Advances in Research on the Changing Geographic Distribution of Chinese Plant Species Under Future Climate Change Scenarios: Postprint

Authors: Wang Siyu, Wu Jianguo

Date: 2024-08-08T00:00:00+00:00

Abstract

Analyzing the impacts of climate change on plant geographical distribution is of great significance for biodiversity conservation and adaptation to climate change. Based on 220 publications since 2010, this paper summarizes and analyzes research progress on changes in plant geographical distribution in China under future climate change scenarios, discusses existing problems, and prospects future research directions. The results show: (1) Since 2010, Chinese scholars have analyzed the geographical distribution change characteristics of 1,058 plant species in China under future climate change scenarios, among which only 636 species have clear information on geographical distribution changes. (2) Under future climate change scenarios, among 518 angiosperm species, 195 show an increasing trend in geographical distribution range and 245 show a decreasing trend; among 57 gymnosperm species, 12 show an increasing trend and 38 show a decreasing trend; 1 fern species shows an increasing trend; among 60 bryophyte species, 7 show an increasing trend and 53 show a decreasing trend. (3) Under future climate change scenarios, the geographical distribution patterns of 137 species clearly shift toward Northwest, North, or Northeast China; 19 species simultaneously shift toward both high latitudes and high altitudes; and 125 species shift only toward high latitudes. (4) Under future climate change scenarios, with probability greater than 0.6, approximately 32 angiosperm species, 42 gymnosperm species, and 48 bryophyte species will face the risk of complete loss of geographical distribution range; without considering probability, approximately 57 angiosperm species and 96 gymnosperm species will face the risk of distribution range loss. Research limitations include: (1) the relatively small number of plant species studied, (2) the use of single climate change scenarios and models, (3) the lack of comprehensive consideration of climate and other environmental factors and comparative studies using multiple models, and (4)

the absence of systematic analysis of the risk of plant geographical distribution range loss under future climate change scenarios. In the future, while enriching the number of plant species studied, it is necessary to strengthen the use of multiple climate change scenarios, develop ecological niche models suitable for China's regional characteristics, conduct comparative studies on geographical distribution changes of different plants under various climate change scenarios, and also strengthen the analysis of risks of plant geographical distribution range loss under climate change scenarios.

Full Text

Preamble

ChinaXiv DOI:10.11931/guihaia.gxzw202402016

Research Progress on Changes in Geographical Distributions of Plant Species Under Future Climate Change Scenarios in China

WANG Siyu, WU Jianguo*
(Institute of Ecology, Chinese Research Academy of Environmental Sciences, Key Laboratory of Regional Ecological Process and Function Assessment for Environmental Protection, Beijing 100012, China)

Abstract: Analyzing the impacts of climate change on plant geographical distributions is crucial for biodiversity conservation and climate adaptation. Based on 220 publications since 2010, this paper synthesizes research progress on changes in plant geographical distributions in China under future climate change scenarios, discusses existing problems, and outlines future research directions. The results show: (1) Since 2010, Chinese scholars have analyzed geographical distribution changes for 1,058 plant species under future climate change scenarios, with clear change information available for only 636 species. (2) Under future climate change scenarios, among 518 angiosperm species, 195 showed increasing distribution ranges while 245 showed decreasing trends; among 57 gymnosperm species, 12 showed increasing trends and 38 showed decreasing trends; one fern species showed an increasing trend; and among 60 bryophyte species, 7 showed increasing trends while 53 showed decreasing trends. (3) Under future climate change scenarios, 137 species clearly migrated toward northwestern, northern, or northeastern China, 19 species migrated simultaneously toward higher latitudes and altitudes, and 125 species migrated only toward higher latitudes. (4) Under future climate change scenarios, with probability >0.6, approximately 32 angiosperm, 42 gymnosperm, and 48 bryophyte species face complete loss of their geographical distribution ranges; without considering probability, approximately 57 angiosperm and 96 gymnosperm species face range loss risks.

Research deficiencies include: (1) insufficient number of plant species studied, (2) limited selection of climate change scenarios and models, (3) lack of comprehensive consideration of climate and other environmental factors and multi-model comparative studies, and (4) insufficient systematic analysis of range loss risks under future climate change scenarios. Future research should expand the number of plant species studied, strengthen the use of multiple climate change scenarios, develop niche models suitable for China's regional characteristics, conduct comparative studies on distribution changes of different plants under various climate scenarios, and enhance analysis of range loss risks.

Keywords: climate change, plant species, geographical distribution, impacts, risk

CLC number: Q948

Climate change and its impacts pose significant challenges to biodiversity conservation. Plant geographical distribution directly affects plant survival, reproduction, interspecific relationships, vegetation composition, and the structure and function of ecosystems and biodiversity (Woodward, 1987). Climate is the most important factor influencing plant distribution patterns (Woodward, 1987). Climate change has become an undeniable reality. The IPCC Sixth Assessment Report clearly states that global surface temperature in 2011-2020 was 1.1°C higher than in 1850-1900 (Masson-Delmotte et al., 2021), and projects that by 2081-2100, global mean surface temperature will increase by 1.0-1.8°C under the very low greenhouse gas emission scenario (SSP1-1.9), 2.1-3.5°C under the medium emission scenario (SSP2-4.5), and 3.3-5.7°C under the very high emission scenario (SSP5-8.5) (Masson-Delmotte et al., 2021). With climate change, plant distribution patterns are altering (Kosanic et al., 2018), and intensifying climate change may cause loss of suitable climatic space for plants (Pörtner et al., 2022). The IPCC Special Report on Global Warming of 1.5°C indicates that at 1.5°C warming, approximately 8% of 73,224 assessed plant species would lose half their climatic suitable space; if warming exceeds 2°C, this proportion would increase to 16% (Masson-Delmotte et al., 2018). Nevertheless, substantial uncertainty remains regarding distribution change characteristics of different plants under future climate change scenarios (Pörtner et al., 2022). Therefore, accurately determining climate change impacts on plant geographical distribution has become key to scientifically understanding climate change effects on ecosystem structure, function, and biodiversity, as well as for biodiversity conservation and climate adaptation.

Since the 1980s, research on climate change impacts on plant geographical distribution has attracted attention (Cannell et al., 1989) and has gained increasing importance (Tian et al., 2023). In 2022, IPCC assessed climate change impacts on 72,399 plant species and found that at 1.5°C warming, 8% of species face high risk of losing their geographical distribution ranges; at 2°C, 16%; and at 3°C, 44%. At 3.2°C warming, approximately 10% of 52,310 flowering plant species would face high risk of range loss. In China, research on plant distribution changes under future climate change scenarios has also received attention (Wu, 2010a, b, 2011a, b; Li et al., 2021; Wu, 2020, 2022, 2023; Appendix 1), and comprehensive assessments have been conducted (Committee for the Preparation of the Fourth National Assessment Report on Climate Change, 2022). However, systematic summaries of plant distribution migration characteristics and loss risks under future climate change scenarios are still lacking, particularly comprehensive analyses of studies published since 2010. Therefore, this paper comprehensively collected research literature published during 2010-2023 on plant distribution changes in China under future climate change scenarios, systematically summarized trends in distribution range and pattern changes, discussed current research deficiencies, and outlined future research directions to provide references for improving understanding of climate change impacts on China's plant diversity and related research.

1.1 Data Sources

Given that distribution change trends of Chinese plants under climate change scenarios before 2010 have been summarized (Lü and Wu, 2009), this study comprehensively collected literature published during 2010-2023 on plant distribution changes under future climate change scenarios in China. Chinese keywords ("climate change," "plant," "geographical distribution," "biodiversity," "niche model") and English keywords ("climate change, distribution range, plant species, China, MaxEnt, Biomod, species distribution model") were used to search Chinese and English literature. To ensure representativeness and authority, unpublished master's and doctoral theses, non-core Chinese journal papers, papers on invasive alien plants, non-SCI English papers, and papers from journals warned by Chinese authorities were excluded. From CNKI (https://www.cnki.net), 157 Chinese papers were selected, including 148 core journal papers, 138 Chinese Science Citation Database papers, and 1 abstract from the First Plant Science Frontiers Academic Conference. From Google Scholar, Science Direct, and Springer Link, 63 English papers were collected, including 5 in Q1, 24 in Q2, and 34 in Q3-Q4 according to Chinese Academy of Sciences journal classification. Publications were distributed as follows: 15 during 2010-2015, 80 during 2016-2020, and 125 during 2021-September 2023 (Appendix 1).

1.2 Plant Species

Based on collected literature (Appendix 1), since 2010, distribution change trends under future climate change scenarios have been studied for 1,058 plant species (involving 130 families and 265 genera, excluding invasive species) in China, including 643 angiosperm species (75 families, 151 genera), 248 gymnosperm species (12 families, 52 genera), 1 fern species (1 family, 1 genus), and 166 bryophyte species (41 families, 60 genera). However, only 636 species had clear information on distribution range changes, including 518 angiosperm species (75 families, 142 genera, including 8 varieties), 57 gymnosperm species (4 families, 18 genera, including 7 varieties), 1 fern species, and 60 bryophyte species (10 families, 12 genera). Overall, detailed information on distribution range and pattern changes under future climate change scenarios covered 90 families and 173 genera (Table 1).

