Trees; Genetic Systems of Forest Trees; Population, Conservation and Ecological Genetics. **Temperate and Mediterranean Forests**: Subalpine and Boreal Forests; Temperate Broadleaved Deciduous Forest. **Tree Physiology**: Physiology of Sexual Reproduction in Trees.

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Fagaceae

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Introduction

The following sections characterize members of the beech family (Fagaceae) in relation to their taxonomy, distribution, ecology, and silviculture. Also included is information about their botanical importance as well as their significance in meeting human needs.

The beech family contains some of the world's most important trees to human culture. Uses are myriad and include such things as woven baskets, toys, storage containers, ship timbers, and food sources. However, members of the beech family are generally acknowledged as most important sources of hardwood timber (oak (*Quercus*), beech (*Fagus*), and chestnut (*Castanea*)), chestnut, and cork and tannins from the oaks (**Figure 1**).

Figure 1 Cork oak (*Quercus suber*) plantation in Portugal showing tree trunks whose bark has been stripped for cork. Photograph courtesy of Heinrich Speicker, Institut für Waldwachstum, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.

Taxonomy

The beech family contains from six to nine genera (*Fagus*, *Nothofagus*, *Lithocarpus*, *Castanopsis*, *Colombobalanus*, *Castanea*, *Chrysolepis*, *Quercus*, and *Trigonobalanus*) and includes between 600 and 900 species, although numerous classification issues exist which accounts for the variation in the number of genera (**Table 1**). Perhaps the best-known members of the beech family are the oaks which are recognized by their distinctive fruit, the acorn (**Figure 2**). The genera of Fagaceae as we know them probably became established about 60 million years ago during the late Cretaceous period in geologic history following migration from areas centered in tropical mountains.

Characteristics that unite members of the family include leaves with a single blade that are either persistent or deciduous and which often remain on the tree after withering and dying. Leaflike appendages (stipules) are present at the base of a relatively short leaf stem (petiole). Leaves are arranged in an alternate pattern on the stem. Veins of the leaves are featherlike and have branches that are laterally connected to a central stem.

Male and female flowers are found within the same tree. Female flowers are wind pollinated. Male flowers are pendulous spikelike structures while female flowers are on short spikes with few flowers or may be grouped in clusters near the base of the male flowers. Although female flowers may contain one or two ovules, only one develops to maturity.

The fruit is distinctive and consists of a nut that is surrounded by an outer somewhat firm yet elastic coat that is partially or completely enclosed by a cluster of bracts (**Figure 3**). The nut contains only one seed which lacks food reserves associated with the embryo but which has large, fleshy primary

Table 1 Distribution of the beech family (Fagacaeae)

Genus	*Number of species*	*Range*
Beech (Fagus)	10	Northern hemisphere
Oak (Quercus)	400	Northern hemisphere; red oak group (Lobatae) restricted to North America
Southern beech (Nothofagus)	40	Australia, Chile, Argentina, New Zealand, New Guinea, and New Caledonia
Chestnut (Castanea)	10	Southern Europe, northern Africa, southwestern and eastern Asia, and eastern United States
Chinkapin (Castanopsis)	150	North America, China, India, and Malayan archipelago
Tanoak Lithocarpus	100–200	North America (1 species), Asia
Chinquapin (Chrysolepis)	2	Western United States
Colombobalanus	1	Columbia, South America
Trigonobalanus	2	China, Malaysia

Figure 2 Acorns of northern red oak (*Quercus rubra*).

Figure 3 Fruit of tanoak (*Lithocarpus densiflorus*).

leaves that it uses for its initial nourishment upon germination. The fruit matures in one or two seasons. A botanic comparison of the well known genera is given in **Table 2**.

