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Report

Invasive alien plants in China: An update

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China is the largest country in eastern Asia and contains habitats that range from cold temperate to tropical rainforest. The Chinese have a long history of plant cultivation and domestication. Although most cultivated plants in China are native species, many are non-native plants introduced throughout Chinese history for food, medicine, horticulture or ornamental purposes (Xie et al., 2001; Axmacher and Sang, 2013). The *Catalogue of Alien Plants in China* records a total of 14,710 alien plants (Lin and Ma, 2022). Among these, some, such as corn and potato, are used as food to meet the demands of China's large population. Non-native plants that have established populations and colonized local environments are called naturalized plants. Previous studies indicate that the number of naturalized plant species in China ranges from 861 (Jiang et al., 2011) to 933 (Yan et al., 2019). Of those, between 126 (Liu et al., 2005) to 402 (Ma, 2020a) have been designated as Invasive Alien Plants (hereafter, invasive plants) (Weber et al., 2008). In China, invasive plants have been detrimental to the conservation of biodiversity and native ecosystems, particularly since the 1990s (An et al., 2007; Wan et al., 2011). Thus, it is critical to use multidisciplinary, nation-wide approaches to investigate invasive plants in China. Here we present an analysis of 403 invasive plant species based on the *Alien Invasive Flora of China* and other recently published works.

Data sources for this study included *The Checklist of the Chinese Invasive Plants* (Ma, 2013), *The Survey Reports on Chinese Alien Invasive Plants* (Ma, 2014), *The Checklist of the Alien Invasive Plants in China* (Ma and Li, 2018), and *Alien Invasive Flora of China* (Ma, 2020a). Information on invasive plant species was mainly extracted from the five volumes of *Alien Invasive Flora of China*. This information included detailed descriptions of taxonomic and morphological characteristics, geographic distribution patterns, introduction and intrusion modes, known hazards and management efforts. For data analysis, we used GraphPad Prism software to draw pie and bar charts and two chord diagrams based on Turbelin et al. (2017). The relevant information on invasive plants is summarized in Table S1. Angiosperms are arranged according to *Alien Invasive Flora of China* (Ma, 2020a). The origin of the invasive plants is arranged according to their source: Africa, Asia, Europe, North America, Oceania, and South America.

The geographical vegetation classification is based on geography, climate, soil, and vegetation conditions according to Vegetation Regionalization Map of China of Wu (1980). Eight regions are recognized: I, cool temperate coniferous forest region; II, temperate coniferous deciduous broadleaf mixed forest region; III, warm temperate deciduous forest region; IV, subtropical evergreen broadleaf forest region; V, tropical monsoon and rainforest region; VI, temperate steppe region; VII, temperate desert region; VIII, Qinghai-Tibet plateau vegetation region (Zhong and Miao, 1986). We integrated the above vegetation regions with the present provincial administrative regions into seven different regions (Fig. 1C, Regions II–VIII). Region I of the vegetation regionalization map, which contained parts of the Heilongjiang and Inner Mongolia regions, were merged into Region II to facilitate statistics. Regions II–VIII agree with the vegetation map of Wu (1980).

Province details corresponding to the simplified geographical vegetation area are as follows: II (2): Heilongjiang (HL) and Jilin (JL); III (8): Beijing (BJ), Henan (HA), Hebei (HE), Liaoning (LN), Shandong (SD), Shaanxi (SN), Shanxi (SX) and Tianjin (TJ); IV (15): Anhui (AH), Chongqing (CQ), Fujian (FJ), Guangdong (GD), Guangxi (GX), Guizhou (GZ), Hubei (HB), Hunan (HN), Jiangsu (JS), Jiangxi (JX), Sichuan (SC), Shanghai (SH), Taiwan (TW), Yunnan (YN) and Zhejiang (ZJ); V (3): Hainan (HI), Hongkong (HK) and Macao (MO); VI (3): Gansu (GS), Inner Mongolia (NM) and Ningxia (NX); VII (1): Xinjiang (XJ); VIII (2): Qinghai (QH) and Xizang (XZ). The codes for the province were issued by the Ministry of Information Industry of the People's Republic of China in 2008.

Mode of introduction is divided into two groups: intentional (ornamentals, medicines, fuel, fruits and vegetables, green manure and forage, textile, slope and silt stabilization) and unintentional.

