Original Article

Fern Diversity and Resource Utilization in the Three Northeastern Provinces of China

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Abstract

Ferns have a significant role as a phytogenetic intermediary connecting lower and higher plants. Throughout history, humans have employed them for many purposes, such as adorning landscapes, serving as household implements, providing sustenance, and facilitating the creation of artisanal products. Furthermore, many plants have been discovered to possess medicinal properties. Ferns exhibit a diverse range of secondary metabolites possessing various bioactivities, which hold potential for therapeutic use in numerous disease treatments. The present study was to investigate the species composition, floristic distribution features, ecological characteristics, and resource preservation and utilisation of ferns in three provinces located in northeastern China, namely Liaoning, Jilin, and Heilongjiang. This investigation was conducted by means of literature analysis and data sorting. The findings of the study indicate that the surveyed areas had a total of 16 families, 39 genera, and 164 species of ferns, excluding Lycopodium. The most prevalent families observed in these regions were Dryopteridaceae and Athyriaceae, while the dominant genera were Athyrium, Dryopteris, and Equisetum. The dominant distribution types seen in the family were the northern temperate distribution type and the old world temperate distribution type. Similarly, the dominant distribution types observed in the genus were the north temperate distribution type and the H-S-J distribution type. Within this region, there exists a total of eight fern species that are exclusive to this particular area. The predominant ecological classification of fern species in this region primarily consists of soil ferns. Habitats had a vertical distribution spanning from 30 to 2040 metres, predominantly concentrated within the altitude range of 500 to 1000 metres. From a conservation standpoint, Cystopteris sudetica can be classified as near threatened (NT) in terms of fern resource protection, while Asplenium scolopendrium subsp. japonicum is categorised as vulnerable (VU). Ophioglossum thermale Kom. is classified as a nationally protected plant of Grade-II status in China. In relation to the utilisation of fern resources, it was observed that there existed various categories of ferns, namely edible, medicinal, ornamental, and multifunctional ferns.

Keywords: Fern; Three Northeastern Provinces of China; Diversity; Resource Utilization

Introduction

Flora is a general term that refers to all plant species in a particular area, period, or taxonomic group and type. The flora can reflect the uniformity of the composition of plant species in areas of a specific geographic type and the differences in the composition of plant species in different geographic areas. Classic analysis[1] methods are designed to conduct statistical analysis of the floristic composition in an area based on the richness of families, genera, and species, and the types of distribution regions to explore the origin and evolution of flora in a region.

Within the realm of botany, ferns hold significant importance as an evolutionary intermediary connecting plants of lower and higher classifications. Due to their distinctive evolutionary lineage and physiological characteristics, these organisms synthesise a specific array of secondary metabolites, a substantial proportion of which are absent in other botanical species. The examination of

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phytochemicals in ferns has yielded findings indicating the presence of a diverse array of alkaloids,[2] flavonoids,[3] polyphenols,[4] terpenoids,[5] and steroids.[6] The structural characteristics of these molecules often exhibit variations when compared to analogous secondary metabolites synthesised by other higher plants, so rendering them a potentially rich reservoir of chemical diversity.

Ferns are considered to be one of the earliest and most prevalent types of vascular plants,[7] with a global distribution of over 12,000 species.[8] China is home to a diverse array of biological taxa, encompassing 63 families, 221 genera, and 2,452 species. Notably, within this rich biodiversity, there exist 1,218 species that are indigenous to China.[9] Ferns are regarded as exhibiting a very uniform distribution throughout various climatic conditions when compared to other vascular plant taxa.[10,11] Moreover, they hold significant ecological significance within the broader floral ecosystem. There are notable variations in the species richness of ferns across different geographical regions.[12] This variation is thought to be influenced by environmental conditions.[13,14] Hence, ferns represent a suitable taxonomic group of vascular plants for investigating the geographical and ecological patterns, as well as the underlying factors, that contribute to plant diversity on a global and regional scale.[15] This research is of considerable importance in elucidating the origins and evolution of regional flora, as well as in promoting the conservation of biodiversity.

In recent years, extensive research has been undertaken into the fern flora. A literature search was conducted using the keyword "Fern Flora" in the China National Knowledge Infrastructure database, resulting in the retrieval of 195 items from Chinese journals and 47 papers from English journals. Previous research has predominantly concentrated on the botanical composition of particular geographical regions, primarily within nature reserves, or on individual plant species belonging to particular families and genera.[16-23] Taxonomic richness is a measure that allows for the visual identification of the richness of a taxon.[24,25] In the field of phytogeography, it is crucial to do a statistical examination of the floristic composition of a given area, taking into account the abundance and distribution patterns of families, genera, and species. This analysis serves to investigate the origins and evolutionary processes of plant communities within that particular region.[26] The endemic elements of the flora play a significant role in serving as indications of the historical patterns of plant distribution within a given region.