Beech (*Fagus*)

There are 10 species of beeches all of which are found in the northern hemisphere. One species is found in North America, one is European, one is found in the Caucasus Mountains on the border between Europe and Asia, and the rest are found within the temperate regions of eastern Asia. Although the beech genus is relatively small, the European beech has been used extensively for ornamental purposes and many horticultural varieties exist which display a vast array of morphological characteristics such as coloration and form (**Figure 4**).

Oak (*Quercus*)

Worldwide there are about 400 species of oaks, and they are taxonomically divided into three groups: (1) the red oak group (*Quercus* section *Lobatae*), (2) the white oak group (*Quercus* section *Quercus*), and (3) the intermediate group (*Quercus* section *Protobalanus*). All three groups include tree and shrub species. The red oaks and white oaks include evergreen and deciduous species, whereas the intermediate oaks are all evergreen. The red oaks are found only in the western hemisphere where their north–south range extends from Canada to Colombia. In contrast, the white oaks are widely distributed across the northern hemisphere. The intermediate group comprises only five species, all of which occur within southwestern USA and northwestern Mexico. Many of the world's oaks occur in regions with arid climates, including Mexico, North Africa, and Eurasia, where they are often limited in stature to shrubs and small trees. About 80% of oaks occur below 35° N latitude and fewer than 2% (six or seven species) reach 50° N.

The most reliable distinction between the white oaks and red oaks is the inner surface of the acorn shell. In the white oaks it is hairless or nearly so, whereas in the red oaks it is conspicuously hairy or velvety. In the intermediate group, this characteristic is not consistent among species. The

Table 2 Summary of characteristics of the more common genera in the beech family

Genus	*Leaves*	*Flowers*	*Fruit*
Beech (*Fagus*)	Deciduous	Male are in heads, female are in short spikes with two to four flowers	A triangular nut occurring in twos enclosed by a bur covered by weak unbranched spines; matures in one season
Chestnut (*Castanea*)	Deciduous	Male, female, or both borne on erect many-flowered apetalous spikes	A rounded nut occurring singly or in twos or threes covered by a bur having sharp, rigid, branched spines; matures in one season
Chinkapin (*Castanopsis*)	Persistent	Similar to chestnut	The same as chestnut but takes 2 years to mature
Tanoak (*Lithocarpus*)	Persistent	Similar to chestnut	An acorn which matures in 2 years
Oak (*Quercus*)	Deciduous or persistent	Male are borne in many-flowered apetalous spikes; female are borne in several-flowered spikes	An acorn which matures in 1 or 2 years
Southern beech (*Nothofagus*)	Deciduous or persistent which are small, oval, and have finely toothed edges	Male are bell-shaped of varying numbers; female are generally few in number and borne on stalks	Similar to beech
Chinquapin (*Chrysolepis*)	Persistent	Chestnutlike spikes of creamy-white; male flowers are borne in the leaf axils; female flowers usually occur in a cluster at the base of male spikes	Spine-covered bur which encloses from one to three nuts

Figure 4 Leaves of copper beech (*Fagus sylvatica* '*Purpurea*'). Photograph courtesy of Heinrich Speicker, Institut für Waldwachstum, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.

Figure 5 Leaves of white oak (*Quercus alba*). Note absence of bristles at the ends of the leaf lobes.

leaves of the white oaks are usually rounded and without bristle tips (**Figure 5**), whereas the leaf lobes of the red oaks are usually pointed and often bristle-tipped (**Figure 6**). To many botanists and others, the most important difference between the white oaks and red oaks is the length of the acorn maturation period. Acorns of species in the white oak group require one season to mature whereas species in the intermediate and most of the red oak group require two seasons. The white oaks and intermediate oaks are characterized by the presence of tyloses (occlusions) in the latewood vessels (water-conducting cells) of the xylem whereas tyloses are usually absent in the red oaks. These vessel-plugging materials confer greater decay resistance to the wood of the white and intermediate oaks than the red oaks. Other morphological features that differentiate the three groups and species within them are presented in various taxonomic treatments.