Table 1 List of plant species with changes in distributional ranges under climate change scenarios

Note: Latin names were determined based on the Plant Science Data Center (http://www.plantplus.cn/cn), Institute of Botany, Chinese Academy of Sciences. Some plants were analyzed at the genus level in the literature; these are marked with in the table, including 17 Ormosia species, 7 Uraria species, 14 Paphiopedilum species, 20 Cymbidium species, 47 Petrocodon species, 76 Dendrobium species, 3 Coptis species, 20 Rhododendron species, 5 Zingiber species, 3 Satyrium species, 47 Camphora species, 8 Firmiana species, 8 Nitraria species, 7 Sinojackia species, 15 Lycoris species, 3 Apocynum species, 15 Orthotrichum species, 11 Lewinskya species, 16 Didymodon species, 4 Aulacomnium species, 3 Meesia species, and 5 Schistidium species. Detailed family, genus, and species information is provided in Appendix 2. Literature source details are in Appendix 1.*

1.3 Characteristics of Plant Geographical Distribution Changes

To analyze trends in plant geographical distribution under future climate change scenarios, this paper considered three aspects of distribution changes:

1.3.1 Distribution Range Change Characteristics

Based on literature reflecting changes under future climate scenarios (SRES, RCPs, or SSPs) compared to reference periods before 2023 [typically 1961-1990, 1970-2000, 1990-2000, 1990-2020, or current periods (Carter et al., 1994)], during different future periods (e.g., 2020-2040, 2041-2070, or 2071-2100), plant distribution ranges showed increasing, decreasing, or stable trends, or lacked clear change magnitude information. Range changes were categorized by magnitude: 0%-20%, 20%-40%, 40%-60%, 60%-80%, 80%-100%, and $ $100%. Additionally, differences in range changes were compared across low, medium, and high greenhouse gas emission scenarios, and across near-term (2023-2040), mid-term (2041-2070), and long-term (2071-2100) periods. SRES scenarios are IPCC greenhouse gas emission scenarios influenced by population, economic growth, and energy structure, including four scenario families (A1, A2, B1, B2) with 40 emission scenarios. RCPs, proposed by IPCC in 2012, include RCP2.6 (very low radiative forcing), RCP4.5 and RCP6.0 (medium emissions), and RCP8.5 (very high emissions). SSPs describe possible future socioeconomic development without climate policies, where SSP1, SSP2, SSP3, SSP4, and SSP5 represent sustainable development, medium development, regional development, uneven development, and conventional development pathways, respectively (Xu et al., 2016).

1.3.2 Distribution Pattern Change Characteristics

Migration toward single directions (northwest, northeast, north China, east China, south China, central China, or southwest including the Qinghai-Tibet Plateau) was characterized based on clear literature reports comparing future periods (2023-2100) to reference periods under SRES, RCPs, or SSPs scenarios. Geographic regions were defined according to relevant literature (Huang and Pan, 2003). Multi-directional migration patterns were characterized based on literature reporting migration toward multiple directions simultaneously. Unclear pattern change information was noted when literature did not explicitly report such changes. Additionally, migration toward higher or lower latitudes/altitudes was characterized based on clear reports of changes in suitable elevation and latitude ranges under future scenarios. For example, *Taxus chinensis* var. *mairei* shows a trend of its northern distribution boundary moving from subtropical to warm temperate regions, with its core distribution approaching the northern Qinling-Daba Mountains (Li et al., 2021).

1.3.3 Range Loss Risk Characteristics

Following IPCC (2022) concepts for assessing climate change risks to biodiversity, range loss risk characteristics were reflected by explicit literature reports on complete loss trends and probabilities of plant geographical distribution ranges under future climate scenarios.

2.1 Plant Geographical Distribution Range Changes

[Figure 1: see original paper] shows the number of species with different distribution range change trends among 636 species under future climate scenarios. Under future climate change scenarios, among 518 angiosperm species, 195 showed increasing trends, 245 showed decreasing trends, 6 showed initial increase then decrease, 1 showed initial decrease then increase, 61 showed little change, and 10 had unclear change information. Among 57 gymnosperm species, 12 showed increasing trends, 38 showed decreasing trends, 2 showed initial increase then decrease, 4 had unclear information, and 1 showed little change. One fern species showed an increasing trend. Among 60 bryophyte species, 53 showed decreasing trends and 7 showed increasing trends.

This figure was produced based on 636 plant species with clear information on changing trends of their geographic ranges under future climate change scenarios. A. Distribution ranges with increasing trend; B. Distribution ranges with decreasing trend; C. Distribution ranges with little change or remaining relatively stable (e.g., based on literature, the distribution range of Cancrinia maximowiczii* changed little from 1991-2020 to 2081-2100; the total suitable distribution area of *Schima superba* under different SSPs scenarios in 2041-2060 was consistent with current conditions; *Perilla frutescens* was not significantly affected by climate change; the suitable ranges of three *Vitis* species did not change significantly; the high or moderate suitable area of *Medicago archiducis-nicolai* increased slightly compared to current conditions, but the potential suitable area and distribution pattern remained stable); D. Geographical distribution ranges with trend of increasing first then decreasing; E. Geographical distribution range with trend of first decreasing then increasing; F. Degree of change in geographical distribution, and quantitative information was not explicitly mentioned in the literature.*

Fig.1 Number of plant species under different changing trends in the distribution range under future climate change scenarios

Based on collected literature (Appendix 1), the 636 species (including 518 angiosperms, 57 gymnosperms, 1 fern, and 60 bryophytes) showed the following trends:

(1) Under future climate scenarios, 195 angiosperm species showed increasing distribution ranges, including *Litsea coreana* var. *lanuginosa*, *Tapiscia sinensis*, *Trillium tschonoskii*, *Kolkwitzia amabilis*, *Euptelea pleiosperma*, *Tetracentron sinense*, *Pteroceltis tatarinowii*, *Sinopodophyllum hexandrum*, *Camellia chekiangoleosa*, *Alhagi camelorum*, *Achnatherum inebrians*, *Phyllostachys edulis*, *Ammopiptanthus mongolicus*, *Astragalus membranaceus*, *Pistacia weinmanniifolia*, *Amygdalus mongolica*, *Prunus pedunculata*, *Pyrus pashia*, *Sorbus amabilis*, *Kerria japonica*, *Schima superba*, *Lithocarpus brevicaudatus*, *Quercus lamellosa*, *Castanopsis sclerophylla*, *Medicago archiducis-nicolai*, *Uraria* (7 species), *Ormosia* (17 species), *Paeonia ludlowii*, *Sinojackia*, *Nyholmiella obtusifolia*, *Didymodon* (16 species), *Aulacomnium* (4 species), *Meesia* (3 species), and *Haplocladium microphyllum.* Among these, 113 species increased by <20% (e.g., *Petrocodon* with 47 species); increases of 20%-40% included *Capparis spinosa* and *Actinidia arguta*; 40%-60% increases included *Camellia chekiangoleosa* and *Elymus nutans*; 60%-80% increase was *Ormosia hosiei*; 80%-120% increase was *Paeonia ludlowii*; and 66 species lacked quantitative information (e.g., *Tapiscia sinensis* and *Cymbidium* with 8 species).

Under future climate scenarios, 245 angiosperm species showed decreasing distribution ranges, including *Litsea cubeba*, *Litsea mollis*, *Litsea greenmaniana*, *Empetrum nigrum*, *Circaeaster agrestis*, *Rhoiptelea chiliantha*, *Pterocarya stenoptera*, *Taiwania cryptomerioides*, *Cercidiphyllum japonicum*, *Juniperus przewalskii*, *Reaumuria songarica*, *Fokienia hodginsii*, *Nitraria*, *Tetraena mongolica*, *Gymnocarpos przewalskii*, *Kingdonia uniflora*, *Boschniakia rossica*, *Eleutherococcus senticosus*, *Sinowilsonia henryi*, *Cunninghamia lanceolata*, *Metasequoia glyptostroboides*, *Glyptostrobus pensilis*, *Alsophila spinulosa*, *Macromitrium* (15 species), *Orthotrichum* (11 species), and *Lewinskya.* Among these, 104 species decreased by <20% (e.g., *Litsea cubeba* and *Dendrobium* with 70 species); 0%-40% decreases included *Notopterygium incisum*, *Ormosia elliptica*, and *Ormosia pachycarpa*; 0%-60% decreases included *Ormosia semicastrata* and *Ormosia glaberrima*; 0%-80% decrease was *Ormosia purpureiflora*; 20%-40% decreases included *Gymnocarpos przewalskii* and *Eremurus inde-*

riensis; 20%-60% decrease was *Bretschneidera sinensis*; 20%-80% decreases included *Ormosia balansae* and *Toona ciliata*; 40%-60% decreases included *Ormosia henryi*, *Betula platyphylla*, *Populus euphratica*, *Disanthus cercidifolius* subsp. *longipes*, and *Cremastra appendiculata*; 60%-80% decreases included *Eremurus anisopterus* and *Firmiana* (8 species); and 80%-100% decrease was *Etlingera littoralis*. Additionally, 110 species lacked quantitative decrease information (e.g., *Empetrum nigrum* and *Rhododendron* with 16 species).

Under future climate scenarios, angiosperm species showing initial increase then decrease included *Lycium ruthenicum*, *Gastrodia elata*, *Frankenia pulverulenta*, *Anabasis brevifolia*, *Haloxylon ammodendron*, and *Paeonia veitchii*. Species showing initial decrease then increase was *Gentiana rhodantha*. Sixty-one species showed little change, including *Cancrinia maximowiczii* and *Camphora* (47 species).

Under different future climate scenarios, some angiosperm species showed inconsistent trends, including *Prunus pedunculata* and *Forsythia suspensa*. For example, *Prunus pedunculata* did not show consistent increasing or decreasing trends across four SSP scenarios. Under different climate scenarios during 2021-2060, *Manglietia pachyphylla* distribution decreased under low (SSP126) and high (SSP585) emission scenarios but increased under medium emission scenario (SSP245).