The northeastern region of China comprises three provinces, namely Heilongjiang, Jilin, and Liaoning. This area serves as the meeting point for three distinct floras: the Greater Khingan flora, the Changbai flora, and the North China flora.[27] Regions encompassing the cold temperate zone, medium temperate zone, and warm temperate zone exhibit significant abundance of plant resources. From a geographical perspective, the region exhibits intricate and varied landforms, mostly characterised by mountains, plains, and terraces. Additionally, the area predominantly has soils of dark brown, black, lithic, and meadow compositions. The distinctive geographical setting has had a significant role in the development of abundant biological resources. Wild veggies in Northeast China have gained significant recognition nationwide and are renowned for their substantial annual export volume. Ferns, including Pteridium aquilinum var. latiusculum, Athyrium multidentatum, and Matteuccia struthiopteris, constitute a significant fraction of the wild vegetable species, as indicated by studies conducted by Xiao[28], Zhang[29], and Wang[30]. The present study utilised the PPG I system (2016) to classify Lycopodium and ferns. Data pertaining to ferns and their corresponding specimens were gathered from the Chinese Virtual Herbarium database and scientific literature sources such as the Flora of China. This information was then organised to provide an overview of the available resources on ferns within the three northeastern provinces of China. In addition, this study examines the resources of ferns in Northeast China, focusing on the floristic composition, geographical elements, and geographical origin of ferns. Furthermore, an investigation was conducted to determine the vertical distribution of fern habitats, aiming to gain insights into the distribution characteristics and geographical origin of fern communities in the three provinces. The classification of fern resources in the three provinces was conducted, and subsequent protection policies and development strategies were established for the preservation of major protected fern species.

The utilization of plant-derived compounds in various pharmacological contexts has been extensively documented in the literature.[28, 31-35] Nevertheless, the current body of research on the pharmacology of phytochemicals has predominantly concentrated on angiosperms, with relatively limited attention given to pteridophytes as a whole. The potential reason for this phenomenon could be attributed to the fact that angiosperms have a higher level of biodiversity, possess a wider range of adaptations, and have a more extensive distribution, hence rendering them more accessible to a larger number of study collectives. Pteridophytes, exhibit a narrower geographical range compared to angiosperms. However, their utilization for medicinal purposes in regions where they are found implies the presence of secondary metabolites that serve specific ecological roles in herbivore defence.[36] The pteridophytes represent a category of vascular plants that can be classified into two distinct monophyletic lineages, namely the lycophytes and the ferns. These two lineages exhibit phylogenetic differences, with the ferns displaying a closer resemblance to seed-bearing plants.[37]

Material and Methods

Overview of the Study Area

The three provinces situated in Northeast China, often referred to as the three northeastern provinces, encompass Liaoning, Jilin, and Heilongjiang provinces. These provinces collectively span an area of 1.243 million square kilometres[38] and are geographically positioned within the middle latitudes of the northern hemisphere. The region under consideration is situated in the northeastern part of China, spanning a longitude

range of 118°E–135°E and a latitude range of 48°N–55°N. It is bordered by the Bohai Sea and Yellow Sea to the south, the Sanjiang Plain to the northeast, the Songliao Plain to the central region, and the Greater Khingan Mountains and Lesser Khingan Mountains to the north and west, respectively. The topography of the three northeastern provinces predominantly comprises flatlands and elevated regions. Located in the western region, one can find the Greater Khingan Mountains to the northeast, followed by the Lesser Khingan Mountains. Towards the southeast lies the Changbai Mountains, while the centre area is occupied by the Northeast Plain, which happens to be the largest plain in China. The climatic conditions prevailing in these three provinces can be characterised as temperate monsoon. The climate exhibits characteristics of low temperatures and high levels of humidity. The winter season is characterised by low temperatures and extended duration, whereas the summer season is rather brief and has moderate temperature levels. Summers are absent in regions situated in the northern latitudes or characterised by significant mountainous terrain.

