Wingnuts (*Pterocarya*) & walnut family

Relict trees: linking the past, present and future

Gregor Kozlowski – Sébastien Bétrisey – Yi-Gang Song

Erick Viquez Alvarado – Daniel Belchí – Adam Boratyński – Adriana Corrales
Nino Davitashvili – Jan De Langhe – Min Deng – Yann Fragnière – Emanuel Gerber
Anna K. Jasińska – Evelyne Kozlowski – Martina Löwy – Steven Manchester – Hitoshi Sakio
Hoàng Văn Sâm – Hans-Rüdiger Siegel – Hamed Yousefzadeh

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AUTHORS

Professor Dr. Gregor Kozlowski is a researcher at the University of Fribourg, Scientific Director of the Botanic Garden of Fribourg and curator at the Natural History Museum in Fribourg (Switzerland). His main research interests are the biogeography and conservation biology of relict, endemic and threatened species.

Sébastien Bétrisey is a biologist leading the *Pterocarya* project in Transcaucasia and Eastern Asia. He is working on the biogeography and conservation biology of relict trees at the Botanic Garden of the University of Fribourg and at the Natural History Museum Fribourg (Switzerland). He is also an expert on rare and threatened plants of the Canton of Fribourg (Switzerland).

Yi-Gang Song is studying for a PhD at the University of Fribourg (Department of Biology) in collaboration with the Shanghai Chenshan Plant Science Research Centre (SCPSRC) of the Chinese Academy of Sciences in Shanghai, China. His main research interests are seed physiology, phylogeny, phylogeography and conservation biology of *Pterocarya* (Juglandaceae) and *Quercus* (Fagaceae).

CONTRIBUTORS

Erick Víquez Alvarado, National Technical University, Atenas (Costa Rica)

Daniel Belchí, Murcia (Spain)

Professor Dr. Adam Boratyński, Institute of Dendrology, Polish Academy of Sciences, Kórnik (Poland)

Dr. Adriana Corrales, University of Florida, Gainesville (USA)

Dr. Nino Davitashvili, Ilia State University, Tbilisi (Georgia)

Jan De Langhe, Ghent University Botanic Garden in collaboration with Arboretum Wespelaar (Belgium)

Professor Dr. Min Deng, Chenshan Plant Science Research Centre, Chinese Academy of Sciences, Shanghai (China)

Yann Fragnière, University of Fribourg and Natural History Museum Fribourg (Switzerland)

Dr. Emanuel Gerber, Natural History Museum Fribourg (Switzerland)

Dr. Anna K. Jasińska, Institute of Dendrology, Polish Academy of Sciences, Kórnik (Poland)

Evelyne Kozlowski, University of Fribourg and University of Bern (Switzerland)

Martina Löwy, Wädenswil (Switzerland)

Professor Dr. Steven Manchester, Florida Museum of Natural History, Gainesville (USA)

Professor Dr. Hitoshi Sakio, Niigata University, Niigata (Japan)

Professor Dr. Hoàng Văn Sâm, Vietnam National University of Forestry, Hanoi (Vietnam)

Hans-Rüdiger Siegel, Natural History Museum Fribourg (Switzerland)

Professor Dr. Hamed Yousefzadeh, Tarbiat Modares University, Tehran (Iran)

Image credits
ac – Adriana Corrales
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ek – Evelyne Kozlowski
er – Ehsan Rajaei
eva – Erick Víquez Alvarado
gk – Gregor Kozlowski
hhm – Hong-Hu Meng
hrs – Hans-Rüdiger Siegel
hs – Hitoshi Sakio
hvs – Hoàng Văn Sâm
hw - Hongshan Wang
hy – Hamed Yousefzadeh
im – Izolda Matchutadze
jd – Jim Dalling
jdl – Jan De Langhe
jz – Jinlong Zhang
lf – Laurence Fazan
mpn – Mansour Pouramini Nave
nd – Nino Davitashvili
pb – Peter Brownless
pth – Pham Thanh Ha
sb – Sébastien Bétrisey
sm – Steven Manchester
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ygs – Yi-Gang Song
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xxz – Xin-Xin Zhu

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Pterocarya fraxinifolia, Ismayilli, Azerbaijan (ek)

Artwork
Daniel Belchí, Murcia, Spain
Norbert Frotzler, University of Vienna, Austria
Martina Löwy, Wädenswil, Switzerland

English editing
Languages4you, Zurich, Switzerland

Design
NG Tornay, Fribourg, Switzerland

For further information, please contact:

Natural History Museum Fribourg (NHMF)
Chemin du Musée 6
1700 Fribourg
Switzerland
Tel +41 (0) 26 305 89 00
MuseumFribourg@fr.ch
www.fr.ch/mhn

Botanic Garden of the University of Fribourg (BGF)
Chemin du Musée 10
1700 Fribourg
Switzerland
Tel +41 (0) 26 300 88 86
jardin-botanique@unifr.ch
www.unifr.ch/jardin-botanique

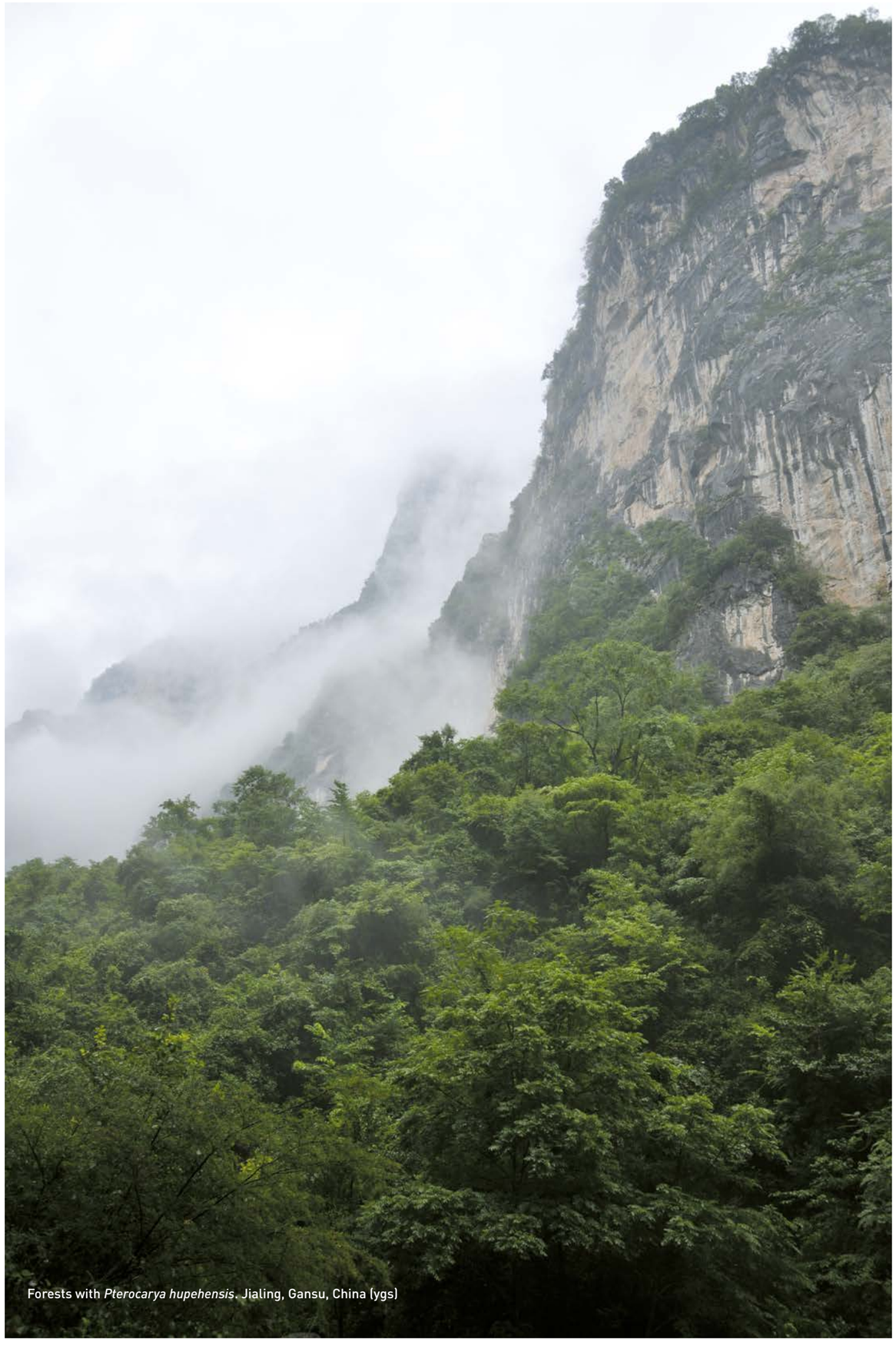
Shanghai Chenshan Botanical Garden (SCBG) / Shanghai Chenshan Plant Science Research Centre (SCPSRC)
Chinese Academy of Sciences (CAS)
3888 Chenhua Road, Songjiang
Shanghai 201602
China
Tel +86 (0) 21 3779 2288
sibs@siba.ac.cn
www.scpsrc.ac.c

Pterocarya fraxinifolia (painting by Daniel Belchí)

NATURAL HISTORY MUSEUM FRIBOURG (NHMF), is part of the Department of Education, Culture and Sport of the State of Fribourg (Switzerland). Created in 1824, the NHMF is one of the oldest museums in the country. Boasting a long history, first-rate curatorial expertise and diverse collections, the museum is a leading institution in conservation. Since its inception, the NHMF has actively participated in numerous national and international research and conservation programmes focusing in particular on alpine and aquatic plants and, more recently, relict flora.

BOTANIC GARDEN OF THE UNIVERSITY OF FRIBOURG (BGF), Switzerland, is a centre of expertise for the scientific study and conservation of relict trees. BGF also leads a number of basic and applied national and international research and conservation projects on various biological and biogeographical aspects of aquatic, alpine and endemic plants. It also devised and co-ordinates the *Zelkova* and *Pterocarya* global projects.

SHANGHAI CHENSHAN BOTANICAL GARDEN (SCBG) / SHANGHAI CHENSHAN PLANT SCIENCE RESEARCH CENTRE (SCPSRC) / CHINESE ACADEMY OF SCIENCES (CAS). In October 2009, the Chinese Academy of Sciences (CAS) and the Shanghai Municipality Government created the Shanghai Chenshan Plant Science Research Centre, a non-profit-making institution focusing on plant science research. It provides scientific and technological support for the development of the Shanghai Chenshan Botanic Garden. The mission of the centre is to preserve plants in Eastern China, discover sustainable ways of using them and to inform and motivate the general public.



Forests with *Pterocarya hupehensis*. Jialing, Gansu, China (ygs)

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Numerous experts at universities, botanic gardens, arboreta, museums and other affiliated institutions around the world have provided information and plant material to promote the development of this global overview of the genus *Pterocarya* and the walnut family (Juglandaceae). Their contributions are invaluable and greatly appreciated (in country order):

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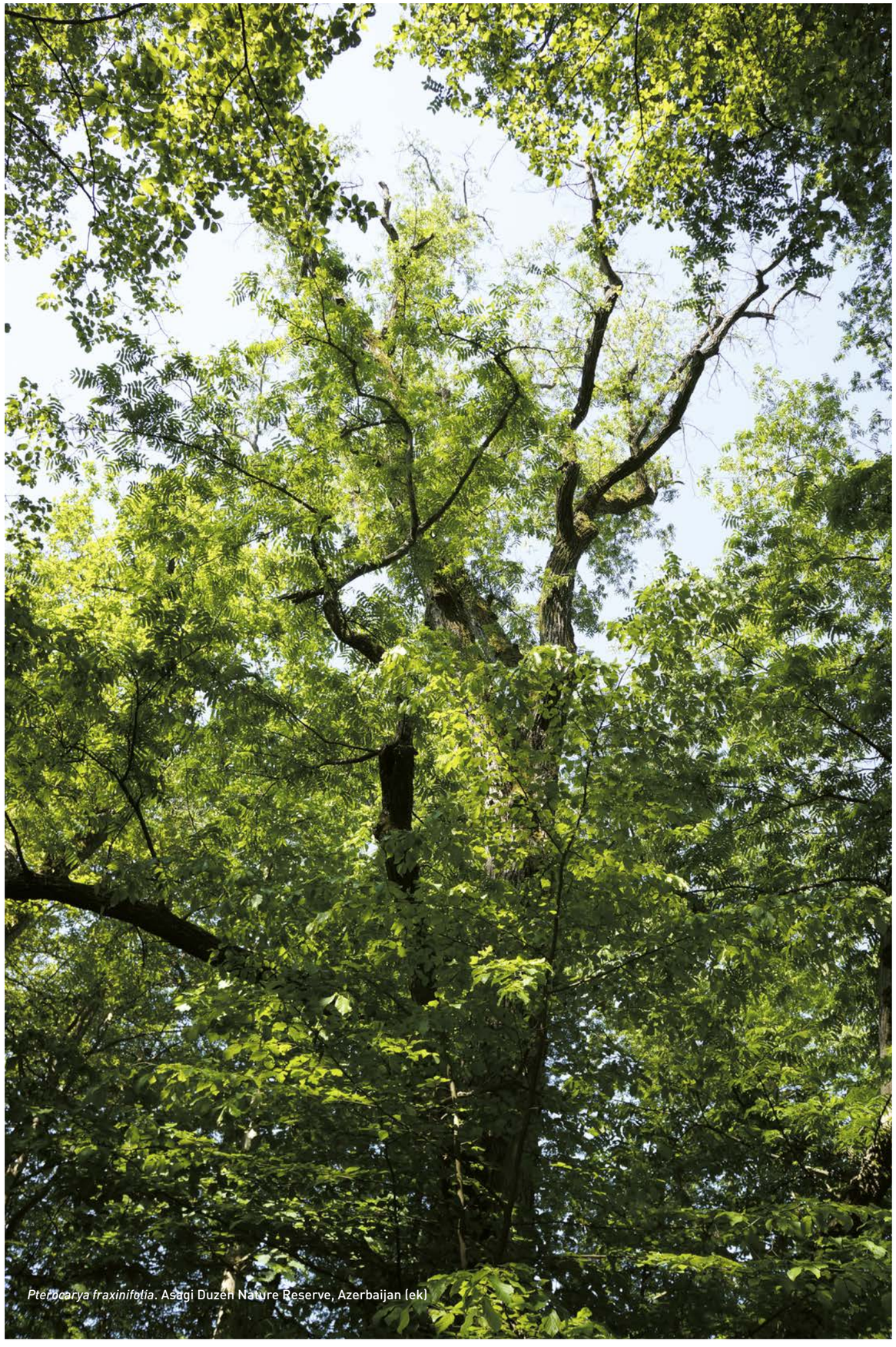
Above all however, Project *Pterocarya* would not have been possible without the generous support provided by Fondation Franklinia; their profound commitment to biodiversity conservation is exemplary and is sincerely acknowledged.



Pterocarya fraxinifolia. Asagi Duzen Nature Reserve, Azerbaijan (ek)

Foreword

JEAN-PIERRE SIGGEN
State Councillor
Department of Education, Culture and Sport of the State of Fribourg (Switzerland)

Trees are the biggest and longest-living organisms on our planet. Just like biodiversity *per se*, they provide the foundations for healthy ecosystems. Hence trees are essential for human well-being given that societies and cultures depend on a diverse plant kingdom. Trees therefore have a high economic, social, cultural and aesthetic value.

In recent years, the Natural History Museum Fribourg and the Botanic Garden of the University of Fribourg have joined forces to develop numerous regional and international research projects in the field of biodiversity research and species conservation, focusing essentially on research into and protection of rare forests and trees under threat. Both institutions come under the aegis of the Department of Education, Culture and Sport of the Canton of Fribourg, and are proudly in line with the maxim «collect, preserve and pass on knowledge». Publications as well as exhibitions are important for the effective dissemination of the research-fed knowledge of nature to a broad audience in Fribourg and abroad.

This book provides a basic insight into dendrology and is the first monograph of the wingnut (*Pterocarya*) genus for more than a half-century. Furthermore, it is the most up-to-date and comprehensive study of the diversity, distribution and significance of the walnut family (Juglandaceae). It also highlights the threats to which the Juglandaceae are currently exposed. Never before has this group of plants been presented in such a colourful, versatile manner along with their habitats and companion species.

The book has received significant support from researchers and institutions in China – the country with the world's largest variety of Juglandaceae. In addition, contributions have been welcomed from experts in over 15 countries across Asia and Europe as well as North and Central America. This book project was initiated and coordinated in Fribourg, where all findings were collated and evaluated. This clearly reflects the scientific importance of the Natural History Museum and the Botanic Garden in this international field of research.

On behalf of the Department of Education, Culture and Sport, I have great pleasure in congratulating the authors on this remarkable publication. The Department is very proud of the Natural History Museum and Botanic Garden, and wishes both institutions continued, resounding success in the years ahead.

CONTENTS

Pterocarya fraxinifolia (painting by Daniel Belchí)

The world of Juglandaceae – an extraordinary journey

Although the walnut family (Juglandaceae) with approximately 60 species ranks among the smallest in the plant kingdom, its scientific and conservation value is inestimable. From a palaobotanical perspective, all living Juglandaceae are relict trees, meriting more in-depth research programmes and joint international protection efforts. For any researcher exploring the family's diversity, ecology or biogeography, it offers a unique opportunity to embark on a fascinating voyage of discovery, focusing on the evolutionary history of our planet over the last million years. Furthermore, the walnut family belongs to the group of commercially significant timber and nut-producing trees such as walnut, pecan and hickory.

The book is the culmination of more than four years of exploration and international co-operation. The authors recount an extraordinary journey to the most beautiful and, at the same time, the most threatened relict forests. They have visited natural populations of Juglandaceae in more than 10 countries around the globe including the USA, Cuba, Costa Rica, Georgia, Azerbaijan, Iran, China, Vietnam and Japan. In addition, countless botanic gardens and arboreta were visited, essentially in Europe (United Kingdom, Germany, France, Switzerland and Poland) but also in Central and North America as well as Western and Eastern Asia.

The project benefited from the skills of several photographers. Besides the authors' pictures, the vast majority of photographs were taken by Evelyne Kozlowski (University of Fribourg and University of Bern), and Emanuel Gerber and Hans-Rüdiger Siegel (Natural History Museum Fribourg). Furthermore, many drawings and paintings were produced by talented artists and scientific illustrators such as Martina Löwy (Switzerland), Daniel Belchí (Spain) and Norbert Frotzler (Austria).

The book starts by examining the last 70 or so Mya in the evolution of the Juglandaceae, presenting selected highlights of the rich paleontological history. This chapter is followed by an exhaustive presentation of the *Pterocarya* genus - the main subject of the book - introducing all extant species, namely *P. fraxinifolia, P. stenoptera, P. tonkinensis, P. hupehensis, P. macroptera* and *P. rhoifolia*. Detailed information on distribution, morphology, ecology and threats is provided for each species.

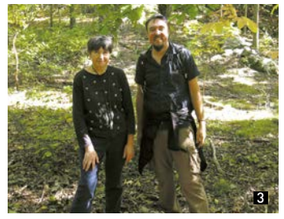
The second half of the book presents the nine remaining genera of the Juglandaceae: *Rhoiptelea, Engelhardia, Alfaropsis, Oreomunnea, Alfaroa, Carya, Platycarya, Cyclocarya* and *Juglans*. After a brief introduction to the global diversity, distribution and phylogeny of the Juglandaceae family, each genus is succinctly presented with details of its fossil history, morphology, ecology and distribution.

Finally, the book describes the uses as well as the most diverse and/or interesting regions of the world in terms of the highest number of Juglandaceae species (China, USA), the highest number of genera (China, Vietnam) or the most impressive or threatened members of the family (Costa Rica, Cuba).

The future of relict trees is uncertain. Many species are threatened by changes in accelerated land use and climate change. This book, which portrays the beauty and diversity of this unique family in all its glory, should encourage on-going conservation and research efforts worldwide.

1. G. Kozlowski investigating *Carya sinensis* and *Pterospermum truncalobatum* (Malvaceae) in the Cuc Phuong National Park, Vietnam (ek)

2. N. Davitashvili, D. Ducry and S. Bétrisey in the Babaneuri Protected Area, Georgia



3. I. Kadis and S. Bétrisey searching for *Carya glabra* and *C. cordiformis* in the Blue Hills Reservation, Massachusetts, USA

4. Opening ceremony of the «Green treasure of Azerbaijan» exhibition in Baku, Azerbaijan

5. Y. Song and Z. Liu in the Funiu Shan Nature Reserve, Henan, China

6. G. Kozlowski, H.V. Sam and P.T. Ha at the Vietnam National University of Forestry, Hanoi, Vietnam (ek)

7. H. Yousefzadeh investigating *Pterocarya fraxinifolia* in the Hyrcanian Forest, Minoudasht, Iran (sy)

8. Participants of the (2017) annual meeting of the *Zelkova/Pterocarya* networks on the Moléson Mountain, Switzerland (lf)

9. S. Bétrisey and Y. Song in front of the *Pterocarya hupehensis* population in the Leigong Mountains, Guizhou, China

10. Participants of the (2016) annual meeting of the *Zelkova/Pterocarya* networks in the Kolkheti National Park, Georgia

11. S. Bétrisey, J.R. Campa and his son, looking for *Juglans jamaicensis* in the Topes de Collantes Nature Reserve, Cuba

12. E. Kozlowski documenting *Oreomunnea mexicana* in the Tapanti National Park, Costa Rica (gk)

13. T. Nagashima, M. Takahashi, H. Sakio and Y. Nakano in the *Pterocarya rhoifolia* forest, Sado Island, Japan

14. H. Safarov and G. Kozlowski in the Hyrcanian National Park, Azerbaijan (ek)

Pterocarya network – an overview

In 2015, the Botanic Garden of the University of Fribourg (Switzerland), in collaboration with the Natural History Museum in Fribourg (Switzerland) initiated an interdisciplinary and international project to undertake a scientific review of the relict tree family, Juglandaceae, with special focus on the genus *Pterocarya*. Additional research partners around the globe have joined the *Pterocarya* network in the last few years, including:

- Shanghai Chenshan Botanic Garden, Plant Science Research Centre, Chinese Academy of Sciences, Shanghai (China)
- Institute of Dendrology of the Polish Academy of Sciences, Kórnik (Poland)
- Niigata University, Niigata (Japan)
- Vietnam National University of Forestry, Hanoi (Vietnam)
- Tarbiat Modares University, Tehran (Iran)
- Ilia State University, Tbilisi (Georgia)
- Institute of Botany, Azerbaijan National Academy of Sciences, Baku (Azerbaijan)
- Florida Museum of Natural History, Gainesville (USA)
- University of Florida, Gainesville (USA)
- Ghent University Botanic Garden, Ghent (Belgium)

The scientific and conservation activities of the *Pterocarya* network address four key objectives:

(1) A review of existing knowledge of the *Pterocarya* genus and of the entire walnut family (Juglandaceae).

(2) Building bridges between different regions, countries and institutions working on various aspects of the biology and conservation of *Pterocarya*, Juglandaceae and, more generally, on relict and threatened woody plants.

(3) Basic and applied research into various aspects of the biology and conservation of Juglandaceae (with special focus on the genus *Pterocarya*) as well as on other relict and threatened woody plants.

(4) Boosting public awareness and outreach programmes focusing on relict and threatened woody plants, including publications, promoting exhibitions and organising national and international seminars to pool knowledge and share individual expertise.

Juglandaceous leaf (with three intact leaflets) attributed to *Polyptera manningii* from Paleocene (56-64 Mya), Dry Canyon, Sweetwater County, Wyoming, USA (cs, hw)

PAST

Fossil history and extinct genera of Juglandaceae

The Juglandaceae is an old plant family with an extensive fossil record. Most of the fossils are found in North America, Europe and Asia, and include pollen, leaves, wood, inflorescences and fruits. The first members of the family probably evolved as far back as the late Cretaceous period (> 66 Mya). However, major diversification occurred during the Paleocene epoch (66-55 Mya).

Some of these early Juglandaceae nevertheless disappeared from the fossil record prior to the Oligocene epoch. The most prominent extinct taxa examples of this period are *Polyptera* and *Cruciptera* (see below). These genera occupied a relatively small geographic area and were probably intolerant of the climatic fluctuations of this era (especially the cooling period at the end of the Eocene epoch). On the other hand, by the early Oligocene, many Juglandaceae genera had already spread far and wide, spanning continents and surviving up until the present day (e.g., *Platycarya, Cyclocarya, Juglans, Carya*, etc.). Although not all extant genera have a well-documented fossil history, it is evident from a paleobotanical perspective that all living Juglandaceae are relict trees.

The earliest centre of Juglandaceae diversity appears to have been North America (although the possibility of an Arctic or European family origin cannot be ruled out). Nowadays, however, Eastern Asia is the centre of generic diversity (with 8 genera compared to just 2 extant genera in North America without Mexico). From the fossil record, the East-Asian region has clearly served as the refugium as opposed to the birthplace of members of the Juglandaceae family.