Figure 6 Leaves of northern pin oak (*Quercus ellipsoidalis*) showing bristle-tipped leaves.

Of the more than 250 oak species occurring in the western hemisphere, the largest number occur in Mexico and Central America. About 10 species occur in Canada while 90 species of oaks are native to the continental USA. Oak hybrids are not uncommon where species ranges overlap as evidenced by the more than 80 hybrids recognized in the USA alone.

The oaks are distinguished from other members of the beech family (e.g., the beeches and chestnuts) by their fruit, the acorn. With one exception, all plants that produce acorns are oaks. The exception is the genus *Lithocarpus*, which includes the tanoak of Oregon and California. Although represented by only one North American species, *Lithocarpus* is represented by 100 to 200 species in Asia. Some taxonomists think *Lithocarpus* may be an evolutionary link between the chestnut and the oak.

Southern Beech (*Nothofagus*)

Southern beech or *Nothofagus* is a genus of some 40 species that only occur in the temperate regions of the southern hemisphere. The name *Nothofagus* means 'false beech'; however, *Notofagus* meaning 'southern beech' might have been more appropriate and in fact the original intent of the nomenclature. Some plant historians have suggested that the original name was mis-spelled by inserting the *h*. Nine species of *Nothofagus* occur in South America while three occur in Australia. The importance of their timber is second only to that of the eucalypts.

Besides Australia, Chile, and Argentina, *Nothofagus* is also represented in New Zealand, New Guinea, and New Caledonia. Paleobotanists believe the current distribution of *Nothofagus* species resulted from the continental drift that occurred following the break-up of the Great Southern land. Forests of *Nothofagus* were noted as early as the mid-nineteenth century by the botanist Sir Joseph Hooker who accompanied James Ross on exploratory trips to the Southern Ocean between 1839 and 1843.

Chestnut (*Castanea*)

Castanea is the generic name for the chestnuts whose alternate name is chinkapin, not to be confused with *Castanopsis* and *Chrysolepis*, genera whose species are also commonly referred to as chinkapins or chinquapins. *Castanea* is a relatively small genus consisting of 10 species distributed across southern Europe, northern Africa, southwestern and eastern Asia, and the eastern United States. Prior to the 1930s in the eastern USA, the American chestnut (*Castanea dentata*) was prized for its high-quality, durable wood and sweet fruit but it is now relegated to a shrubby form because of its susceptibility to a pathogenic organism, the chestnut blight (*Endothia parasitica*). The blight eventually kills the stem but the root system is resistant to infection and results in sprout growth which is in turn killed back in a never-ending cycle.

Chinkapin (*Castanopsis*)

Most botanists agree that the taxonomy of *Castanopsis* is poorly understood. Only two of about 150 species of *Castanopsis* are found in North America whereas the rest are found in the forests of China, India, and the Malayan archipelago. These two are distinct from their Asian relatives, and systematists have created a new genus for them called *Chrysolepis*. The American species have a flower structure that is intermediate between *Castanopsis* and *Lithocarpus* suggesting a more primitive form within the family Fagaceae. The new scientific names for the American species, with the older names in parentheses, are *Chrysolepis chrysophylla* (Dougl.) Hjelmqvist (*Castanopsis chrysophylla* (Dougl.) A. DC.) for giant chinkapin and *Chrysolepis sempervirens* (Kell.) Hjelmqvist (*Castanopsis sempervirens* Dudl.) for evergreen chinkapin.

Ecology

Beech (*Fagus*)

Approximately 12% of all species in Fagaceae appear in the 2003 IUCN *Red List of Threatened Plants*.

Beech is found mixed with other temperate deciduous species and requires a site with a well-drained soil with good moisture holding capacity; it is more particular in that regard than many of the

species it associates with. However, it does not tolerate soils that experience either prolonged flooding or dry periods. Beeches are extremely tolerant of shade and can persist under the shade of other species for decades.