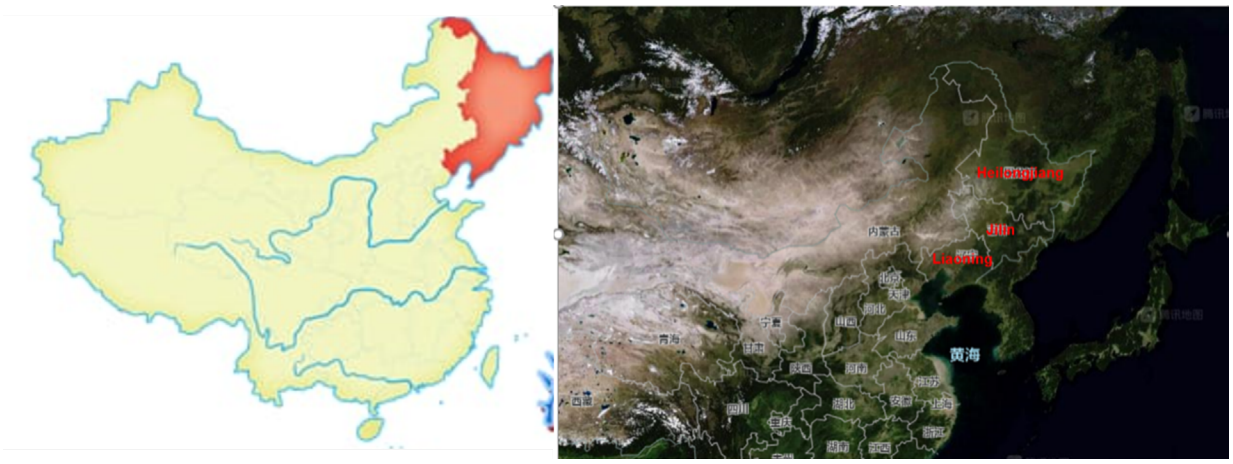

Figure 1: Satellite hybrid map of the three northeastern provinces of China

Collection of Data of Ferns

By communicating with the Liaoning Institute of Ecology of the Chinese Academy of Sciences, we collected fern resources from seven nature reserves in the province, including the Baishilazi National Nature Reserve, Laotuding Provincial Nature Reserve, and Liaoning Xianrendong National Geological Park. The main surveys in Jilin and Heilongjiang were through model specimens deposited in herbaria, involving the Herbarium of the Chinese Academy of Sciences, the Northeast Biological Herbarium of the Shenyang Institute of Applied Ecology, and the Herbarium of the Northeast Forestry University.[39] These were combined with a survey on fern resource literature published by the three northeastern provinces published in recent years,[40] such as *Flora of China* (2004),[41] *Flora of Northeast China* (1995),[42] *Key to Plants of Northeast China* (1995),[42] *Flora of Liaoning* (1988),[43] *Wild Economic Flora of Jilin Province* (1960),[44] and *Flora of Heilongjiang* (1992).[45] Using relevant records from databases such as *Flora of China* and Chinese Virtual Herbarium (http://www.cvh.ac.cn), the families, genera, and species of ferns were analyzed, and the catalog of ferns in Northeast China was sorted. For *Lycopodium* and ferns, plant classification was based on the latest PPG I system.[46] The analysis of floristic geographical elements was conducted according to the distribution types proposed by Wu *et al*.[47,48] and Lu,[49,50] and the distribution areas of ferns in the three northeastern provinces were divided.

Analysis of the Ecological Characteristics of Ferns

We used the Chinese Virtual Herbarium and other platforms to collect data on the habitat and distribution altitude of ferns in the three northeastern provinces. In addition, ferns were classified to understand their ecological characteristics in the three northeastern provinces.

Protection and Utilization of Ferns

According to the *IUCN Red List of Threatened Species* promulgated,[51] the *National Key Protected Wild Plants List* promulgated,[52] and the *China Biodiversity Red List—Higher Plant Volume* promulgated in 2013,[53] the protection types of ferns in the three northeastern provinces were determined, and the fern were classified into edible, medicinal, ornamental, or multifunctional types, providing data support for the further exploitation of ferns.

Results and Discussion

Floristic Composition of Ferns in the Three Northeastern Provinces of China

As shown in Table 1, there were 16 families, 39 genera, and 164 species of ferns in the three northeastern provinces of China, including 16 families, 37 genera, and 114 species of ferns in Liaoning; 14 families, 33 genera, and 133 species in Jilin; and 14 families, 30 genera, and 115 species in Heilongjiang. According to Zhou *et al*.[40], there are 37 families, 170 genera, and 2,123 species of ferns distributed in China (excluding *Lycopodium* species), and ferns in the three northeastern provinces account for 40.54%, 22.35%, and

7.67% of the total families, genera, and species, respectively, in China. Among the provinces of China, Liaoning, Jilin, and Heilongjiang ranked 22nd, 23rd, and 26th in terms of the number of fern species, indicating their relatively minor share of ferns in China. For the factors affecting the distribution of ferns, water availability has been suggested as the main factor determining pteridophyte distribution.[54] Qian *et al.*[55] consented that climate factors strongly influence species richness along elevation gradients, with the gradual cold climate, the species of pteridophytes in Jilin and Heilongjiang gradually decrease. The complex terrain has caused significant differentiation of vegetation. At the species level, because Jilin contains Changbai Mountain, large and small Xing 'an Mountains and other complex terrain, the vegetation has been significantly differentiated, and there are obviously many kinds of ferns.

