Population age structure and conservation status of *Ferula sinkiangensis* (Apiaceae) in Xinjiang, China

Tianxing Liu†[1], Qiumei Cao†[2], Lei Yang[2,3] Zhaoping Yang*[1] and Wenjun Li*[2,4,5,6]

Abstract *Ferula sinkiangensis* K.M. Shen is a threatened medicinal plant endemic to Xinjiang, China, with a small population size and a narrow distribution range. We assessed the status of this species with respect to its population age structure, the level of threat and extinction risk. Only one population remains, in Yining County, Xinjiang. We conducted field surveys of the population in 2022 and 2023, counting 2,033 and 1,515 individuals, respectively, in 144 sample quadrats. We assessed the age structure of the population by counting the number of basal leaves of each individual. The frequency distribution had an inverted J-shape, indicative of a relatively stable age structure. However, the number of mature individuals was small, raising concerns about the risk of genetic drift and inbreeding. This species is also threatened by habitat destruction and inappropriate collection practices. We recommend that *F. sinkiangensis* is categorized as Critically Endangered on the IUCN Red List on the basis of criteria B2ab(iii), C2a(i) and D.

Keywords Apiaceae, China, Critically Endangered, *Ferula sinkiangensis*, IUCN Red List, plant conservation, population age structure, Xinjiang

Apiaceae, one of the largest families of angiosperms, comprises 3,820 species in 466 genera (Plunkett et al., 2018) mostly distributed in northern temperate regions and high-altitude areas in the tropics (Sayed-Ahmad et al., 2017). The genus *Ferula* is one of the largest genera in Apiaceae, distributed from Central Asia (mainly in Iran and Afghanistan) westward to the Mediterranean region (Pimenov & Leonov, 1993; Sahebkar & Iranshahi, 2011; Estekhdami & Dehsorkhi, 2019; Mohammadhosseini et al., 2019). It includes c. 170 species, most of which are important medicinal plant resources in montane regions, with a few in arid climates (Yaqoob & Nawchoo, 2016). Some *Ferula* species are known for their medicinal value in the treatment of stomach disorders, wheezing, lymphatic tuberculosis, intestinal ulcers and tonsillitis, and for detoxification, detumescence and analgesia (Shan et al., 1992).

Ferula sinkiangensis K.M. Shen was reported as a new species in 1975 based on its holotype (herbarium XJBI, A093) and some paratypes (A069, A072 and A119), all of which were collected in Baishidun, Yining County, Xinjiang, China (Shen et al., 1975). Endemic to Xinjiang, it is a herbaceous perennial and monocarpic plant that grows in semiarid steppe ecosystems (She & Watson, 2005). The species is believed to grow vegetatively for c. 7 years before flowering and fruiting (Shen, 1987), and takes 15 years to complete its life cycle (D.-Y. Tan, unpubl. data, 1995–2009). It is recorded in the Chinese Pharmacopoeia (Chinese Pharmacopoeia Commission, 1978) and is used as a medicinal herb in China for the treatment of stomach disorders, wound infections, joint pain, and symptoms of ovarian cysts, and for detumescence (Shen, 2011). Since 1970, *F. sinkiangensis* has been threatened by habitat loss, environmental changes and overexploitation (Zhao et al., 2009). In China, *F. sinkiangensis* is categorized as a Critically Endangered species (Wang & Xie, 2004; Qin et al., 2017) and a national second-class protection plant (Fu, 1992; National Forestry and Grassland Administration, 2021), but it has not yet been assessed on the IUCN Red List. Because of its narrow distribution range, medicinal value and threatened status, a c. 67 ha fenced reserve was established in 2004 in Yining County to protect the species.

The study site is located on the north-west border of Xinjiang in the centre of the Yili River Valley Basin. This area is characterized by desert conditions and gravelly clay slopes (Fig. 1).

We first examined the specimens of *F. sinkiangensis* in the Chinese Virtual Herbarium and found that the species has also been collected from Nileke and Manashi counties in Xinjiang. Based on the collection sites and habitat records of these specimens we surveyed the distribution range during 2016–2022 in three counties in Xinjiang: Yining, Nileke and Manashi. After 7 years of investigation we found two populations of *F. sinkiangensis*, in Yining and Nileke, but not in Manashi. The Nileke population had only four individuals, but these disappeared in 2018 (Li et al., 2020) as a result of unknown causes (it is possible they were harvested by local people). There is therefore only one remaining

†Contributed equally
*Corresponding author, liwenjunao@ms.xjb.ac.cn, yzpzky@163.com
[1]College of Life Sciences and Technologies, Tarim University, Xinjiang, China
[2]State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Xinjiang, China
[3]Xinjiang Key Lab of Conservation and Utilization of Plant Gene Resources, Urumqi, China
[4]Sino-Tajikistan Joint Laboratory for Conservation and Utilization of Biological Resources, Xinjiang, China
[5]IUCN Species Survival Commission Chinese Plant Specialist Group
[6]IUCN Species Survival Commission China Species Specialist Group

Received 8 August 2023. Revision requested 30 October 2023. Accepted 25 March 2024.