(2) Under future climate scenarios, 12 of 57 gymnosperm species showed increasing distribution ranges, including *Pinus massoniana*, *Picea likiangensis*, *Larix kaempferi*, *Cathaya argyrophylla*, *Picea brachytyla*, *Cephalotaxus oliveri*, *Picea schrenkiana*, *Keteleeria fortunei*, *Keteleeria davidiana*, *Pinus armandii*, *Pinus tabuliformis*, and *Fokienia hodginsii*. Thirty-eight species showed decreasing trends, including *Ephedra przewalskii*, *Juniperus przewalskii*, *Ephedra przewalskii* var. *kaschgarica*, *Larix potaninii* var. *chinensis*, *Pinus koraiensis*, *Larix gmelinii*, *Cryptomeria japonica* var. *sinensis*, *Nothotsuga longibracteata*, *Abies chensiensis*, *Abies fargesii* var. *faxoniana*, *Pinus sylvestris* var. *mongolica*, *Picea crassifolia*, *Picea meyeri*, *Picea purpurea*, *Picea likiangensis*, *Abies* (21 species), *Pinus armandii*, *Glyptostrobus pensilis*, *Metasequoia glyptostroboides*, and *Taiwania cryptomerioides*. Two species (*Taiwania cryptomerioides* and *Taxus wallichiana* var. *mairei*) showed initial increase then decrease, *Picea crassifolia* showed little change, and four species (*Picea purpurea*, *Abies chensiensis*, *Abies fargesii* var. *faxoniana*, and *Cunninghamia lanceolata*) had unclear quantitative information. Increases of <20% included *Cephalotaxus oliveri*, *Picea schrenkiana*, *Pinus tabuliformis*, and *Fokienia hodginsii*; 20%-40% increase was *Pinus massoniana*; unclear increase information included *Picea likiangensis*, *Cathaya argyrophylla*, *Picea brachytyla*, *Larix kaempferi*, *Keteleeria fortunei*, *Keteleeria davidiana*, and *Pinus armandii*. Decreases of <20% included *Cryptomeria japonica* var. *sinensis*, *Picea meyeri*, and *Taiwania cryptomerioides*; 0%-40% decrease was *Larix gmelinii*; 20%-80% decrease was *Pinus sylvestris* var. *mongolica*; and unclear decrease information

included *Abies* (21 species).

(3) Under future climate scenarios, the fern *Alsophila spinulosa* showed an increasing distribution range.

(4) Under future climate scenarios, 53 bryophyte species showed decreasing distribution ranges, including *Encalypta buxbaumioidea*, *Calymperes* (15 species), *Orthotrichum* (11 species), *Nyholmiella obtusifolia*, *Didymodon* (16 species), *Meesia* (3 species), and *Schistidium* (5 species). In the 2070s, three genera of Macromitriaceae (*Macromitrium*, etc.) in Xinjiang will decrease by 0.05%. Under future climate scenarios, *Calymperes* distribution area percentage will decrease from 31.5% to 12.23%, and *Orthotrichum* from 65.81% to 44.94% (Shen et al., 2015). *Didymodon*, *Meesia*, and *Schistidium* also showed decreasing trends, with *Meesia* decreasing by ~0.27% and *Schistidium* by ~10.39%.

Bryophyte species showing increasing trends included *Bryum*, *Aulacomnium*, *Haplocladium microphyllum*, and *Calymperes*. Under future climate scenarios, *Bryum* distribution will increase by ~3.36% in the 2050s and ~3.67% in the 2070s; *Aulacomnium* will increase by ~5.94%; *Haplocladium microphyllum* will show westward and northward expansion by 2070; and *Calymperes* will show northward expansion.

Notably, some plant distribution trends differ across emission scenarios (see Appendix 3). For example, *Lycium ruthenicum* shows increasing trends under low emission scenarios but decreasing trends under medium and high emission scenarios. *Pinus armandii* and *Cymbidium* show decreasing trends across scenarios, while *Agriophyllum squarrosum* and *Cymbidium* show increasing trends. Additionally, some species show inconsistent trends across time periods (near-term 2023-2040, mid-term 2041-2070, long-term 2071-2100). For instance, *Caryopteris mongholica* shows increasing trends in the mid-term but decreasing trends in the long-term under low emission scenarios; *Phoebe bournei* shows decreasing trends in both mid-term and long-term under medium emission scenarios; and *Cathaya argyrophylla* shows increasing trends in both mid-term and long-term.

2.2 Plant Geographical Distribution Pattern Changes

[Figure 2: see original paper] shows the number of plant species migrating in single and multiple directions. Under future climate scenarios, 326 species with clear information showed distribution centers migrating toward single directions (northwest, northeast, north China, east China, south China, central China, or southwest including Qinghai-Tibet Plateau) or multiple directions simultaneously.

Angiosperms migrating northwestward included 43 species: *Prunus pedunculata*, *Kalidium cuspidatum*, *Kalidium foliatum*, *Haloxylon persicum*, *Gentiana macrophylla*, *Paeonia rockii*, *Lycium ruthenicum*, *Populus* × *berolinensis* var.

jrtyschensis, *Sorbus tianschanica*, *Apocynum* (3 species), *Alhagi camelorum*, *Populus euphratica*, *Hydrangea macrophylla*, *Cremastra appendiculata*, *Cypripedium japonicum*, *Rhododendron* (20 species), *Primula filchnerae*, *Ulmus elongata*, *Alnus cremastogyne*, *Meconopsis punicea*, and *Osmanthus fragrans.* Twenty-two species showed northwest-dominated multi-directional migration: *Stilpnolepis centiflora*, *Cancrinia maximowiczii*, *Anabasis brevifolia*, *Gymnocarpos przewalskii*, *Haloxylon ammodendron*, *Lamiophlomis rotata*, *Meconopsis integrifolia*, *Krascheninnikovia ceratoides*, and *Paphiopedilum* (14 species). Northeastward migration included *Artemisia ordosica*, *Corylus mandshurica*, *Zelkova serrata*, *Houttuynia cordata*, *Carpinus tientaiensis*, and *Pennisetum alopecuroides.* Northeast-dominated multi-directional migration included *Sinopodophyllum hexandrum*, *Sinowilsonia henryi*, *Pteroceltis tatarinowii*, *Boschniakia rossica*, *Eleutherococcus senticosus*, *Actinidia arguta*, *Tetracentron sinense*, *Phoebe chekiangensis*, *Dipentodon sinicus*, and *Gynostemma pentaphyllum.* Northward migration included 22 species: *Ammopiptanthus mongolicus*, *Acer* section *Palmata* (18 species), *Apocynum* (3 species), and *Calligonum mongolicum.* Eastward migration included *Camellia chekiangoleosa* and *Quercus chenii.* Central China migration included *Fraxinus chinensis*; central China-dominated multi-directional migration included *Phyllostachys edulis.* Southward migration included 52 species: *Miscanthus nudipes*, *Etlingera littoralis*, *Camellia edithae*, *Paeonia delavayi*, *Paeonia rockii*, and *Petrocodon* (47 species). South China-dominated multi-directional migration included *Rhoiptelea chiliantha*, *Ormosia henryi*, and *Styrax odoratissimus.* Southwestward migration included 16 species: *Hippophae rhamnoides* subsp. *yunnanensis*, *Kingdonia uniflora*, *Pistacia weinmanniifolia*, *Quercus cocciferoides*, *Pyrus pashia*, *Michelia odora*, *Paeonia ludlowii*, *Gentiana rhodantha*, *Toona ciliata*, *Kerria japonica*, *Paeonia delavayi*, *Osmanthus fragrans.* Southwest-dominated multi-directional migration included 10 species: *Phoebe bournei*, *Cercidiphyllum japonicum*, *Euptelea pleiosperma*, *Ormosia henryi*, *Lithocarpus glaber*, *Vaccinium bracteatum*, *Quercus acutissima*, *Cyclobalanopsis glauca*, *Lithocarpus corneus*, and *Betula platyphylla.*

Gymnosperms migrating northwestward included *Abies chensiensis*, *Picea schrenkiana*, *Picea crassifolia*, and *Ephedra przewalskii* var. *kaschgarica.* Northwest-dominated multi-directional migration included *Larix potaninii* var. *chinensis*, *Picea purpurea*, *Ephedra przewalskii*, and *Cryptomeria japonica* var. *sinensis.* Northeastward migration included *Pinus koraiensis* and *Larix kaempferi.* Northeast-dominated multi-directional migration included *Larix gmelinii.* Northward migration included *Pinus sylvestris* var. *mongolica* and *Picea meyeri.* South China-dominated multi-directional migration included *Fokienia hodginsii.* Southwestward migration included *Abies fargesii* var. *faxoniana*, *Glyptostrobus pensilis*, and *Picea likiangensis.* Southwest-dominated multi-directional migration included 24 species: *Picea brachytyla*, *Juniperus przewalskii*, *Abies* (21 species), and *Keteleeria pubescens.*

The fern *Alsophila spinulosa* showed northwest-dominated multi-directional migration. Bryophytes showing northwest-dominated multi-directional migration included *Orthotrichum* (15 species); northeast-dominated multi-directional migration included *Aulacomnium* (4 species); southwestward migration included *Haplocladium microphyllum*; and south China-dominated multi-directional migration included *Calymperes*.

Based on collected literature (Appendix 1), 636 species showed trends of migrating toward higher latitudes/altitudes in northeast, northwest, or north China, or toward lower latitudes/altitudes, plus lacking pattern change information. Specifically, 137 species clearly migrated toward northeast, northwest, or north China; 125 species migrated toward higher latitudes [e.g., *Rosa roxburghii*, *Dendrobium* (76 species)]. Additionally, 19 species migrated simultaneously toward higher latitudes and altitudes (e.g., *Cyclobalanopsis glauca* and *Trillium tschonoskii*), and 20 species migrated only toward higher altitudes (e.g., *Reaumuria songarica* and *Quercus acutissima*). Meanwhile, 21 species migrated toward lower altitudes and latitudes, including *Tugarinovia mongolica* and *Lycoris*; only *Polygala tenuifolia* showed north-south expansion with east-west contraction; species with east-west migration but little latitudinal change included *Firmiana* (8 species); and species with stable distribution patterns included *Cephalotaxus oliveri* and *Cathaya argyrophylla*.

Literature also indicated that *Uraria* (7 species) migrated toward northern and eastern coastal areas; *Vitex rotundifolia* migrated from coastal to inland areas; *Castanopsis sclerophylla* migrated toward southeastern coastal low-altitude humid regions; *Meesia* (3 species) migrated toward the western edge of the eastern Qinghai-Tibet Plateau with southward expansion; *Helianthemum songaricum* migrated from the border of Inner Mongolia and Ningxia toward eastern areas; and *Amygdalus mongolica* migrated toward northern Qilian Mountains and higher latitudes.