Table 1: Statistics on the families of lycophytes and ferns in the three northeastern provinces of China

Family	Genus	Species	Family	Genus	Species
Athyriaceae	3	33	Thelypteridaceae	3	8
Dryopteridaceae	4	29	Cystopteridaceae	2	6
Equisetaceae	1	20	Dennstaedtiaceae	2	5
Woodsiaceae	2	14	Onocleaceae	2	4
Pteridaceae	4	10	Osmundaceae	2	3
Aspleniaceae	1	10	Salviniaceae	2	2
Ophioglossaceae	5	9	Marsileaceae	1	1
Polypodiaceae	4	8	Davalliaceae	1	1
Total: 16	39	164			

Floristic Characteristics of the Families

The Dominant families were determined based on the criterion that the number of species distributed in the family was greater than 20. From Table 1, it can be seen that the dominant families in the three northeastern provinces include Athyriaceae (33 species), Dryopteridaceae (29 species), and the Wood Thief family (Equisetaceae). These 3 dominant families included 8 genera and 84 species, accounting for 13.33% of the total families, 21.05% of the total genera, and 51.21% of the total species. These include 4 genera and 33 species of Athyriaceae, which are widely distributed in tropical to cold temperate regions worldwide, mostly in tropical and subtropical mountains, with 29 species in 3 genera of Dryopteridaceae and 20 species in 1 genus of Equisetaceae. The families containing 10–19 species were Woodsiaceae, Pteridaceae, and Aspleniaceae, with 6 genera and 34 species. The families containing 5–9 species were Ophioglossacea, Polypodiaceae, Thelypteridaceae, Cystopteridaceae, and Dennstaedtiaceae, with 17 genera and 38 species. The families containing fewer than 5 species were Onocleaceae, Osmundaceae, Salviniaceae, Marsileaceae, and Davalliaceae, with a total of 8 genera and 11 species.

Floristic Characteristics of the Genera

Determination of the dominant genera was based on the criterion that the number of species distributed in a genus was greater than 15. As shown in Table 2, there were 3 dominant genera, including 68 species, which accounted for 41.71% of the total species in this area. Among these, there were 24 species of *Athyrium*, 20 species of *Dryopteris*, and 20 species of *Equisetum*.

Table 2: Statistics on lycophyte and fern genera in the three northeastern provinces of China

Genus	Species	Genus	Species
Athyrium	24	*Osmunda*	2
Dryopteris	20	*Parathelypteris*	2
Equisetum	20	*Diplazium*	2
Woodsia	13	*Botrychium*	2
Asplenium	10	*Sceptridium*	2
Polystichum	8	*Pyrrosia*	2
Deparia	8	*Polypodium*	2
Gymnocarpium	4	*Cyrtomium*	1
Dennstaedtia	3	*Leptorumohra*	1
Phegopteris	3	*Claytosmunda*	1
Thelypteris	3	*Salvinia*	1
Ophioglossum	3	*Azolla*	1
Platygyria	3	*Physematium*	1
Adiantum	3	*Botrypus*	1
Aleuritopteris	3	*Sahashia*	1
Coniogramme	3	*Selliguea*	1
Cystopteris	2	*Pteris*	1
Pteridium	2	*Marsilea*	1
Matteuccia	2	*Davallia*	1
Onoclea	2		

Geographical Features of Ferns in the Three Northeastern Provinces of China

According to Lu[49] analysis of the families and genera of ferns, the families and genera of ferns in the three northeastern provinces are divided into 10 distribution area types and 3 subtypes, which are classified into 3 major categories: cosmopolitan, tropical, and temperate.