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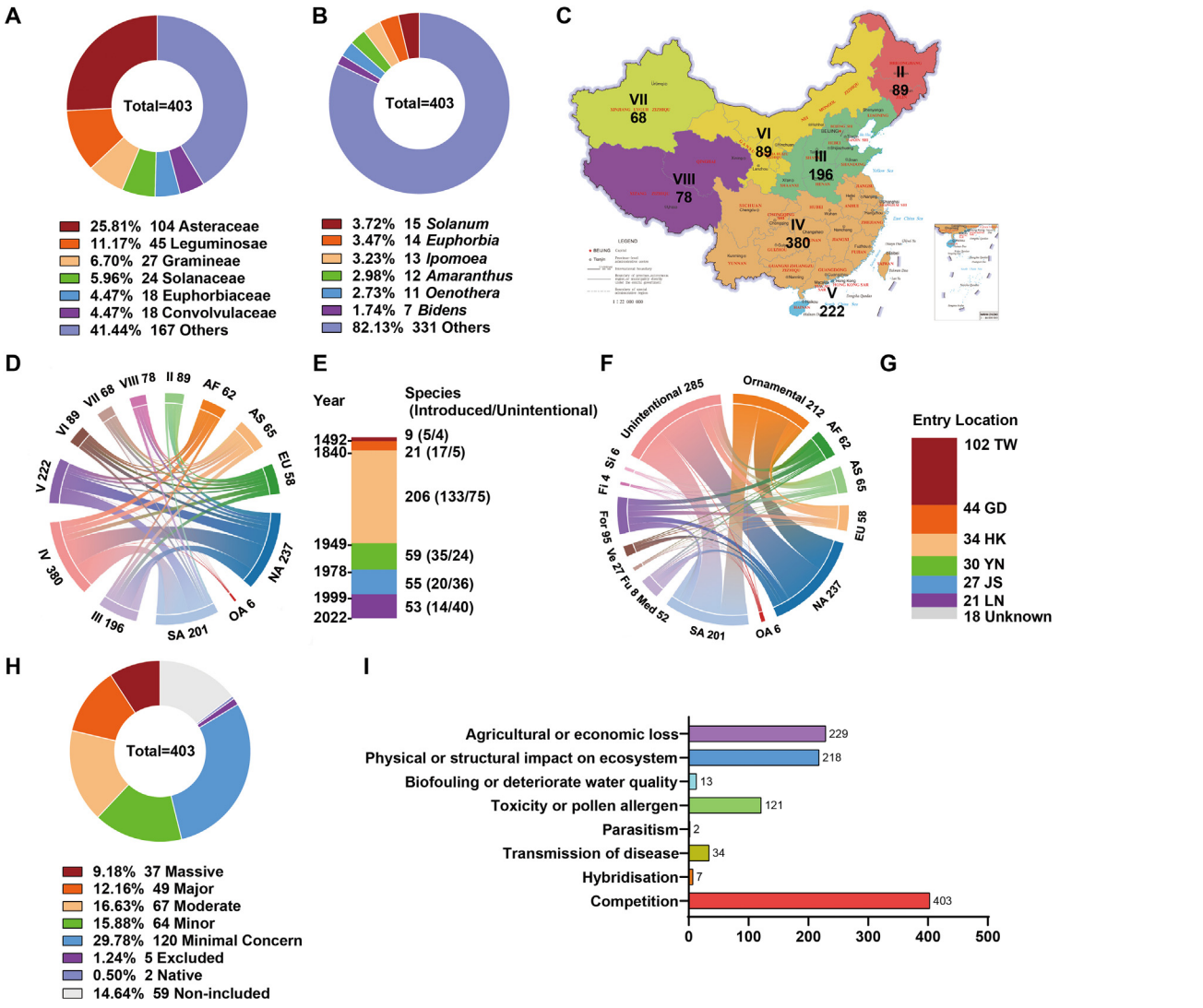

Fig. 1. Characteristics of invasive alien plants in China. A. Family component; B. Genus component; C. Geographic distribution; D. Chord diagram of origin and geographic distribution; E. Entry Time; F. Chord diagram of origin and method of importation; G. Entry Location; H. Invasive Grade; I. Impact. (Abbreviation in D, F and G: AF, Africa; EU, Europe; NA, North America; OA, Oceanica; SA, South America; Fi, Fiber; Si, Slope and silt consolidation; For, Forage; Ve, Vegetables and fruits; Fu, Fuel; Med, Medicine; TW, Taiwan; GD, Guangdong; HK, Hongkong; YN, Yunnan; JS, Jiangsu; LN, Liaoning).