The Engelhardioidae subfamily, characterised amongst other things by highly typical fruits with trilobate wings, possesses an interesting fossil history contrasting with the modern biogeographical pattern. Copious quantities of fossil engelhardioid fruits have emerged from the Eocene epoch of North America and Europe, which are the most likely areas of origin of this taxon. Today, the engelhardioids are found in only two disjunct regions of Eastern Asia (*Engelhardia* and *Alfaropsis*) and Central America (*Oreomunnea* and *Alfaroa*). The Engelhardioideae are thus an exclusively tropical element, which is rather exceptional amongst the otherwise temperate Juglandaceae.

During the Oligocene and Miocene epochs, the range of all Juglandaceae genera expanded significantly. Many taxa now present only in Asia witnessed very broad, intercontinental distribution. However, extensive reductions in the range of Juglandaceae occurred at the end of the Pliocene epoch as a result of climate cooling and glaciation. Western Europe experienced the most dramatic local extinctions with the disappearance of *Carya*, *Pterocarya*, *Cyclocarya* and *Juglans*. The *Pterocarya* genus also became extinct in North America at this time whilst *Juglans* and *Carya* ranges were substantially reduced.

Cruciptera

According to the fossil record, the genus appears in the early Eocene epoch of North America, spreading to Europe during the mid-Eocene epoch. Its fruits resemble those of *Polyptera* in having multiple wings attached to the central nutlet. However, the nutlet is globose (not pyramidal) and there are only 4 (rarely 5-6) elongate-spatulate wings. The whole fruit with wings measures 2-4 cm in diameter. The genus was extinct at the end of the Oligocene epoch (picture: *Cruciptera* sp. from the Eocene epoch, Messel, collection of the Senckenberg Museum, Frankfurt, Germany, sm).

Palaeocarya

This genus, along with other engelhardioid fossil genera such as *Paleooreomunnea* and *Paraengelhardia*, appears during the Eocene epoch. Today, almost 20 fossil species of *Palaeocarya* have been described and are broadly distributed across the Northern Hemisphere. One or more lineages presumably gave rise to the extant Engelhardioideae. In fact, some fossils cannot be clearly differentiated from the extant taxa and are sometimes assigned to living genera of *Alfaropsis, Engelhardia* or *Oreomunnea* (picture: *Palaeocarya* sp. from the Eocene epoch, Messel, collection of the Senckenberg Museum, Frankfurt, Germany, sm).

Polyptera

The *Polyptera* genus evolved in North America during the Paleocene epoch (56-64 Mya). It was characterised by pyramidal nutlets surrounded by 8-12 wings. The small fruit, barely 1.5 cm in diameter, was well adapted to wind dispersal (anemochory). The fruit structure of *Polyptera* is unique among all fossil and extant Juglandaceae. The genus, probably closely related to *Cyclocarya*, became extinct very early on, before the end of the Paleocene epoch, c. 55 Mya.

Well-preserved and abundant fossils indicate that *Polyptera* was a dominant component of floodplain forests. It was commonly associated with *Nyssidium* (Cercidiphyllaceae), *Platanus* and *Platanites* (Platanaceae), and *Palaeocarpinus* (Betulaceae), amongst others. All these taxa allegedly colonised the banks of streams and floodplains. Being part of such communities and possessing wind-dispersed fruits and pollen, *P. manningii* was probably an early species for succession (pictures: *Polyptera manningii* from Paleocene, Little Bitter Creek, Wyoming, USA, sm)

Reconstruction of *Polyptera manningii* (painting by Martina Löwy based on fossils of the Florida Museum of Natural History, and Manchster & Dilcher 1997).

The genus *Pterocarya* - a global view and individual species profiles

Pterocarya rhoifolia. Royal Botanic Garden Edinburgh, UK (ek)

The genus *Pterocarya* – a brief introduction

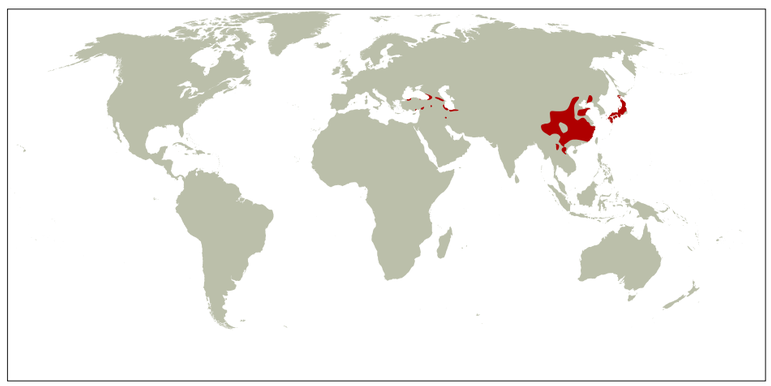
Age and origin The oldest confirmed fruits date from the early Oligocene epoch (34-28 Mya) of North America.

Extant species There are 6 generally accepted species: *P. fraxinifolia, P. hupehensis, P. macroptera* (with three varieties: *delavayi, insignis* and *macroptera*), *P. rhoifolia, P. stenoptera* and *P. tonkinensis*. More taxonomic research based on exhaustive field sampling is clearly needed. For example, *P. tonkinensis* should probably be integrated into *P. stenoptera*. On the contrary, some *P. macroptera* varieties might be deemed to be separate species (e.g. var. *delavayi*).

Habit Deciduous, fast-growing trees, reaching a height of 15-30(-40) m. Branchlets with chambered pith. Leaves alternate, odd- or even-pinnate. Monoecious plants. Male and female spikes, inflorescences, separate, pendulous. Male spike solitary, lateral on old growth or at the base of new growth. Female spike terminal on new growth. Fruiting spike elongated and pendulous, 15-45 cm long with 20-80 fruits. Fruit is a 2-winged nutlet with 4 compartments.

Ecology In Eastern Asia, *Pterocarya* is a typical element of moist, riparian forests, growing along riverbanks and streams, from sea level to 3,500 m a.s.l. *Pterocarya tonkinensis* is clearly the most tropical member of the genus, whereas all other species are covered in snow occasionally (*P. macroptera* and *P. hupehensis*) or practically every winter (*P. fraxinifolia*, *P. stenoptera* and *P. rhoifolia*). *Pterocarya rhoifolia* in particular is a typical element of the cool-temperate riparian forests of Japan, growing mainly at higher elevations (600-1,600 m a.s.l.) and supporting long and heavy snow cover in winter. In Transcaucasia and Iran, *P. fraxinifolia* is also a riparian tree growing along watercourses in lowland and ravine forests, and ascending along mountain streams up to 1,200 m a.s.l.

Distribution Main distribution is in China (4-5 species, 2 endemics: *P. hupehensis* and *P. macroptera*). *Pterocarya stenoptera* has the largest distribution area, starting in China and extending to the Korean Peninsula, Taiwan and Vietnam. *Pterocarya tonkinensis* is found in southern Yunnan, Laos and Vietnam, whereas *P. rhoifolia* grows exclusively in Japan, extending as far as Hokkaido Island to the north. *Pterocarya fraxinifolia* is the only species to be found in Western Eurasia (Transcaucasia) with very scattered distribution in Turkey, Georgia, Azerbaijan and Iran. The highest latitude is reached by *P. fraxinifolia* (c. 43.5°N), followed by *P. stenoptera* and *P. rhoifolia* (c. 42°N). The lowest latitude is reached by *P. tonkinensis* (c. 17°N).



SPECIES IDENTIFICATION KEY

1a Terminal leaflet predominantly absent (picture **1**). Nut wings narrow to linear (picture **2**).....2

1b Terminal leaflet predominantly present (picture **3**). Nut wings broad, ovate to orbicular (picture **4**).....3

2a Rachis winged over its total length (picture **5**). .....*Pterocarya stenoptera*

2b Rachis wingless.....*Pterocarya tonkinensis*

3a Terminal bud with 2-4 caducous bud scales, which initially overlap (picture **6**).....4

3b Terminal bud naked, bud scales absent (picture **7**).....5

4a Leaflets 11-21 (picture **8**). Petiole and rachis initially pubescent. Nut wings +/-orbicular, up to +/-2 cm long.....*Pterocarya rhoifolia*

4b Leaflets 7-13 (picture **3**). Petiole and rachis initially tomentose. Nut wings +/- orbicular, ovate to rhombic, to +/- 3 cm long....*Pterocarya macroptera*

5a Leaf <30 cm. Leaflets 5-11(-15), base not overlapping rachis (picture **9**)..... *Pterocarya hupehensis*

5b Leaf 20-60 (more) cm. Leaflets 9-21 (7-27), base often overlapping rachis (picture **10**).....*Pterocarya fraxinifolia*

Key based on: (1) De Langhe J. 2012. "Juglandaceae - Vegetative key to species cultivated in Western Europe", Ghent University Botanic Garden (www.identificationkeys.be) in collaboration with the Arboretum Wespelaar (Belgium); (2) Flora of China (www.eFloras.org); and (3) Personal observations. Pictures: jdl (1, 3, 5, 7-10), hvs (2), ek (4), ygs (6)

Pterocarya fraxinifolia (Poir.) Spach (1834)

Caucasian wingnut, lapani (Georgia), kanatlı ceviz (Turkey), qanadmeyvə yalanqozı (Azerbaijan)

The Caucasian wingnut has the westernmost distribution and is the only representative of the genus outside Eastern Asia. It is one of the most symbolic trees of the Colchis and Hyrcanian regions. Its extremely fragmented populations nowadays face severe threats due to loss of habitat and urbanisation.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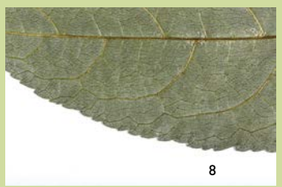
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HABIT

Tree growing to a maximum height of 35 m and up to 2 m in diameter. The bark is dark and cracked. As the species produces numerous suckers from its roots and trunk, it is also often found in the shrub layer. Characteristic features of this species include the absence of bud scales, the large odd-pinnate leaves up to 60 cm long with the presence of many leaflets [9-21(-27)]. The winged nuts are orbicular ovate to elliptic rhomboid.

DISTRIBUTION

Pterocarya fraxinifolia grows along the eastern shore of the Black Sea (Georgia), on the southern side of the Greater Caucasus, in the Talysh Mountains (Azerbaijan) and along the southern shore of the Caspian Sea (Elburz Mountains, Iran). Some isolated populations exist in Turkey and one disjunct population can be found in the Zagros Mountains (Iran). The species reaches the northernmost latitude of the entire genus (c. 43.5°N) at the Russian-Georgian border in Abkhazia.

1-2. Upper surface and underside of an entire leaf (hrs)

3-4. Upper surface and underside of a leaflet (hrs)

5-6. Closer view of the upper surface and underside of a rachis (hrs)

7-8. Closer view of the upper surface and underside of a leaflet margin (hrs)

9-10. Closer view of the upper surface and underside of a leaflet (hrs)

11. Flowering branch of *P. fraxinifolia*. Thick, green male catkins. Red female catkins with less dense flowers (ek)

12. Leaf of *P. fraxinifolia*. Xanbulan, Talysh Mountains, Azerbaijan (eg)


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1. Male flowers. Botanic Garden Lyon, France (ek)

2. Female flowers. Botanic Garden Lyon, France (ek)

3. Naked terminal bud. Arboretum Aubonne, Switzerland (ek)

4. Fruits. Talysh Mountains, Azerbaijan (ek)

5. Fruiting spikes. Talysh Mountains, Azerbaijan (eg)

Drawing by Martina Löwy

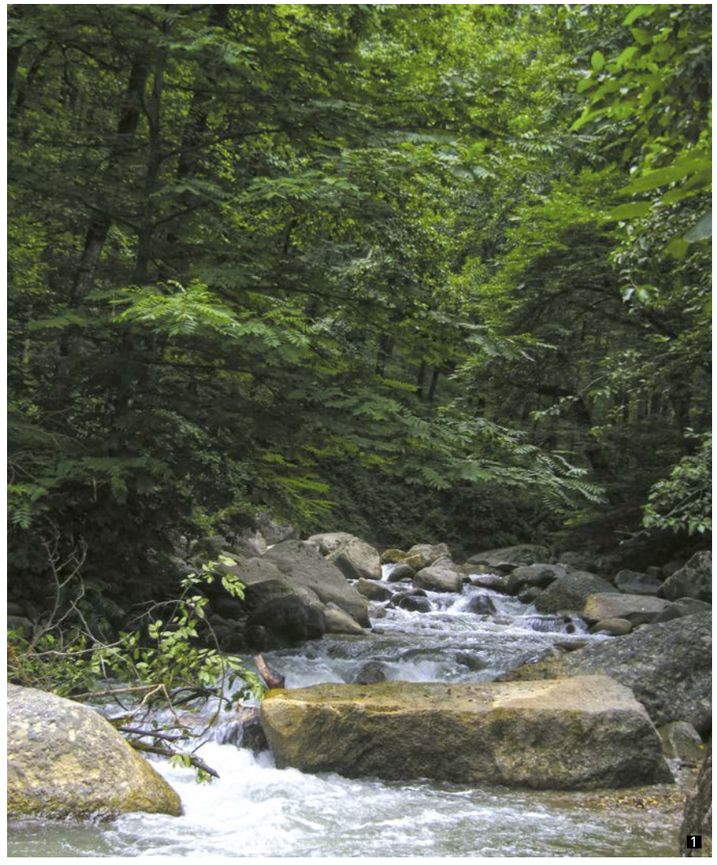
Morphology of *P. fraxinifolia*:
a – branch with leaves and fruiting spike, b – male (left) and female (right) catkins,
c – female flowers, d – male flowers, e – naked terminal buds.

ECOLOGY

It is a fast-growing tree restricted to the vicinity of rivers and only rarely expanding to alluvial plains. *Pterocarya fraxinifolia* prefers low altitudes (0 - 800 m a.s.l), although isolated specimens sometimes grow in the Caucasus and Elburz Mountains at higher altitudes (1,200 m a.s.l.). The isolated population in the Zagros Mountains grows at an altitude of 1,730 m a.s.l. It has a predilection for wet conditions and deep, moist soils, and can tolerate flooding for short periods through the year. It is often found with typical riparian trees (e.g., *Alnus subcordata, A. glutinosa* subsp. *barbata, Ficus carica/hyrcana, Fraxinus excelsior*) or with trees typically found in a mixed deciduous forest (e.g., *Acer campestre/orthocampestre, Albizia julibrissin, Populus caspica*).

THREATS

The species is under severe threat from loss of habitat as low-altitude, riparian forests are often cut or converted into grassland or monospecific forest stands. Logging and cutting by local people continue to pose problems, even in protected areas. The future of the species will also depend on the transformation of low-altitude watercourses and river banks for hydroelectric power stations. The relatively wide distribution of the species masks the risks and threats it faces in its natural habitats. According to the IUCN Red List, the species is classified as Least Concern (LC) but this must ultimately be reviewed since the populations are highly fragmented and declining throughout their entire range.



1. Population of *P. fraxinifolia* along the Nav River. Asalem, 420 m a.s.l., Western Hyrcanian Forest, Iran (mpn)

2. Heavy snowfall in the Hyrcanian Forest. Population of *Populus caspica* and *P. fraxinifolia*. Iran (hy)

3-4. *Ficus carica/hyrcana* (Moraceae). Xanbulan, Talysh Mountains, Azerbaijan (ek)

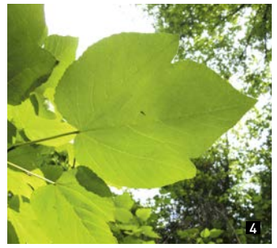
5-6. *Albizia julibrissin* (Fabeceae). Flowers (Botanic Garden of the University of Fribourg, Switzerland, eg) and leaves (Xanbulan, Talysh Mountains, Azerbaijan, ek)

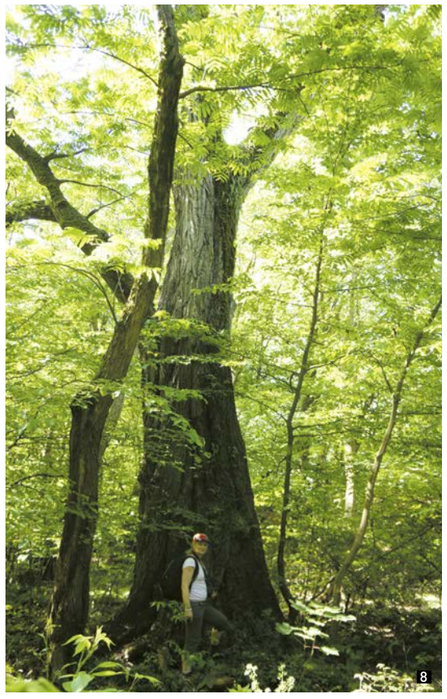
7. Logged *P. fraxinifolia* trees. Areshi River, Eastern Georgia (nd)

8. E. Kozlowski in front of an old *P. fraxinifolia* tree. Asagi Duzen Nature Reserve – one of the last remnants of lowland forests in the Hyrcanian National Park, Azerbaijan (gk)

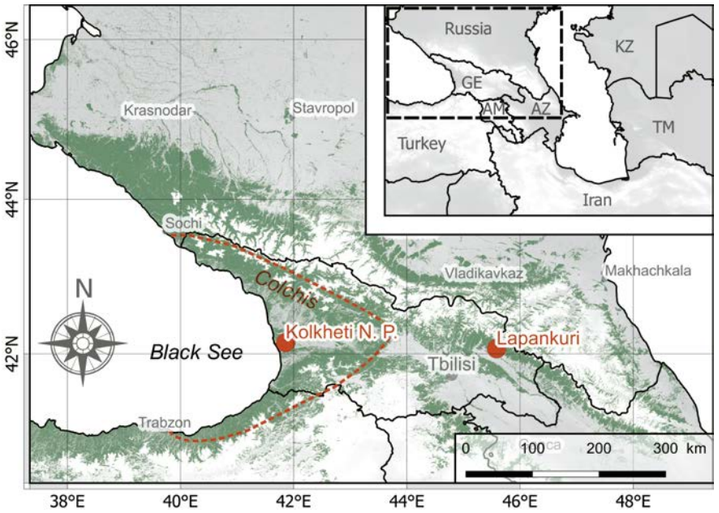
9. *Alnus subcordata* (Betulaceae). Xanbulan, Talysh Mountains, Azerbaijan (ek)

10. Pastures surrounding *P. fraxinifolia* forests along the Pichori River, Western Georgia (sb)





GEORGIA



PTEROCARYA FRAXINIFOLIA IN THE COLCHIS AND GREAT CAUCASUS REGIONS

Georgia has the highest number of *P. fraxinifolia* in the Transcaucasia region. The focal points of the Caucasian wingnut are the **Colchis** in Western Georgia and adjacent areas. Colchis is characterised by a warm, humid climate, promoting the development of lush forest vegetation. It is also one of the main refugia of relict trees in this part of the Western Eurasia region. In Eastern Georgia, which has a more arid, continental climate, *P. fraxinifolia* grows exclusively on the southern slopes and plains in the vicinity of the **Great Caucasus** mountain range.

KOLKHETI NATIONAL PARK (WESTERN GEORGIA)

Created in 1999, the Kolkheti National Park lies in the centre of the Colchis, on the shores of the Black Sea, and hosts several habitats, namely wetlands, forests, mires and sand dunes. Kolkheti lowland forests, which are unique to the entire region, shelter many relict and endemic trees (e.g., *Quercus hartwissiana, Quercus robur* subsp. *imeretina, Buxus colchica, Pterocarya fraxinifolia*). Only a few remaining Kolkheti lowland forests have stayed relatively undisturbed with a rich forest portfolio. In the riparian forests, *Alnus glutinosa* subsp. *barbata* and *Pterocarya fraxinifolia* are the two most dominant species in the upper layers of vegetation with some isolated specimens of *Quercus hartwissiana* and *Ficus carica*, whereas numerous shrubs and lianas form a dense understory (*Cornus sanguinea, Acer campestre, Smilax excelsa*).

THREATS

The Kolkheti National Park faces many challenges, such as the impact of mass tourism which affects coastal areas, or the socio-economic conditions of the indigenous population. The human pressure and impact on river ecosystems are very significant since many small villages nestle in the vicinity of the Kolkheti NP. The natural habitats provide extremely important ecosystem services for local people (e.g. pasture, charcoal, food, drinking water).

1. Mass tourism. Black Sea beach next to Batumi (sb)

2. Small village within the Kolkheti National Park (sb)

3. Undisturbed shores with *P. fraxinifolia* along the Pichori River (sb)

4. Plantlets of *P. fraxinifolia* (gk)

5. Nursery with the most symbolic trees of the Kolkheti National Park, established in 2016 by the Batumi Shota Rustaveli State University (gk)

6. The same *ex situ* culture in 2017, with plantlets ready for forest renaturation (im)

Furthermore, many Kolkheti lowland areas are already highly fragmented and degraded, especially along the riverbanks within the national park. In many places, pure *Alnus* stands can be observed with very little plant diversity. In the vicinity of the Pichori River, for example, *Alnus glutinosa* subsp. *barbata* dominates over a large proportion of the forests. It forms dense monospecific stands with evidence of very few species. Moreover, the tree layer looks even-aged, indicating that light conditions in the understory are unsuitable for regeneration or that a sudden event (probably floods or repeated short-rotation clearcutting) occurred in the past and affected a large area.

The spread of invasive alien species near and within the Kolkheti NP poses another very serious issue. The precious riparian ecosystem warrants urgent action and special attention. On the banks of the Pichori River, invasive species have already modified completely the general physiognomy of the riparian vegetation. *Amorpha fructicosa*, a shrub originating from the USA, is the main threat to vegetation along the river banks. This species, which belongs to the Fabaceae family, severely modifies soil fertility by fixing nitrogen in the soil. It also occupies the river banks instead of several native woody species of high conservation value such as *Pterocarya fraxinifolia* and *Quercus hartwissiana*. The situation further inland also gives cause for concern as the ground is sometimes completely covered by another invasive alien species, namely *Polygonum thunbergii*, which proliferates unrestrained in the understory. In addition to the very thick, natural canopy, it can hamper seed germination and the seedling establishment of tree species to considerable extent, thus preventing potential forest regeneration. Moreover, the high proportion of other invasive species on the periphery of the Kolkheti NP (*Gleditsia triacanthos* and *Ambrosia artemisiifolia*) must also be mentioned. These will continue to advance right at the heart of the protected area if nothing is done to halt their progression.

PROPOSED MEASURES AND SOLUTIONS:

1) Issues regarding invasive species: Inventory and mapping of the current status of invasive species within the Kolkheti NP as well as in the direct vicinity. An Action Plan must be drawn up to counteract invasive species throughout the entire area.

2) Forest renaturation: Establishment of an *ex situ* culture with the most symbolic native trees (e.g., *Pterocarya fraxinifolia, Quercus hartwissiana, Ficus carica*) for renaturation purposes.

3) Involvement of local people: The Kolkheti NP Management Plan should include a global strategy to share the resources and benefits of the national park with local stakeholders.

1. Kolkheti National Park next to Poti village (sb)

2. Invasive alien species *Polygonum thunbergii* (Polygonaceae) in monoculture of *Alnus glutinosa* subsp. *barbata* (Betulaceae) (sb)

3. *Amorpha fruticosa* (Fabaceae), another invasive alien species, dominating the shores of the Pichori River (sb)

4. Close to the riverbanks, many *P. fraxinifolia* trees display dried branches. The cause and severity of this phenomenon are not known (gk)

THE UNIQUE *P. FRAXINIFOLIA* STAND IN LAPANKURI (EASTERN GEORGIA)

In 2015, a new stand of *P. fraxinifolia* was discovered in the eastern region of the Great Caucasus mountain range, near the village of Lapankuri. This stand is unique since the Caucasian wingnut grows here, not only along the main river (Lopota), but also in a broad strip up to 40 m away from the riverbed. Many other large, old relict trees can also be found alongside *P. fraxinifolia* in this area. Conservation of this forest should therefore be a priority.

The *P. fraxinifolia* stand in Lapankuri is vital and comprises trees of different ages, with young and old trees still in evidence here. Particular attention should be paid to the appearance of very large trees which is not replicated with any of the other tree populations known to exist in the eastern Great Caucasus region. The successful reproduction and good health of the Lapankuri population is confirmed by its ability to largely produce seeds and by the presence of seedlings. The Caucasian wingnut generates a self-sustaining population in this area.

1. Lapankuri village (sb)

2. View of the Lopota River with the *P. fraxinifolia* population (sb)

3. Maize field bordering the *P. fraxinifolia* riparian forest (sb)

PROPOSED MEASURES AND SOLUTIONS:

1) Mapping of the *P. fraxinifolia* population and an inventory of all large fruiting individual specimens as well as an inventory of all other rare and relict species.

2) Establishment of a *National Nature Monument* to incorporate the entire stand of *P. fraxinifolia*. The unique Lapankuri stand requires special protection status in order to prevent further damage, especially via logging and extension of arable fields and pastures. The long-term future of this stand is not guaranteed at the present time as a large-scale hydropower project has been earmarked for this region.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STRUCTURE AND COMPOSITION OF THE LAPANKURI FOREST:

The upper layer is dominated by *P. fraxinifolia* and to lesser extent by *Carpinus betulus*, often covered with climbing *Hedera pastuchovii*. The understory is species-rich and well developed with interesting woody species such as *Diospyros lotus*, *Alnus glutinosa* subsp. *barbata* and *Quercus pedunculiflora* (closely related to *Q. robur*). Close to the Lopota River, willows (*Salix alba*, *S. purpurea*) and poplar species (*Populus alba*) are restricted to exposed places. Other taxa such as *Acer orthocampestre*, *Cornus mas*, *Morus nigra*, *Mespilus germanica*, *Crataegus pentagyna* and *Juglans regia* are also found in this forest.