Additionally, 74 angiosperm species (e.g., *Litsea coreana* var. *lanuginosa*), 5 gymnosperm species (*Keteleeria fortunei*, *Keteleeria davidiana*, *Pinus armandii*, *Juniperus pseudosabina*, *Pinus armandii*), and 29 bryophyte species (e.g., 15 *Orthotrichum* species) had unclear migration direction information.

Notably, some species showed inconsistent migration directions across climate scenarios. For example, under SSP126 and SSP585 scenarios in the 2050s, *Cerasus clarofolia* clearly migrated toward east China while expanding into central Shaanxi and central-eastern Henan; by the 2070s, it extended toward northwestern Yunnan and southeastern Tibet. In the 2050s, *Cerasus conradinae* showed decreasing distribution, but by the 2070s showed migration toward higher latitudes in the northeast and lower latitudes. Under RCP2.6, *Pinus tabuliformis* distribution changed little, but under RCP8.5, highly suitable areas extended to northern Jiangsu and most of Guizhou, moderately suitable areas extended to parts of Anhui and Hebei, while low-suitability areas expanded northward.

2.3 Risk of Plant Geographical Distribution Range Loss

Under future climate scenarios, some plants face range loss risks. [Figure 3: see original paper] shows the number of species facing range loss risks under probability >0.6 and without considering probability. Under future climate scenarios with probability >0.6, approximately 32 angiosperm, 42 gymnosperm, and 48 bryophyte species face suitable distribution range loss risks; without considering probability, approximately 57 angiosperm and 96 gymnosperm species face complete range loss risks.

This figure was produced based on the number of plant species at risk of range loss in literature on phytogeographic range loss risk under probabilities over 0.6 and without considering probability (Wu, 2020, 2022, 2023; Wu, 2010a, b, 2011a; Gan et al., 2023; Miao et al., 2021; Li et al., 2023; Xiao et al., 2021; Xiao et al., 2019; Yu et al., 2019; Zhang et al., 2020; Xie et al., 2021, 2022; Li et al., 2021). A. Angiosperms; B. Gymnosperms; C. Pteridophyta; D. Bryophytes.

Fig.3 Number of plant species at risk of range loss under future climate change scenarios with probabilities over 0.6 and without considering probability

Under future climate scenarios, *Empetrum nigrum* will lose its distribution range during 2051-2080 (Wu, 2011a), and *Larix potaninii* var. *chinensis*, *Boschniakia rossica*, and *Eleutherococcus senticosus* will lose their ranges during 2081-2100 (Wu, 2010a, b). *Amygdalus mongolica* will lose distribution in southern and southeastern Qilian Mountains under SSP scenarios (Gan et al., 2023). *Castanopsis sclerophylla* will lose high-latitude distribution under RCP8.5 (Miao et al., 2021). *Phoebe bournei* faces fragmentation and potential loss of suitable areas in 2050 and 2070 (Xiao et al., 2021). *Firmiana* (8 species) distribution will shrink by 67.51% (Li et al., 2023). Under RCP8.5 by 2070, *Anabasis aphylla* will completely lose its distribution (Xiao et al., 2019). Under RCP2.6, RCP4.5, and RCP8.5, *Rhododendron* (one species) will completely lose its distribution (Yu et al., 2019).

Under future climate scenarios with probability >0.6, among 79 *Kobresia* species, about 32 face extinction risk due to climate change (Wu, 2023) (Appendix 4). Under RCP6.0, 69 Chinese gymnosperm species (Appendix 5) face extinction risk with >80% range loss (Xie et al., 2021); 17 native Chinese conifer species face high range loss risk (Xie et al., 2022) (Appendix 6); 42 gymnosperm species face climate change-induced extinction risk (Wu, 2020) (Appendix 7); 95 gymnosperm species face severe climate threats (Li et al., 2021) (Appendix 8); 48 bryophyte species face extinction risk from climate warming (Wu, 2022) (Appendix 9); and under RCP6.0, 48 Theaceae species will completely lose their distribution ranges (Zhang et al., 2020) (Appendix 10). However, no published studies have assessed range loss risks for ferns under future climate scenarios.

3.1 Trends in Plant Geographical Distribution Area Changes

Since 2010, distribution change trends have been analyzed for 1,058 plant species in China under future climate scenarios, but only 636 species had clear trend information. Compared to 36 species assessed before 2010 (Lü and Wu, 2009), the number of studied species has increased significantly, likely due to greater research attention and methodological development (Committee for the Preparation of the Fourth National Assessment Report on Climate Change, 2022). However, compared to China's total flora (~30,000 angiosperms, 300 gymnosperms, 2,000 ferns, and 2,800 bryophytes) (Institute of Botany, Chinese Academy of Sciences, 2023), the number of assessed species remains small. Compared to international assessments (~72,399 species) (Parmesan et al., 2022), China's assessed species are extremely limited. This indicates that research on plant distribution changes under future climate scenarios needs strengthening to meet biodiversity conservation needs.

This study shows that most plant distribution ranges will decrease under future climate scenarios: 245 of 518 angiosperms, 38 of 57 gymnosperms, and 53 of 60 bryophytes showed decreasing trends. This aligns with pre-2010 summaries showing 29 of 36 species decreasing and 2 completely lost (Lü and Wu, 2009) and with international trends (Pörtner et al., 2022). This suggests future climate change will be unfavorable for most assessed plants, likely because research has focused on rare and endangered species with narrow distributions and strict climatic requirements that are vulnerable to range contraction (Taheri et al., 2021). However, some species show increasing trends: 195 angiosperms, 12 gymnosperms, 7 bryophytes, and 1 fern showed increasing distribution ranges, possibly due to broader suitable climate and environmental niches. Since distribution changes are primarily related to niche characteristics, narrow-niche species are vulnerable to range loss while broad-niche species may expand (Taheri et al., 2021), indicating need for conservation of resources adapting to climate change. Additionally, different plant groups show varying responses, related to differences in environmental niche characteristics. Most bryophytes have narrower niches than angiosperms, while most studied gymnosperms are rare, endangered, or relict species with high environmental requirements (Taheri et al., 2021). This necessitates strengthened protection of new suitable distribution areas and assisted migration for these plants. Some species also showed initial increase then decrease or initial decrease then increase trends (Appendix 1), reflecting temporal differences in climate variables and strict limits of plant climatic adaptation.

This study shows that 137 species migrated toward northeast, northwest, and north China; 57 toward south China; and 54 toward southwest China. This reflects a pattern of Chinese plant distribution migrating toward the "Three North" regions (northeast, north, northwest), southwest, and south China under climate change, likely related to China's large-scale geographic patterns and regional climate change characteristics. Regional climate differences may be important factors affecting plant migration patterns (Pörtner et al., 2022). Under future climate scenarios, northeast China and the Qinghai-Tibet Plateau will warm significantly, while northwest, northern, and southwestern regions will experience substantial precipitation and temperature changes, and parts of south China will see large precipitation changes (Committee for the Preparation of the Fourth National Assessment Report on Climate Change, 2022). Additionally, 19 species migrated simultaneously to higher latitudes and altitudes, and 125 migrated only to higher latitudes, consistent with international trends (Loehle, 2020; Pörtner et al., 2022). Some species also showed different or local migration trends, likely due to varying climate trends within species' ranges and different plant adaptation characteristics (Loehle, 2020).

This study shows that with probability >0.6, about 32 angiosperm, 42 gymnosperm, and 48 bryophyte species face complete range loss risks; without considering probability, about 57 angiosperm and 96 gymnosperm species face complete range loss. These risks partly relate to narrow distribution ranges (Xie et al., 2022). Threatened plants have narrow suitable elevation ranges, while broad elevation ranges can provide different environmental conditions meeting special habitat requirements (Xie et al., 2022). Some plants may adapt through migration to more suitable areas, while others may persist through phenotypic plasticity or adaptive evolution (Taheri et al., 2021). When neither option is viable, species face extinction risk from range loss. Thus, future range changes depend on adaptive responses (Taheri et al., 2021). Notably, only 60 threatened gymnosperm species are protected in nature reserves, accounting for 87% of threatened gymnosperms (Xie et al., 2022). This indicates the need for systematic analysis of climate change impacts on range loss risks to identify protection gaps.

3.2 Differences in Plant Distribution Change Studies

Different studies on the same species show substantial differences under future climate scenarios, 主要体现在三个方面:

(1) Different niche models and climate scenarios produce large differences in simulated distribution changes. For *Sinopodophyllum hexandrum*, Wu (2010a) using CART model and A2/B2 scenarios found increasing distribution range with expansion toward north, northeast, west, southwest, and northwest during 1991-2020 to 2081-2100; while Guo et al. (2014) using MaxEnt and SRES-A1B/A2/B1 scenarios found large initial decrease then increase, with suitable elevation increasing and initial northward migration then westward expansion to high-altitude Tibetan Plateau areas. For *Abies chensiensis*, Wu (2011b) using CART and A2/B2 scenarios found initial decrease then increase with expansion toward southwest, northwest, and west during 1991-2020 to 2021-2050; while Gao et al. (2015) using MaxEnt found decreasing suitable distribution. For *Ormosia henryi*, Song et al. (2021) found relatively stable distribution under SSP1-2.6, SSP2-4.5, and SSP5-8.5; while Jiang et al. (2024) found significantly in-

creasing distribution.

(2) Using the same niche model but different climate scenarios produces different trends. For *Camphora*, Zhou et al. (2021) studied 47 subtropical species using MaxEnt under RCP2.6 and RCP8.5, finding hotspot area contraction of 8.4% and 10.0% by 2080; Li et al. (2023) analyzed *Camphora* trees, finding northward expansion for 17 rare and endangered species except *Cinnamomum appelianum* and *Cinnamomum validinerve*. Both using MaxEnt, Li et al. (2022) under SSP245 found *Caryopteris mongholica* expanding to higher latitudes during 2021-2060 then contracting to lower latitudes during 2061-2100; while He et al. (2023) under RCPs found increasing distribution with northward migration under RCP4.5 but initial northeastward migration then contraction under RCP8.5. Ran et al. (2019) found *Cathaya argyrophylla* distribution increasing under different RCPs by 2050s and 2070s; Luo et al. (2024) found expansion toward Yunnan, Zhejiang, Fujian, and Guizhou under three SSPs.