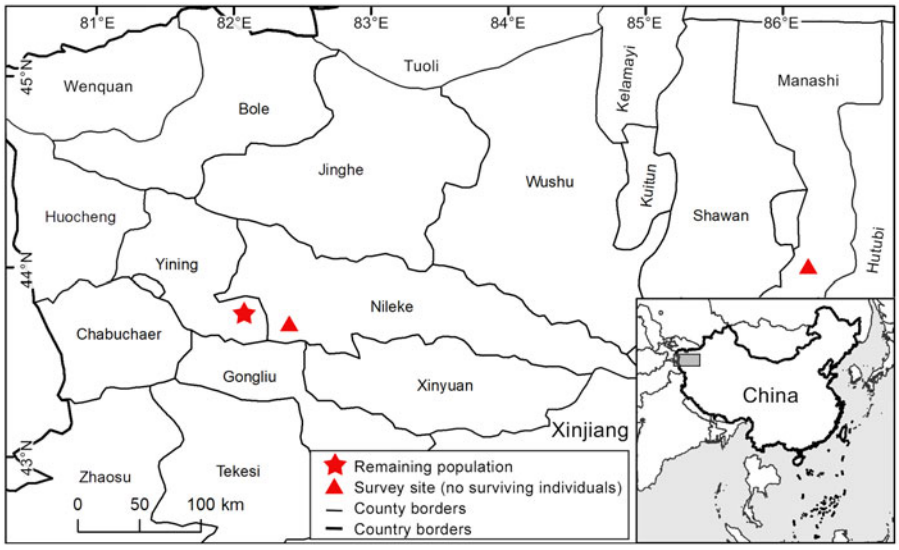

FIG. 1 Location of the remaining population of *Ferula sinkiangensis* in Yining County, and the survey sites in Nileke County and Manashi County, Xinjiang, China.

TABLE 1 Number of *Ferula sinkiangensis* individuals recorded in our surveys of two subpopulations in Yining County, Xinjiang, China (Fig. 1), in 2022 and 2023.

		Total individuals		Mature individuals	
Subpopulation	Altitude (m)	2022	2023	2022	2023
I	1,065–1,127	673	568	0	0
II	1,066–1,139	1,360	947	0	5
Total		2,033	1,515	0	5

population of *F. sinkiangensis*, with one subpopulation in each of two valleys in Yining, at altitudes of 1,065–1,139 m, separated by a small hill. We investigated population age structure during April–May in 2022 and 2023. We established 18 survey plots (each measuring 20 × 20 m) in each of the two subpopulations and placed four 3 × 3 m quadrats in each plot, resulting in a total of 144 sample quadrats. We counted the number of surviving individuals and the number of basal leaves of each individual in each quadrat. Considering the small population size and degree of threat, we used space instead of time to identify age groups according to the number of basal leaves, which increases with age (Harper & White, 1974), identifying nine age classes. We calculated the area of occupancy and extent of occurrence using the IUCN Guidelines (IUCN, 2022).

In 2022 and 2023, we found a total of 673 and 1,360 individuals, respectively, in the surveyed plots of subpopulation I and 568 and 947 in the surveyed plots of subpopulation II. We found no flowering individuals in 2022 and only five flowering individuals in 2023 (Table 1). The number of basal leaves per individual had an inverted J-shaped distribution in both subpopulations. The highest number of individuals was in the 3–4 year age group, after which the number of individuals declined with increasing age (Fig. 2), indicative of a relatively stable age structure.