European beech (*Fagus sylvatica*) is a dominant species in the broadleaved forests of Europe located principally in the foothills of mountainous areas. It was once more extensive in its distribution and composition than nowadays because of forest exploitation practices of past centuries which resulted in reforesting former broadleaved forests with faster growing species such as Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). Efforts are under way to increase the proportion of broadleaved forests in Europe and in Germany in particular in order to return to the 'more natural' forest conditions of former times. Sessile oak (*Quercus petraea*), English oak (*Q. robur*), and European hornbeam (*Carpinus betulus*) are frequent associates.

Similarly, the American species, American beech (*F. grandifolia*) enjoys a wide range covering all of the eastern part of the USA on mesic sites and is associated with a large number of trees in a number of forest types. Like its European cousin, it has a distinctive smooth light-gray bark that remains so until maturity. Some of its principal associates include sugar maple (*Acer saccharum*), red maple (*A. rubrum*), yellow birch (*Betula alleghaniensis*), American basswood (*Tilia americana*), black cherry (*Prunus serotina*), eastern white pine (*Pinus strobus*), and red spruce (*Picea rubra*), as well as several hickories and numerous oaks and, in the southern part of its range, southern magnolia (*Magnolia grandiflora*). Beech is an important component of 20 forest cover types in eastern US forests and is one of the dominant species in three types; sugar maple–beech–yellow birch, red spruce–sugar maple–beech, and beech–sugar maple. It is found in lesser amounts in 17 other types.

American beech reproduces by seed which germinates on mineral soils but is best on forest soils containing humus. It is prevalent on podzolic soils. The largest species are found on alluvial bottom lands of Ohio and the lower Mississippi River valleys, and along the western slopes of the southern Appalachian Mountains. American beech also reproduces by root sprouts which can develop into desirable trees. Root systems are generally shallow compared to species with which it associates. Beech are long-lived trees only being exceeded by white oak (*Q. alba*) and sugar maple. Crown spread typically is wide compared to its associates. However, they can prune themselves well provided that stand density is not too low.

Southern Beech (*Nothofagus*)

The temperate regions of the southern hemisphere do not have direct counterparts of the northern temperate broadleaf deciduous forest. Instead the humid subtropical climate regions have a mixed (broadleaf and needleleaf) evergreen forest whose biogeographic interest stems from the occurrence of Gondwanan relicts: *Araucaria* pines (South America and Australia), *Podocarpus* pines (South America, Africa, and Australia), and the evergreen southern beech *Nothofagus* (South America, Australia, and New Zealand).

In general, southern beeches are slow-growing trees found in temperate rainforests of the southern hemisphere whose origins are believed to have been derived from a time when there was a single primordial landmass in the southern hemisphere called Gondwana. Continental drift is presumed to be the reason for the widespread occurrence of the genus across the southern hemisphere in essentially similar habitats in such places as South America, Australia, New Zealand, New Caledonia, and Papua New Guinea. Trees of some species can be quite large and may reach a height of 30 m or more with diameter at 1.3 m above the ground (diameter at breast height, dbh) of 1 m and occasionally up to 2 m. The strong similarity of form and the persistence of these trees in comparable habitats across southern hemisphere landmasses supports other evidence that these trees have survived largely unchanged since continental separation. In fact, fossil *Nothofagus* leaves have even been found on the Antarctic continent. Interestingly, other plant and animal species exclusively associated with southern beech forests also have close relatives associated with the comparable trees all across the southern landmasses. Beech orange fungus and the Peloridiidae bugs are good examples.

The extent of southern beech forests has been reduced in certain places. Southern beech forests in Australia were once far more widespread, when the climate was wetter and fire was less frequent.