(3) Using the same model and climate scenarios produces different results for the same species. Liu et al. (2018) found *Abies* (23 species) distribution would significantly decrease and shift northward, including *Abies fargesii* var. *faxoniana* and *Abies chensiensis*, differing from Pan et al. (2022) and Wu (2011b).

These differences may arise from: insufficient or inconsistent environmental variables, as most studies only considered climate factors without adequately incorporating soil, topography, species dispersal ability, or species interactions, and lacked consideration of multicollinearity and factor inconsistency (Thuiller et al., 2008; Araújo et al., 2019), causing uncertainty in simulating climate impacts; reliance on single niche models, with >90% of 220 reviewed papers using MaxEnt, which ignores species environmental adaptation and interspecific competition, contributing to uncertainty (Thuiller et al., 2008; Araújo et al., 2019); inadequate future time period selection, with ~22% of papers using single years 2050 and 2070, which introduces uncertainty given large climate variability across periods (Thuiller et al., 2008; Araújo et al., 2019). Additionally, insufficient plant distribution data causes uncertainty.

Some studies using different models and scenarios produced similar trends, such as Wu (2011b) and Pan et al. (2021) both finding decreasing *Phoebe bournei* distribution, and Wu (2010a) and Zhang et al. (2021) both finding increasing *Alsophila spinulosa* distribution with northwestward migration, possibly because these widely distributed species have strong climate relationships (Araújo et al., 2019).

3.3 Deficiencies in Quantitative Research on Plant Distribution Changes

Although 1,058 species have been studied, only 636 had clear quantitative change information. Quantitative analysis of range increases/decreases was insufficient: among 518 angiosperms, 66 lacked quantitative increase information, 110 lacked decrease magnitude information, and 10 showed inconsistent changes; among 57 gymnosperms, 4 lacked quantitative change information, 8 lacked increase information, and 23 lacked decrease information. This indicates uncertainty in analyzing distribution change trends.

Since 2010, quantitative analysis of distribution pattern changes has also been insufficient: 102 species (68 angiosperms, 5 gymnosperms, 29 bryophytes) had unclear migration direction information. Additionally, species like *Cerasus clarofolia* and *Pinus tabuliformis* showed inconsistent migration characteristics across scenarios. Understanding of distribution changes under different emission scenarios and time periods remains limited. Particularly due to taxonomic difficulties, some studies analyzed trends at genus level. For example, Shen et al. (2015) considered *Calymperes* and *Orthotrichum* taxonomically difficult but stable taxonomic units, choosing genus-level analysis. These results have large errors for interpreting species-level distribution changes, indicating substantial uncertainty in analyzing distribution pattern trends.

Although international frameworks for climate change risk assessment exist (Pörtner et al., 2022), research on range loss risks for Chinese plants and impacts of extreme events remains very limited, with no published studies on fern range loss risks under future climate scenarios.

4.1 Conclusions

(1) China has analyzed distribution changes for 1,058 plant species across different groups under future climate scenarios, but only 636 species had detailed change information, involving 518 angiosperm species (75 families, 142 genera), 57 gymnosperm species (4 families, 18 genera), 1 fern species (1 family, 1 genus), and 60 bryophyte species (10 families, 12 genera).

(2) Under future climate scenarios, among 518 angiosperm species, 195 showed increasing and 245 showed decreasing distribution ranges; among 57 gymnosperm species, 12 showed increasing and 38 showed decreasing trends; 1 fern species showed increasing trend; among 60 bryophyte species, 53 showed decreasing and 7 showed increasing trends. Some species showed initial increase then decrease or initial decrease then increase trends, while others showed inconsistent changes or lacked information.

(3) Most plant distribution patterns showed single-direction and multi-direction migration trends under future climate scenarios. Angiosperms: 43 species migrated northwestward, 22 northwest-dominated multi-directional, 11 northeast-dominated multi-directional, 22 northward, 52 southward, and 10 southwest-dominated multi-directional. Gymnosperms: 24 species showed southwest-dominated multi-directional migration. Bryophytes: 15 species showed northwest-dominated multi-directional migration. Other species showed different directional trends or lacked information.

(4) Under future climate scenarios with probability >0.6, about 32 angiosperm, 42 gymnosperm, and 48 bryophyte species face complete range loss risks; without considering probability, about 57 angiosperm and 96 gymnosperm species face complete range loss risks.

(5) Research deficiencies include: insufficient number of species studied, limited climate scenario and model selection, lack of comprehensive climate and other environmental factor analysis and multi-model comparisons, and insufficient range loss risk analysis under future climate scenarios.

4.2 Outlook

Currently assessed plant species under future climate scenarios remain very limited. Future research should systematically analyze distribution range and pattern changes for different plants under various climate scenarios, particularly comprehensively assessing climate change impacts on all Chinese plants. Additionally, most current models are foreign-developed (Araújo et al., 2019); future research should develop internationally recognized, China-specific species distribution models using China-appropriate climate scenarios, unified time periods, comprehensive environmental factors, and factor correlation considerations to conduct comparative studies across different climate scenarios and models.

Current understanding of mechanisms underlying plant distribution changes remains limited. With improved plant distribution survey data and research methods, future studies should strengthen mechanistic research, particularly analyzing impacts of migration rates and adaptive capacity on distribution ranges (Araújo et al., 2019).

With increasing attention to plant diversity conservation, future research should strengthen assessments of range loss risks and quantification of distribution change trends, particularly evaluating risks from extreme weather and climate events on plant distribution loss.

References

ARAÚJO MB, ANDERSON RP, MÁRCIA BARBOSA A, et al., 2019. Standards for distribution models in biodiversity assessments[J]. Science Advances, 5(1): eaat4858.

CANNELL MGR, GRACE J, BOOTH A, 1989. Possible impacts of climatic warming on trees and forests in the United Kingdom: a review[J]. Forestry, 62: 337-364.

CARTER TR, PARRY ML, HARASAWA H, et al., 1994. IPCC technical guidelines for assessing climate change impacts and adaptations[M]. Department of Geography, University College London, UK and the Center for Global Environmental Research, National Institute for Environmental Studies, Japan: 59.

Committee For The Preparation Of The Fourth National Assessment Report On Climate Change, 2022. Fourth national assessment report on climate change[M]. Beijing: Science Press.

GAN XL, CHANG YP, JIANG Y, et al., 2023. Impact of climate change on potential distribution of Amygdalus mongolica in the Qilian Mountains[J]. Acta Ecologica Sinica, 43(2): 768-776.

GAO B, WEI HY, GUO YL, et al., 2015. Using GIS and MaxEnt to analyze the potential distribution of Abies chensiensis[J]. Chinese Journal of Ecology, 34(3): 843-852.

GUO YL, WEI HY, LU CY, et al., 2014. Predictions of potential geographical distribution of Sinopodophyllum hexandrum under climate change[J]. Chinese Journal of Plant Ecology, 38(3): 249-261.

HE YM, WANG C, WANG HT, et al., 2023. Effects of climate change on the potential suitable distribution area of Caryopteris mongolica[J]. Acta Agrestia Sinica, 31(2): 540-550.

HUANG Y, PAN J, 2003. The latest practical atlas of China[M]. Chengdu: Chengdu Map Publishing House.

Institute of Botany, Chinese Academy of Sciences, 2023. List of plant species of China (2023 ed)[M]. Beijing: Plant Science Data Center, Chinese Academy of Sciences.

JIANG L, HU YH, WU YF, et al., 2024. Study on the potential suitable area of Ormosia in Guangdong province based on the MaxEnt model[J]. Guangxi Sciences, 31(1): 149-166.

KOSANIC A, ANDERSON K, HARRISON S, et al., 2018. Changes in the geographical distribution of plant species and climatic variables on the West Cornwall peninsula (South West UK)[J]. PLoS ONE, 13(2): e0191021.

LI G, XIAO NW, LUO ZL, et al., 2021. Identifying conservation priority areas for gymnosperm species under climate changes in China[J]. Biological Conservation, 253: 108914.

LI H, TENG J, YIN XJ, et al., 2023. Simulation prediction of suitable distribution area of rare and endangered species of Cinnamomum in China under different climatic environment[J]. Journal of Northeast Forestry University, 51(2): 43-53.

LI RZ, HU XJ, WEI BJ, et al., 2023. Potential distribution simulation of eight Firmiana species in China under climate change[J]. Acta Ecologica Sinica, 43(14): 5937-5955.

LI YH, ZHANG LJ, ZHU WB, et al., 2021. Changes of Taxus chinensis var. mairei habitat distribution under global climate change[J]. Journal of Natural Resources, 36(3): 783-792.

LI ZH, LI ZF, HONG GY, et al., 2022. Prediction of potential distribution of Caryopteris mongholica based on MaxEnt model in climate change context[J]. Acta Botanica Boreali-Occidentalia Sinica, 42(7): 1232-1238.

LIU R, WANG CJ, HE J, et al., 2018. Analysis of geographical distribution of Abies in China under climate change[J]. Bulletin of Botanical Research, 38(1): 37-46.

LOEHLE C, 2020. Quantifying species' geographic range changes: conceptual and statistical issues[J]. Ecosphere, 11(3): e03070.

LUO CY, SHE JY, TANG ZC, 2024. Prediction of potential distribution areas of endangered plant Cathaya argyrophylla based on SSPs climate scenarios[J]. Journal of Nanjing Forestry University (Natural Sciences Edition), 48(1): 161-168.

LÜ JJ, WU JG, 2009. Advances in the effects of climate change on the distribution of plant species and vegetation in China[J]. Environmental Science & Technology, 32(6): 85-95.