Table 3 Areal types of fern families, genera, and species in the three northeastern provinces

Distribution elements	Family		Genus	
	Quantity	Percent (%)	Quantity	Percent (%)
1. Cosmopolitan	7	NA	11	NA
2. Pantropic	3	33.3	5	17.9
3. Old World Tropics	1	11.1	1	3.6
4. Tropical Asia to Tropical Australasia	0	0	1	3.6
5. Tropical Asia to Tropical Africa	0	0	3	10.7
Tropical elements	4	44.5	10	35.7
6. North temperate	3	33.3	10	35.8
7. E. Asia & N. Amer. Disjuncted	0	0	2	7.1
8. Old World Temperate	2	22.2	2	7.1
9. Temperate Asia	0	0	1	3.6
10. (H-S-J)	0	0	3	10.7
Temperate elements	5	55.5	18	64.2

Geographical Component Analysis of Families

Table 3 shows that among the 15 families of plant species in the three northeastern provinces, there were 7 cosmopolitan families: Sinopteridaceae, Adiantaceae, Athyriaceae, Aspleniaceae, Dryopteridaceae, Marsileaceae, and Salviniaceae. There were 4 tropical families and 3 pantropic families: Dennstaedtiaceae, Pteridaceae, and Thelypteridaceae. There was one Old World tropical family, Davalliaceae. There were 2 families distributed in temperate zones and 3 north temperate families: Onocleaceae, Osmundaceae, and Equisetaceae. There were 2 families distributed in the old world temperate zone: Woodsiaceae and Cystopteridaceae, and this flora of ferns includes no families endemic to China. From the perspective of the distribution area type of the families, the fern flora in the three northeastern provinces was transitional from tropical to temperate, showing both obvious tropical attributes and a close relationship with the fern flora in the temperate zone.

Geographic Composition Analysis of the Genera

Among the 39 genera of ferns in the three northeastern provinces, there were 11 cosmopolitan genera: *Asplenium*, *Pteridium*, *Arachniodes*, *Polystichum*, *Salvinia*, *Azolla*, *Thelypteris*, *Aleuritopteris*, *Botrychium*, *Marsilea*, and *Ophioglossum*. Nine genera belonged to the tropical element genera, of which 5 were pantropical genera: *Dennstaedtia*, *Pteris*, *Coniogramme*, *Parathelypteris*, and *Davallia*. There is one Old World tropical genus, *Pyrrosia*. There is only 1 genus (*Deparia*) of the North temperate type and three genera from Tropical Asia to Tropical Africa: *Cyrtomium*, *Lepisorus*, and *Cornopteris*. There were 18 temperate element genera and 10 North temperate genera: *Gymnocarpium*, *Equisetum*, *Matteuccia*, *Osmunda*, *Claytosmunda*, *Phegopteris,* *Sceptridium*, *Sahashia*, *Polypodium*, and *Botrypus*. In the type of E. Asia and N. Amer. disjuncted, there are 2 genera, *Onoclea* and *Diplazium*. There are 2 genera of Old World Temperate: *Cystopteris* and *Woodsia*, and there are 3 genera of the H-S-J type: *Athyrium*, *Adiantum,* and *Selliguea*. There is only one genus in Temperate Asia: *Dryopteris*. According to the type of distribution area, the fern flora in the three northeastern provinces had an obvious temperate nature.

Among the distribution area types at the family and genus level, temperate elements occupy an absolutely dominant position, indicating that the three northeastern provinces have been strongly influenced by temperate features during evolution. Among the temperate features, the number of families and genera of the North temperate type was the largest, indicating that the families and genera of the North temperate type have wider adaptability.

Species Endemic to the Three Northeastern Provinces

There were 163 species of ferns in the three northeastern provinces, and 8 of them were distributed only in the three northeastern provinces: *Dryopteris expansa* distributed only in Northeast China, *Dryopteris saxifraga* and *Dryopteris monticola* in Liaoning and Jilin, *Dryoathyrium pterorachis* in Heilongjiang and Jilin, *Botrychium manshuricum* in Heilongjiang and Liaoning, *Parathelypteris changbaishanensis* in Changbai Mountain area of Jilin, and *Athyrium rubripes* and *Lunathyrium pycnosorum* only in Heilongjiang.

Ecological Characteristics of Ferns in the Three Northeastern Provinces of China

Habitat Distribution Characteristics of Ferns in the Three Northeastern Provinces of China

The fern habitats in the three northeastern provinces of China were divided into soil, stone, epiphytes, hydrophytes, and wet types. Soil ferns include meadow

