

# Comment on the Article Regarding Chinese Caterpillar Fungus Range Shifts in Response to Climate Change Based on the Interspecific Relationships on the Qinghai-Tibet Plateau in Fungal Ecology

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## Commentary

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## About the Study

Recently, the response of *Ophiocordyceps sinensis* to climate change on the Qinghai-Tibet Plateau was analyzed based on the relationship between *O. sinensis*, its host moths, and moth-feeding plants. This study simulated the distribution dynamics of *O. sinensis* in suitable areas during four different time periods, i.e., the last glacial maximum, the middle Holocene, the present day, and 2050.

The maximum entropy model was used to construct the distribution pattern of *O. sinensis*, its host moths, and moth-feeding plants during the four different time periods based on the biological chain dependency between them. The distribution pattern was divided into high, medium, and low redundancy regions based on the stability of the biological chain. It was found that the geographical distribution patterns of the suitable areas for these organisms with high redundancy were significantly similar. This finding provides a foundation for comprehending the close interdependence and coevolution between these organisms.

The sample plots in the core area of the Qinghai-Tibet Plateau exhibit a relatively uniform altitude-climate distribution pattern. Against the backdrop of climate warming, precipitation becomes the most important limiting factor for the continuous expansion of *O. sinensis*, its host moths, and moth-feeding plants. The core area of the Qinghai-Tibet Plateau, namely northern Tibet and Qinghai, is the main production area of *O. sinensis*. The altitude-climate distribution pattern is relatively uniform, which facilitates the extensive distribution of *O. sinensis*, its host moths, and moth-feeding plants with the widest range. It is an important region for the present and future sustainable utilization of *O. sinensis*.

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The distribution pattern of *O. sinensis*, its host moths, and moth-feeding plants is consistent with the altitudinal climate-vegetation distribution pattern. This indicates a decisive restriction relationship between altitudinal topography-climate-vegetation and the biological chain network of these organisms. From the middle Holocene to the present and future, certain areas in the Hengduan Mountains of southeast Tibet, northwest Yunnan, and western Sichuan have served as centers for species diversity and genetic diversity of *O. sinensis*, its host moths, and moth-feeding plants. The biological chain network between these organisms has remained relatively stable over a long period of time. This stability has acted as a "shelter" for these organisms during the Quaternary ice age. Therefore, protecting this key area is crucial for maintaining the long-term preservation of this biological chain network.

Considering that for over twenty years, the annual production of *O. sinensis* has consistently maintained an astonishingly sustainable yield, averaging around  $145 \times 10^3$  kg per year, there has been a clear upward trend in the total annual production of *O. sinensis* from 2009 to 2023 without any decrease. The sustainable production of *O. sinensis* has become the primary economic pillar for farmers and herdsmen in the primary producing areas on the Qinghai-Tibet Plateau. From the mid-Holocene to present and into the future, climate change will favor the expansion of habitats for *O. sinensis*, its host moths, and moth-feeding plants.

The suitable area of *O. sinensis* has generally shifted towards the northwest direction and higher elevations. The area continues to expand with climate change, and the degree of concentrated contiguity is strengthened. This contributes significantly to the sustained increase in total annual production while maintaining sustainability in harvesting practices within primary producing areas on the Qinghai-Tibet Plateau. More importantly, the local governments in the main production areas of *O. sinensis* have issued a series of corresponding laws and regulations on mining standards for *O. sinensis*. These include the Interim Measures for the Management of *O. sinensis* collection in Tibet autonomous region in 2006 and the interim measures for the management of *O. sinensis* trade in Tibet autonomous region in 2009. In 2014, Qinghai Province's people's government issued the working opinions on strengthening the protection and management of *O. sinensis* resources. These have played an effective and positive role in promoting sustainable utilization and protection.

In the past two decades, with the introduction and continuous improvement of protection and supervision policies for *O. sinensis* in the main producing areas, significant progress has been made in the sustainable utilization and conservation of *O. sinensis*. Long-term practical experience has proven that the sustainable capacity of annual output of *O. sinensis* mainly depends on moderate and reasonable mining methods. Since the prosperity of *O. sinensis*, a mining and management model conducive to the sustainable utilization of *O. sinensis* has gradually been formed through intense conflicts and corresponding processing among stakeholders. For example, the government has transitioned from being the main recipient of *O. sinensis* income to becoming a public service provider. This includes implementing a land contract transfer system, restricting the entry of external mining personnel, limiting both the density and duration of mining activities, standardizing mining tools, as well as implementing measures for sod backfilling. Currently, the content of environmental protection is primarily incorporated into the mining contract for *O. sinensis* grown in the mountains, aiming to achieve sustainable management. This indicates that sustainable utilization and management have become a consensus among all stakeholders.

The assessment of the sustainable annual yield of *O. sinensis* has been conservative and pessimistic for more than two decades. However, the results of this study differ from the views held by scientists, journalists, and administrative leaders over the past 20 years. As a result, countermeasures for sustainable utilization and protection of *O. sinensis* are proposed. It is suggested that *O. sinensis* should be removed from the list of national key protected wild plants of China in 2021 as a second-class protected species, and its status as a vulnerable species should also be lifted. These changes will contribute to the sustainable utilization and protection of biological resources of *O. sinensis*, promote sustainable economic development for farmers and herdsmen in Tibetan areas on the Qinghai-Tibet Plateau, and foster unity, stability, prosperity, and progress among ethnic groups residing there.