MA SM, WEI B, LI XC, et al., 2017. The impacts of climate change on the potential distribution of Haloxylon ammodendron[J]. Chinese Journal of Ecology, 36(5): 1243-1250.

MASSON-DELMOTTE V, ZHAI P, PIRANI A, et al., 2021. IPCC, 2021: Summary for policymakers[M]// Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change. Cambridge and New York: Cambridge University Press: 3-32.

MASSON-DELMOTTE V, ZHAI P, PÖRTNER HO, et al., 2018. IPCC, 2018: Summary for policymakers[M]// Global warming of 1.5℃. An IPCC special report on the impacts of global warming of 1.5℃ above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Cambridge and New York: Cambridge University Press: 3-24.

MIAO Q, WANG Y, WANG L, et al., 2021. Prediction of potential geographical distribution pattern change for Castanopsis sclerophylla on MaxEnt[J]. Journal of Nanjing Forestry University(Natural Sciences Edition), 45(3): 193-198.

PAN SA, LI XH, FENG QH, et al., 2022. Response of Abies faxoniana to future climate change and its potential distribution patterns in Sichuan Province[J]. Acta Ecologica Sinica, 42(10): 4055-4064.

PAN YY, OUYANG XH, WANG XL, et al., 2021. Geographical distribution of Phoebe zhennan and potential distribution area[J]. Journal of Zhejiang Forestry Science and Technology, 41(2): 35-40.

PARMESAN C, MORECROFT MD, TRISURAT Y, et al., 2022. Terrestrial and freshwater ecosystems and their services[M]// Climate change 2022: Impacts, adaptation and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change. Cambridge and New York: Cambridge University Press: 197-377.

PÖRTNER HO, ROBERTS DC, POLOCZANSKA ES, et al., 2022. IPCC, 2022: Summary for policymakers. [M]// Climate change 2022: Impacts, adaptation and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change. Cambridge and New York: Cambridge University Press: 3-33.

RAN Q, WEI HY, ZHAO ZF, et al., 2019. Impact of climate change on the potential distribution and habitat fragmentation of the relict plant Cathaya argyrophylla Chun et Kuang[J]. Acta Ecologica Sinica, 39(7): 2481-2493.

SHEN Y, YU J, GUO SL, 2015. Macromitrium and Orthotrichum distribution patterns under different climate warming scenarios in China[J]. Acta Ecologica Sinica, 35(19): 6449-6459.

SONG Y, ZHANG GL, JIA QQ, et al., 2021. Prediction of potential distribution of Ormosia henryi in China under climate change[J]. Journal of Northwest Forestry University, 36(6): 108-115.

TAHERI S, NAIMI B, RAHBEK C, et al., 2021. Improvements in reports of species redistribution under climate change are required[J]. Science Advances, 7(15): eabe1110.

THUILLER W, ALBERT C, ARAÚJO MB, et al., 2008. Predicting global change impacts on plant species' distributions: future challenges[J]. Perspectives in Plant Ecology, Evolution and Systematics, 9(3/4): 137-152.

TIAN P, LIU Y, OU J, 2023. Meta-analysis of the impact of future climate change on the area of woody plant habitats in China[J]. Frontiers in Plant Science, 14: 1139739.

WOODWARD FI, 1987. Climate and plant distribution[M]. New York: Cambridge University Press.

WU JG, 2010a. Potential effects of climate change on the distribution of seven protected plants in China[J]. Plant Science Journal, 28(4): 437-452.

WU JG, 2010b. Potential effects of climate change on the distributions of 5 plants in China[J]. Journal of Tropical and Subtropical Botany, 18(5): 511-522.

WU JG, 2011a. The potential effects of climate change on the distributions of 7 plants in China[J]. Guihaia, 31(5): 595-607.

WU JG, 2011b. The potential effects of climate change on the distributions of seven Arbors plants in China[J]. Plant Diversity, 33(3): 335-349.

WU JG, 2020. Risk and uncertainty of losing suitable habitat areas under climate change scenarios: a case study for 109 Gymnosperm Species in China[J].

Environmental Management, 65: 517–533.

WU JG, 2022. The danger and indeterminacy of forfeiting perching space of bryophytes from climate shift: a case study for 115 species in China[J]. Environmental Monitoring and Assessment, 194: 233.

WU JG, 2023. Uncertainty and risk of pruned distributional ranges induced by climate shifts for alpine species: a case study for 79 Kobresia species in China[J]. Theoretical and Applied Climatology, 151: 1651-1672.

XIAO J, EZIZ A, ZHANG H, et al., 2019. Responses of four dominant dryland plant species to climate change in the Junggar Basin, northwest China[J]. Ecology and Evolution, 9(23): 13596-13607.

XIAO JH, DING X, CAI CN, et al., 2021. Simulation of the potential distribution of Phoebe bournei with climate changes using the maximum-entropy (MaxEnt) model[J]. Acta Ecologica Sinica, 41(14): 5703-5712.

XIE D, DU H, XU WH, et al., 2022. Effects of climate change on richness distribution patterns of threatened conifers endemic to China[J]. Ecological Indicators, 136 (8): 108594.

XIE D, LIU XQ, CHEN YX, et al., 2021. Distribution and conservation of threatened gymnosperms in China[J]. Global Ecology and Conservation, 32: e01915.

XU YL, PAN J, FENG Q, 2016. Projection on future climate change in China: Constructing high resolution SRES climate scenarios using PRECIS[M]. Beijing: Science Press.

YU FY, WANG TJ, GROEN TA, et al., 2019. Climate and land use changes will degrade the distribution of Rhododendrons in China[J]. Science of The Total Environment, 659: 515-528.

ZHANG H, ZHAO HX, XU CG, 2021. The potential geographical distribution of Alsophila spinulosain under climate change in China[J]. Chinese Journal of Ecology, 40(4): 968-979.

ZHANG YB, MENG QX, WANG YZ, et al., 2020. Climate change-induced migration patterns and extinction risks of Theaceae species in China[J]. Ecology and Evolution, 10(10): 4352-4361.

ZHOU R, CI XQ, XIAO JH, et al., 2021. Effects and conservation assessment of climate change on the dominant group—The genus Cinnamomum of subtropical evergreen broad-leaved forests[J]. Biodiversity Science, 29(6): 697-711.

Appendix 1 Literature

Complete literature list follows in original format

Appendix 2 List of Plant Species

This appendix provides a comprehensive inventory of plant species analyzed in this study. The list includes species names, families, and corresponding references. Due to formatting constraints in the original document, the tabular data appears fragmented; however, the complete species information is retained in the database.

The note below the table clarifies several taxonomic groups analyzed at the genus level: *Ormosia* (17 species), *Uraria* (7 species), *Paphiopedilum* (14 species), *Cymbidium* (20 species), *Petrocodon* (47 species), *Cinnamomum* (47 species), *Firmiana* (8 species), *Nitraria* (8 species), *Sinojackia* (7 species), *Lycoris* (15 species), *Apocynum* (3 species), *Orthotrichum* (15 species), *Lewinskya* (11 species), *Didymodon* (16 species), *Aulacomnium* (4 species), *Meesia* (3 species), *Schistidium* (5 species), *Dendrobium* (76 species), *Coptis* (3 species), *Rhododendron* (20 species), *Zingiber* (5 species), and *Satyrium* (3 species). Empty cells in the species column indicate that analysis was conducted only at the genus level, not at the specific species level.

Appendix 3 Comparison of Variation Trends in Plant Geographical Distribution Across Different Climate Scenarios and Time Periods

Low Emission Scenario

The low emission scenario corresponds to RCP2.6, SSP1-2.6, and SRES-B1, characterized by atmospheric CO_2 concentrations rising from 380 ppm in 2000 to 520 ppm by 2080, with a maximum global temperature increase of 1.98°C. Under this scenario, angiosperms show varied distribution responses across time periods. In the near-term (2023–2040), the genus *Kobresia* exhibits range contraction. During the medium-term (2041–2070), species such as *Lycium ruthenicum*, *Caryopteris mongholica*, *Hippophae rhamnoides subsp. yunnanensis*, *Agriophyllum squarrosum*, *A. lateriflorum*, *A. minus*, *A. lati-folium*, *A. montasiri*, *Tugarinovia mongolica*, *T. mongolica var. ovatifolia*, *Salix psammophila*, *Actinidia arguta*, *Ziziphus jujuba var. spinosa*, *Sorbus tianschanica*, *Salvia miltiorrhiza*, *Cymbidium dayanum*, *C. macrorhizon*, *C. sinense*, *C. serratum*, *C. lowianum*, *C. lancifolium*, *C. aloifolium*, *C. eburneum*, *C. tracyanum*, *C. hookerianum*, *C. erythraeum*, *C. elegans*, *C. mannii*, *C. cyperifolium*, *C. floribundum*, *C. kanran*, *C. faberi*, *C. goeringii*, *C. iridioides*, *C. ensifolium*, *Paeonia delavayi*, *P. rockii*, *Paeonia veitchii*, and *Alnus cremastogyne* show range expansion, while *Pyrus xerophila*, *Camellia rubo-anthera*, *Sorbus amabilis*, *Etlingera littoralis*, *Paeonia jishanensis*, *Lycoris* spp., *Betula platyphylla*, *Pistacia weinmanniifolia*, *Disanthus cercidifolius subsp. longipes*, *Ormosia henryi*, *Bretschneidera sinensis*, *Populus* × *berolinensis var. jrtyschensis*, *Sinojackia* spp., *Kobresia* spp., and *Rhododendron* spp. show range contraction. *Schima superba* and *Ormosia henryi* show minimal change. In the long-term (2071–2100), range expansion is observed in *Lycium ruthenicum*, *Hippophae rhamnoides subsp. yunnanensis*, *Agriophyllum squarrosum*, *A. lateriflorum*, *A. minus*, *A. lati-folium*, *A. montasiri*, *Tugarinovia mongolica*, *T. mongolica var. ovatifolia*, *Actinidia arguta*, *Ziziphus jujuba var. spinosa*, *Ulmus elongata*, *Lithocarpus brevicaudatus*, *L. elizabethiae*, *Altingia chinensis*, *Salvia miltiorrhiza*, *Paphiopedilum* spp., *Cymbidium* spp., *Sorbus tianschanica*, *Zelkova serrata*, *Houttuynia cordata*, *Rhododendron* (4 species), *Paeonia delavayi*, *P. rockii*, *Hylomecon japonica*, *Alnus cremastogyne*, and *Satyrium* spp., while contraction occurs in *Caryopteris mongholica*, *Pyrus xerophila*, *Stipa bungeana*, *Camellia rubo-anthera*, *Litsea cubeba*, *L. mollis*, *Cymbidium* spp., *Lithocarpus glaber*, *L. dealbatus*, *L. corneus*, *Lycium barbarum*, *Forsythia suspensa*, *Betula platyphylla*, *Amygdalus mongolica*, *Pistacia weinmanniifolia*, *Populus × berolinensis var. jrtyschensis*, *Disanthus cercidifolius subsp. longipes*, *Ormosia henryi*, *Bretschneidera sinensis*, *Sinojackia* spp., *Cremastra appendiculata*, and *Rhododendron* (16 species). *Paeonia veitchii* also shows range contraction.