forest margins and forest soil types; stone ferns include stone, rock, and soil or stone types; wet ferns include hydrophytes or soil types, damp shores, and swamp types. As shown in Figure 2, there were 95 species of soil ferns, accounting for the largest proportion (60.51%); 15.29% were forest soil types and 45.22% were meadow forest margin types, with *Dryopteris*, *Equisetum*, and *Athyrium* as the main species. This category was followed by 41 species of stone ferns, accounting for 26.11%, with *Woodsia*, *Adiantum*, and *Asplenium* as the main species. There were 5 species of epiphyte ferns, accounting for 3.18%, including *Polypodium virginianum, Polypodium sibiricum*, *Lepisorus obscure-venulosus*, *Davallia mariesii*, and *Asplenium ternuicaule*, which are parasitic on tree trunks or rocks. There were 3 species of hydrophyte ferns, *Marsilea quadrifolia*, *Salvinia natans*, and *Azolla imbricata*, accounting for 1.91%. Thirteen species of wet ferns that grow in swamps and shores, included *Ophioglossum vulgatum* Linn., *Ophioglossum thermale* Kom, *Equisetum ramosissimum*, *Equisetum sylvaticum*, *Equisetum palustre*, *Equisetum fluviatile*, and *Equisetum fluviatile*. The ferns in the three northeastern provinces are dominated by soil ferns and the proportions of epiphyte ferns and hydrophyte ferns is relatively low. They have the distribution characteristics of the ecological types of ferns in typical temperate ecosystems, which is in agreement with the climatic characteristics of the geographical units in this area.

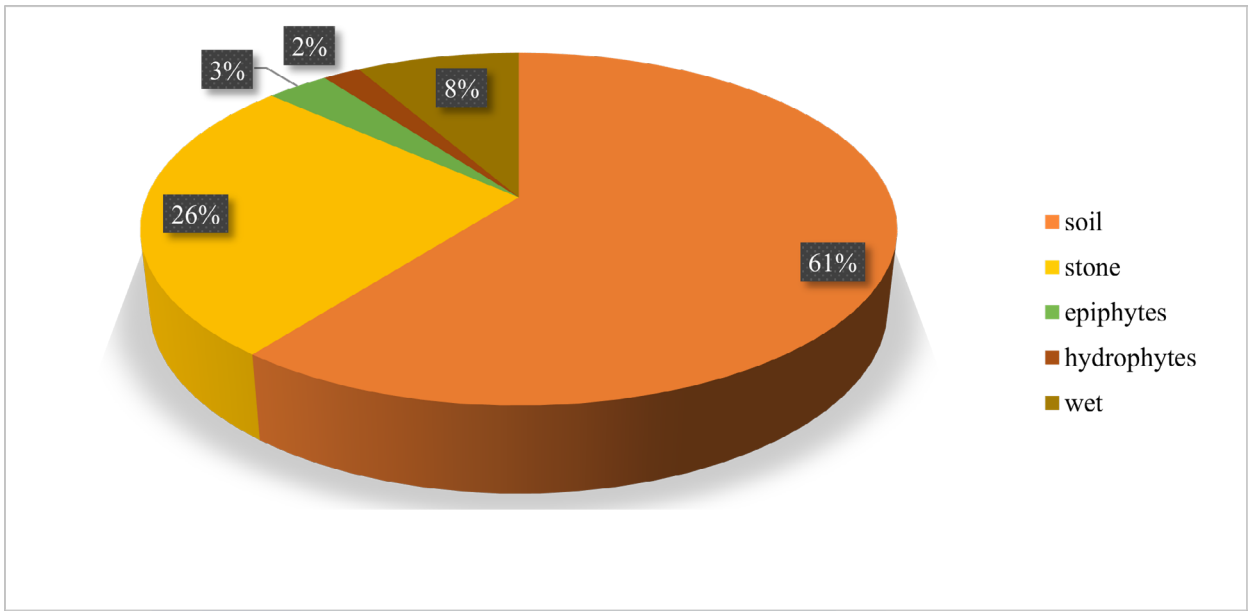

Figure 2: Investigation of fern habitats in the three northeastern provinces

Vertical Distribution Characteristics of Ferns in Three Northeastern Provinces

The terrain of the three northeastern provinces is dominated by plains and mountains, including Changbai Mountain, Greater Khingan Mountains, and the Lesser Khingan Mountains. The highest mountain range is Changbai Mountain, and the highest altitude of the main peak is 2,691 meters. According to the distribution of ferns in the three northeastern provinces, as the distribution of ferns is represented by intervals of numbers, the highest altitude is used as a reference for statistical convenience, and the altitude is divided into four ranges: below 500m, 500–1000m, 1000–1500m, and 1500–2100m. As shown in Figure 3, the ferns in the zone with an altitude of 500–1000 m were the most abundant, including 95 species, accounting for 58.28% of the total; 32 species in the zone with an altitude below 500m, accounting for 19.63% of the total; 29 species in the zone with an altitude of 1000–1500 m, accounting for 17.79%, and only 7 species in the zone with an altitude of 1500–2000 m, accounting for 4.29% of the total. Considering that only the northern temperate distribution type presented obvious floristic representativeness, 36 species of ferns were found to be distributed in the zone with an altitude above 1000m, including 16 species of the northern temperate distribution type, with more plants belonging to the genera *Woodsia*, *Sceptridium*, and *Cystopteris*. According to the analysis, as the vertical climate variation in Northeast China is relatively large and the temperature decreases with altitude, cold-resistant ferns adapting to the temperate zone can be distributed at higher altitudes. However, temperature and elevation have been also found to be positively related to pteridophyte species richness.[56,57] low altitude is suitable for fern growth, which may be due to the ampler heat and moisture environment at lower altitudes. The temperature in the three northeastern provinces is relatively low and drops rapidly with increasing altitude; therefore, it is not suitable for the survival of ferns with poor cold resistance.

