively immature—lacking spores in the stromata at the time of harvest. Therefore, current harvesting practice almost certainly impedes the timely release of spores into the soil, inhibiting reproduction. Most of the harvesters we interviewed are aware of these problems and consider current harvesting practice unsustainable.

Apart from over-harvesting and harvesting of immature individuals, other factors may be contributing to the decline of populations. These include (a) decrease in moth and larval populations due to loss or degradation of host plant resources for moths and larvae; (b) modification of the soil microhabitats congenial to fungal spores by the harvesters; (c) increased grazing intensity in high-altitude pastures as local harvesters take their cattle with them; and (d) climate changes. In Japan, along with market demand, loss of favorable habitat particularly mortality of host tree (Japanese Red Pine) has been implicated as the primary cause of decline of mycorrhizal mushroom—Matsutake (*Tricholoma matsutake*) (Saito and Mitsumat, 2008). In our case, the host populations of moths may have declined due to degradation of host food resources. Climate effects such as less snow, early melting of snow-pack, erratic rainfall, increased mean temperatures and increasing extremes in temperature and precipitation experienced by harvesters (*unpublished data*) may be modifying habitats for both larvae and fungi. Growth and development of fungi are strongly influenced by soil temperature and moisture (Pinna et al., 2010; Kauserud et al., 2010), and climate change has been shown to impair host-pathogen interactions of many Lepidoptera species (Stireman et al., 2005).

Ultimately, increasing trade-induced over-harvesting seems almost certainly responsible for declining populations. The caterpillar fungus is largely used in China. Demand for the fungus has increased with the economic prosperity of people in China. The demand started to increase in 1990s, coinciding with the start of rapid economic growth in China.

Cunningham (2001) described five phases of the trade in medicinal plants: discovery, expansion, stabilization, decline, and cultivation. This trajectory may be applicable to caterpillar fungus. Based on our findings and other reports, it is apparent that the caterpillar fungus is either heading towards or already in a declining phase. Cunningham (2001) predicts the development of a formal cultivation system during or after the declining phase. However, given the complex biology of caterpillar fungus, artificial propagation has not yet been cost-effective or technically successful (Zhang et al., 2012). Very recently artificial culture of only fungal part of the caterpillar fungus complex was claimed and patented (Cleaver et al., 2011) but successful production of the caterpillar fungus complex with larvae has not been reported yet. In addition, commercialization could present yet another threat to the livelihoods of poor people. *In situ* management of the caterpillar fungus is thus preferable not only for conservation *per se*, but for economic wellbeing of the indigenous communities.

Hall and Bawa (1993) defined sustainable harvest as the level of harvest that does not impair the ability of the harvested population to replace itself. Since a detailed assessment of the natural stock of this species is lacking, and since information on the natural productivity and the natural rate of replenishment of caterpillar fungus remains unknown, sustainable management is a challenge. Furthermore, due to the complex natural history of this species, sustainable harvest strategies for this resource are still not established. Detailed analyses of the ecology, life history and population dynamics, and an assessment of habitat condition and natural stocks, are all prerequisites for scientific progress towards sustainable use of this valuable resource.

Harvests can be altered by changing policies and creating regulatory mechanisms (Olsen, 2005; Weckerle et al., 2010) or in extreme cases by provision of economic incentives for not harvesting (Varghese and Ticktin, 2008). However, restrictions on harvest have been unsuccessful in Nepal due to the remoteness of the habitat, inadequate government presence to prevent unauthorized collection, and the critical role the harvest plays in livelihoods of collectors. Thus a ban on harvesting, collecting and trading was uplifted in 2001 in Nepal. Existing institutions cannot offer sufficient economic incentives to the harvesters not to harvest as the transaction cost is too high. For management of open access resources, a necessary first step for sustainable management will be the creation of institutions governing resource access and use (Belcher and Schreckenberg, 2007). Such institutions have been emerging in various parts of Dolpa in recent years. Thus for example there is now a ban on cutting green trees, and emphasis on recycling of solid wastes in the pastures. Taxes on harvests that could support conservation have been put in place, starting date for the harvest has been fixed, and in some areas rotational harvesting is being practiced by local nascent institutions. However, the technical capacity and governance structure remain poor. Therefore, interventions to strengthen governance, and enhance investments in generating knowledge about the biology of the species, and to increase awareness among harvesters for the need for sustainable management of the caterpillar fungus are urgently needed.