For gymnosperms under low emissions, near-term range contraction occurs in *Metasequoia glyptostroboides*, *Chamaecyparis formosensis*, *Cupressus gigantea*, *Thuja koraiensis*, *Fokienia hodginsii*, *Juniperus recurva*, *J. sabina var. davurica*, *J. sabina*, *J. gaussenii*, *Keteleeria hainanensis*, *Picea obovata*, *P. spinulosa*, *Pinus fenzeliana*, *P. sibirica*, *P. takahasii*, and *P. wangii*. Medium-term expansion occurs in *Cephalotaxus oliveri*, *Picea schrenkiana*, *Larix kaempferi*, *Cathaya argyrophylla*, *Taxus wallichiana var. mairei*, and *Picea likiangensis*, while contraction affects the same species as in the near-term plus *Juniperus tibetica*. *Picea crassifolia* shows minimal change. Long-term expansion includes *Cephalotaxus oliveri*, *Picea schrenkiana*, *Larix kaempferi*, *Cathaya argyrophylla*, and *Picea likiangensis*, with contraction in *Juniperus tibetica* and *Nothotsuga longibracteata*. For ferns, *Alsophila spinulosa* shows long-term expansion. For bryophytes, *Aulacomnium* spp. show long-term expansion while *Meesia* spp. show contraction.

Medium Emission Scenario

The medium emission scenario includes RCP4.5, RCP6.0, SRES-A2, SRES-B2 (CO_2 rising to 700 ppm or 550 ppm by 2080, with temperature increases of 3.79°C or 2.69°C), and SSP2-4.5, SSP4-6.0. For angiosperms, near-term range expansion occurs in *Ulmus lamellosa*, while contraction occurs in *Kobresia* spp. Medium-term expansion is observed in *Sorbus tianschanica*, *Salvia miltiorrhiza*, *Cymbidium* spp., *Forsythia suspensa*, *Magnolia pachyphylla*, *Chimonocalamus fimbriatus*, *Lycium ruthenicum*, *Gynostemma pentaphyllum*, *Potaninia mongolica*, *Hippophae rhamnoides subsp. yunnanensis*, *Ziziphus jujuba var. spinosa*, *Littledalea* spp., *Salix psammophila*, *Actinidia arguta*, *Paeonia ludlowii*, *Agriophyllum squarrosum*, *A. lateriflorum*, *A. minus*, *A. lati-folium*, *A. montasiri*, *Sorbus tianschanica*, *Alhagi camelorum*, *Disanthus cercidifolius subsp. longipes*, *Houttuynia cordata*, and *Alnus cremastogyne*. Medium-term contraction affects *Taxus wallichiana var. mairei*, *Camellia rubo-anthera*, *Cymbidium* spp., *Chuanminshen violaceum*, *Betula platyphylla*, *Actinidia chinensis*, *Pistacia weinman-*

niifolia, *Littledalea racemosa*, *Sorbus amabilis*, *Ormosia henryi*, *Artemisia ordosica*, *Bretschneidera sinensis*, *Populus* × *berolinensis var. jrtyschensis*, *Kobresia* spp., *Phoebe bournei*, and *Cremastra appendiculata*, while *Schima superba*, *Ormosia henryi*, and *Meconopsis integrifolia* show minimal change. Long-term expansion includes *Salvia miltiorrhiza*, *Cymbidium* spp., *Picea likiangensis*, *Forsythia suspensa*, *Chimonocalamus fimbriatus*, *Gynostemma pentaphyllum*, *Potaninia mongolica*, *Hippophae rhamnoides subsp. yunnanensis*, *Ziziphus jujuba var. spinosa*, *Nitraria* spp., *Rosa roxburghii*, *Littledalea* spp., *Actinidia arguta*, *Paeonia ludlowii*, *Agriophyllum squarrosum*, *A. lateriflorum*, *A. minus*, *A. lati-folium*, *A. montasiri*, *Sorbus tianschanica*, *Alhagi camelorum*, *Zelkova serrata*, *Houttuynia cordata*, *Rhododendron* (4 species), and *Alnus cremastogyne*. Long-term contraction affects *Camellia rubo-anthera*, *Cymbidium* spp., *Lycium barbarum*, *Betula platyphylla*, *Amygdalus mongolica*, *Lycium ruthenicum*, *Pistacia weinmanniifolia*, *Littledalea racemosa*, *Disanthus cercidifolius subsp. longipes*, *Ormosia henryi*, *Artemisia ordosica*, *Bretschneidera sinensis*, *Populus* × *berolinensis var. jrtyschensis*, *Empetrum nigrum*, *Boschniakia rossica*, *Eleutherococcus senticosus*, *Larix chinensis*, *Cremastra appendiculata*, *Rhododendron* (16 species), and *Carpinus tientaiensis*, while *Meconopsis integrifolia* shows minimal change.

For gymnosperms, near-term contraction mirrors the low emission scenario. Medium-term expansion includes *Cephalotaxus oliveri*, *Larix kaempferi*, *Cathaya argyrophylla*, *Picea schrenkiana*, and *Picea likiangensis*, while contraction affects the same near-term species plus *Abies* spp., *Pinus armandii*, and *Nothotsuga longibracteata*. *Picea crassifolia* shows minimal change. Long-term expansion includes *Cephalotaxus oliveri*, *Larix kaempferi*, *Cathaya argyrophylla*, *Picea schrenkiana*, *Picea purpurea*, and *Picea likiangensis*, with contraction in *Juniperus tibetica*, *Pinus armandii*, and *Nothotsuga longibracteata*. For bryophytes, medium-term expansion occurs in *Bryum* spp., while contraction occurs in *Didymodon* spp. Long-term expansion includes *Bryum* spp. and *Calymperes* spp., while contraction affects *Macromitrium* spp., *Orthotrichum* spp., *Didymodon* spp., and *Schistidium* spp.

High Emission Scenario

The high emission scenario corresponds to RCP8.5, SRES-A1 (CO_2 rising to 800 ppm by 2080, with 4.49°C warming), and SSP5-8.5. For angiosperms, near-term contraction occurs in *Kobresia* spp. Medium-term expansion includes *Sorbus tianschanica*, *Salvia miltiorrhiza*, *Cymbidium* spp., *Forsythia suspensa*, *Chuanminshen violaceum*, *Gynostemma pentaphyllum*, *Ziziphus jujuba var. spinosa*, *Littledalea* spp., *Potaninia mongolica*, *Salix psammophila*, *Actinidia arguta*, *Paeonia ludlowii*, *Agriophyllum squarrosum*, *A. lateriflorum*, *A. minus*, *A. latifolium*, *A. montasiri*, *Sorbus tianschanica*, *Alhagi camelorum*, *Pistacia weinmanniifolia*, *Hippophae rhamnoides subsp. yunnanensis*, *Houttuynia cordata*, *Paeonia delavayi*, *P. veitchii*, *Alnus cremastogyne*, and *Satyrium* spp. Medium-term contraction affects *Taxus wallichiana var. mairei*, *Pyrus xerophila*, *Camellia* *rubo-anthera*, *Disanthus cercidifolius subsp. longipes*, *Etlingera littoralis*, *Ormosia henryi*, *Cymbidium* spp., *Fraxinus chinensis*, *Magnolia pachyphylla*, *Chimonocalamus fimbriatus*, *Lycoris* spp., *Betula platyphylla*, *Littledalea racemosa*, *Meconopsis integrifolia*, *Artemisia ordosica*, *Lycium ruthenicum*, *Bretschneidera sinensis*, *Populus* × *berolinensis var. jrtyschensis*, *Kobresia* spp., *Castanopsis sclerophylla*, *Cremastra appendiculata*, *Paeonia rockii*, and *Carpinus tientaiensis*, while *Schima superba* and *Ormosia henryi* show minimal change. Long-term expansion includes *Lithocarpus brevicaudatus*, *L. elizabethiae*, *Salvia miltiorrhiza*, *Cymbidium* spp., *Picea likiangensis*, *Forsythia suspensa*, *Gynostemma pentaphyllum*, *Ziziphus jujuba var. spinosa*, *Nitraria* spp., *Littledalea* spp., *Actinidia arguta*, *Paeonia ludlowii*, *Agriophyllum squarrosum*, *A. lateriflorum*, *A. minus*, *A. lati-folium*, *A. montasiri*, *Sorbus tianschanica*, *Alhagi camelorum*, *Pistacia weinmanniifolia*, *Hippophae rhamnoides subsp. yunnanensis*, *Zelkova serrata*, *Hydrangea macrophylla*, *Houttuynia cordata*, *Calligonum mongolicum*, *Rhododendron* (4 species), *Paeonia delavayi*, *P. veitchii*, *Alnus cremastogyne*, and *Satyrium* spp. Long-term contraction affects *Altingia chinensis*, *Pyrus xerophila*, *Stipa bungeana*, *Camellia rubo-anthera*, *Disanthus cercidifolius subsp. longipes*, *Ormosia henryi*, *Cymbidium* spp., *Lithocarpus glaber*, *L. dealbatus*, *L. corneus*, *Lycium barbarum*, *Chimonocalamus fimbriatus*, *Betula platyphylla*, *Amygdalus mongolica*, *Potaninia mongolica*, *Meconopsis integrifolia*, *Littledalea racemosa*, *Artemisia ordosica*, *Lycium ruthenicum*, *Bretschneidera sinensis*, *Populus* × *berolinensis var. jrtyschensis*, *Litsea cubeba*, *L. mollis*, *Sinojackia* spp., *Empetrum nigrum*, *Boschniakia rossica*, *Eleutherococcus senticosus*, *Larix chinensis*, *Coptis* spp., *Anabasis aphylla*, *Rhododendron* (16 species), *Paeonia rockii*, and *Carpinus tientaiensis*.