1. Dense and species-rich Lapankuri riparian forest (sb)

2. *Mespilus germanica* (Rosaceae) (ek)

3. *Diospyros lotus* (Ebenaceae) (ek)

4. *Alnus glutinosa* subsp. *barbata* (Betulaceae) (ek)

5. *Hedera pastuchovii* (Araliaceae) (eg)


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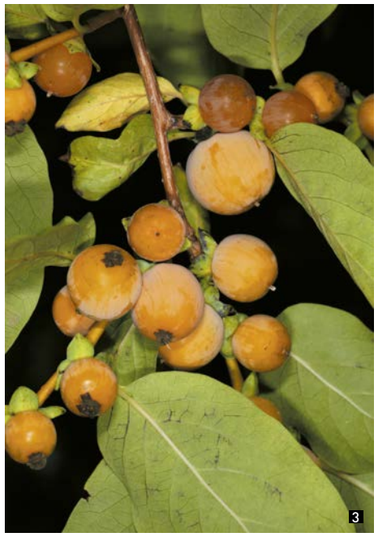
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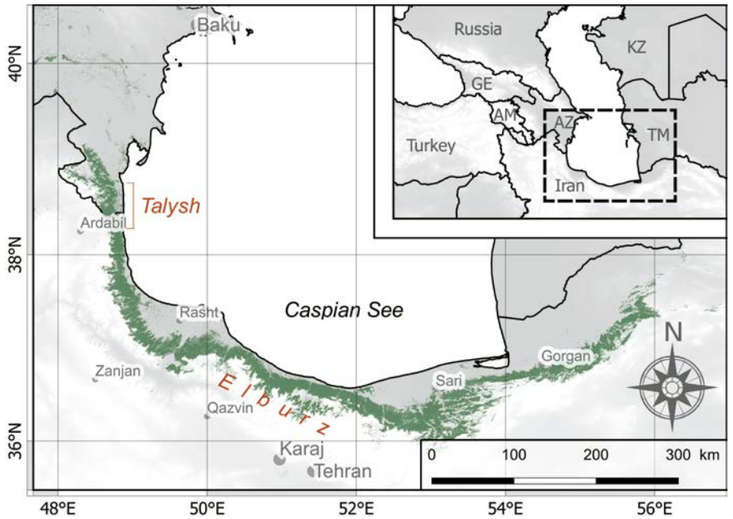
Drawing by Norbert Frotzler

AZERBAIJAN & IRAN



THE HYRCANIAN FOREST: A HOTSPOT OF RELICT TREES

The **Hyrcanian Forest** follows the south-western and southern coasts of the Caspian Sea. It forms a narrow, arching forest region extending southwards from South-Eastern Azerbaijan and subsequently covering eight lines of longitude towards the east as far as the Golestan Province of Iran. Since the original coastal plain forests were almost completely cleared and intensively farmed by humans, the modern-day range of this unique forest community is limited to the north-eastern slopes of the **Talysh Mountains** (Azerbaijan) and the northern slopes of the **Elburz Mountains** (Iran).

A FOREST COMMUNITY FROM THE PAST

Fossil records confirm that the Hyrcanian Forest is a descendant of forest communities that were widespread throughout the Northern Hemisphere during the Miocene period (between 23 and 5.3 million years ago) but whose range significantly retreated during the climate change that occurred during the Pleistocene epoch. The Hyrcanian Forest owes its survival to the special topography of the Southern Caspian region and the relatively mild and humid regional climate it enjoyed even during the ice age. This unique diversity gives the Hyrcanian Forest global significance and justifies every effort to appreciate and maintain it.

Some of the undisputed highlights of these areas include the following symbolic relic trees: the Cappadocian and the velvet maples (*Acer laetum, A. velutinum*); Persian silk tree (*Albizia julibrissin*); Caucasian alder (*Alnus subcordata*); Caucasian persimmon (*Diospyros lotus*); Caspian locust (*Gleditsia caspica*); Persian ironwood (*Parrotia persica*); chestnut-leaved oak (*Quercus castaneifolia*) and the Caucasian zelkova (*Zelkova carpinifolia*).

1. Today, the coastal plain forests of the Hyrcanian region are almost completely cleared and replaced by urban or agricultural areas. Chalous, Iran (er)

2. Intact riparian forests are mainly found at higher altitudes. Population of *P. fraxinifolia* along the Lavanvil River, 300 m a.s.l., Iran (ad)

Lush, species-rich Hyrcanian Forest close to Nowshahr, 700-1,000 m a.s.l., Iran (er)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1. Forests with *Parrotia persica* (Hamamelidaceae) in the autumn. Talysh Mountains, Azerbaijan (sb)

2. Trunk and roots of *Parrotia persica* in the Hyrcanian National Park, Talysh Mountains, Azerbaijan (gk)

3. Leaves of *Parrotia persica* (gk)

4. *Zelkova carpinifolia* (Ulmaceae). Lerik, Talysh Mountains, Azerbaijan (eg)

5. *Zelkova carpinifolia* (centre) and *Quercus castaneifolia* (Fagaceae). Talysh Mountains, Azerbaijan (ek)

6. Old *P. fraxinifolia* tree. Apo, Talysh Mountains Azerbaijan (ek)

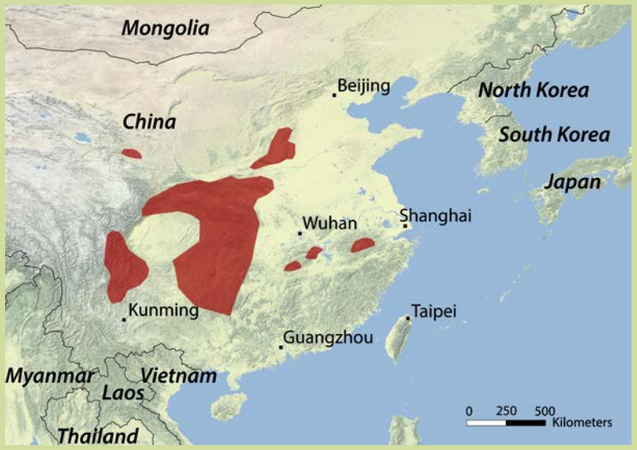
7. *Pterocarya fraxinifolia* fruits. Nav River by Asalem, Iran (mpn)

8-9. *Acer velutinum* (Sapindaceae). Xanbulan, Talysh Mountains, Azerbaijan (eg, ek)

Pterocarya hupehensis Skan (1899)

Hubei wingnut, 湖北枫杨 hu bei feng yan (China)

Pterocarya hupehensis is endemic to Central China. Interestingly, genetic studies indicate that it is probably the closest relative of the Transcaucasian *P. fraxinifolia*. Furthermore, European *Pterocarya* fossils share strong similarities with this taxon, suggesting that the species was once widely distributed across Eurasia.

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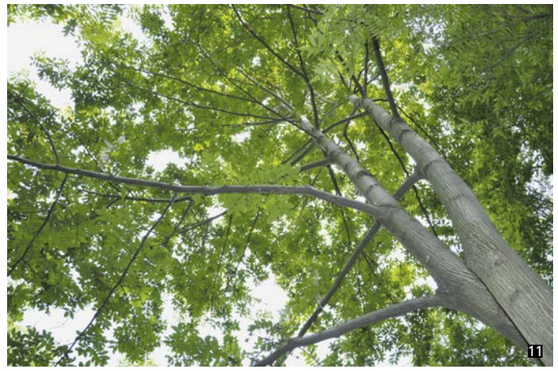
HABIT

Trees grow to a height of 20 m. Naked terminal buds. Leaves are odd-pinnate, 12-30 cm long, with glabrous petioles (5-7 cm). Rachis wingless and glabrous. Leaflets 3-15, with petiolules up to 2 mm long. Leaflet blades are long elliptic to ovate-elliptic, abaxially glabrous except for hairs along the mid-vein (in dense clusters in axils, and scattered along secondary veins). Fruiting spike 30-45 cm. Nutlets sub-globose, slightly ribbed, 7-8 mm in diameter, with broad, elliptic-ovate wings (1-1.5 × 1.2-1.5 cm).

DISTRIBUTION

Pterocarya hupehensis is endemic to China, occurring in Northern Guizhou, Western Sichuan, Western Hubei, South Shaanxi, South Gansu and South Western Henan. There is also evidence of sporadic distribution in the mountainous regions of Eastern China. However, further investigations and confirmation are required in this area. The distribution of this species overlaps with *P. stenoptera* and *P. macroptera* in a number of locations.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1-2. Upper surface and underside of an entire leaf (eg)

3-4. Upper surface and underside of a leaflet (eg)

5-6. Closer view of the upper surface and underside of a rachis (eg)

7-8. Closer view of the upper surface and underside of a leaflet margin (eg)

9-10. Closer view of the upper surface and underside of a leaflet (eg)

11. *Pterocarya hupehensis* tree. Huang Shi An, Henan, China (ygs)

12. Trunks of *P. hupehensis*. Laoyang Valley, Gansu, China (ygs)

13. Naked buds of *P. hupehensis*. Huang Shi An, Henan, China (ygs)

14-15. Upper surface and underside of an entire leaf. Huang Shi An, Henan, China (ygs)

16. Fruiting individual of *P. hupehensis*. Cao Hu Yu, Henan, China (ygs)

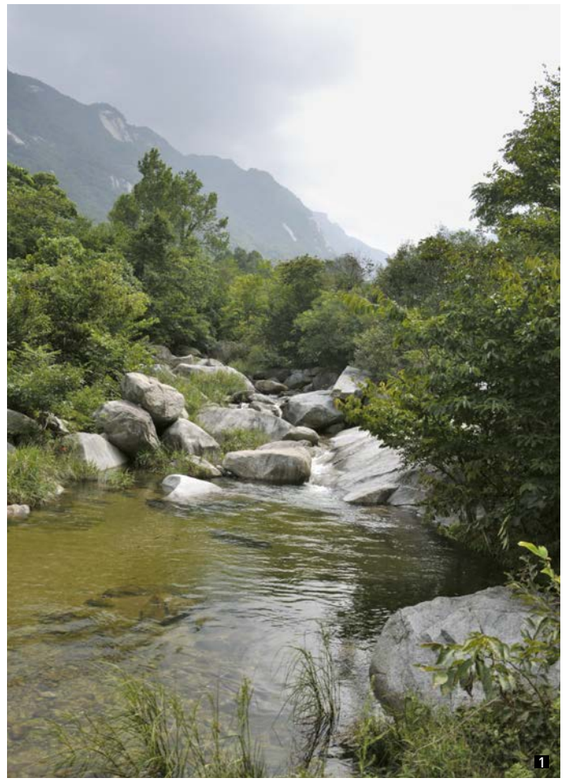
17-19. Fruiting spikes of *P. hupehensis*. Laoyang Valley, Gansu (17, 19) and Hekou village, Henan (18), China (ygs)

ECOLOGY

The Hubei wingnut mainly grows in the mid-sections of rivers, in mountainous areas between 700 and 2,000 m a.s.l. The species needs relatively high soil moisture levels and a humid microclimate. It therefore seldom grows further than 50 m away from the riverbank. Many other relict trees grow alongside *P. hupehensis*, such as *Zelkova sinica*, *Davidia involucrata*, *Litsea auriculata* and *Diospyros lotus*, together with other Juglandaceae (e.g., *Cyclocarya paliurus*, *Platycarya strobilacea* and *Juglans cathayensis*). Additional concomitant species include numerous Fagaceae such as *Castanea henryi, Castanopsis carlesii, Quercus fabri, Q. serrata, Q. dolicholepis* and *Q. glauca*, as well as *Aesculus wilsonii, Actinidia chinensis, Dalbergia dyeriana, Rhus vernicifera, Acer griseum, A. henryi* and *Cephalotaxus sinensis*.

THREATS

Based on recent investigations, globally there are no more than 100 populations across its distribution area. The majority of these populations are formed by less than 50 individual trees, with very poor seedling production. Furthermore, in many regions, *P. hupehensis* populations have been destroyed by the planting of economically viable tree crops and road construction. The species merits greater conservation efforts as it faces multiple threats.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1-3. Habitat of *P. hupehensis*. Youlu valley, Henan (1, 2) and Laoyang valley, Gansu (3), China (ygs)

4. *Quercus serrata* (Fagaceae). Laojiangba, Gansu, China (ygs)

5. *Actinidia chinensis* (Actinidiaceae). Youlu valley, Henan, China (ygs)

6. *Dalbergia dyeriana* (Fabaceae). Laojiangba, Gansu, China (ygs)

7. *Davidia involucrata* (Nyssaceae). Botanic Garden of the University of Fribourg, Switzerland (eg)

8. *Lycoris aurea* (Liliaceae). Laojiangba, Gansu, China (ygs)

9-10. *Zelkova sinica* (Ulmaceae). Henan, China (ygs)


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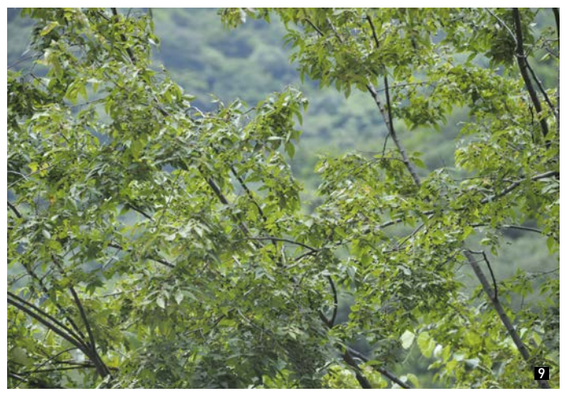
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Pterocarya stenoptera C.DC. (1862)

Chinese wingnut, 枫杨 feng yan (China)

The species has the largest natural distribution area of all members of the genus *Pterocarya*. Additionally, the Chinese wingnut grows rapidly, forming large crowns, and is therefore widely planted as a shade tree in Eastern Asia. In many regions, it is cultivated for wood, and its bark and leaves are used in traditional Chinese medicine.


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HABIT

Trees grow to a height of 30 m and diameter of 2 m. Naked terminal buds. The bark of *P. stenoptera* is smooth on young trees, developing deep slits with age. Leaves are even-pinnate, 8-16(-25) cm, with petioles of 2-6.5 cm. Rachis often winged (rarely only ridged or sulcate). Fruiting spike very long (20-45 cm). Nutlets long ellipsoid, 6-7 mm in diameter, with linear wings (1.2-2.5 × 3-6 mm).

DISTRIBUTION

Pterocarya stenoptera is the most widespread species of the genus. Its distribution covers almost all of South-Eastern China and extends to Taiwan, North-Eastern Vietnam and potentially also to North Korea. The highest latitude is reached by this species at c. 42°N (North of Beijing and Shenyang). The southernmost populations grow in Yunnan and North-Eastern Vietnam. Its distribution area overlaps in a number of locations with *P. hupehensis* and *P. macroptera*. However, the species occupies different niches (*P. stenoptera* generally grows downstream of rivers, at lower elevations than the other *Pterocarya* species).

1-2. Upper surface and underside of an entire leaf (hrs)

3-4. Upper surface and underside of a leaflet (hrs)

5-6. Closer view of the upper surface and underside of a rachis (hrs)

7-8. Closer view of the upper surface and underside of a leaflet margin (hrs)

9-10. Closer view of the upper surface and underside of a leaflet (hrs)

11. *Pterocarya stenoptera* tree. Qinling, Shaanxi, China (ygs)

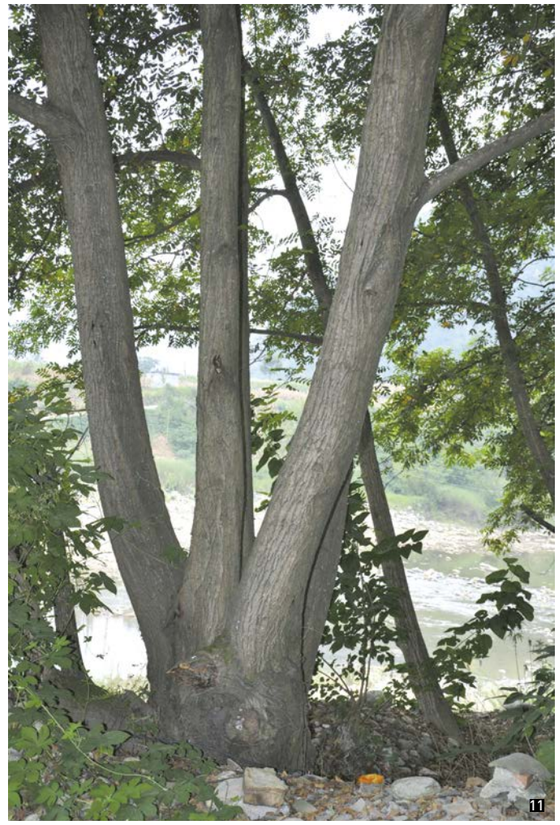
12. Bark of *P. stenoptera*. Royal Botanic Garden Edinburgh, UK (ek)

13. Leaves of *P. stenoptera*. Arboretum Aubonne, Switzerland (ek)

14-15. Closer view of the upper surface and underside of a *P. stenoptera* leaf, with clearly visible winged rachis. Arboretum Aubonne (14), Switzerland and Botanic Garden Tokyo (15), Japan (ek)

16. Leaves of *P. stenoptera*. Jialing, Gansu, China (ygs)

17. Fruiting spikes of *P. stenoptera*. Wuxingcuan, Guizhou, China (sb)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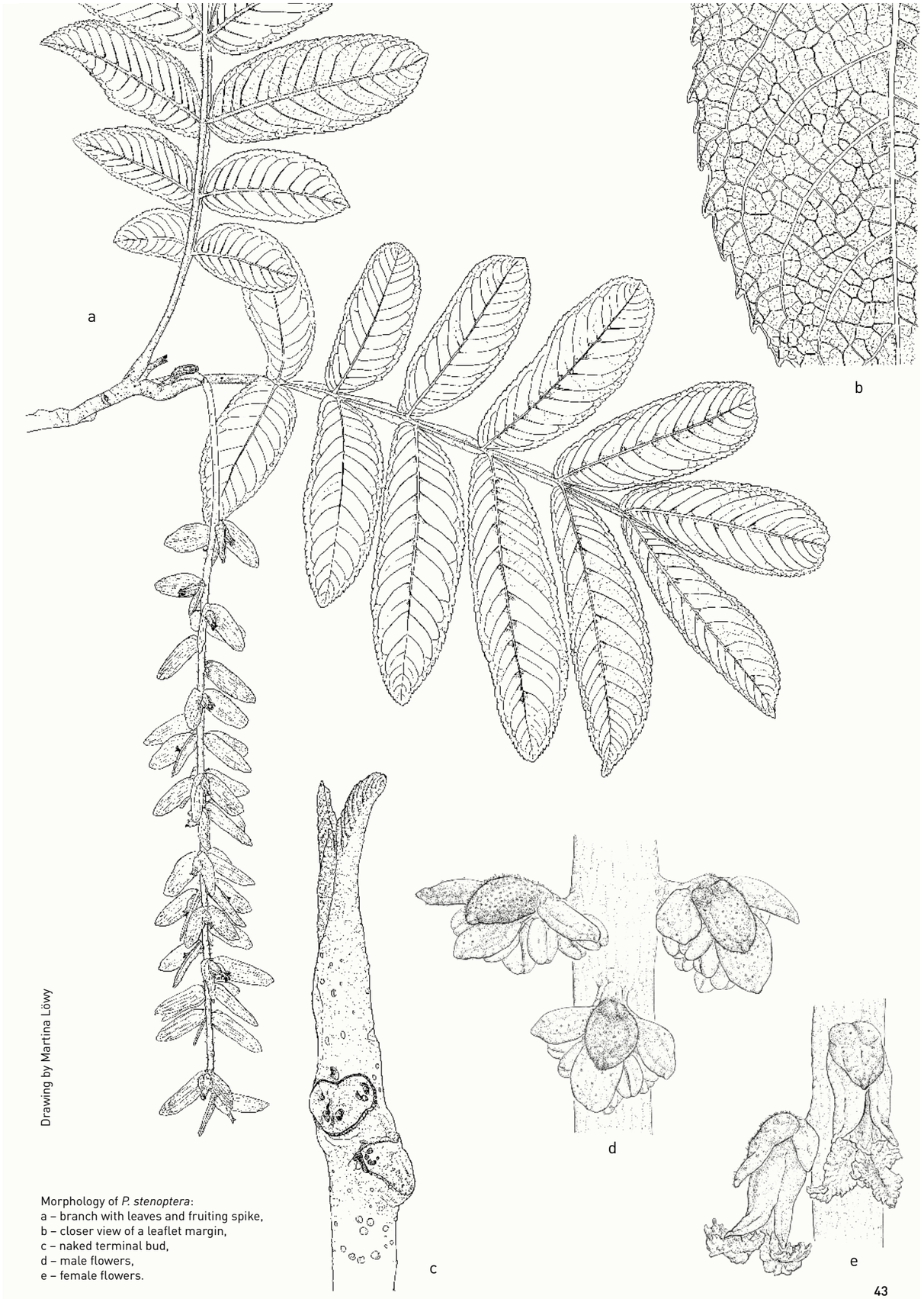
1. Female flowering catkins of *P. stenoptera*. Royal Botanic Garden Edinburg, UK (ek)

2. Fruiting spikes of *P. stenoptera*. Arboretum Aubonne, Switzerland (ek)

3. Winged fruits of *P. stenoptera*. Arboretum Aubonne, Switzerland (ek)

4. Fruiting individual of *P. stenoptera*. Wuxingcuan, Guizhou, China (sb)



Drawing by Martina Löwy

Morphology of *P. stenoptera*:
a – branch with leaves and fruiting spike,
b – closer view of a leaflet margin,
c – naked terminal bud,
d – male flowers,
e – female flowers.

ECOLOGY

The Chinese wingnut favours warm, temperate and subtropical zones with deep, fertile, moist soils. Growing mainly in valleys and along rivers below 1,500 m a.s.l., *P. stenoptera* can withstand flooding by forming monospecific stands. However, the species can also grow in mixed forests. Numerous trees of the Fagaceae family co-exist across its large distribution area, including *Castanopsis carlesii, Quercus dentata, Q. aliena* and *Q. glauca* as well as *Celtis tetrandra, Trema dielsiana, Ficus erecta, Cyclocarya paliurus, Zelkova sinica* and *Z. schneideriana*.

THREATS

As for other riparian trees, the main threats reside in changes in land use and the transformation of river-banks for agricultural or urban purposes. However, *P. stenoptera* is capable of clonal propagation. Furthermore, seed dispersal is generally very effective along rivers, which provide good conditions for seed germination and seedling establishment. Due to these ecological features and its large distribution area, the species is not under threat on a global scale.

1. Small group of *P. stenoptera* in Dong Jia Ba village, Shaanxi, China (ygs)

2. Sacred *P. stenoptera* tree in Dong Jia Ba village, Shaanxi, China (ygs)

3. Population of *P. stenoptera* growing in a cultural landscape along the Kanshang River, Guizhou, China (sb)

4. Natural *P. stenoptera* population. Huang Shi An, Henan, China (ygs)

5. Habitat of *P. stenoptera*. Kangxian, Gansu, China (ygs)

6. *Ficus erecta* (Moraceae) (ek)

7. *Quercus aliena* (Fagaceae). Huang Shan, Anhui, China (ek)

8. Population of *P. stenoptera*. Youlu valley, Henan, China (ygs)

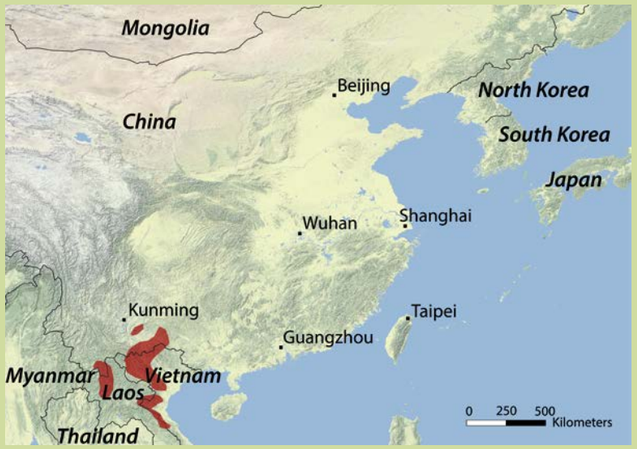
9. *Quercus dentata* (Fagaceae). Huang Shan, Anhui, China (ek)

10. *Zelkova schneideriana* (Ulmaceae). Lu Shan, Jiangxi, China (ek)

Pterocarya tonkinensis (Franchet) Dode (1929)

Tonkin wingnut, 越南枫杨 yue nan feng yan (China)

The Tonkin wingnut is the most tropical species of the genus but, at the same time, it has the smallest distribution area between Yunnan in China, Vietnam and Laos. Ecologically and morphologically, the taxon is very similar to *P. stenoptera*, and should perhaps be merged within it or treated as its subspecies.