For dispersibility of invasive plants, four different categories are recognized: abundant seeds, small or light seeds, spiny or bristle-covered seeds or fruits, and vegetative propagation.

For impact of invasive plants, eight categories are recognized, using the IUCN Environmental Impact Classification for Alien Taxa (EICAT) impact criteria (IUCN, 2020) with slight modification: competition, hybridization, transmission of disease, parasitism, toxicity, biofouling or sheltering water bodies, chemical, physical or structural impact on the ecosystem, reducing agricultural production and harming the landscape. Invasive grades were extracted from *The Checklist of the Alien Invasive Plants in China* (Ma and Li, 2018) matched to the five impact categories of the IUCN EICAT: massive, major, moderate, minor, and minimal concern. Three additional classes were included: recommended exclusion, native, and non-included.

Four hundred and three species of invasive plants are recognized in China. Four hundred species are reported in the five-volume *Alien Invasive Flora of China* (Ma, 2020a); two species of *Phalaris* L. and one of *Impatiens* L. have been added based on recent reports (Tang et al., 2018; Qin et al., 2022). These plants belong to 226 genera in 69 families. The largest six families are Asteraceae (104 species), Fabaceae (Leguminosae, 45 species), Poaceae (Gramineae, 27 species), Solanaceae (24 species), Euphorbiaceae (18 species), and Convolvulaceae (18 species) (Fig. 1A). The largest genera are *Solanum* L. (15 species), *Euphorbia* L. (14 species), *Ipomoea* L. (12 species), *Amaranthus* L. (12 species), *Oenothera* L. (11 species), and *Bidens* L. (7 species) (Fig. 1B). Most invasive plant species in China are terrestrial (389 species); only 16 species are aquatic (Table S1).

Vegetation regionalization and geographic patterns are generally closely related to plant diversity. Based on the Vegetation Regionalization Map of China of Wu (1980) and the provincial administrative regions, the integrated geographical vegetation of China is divided into seven different regions (Fig. 1C, Regions II–VIII). Invasive plant species are most abundant in subtropical (IV, 380 species) and tropical (V, 222 species) regions, followed by warm temperate deciduous broad-leaved forests (III, 196 species) and temperate coniferous and broad-leaved mixed forests (II, 89 species). Fewer invasive plant species occur in regions lacking water, including in temperate grasslands (VI, 89 species), the cold

and high-altitude Qinghai-Tibet Plateau (VIII, 78 species), and temperate desert (VII, 68 species). These findings imply that temperature and humidity are decisive environmental factors that determine the distributions of invasive plant species in China. The number of invasive plant species are categorized by origin of geographical region in Fig. 1D. Of the 403 invasive plant species in China, most are from North America (237 species) and South America (201 species), then from Asia (65 species), Africa (62 species), Europe (58 species), and Oceania (6 species). Invasive plants from the same origin may spread to different geographical regions, indicating that origin does not determine geographic distribution (Fig. 1D).

More than 92% of the invasive plant species (373 species) entered China after 1840, when China opened to the world. Since the reform and opening-up in 1978, 108 invasive plant species entered China, nearly twice as many as between 1949 and 1978 (59 species; Fig. 1E). Among the 403 invasive plant species, 238 species (about 60% of all invasive plants) were intentionally introduced; 185 species (about 40%) were accidently introduced (Fig. 1E). Among the intentionally introduced species, most (139 species) were introduced for ornamental purposes, followed by herbage (54 species), medicine (31 species), fruit and vegetables (16 species), fuel (6 species), slope and silt stabilization (5 species), and fibers (4 species) (Table S1). The main source of invasive plant species were the Americas. The dominant factor for introducing invasive plant species was their ornamental value, although unintentional importation also accounts for a large portion of the invasive plants (Fig. 1F).

The six provinces with the greatest number of invasive plant species are Taiwan (102 species), Guangdong (44 species), Hongkong (34 species), Yunnan (30 species), Jiangsu (27 species) and Liaoning (21 species) (Fig. 1G). Most invasive plant species entered China along coastal areas or seaways; thus, provinces with port cities are among the top six. Due to its border with three countries (Laos, Myanmar, and Vietnam), Yunnan in southwest China was also an important entry port.