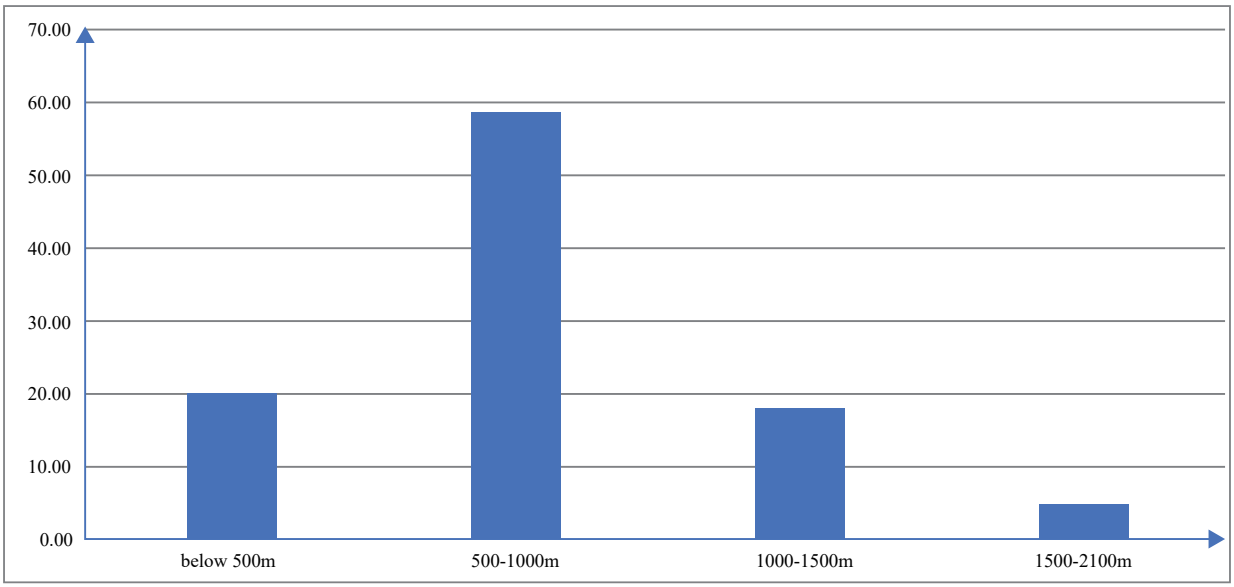

Figure 3: Characteristics of the vertical distribution of ferns in the three northeastern provinces

Protection and Utilization of Fern Resources in the Three Northeastern Provinces of China

Resource Protection

After consulting the "IUCN Red List of Threatened Species" (IUCN 2016 ver. 3.1), and referring to the China Rare and Endangered Plant Information System, *Cystopteris sudetica* is listed as near threatened (NT) and *Asplenium scolopendrium* subsp. *japonicum* as vulnerable (VU). Moreover, *Ophioglossum thermale* Kom. is a national-level-II protected plant species. Thirteen species of ferns, including *Phegopteris polypodioides,* were labeled as least concern (LC) in the "China Biodiversity Red List—Higher Plant Volume" (September 2, 2013).[58]

Resource Utilization

According to common uses, ferns in the three northeastern provinces were divided into four categories: edible ferns, medicinal ferns, ornamental ferns, and multifunctional ferns, which can be used for edible, medicinal, and ornamental purposes. There were 22 species of edible ferns (accounting for 8.59% of the total species), including *Pteridium aquilinum* var. *latiusculum*, *Polystichum braunii*, *Matteuccia orientalis*, *Osmunda cinnamomea* Linn. var. *asiatica*, *Osmunda cinnamomea* var. *asiatica*, *Athyrium yokoscense*, *Dryoathyrium coreanum*, and *Ophioglossum vulgatum*.