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HABIT

Trees grow to a height of 30 m. Naked terminal buds. Leaves are even-pinnate, rarely odd-pinnate, 20 cm long, with glabrescent petioles (4.5-7 cm). Rachis wingless, rarely ridged or sulcate, pubescent or glabrescent. The leaflets 6-14, abaxially glabrous, except for hairs along the mid-vein and secondary veins. Their base is oblique, rounded or broadly cuneate, apex acute to acuminate. Fruiting spikes 13-30 cm long. Nutlets rhomboid, 6-7 mm in diameter and with linear wings (1-1.7 × 2-6 mm).

DISTRIBUTION

The Tonkin wingnut is found in Southern Yunnan, Northern and Central Vietnam and Laos. Therefore, most of the known populations do not grow in the historical province of Tonkin, in North Eastern Vietnam, from which the species takes its name. The species reaches the lowest latitude of all the *Pterocarya* species at c. 17°N in Laos (in Nakai-Nam Theun National Biodiversity Conservation Area).

1-2. Upper surface and underside of an entire leaf (hrs)

3-4. Upper surface and underside of a leaflet (hrs)

5-6. Closer view of the upper surface and underside of a rachis (hrs)

7-8. Closer view of the upper surface and underside of a leaflet margin (hrs)

9-10. Closer view of the upper surface and underside of a leaflet (hrs)

11. *Pterocarya tonkinensis* tree. Cuc Phuong National Park, Vietnam (sb)

12. Leaves of *P. tonkinensis*. Cuc Phuong National Park, Vietnam (sb)

13. Fruiting individual of *P. tonkinensis*. Cuc Phuong National Park, Vietnam (sb)

14. Naked buds of *P. tonkinensis*. Pu Mat National Park, Vietnam (hvs)

15. Male catkin of *P. tonkinensis*. Pu Mat National Park, Vietnam (hvs)

16. Fruiting individual of *P. tonkinensis*. Pu Mat National Park, Vietnam (hvs)

17-18. Fruiting spikes of *P. tonkinensis*. Cuc Phuong National Park (17, sb) and Pu Mat National Park (18, hvs), Vietnam


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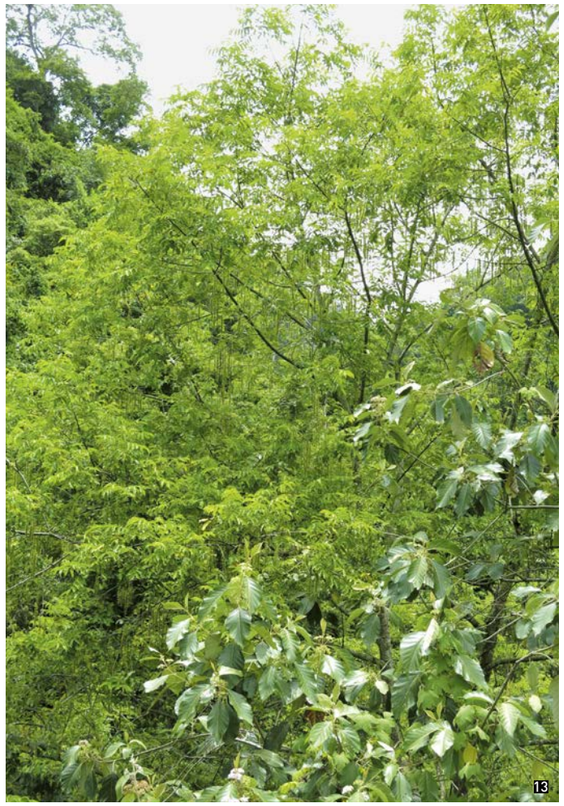
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ECOLOGY

This deciduous tree is an element of the tropical monsoon forests, growing along small to medium-sized riverbanks, mainly in lowland areas between 100 and 700 m a.s.l. (but ascending sometimes to 1,200 m a.s.l.). *Pterocarya tonkinensis* is a heliophilous, fast-growing and flood-tolerant species. Well adapted to riparian habitats on river flood plains, it often forms monodominant communities. It is occasionally accompanied by *Alfaropsis roxburghiana, Ficus hispida, Pandanus furcatus, Celtis timorensis* or *Acronychia pedunculata*.

THREATS

Pterocarya tonkinensis populations are rapidly disappearing due to the destruction of river-banks and transformations for human activities (agriculture, urbanisation, etc.). Additionally, in many regions, *P. tonkinensis* is an important timber tree for local communities. Moreover, natural regeneration via seedlings is rarely observed and its communities develop into mixed forests. The species is therefore the most threatened taxon of the genus.

1-2. Natural populations of *P. tonkinensis* growing along rivers and streams in the Cuc Phuong National Park, Vietnam (sb)

3. *Ficus hispida* (Moraceae). Cuc Phuong National Park, Vietnam (sb)

4. Population of *P. tonkinensis* growing along streams, surrounded by agricultural land. Cuc Phuong National Park, Vietnam (sb)

5. *Callicarpa tomentosa* (Lamiaceae). Cuc Phuong National Park, Vietnam (sb)

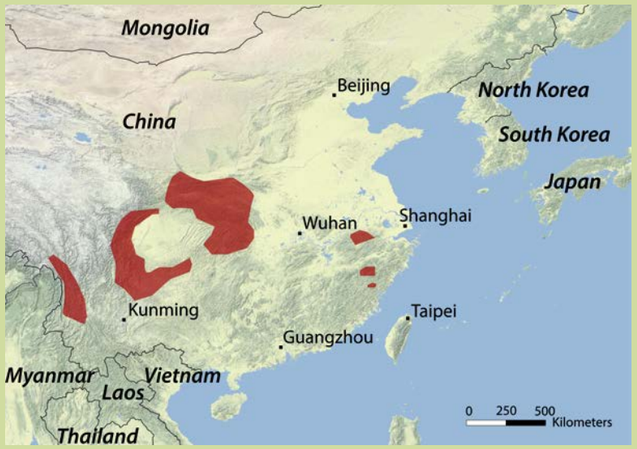
6. *Celtis timorensis* (Cannabaceae). Hong Kong, China (jz)

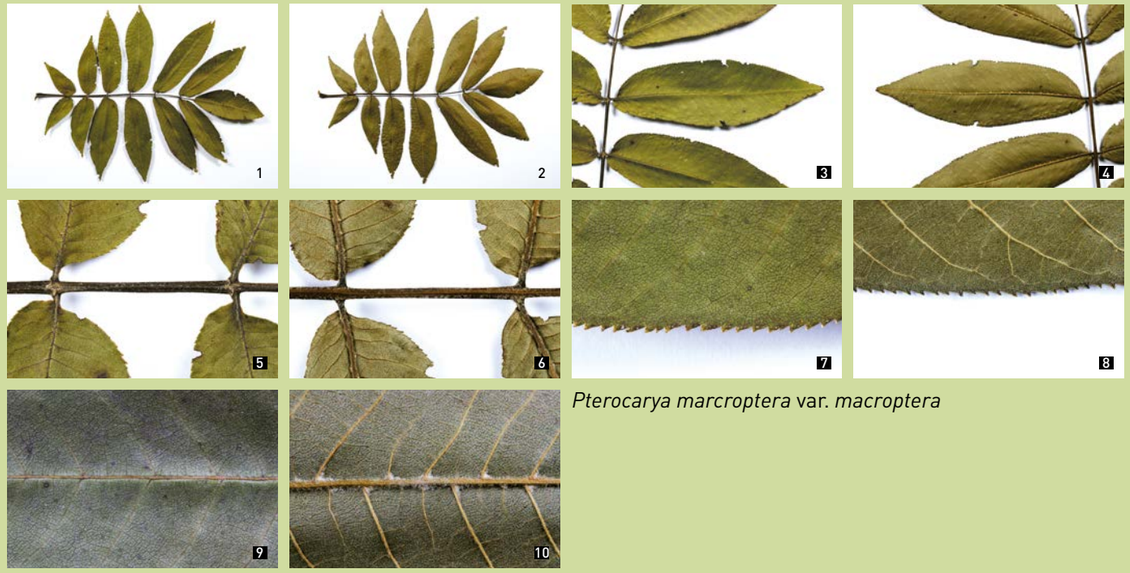
7-8. *Pandanus urophyllus* (Pandanaceae). Ma Li Po, Yunnan, China (xxz)

Pterocarya macroptera Batalin (1893)

Large-winged wingnut, 甘肃枫杨 gan su feng yan (China)

Endemic to China, this species is the closest relative of the Japanese *P. rhoifolia*. Unlike other *Pterocarya* taxa, both species have terminal buds covered with scales. Morphologically, the species differs considerably and traditionally comprises three varieties (var. *macroptera*, var. *delavayi* and var. *insignis*). Recent genetic studies suggest that some of these varieties might merit species status.





Pterocarya marcroptera var. *macroptera*

HABIT

Trees grow to a height of 15-30 m. Terminal buds with caducous scales. Leaves are odd-pinnate, 23-45 cm long, with tomentose petioles (2-13 cm). Rachis is wingless and also tomentose. Leaflets 5-13, with terminal petiolule 1-2.5 cm long. Fruiting spike 45-70 cm, with glabrous or tometose axis. Nutlets 7-9 mm in diameter, with orbicular-ovate to elliptic-rhomboid wings (1-3 × 1-2.5 cm).

DISTRIBUTION

The large-winged wingnut grows in South Eastern Gansu, West Hubei, South Shaanxi, West and South Western Sichuan, North Western Yunnan and the Zhejiang province. The three varieties differ somewhat in distribution, with var. *macroptera* predominating in the North, var. *insignis* growing further South and East, and var. *delavayi* in Western China.

1-2. Upper surface and underside of an entire leaf (eg)

3-4. Upper surface and underside of a leaflet (eg)

5-6. Closer view of the upper surface and underside of a rachis (eg)

7-8. Closer view of the upper surface and underside of a leaflet margin (eg)

9-10. Closer view of the upper surface and underside of a leaflet (eg)

11-12. Tree crown and bark of *P. macroptera* var. *delavayi*. Royal Botanic Garden Edinburgh, UK (ek)

13. Bud scales of *P. macroptera* var. *insignis*. Jiu Long Shan Nature Reserve, Zhejiang, China (ygs)

14. Bud scales of *P. macroptera* var. *macroptera*. Huang Bai Yun, Shaanxi, China (ygs)

15-16. Upper surface and underside of a leaf of *P. macroptera* var. *insignis*. Hua Long Shan Nature Reserve, Shaanxi, China (ygs)

17-18. Male catkin of *P. macroptera* var. *macroptera*. Royal Botanic Garden Edinburgh, UK (ek)

19. Fruits of *P. macroptera* var. *macroptera*. Dian Jiang Tai, Shaanxi, China (ygs)

ECOLOGY

Pterocarya macroptera tends to grow as single trees in temperate, species-rich forests along river valleys, mountain streams or on slopes. They seldom form small pure stands on flat scours and in wetter habitats. The species reaches the highest elevations compared to other species of the *Pterocarya* genus, growing on mountains at 1,100 to 3,500 m a.s.l. Thus, forests with *P. macroptera* range from sub-tropical at lower altitudes to temperate at the snow line. Their leaves change to dark yellow earlier than those of *P. hupehensis*, which often grows on lower elevations along the same valley. *Pterocarya macroptera* is accompanied by several species of *Quercus* (e.g., *Q. glauca, Q. dolicholepis, Q. spinosa*), *Cercidiphyllum japonicum, Tetracentron sinense, Davidia involucrata* and several representatives of the temperate tree genera, such as *Juglans, Zelkova* and *Carpinus*.

THREATS

Populations of *P. macroptera* growing in deep mountain valleys and especially at higher elevations, are still well preserved. However, these populations are widely scattered with each comprising no more than 50 individual trees. Furthermore, the plants mainly reproduce through cloning and the fruits are often sterile. According to recent investigations, there are no more than 120 populations of *P. macroptera* overall, taking all varieties into account.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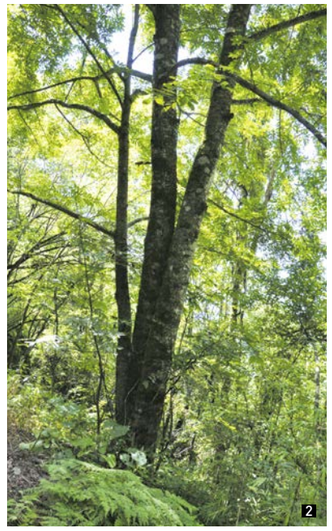
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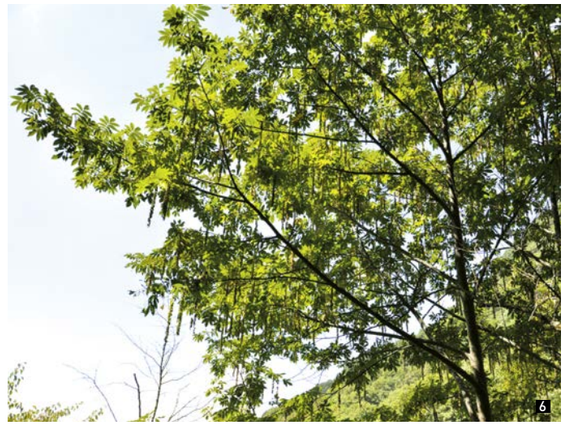
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1. Nan Gong Shan National Forest Park, Shaanxi, China (ygs)

2. *Pterocarya macroptera* var. *insignis*. Nan Gong Shan National Forest Park, Shaanxi, China (ygs)

3-4. Populations of *P. macroptera* var. *macroptera*. Dian Jiang Tai, Shaanxi, China (ygs)

5. Population of *P. macroptera* var. *macroptera*. Hua Long Shan Nature Reserve, Shaanxi, China (ygs)

6. Fruiting individual of *P. macroptera* var. *insignis*. Nan Gong Shan National Forest Park, Shaanxi, China (ygs)

7. Fruiting individual of *P. macroptera* var. *macroptera*. Dang Chuan, Gansu, China (ygs)

8. *Carpinus stipulata* (Betualecae). Baotianman, Henan, China (ygs)

9. *Quercus glauca* (Fagaceae). Huang Shan, Anhui, China (ek)


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Pterocarya rhoifolia Siebold & Zuccarini (1845)

Japanese wingnut, 水胡桃 shui hu tao (China), 沢胡桃 sawagurumi (Japan)

Pterocarya rhoifolia **is the only species of the genus growing on the Japanese archipelago and one of the main components of riparian forests across this country. The species can withstand long, hard winters under heavy snow.**


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HABIT

Trees with grey bark, growing to a maximum height of 30 m and diameter of 1 m. The maximum age of the trees is about 150 years. The species produces some sprouts around the main stem, but does not have any root suckers. Juvenile trees often wait for openings in the canopy to grow into adult trees. The rachis of its leaves is not winged and the terminal bud has 1-3 caducous bud scales (similarly to its closest relative, *P. macroptera*, from China). The petiole and rachis are finely pubescent. The leaves have 11-21 leaflets. Nutlets 8-9 mm in diameter. The wings of the nut are semiorbicular (1.3-2.1 x 0.9-1.8 cm).

DISTRIBUTION

The species is widely distributed across Japan (South Hokkaido, Honshu, Shikoku and Kyushu). The literature often refers to the presence of a disjunct population from China (Laoshan, East Shandong) based on a few dubious findings from the early 20th century. Thus, there is no reliable record of this species in China and local botanists and specialists were unable to confirm its presence during recent fieldtrips.


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1-2. Upper surface and underside of an entire leaf (hrs)

3-4. Upper surface and underside of a leaflet (hrs)

5-6. Closer view of the upper surface and underside of a rachis (hrs)

7-8. Closer view of the upper surface and underside of a leaflet margin (hrs)

9-10. Closer view of the upper surface and underside of a leaflet (hrs)

11. Trunk and young leaves of *P. rhoifolia*. Royal Botanic Garden Edinburgh, UK (ek)

12. Bud scales of *P. rhoifolia*. Arboretum Kórnik, Poland (ek)

13. Large leaves on juvenile branches of *P. rhoifolia*. Chichibu Mountains, Japan (ek)

14-15. Entire leaf (14) and closer view of the rachis (15) of *P. rhoifolia*. Chichibu Mountains, Japan (ek)


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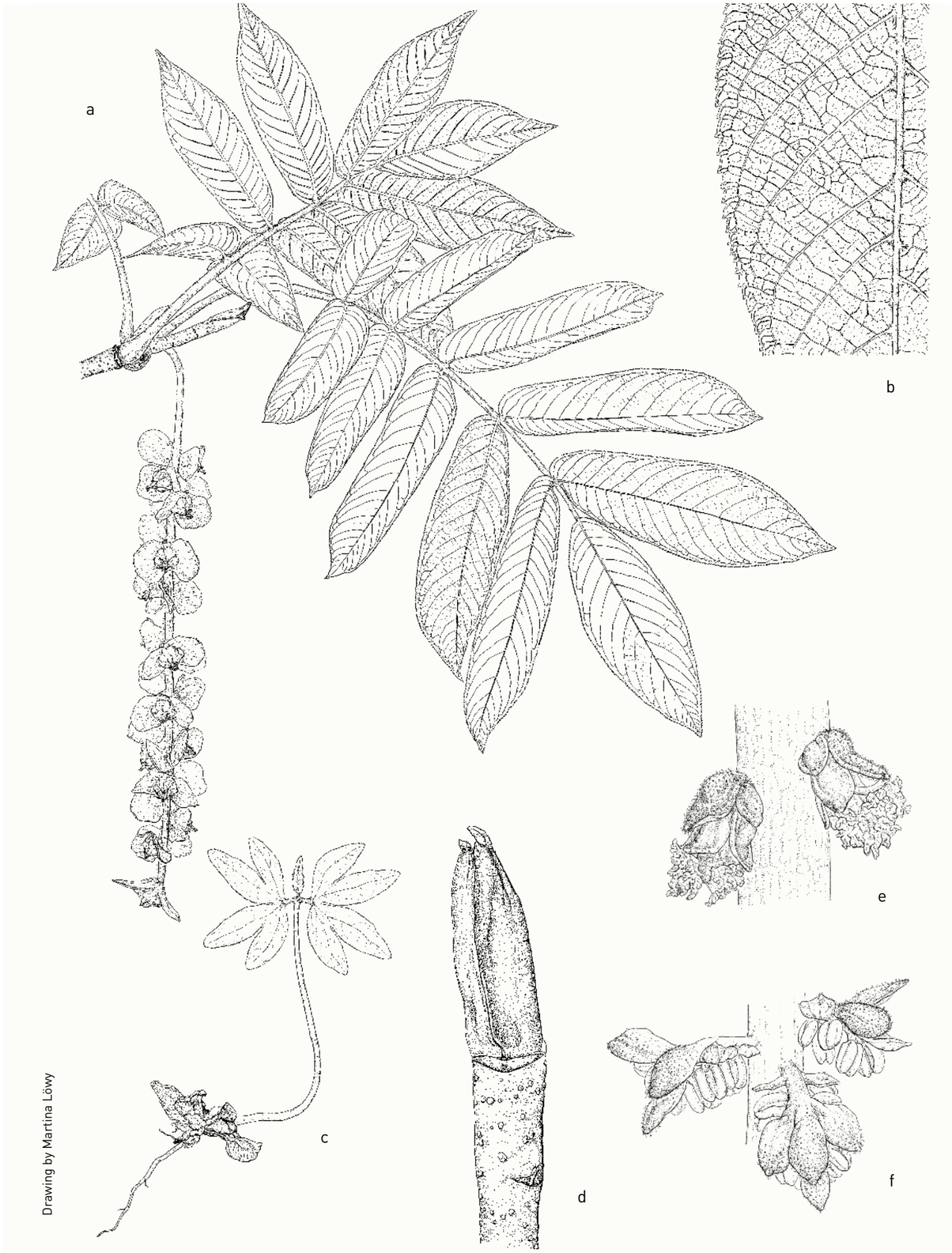
1. Flowering branch of *P. rhoifolia* with numerous green male catkins and a few reddish, terminal female catkins. Royal Botanic Garden Edinburgh, UK (ek)

2. Closer view of male flowers of *P. rhoifolia*. Royal Botanic Garden Edinburgh, UK (ek)

3. Male (green) and female (reddish) catkins of *P. rhoifolia*. Royal Botanic Garden Edinburgh, UK (ek)

4. Fruiting spike and leaf of *P. rhoifolia*. Royal Botanic Garden Edinburgh, UK (pb)

5. Seedling of *P. rhoifolia* with the characteristic 4-lobed cotyledons. Chichibu Mountains, Japan (ek)



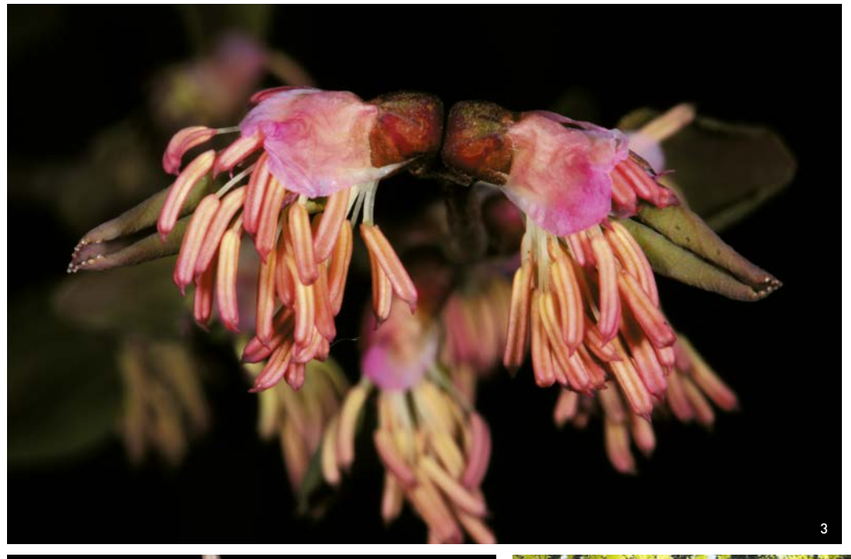
Morphology of *P. rhoifolia:*
a – branch with leaves and fruiting spike, b – closer view of a leaflet margin,
c – seedling with cotyledons, d – terminal bud covered with scales,
e – female flowers, f – male flowers.

ECOLOGY

The species grows along riverbanks and mountain streams, mainly at higher elevations (600-1,600 m a.s.l.). It needs a moist, wet environment and often initially occupies niches next to the water. It can also dominate floodplains and landslides after a major disturbance. *Pterocarya rhoifolia* is often associated with *Aesculus turbinata*, *Fraxinus platypoda* and *Cercidiphyllum japonicum*, and less frequently with *Alnus hirsuta, A. sieboldiana, Acer nipponicum, A. mono, A. pictum, A. distylum, A. shirasawanum, Quercus mongolica, Fagus crenata, Ulmus laciniata* and *Cryptomeria japonica*.

THREATS

The species is still common along streams and riverbanks in mountainous areas of Japan. Nevertheless, riparian habitats face the construction of forestry roads and erosion control works. It is important to monitor key populations in terms of size and genetic diversity.



1. Species-rich riparian forests with dominant canopy trees *P. rhoifolia*, *Fraxinus platypoda* (Oleaceae) and *Cercidiphyllum japonicum* (Cercidiphyllaceae). Some trees can grow to a height of over 30 m. Ooyamazawa Riparian Forest Research Site, Chichibu Mountains, Japan (ek)

2. *Cercidiphyllum japonicum* (Cercidiphyllaceae). Ooyamazawa Riparian Forest Research Site, Chichibu Mountains, Japan (ek)

3-4. *Cercidiphyllum japonicum* (Cercidiphyllaceae) is a dioecious species: male (3) and female (4) flowers. Arboretum Kórnik, Poland (ek)

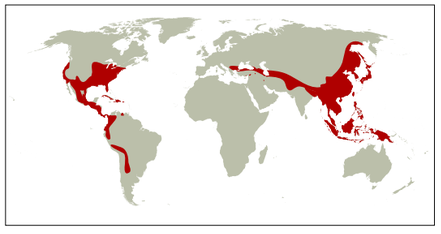
5. Canopy view with *Cercidiphyllum japonicum* (Cercidiphyllaceae) and *Acer shirasawanum* (Sapindaceae). Ooyamazawa Riparian Forest Research Site, Chichibu Mountains, Japan (ek)

6-8. Leaves of *Acer shirasawanum* (6), *A. distylum* (7) and *Alnus sieboldiana* (Betulaceae). Ooyamazawa Riparian Forest Research Site, Chichibu Mountains, Japan (ek)

9. Snow-covered population of *P. rhoifolia*. Akakurasawa stream, 798 m a.s.l., Fukushima, Japan (hs)

10. Mountain forest with *P. rhoifolia* and *Cryptomeria japonica* (Cupressaceae). Sado Island, Japan (yn)

11. Population of *P. rhoifolia* in winter. Tadamisawa stream, 567 m a.s.l., Fukushima, Japan (yn)



The Juglandaceae family is concentrated in the temperate regions of Asia and North America, but extends southwards into the montane areas of South-Eastern Asia, the Caribbean, Central and South America.