Decline in availability and calls for sustainable management have also come from Bhutan (Cannon et al., 2009), northern India (Negi et al., 2006), and Tibet (Stone, 2008) in recent years. Therefore, measures for the conservation of this species should be discussed and implemented at the regional scale throughout the Himalayas.

Acknowledgements

This work is supported by Rufford Small Grants for Nature Conservation (RSGs), UK and National Geographic Society, USA. We are grateful to Sujata Shrestha, Bharat Babu Shrestha, Shivaraj Ghimire, Puspa Shahi and all the people of Dolpa for their support in the field. We thank Reinmar Seidler and two anonymous reviewer for valuable comments for improving the manuscript.

References

Agile News, 2012. 800 Super Gold the Kunming Grade Cordyceps Price of Premium Cordyceps is 650 yuan per gram. <http://www.agile-news.com/news-1184723-800-super-gold-the-Kunming> (published 30.03.12, accessed 31.03.12).

Belcher, B., Schreckenberg, K., 2007. Commercialization of non-timber forest products: a reality check. Develop. Policy Rev. 25 (3), 355–377.

Broad, S., Mulliken, T., Roe, D., 2003. The nature and extent of legal and illegal trade in wildlife. In: Oldfield, S. (Ed.), The Trade in Wildlife: Regulation for Conservation. Earthscan Publications, London.

Cannon, P.F., Hywel-Jones, N.L., Maczey, N., Norbu, L., Samdup, T., Lhendup, P., 2009. Steps towards sustainable harvest of *Ophiocordyceps sinensis* in Bhutan. Biodivers. Conserv. 18, 2263–2281.

Cleaver, P.D., Holliday, J.C., Powers, M.L., 2011. Method for Growing *Cordyceps sinensis* on a Substrate. US Patent No. US 8008060B2 USA.

Corlett, R.T., 2007. The impact of hunting on the mammalian Fauna of tropical Asian forests. Biotropica 39, 292–303.

Cunningham, A.B., 2001. Applied Ethnobotany. People, Wild Plant Use and Conservation. Earthscan, UK.

Devkota, S., 2010. *Ophicordyceps sinensis* (Yarsagumba) from Nepal Himalaya: status, threats and management strategies. In: Zhang, Ping Hao-wei (Ed.), Cordyceps Resources and Environment. Grassland Supervision Center by the Ministry of Agriculture, People's Republic of China. pp. 91–108.

DFO-Dolpa, 2010. Dolpa Jillama Yarsagumba Sankalan Tatha Babasthapan Ek Parichaye. District Forest Office, Dunai, Dolpa (in Nepali).

Hall, P., Bawa, K.S., 1993. Methods to assess the impact of extraction of non-timber forest products on plant populations. Econ. Bot. 47, 234–247.

Holliday, J., Cleaver, M., 2008. Medicinal value of the Caterpillar Fungi species of the genus *Cordyceps* (Fr.) Link (Ascomycetes). A review. Int. J. Med. Mushrooms 10, 219–234.

Kauserud, H., Heegaard, E., Semenov, M.A., Boddy, L., Halvorsen, R., Stige, L.C., Sparks, T.H., Gang, A.C., Stenseth, N.C., 2010. Climate change and spring-fruiting fungi. Proc. Royal Soc. B 277, 1169–1177.

Leng, L.W., 2012. Will Lemon Law Affect Herb Sellers? <http://www.channelnewsasia.com/stories/singaporelocalnews/view/1193893/1/.html> (published 08.04.12, accessed 10.04.12).

Negi, C.S., Koranga, P.R., Ghinga, H.S., 2006. Yartsa Gumba (*Cordyceps sinensis*): a call for its sustainable exploitation. Int. J. Sust. Dev. World 13, 165–172.

Nijman, V., 2010. An overview of international wildlife trade from Southeast Asia. Biodivers. Conserv. 19, 1101–1114.

NPR, 2011. Caterpillar Fungus: The Viagra of the Himalayas. <http://www.npr.org/2011/10/09/141164173/caterpillar-fungus-the-viagra-of-the-himalayas>.

Olsen, C.S., 2005. Trade and conservation of Himalayan medicinal plants: *Nardostachys grandiflora* DC. and *Neopicrorhiza scrophulariiflora* (Pennell) Hong. Biodivers. Conserv. 125, 505–514.