Dispersibility of invasive plant species is determined by their reproductive characteristics, including seeds and vegetative propagation (Elton, 1958, 2020). Among 403 invasive plant species, 389 species reproduce by seeds, 110 species multiply through vegetative propagation and 96 species multiply by both means. Seed characteristics of invasive plant species determine their long-distance dispersal capacity. One hundred and fifty invasive plants have light or small seeds that spread easily by wind, water or other similar media. Thirty-nine invasive plant species have spiny or bristle-covered seeds or fruits; they can spread themselves through the activities of humans and animals (Table S1).

Grades for invasive plant impact categories were recently established for the first time in China (Ma and Li, 2018). For each invasive plant species, we matched these impact grades with impact categories of the IUCN Environmental Impact Classification for Alien Taxa (EICAT) (IUCN, 2020). As shown in Fig. 1H, five impact grades and three extra classes were used. The five grades include massive (37 species, 9.18%), major (49 species, 12.16%), moderate (67 species, 16.63%), minor (64 species, 15.88%), and minimal concern (120 species, 29.78%). The impact of these 338 invasive plant species (83.87%) were evaluated previously. Three additional classes still exist: excluded (5 species, 1.24%), native (2 species, 0.50%), not included (58 species, 14.39%) (Fig. 1H). These 65 reclassified invasive plant species (16.13% of total 403 IAPs) reflect the rapidly changing number of invasive plant species as well as the difficulties in identifying species and the importance and accuracy of plant taxonomy (Pyšek et al., 2004).

To analyze the impact of invasive plant species in China, we used eight slightly modified IUCN EICAT impact criteria (IUCN, 2020). All 403 invasive plant species threaten local biodiversity, 229 species cause serious agricultural and economic loss, 218 species have a physical or structural impact on the ecosystem, 121 species are toxic or their pollen is allergenic, 34 species are able to transmit diseases, 13 lower water quality or are biofouling, 7 species hybridize with native taxa and 2 species parasitize native taxa (Fig. 1I). Although the five-volumes of the *Alien Invasive Flora of China* (Ma, 2020a) recommended various preventative and control methods for each species, there are still great difficulties in implementing these recommendations. Standardized introduction and cultivation are the fundamental to preventing and controlling alien invasive plants.

Understanding changing trends in the number and distribution of invasive plant species is complicated and dynamic. Both numbers and distribution of invasive plant species are affected by various factors, including temperature and elevation, but human activities are surely the dominant determinant (Elton, 1958, 2020). Over the past two decades, we have investigated and provided preliminarily details on the general status of invasive plant species in China. However, the following issues still need to be considered seriously.

1. Problems and deficiencies of current research

Although a national census of invasive species has been carried out, data on invasive plants in China are still insufficient or lacking in detail, particularly when compared with the geographic distribution information, population numbers of specific invasive species and investigation of aquatic invasive plant species in developed countries (Pyšek et al., 2004). Domestic investigation standards and processes still need to be brought in line according to international standards. Communication and cooperation with international organizations, such as the Convention on Biological Diversity (CBD, https://www.cbd.int/), Intergovernmental Science-Policy Platform on Biodiversity, Ecosystem Services (IPBES, https://ipbes.net/), should be strengthened to ensure scientific and standardized investigation methods, a cost-effective investigation process, and open sharing of investigation results and data. The National Specimen Information Infrastructure (NSII, http://nsii.org.cn/), Invasive Alien Species of China (IASC, http://www.iplant.cn/ias/) and Chinese invasive organisms database (alien.especies.cn) should integrate and update data into international databases such as Global Invasive Species Database (GISD, http://www.iucngisd.org/gisd/), CABI Invasive Species Compendium (CABI ISC, https://www.cabi.org/ISC/) (Turbelin et al., 2017), and Global Naturalized Alien Flora (GloNAF, https://glonaf.org/) (van Kleunen et al., 2015).

The investigation of aquatic plants is far from sufficient and is deficient in detail and scope. Surveys of major rivers, lakes, and wetlands, as well as islands, are extremely lacking. In recent years, an increasing number of aquatic plants have been brought into China for ornamental purposes through commercial companies and enthusiasts. Additional factors that limit our current understanding of aquatic invasive plants include technical difficulties related to sample collection and inadequate taxonomic knowledge. We recommend learning from work done at the National Invasive Species Information Center in America and the Invasive Species Centre in Canada.