Walnut family – Juglandaceae of the world

Large picture: Flowering branches of shagbark hickory (*Carya ovata*). Botanic Garden Bern, Switzerland (eg)
Small picture: Fruits of shagbark hickory (*Carya ovata*). Botanic Garden Tokyo, Japan (ek)

The diversity and distribution of extant Juglandaceae

SUBFAMILIES

1. RHOIPTELEOIDEAE
(1 genus, 1 species)
comprising a single species
Rhoiptelea chiliantha
native to China and Vietnam.

2. ENGELHARDIOIDEAE
(4 genera, c. 13 species)
comprising two genera in
Eastern Asia (*Engelhardia*
and *Alfaropsis*) and two
genera in Central America
(*Oreomunnea* and *Alfaroa*).

3. JUGLANDOIDEAE
(5 genera, c. 48 species)
comprising two genera present
both in the New and Old World
(*Juglans* and *Carya*).
Three genera only in Eurasia
(*Pterocarya*, *Platycarya* and
Cyclocarya).

SELECTED FEATURES OF THE MODERN JUGLANDACEAE GENERA:

fruit types:
(1) small 2-winged
samaroid nutlets (*Rhoiptelea*,
Platycarya);
(2) small 3-winged nutlets, with
(*Engelhardia*, *Oreomunnea*) or without
prophyllum (*Alfaropsis*);
(3) large 2-winged nutlets (*Pterocarya*),
(4) disc-winged nutlets (*Cyclocarya*);
(5) walnut-like dehiscent nuts (*Carya*);
(6) walnut-like indehiscent nuts
(*Juglans*, *Alfaroa*)

nutlet / nut compartmentation: 2, 4 or
8 compartments.

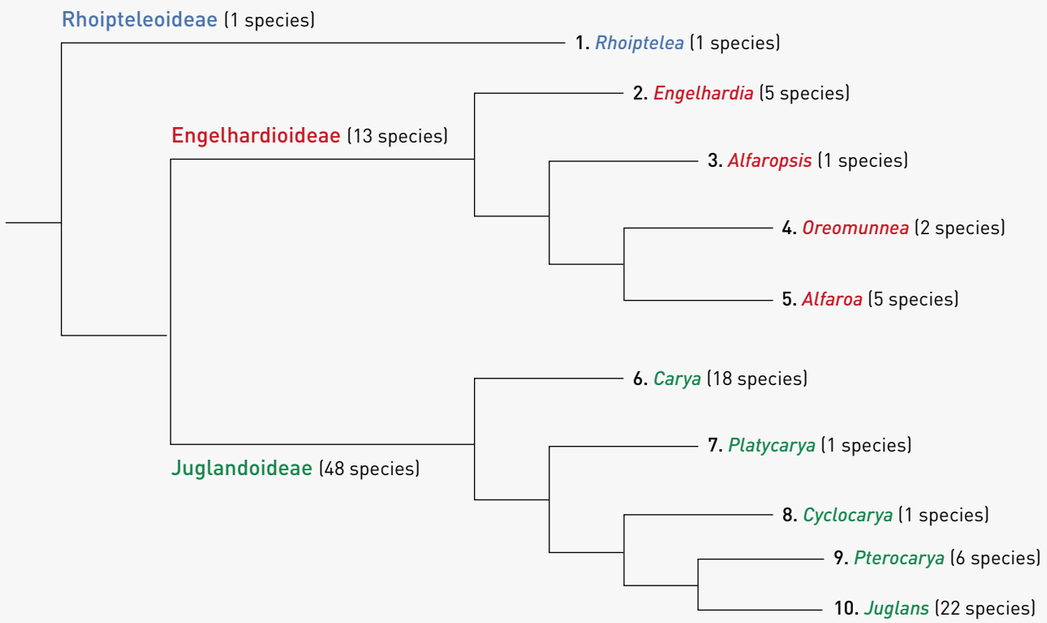
phyllotaxy, arrangement of leaves on a stem: alternate or opposite.

type of pinnately compound leaves:
odd-pinnate or even-pinnate.

condition of pith: chambered or solid.

PHYLOGENETIC TREE

Modern molecular phylogenetics suggests the following relationships within the Juglandaceae family:



genus	fruit	compart-mentation	phyllotaxy	leaves	pith
Rhoiptelea					
Engelhardia					
Alfaropsis					
Oreomunnea					
Alfaroa					
Carya					
Platycarya					
Cyclocarya					
Pterocarya					
Juglans					

Paintings by Martina Löwy

Rhoiptelea (horsetail tree)

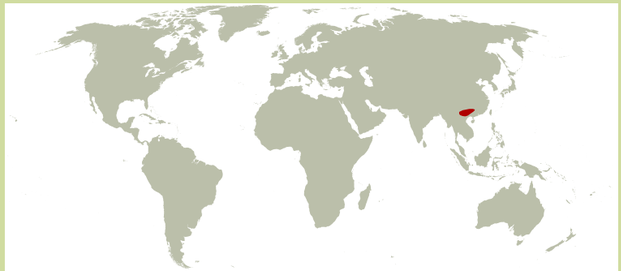
Age and origin Undoubtedly, the most ancient and primitive member of the family. However, the fossil record is not explicit. The genus originated probably in North America, perhaps already in the Cretaceous (> 66 Mya).

Extant species Only one species: *R. chiliantha*. This genus was previously recognised in its own family (Rhoipteleaceae) but is now placed in the Juglandaceae. Genetically the most isolated member of the family.

Habit Deciduous, trees to 20 m tall with aromatic, alternate and odd-pinnate leaves with stipules. Flowers in triads (central flower hermaphrodite) aggregated in large, 15-30 cm long panicles. Fruits are very small two-winged samaroid nutlets, 5-8 mm wide, slightly compressed (2-3 mm). Morphologically, especially taking the flowers and inflorescences into consideration, *Rhoiptelea* can be considered as hypothetical prototype for the remaining, evolutionary younger Juglandaceae.

Ecology It grows in mixed mesophytic forests and evergreen broad-leaved forests on hill slopes, in valleys, and in streamside, between 700 and 2,500 m a.s.l. The flowering season is from March to August, and fruits are appearing from July to August.

Distribution Restricted to Southwest China (Guangxi, Guizhou and Yunnan) and North of Vietnam (Lao Cai, Yen Bai).

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1. Fruiting tree of *R. chiliantha*. Mengdong, Yunnan, China (xxz)

2. Young leaf of *R. chiliantha* with clearly visible stipules (jdl)

3. Flowering branches of *R. chiliantha*. Fadou, Yunnan, China (xxz)

4. Leaf of *R. chiliantha* (jdl)

5. Fruits of *R. chiliantha*. Malipo, Yunnan, China (xxz)

6. Closer view of nutlets of *R. chiliantha*. Malipo, Yunnan, China (xxz)


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Engelhardia

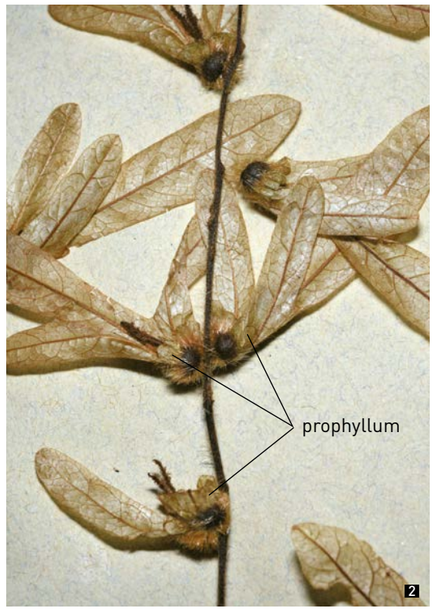
Age and origin Not completely elucidated. Engelhardioid fossils known since the Eocene epoch (55-34 Mya) of North America and Europe.

Extant species There are 5 generally accepted species: *E. apoensis, E. hainanesis, E. rigida, E. serrata* and *E. spicata*. *Egelhardia roxburghiana* is now treated as a separate genus - *Alfaropsis*. However, the number of species is open to question, since several taxa, many of them narrow endemics, were described in Borneo and New Guinea. Their taxonomic status remains dubious.

Habit Large to medium-sized deciduous (rarely evergreen) trees, reaching a height of 10-30(-40) m, sometimes with well-developed buttresses. Branchlets with solid pith. Leaves alternate, even-pinnate (rarely odd-pinnate). Plants monoecious or dioecious. Male and female inflorescences separate, lateral on old wood. Fruiting spike elongate, pendulous, up to 40-60 cm long. Fruit a 3-winged, small hairy nutlet with relatively large prophyllum. Nutlet with 2 (maximum 4) compartments.

Ecology The majority of species are typical elements of primary forests (only rarely observed in secondary forests). They appear as scattered individuals in lowland evergreen and mixed forests between sea level and 2,000 m a.s.l. (rarely in savannas) - but becoming common, although never dominant, on mountain slopes at higher elevations of up to 2,500-2,700 m a.s.l. (e.g. *E. spicata* in China or *E. rigida* on the Sunda Islands in the Malaya archipelago).

Distribution South-Eastern Asia, from Nepal to New Guinea. *Engelhardia spicata* has the largest range, growing in Nepal, Bhutan, India, Pakistan and Western China (up to 30° N, the only species of the genus in these northern regions) and extending south- and eastwards to Philippines and New Guinea. The highest diversity occurs in Malaysia, Indonesia (mainly Borneo) and Philippines. *Engelhardia apoensis* is known to grow only on the islands of Borneo and Mindanao, whereas *E. hainanensis* is endemic on the Chinese island of Hainan.



1. Fruiting spikes of *E. spicata*. Malipo, Yunnan, China (hhm)

2. Fruits of an unidentified species of *Engelhardia*, specimen collected in New Guinea. Geneva Herbarium (G), Switzerland (gk)

3. Large *E. spicata* trees. Xi Shuang Ban Na, Yunnan, China (ygs)

4. Fruiting individual of *E. spicata*. Malipo, Yunnan, China (hhm)

5. Leaf of *E. spicata*. Vietnam (hhm)

6. Leaf of *E. spicata*. Con Dao National Park, Vietnam (ek)

7-8. Upper surface and underside of an even-pinnate leaf of *E. spicata*. Con Dao National Park, Vietnam (ek)

9. Young leaves of *E. spicata*. Con Dao National Park, Vietnam (ek)

Alfaropsis

Age and origin Not completely elucidated. Engelhardioid fossils very similar to *Alfaropsis* known since the Eocene epoch (55-34 Mya) of North America and Europe.

Extant species Only one species: *A. roxburghiana* (the former name, *Engelhardia roxburghiana*, still appears in many publications). Morphologically and genetically, it is an intermediate taxon between the East-Asian *Engelhardia* and Central-American *Oreomunnea* and *Alfaroa*.

Habit Large evergreen or rarely semi-evergreen trees (reaching a height of 30 m) with alternate and even-pinnate leaves. Branchlets with solid pith. Plants monoecious. Inflorescences forming androgynous panicle (sometimes separate), terminal on new wood (occasionally lateral, and if so on old wood). Fruiting spike elongate, pendulous, 10-20(-25) cm long. Fruit a 3-winged, small and glabrous nutlet. Prophyllum absent.

Ecology Mixed broad-leaved or evergreen forests on loam, or on steep and dry slopes with sandy soils, between 200 and 1,500 m a.s.l. in China and up to 1,750 m a.s.l. on clay-rich and relatively fertile soils on the Sunda Islands.

Distribution Eastern Pakistan, Bangladesh, India, South-Eastern China, Taiwan, Cambodia, Indonesia, Laos, Myanmar, Thailand and Vietnam.

1. *Alfaropsis roxburghiana* tree. Cuc Phuong National Park, Vietnam (ek)

2. Bark of *A. roxburghiana*. Pu Mat National Park, Vietnam (hvs)

3. *Ex situ* collection of *A. roxburghiana* in the Botanic Garden of the Vietnam National University of Forestry, Hanoi, Vietnam (ek)

4-5. Underside and upper surface of an even-pinnate leaf of *A. roxburghiana*. Cuc Phuong National Park, Vietnam (ek)

6. Young leaf of *A. roxburghiana*. Cuc Phuong National Park, Vietnam (ek)

7-8. Fruits of *A. roxburghiana*. Tay Yen Tu Nature Reserve, Bac Giang, Vietnam (pth)

Oreomunnea

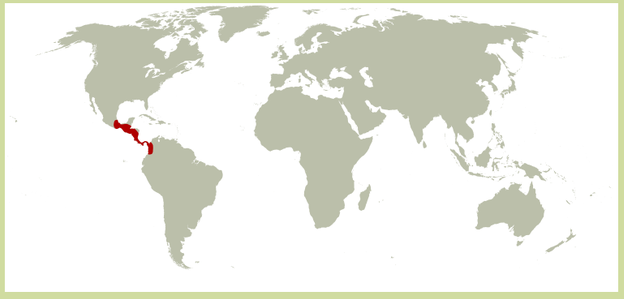
Age and origin Not completely elucidated. Engelhardioid fossils very similar to *Oreomunnea* have been known since the Eocene epoch (55-34 Mya) of North America and Europe.

Extant species There are 2 generally accepted species: *O. mexicana* and *O. pterocarpa*. The third taxon, discovered in 1993 in Colombia, was described as *O. munchiquensis*. However, it is very similar to *O. pterocarpa* and its taxonomic status needs revision. *Oreomunnea* is very closely related to the second tropical and Central-American genus, *Alfaroa*.

Habit Evergreen trees reaching a height of 60 m (sometimes with well-developed buttresses), with opposite and even-pinnate leaves. Branchlets with solid pith. The bark is tight in *O. pterocarpa* and strongly exfoliating in *O. mexicana*. Plants monoecious. Inflorescences born terminally. Female and male catkins either separate and terminal or combined in an androgynous panicle. Fruit 3-winged, with large and long wings. The nutlet is small, globose and 8-chambered with a very thin papery shell, enveloped by a frontal lobe (prophyllum).

Ecology Large canopy trees growing in the rainforests from 75 to 1,900 m a.s.l. (mainly in mid-elevations between 500 and 1,500 m a.s.l.). The genus is a typical element of the tropical montane cloud forests, where it dominates locally and can form monospecific stands. However, it can be associated with other relict trees (e.g., *Liquidambar styraciflua, Ticodendron incognitum*, various species of *Quercus*) as well as with the sister genus *Alfaroa* (e.g., *A. williamsii, A. costaricensis, A. manningii*). Flowering occurs with a flush of new growth, usually between March and August.

Distribution *Oreomunnea* is a strictly tropical American element, exhibiting discontinuous distribution. *Oreomunnea mexicana* grows in South-Eastern Mexico (Chiapas, Oaxaca and Veracruz), Guatemala, Nicaragua, Costa Rica and Panama. *Oreomunnea pterocarpa* was considered as endemic to Costa Rica. However, recently there are new records from Mexico (Chiapas) and Panama (Coclé). The third taxon described as *O. munchiquensis* was described from the Munchique National Park in Western Cordillera, Colombia. This indicates that the chorology of the genus needs more research.



1. Tapanti National Park in Costa Rica has well-preserved populations of *O. mexicana* (ek)

2. Leonel Coto, researcher from the *Centro Agronómico Tropical de Investigación y Enseñanza* (CATIE), in front of a large *O. mexicana* tree. Primary forest in the Tapanti National Park, Costa Rica (gk)

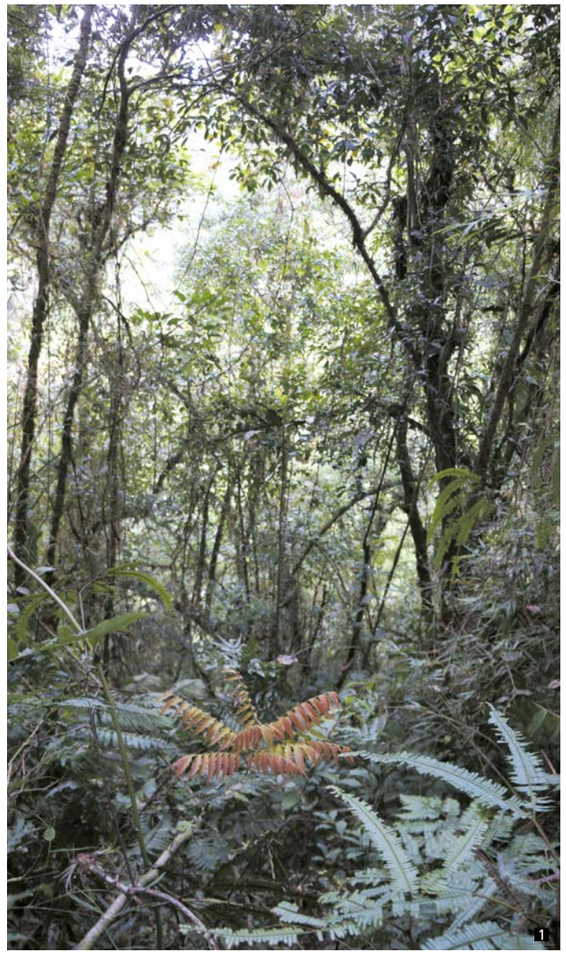
3. Epiphytes growing on *O. mexicana*. Primary forest in Tapanti National Park, Costa Rica (ek)

4. Exfoliating bark of *O. mexicana* – one of the main characteristics used to spot this species in dense tropical forests. Tapanti National Park, Costa Rica (ek)

5-6. Upper surface and underside of an even-pinnate leaf of *O. mexicana*. Tapanti National Park, Costa Rica (ek)

7. *O. mexicana* shoot with very young leaves. Tapanti National Park, Costa Rica (ek)

8. Typical auricles at the base of *O. mexicana* leaflets. Tapanti National Park, Costa Rica (ek)



1-3. Members of the Juglandaceae family are not easy to spot in lush tropical forests. *Oreomunnea mexicana* can be detected by the presence of large flushes of young, reddish leaves (1), seedlings with very characteristic pennate and dentate leaves (2), and by the presence of fallen old leaflets with typical auricles at their bases. Tapanti National Park, Costa Rica (ek)

4-5. *Oreomunnea pterocarpa* can be detected by the presence of very distinctive fruits on the forest floor. The winged fruits of this species are, in fact, the largest of all the Juglandaceae as the central wing can exceed 16-17 cm. The prophyllum covering the nutlets is also the largest of its kind among engelhardioid taxa (up to 2 cm in diameter). Pictures taken at the Geneva Herbarium (4, gk) and in Aquiares at 1,000 m a.s.l. in Costa Rica (5, eva)

Painting by Martina Löwy

Oreomunnea mexicana: fruits of this species are smaller than those of *O. pterocarpa*, with a central wing length of 4 cm.

Alfaroa

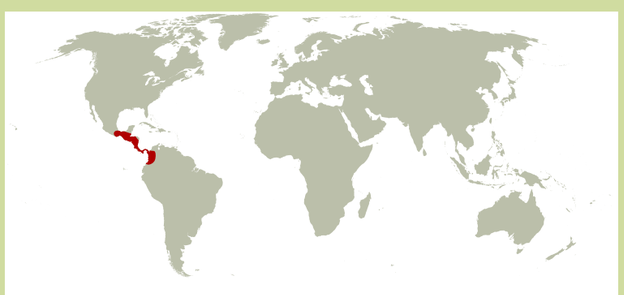
Age and origin The only genus of the Juglandaceae without any known fossil record. However, *Alfaroa* is very closely related to the second tropical and Central-American genus, *Oreomunnea*. Thus, the taxon is believed to have recently differentiated from *Oreomunnea "in situ"* (Central America).

Extant species There are 5 generally accepted species: *A. costaricensis, A. guatemalensis, A. manningii, A. mexicana* and *A. williamsii*. Three further taxa have been described, namely: *A. colombiana, A. guanacastensis* and *A. hondurensis*. However, according to recent morphological comparisons across the whole of Mesoamerica, *A. hondurensis* should be included with *A. guatemalensis, A. guanacastensis* with *A. manningii*, and *A. colombiana* with *A. williamsii*. The genus needs thorough phylogenetic revision. Furthermore, the discovery of new species cannot be ruled out.

Habit Evergreen trees reaching a height of 35 m (sometimes with well-developed buttresses) or occasionally large shrubs, with opposite and even-pinnate leaves. Branchlets with solid pith. Plants monoecious. Inflorescences terminal on new wood (with flush of new growth of pink leaves) or occasionally terminal on axillary shoots of old wood. Female and male inflorescences either separate and terminal or combined into an androgynous panicle with central female catkin. Fruit medium-sized to large walnut-like nuts, mostly glabrous (only in *A. costaricensis* hirsute), with 8 compartments and without wings (the trilobed bracts and prophyllum are extremely reduced and visible only in the early flowering stage). The thick husk is leathery or hard, and indehiscent.

Ecology Trees of mid-elevations growing in the premontane rainforests, mainly between 500 and 2,250(-3,200) m a.s.l. They can grow in abundance locally but populations are often disjunct since their distribution coincides with isolated volcanoes or mountain ranges. Flowering and fruiting can be observed virtually all year round. However, February and March seem to be the peak flowering months and fruits are mainly produced between March and August.

Distribution *Alfaroa* is a strictly tropical American element, exhibiting discontinuous distribution from South-Eastern Mexico (Oaxaca, Veracruz), Guatemala, Honduras, Nicaragua, Costa Rica, Panama to Colombia. The largest range has *A. costaricensis* (from Mexico to Panama). Costa Rica is undoubtedly the richest region in terms of species (4 species). The only species spreading to South America is *A. williamsii* (referred to as *A. colombiana* in local literature).



1. *Alfaroa williamsii*. Although very closely related to *Oreomunnea*, the fruits of all *Alfaroa* species are large and walnut-like without any wings. Castro Blanco National Park, Costa Rica (eva)

2. Young *A. williamsii* plant. Castro Blanco National Park, Costa Rica (eva)

3. *Alfaroa manningii* in a primary forest of the Tapanti National Park, Costa Rica (ek)

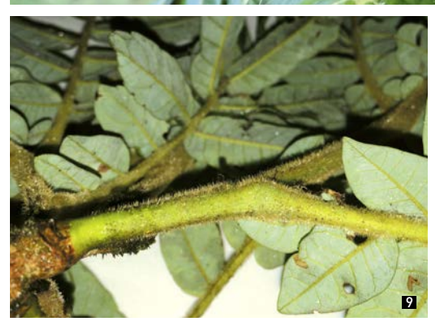
4. *Alfaroa costaricensis* with typical red colouration of leaves on young shoots. This feature is used to spot Juglandaceae in the tropical forests of Mesoamerica. Fortuna Forest Reserve, Chiriqui, Panama (jd)

5. *Alfaroa costaricensis*. Vara Blanca, Costa Rica (eva)

6. Glabrous leaflets of *A. manningii*. The species has the largest leaves of the genus (with rachis of up to 40-50 cm long). Tapanti National Park, Costa Rica (ek)

7. Newly formed leaves of *A. manningii* on a naked terminal bud. Tapanti National Park, Costa Rica (ek)

8-10. *Alfaroa costaricensis*. Female inflorescence (8), densely hirsute young branches (9) and rounded leaflets (10). Vara Blanca, Costa Rica (eva)



Carya (hickories and pecans)

Age and origin The oldest fossils date back to the Eocene epoch (55-34 Mya) in Europe and the late Eocene epoch (38-34 Mya) of North America.

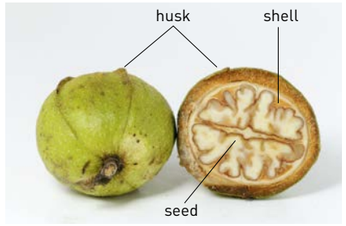
Extant species This is the second largest genus of the Juglandaceae after *Juglans* (with c. 18 species) with 6 species in South-Eastern Asia (*C. cathayensis*, *C. hunanensis*, *C. kweichowensis*, *C. poilanei*, *C. sinensis*, *C. tonkinensis*), and 12 species in North America (*C. aquatica*, *C. cordiformis*, *C. floridana*, *C. glabra*, *C. illinoinensis*, *C. laciniosa*, *C. myristiciformis*, *C. ovata*, *C. pallida*, *C. palmeri*, *C. texana*, *C. tomentosa*). More taxonomic research based on intensive field sampling is clearly needed. *Carya sinensis*, although sometimes treated as a monotypic genus (*Annamocarya sinensis*), has all of the essential features of the *Carya* genus. Recent genetic studies support these findings.

Habit Deciduous trees (*C. sinensis* evergreen) reaching a height of 30(-50) m, rarely shrubs. Branchlets with solid pith. Leaves alternate, odd-pinnate. Plants monoecious. Male and female spikes separate. Male spike in clusters of 3 (in *C. sinensis* 5-8 spikes per cluster), lateral at base of new growth, pendulous. Female spike terminal on new growth and erect. Fruiting spike erect. The fruit is a drupaceous large nut with a thick, 4-valved husk (*C. sinensis* 4-9-valved) containing a smooth or wrinkled shell with 2 or 4 compartments. Husks completely or partially dehiscing.

Ecology In Northern America, *Carya* is found in a variety of habitats but mainly on river floodplains, along the banks of streams, on rolling hills and rocky hillsides, sometimes on dry rocky soils, limestone glades, calcareous prairie soils and marl ridges, between 0 and 1,000 m. a.s.l. In Asia, *Carya* is a typical element of forest growth on mountain slopes, in valleys and along riverbanks, between 400 and 1,500 m a.s.l. (*C. tonkinensis* up to 2,200 m a.s.l.). *Carya sinensis*, probably the most tropical of all the species, grows in lowland forests at 200-700 m a.s.l.