The subantarctic forests of evergreen southern beech in Patagonia are threatened with extinction. They occupy a 60-km wide strip along the base of the Andes and extend, in pockets, 1500 km from the Province of Neuquén south to Tierra del Fuego. Two indigenous species – the lenga (*Nothofagus dombeyi*) and ñire (*N. procera*) trees – dominate the forest, which serves as home to pumas, guanacos, southern river otters, geese, Andean condors, and huemul deer. Logging and forest clearing have been extensive in the region's northerly latitudes, and now threaten the southern forests of lenga and ñire. However, the

boundaries of Perito Moreno National Park in Patagonia are being expanded through land donated by the Patagonian Land Trust in an effort to preserve these forests of evergreen southern beech.

The American Chinquapins (*Chrysolepis*)

The uniqueness of the two species of the American genus *Chrysolepis* in relation to the species within *Castanopsis* level does not translate to differences between the American species. The ranges of the shrub form of giant chinkapin and of evergreen chinkapin overlap from northern coastal California into the Cascade Range of Oregon. The two species probably hybridize where they co-exist. An apparently continuous intergradation of characters can be found in the Cascades in southern Oregon and in the Siskiyou Mountains.

The two growth forms of giant chinkapin are probably not the result of plastic phenotypic response to site conditions, although they may be in portions of the species range. In the northern Coast Ranges of California, the tree form occupies relatively moist conditions; the shrub form grows on dry, sterile ridgetops in chapparal communities. In the central part of the Cascades of Oregon, the pattern is reversed – the tree form is found primarily in relatively open and dry ridgetop forest communities, and the shrub form is spread through the more mesic forest stands. Only the shrub form is found at high elevations in the Cascade Range.

This variation is due to the probable existence of at least three ecotypes of giant chinkapin: (1) a dry-site chaparral shrub ecotype of southwestern Oregon and northwestern California which probably matches the taxonomic category of *Castanopsis chrysophylla* var. *minor*; (2) a high-elevation ecotype adapted to heavy snowpack, cool temperatures, and short growing seasons found along the Oregon Cascades and in eastern Oregon; and (3) a tree form that occurs in forest stands at lower elevations. The latter ecotype seems well adapted to dry, relatively infertile sites but can and does do well in more mesic conditions that have a history of disturbance by fire.

Oaks (*Quercus*)

It is an understatement to say that oaks are found on a wide variety of sites, soil conditions and landforms throughout its range in the northern hemisphere. It is worth noting that one species (*Quercus humboldtii*) crosses the equator and is found in Ecuador.

Located between 5900 and 8600 feet (1800 and 2600 meters) above sea level, the Cachalú Biological Reserve in Colombia features one of the last remnants of pristine oak forests of this species. The 2000-acre (800-hectare) reserve is in northern Colombia in the Eastern Cordillera Montane Forest and is part of a 'globally outstanding' ecoregion. Oak prefers high altitudes, 1000–2600 m above sea level, with annual precipitation of 1500–2500 mm and temperatures of 16–24°C. Ecologically very plastic, it can be found both in moderately fertile and deep soils and in degraded, almost barren soils. Nevertheless, it grows better on shallow soils with a thick layer of humus, and relatively loose soils with good drainage and a pH between 5.8 and 7.0. It is intolerant of shade and will dominate competing species.

The oaks are widely distributed throughout the temperate regions of the northern hemisphere. Generalizing about the ecological relations of the genus is dangerous at best given the enormous number of species and their genetic, morphological, and life history diversity. The reader is directed to local or regional guides to the various species.

The oaks of the Mediterranean region of southern Europe and northern Africa typically are shrubby or low-growing trees that are adapted to dry growing conditions. They typically are found in savanna like environments and may co-exist with various agricultural crops. The world's cork supply comes chiefly from cork oak growing in Portugal, Spain, and north Africa.

Conversely, oaks can be found on extremely dry sites to those inundated by flood waters and span the shade tolerance spectrum from intolerant to moderately tolerant. Oaks have been known to reproduce by seed and by sprouting from stumps, seedlings, and rhizomes. Regeneration strategies are largely species-site dependent and the anomalies in regeneration strategy among the oaks emphasize the difficulty of generalizing their regeneration ecology across species and habitats. Different oaks have solved their regeneration problems in different ways and some are more flexible than others in reaching a successful establishment. Each species, environment, physiology, and genetics determine its ability to regenerate successfully.