The prevention and control of invasive plants are complex, involving not only many governmental departments, such as the Ministry of Ecology and Environment, the Ministry of Agriculture and Rural Affairs, the National Forestry and Grassland Administration and Customs, but also local universities, research institutes, and botanical gardens as well as related organizations and communities. Coordination and communication between different departments is particularly important and determines the

effectiveness and cost of this task national wide. Especially in terms of data sharing, it is necessary to build a public platform to ensure that projects from different funding sources can upload data uniformly and be used widely. Undoubtedly, the Measures for the Management of Alien Invasive Species, implemented on 1 August 2022, is a milestone in the research and management of invasive plant species. The keys to monitoring and regulating invasive plant species include standardized investigative steps, sensitive data collection, as well as timely data processing and sharing.

2. Invasive plants and weeds

The concept of weeds is often used when evaluating the harmfulness of invasive plants. Indeed, weeds and invasive plant species are harmful in overlapping ways. Generally, invasive plants contribute to the destruction of ecosystems and biodiversity in nature, whereas weeds usually refer to herbaceous plants that cause economic loss to agriculture and animal husbandry or landscape (Elton, 1958, 2020). The term “invasive plant” is used by researchers to emphasize biosafety and ecological impact, whereas the term “weed” is usually applied to plants that affect agricultural production. Most invasive plant species can be considered weeds when they endanger human production and the environment. Invasive plants also include many woody and aquatic plants, which are not weeds. *Weeds Flora of China* (Li, 1998), the first national publication on weed research, lists 1290 species of weeds belonging to 560 genera in 105 families. Among these species, at least 95 are designated as invasive plant species. Compared with invasive plants, weeds are an ancient topic. Current methods used to analyze invasive plant species are clearly related to the risk assessment process used for weeds. Evaluation of both weeds and invasive plant species is based on similar analyses and rank calculation methods. The strategies for weed prevention and control can be used to control invasive plants in farmlands and urban ecosystems. However, in wild areas, such as nature reserves and national parks, it is necessary to carry out invasive plant surveys and formulate targeted measures to protect rare and endangered plants and to maintain the stability of native biodiversity and ecosystems.

3. The importance of plant taxonomy

An additional key to studies on invasive plant species is the correct application of scientific names. We must check the accuracy of the names of invasive plant species in previous reports because specimens may be misidentified. For example, 283 native species have been identified from the literature as invasive plant species (Ma and Li, 2018). The scientific name of each invasive plant species was based on at least one voucher specimen after many erroneous identifications were discovered (Ma, 2020a). A prominent example is *Solanum viarum* Dunal (Solanaceae), a toxic plant. In 2017, it was included in the list of alien invasive species in China's natural ecosystem (the fourth batch) released by the Department of Natural Ecology Protection of the Ministry of Ecology and Environment; however, it was misidentified as *Solanum aculeatissimum* Jacquin (synonym: *Solanum khasianum* C.B. Clarke). It has invaded more than 17 provinces in southern China. In fact, in China *S. khasianum* was initially used as an ambiguous name (or *sensu lato*, a broad circumscription of taxa) that included *S. aculeatissimum* and *S. viarum*. The latter species is invasive; the former is rare in China. Another similar example is *Hydrocotyle verticillata* Thunb. It has often been incorrectly identified as *H. leucocephala* Cham. & Schltdl. or *H. vulgaris* L.

Over the past thirty years, alien invasive plants from different provinces or regions have rapidly increased in China. Here we have updated and provided a brief report on 403 invasive plants species based on recently published studies in China and hope that it will be both an important resource for the study of plant invasions, the conservation of biodiversity and also a basic or starting point for further research work on the biology of invasive plants in China. China is still a developing country, particularly in the field of plant taxonomy, with little more than 100 years of history since the first paper was published by a Chinese taxonomist in 1916 (Ma, 2020b). Even though two national floras of China have been published (Wu et al., 2004, 2013), much nation-wide work is still to be done. Plant surveys are particularly important. Only then can we achieve a deep understanding of invasive plants and weeds in China, especially from an international viewpoint (Pyšek et al., 2004).

Author contributions

JSM designed the study; QH and JSM collected data, performed analysis, and wrote the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pld.2022.11.004.