Distribution *Carya* has two disjunct distribution areas: temperate North America and sub-tropical/tropical South-Eastern Asia. Out of six Asian taxa, three species are endemic to China (*C. cathayensis*, *C. hunanensis*, *C. kweichowensis*). Three further species are mostly found in tropical regions: *C. sinensis* occurs in South-Western China and Northern Vietnam, *C. tonkinensis* in North-Eastern India, Southern China and Northern Vietnam, and *C. poilanei* in Laos and Northern Vietnam. The 12 New World species are nearly all concentrated in Eastern USA. Only a few species extend to Quebec in Canada (e.g. *C. ovata* or *C. cordiformis*) and three are found additionally in a disjunct southern area of Eastern Mexico (*C. myristiciformis*, *C. illinoinensis* and *C. ovata*). The eastern highlands of Mexico (from Nuevo Leon as far as Veracruz to the south) are also the homeland of the only Mexican endemic *C. palmeri*.

Carya cordiformis



Carya ovata

In all *Carya* species, the green, fleshy cupula (commonly known as «husk») encloses the hard nut. The husk comprises a fused floral envelope (mainly of bract), is dehiscent at maturity and usually splits into 4 parts. The seeds are enclosed in a smooth or wrinkled shell (pericarp). *Carya* nuts can contain 2 or 4 compartments, depending on the number of septa (hrs)

1. Pignut hickory (*C. glabra*) is still quite common in the Eastern USA (ac)

2. All *Carya* species possess edible seeds. However, the pecan (*C. illinoinensis*) undoubtedly produces the most nuts. Although native to USA and Mexico, it is nowadays cultivated in many other regions as well as on other continents (ek)

3. Water hickory tree (*C. aquatica*). South Eastern USA (ac)

4. Bitternut hickory nuts (*C. crodiformis*), native to Eastern USA (ek)

5-6. Typical characteristics of shagbark hickory (*C. ovata*), native to Eastern USA and Mexico: leaves with only few wide leaflets (5) and exfoliating bark on older trees (6). Pictures taken in the Botanic Garden Tokyo, Japan (5, ek) and Arnold Arboretum of Harvard University (one of the best *ex situ* collections of *Craya*), USA (6, sb)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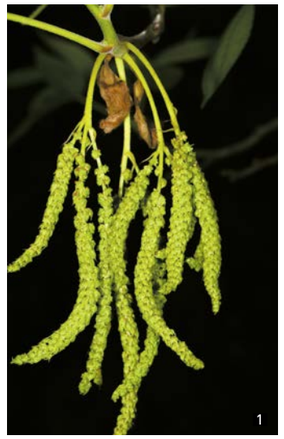



1. Male shagbark hickory flowers (*C. ovata*). Botanic Garden Bern, Switzerland (eg)

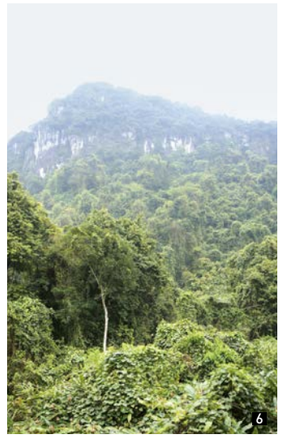
2-3. Mockernut hickory (*C. tomentosa*). Duke Forest, North Carolina, USA (ac)

4. Pignut hickory (*C. glabra*). Eastern USA (ac)

5. *Carya tonkinensis* native to South China, India and Vietnam. Son La, Vietnam (hvs)

6. Dense forest with *C. sinensis* in Northern Vietnam. Cuc Phuong National Park, Vietnam (ek)

7-10. *Carya sinensis* is one of the most endangered species of the Juglandaceae family. Closer view of its bark (7), leaves (8), habitat (9), and young leaves with reddish coloration (10). Cuc Phuong National Park, Vietnam (ek)



Platycarya

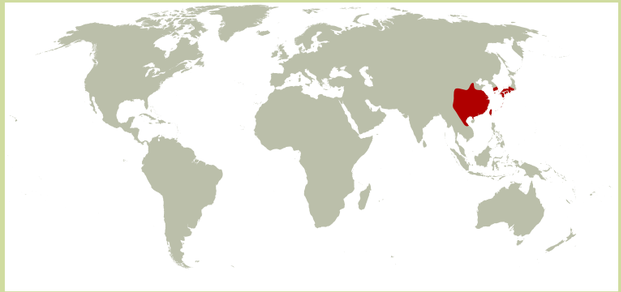
Age and origin The oldest fossils date back to the early Eocene epoch (55-48 Mya) of North America and Europe.

Extant species Only one species: *P. strobilacea* (although several additional species were recognised in earlier and recent treatments: *P. longipes, P. simplicifolia, P. longzhouensis*).

Habit Deciduous trees (occasionally shrubs) reaching a height of 15 m with alternate and odd-pinnate leaves. Branchlets with solid pith. Plants monoecious. In terms of its flowers and fruits, this is one of the most unusual members of the Juglandaceae. The cylindrical male catkins are erect and clustered around the female cone-like catkin in a candelabra-style arrangement. Female flowers are subtended by an entire bract. The mature bracts are almost black, rigid and persistent. Fruits are very small (3-6 x 3-6 mm), flattened, narrowly 2-winged nutlets, with 2 compartments.

Ecology Growing as scattered individuals in evergreen and mixed forests on mountain slopes, sometimes on limestone, between 400 and 1,500 (-2,200) m a.s.l.

Distribution Southern and Eastern China, Taiwan, Korean Peninsula, Japan and Vietnam.

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1-2. Upper surface and underside of a *P. strobilacea* leaf. Botanic Garden Tokyo, Japan (ek)

3. Natural population of *P. strobilacea*. Zhenwuding, Henan, China (ygs)

4. *Ex situ* culture of *P. strobilacea*. Botanic Garden Tokyo, Japan (ek)

5. Flowering male catkins with clearly visible anthers and one solitary female catkin in the centre. Dabie Shan, Hubei, China (sb)

6. Male catkins surrounding the central female catkin. Koishikawa Arboretum, Japan (sb)

7-8. Fruiting spikes of *Platycarya* are atypical among all other Juglandaceae. They are cone-like, up to 5 cm long, erect, with rigid and persistent bracts. The bracts cover very small 2-winged nutlets. Cambridge University Botanic Garden, UK (7, eg), Botanic Garden Tokyo, Japan (8, ek)


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Cyclocarya (wheel wingnut)

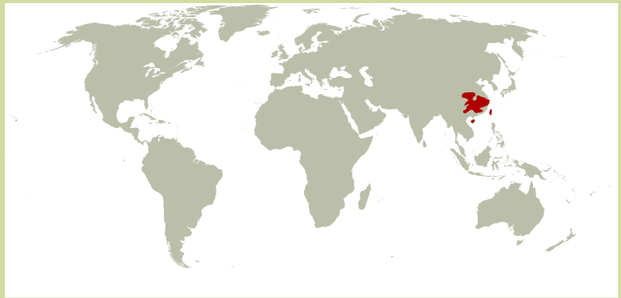
Age and origin The genus is one of the oldest extant genera of Juglandaceae (probably surpassed only by *Rhoiptelea*), with well-documented fossils from the Paleocene epoch (65-55 Mya) of North America.

Extant species Only one species: *C. paliurus*.

Habit Deciduous trees (occasionally shrubs) reaching a height of 30 m with alternate and odd-pinnate leaves. Branchlets with chambered pith. Plants monoecious. Male and female inflorescences separate. Male spikes in clusters of 3-5, lateral on old growth. Female spike solitary, terminal on new growth. Fruiting spike elongate (25-30 cm) and pendulous. The fruit a disc-winged nutlet with 2 or 4 compartments. The disc wing is leathery, orbicular to ovate, 3-6 cm in diameter.

Ecology Growing in moist mountain forests, between 400 and 2,500 m a.s.l.

Distribution *Cyclocarya paliurus* is endemic to South-Eastern China, extending also to the Hainan and Taiwan islands.



1-2. Natural populations of *C. paliurus*. Youlu, Henan (1) and Cao Hu Yu, Henan, China (ygs)

3. Fruiting individual of *C. paliurus*. Cao Hu Yu, Henan, China (ygs)

4-5. Upper surface and underside of a *C. paliurus* leaf. Youlu, Henan, China (ygs)

6-7. Disc-winged nutlets of *C. paliurus* cannot be confused with any other member of the Juglandaceae family. The disc is leathery with a diameter of up to 5-6 cm (ygs)

Juglans (walnuts)

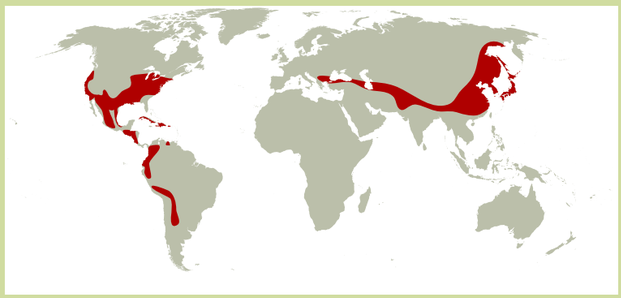
Age and origin The oldest fossils date back to the Eocene epoch (55-34 Mya) of North America.

Extant species This is the largest genus of Juglandaceae (with c. 22 species): Eurasia with 6 species (*J. ailantifolia, J. cathayensis, J. hopeiensis, J. mandshurica, J. regia* and *J. sigillata*), North America with 8 species (*J. californica, J. cinerea, J. hindsii, J. hirsuta, J. nigra, J. major, J. microcarpa* and *J. mollis*), Southern Mexico, Mesoamerica and Caribbean with 4-5 species (*J. jamaicensis, J. olanchana, J. pyriformis, J. steyermarkii* and potentially also *J. guatemalensis*), South America with 5 species (*J. australis, J. boliviana, J. neotropica, J. soratensis* and *J. venezuelensis*). More taxonomic research based on exhaustive field sampling is clearly needed.

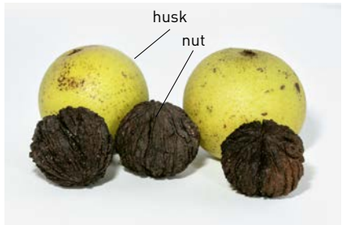
Habit Deciduous trees reaching a height of 30(-55) m (rarely shrubs). Branchlets with chambered pith. Leaves alternate, odd-pinnate (rarely even-pinnate). Plants monoecious. Male and female spikes separate. Male spike solitary, lateral on old growth, pendulous. Female spike terminal on new growth and erect. Fruiting spike erect or pendulous. The fruit is a drupaceous large nut with thick, indehiscent husk (only *J. regia* irregularly dehiscent), containing a wrinkled (sometimes rough) shell with 2-4 compartments.

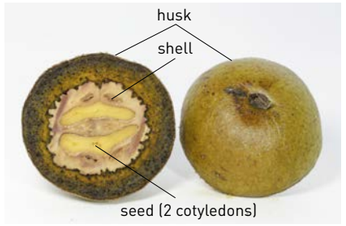
Ecology In Eastern Asia, the *Juglans* species grow mainly in mixed forests on mountain slopes between 500 and 2,800(-4,000) m a.s.l. In North America, they are a typical element of rich woods on riverbanks, along streams and in valleys (seldom on dry rocky slopes or canyons), from lowlands to 2,000 m a.s.l. In Mesoamerica, they are found in deciduous mountain forests between lowlands and 1,800 m a.s.l.

Distribution *Juglans* has the largest distribution area of all the Juglandaceae genera. Although growing mainly in temperate and sub-tropical areas of the Northern Hemisphere, it extends to Central and South America (mainly at high elevations). In fact, in the New World, *Juglans* species are distributed more or less continuously from South-East Canada (*J. cinerea*) through Central America to Northern Argentina (*J. australis*), but the genus is conspicuous by its absence from Costa Rica and Panama. One species, namely *J. jamaicensis*, is endemic to the Caribbean (Cuba, Hispaniola and Puerto Rico). The main distribution area of all 6 Eurasian species lies in the Himalayas and China. Unlike the New World, there are no *Juglans* species in tropical Asia. *Juglans ailantifolia* is endemic to Japan. *Juglans regia*, cultivated virtually worldwide, is native to the mountain ranges of Central Asia (extending from Western China to Turkey, and possibly even to the Balkan Peninsula).

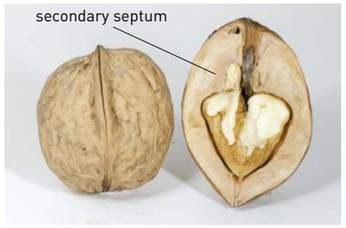


Juglans nigra





Juglans regia



In all *Juglans* species (similar to the *Carya* genus), the green, fleshy cupula (commonly known as «husk») encloses the hard nut. The husk comprises a fused floral envelope (mainly of bract and bracteoles), is indehiscent at maturity (with the exception of *J. regia*). The seeds are enclosed in a usually wrinkled and very hard shell (pericarp). *Juglans* nuts contain 2 compartments (due to the major septum) or sometimes 4, if the secondary septum is well developed (hrs)

1. Butternut tree (*J. cinerea*). North Carolina, USA (ac)

2-3. *Juglans neotropica*. Young tree (2) and closer view of a leaf with typical rounded and sessile leaflets (3). Ecuador (adm)

4-5. Nuts of the black walnut (*J. nigra*), native to Eastern USA (ek)

6. Immature fruits of Hind's black walnut (*J. hindsii*), endemic to California and one of the most endangered Juglandaceae in the world. Sunrise Park, California, USA (bf)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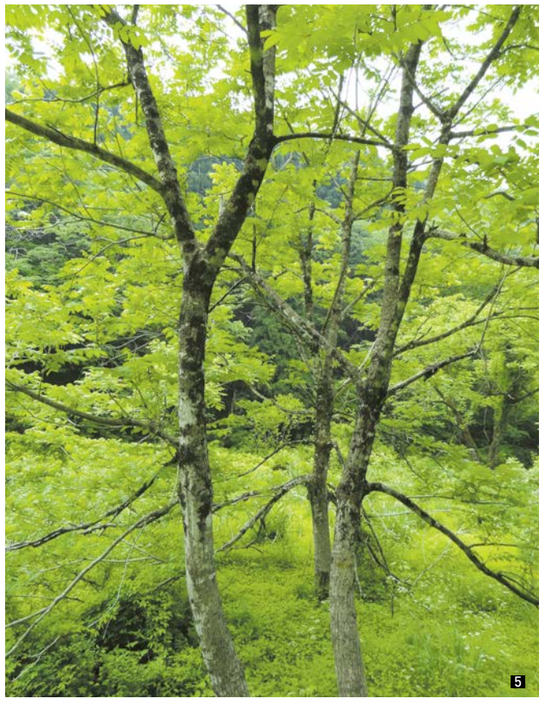


1-3. Persian, English or common walnut (*J. regia*) is widely planted and cultivated for its edible fruits. However, its natural range is subject to debate. Pictures show male catkins surrounding female flowers (1), mature fruits (2) and young shoot with female flowers (3). Mont Vully, Switzerland (1, 3, ek) and Upton Wold, UK (2, sb)

4. Fruits and leaves of *Juglans cathayensis*. Nanyang, Henan, China (sb)

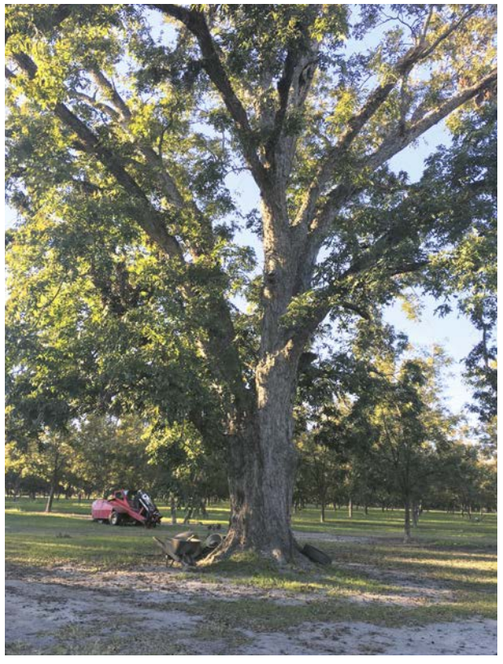
5-6. *Juglans ailantifolia*. Young trees (5) and flowering branches with clearly visible male catkins (6). Tataoki river, Japan (sb)

7. Fruits of *J. ailantifolia*. Chichibu Mountains, Japan (ek)

8. Very decorative female flowers of *J. ailantifolia*. Tataoki river, Japan (sb)

9. Nuts of *J. ailantifolia* (ek)

10. Nuts of *J. ailantifolia* var. *cordiformis* (ek)



The pecan (*Carya illinoinensis*) is one of the most important fruit crops of Juglandaceae.

Juglandaceae - relict trees of inestimable value

Large picture: nuts and edible seeds of *C. illinoinensis* (ek)
Small picture: an old *C. illinoinensis* tree (more than 200 years) in a pecan orchard in Georgia, USA (ag)

Juglandaceae: important useful plants

Nearly all species of Juglandaceae are important useful plants. On a large economic scale, they are mainly used for their high-quality wood and edible fruits. On a much smaller scale, they are used by local societies in traditional medicine, for tanning and staining/dyeing, oil manufacture and fish poisoning. They are also very popular in parks and gardens due to their ornamental potential. Additionally, given the numerous active substances and chemical constituents, nearly all members of Juglandaceae possess an enormous potential for modern medicine.

Juglandaceae as useful and economic plants

	forestry / plantations	wood / handicraft	fruits / food	oil	tanning / staining	traditional medecine	poisoning	parks / garden trees
Rhoiptelea	●	●			●			
Engelhardia		●			●	●	●	
Alfaropsis	●	●				●	●	●
Oreomunnea		●						
Alfaroa		●						
Carya	●	●	●	●	●	●	●	●
Platycarya	●	●			●	●	●	●
Cyclocarya		●			●	●		●
Pterocarya	●	●		●	●	●	●	●
Juglans	●	●	●	●	●	●	●	●

1. Plantation of *Pterocarya rhoifolia*. Urayama, Japan (hs)

2. Recreation park with *Juglans hindsii*. Sunrise Park, California, USA (bf)

3. *Juglans sigillata* in Upton Wold arboretum, one of the finest collections of *Juglans* worldwide. UK (sb)

SYLVICULTURE

Relatively few Juglandaceae are cultivated using intensive, profit-oriented sylviculture methods (planting of trees in large and often monospecific stands). This is primarily the case with temperate members of *Juglans* (*J. nigra, J. cinerea, J. regia, J. mandshurica*) and *Carya* (*C. ovata, C. laciniosa, C. cordiformis*, and to lesser extent with *C. glabra* and *C. illinoinensis*). The lead contries in Juglandaceae timber production are Russia (mainly *J. mandshurica*) and the USA (mainly *J. nigra*). In some regions of Eastern Asia, several *Pterocarya* species are also used for forest plantations (e.g. *P. stenoptera* in China and *P. rhoifolia* in Japan).

LANDSCAPE ARCHITECTURE

By virtue of their ornamental qualities (e.g., shadow-spending large crowns, large leaves, decorative fruits, etc.) the Juglandaceae are highly prized in landscape architecture. However, their use in parks and municipal gardens is still very restricted. The main species growing in Europe is *Juglans regia* followed to lesser extent by other *Juglans, Carya* and *Pterocarya* species (mainly *J. nigra, P. fraxinifolia* and *C. ovata*). Other Juglandaceae such as *Cyclocarya paliurus* or *Platycarya strobilacea* are very occasionally cultivated in botanic gardens and renowned parks. Nevertheless, there are some exceptional collections, especially in the United Kingdom, such as the *Pterocarya* collection of the Royal Botanic Garden Edinburgh and one of the best collections of *Juglans* in the Upton Wold arboretum near Moreton-in-Marsh, as well as in the United States the *Carya* collection of the Arnold Arboretum (Harvard University). Some Juglandaceae are very popular as park and street trees, for example *Juglans hindsii* in California (USA), *J. neotropica* in Colombia or *Pterocarya stenoptera* in China. The tropical genera, and thus all engelhardioids, are rarely planted in parks and botanic gardens, even in their countries of origin. They cannot be cultivated in the temperate regions of the Northern Hemisphere.

1. Large crown of *Pterocarya stenoptera* in the Royal Botanic Garden Edinburgh, UK (ek)

WOOD AND WOODEN HANDICRAFTS

The wood of many Juglandaceae is prized for its durability - but only for interior accessories, since it is generally not very durable and soon decays outside. It is used for high-end flooring, furniture and veneers, as well as for guitars, paddles, coffins, knobs, gunstock handles and a variety of other wood products. However, its high price is not only justified by the quality but also by the scarcity of the wood since, as mentioned above, the Juglandaceae are not readily available for mass timber production. In the past and up until now in tropical regions, Juglandaceae trees were highly sought-after and overexploited. They therefore became extremely rare locally. They are very often the first species to be removed when virgin forests are logged.

Some members of the *Juglans* genus undoubtedly possess wood of the highest quality, mainly *J. regia, J. cinerea, J. nigra*, and to lesser extent, *J. ailantifolia* and *J. mandshurica*. Given its technical and aesthetic qualities, walnut wood has historically been rated and marketed on a par with mahogany.

The wood of the *Carya* species also has multifunctional uses, mainly due to its elasticity. The best quality wood is obtained from the so-called "true hickories" (*C. ovata, C. laciniosa, C. tomentosa* and *C. glabra*). The wood quality of the "pecan-hickories" (*C. illinoinensis, C. aquatica, C. cordiformis* and *C. myristiciformis*) is inferior but nevertheless exceeds that of ash or oak.

Nearly all other Juglandaceae are exploited by local societies and/or by the regional timber industry. *Pterocarya fraxinifolia* wood is used in Transcaucasia for furniture and match production, whilst in Japan, *P. rhoifolia* is used to make tea-chests and for firewood. Tropical Engelhardioideae wood is soft, light and not very weather-resistant. Nonetheless, the *Engelhardia* species is a popular choice for interior accessories, tea-chests, piles and even in canoe production. *Alfaropsis roxburghiana* wood is used in various aspects of construction and gardening tools. The wood of the Central American taxa (*Alfaroa* and *Oreomunnea*) is also light-weight, very soft and not very durable. However, it has been used in house construction, interior finishes, cabinet-making and even in the production of baseball bats (*O. mexicana*).

2-3. Wood and furniture made of *Juglans regia*.





FRUITS

Fruit-growing is only important for genera with large, edible seeds: *Juglans* and *Carya*. There are no reports on the utilisation of *Alfaroa* fruits in Central America, the third genus of Juglandaceae with relatively large nuts.

The Persian walnut (*Juglans regia*) undoubtedly produces the most fruit. Its seed kernels are eaten raw, roasted, salted as snacks or used in cooking, confectionery, pastries, cakes and ice creams, etc. The combination of fats, protein, and fibre in walnuts increases satiety, which makes them a great snack compared to simple carbohydrate foods such as chips or crackers. Young green fruits are pickled in vinegar and eaten ("pickled walnuts") in the United Kingdom. Walnuts can be preserved in sugar syrup and eaten whole in Armenian and Azerbaijan cuisine. In Italy, liqueurs called *Nocino* and *Nocello* are flavoured with walnuts. China, Iran and USA are the main producers of Persian walnut fruits. Nearly all other *Juglans* seeds are edible and widely appreciated locally, especially *J. nigra, J. cinerea* and *J. cordiformis* in North America, *J. neotropica* in the South American Andes, or *J. cathayensis* in China.

The pecan (*Carya illinoinensis*) is the second most important fruit crop of Juglandaceae. The seeds have a buttery flavour and a high percentage of lipids. They can also be eaten fresh or used in cooking and in confectionery (desserts, cakes, bread, candies, etc.). The main producer is the USA but important production areas also exist in Australia, Brazil, China and South Africa. Several other hickories are cultivated for their fruits, either on an industrial scale (especially in North America: *C. ovata, C. laciniosa* and *C. glabra*), or on a local scale (e.g., *C. tonkinensis* in Vietnam, and *C. cathayensis* and *C. hunanensis* in China).

1-2. *Juglans regia* orchard. Broye, Switzerland (sb)

3-4. The edible seeds of *Juglans regia* are the most popular of all the Juglandaceae. Walnuts from Turkey (3) and Switzerland (4) (ek)

5-7. The pecan (*Carya illinoinensis*) is the second most important fruit crop of Juglandaceae (ek)

8. Keychain made from *Juglans neotropica* nuts. Colombia (ac)

OIL

In Europe and Asia, the oil is extracted mainly from *Juglans regia* seeds (both cold-pressed and refined). Given its high prices and because heating reduces the flavour of the oil and produces a slight bitterness, walnut oil is used less often than other oils for cooking purposes but is the oil of choice in cold dishes such as salad dressings. Walnut oil was one of the main oils used by Renaissance painters. It is still used by some carpenters today as a finish to improve the shine on furniture. This high-quality oil can also be extracted from *J. nigra* and *J. ailantifolia*, as well as from the seeds of some *Carya* species. So-called "pecan-oil" is obtained from *C. illinoinensis* and is used mainly for culinary purposes and occasionally for heating or lighting. In China and Vietnam, oil extracted from *C. tonkinensis* and *C. hunanensis* seeds is used for cooking, sometimes in soap production and for lighting.