Oaks are one of the most, if not the most, important hardwood species of the USA. The genus is represented throughout the USA except for the Great Plains area to the west of the Mississippi and east of the Rocky Mountains. The greatest variety of oaks occurs in the eastern deciduous forest most of which is classified as the oak-hickory forest region. Of the 145 forest cover types defined by the Society of American Foresters in the USA 31 contain oak in the name or are included as part of a species list defining a name. Of these, 23 oak types are found east of the Mississippi River. In addition, many of the non-oak types have oak as a common associate.

Although oaks are relatively intolerant of shade, species vary considerably in this regard. In some habitats, oaks are vulnerable to replacement by more tolerant species such as maples and beeches. Compared to other competitors, oak seedlings grow more slowly during the years following establishment. When young oaks are overtopped and heavily shaded few survive for very long. However, oaks tend to be relatively drought tolerant and often survive on sites that limit the establishment and development of associated species with less drought tolerance. On droughty sites oak stems and shoots often die back but have a remarkable capacity to sprout from the roots when growing conditions become favorable again. These sprouts often have the capacity to outgrow competitors. Oaks tend to accumulate on these dry sites and may eventually dominate the overstory vegetation.

Most forest ecologists class oaks as a genus whose species for the most part become established following disturbances to the forest overstory. These disturbances may be natural such as fire and windstorm, extensive or intensive, or may result from harvesting activities. Much of the current oak forest in the USA is the result of early forest exploitation and fires used to clear land for agriculture during settlement times. Oak opportunistically occupied sites in the Appalachian Mountains following the destruction of the American chestnut (*C. dentata*) by the chestnut blight in the 1930s.

Silviculture

Beech (*Fagus*)

Beech is classed as very tolerant of shade and hence possesses the ability to regenerate beneath tree canopies. However, on very poor soils or in very cold climates, beech may be less tolerant. This suggests silvicultural systems that retain an overstory component such as individual tree selection or group selection methods of harvesting. Beech prune themselves in well-stocked stands but open-grown trees tend to have wide crowns and lower limbs close to the ground. Often other species are purposely introduced into beech stands to increase stand density and act as 'trainers' in order to promote self-pruning. For example, European hornbeam is used to 'train' European beech in order to promote straight stems and encourage early self-pruning of lower branches. Beech responds readily to thinnings even at late ages and rapidly expands its crown following thinning. Thus beech is capable of producing high volume increment even to relatively old ages (130–150 years). When grown for high-quality wood the silvicultural target is to grow beech to 60 cm dbh in 110–140 years at a density of 80–110 trees per hectare. Thinnings are restricted to these 'crop trees' to keep their crowns in a free-to-grow condition. This sometimes means that thinnings must be from above (i.e., removing some dominant trees).

Southern Beech (*Nothofagus*)

Clear-felling has been the common way of harvesting southern beech in New Zealand and other areas across its distribution in the southern hemisphere. However, research is ongoing in New Zealand to find out if group selection (an uneven-aged silvicultural method) could be used to sustain southern beech forests. The group selection method is a modification of the single-tree selection method whereby openings larger than the crowns of the largest trees are made in the forest canopy. Typical openings range from 0.1 to 0.25 hectare. In large part, this method requires adequate advance regeneration to successfully regenerate the stand.

Oak (*Quercus*)

As a genus, oak has a wide ecological amplitude, that is it has a wide range of habitat conditions that individual species can tolerate. Therefore making silvicultural generalizations is difficult at best and an interested reader is best advised to seek regional or local information about the oak species and the location in which it is found.