There were 56 species of medicinal ferns, accounting for 15.3% of the total, including *Asplenium incisum*, *Camptosorus sibiricus*, *Dennstaedtia wilfordii*, *Polystichum tripteron*, *Polystichum braunii*, and *Dryopteris chinensis*.

Ten species of ornamental ferns accounted for 4.29 % of the total, including *Dennstaedtia hirsuta*, *Dryopteris expansa*, *Onoclea sensibilis* var. *interrupta*, *Protowoodsia manchuriensis*, and *Woodsia macrochlaena*.

There were 6 species of multifunctional ferns, accounting for 3.68% of the total, including *Pyrrosia petiolosa*, *Dryopteris crassirhizoma*, *Lunathyrium pycnosorum*, *Matteuccia struthiopteris*, *Marsilea quadrifolia*, and *Athyrium sinense*.

The Northeast region is the largest region in China for the export of wild vegetables. Ferns account for a large proportion of wild vegetables; however, in general, most wild vegetable species are not domesticated or planted on a large scale. Even for wild vegetables that have been planted and produced, high-tech processing and testing is lacking. Most wild vegetable species are harvested directly from mountains in a non-sustainable manner. Therefore, it is necessary to step up research efforts on the artificial propagation and domestication of fern vegetables, aiming to protect resources and apply them scientifically and rationally.

Fern species play a crucial role in ecosystems and are responsible for the production of a vast range of bioactive components that exhibit various actions. A considerable number of these substances are employed in traditional medicinal practises and hold potential for therapeutic applications in the treatment of diverse ailments. Nevertheless, wild fern plants across the globe are confronted with numerous grave challenges as a result of environmental change, resulting in substantial declines in fern species and their respective habitats. Consequently, this has led to a dramatic depletion of biodiversity. Currently, there is a scarcity of research on the phytochemistry of ferns and their bioactivities, despite their potential as valuable sources of innovative bioactive chemicals. Conducting additional investigation and experimentation on wild ferns to ascertain their biological characteristics and identify their active components could potentially provide significant advancements in human healthcare and contribute to the appreciation of natural biodiversity. In order to achieve this objective, a survey will be conducted with the purpose of identifying uncommon, conventional, and untamed species of ferns that are utilised in the context of culinary

and medicinal applications. Sustainable harvesting of ferns will be conducted to obtain high-value goods, such as pharmaceuticals and bioactive food ingredients. These products will then undergo analysis to examine their nutritional and phytochemical profiles. The objective is to assess the bioactivity and toxicity of the extracted compounds and components. Furthermore, the investigation will focus on evaluating the antioxidant and anti-inflammatory properties of certain fractions, purified substances, and components through the use of in vitro and cellular models. The study aims to evaluate the impact of a diet supplemented with fern-based meals and ingredients, chosen through laboratory studies conducted in test tubes and outside of a living organism, on many important indicators such as oxidative and inflammatory stress, cardiovascular function, and clinically relevant parameters in individuals who are overweight.

Conclusions

1. According to the plant specimens provided by the Chinese Virtual Herbarium, there are 16 families of ferns belonging to 39 genera and 164 species in the three northeastern provinces. Fern resources are relatively scarce.
2. Among the ferns in the three northeastern provinces of China, dominant families and genera were evident. The dominant families included Dryopteridaceae, Athyriaceae, and Equisetaceae, whereas the dominant genera included *Athyrium*, *Dryopteris*, and *Equisetum*.
3. Among the types of distribution areas at the family and genus levels, temperate elements played a dominant role. There are 164 species of ferns in the three northeastern provinces of China, including 8 that are distributed only in these provinces.
4. In terms of the ecological types of plants, the ecological types of ferns in the three northeastern provinces of China are rich and diverse, mainly including soil ferns (accounting for 60.51%), stone ferns (accounting for 26.11%), and epiphyte ferns (accounting for 3.18%). There are 3 species of hydrophyte ferns, accounting for 1.91%, and 13 species of wet shore ferns, accounting for 8.28%.
5. The vertical distribution of ferns in the three northeastern provinces of China first increased and then decreased, and the species are the most abundant at an altitude range of 500–1000 m. There are 95 species in this range, accounting for 58.28% of all species; 32 species at altitudes below 500m, accounting for 19.63% of all species; and 29 species in the altitude range of 1000–1500 m, accounting for 17.79% of all species. The range of 1500-2000m harbors the least number of species (only 7).
6. Fern resources in the three northeastern provinces are divided into edible, medicinal, ornamental, and multifunctional types. There are 8 edible, 25 medicinal, 7 ornamental, and 8 multifunctional species, accounting for 4.9%, 15.3%, 4.29%, and 3.68% of the total species, respectively.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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