For gymnosperms, near-term and medium-term patterns are similar to the medium emission scenario, with long-term expansion in *Cephalotaxus oliveri*, *Larix kaempferi*, *Cathaya argyrophylla*, and *Picea likiangensis*, and contraction in *Juniperus tibetica*, *Pinus armandii*, *Nothotsuga longibracteata*, *Abies* spp., *Picea purpurea*, *P. asperata*, *P. retroflexa*, *P. schrenkiana*, *Tsuga chinensis var. tchekiangensis*, *Pseudotaxus chienii*, *Taxus wallichiana var. mairei*, *Torreya fargesii*, *T. jackii*, *Cupressus chengiana*, and *Juniperus tibetica*.

Appendix 4 List of 79 Kobresia Species

This appendix enumerates 79 species, varieties, and subspecies of the genus *Kobresia*, including *K. angusta*, *K. burangensis*, *K. capillifolia*, *K. caricina*, *K. cercostachys* (and its varieties), *K. clarkeana*, *K. cuneata*, *K. curvata*, *K. daqingshanica*, *K. deasyi*, *K. duthiei*, *K. filicina* (and its varieties), *K. filifolia*, *K. fragilis*, *K. glaucifolia*, *K. graminifolia*, *K. helanshanica*, *K. humilis*, *K. inflata*, *K. kansuensis*, *K. kuekenthaliana*, *K. lacustris*, *K. laxa*, *K. lepidochlamys*, *K. littledalei*, *K. loliacea*, *K. longearistita*, *K. macrantha*, *K. macroprophylla*, *K. maquensis*, *K. menyuanica*, *K. minshanica*, *K. myosuroides*, *K. nepalensis*, *K. persica*, *K. pinetorum*, *K. prainii*, *K. pusilla*, *K. pygmaea* (and its varieties), *K. robusta*, *K. royleana*, *K. schoenoides*, *K. setchwanensis*, *K. seticulmis*, *K.*

squamaeformis, *K. stenocarpa*, *K. stolonifera*, *K. tibetica* (and its subspecies), *K. trinervis*, *K. tunicata*, *K. uncinoides*, *K. vaginosa*, *K. vidua*, *K. williamsii*, *K. yadongensis*, *K. yangii*, and *K. yushuensis*.

Note: Species information is sourced from the Data Center for Plant Sciences, Chinese Academy of Sciences (https://www.plantplus.cn/cn). The symbol # indicates 32 *Kobresia* species at risk of extinction in random scenarios with probability >0.6. The symbol * indicates revised names: *K. daqingshanica*, *K. helanshanica*, and *K. pusilla* are revised to *Carex coninux*; *K. curticeps* var. *gyirongensis*, *K. yuennanensis*, and *K. clarkeana* are revised to *Carex bonatiana*; *K. yushuensis* and *K. capillifolia* are revised to *Carex capillifolia*; *K. lepidochlamys* is revised to *Carex lepidochlamys*; and *K. menyuanica*, *K. royleana*, and *K. stenocarpa* are revised to *Carex kokanica*. Cited from WU JG, 2023. Uncertainty and risk of pruned distributional ranges induced by climate shifts for alpine species: a case study for 79 *Kobresia* species in China. *Theoretical and Applied Climatology*, 151: 1651-1672.

Appendix 5 List of 69 Threatened Gymnosperms

This appendix catalogs 69 threatened gymnosperm species across families including Cycadaceae, Ginkgoaceae, Pinaceae, Podocarpaceae, Cupressaceae, Taxaceae, and Ephedraceae. The list includes genera such as *Cycas*, *Ginkgo*, *Abies*, *Cathaya*, *Pinus*, *Pseudolarix*, *Pseudotsuga*, *Tsuga*, *Dacrydium*, *Podocarpus*, *Calocedrus*, *Chamaecyparis*, *Cunninghamia*, *Cupressus*, *Fokienia*, *Glyptostrobus*, *Juniperus*, *Metasequoia*, *Taiwania*, *Thuja*, *Xanthocyparis*, *Cephalotaxus*, *Amentotaxus*, *Pseudotaxus*, *Taxus*, and *Torreya*.

Note: * indicates species endemic to China. # indicates 14 species duplicated in Table 2. Cited from XIE D, LIU XQ, CHEN YX, et al., 2021. Distribution and conservation of threatened gymnosperms in China. *Global Ecology and Conservation*, 32: e01915.

Appendix 6 List of 17 Endangered Conifer Species

This appendix provides a specialized list of 17 endangered conifer species, including *Abies fabri*, *A. recurvata*, *A. squamata*, *Cathaya argyrophylla*, *Larix mastersiana*, *Picea asperata*, *P. aurantiaca*, *P. neoveitchii*, *P. retroflexa*, *Tsuga forrestii*, *Cephalotaxus oliveri*, *Pseudotaxus chienii*, *Taxus mairei*, *Torreya fargesii*, *T. jackii*, *Cupressus chengiana*, and *Juniperus tibetica*.

Note: # indicates species duplicated in Table 2 and Appendix 5. Cited from XIE D, DU H, XU WH, et al., 2022. Effects of climate change on richness distribution patterns of threatened conifers endemic to China. *Ecological Indicators*, 136(8): 108594.

Appendix 7 List of 103 Gymnosperms in China

This appendix enumerates 103 gymnosperm species representing major families (Pinaceae, Cupressaceae, Taxaceae, Cycadaceae, Podocarpaceae, Gnetaceae, Ephedraceae) and genera distributed across China. The list includes many endemic and threatened species.

Note: # indicates 42 species duplicated in Table 2 and Appendix 5. * indicates 42 species classified as threatened. Cited from WU JG, 2020. Risk and uncertainty of losing suitable habitat areas under climate change scenarios: a case study for 109 gymnosperm species in China. *Environmental Management*, 65: 517-533.

Appendix 8 List of 196 Gymnosperms of China

This comprehensive list includes 196 gymnosperm species with taxonomic revisions noted. The symbol * indicates revised names, while # indicates 121 species duplicated in Table 2, Appendix 5, or Appendix 7. Cited from LI G, XIAO NW, LUO ZL, et al., 2021. Identifying conservation priority areas for gymnosperm species under climate changes in China. *Biological Conservation*, 253: 108914.

Appendix 9 List of 106 Bryophyte Species

This appendix documents 106 bryophyte species across families including Pottiaceae, Ditrichaceae, Hypnaceae, Dicranaceae, Fontinalaceae, Hookeriaceae, Brachytheciaceae, Cephaloziaceae, Lepidoziaceae, Plagiochilaceae, Pleuroziaceae, Lepidolaenaceae, Jungermanniaceae, Targioniaceae, Porellaceae, Herbertaceae, Pseudolepicoleaceae, Balantiopsidaceae, Lepicoleaceae, Trichocoleaceae, Lophoziaceae, Mniaceae, Bartramiaceae, and Pterobryaceae. The list includes genera such as *Aloina*, *Ditrichopsis*, *Pringleella*, *Astomiopsis*, *Ditrichum*, *Tristichium*, *Gollania*, *Hypnum*, *Microdus*, *Oreoweisia*, *Dicranella*, *Fontinalis*, *Cyclodictyon*, *Distichophyllum*, *Sciaromiopsis*, *Brachythecium*, *Nowellia*, *Zoopsis*, *Bazzania*, *Kurzia*, *Plagiochila*, *Xenochila*, *Pleurozia*, *Trichocoleopsis*, *Neotrichocolea*, *Scaphophyllum*, *Cyathodium*, *Ascidiota*, *Porella*, *Herbertus*, *Pseudolepicolea*, *Blepharostoma*, *Isotachis*, *Mastigophora*, *Trichocolea*, *Anastrophyllum*, *Lophozia*, *Orthomnion*, *Bartramia*, *Pseudopterobryum*, *Andreaea*, *Gymnomitrion*, *Scapania*, *Leptoscyphus*, *Heteroscyphus*, *Haplomitrium*, and *Takakia*.

Note: Cited from WU JG, 2022. The danger and indeterminacy of forfeiting perching space of bryophytes from climate shift: a case study for 115 species in China. *Environmental Monitoring and Assessment*, 194: 233.

Appendix 10 List of 48 Theaceae Species

This appendix lists 48 species from the family Theaceae, including genera *Euryodendron*, *Ternstroemia*, *Camellia*, *Eurya*, *Schima*, *Stewartia*, *Cleyera*, *Apteros-*

perma, *Pyrenaria*, and *Adinandra*. The list includes both common and rare species such as *Euryodendron excelsum*, *Ternstroemia hainanensis*, *Camellia chrysanthoides*, *C. hongkongensis*, *C. reticulata*, *Schima superba*, and *Stewartia calcicola*.

Note: Cited from ZHANG Y, MENG Q, WANG Y, et al., 2020. Climate change-induced migration patterns and extinction risks of Theaceae species in China. *Ecology and Evolution*, 10(10): 4352-4361.

Note: Figure translations are in progress. See original paper for figures.