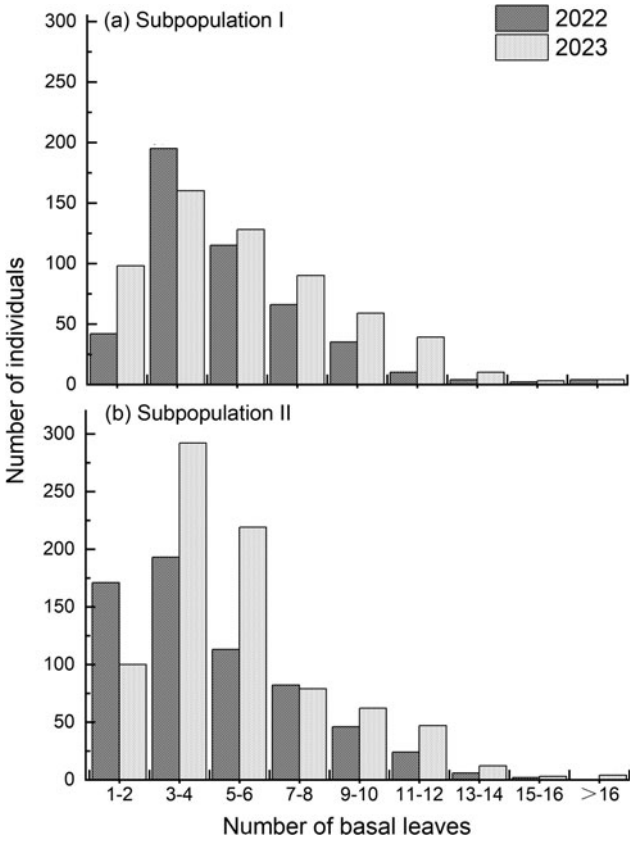

FIG. 2 Frequency distribution of the number of basal leaves in the two *Ferula sinkiangensis* subpopulations in Yining County, Xinjiang, China (Fig. 1).

Although *F. sinkiangensis* was previously widely distributed in the premountain desert areas of the western Junggar Basin, these areas have been converted into farmland,

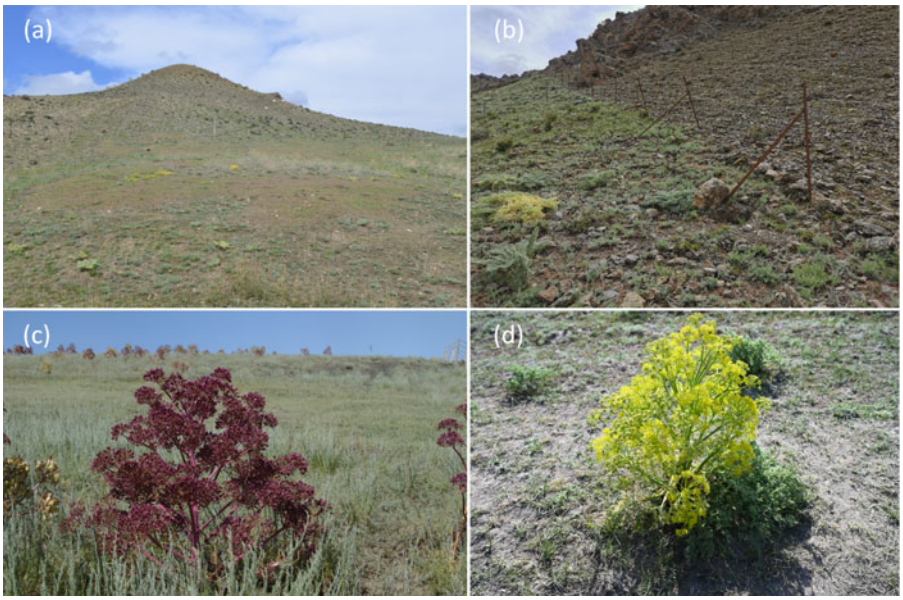

PLATE 1 (a) The remaining population and habitat of *Ferula sinkiangensis* in Yining County, Xinjiang, China, (b) the effects of grazing, (c) the fruiting stage and (d) the flowering state. Photos: Wenjun Li; (a), (b) and (d) photographed in 2023, (c) in 2018.

resulting in the destruction and loss of the species' habitat (Li et al., 2016). Additionally, extensive grazing around the *F. sinkiangensis* reserve constrains its growth, as any plants that grow outside the reserve are consumed by cattle and sheep, preventing the population from expanding (Plate 1). Furthermore, despite legal prohibitions against harvesting *F. sinkiangensis*, this still occurs, threatening the species' survival. Because of its narrow distribution range and decreasing number of individuals, *F. sinkiangensis* is categorized as Critically Endangered on the Threatened Species List of China's Higher Plants based on criterion A2c (Qin et al., 2017). We propose that the species should be categorized as Critically Endangered on the IUCN Red List based on criterion B2ab(iii), C2a(i) and D (IUCN, 2022); i.e. we calculate the area of occupancy to be the same as the extent of occurrence at 4 km² (B2), there is a single location (a), which is affected by cattle and sheep grazing, and human disturbance, resulting in a continuing decline in extent and quality of habitat (b(iii)), and the results of the surveys conducted in both years show that there are fewer than 50 mature individuals within each subpopulation (C2a(i)) and the whole population (D). The area occupied by the two subpopulations falls within a single cell of a 2 × 2 km grid, and therefore both the extent of occurrence and area of occupancy are < 4 km².