Having said that, the potential exists for applying both even-aged and uneven-aged silvicultural methods to stands dominated by oak. In order for uneven-aged silvicultural methods to succeed there must be a sustained, periodic recruitment of oak reproduction into the overstory. This is a necessary prerequiste to create and maintain a negative exponential diameter distribution, a stand structure characteristic of uneven-aged stands. Although it may be possible, through thinning, to create the requisite diameter distribution without adequate regeneration, it cannot be sustained. Any event, natural or otherwise, that interrupts this process, will disrupt the recruitment of stems into succeeding size classes. The single-tree selection method is one way of creating this type of stand structure. From outward appearances, the single-tree selection method may seem to represent the most 'natural' of the silvicultural systems. The naturalness of the method nevertheless may be deceptive because there must be silvicultural control of the rate of natural reproduction, stand structure, and density. For all but the most shade-tolerant species, greater silvicultural control is obtained through single-tree selection than any other silvicultural method. Applying this method to the relatively

shade-intolerant oaks with their erratic seed production cycles, seedling establishment, and other regeneration uncertainties is problematic. However, despite these problems, there is evidence that the method is suited to some oak forests.

Stands that are managed using even-aged silvicultural methods are regenerated naturally at the end of their rotation by one of three techniques: (1) clear-cutting, (2) shelterwood, or (3) seed tree. Although all three methods can be used to regenerate the spectrum of shade tolerant to shade intolerant oaks, they are most suited to the intolerant to mid-tolerant species. If clear-cutting is contemplated one should consider the suitability of the ecosystem for meeting oak reproduction requirements, the likelihood of regeneration success, and economic, social, and ecological implications. Clear-cutting is successful if oak regeneration of sufficient size is present in the stand before it is harvested.

The shelterwood method is employed principally to create conditions suitable for the establishment and development of tree reproduction. Typically, there is a preparatory cut to facilitate crown expansion and seed production, an establishment cut to prepare a seedbed, and a removal cut to release the newly established regeneration. There are several variants of this system in the way the cuts are carried out and how long trees are retained. The key to using shelterwood successfully to establish and maintain oak stands is in manipulating stand density in order to control light and competition on the forest floor. This may entail controlling the understory vegetation in addition to manipulating the overstory.

The seed tree method leaves 20 or fewer seed trees per hectare. Although applied successfully in certain locations, the seed tree method generally provides too little regeneration too late. However, it could be useful in providing mast for wildlife and may have a greater visual appeal than a clear-cut.

Tree diameter growth is sensitive to stand density. If the goal of a forest management program is to produce large diameter trees in the shortest time possible, then stand density needs to be reduced as early as 15 years for some species to provide the maximum amount of growing space needed by the average tree. However, this approach may not be economically feasible. Thinning only around a smaller number of 'crop' trees ensuring that they have sufficient growing space may be a more cost effective solution.

Special situations require special considerations. The leaves of Mongolian oak (*Q. mongolica*) furnish food for the silk worm in northeastern China. The silviculture of these stands aims to create large crowns with nutritious leaves and to manage the density of silkworms that feed on the leaves. In the cork oak forests of Portugal and Spain, silvicultural techniques focus on the timing, method, and intensity of stripping bark from the trees.

Chinkapin, Chinquapin

Chinquapins are vigorous sprouters and most trees originate as root crown sprouts. Mature trees tend to have straight boles and narrow crowns. They exist singly or in small groves. Natural regeneration is usually sparse or lacking. The best evidence suggests that the greatest success in regenerating chinquapin is achieved by covering seed in partially shaded, moist conditions.