References

An, S.Q., Gu, B.H., Zhou, C.F., et al., 2007. Spartina invasion in China: implications for invasive species management and future research. Weed Res. 47, 183–191.
Axmacher, J.C., Sang, W.G., 2013. Plant invasions in China-challenges and chances. PLoS One 8, e64173.
Elton, C.S., 1958. The Ecology of Invasions by Animals and Plants. Methuen, London, UK.
Elton, C.S., 2020. The Ecology of Invasions by Animals and Plants. Springer, Cham, Switzerland, p. 2.
IUCN, 2020. The Environmental Impact Classification for Alien Taxa, first ed. In: IUCN EICAT categories and criteria. IUCN, Gland, Switzerland and Cambridge, UK, p. 22.
Jiang, H., Fan, Q., Li, J.T., et al., 2011. Naturalization of alien plants in China. Biodivers. Conserv. 20, 1545–1556.
Li, Y.H., 1998. Weeds Flora of China. Chinese Agricultural Press, Beijing (Chinese).
Lin, Q.W., Ma, J.S., 2022. Catalogue of Alien Plants in China. China Forestry Publishing House, Beijing (Chinese).
Liu, J., Liang, S.C., Liu, F.H., et al., 2005. Invasive alien plant species in China: regional distribution patterns. Divers. Distrib. 11, 341–347.
Ma, J.S., 2013. The Checklist of the Chinese Invasive Plants. Higher Education Press, Beijing (Chinese).
Ma, J.S., 2014. The Survey Report on Chinese Alien Invasive Plants, Part I & II. Higher Education Press, Beijing (Chinese).
Ma, J.S., Li, H.R., 2018. The Checklist of the Alien Invasive Plants in China. Higher Education Press, Beijing (Chinese).
Ma, J.S., 2020a. Alien Invasive Flora of China, s. 1–5. Shanghai Jiaotong University Press, Shanghai (Chinese).
Ma, J.S., 2020b. A Chronicle of Plant Taxonomy in China. Henan Scientific and Technological Press, Zhengzhou (English and Chinese).
Pyšek, P., Richardson, D.M., Rejmánek, M., et al., 2004. Alien plants in checklists and floras: towards better communication between taxonomists and ecologists. Taxon 53, 131–143.

Qin, F., Zhang, W.D., Liu, Q., et al., 2022. *Impatiens glandulifera* (Balsaminaceae), a newly naturalized alien species in China. J. Trop. Subtropical Bot. 1–6. https://doi.org/10.11926/jtsb.4544.
Tang, D.S., Yang, X.Y., Li, Y.C., et al., 2018. Investigation on the occurrence, damage and control of the invasive weed *Phalaris* spp. in Yunnan Province. Plant Prot. 44, 167–169.
Turbelin, A.J., Malamud, B.D., Francis, R.A., 2017. Mapping the global state of invasive alien species: patterns of invasion and policy responses. Glob. Ecol. Biogeogr. 26, 78–92.
van Kleunen, M., Dawson, W., Essl, F., et al., 2015. Global exchange and accumulation of non-native plants. Nature 525, 100–103.
Wan, F.H., Xie, B.Y., Yang, G.Q., et al., 2011. Invasion Biology. Science Press, Beijing (Chinese).
Weber, E., Sun, S.G., Li, B., 2008. Invasive alien plants in China: diversity and ecological insights. Biol. Invasions 10, 1411–1429.
Wu, C.Y., 1980. The Vegetation of China. Science Press, Beijing (Chinese).
Wu, C.Y., Peng, H., Li, D.Z., 2004. Flora Reipublicae Popularis Sinicae. In: Introduction, volume 1. Science Press, Beijing (Chinese).
Wu, C.Y., Raven, P.H., Hong, D.Y., 2013. Flora of China, volume 1. Science Press, Beijing, and Missouri Botanical Garden Press, St. Louis.
Xie, Y., Li, Z.Y., Gregg, W.P., et al., 2001. Invasive species in China — an overview. Biodivers. Conserv. 10, 1317–1341.
Yan, X.L., Wang, Z.H., Ma, J.S., 2019. The Checklist of the Naturalized Plants in China. Shanghai Scientific and Technical Publishers, Shanghai.
Zhong, Z.C., Miao, S.L., 1986. The Chinese vegetation and its regularities of distribution. J. Southwest Teachers Univ. 1, 1–36.