Rare and threatened species often face increased risk of genetic drift and inbreeding because of their small population sizes and limited geographical ranges (Nei et al., 1975; Hamrick et al., 1992; Hamrick & Godt, 1996; Frankham, 1997; Nybom, 2004). It is crucial to prioritize measures aimed at preventing population degradation for such species, including in situ and ex situ conservation strategies (Li et al., 2014; Wang et al., 2016; Han et al., 2020). The stable age structure of the *F. sinkiangensis* population in Yining County can be attributed to the construction of the fence around the reserve in 2004 and the implementation of grazing bans inside the reserve. However, the population faces challenges to its regeneration, with only a few seeds produced by mature plants (of which there are < 50). To protect this species effectively, we recommend the following in situ and ex situ conservation actions: (1) further studies on the species' phenology, pollination, seed dispersal, population dynamics and genetic variation; (2) development of an ex situ conservation plan, including artificial cultivation, tissue culture and core germplasm preservation; and (3) strengthening of reserve management practices and increasing awareness among local residents regarding the importance of conserving this species (Li et al., 2014; Wang et al., 2016; Han et al., 2020; Zhang et al., 2020; Paglia et al., 2022).

Author contributions Study design, fieldwork: TL, QC, LY, WL; data analysis: TL, QC, WL; writing: TL, ZY, WL.

Acknowledgements We thank Song Shiqiang, Chen Sheng, the local government and residents for their assistance during fieldwork. This study was supported by grants from the Tianshan Youth Program of Xinjiang Uygur Autonomous Region (2022TSYCCX0088), the Western Young Scholars Project of the Chinese Academy of Sciences (2022-XBQNXZ-003) and Shanghai Cooperation Organization Partnership and International Technology Cooperation Plan of Science and Technology Projects (2021E01020).

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

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

References

Chinese Pharmacopoeia Commission (1978) *Pharmacopoeia of the People's Republic of China: Part A*. Ministry of Health of the People's Republic of China, Beijing, China.

Estekhdami, P. & Dehsorkhi, A.N. (2019) Chemical composition of volatile oil of *Ferula assafoetida* L. *International Journal of Research Studies in Agricultural Sciences*, 5, 9–14.

Frankham, R. (1997) Do island populations have less genetic variation than mainland populations? *Heredity*, 78, 311–327.

Fu, L.G. (1992) *Red Book of Chinese Plants*. Science Press, Beijing, China.

Hamrick, J.L. & Godt, M.J.W. (1996) Effects of life history traits on genetic diversity in plant species. *Philosophical Transactions of the Royal Society of London B*, 351, 1291–1298.

Hamrick, J.L., Godt, M.J.W. & Sherman-Broyles, S.L. (1992) Factors influencing levels of genetic diversity in woody plant species. In *Population Genetics of Forest Trees* (eds W.T. Adams, S.H. Strauss, D.L. Copes & A.R. Griffin), pp. 95–124. Springer, Dordrecht, The Netherlands.

Han, C., Tao, L. & Sun, W. (2020) Distribution and conservation status of *Magnolia ovoidea* (Magnoliaceae): a Critically Endangered species in Yunnan, China. *Oryx*, 54, 466–469.

Harper, J.L. & White, J. (1974) The demography of plants. In *Annual Review of Ecology and Systematics*, vol. 5 (eds R.F. Johnston, P.W. Frank & C.D. Michener), pp. 419–463. Annual Reviews, Palo Alto, USA.

IUCN (2022) *Guidelines for Using the IUCN Red List Categories and Criteria*. IUCN Species Survival Commission, Gland, Switzerland. iucnredlist.org/resources/redlistguidelines [accessed April 2024].

Li, B., Zhang, Z. & Zhang, D. (2014) Conservation status of the unique populations of *Wenchengia alternifolia*, an enigmatic plant endemic to Hainan Island, China. *Oryx*, 3, 354–357.

Li, Y.D., Fu, S.Y., He, J., Fan, C.Z. & Li, X.J. (2016) Analysis of specific medicinal plants resources *Ferula sinkiangensis* in Xinjiang. *China Modern Traditional Chinese Medicine*, 19, 714–717. [In Chinese]

Li, W.J., Su, Z.H., Yang, L., Cao, Q.M. & Feng, Y. (2020) Genetic diversity of the critically endangered *Ferula sinkiangensis* K.M. Shen (Apiaceae) and the implications for conservation. *Turkish Journal of Botany*, 44, 145–152.