Utilization

A small market exists for chinkapin wood for furniture and cabinet stock and decorative veneer. However, it is difficult to dry without the wood checking (splits and cracks). Southern beech is noted for its high-quality timber that is used for fine woodwork. The genus is second only to the eucalypts in wood production in the southern hemisphere. Beech is excellent for turning and steam bending. It wears well, is easily treated with preservatives, and is used for flooring, furniture, veneer, and containers. The nut is eaten by people and is an important source of food for wildlife. European beech has many horticultural varieties used in cultivated landscapes. Similar uses can be described for oak. Other well-known uses of oak include staves for barrels used for whiskey and wine, and cork for wine and other stoppers. The wood of tanoak (*Lithocarpus*) is hard, strong, and fine-grained but is mostly used for pulp and firewood. Tannin is extracted from tanoak bark (as well as oak) and used for tanning leather.

See also: **Non-wood Products**: Cork Oak. **Silviculture**: Coppice Silviculture Practiced in Temperate Regions; Natural Stand Regeneration; Silvicultural Systems; Unevenaged Silviculture. **Temperate and Mediterranean Forests**: Mediterranean Forest Ecosystems; Southern Coniferous Forests; Temperate Broadleaved Deciduous Forest. **Tree Breeding, Practices**: Genetics of Oaks. **Tropical Forests**: Tropical Montane Forests.

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Juglandaceae

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Introduction

The following sections characterize members of the walnut family (Juglandaceae) in relation to their taxonomy, distribution, ecology, and silviculture. Also included is information about their botanical importance as well as their significance in meeting human needs.

The walnut family contains tree species that produce some of the world's finest high-quality hardwood that is used to manufacture cabinets and fine furniture (walnut). Moreover, there are species in this family that are important sources of edible nuts (walnut and pecan). Members of the family are found in the north temperate and subtropical regions of the world, extending to India, Indochina, Malaysia, and Andean South America. The family is not present in Africa and Australia.

The walnut family originated during the Eocene epoch of the Tertiary period of geologic time about 65 to 55 million years ago. The climate of Eocene times was subtropical and moist throughout North America and Europe. Palm trees and alligators were found as far north as the Dakotas in the USA, while at high northern latitudes in Greenland and Siberia, moist temperate zone forests were dominated by giant redwoods and deciduous trees such as beech, chestnut, and elm, while cycads, magnolias, and fig trees flourished in Alaska. The walnut family reached its greatest extent in numbers and distribution at that time after which it has steadily declined.

Taxonomy

The most recent taxonomic information indicates that the walnut family (Juglandaceae) comprises eight genera (*Alfaroa*, *Carya*, *Cyclocarya*, *Engelhardtia*, *Juglans*, *Oreomunnea*, *Platycarya*, and *Pterocarya*) with about 50 species (**Table 1**). However, some taxonomists report as few as seven genera (*Cyclocarya* omitted) and as many as nine genera (*Annamocarya* added) that include 60 species.

Members of the walnut family are mostly trees (often resinous), but a few are shrubs. All family members have more or less aromatic leaves which are mostly deciduous and consist of individual leaflets arranged like a feather with a central axis and lateral branches (pinnate) or arranged similar to pinnately compound leaves but leaflets are arranged groups of three (ternate). The leaves of the majority of the species are spirally arranged on twigs but they are oppositely arranged in two genera, *Alfaroa* and *Oreomunnea*. Superposed buds are common (bud found above lateral bud).

Male and female flowers are usually found on the same tree although occasionally sexes are found on separate trees. Flowers are wind pollinated and are mostly in the form of catkins.

Fruit is a nut encased within a husk (drupe-like) or a disk-winged nutlet. A drupe is usually a one-seeded fleshy fruit with the outer layer (husk) fleshy and the inner layer bony. Husks may split to release

Table 1 Distribution of the genera of the walnut family (Juglandaceae)

Genus	*Number of species*	*Range*
Juglans	20	North, Central, South America; Europe, and Asia
Carya	16	North America (13) and Asia (3)
Platycarya	1	China, Japan, Korea, and Vietnam
Englehardia	7	Southern and southeastern Asia, and northern India
Cyclocarya	1	China
Pterocarya	6	Eastern and southwestern Asia
Alfaroa	5	Central and South America
Oreomunnea	3	Mexico, Central and South America