Olsen, C.S., Larsen, H.O., 2003. Alpine medicinal plant trade and Himalayan mountain livelihood strategies. Geograph. J. 169, 243–254.

Pinna, S., Gevry, M.F., Cote, M., Sirois, L., 2010. Factors influencing fructification phenology of edible mushrooms in a boreal mixed forest of Eastern Canada. Forest Ecol. Manage. 260, 294–301.

Saito, H., Mitsumat, G., 2008. Bidding customs and habitat improvement for matsutake (*Tricholoma matsutake*) in Japan. Econ. Bot. 62, 257–268.

Schlaepfer, M.A., Hoover, C., Dodd, C.K., 2005. Challenges in evaluating the impact of the trade in amphibians and reptiles on wild populations. Bioscience 55, 256–264.

Sethi, S.A., Branch, T.A., Watson, R., 2010. Global fishery development patterns are driven by profit but not trophic level. Proc. Natl. Acad. Sci. USA 107, 12163–12167.

Shrestha, U.B., 2012. Asian medicine: a fungus in decline. Nature 482, 35.

Singh, N., Pathak, R., Kathait, A.S., Rautela, D., Dubey, A., 2010. Collection of *Cordyceps sinensis* (Berk.) Sacc. in the Interior Villages of Chamoli District in Garhwal Himalaya (Uttarakhand) and its social impacts. J. Am. Sci. 6 (6), 5–9.

Stireman, J.O., Dyer, L.A., Janzen, D.H., Singer, M.S., Lill, J.T., Marquis, R.J., Ricklefs, R.E., Gentry, G.L., Hallwachs, W., Coley, P.D., Barone, J.A., Greeney, H.F., Connahs, H., Barbosa, P., Morais, H.C., Diniz, I.R., 2005. Climatic unpredictability and

Please cite this article in press as: Shrestha, U.B., Bawa, K.S. Trade, harvest, and conservation of caterpillar fungus (*Ophiocordyceps sinensis*) in the Himalayas. Biol. Conserv. (2013), http://dx.doi.org/10.1016/j.biocon.2012.10.032

parasitism of caterpillars: implications of global warming. Proc. Natl. Acad. Sci. USA 102, 17384–17387.

Stone, R., 2008. Last stand for the body snatcher of the Himalayas? Science 322, 1182.

Taggart, F., 2012. Nepal 'Himalayan Viagra' Harvest Droops to Record Low. <http://www.google.com/hostednews/afp/article/ALeqM5grh-0xAht_u_ye8cJ-_amYWzdWjw> (published 09.06.12, accessed 10.06.12).

Varghese, A., Ticktin, T., 2008. Regional variation in non-timber forest product harvest strategies, trade, and ecological impacts: the case of black dammar (CanariumstrictumRoxb.) Use and Conservation in the Nilgiri Biosphere Reserve, India. Ecology and Society, vol. 13(2), p. 11. <http://www.ecologyandsociety.org/vol13/iss2/art11/>.

Wang, X.L., Yao, Y.J., 2011. Host insect species of *Ophiocordyceps sinensis*: a review. ZooKeys 127, 43–59.

Weckerle, C.S., Yongping, Y., Huber, F.K., Li, Q., 2010. People, money, and protected areas: the collection of the caterpillar mushroom *Ophiocordyceps sinensis* in the Baima Xueshan Nature Reserve, Southwest China. Biodivers. Conserv. 19, 2685–2698.

Winkler, D., 2010a. Caterpillar fungus (*Ophiocordyceps sinensis*) production and sustainability on the Tibetan Plateau and in the Himalayas. Asian Med. 5, 291–316.

Winkler, D., 2010b. *Cordyceps sinensis* a precious parasitic fungus infecting Tibet. Altern.: Field Mycol. 11 (2), 60–67.

Wong, Y.Y., Moon, A., Duffin, R., Barthet-Barateig, A., Meijer, H.A., Clemens, M.J., De Moor, C.H., 2010. Cordycepin inhibits protein synthesis and cell adhesion through effects on signal transduction. J. Biol. Chem. 285, 2610–2621.

Zhang, Y., Li, E., Wang, C., Li, Y., Liu, X., 2012. *Ophiocordyceps sinensis*, the flagship fungus of China: terminology, life strategy and ecology. Mycology 3, 2–10.