1. Oil extracted from the seeds of *Juglans regia*. Switzerland (ek)

POISONING AND TOXICITY

Most indigenous cultures across the world use poisonous plants to catch fish. A variety of chemicals found in these plants (called ichtyotoxins or piscicides) will stun fish, which then float to the surface for easy capture. The most well-known example of the Juglandaceae family involves the use of the crushed leaves and branches of *Pterocarya fraxinifolia* for fishing in Transcaucasia (mainly Iran) and *P. tonkinensis* in Vietnam. Another example comes from the USA, where several indigenous populations (Catawba, Cherokee and Delaware) used bark and unripe green husks of *Juglans nigra* and *Carya illinoinensis* to poison fish. In Nepal, two further Juglandaceae species, *J. regia* (unripe husks) and *Engelhardia spicata* (juice obtained from bark), are used as piscicidal agents. Finally, *Platycarya strobilacea* in Vietnam and *Alfaropsis roxburghiana* in Sumatra serve the same purpose.

Moreover, horses and ponies have been known to contract inflammation of the foot in cases where walnut wood chips or sawdust are used for stall bedding (mainly *J. nigra*). Pollen shedding from walnut trees can cause allergic reactions in people and horses. Furthermore, husks of fallen walnuts can prove toxic to livestock, and lethal to dogs if ingested. This is due to mycotoxin which is produced by the *Penicillium* mould in decomposing and rotten black husks.

The most active substance in the Juglandaceae, namely juglone (5-hydroxy-naphtoquinone), occurs naturally in all parts of the trees, mainly in the genera *Juglans, Carya* and *Pterocarya*. Many cultivated and wild plants (e.g., tomato, potato, blueberry, apple, alder, birch, etc.) may be damaged or killed within the root zone of the Juglandaceae trees (so called allelopathic effect). The toxic zone from a mature tree can extend over a radius of up to 25 metres from the trunk (in the case of *Juglans cinerea, J. nigra* and *J. regia*, for instance).



2-4. Poisoning of fish using Juglandaceae leaves, bark or fruit is very popular in many regions across the world. Picture: use of *Pterocarya tonkinensis*. Nang Phai, Son La province, Vietnam (hvs)

TANNING AND STAINING/DYEING

The leaves, green husks and bark of Juglandaceae contain very high concentrations of tannins, juglone and other related substances which have been widely used for tanning and staining/dyeing purposes for hundreds if not thousands of years. In Europe the main species used in these industries is *Juglans regia*, whilst *J. nigra* and *J. cinerea* are used in North America. Juglone obtained from these taxa is used as a dye for wood, wool, clothes, inks, food and cosmetics, generating a broad palette of brown shades (ranging from yellow to black). Several other Juglandaceae are used for tanning and dyeing purposes. These include *Carya illinoinensis* in the USA, *Juglans neotropica* in the South American Andes, *J. mandshurica* in China as well as *Platycarya strobilacea* and *Rhoiptelea chiliantha* in Eastern Asia.

MEDICINE

The number of studies corroborating the pharmacological properties of Juglandaceae is growing exponentially. The list covering all known and potential uses of these plants in modern medicine exceeds the scope of this book. Large varieties of active substances and other chemical compounds present in Juglandaceae are known to possess antioxidant, antihypercholesterolaemic, antidiabetic, anti-inflammatory, anticancer, anti-amyloidogenic, antiviral and antimicrobial properties. The most promising results have been documented in treatments for Alzheimer's disease and various cancers. It is difficult to imagine how many other compounds and potential medical uses have yet to be discovered, particularly amongst tropical Juglandaceae, which have not been studied in depth.

At the same time, the walnut family has a long history of traditional medicinal use. The most important species from a therapeutic perspective is *Juglans regia*. In Ancient Greece and Rome, and in traditional Chinese medicine, various parts of this tree were used to treat a wide range of ailments and complaints. It is impossible to list all of the ancient and modern-day medicinal uses of this species within the scope of this book. The seeds are reported to possess antilithic, diuretic and stimulant properties. Internally, they are used to treat back pain, frequent urination, weak legs, chronic cough, asthma, constipation and stones in the urinary tract. Externally, the seeds are used in the management of dermatitis and eczema. The bark has anthelminthic, astringent and detergent properties whilst dried, powdered bark is used as a strong purgative infusion.

Many other Juglandaceae are used locally in traditional medicine. In North America, *Carya illinoinensis* is used as a tuberculosis remedy in traditional Mexican medicine (known as the "Kiowa drug"). In Transcaucasia the stem, bark and fruits of *Pterocarya fraxinifolia* have been used as a diaphoretic agent. *Pterocarya stenoptera* is highly revered in traditional Chinese medicine and is used to treat chronic bronchitis, joint pain, itching due to scabies, dermatitis and eczema, burns and scalds. *Cyclocarya paliurus* leaves have been widely used to treat metabolic disorders, including hyperlipidaemia, obesity, diabetes and hypertension. The herbal infusion composed of dried leaves is said to significantly lower sugar and fat levels in the blood. The infructescence of *Platycarya strobilacea* is a well-known traditional medicine in China, Japan and Korea, and is used to treat certain types of cancer.

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1. Black walnut (*Juglans nigra*) tincture can be used in anti-parasite cures (ek)

2-3. *Cyclocarya paliurus* leaves are very popular in traditional Chinese medicine to treat obesity and diabetes amongst other diseases (ygs)

4. *Juglans regia* leaves are used to promote the rapid healing of inflammation on the outer surface of the skin (ek)

Ripening fruits of *Carya illinoinensis* in a pecan orchard. Florida, USA (ag)

The most diverse countries in terms of the highest number of Juglandaceae species (China, USA), the highest number of genera (China, Vietnam), or countries with the most impressive or threatened members of the family (Costa Rica, Cuba).

Hotspots and highlights

Forest dominated by shagbark hickory (*Carya ovata*), with scattered individual bitternut hickory trees (*C. cordiformis*). Blue Hills Reservation, Massachusetts, USA (sb)

CHINA

Mountain forests dominated by *Pinus hwangshanensis* (Pinaceae). Huang Shan, Anhui, China (ek)

China is undoubtedly the primary centre for living Juglandaceae. All but two genera of the walnut family are represented with at least one species within its borders – only the Mesoamerican engelhardioid genera, *Alfaroa* and *Oreomunnea*, are missing here. With more than 20 species (approx. 30% of all Juglandaceae), nearly half of them endemic, the country is simply a *must* for any researcher and enthusiast of these relict trees.

All four monotypic Juglandaceae genera can be found in China: *Rhoiptelea* (*R. chiliantha*), *Platycarya* (*P. strobilacea*), *Alfaropsis* (*A. roxburghiana*) and *Cyclocarya* (*C. paliurus*). Thus, the two oldest members of the family (*Rhoiptelea* and *Cyclocarya*) survived earlier climatic changes in this area.

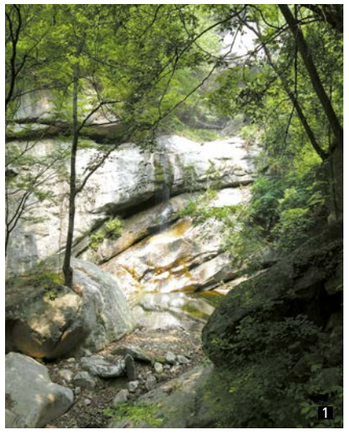
Engelhardia is represented by three Chinese flora species: *E. serrata*, *E. spicata* and the endemic *E. hainanensis*. The *Carya* genus represents 5 species in the country with *C. sinensis, C. tonkinensis* and the three endemic species, namely *C. cathayensis*, *C. hunanensis* and *C. kweichowensis*. Similarly, the *Juglans* genus has 5 recognised species in the country - *J. mandshurica*, *J. regia*, *J. sigillata* and the two narrow endemics, *J. hopeiensis* and *J. cathayensis*.

China is a global centre of the *Pterocarya* genus, with four out of six living species of the genus growing in the country. In addition to widespread *P. stenoptera* and the almost exclusively tropical *P. tonkinensis*, there are two Chinese endemics, *Pterocarya hupehensis* and *P. macroptera*. The presence of *P. rhoifolia*, described by Laoshan (Shandong), is nowadays in doubt.

The Chinese Juglandaceae are mostly concentrated in the country's south-western provinces, growing in temperate and sub-tropical forests. The northernmost distribution comprises *J. mandshurica*, crossing the 50°N line of latitude in North-Eastern China (Mandshuria). On the other hand, some species of Juglandaceae are performing very well in, or are even restricted to, tropical China (e.g. Southern Yunnan and/or Hainan Island). This applies to the *Engelhardia* species, *Rhoiptelea chiliantha*, *Alfaropsis roxburghiana*, *Carya sinensis* and *C. tonkinensis* as well as *Pterocarya tonkinensis*.

1-3. China is an undisputable centre of the generic diversity of extant Juglandaceae. *Platycarya strobilacea* (1, Zhenwuding, Henan), *Pterocarya hupehensis* (2, Hekou, Henan), *Cyclocarya paliurus* (3, Youlu, Henan) (ygs)

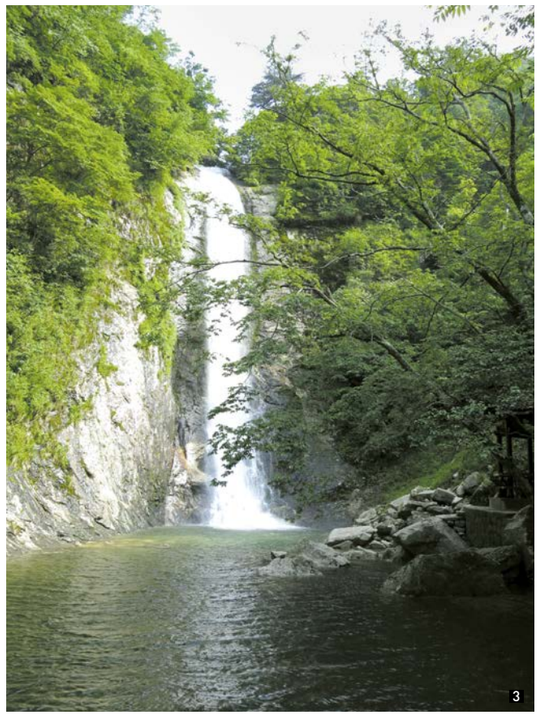
4. China is home to countless protected areas, nature reserves and national parks of unique biodiversity and beauty. Tai Bai Shan National Forest Park, Shaanxi, China (ygs)



1. Relict forests survived in central China almost exclusively in mountainous areas. Nanyang, Henan, China (sb)

2. One of the most symbolic relict trees of China: *Ginkgo biloba* (Ginkgoaceae). Natural population in Tianmu Shan, Zhejiang, China (sb)

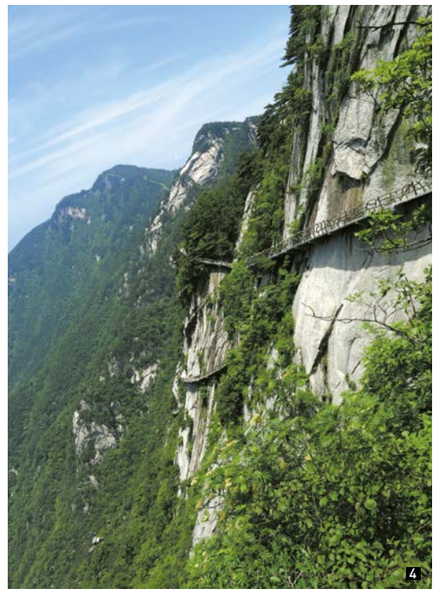
3-5. Forests of *Zelkova schneideriana* (Ulmaceae), yet another famous relict tree endemic to China. Dabie Shan, Hubei, China (sb)



6. *Clerodendron yunnanense* (Lamiaceae), shrub that grows to a height of 2-3 m. Gui Shan, Yunnan, China (ek)

7-8. *Rosa omeiensis* (Rosaceae), another dendrological Chinese treasure. Napahai, Yunnan, China (ek)

9-12. China is a country of contrasts. Old traditions and ancient towns exist alongside high-tech and breath-taking mega cities. Traditional shop with natural products (9, Shu He, Yunnan), Shanghai (10), old town of Shu He in Yunnan (11), member of the Naxi minority collecting mushrooms (Napahai, Yunnan) (ek)



The tropical and sub-tropical forests of China are home to countless insects. Left: jewel bug (*Poecilocoris lewisi*, Scutelleridae). Its iridescence is due to structural coloration. Instead of pigments, the colours are caused by the interference, diffraction, or scattering of light by numerous tiny structures. Right: the cicadas (*Cicada* sp., Cicadidae) are large insects that can easily be detected due to the loud courtship calls of the males. Huang Shan, Anhui (ek)

VIETNAM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Forests with *Carya sinensis*. Cuc Phuong National Park, Vietnam (ek)


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Vietnam is the walnut family's second main centre of generic diversity worldwide. With some 10 known species representing 6 genera, it ranks close behind China. With its complex topography and diverse climatic conditions, the country is home to many astonishing and endangered plants and animals. With 12,300 known vascular plants, including approximately 1,500 tree species, Vietnam is one of the most biodiverse countries on Earth.

The rain-laden mountains of Northern Vietnam are the most diverse area for Juglandaceae. *Rhoiptelea chiliantha*, *Platycarya strobilaceae*, *Carya tonkinensis* and *C. poilanei* in particular are found almost exclusively in this area. Contrastingly, *C. sinensis*, *Alfaropsis roxburghiana* and the two Vietnamese *Engelhardia* species (*E. serrata* and *E. spicata*) can be found from north to south, but mainly at higher elevations.

Two *Pterocarya* species have been identified in this country, namely *P. stenoptera* and *P. tonkinensis*. They grow in lowland riparian forests, mainly in the northern part of the country. The exact distribution area of these and other Juglandaceae, is unclear. New and intensive field work, herbaria and literature searches are clearly needed.

Nearly all Vietnamese Juglandaceae are important useful plants. They are used by local communities for timber production, fruit and oil extraction (e.g. *Carya tonkinensis*), traditional medicine and fish poisoning (e.g. *Pterocarya tonkinensis*). Furthermore, *Juglans regia* (non-native to Vietnam) is very popular and is often cultivated for its edible seeds.

1-3. *Alfaropsis roxburghiana* is one of the Juglandaceae highlights of Vietnam. It is a typical member of the engelhardioid subfamily, with even-pinnate leaves (1, 2) and 3-winged fruits (3). Pictures taken in the Botanic Garden of the Vietnam National University of Forestry, Hanoi (1, ek), Cuc Phuong National Park (2, ek), and Pu Mat National Park (3, hvs)

4. Field surveys of Juglandaceae in tropical forests are a real challenge, requiring considerable endurance and experience. Cuc Phuong National Park (ek)

1-3. *Saraca dives* (Fabaceae) grows in Vietnam together with *Carya sinensis* and *Alfaropsis roxburghiana*. The species is striking thanks to its large orange flowers (1, 2). Its young pendant leaves (3) are edible and highly appreciated by local people. Pictures taken in Cuc Phuong National Park (1, 2) and Ba Vi National Park (3), North Vietnam (ek)

4-5. *Bombax ceiba* (Bombacaceae) grows to a height of up to 60 m. The trunk bears numerous conical spines (4). The large flowers (up to 15 cm in diameter) appear when the tree is bare without any leaves (5). Cuc Phuong National Park, Vietnam (ek)

6. The black bat flower (*Tacca chantrieri*, Dioscoreaceae) is found on the forest floor with *Carya sinensis*. Cuc Phuong National Park, Vietnam (ek)

7-8. Con Dao and 15 small neighbouring islands in the South China Sea are home to many rare and endangered plants and animals. Con Dao National Park, Vietnam (ek)

9-10. An isolated population of *Engelhardia spicata* was discovered in 2017 during the field surveys for this book. It is the first time a Juglandaceae species has been spotted in the Con Dao National Park. Pictures show *E. spicata* fruits from the Geneva Herbarium in Switzerland (9, gk) and the leaves of the newly discovered plants on Con Dao island, Vietnam (10, ek)

11-13 Vietnam is a rapidly developing country that is steeped in history. As in many other regions, the relict trees and their natural populations have survived in mainly remote, mountainous areas (ek)


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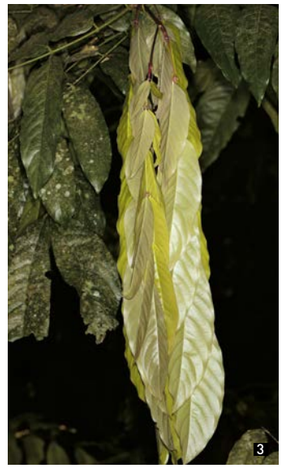
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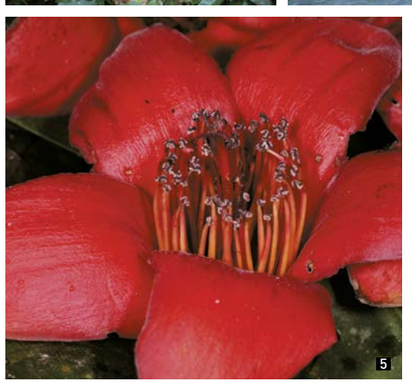
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UNITED STATES OF AMERICA

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The eastern and western coasts of the United States have played a major role as climatic refugia for a variety of relict trees (e.g. *Diospyros*, *Liquidambar*, *Gleditsia*). The country is particularly important for the Juglandaceae family. Six *Juglans* species are found within its borders. Even more remarkable, the USA is the global centre of diversity for the *Carya* genus, boasting 11 of the 18 species found worldwide.

Hickories and pecans (*Carya*) are distributed almost exclusively in the eastern half of the country and are common in numerous forest communities ranging from temperate broad-leaf forests in the north (*C. ovata*, *C. tomentosa*, *C. glabra*, *C. cordiformis*) to strips of inundated forests and flood plains along the south-eastern coast (*C. aquatica*, *C. myristiciformis*, *C. laciniosa*). Two species can be found in the vicinity of the Mississippi river (*C. texana*, *C. illinoinensis*). *Carya pallida* grows along sandy uplands in South-Eastern USA, and *C. floridana* (endemic to Florida) is an element of sand-pine scrubs.

Although the majority of the *Carya* species is not in jeopardy, attention should focus on protecting the last populations of the very rare *C. myristiciformis* and, more generally, the alluvial plains and hydrological dynamics of rivers and flooded forests. The wood of the *Carya* species is in demand because of its hardness, strength and shock resistance. It is also widely used as charcoal for cooking and flavouring food. The pecan (*C. illinoinensis*) is the only species to generate a considerable commercial interest, leading to breeding and selection programmes in the country.

Among the 6 species of walnuts (*Juglans*) native to the USA, only two species (*J. nigra* and *J. cinerea*) have a wide distribution and are frequently found in the country's central and northern forests. *Juglans major* and *J. microcarpa* reach their northern limit of distribution in Southern USA, while significant populations of *J. major* and a few populations of *J. microcarpa* can be found in Mexico. The country's most threatened species are *J. hindsii* and *J. californica*, which are sometimes considered varieties of the same taxon. Both Californian endemic species are extremely rare and final preservation hopes are pinned on an *ex situ* conservation programme.

1-2. The United States is the global centre of two genera, namely *Carya* and *Juglans*. Shagbark hickory (1, *Carya ovata*) and black walnut (2, *Juglans nigra*) (hrs)

3-4. Generally, the North American *Carya* species possess leaves with fewer leaflets compared to members of the *Juglans* genus (longer leaves, with a higher quantity of slender leaflets). Shagbark hickory (1, *Carya ovata*) and little walnut (2, *Juglans microcarpa*) (hrs)

Blue Hills Reservation with forests of shagbark hickory (*Carya ovata*) and bitternut hickory (*C. cordiformis*). Massachusetts, USA (sb)

1. The United States is home to many relict woody species. However, old growth bottomland hardwood forests have been severely downsized for human purposes (mainly forestry and farming) in the southern part of the United States. Bald cypress (*Taxodium distichum*, Cupressaceae) and water tupelo (*Nyssa aquatica*, Nyssaceae). Congaree National Park, South Carolina, USA (sb).

2-4. The Hind's black walnut (*Juglans hindsii*) is endemic to the western region of the United States. Although often planted along roads, its natural populations are extremely rare and the species remains one of the most endangered Juglandaceae worldwide. Sunrise Park, California, USA (bf)

5. The water hickory (*Carya aquatica*) and bald cypress (*Taxodium distichum*, Cupressaceae) along Guilliard Lake, Francis Marion National Forest, South Carolina, USA (sb)

6. Water hickory fruits (*Carya aquatica*). Francis Marion National Forest, South Carolina, USA (sb)

7. Blue Hills Reservation with forests of shagbark hickory (*Carya ovata*) and bitternut hickory (*C. cordiformis*). Massachusetts, USA (sb)

8. Closer view of the exfoliating bark of shagbark hickory (*Carya ovata*). Allandale, Massachusetts, USA (sb)

9. Bitternut hickory fruit (*Carya cordiformis*). The Arnold Arboretum of Harvard University, Massachusetts, USA (sb)

10-11. The US is no exception. Natural forests with relict trees are often restricted to protected and/or mountainous areas. The country has witnessed rapid changes in the use of land over the last few centuries. Vast areas have been transformed into farmland or are under relentless pressure from urbanisation. The mega city of Boston (10) and a cotton plantation (11) in Dorchester County, South Carolina, USA (sb)


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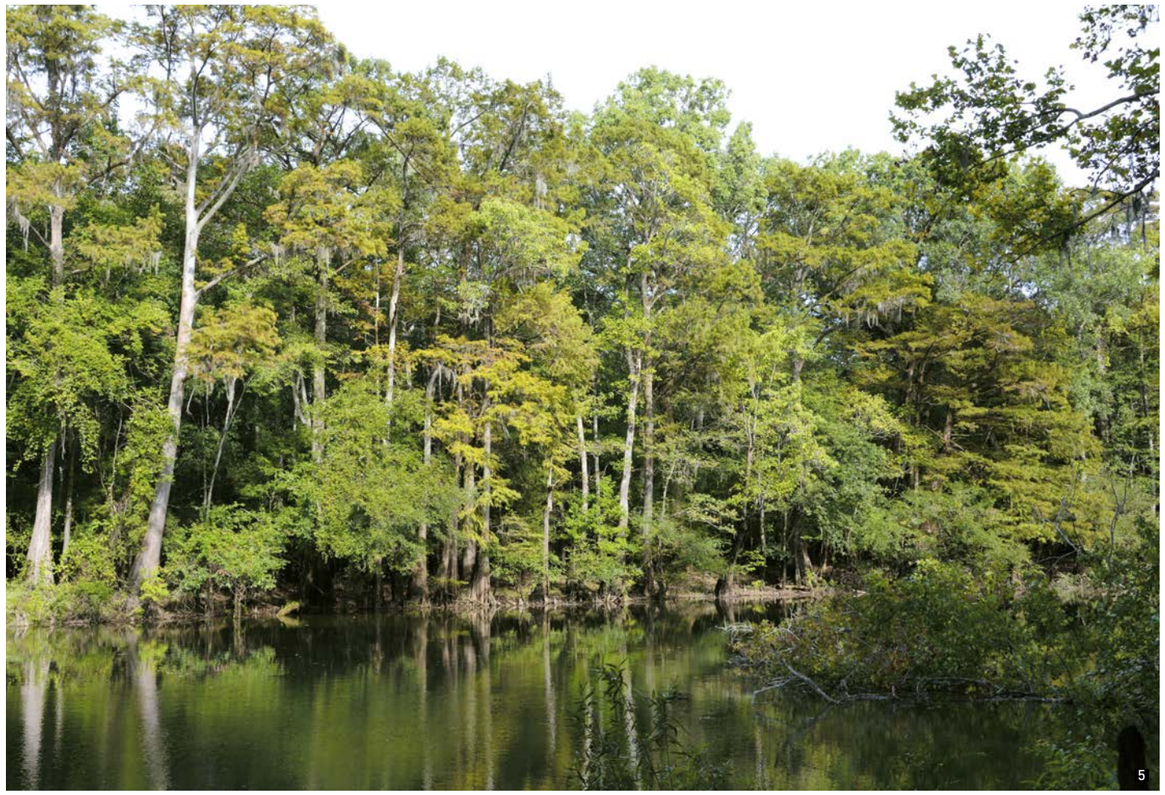
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CUBA

The Escambray Mountains have the most well-preserved mountain ecosystem in the central Cuban region. Topes de Collantes Nature Reserve Park, Cuba. (sb)

The Caribbean island of Cuba displays incredibly diverse ecosystems. The flora is particularly remarkable, with a vast spectrum of endemic species (more than half of the total 7,000 plants) and relatively undisturbed forests to explore. The island is the centre of diversity for many palms (e.g. *Coccothrinax*, *Copernicia*) and is home to numerous rare, endangered species. These include the only Juglandaceae on the island, *Juglans jamaicensis*, which is extremely rare and scattered over a few isolated semi-deciduous montane forests across the country.