Mohammadhosseini, M., Venditti, A., Sarker, S.D., Nahar, L. & Akbarzadeh, A. (2019) The genus *Ferula*: ethnobotany, phytochemistry and bioactivities – a review. *Industrial Crops and Products*, 129, 350–394.

National Forestry and Grassland Administration (2021) *National Key Protected Wild Plants List*. gov.cn/zhengce/zhengceku/2021-09/09/content_5636409.htm [accessed April 2024]. [In Chinese]

Nei, M., Maruyama, T. & Chakraborty, R. (1975) The bottleneck effect and genetic variability in populations. *Evolution*, 29, 1–10.

Nybom, H. (2004) Comparison of different nuclear DNA markers for estimating intraspecific genetic diversity in plants. *Molecular Ecology*, 13, 1143–1155.

Paglia, I., Luber, J., Mansano, V.D. & Freitas, L. (2022) A narrowly endemic species of Begoniaceae: rediscovery, distribution and conservation of *Begonia jocelinoi*. *Oryx*, 56, 935–938.

Pimenov, M.G. & Leonov, M.V.E. (1993) *The Genera of the Umbelliferae: A Nomenclator*. Royal Botanic Gardens, Kew, UK.

Plunkett, G.M., Pimenov, M.G., Reduron, J.P., Kljuykov, E.V., Wyk, B.E.V., Ostroumova, T.A. et al. (2018) Apiaceae. In *Flowering Plants. Eudicots* (eds J.W. Kadereit & V. Bittrich), pp. 9–206. Springer, Cham, Switzerland.

Qin, H., Yang, Y., Dong, S., He, Q., Jia, Y., Zhao, L. et al. (2017) Threatened Species List of China's Higher Plants. *Biodiversity Science*, 25, 696-744.

Sahebkar, A. & Iranshahi, M. (2011) Volatile constituents of the genus *Ferula* (Apiaceae): a review. *Journal of Essential Oil-Bearing Plants*, 14, 504–531.

Sayed-Ahmad, B., Talou, T., Saad, Z., Hijazi, A. & Merah, O. (2017) The Apiaceae: ethnomedicinal family as source for industrial uses. *Industrial Crops and Products*, 109, 661–671.

Shan, R.H., She, M.L., Yuan, C.C., Wang, T.S., Liou, S.L., Shen, K.M. et al. (1992) Umbelliferae. In *Flora Reipublicae Popularis Sinicae, vol. 55(3)* (eds R.H. Shan & M.L. She), pp. 87–117. Science Press, Beijing, China.

She, M.L. & Watson, M.F. (2005) Ferula *L*. In *Flora of China, vol. 14* (eds Z.Y. Wu, P.H. Raven & D.Y. Hong), pp. 174–180. Missouri Botanical Garden Press, St. Louis, Missouri, USA.

Shen, G.M. (1987) Ferula *L*. Volksverlag, Xinjiang, Urumqi, China. [In Chinese]

Shen, G.M. (2011) *Ferula* L. In *Flora Xinjiangensis: Tomus 3* (ed. K.M. Shen), pp. 575–601. Xinjiang Science and Technology Press, Urumqi, China.

Shen, G.M., Ramil, Yang, G. & Xu, L.R. (1975) Two new species of *Ferula* and their economical significances in Sinkiang. *Acta Phytotaxonomica Sinica*, 13, 88–92. [In Chinese]

Wang, S. & Xie, Y. (2004) *China Species Red List,* vol. 1. Higher Education Press, Beijing, China.

Wang, B., Ma, Y.P., Chen, G., Li, C.R., Dao, Z.L. & Sun, W.B. (2016) Rescuing *Magnolia sinica* (Magnoliaceae), a Critically Endangered species endemic to Yunnan, China. *Oryx*, 50, 446–449.

Yaqoob, U. & Nawchoo, I.A. (2016) Distribution and taxonomy of *Ferula* L.: a review. *Research & Reviews: Journal of Botany*, 5, 15–23.

Zhang, X., Zhou, X.L., Liu, Y.H., Mo, J.Q., Zhang, L.Q., Wang, Y.H. & Shen, S.K. (2020) Investigating the status of *Cinnamomum chago* (Lauraceae), a plant species with an extremely small population endemic to Yunnan, China. *Oryx*, 54, 470–473.

Zhao, W.B., Tan, Y., Xiang, Y. & Cheng, Y.H. (2009) Investigation on resource of Resina Ferulae in the Xinjiang Junggar Basin. *Lishizhen Medicine and Materia Medica Research*, 20, 2024–2026. [In Chinese]