Despite its name, *Juglans jamaicensis* was most certainly never present in Jamaica and was reported wrongly from the area. The taxonomy of this species is still unclear and the two subspecies - *J. jamaicensis* subsp. *jamaicensis* and *J. jamaicensis* subsp. *insularis* - are sometimes treated as two separate species. Independently of their taxonomic status, these two taxa need urgent conservation measures both *in situ* and *ex situ*, in order to assure a long term survival. The species often grow in small populations or as isolated individuals near streams or at the border between forested hills and cultivated lowland areas, confronted with high pressure from agriculture. Logging and ranching have also decreased the extension of their habitat.

J. jamaicensis subsp. *jamaicensis* is known from different islands of the Caribbean (Puerto Rico, Haiti, the Dominican Republic and Cuba). The taxon has almost completely disappeared from Puerto Rico (only one surviving population) and is probably under heavy stress in Haiti, due to the high rate of deforestation in the country. The situation seems to be better in the Dominican Republic, with more than twenty population existing in the Cordillera Central and Septentrional. In Cuba, the taxon grows scattered in two distinct areas: in central Cuba, within the Escambray Mountains, and in the east in the Sierra Maestra.

Juglans jamaicensis subsp. *insularis* is endemic to Cuba and grows exclusively in the Pinar del Rio province. However, the recent discovery of a small population of this subspecies in central Cuba shows that the exact distribution of this taxon is not completely known and that field explorations are still necessary.

1-2 Seedling and nuts of *Juglans jamaicensis* subsp. *jamaicensis*. Local communities used to grow a coffee plantation under the shadow of the canopy. Young *J. jamaicensis* seedlings are destroyed and the natural regeneration of the species is no longer guaranteed. Topes de Collantes Nature Reserve Park, Cuba (sb)

3. *Juglans jamaicensis* subsp. *jamaicensis* in an *ex situ* culture at the Botanic Garden of Cienfuegos, Cuba (sb)

1. *Juglans jamaicensis* subsp. *jamaicensis* tree covered with epiphytes. Topes de Collantes Nature Reserve Park, Cuba (sb)

2. *Juglans jamaicensis* subsp. *insularis* sometimes grows just a few meters behind banana and guava plantations. Viñales National Park, Cuba (sb)

3-4. *Rondeletia odorata* (3, Rubiaceae) and *Ginoria americana* (4, Lythraceae) often grow in forest patches with *J. jamaicensis* subsp. *jamaicensis*. Topes de Collantes Nature Reserve Park, Cuba (eg)

5. Viñales National Park, located in the province of Pinar del Rio (western Cuba), is internationally renowned for its cigar production and astonishing landscape comprising steep, isolated hills called *mogotes*. But the National Park also preserves some of the most threatened species of the Caribbean (including *J. jamaicensis* subsp. *insularis*). Viñales National Park, Cuba (sb)

6. *Hypericum styphelioides* (Hypericaceae). Viñales National Park, Cuba (eg)

7. Viñales National Park is an important location for rare and threatened species, such as *Microcycas calocoma* (Zamiaceae), a monospecific genus of cycads. Just 600 individuals exist in the province of Pinar del Rio (sb)

8-9. Cuba is not a virgin island. Agriculture is still vital to local communities who exploit accessible fields even within the national parks. Village of Viñales (8) and Viñales National Park (9), Cuba.

10. Hurricanes pose another threat to local fauna and flora. Banao Ecological Reserve following a hurricane in 2017 (sb)

The northern curly-tailed lizard (*Leiocephalus carinatus*, Leiocephalidae) is relatively easy to observe in Cuba. Playa Jibacoa, Mayabeque, Cuba (eg)

Contrastingly, the Cuban crocodile (*Crocodilus rhombifer*, Crocodylidae) is on the brink of extinction and can be seen in the crocodile-breeding station at Boca de Guamá. Matanzas, Cuba (eg)

COSTA RICA

Cloud forest with *Oreomunnea mexicana*. Tapanti National Park, Costa Rica (ek)

Although Costa Rica is a small country, its diverse habitats are home to nearly 10,000 native plant species, including approximately 2,000 trees. Several environmental factors are responsible for this wealth of diversity: tropical latitude and the country's specific location amidst two big continental masses and two vast oceans combined with its geology and climate. Costa Rica is also a regional centre of species diversity for the two exclusively Neotropical genera of Juglandaceae: *Alfaroa* and *Oreomunnea*.

Four out of five species of *Alfaroa* (*A. costaricensis*, *A. guatemalensis*, *A. manningii* and *A. williamsii*), and the two species of *Oreomunnea* (*O. mexicana* and *O. pterocarpa*) grow in Costa Rica. These are the highest figures recorded in any of the Mesoamerican countries. The Cartago Province in particular, which is a type locality for both genera, has the richest concentration of species. Only *Alfaroa mexicana* has not been found in Costa Rica.

Members of the *Oreomunnea* and *Alfaroa* genera are typical elements of mountain cloud forests, and often grow together with other trees belonging to temperate families and genera (e.g. *Quercus*, *Alnus*, *Viburnum*, *Staphylea*, etc.). Very occasionally, isolated trees of both genera can be found at lower altitudes. Some of the largest trees (especially *O. pterocarpa*) can still be found in certain Costa Rican provinces and are stately once formed, but extensive logging in the past has considerably reduced the populations.

The indisputable highlight of this country is the incredible *Oreomunnea pterocarpa*. Due to its size (some trees can reach a height of 60 m), often buttressed trunk, and its large winged fruits, the tree is one of the most impressive Juglandaceae in the world.

Interestingly, Costa Rica (as well as neighbouring Panama) has no native walnuts (*Juglans*). However, several species naturally occurring in Central and South America, are occasionally planted, such as *J. olanchana* (native from Mexico to Nicaragua) and *J. boliviana* (native to Bolivia and Peru).

1-3. Costa Rica is the diversity centre for the two exclusively Neotropical genera of Juglandaceae: *Alfaroa* and *Oreomunnea*. *Alfaroa williamsii* (1) and *Oreomunnea pterocarpa* (2, 3). Pictures taken in the Juan Castro Blanco National Park, Costa Rica (1, eva), the Geneva Herbarium, Switzerland (2, gk) and in Aquiares next to Turrialba at 1,000 m. a.s.l., Costa Rica (3, eva).

1-2. In the Tapanti National Park, *Oreomunnea mexicana* often co-exists alongside *Quercus bumelioides* (Fagaceae) (ek)

3-4. Trees from the Melastomataceae family often accompany *Oreomunnea* and *Alfaroa*: *Blakea tuberculata* (3) and *B. anomala* (4). Tapanti National Park, Costa Rica (ek)

5. Impenetrable cloud forests of the Tapanti National Park, Costa Rica (ek)

6. *Psychotria poeppigiana* (Rubiaceae). Corcovado National Park, Costa Rica (ek)

7. *Tillandsia insigne* (Bromeliaceae) is a common epiphyte growing on *Oreomunnea mexicana*. Tapanti National Park, Costa Rica (ek)

8. Many lianas and epiphytic Ericaceae are typical elements of Costa Rican cloud forests with *Oreomunnea* and *Alfaroa*. *Satyria warszewiczii*. Tapanti National Park, Costa Rica (ek)


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Costa Rica is also a hotspot of animal diversity (ek):


Northern tamandua (*Tamandua mexicana*, Myrmecophagidae)


Mantled howler (*Alouatta palliata*, Atelidae)


Keel-billed toucan (*Ramphastos sulfuratus*, Ramphastidae)


Plumed basilisk (*Basiliscus plumifrons*, Corytophanidae)


Shield mantis (*Choeradodis rhombicollis*, Mantidae)


Red-eyed tree frog (*Agalychnis callidryas*, Hylidae)


American crocodile (*Crocodilus americanus*, Crocodylidae)

Oreomunnea mexicana tree with very rich epiphyte flora. Tapanti National Park, Costa Rica (ek)

FUTURE

The uncertain future of relict trees

The main aim of this book is to encourage ongoing and new conservation and research efforts focusing on relict trees worldwide, by portraying the beauty, importance and diversity of the Juglandaceae family.

Various stages in the evolution of our planet have resulted in the appearance of more than 60,000 extant tree species (about 20% of all vascular plants). In many regions, trees dominate the landscape. They play an inestimable role in maintaining the high level of biodiversity and provide vital necessities in the daily life of numerous local communities. However, this incredible wealth is in peril as approximately 10,000 trees are threatened with extinction.

The future of relict trees, and therefore of all members of the Juglandaceae family, is uncertain. Many of these ancient organisms and their forests are threatened by deforestation, accelerated land use and climate change.

Relict trees possess an enormous scientific value. Since many of the Juglandaceae genera (and perhaps even species) evolved more than 50 Mya, they represent ancient organisms that have outlived changing environmental conditions for millions of years. They provide a unique opportunity for researchers, serving as a window to the past as well as the future. Relict trees and their communities are ideal natural laboratories for studying how long-term changes impact species and populations. Although many Juglandaceae are rare and threatened, they could well play an important future role in maintaining ecosystem functions in times of rapid global change.

Trees, and especially relict trees, possess all the attributes of charismatic species. Charisma is closely associated with the aesthetic, ecological or corporeal attractiveness of a given species. Trees have fascinated humans for thousands of years by virtue of their age, size, vigour or beauty. However, to date, the notion of a charismatic or flagship species has mostly been applied to wildlife and to megafauna in particular. Recently, several international conservation organisations called for forests and trees to be classed as *megaflora*, giving them a special role in heightening the awareness of the general public, decision makers and the worldwide scientific community. The leading institutions in this field are Fauna and Flora International (FFI, www.fauna-flora.org), the Global Trees Campaign (GTC, www.globaltrees.org), Botanic Gardens Conservation International (BGCI, www.bgci.org), and the IUCN/SSC Global Tree Specialist Group (GTSG). The authors and contributors of this book fully endorse these efforts to promote awareness and conservation actions.

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1-2. Intensive field surveys and new expeditions are necessary in order to improve the biogeographical and biological knowledge of the Juglandaceae family. The pictures show an investigation of *Alfaroa williamsii* leaves (1) in the Juan Castro Blanco National Park, Costa Rica, and identification of the fruit of *Oreomunnea pterocarpa* and *O. mexicana* (2), from Aquiares (Turrialba), Costa Rica (eva)

Conservation and research needs

IUCN RED LIST OF THREATENED SPECIES

Knowledge of the conservation status of the entire Juglandaceae family and of particular species is highly fragmented. To date, only 19 species of Juglandaceae have been globally assessed using IUCN criteria and appear in the IUCN Red List of Threatened Species (www.iucnredlist.org). However, these IUCN assessments were carried out twenty years ago (1998) and require revision. The only exception is *Juglans regia*, the conservation status assessment of which was updated in 2017. Hence over 70% of all members of the walnut family have never been evaluated, either at local or global level. Among the assessed taxa, the IUCN lists the following 4 severely threatened species of Juglandaceae (category EN, endangered): *Oreomunnea pterocarpa*, *Carya sinensis*, *Juglans neotropica* and *J. olanchana*. *Oreomunnea pterocarpa* is also the only Juglandaceae listed in Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora).

The existing IUCN assessments available online reflect the general and severe shortfalls of biogeographic and phylogenetic knowledge of the walnut family. First and foremost, numerous species on the IUCN list need thorough taxonomic and nomenclatural revision. This applies to *Alfaroa hondurensis*, for instance, which, based on the latest findings, should probably be included under *A. guatemalensis*. Similarly, in the *Engelhardia* genus, three narrow endemics described in the Sabah region of Malaysia, with dubious taxonomic status (*E. kinabaluensis*, *E. danumensis* and *E. mendalomensis*), are included as full species in the IUCN Red List. Moreover, *Juglans hindsii* is included in *J. californica* whereas *J. jamaicensis* subsp. *insularis* is treated as a separate species. Furthermore, none of the assessed Juglandaceae species has an electronic distribution map in their online IUCN profiles. This clearly shows that new global conservation status assessments of all extant Juglandaceae species are urgently required.

EX SITU CONSERVATION

According to the Global Strategy for Plant Conservation (GSPC) of the Convention on Biological Diversity (CBD, www.cbd.int/gspc), all signatory countries are obliged to keep *at least 75% of threatened plant species in ex situ collections, preferably in the country of origin, with at least 20% available for recovery and restoration programmes* by 2020 (GSPC Target 8). The global survey of *ex situ* collections of Juglandaceae has never been undertaken. However, it is highly likely that many temperate species are well represented in botanic institutions (botanic gardens and arboreta), especially in countries with a strong horticultural tradition (e.g. USA, Germany, United Kingdom and France). Nevertheless, this is most probably not the case for the majority of tropical taxa, such as *Alfaroa* and *Oreomunnea* species in Mesoamerica, and *Carya* and *Engelhardia* species in South-Eastern Asia, Philippines and/or on the Sunda Islands.

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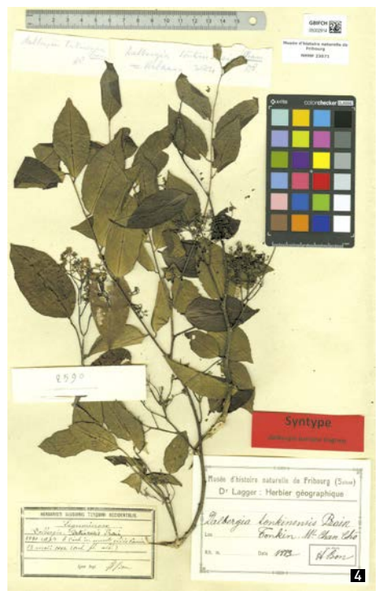

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KNOWLEDGE SHORTFALLS AND RESEARCH NEEDS

The Juglandaceae family has fascinated naturalists and researchers around the world for centuries. Thanks to numerous specific and monographic studies (see the References section at the end of the book), the family is better equipped in terms of general biological knowledge compared to other plant families. Nevertheless, many aspects of Juglandaceae taxonomy, biology and biogeography have barely been explored, if at all, which significantly hampers efficient conservation measures and the setting of priorities. This applies to tropical members of the family in particular.

As for many other plant groups, there are two main knowledge-related shortfalls:
(1) **Linnean shortfall** (named after the famous taxonomist, Carl von Linné) which refers to our limited knowledge of the number of species/taxa in a given group. The *Pterocarya* genus *per se* requires a thorough taxonomic update. The same applies to all other larger genera of Juglandaceae, but especially *Engelhardia*, *Alfaroa*, *Carya* and *Juglans*, with numbers of species still being disputed.

(2) **Wallacean shortfall** (named after the biogeographer and evolutionary biologist, Alfred R. Wallace) which refers to our inadequate knowledge of the global and regional distribution of a given taxon. Distribution knowledge of Juglandaceae is highly fragmented, and published or online maps are very imprecise or sketchy. As for the majority of plant families, there is no centralised database with detailed and georeferenced distribution data on Juglandaceae. Chorological knowledge is particularly sparse in mountainous tropical regions due to complex topography and inaccessibility (e.g. in Central and South America, in the Indo-Malayan region and on the Sunda Islands in South-Eastern Asia).

Apart from these two obvious shortfalls concerning taxonomy and biogeography, more research is also needed in all other domains delivering crucial information for conservation biologists and practitioners in the field (e.g. population genetics, reproductive and germination biology, dispersal biology, mycorrhiza, herbivory, responses to abiotic factors, habitat requirements, community and population structure, etc.). Juglandaceae specialists will not be resting on their laurels any time soon!


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1. Herbaria play an important role in the taxonomic and biogeographical studies of any plant group. Juglandaceae collection of the Geneva Herbarium (G), Switzerland (gk)

2. Type specimen of *Oreomunnea munchiquensis* from Colombia. This recently described taxon requires thorough taxonomic revision. Geneva Herbarium (G), Switzerland (gk)

3. The herbarium of the Natural History Museum Fribourg (NHMF, Switzerland) possesses a unique collection, with a wealth of type specimens of the Vietnamese western Tonkin (*Herbarium missionis Tunquini occidentalis*). The plants were collected by French missionary and botanist Henri-François Bon (1844-1894) and are nowadays a very precious tool for exploring and describing the plant diversity of Vietnam (gk)

4. Example of a herbarium specimen from the Natural History Museum Fribourg (NHMF), Switzerland. The syntype of *Dalbergia boniana* from the Fabaceae family was collected in 1883 by Henri-François Bon in western Tonkin (Vietnam). The species is under threat in Vietnam due to over-exploitation of its precious wood (sb)

5. Botanic gardens and arboreta across the globe participate in the conservation and research of threatened relict woody taxa. *Ex situ* collection of *Pterocarya rhoifolia* at the Royal Botanic Garden Edinburgh, UK (ek)

6. Research partnership and networking are of paramount importance for any research and conservation project involving threatened relict trees. International team (G. Kozlowski, H.V. Sam and P.T. Ha) investigating *Carya sinensis* at the Botanic Garden of the Vietnam National University of Forestry. Hanoi, Vietnam (ek)

Conservation and research needs:

Genus	Linnean shortfall	Wallacean shortfall	IUCN Red List	Conservation needs
Rhoiptelea	Only one phylogenetically isolated and thus well accepted species.	Distribution known only superficially (especially in Northern Vietnam), based mainly on herbarium specimens. Schematic map for China in Fang *et al*. (2011)	*R. chiliantha*: **VU** (1998) Conservation status assessment update needed.	Establishment of new *ex situ* collections in China and Vietnam.
Engelhardia	Number of species debatable. Molecular phylogeny highly desirable using new sampling across the whole distribution range. Thorough taxonomic revision of dubious narrow endemics from the Sunda Islands.	Distribution known only superficially, based mainly on old herbarium specimens and literature. Very schematic distribution maps in Jacobs (1960). Table with distribution indications in Manning (1966).	*E. rigida*, *E. serrata* and *E. spicata*: **LC** (1998) *E. kinabaluensis*, *E. danumensis* and *E. mendalomensis*: **VU** (1998) Conservation status assessment update needed for the whole genus.	Establishment of new *ex situ* collections in countries and on islands of origin.
Alfaropsis	Only one species, displaced recently from *Engelhardia* (Manos *et al*. 2007) but still not always accepted as a separate genus by certain authors.	Distribution known only superficially. No distribution maps available. Table with distribution indications in Manning (1966).	**NE** (not evaluated) Conservation status assessment needed.	Establishment of new *ex situ* collections in countries and on islands of origin.
Oreomunnea	Number of species debatable. Molecular phylogeny highly desirable including the populations from Colombia. Thorough taxonomic revision of dubious *O. munchiquensis* species.	Distribution poorly known, especially for *O. pterocarpa*. An intensive survey of herbaria literature but new field expeditions needed in particular. Schematic map in Herrera *et al*. (2010).	*O. pterocarpa*: **EN** (1998) Conservation status assessment update needed for *O. pterocarpa* as well as new assessment for remaining species.	Establishment of new *ex situ* collections in countries of origin (with special priority given to botanic gardens and arboreta in Costa Rica). Global action plan for *O. pterocarpa* needed.
Alfaroa	Number of species debatable. Potential discovery of new species possible. Molecular phylogeny highly desirable. Thorough taxonomic revision of the dubious *A. colombiana*, *A. guanacastensis*, *A. hondurensis* species.	Distribution known only superficially. An intensive survey of herbaria literature but new field expeditions needed in particular. Schematic map in Herrera *et al*. (2010).	*A. mexicana* and *A. hondurensis*: **VU** (1998) Update of the existing conservation status assessments needed as well as new assessments for the remaining species.	Establishment of new *ex situ* collections in countries of origin (with special priority given to botanic gardens and arboreta in Costa Rica).
Carya	Global molecular phylogeny highly desirable. Number of species still debatable despite some global and regional molecular studies (e.g. Zhang *et al*. 2013a). This applies especially to narrow endemics of South-Eastern Asia.	In Eastern Asia, distribution known only superficially, especially for tropical species in Vietnam and Laos. Maps only for China in Fang *et al*. (2011). The distribution in North America is better documented, with distribution maps in the Flora of North America (www.eFloras.org). Global schematic map in Stone (1962).	*C. sinensis*: **EN** (1998) Update of the existing conservation status assessment needed as well as new assessments for all the remaining species.	Establishment of new *ex situ* collections in countries of origin (especially in Eastern Asia). Global action plan for *C. sinensis* needed. Several other species probably needing conservation actions (e.g. *C. myristiciformis*, and *C. floridana* in the USA, *C. palmeri* in Mexico and *C. kweichowensis* in China).
Platycarya	Generally, only one species is recognised. However, some authors are listing additional species (*P. longzhouensis*, *P. longipes*, *P. simplicifolia*).	Distribution known only superficially, based mainly on herbarium specimens, especially in Vietnam. Map for China in Fang *et al*. (2011) and Japan in Horikawa (1976).	**NE** (not evaluated) Conservation status assessment needed.	Establishment of new *ex situ* collections in countries of origin.
Cyclocarya	Only one phylogenetically isolated and thus well accepted species.	Distribution known only superficially, based mainly on herbarium specimens. Schematic map in Fang *et al*. (2011).	**NE** (not evaluated) Conservation status assessment needed.	Establishment of new *ex situ* collections in China.
Pterocarya	Global molecular phylogeny desirable. Thorough taxonomic revision of *P. tonkinensis* and the varieties of *P. macroptera* needed.	Distribution known only superficially. An intensive survey of herbaria literature but new field expeditions needed in particular. Maps for China in Fang *et al*. (2011) and Japan in Horikawa (1976). Maps for Transcaucasia: Boratyński & Boratynska (1975), Akhani & Salimian (2003).	*P. fraxinifolia*: **LC** (1998) Update of the existing conservation status assessment needed as well as new assessments for the remaining species.	Establishment of new *ex situ* collections in countries of origin. Global action plan needed for *P. fraxinifolia* and perhaps also for *P. tonkinensis*.
Juglans	Global molecular phylogeny highly desirable. Number of species still debatable despite some global and regional molecular studies (e.g. Stanford *et al*. 2000, Aradhya 2007, Dong *et al*. 2017). This applies especially to Central and South American taxa.	In continental Asia, distribution known only superficially. The distribution in North America is better documented but highly fragmentary for Central and South America. Maps for Japan in Horikawa (1976), China in Fang *et al*. (2011), USA and Canada in Flora of North America (www.eFloras.org). Global schematic maps in Aradhya (2007), Aradhya *et al*. (2005), Stone *et al*. (2009).	*J. regia*: **LC** (2017) *J. australis*: **NT** (1998) *J. californica* and *J. jamaicensis*: **VU** (1998) *J. neotropica* and *J. olanchana*: **EN** (1998) Update of the existing conservation status assessments needed as well as new assessments for all remaining species.	Establishment of new *ex situ* collections in countries of origin. Action plans needed at least for the following species: *J. jaimaicensis*, *J. californica*, *J. hindsii*, *J. neotropica*, *J. olanchana*, *J. pyriformis*. Several other species probably needing conservation actions (especially in South America).

Recommended priority actions:

Conservation

- Elaboration and publication of *The Red List of Juglandaceae* including all known species and using IUCN criteria.
- Designation of priority species and elaboration of detailed action plans with defined conservation measures.
- Designation of priority regions for Juglandaceae conservation and research.
- Establishment of new Juglandaceae *ex situ* collections in countries and regions of origin.

Research partnerships and networking

- Launch of an international and interdisciplinary Juglandaceae research and conservation network, forging links with specialists of different Juglandaceae taxa from various research domains, and representing all main geographic regions.
- Organisation of field surveys and joint expeditions in priority regions for Juglandaceae research and conservation.
- Development of joint research programmes on poorly studied or unexplored aspects of Juglandaceae biology and biogeography.
- Exchange of students and researchers between the partner institutions.

Public outreach and education

- Organisation of regional, national and international workshops and conferences.
- Preparation of support materials in the form of brochures and books as well as permanent and temporary exhibitions.

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DIVERSITY OF LEAVES upper surface and underside (hrs)

Carya glabra

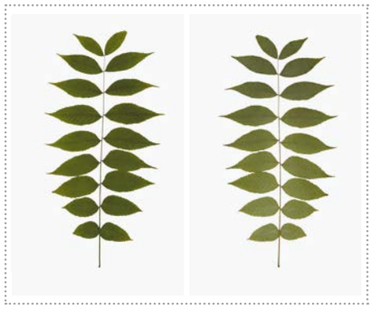
Carya illinoinensis

Cyclocarya paliurus

Juglans cinerea

Juglans mandshurica

Juglans nigra



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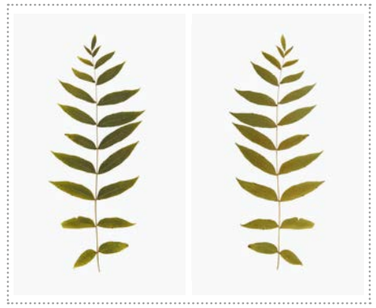
Pterocarya fraxinifolia (painting by Daniel Belchi)

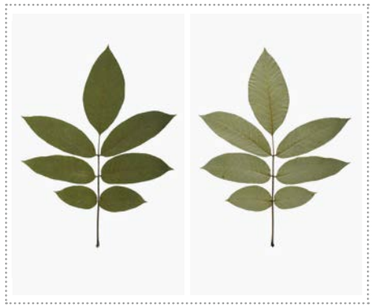
Juglans ailantifolia

Juglans major

Juglans microcarpa



Juglans regia



Platycarya strobilaceae