International Oaks

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contact
Béatrice Chassé
pouyouleix.arboretum@gmail.com or editor@internationaloaksociety.org
0033553621353
Les Pouyouleix
24800 St.-Jory-de-Chalais
France
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Photos. Cover: Guy Sternberg (*Quercus macrocarpa* Michx.); p. 7: Guy Sternberg (*Q. rubra* L.).

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Oaks and the Biodiversity They Sustain

K. Bargali, B. Joshi, S.S. Bargali, and S.P. Singh
Department of Botany, DSB Campus, Kumaun University
Nainital-263002, Uttarakhand, India
kiranbargali@yahoo.co.in

ABSTRACT

The present article describes the biodiversity sustained by oak trees and shrubs, both aboveground and below. They support mammals (e.g., deer, monkeys, rodents, flying squirrel and bears), birds (e.g., jays and woodpeckers); gall-forming and other herbivorous insects, parasites, weevils that depend on oak acorns, and ants that colonize remains of the acorn shells; numerous epiphytes including lichens, bryophytes, ferns, and orchids; semi-parasites that in turn support a variety of birds and fruiting fungi both ectomycorrhizal and non-ectomycorrhizal; earthworms, springtails and others. Oaks also provide fodder for livestock, firewood for cooking, tools for agricultural activity and leaves for fertilizing fields. In India, in terms of natural coverage, no other genus matches *Quercus*.

Keywords: oak leaf, acorn, epiphyte, soil, oak gall, lopping, forest ecosystems

Introduction

The genus *Quercus* is one of the most important groups of woody plants in many regions in the Northern Hemisphere (Nixon 2002). It also contains the most economically useful trees, providing high quality timber, firewood, tannins for leather, natural dyes, long-lived horticulture shade trees, wildlife habitat, food for animals (leaves and acorns) and even food for human beings (acorns are still eaten in parts of Asia) (Nixon 2009). In comparison to other forests such as pine, oak forests are characterized by higher species diversity, stratification, litter production, and soil fertility (Shrestha 2003). The bole and branches of mature oak trees support a luxurious growth of nonvascular (e.g., bryophytes) and vascular (e.g., orchids) epiphytes. Sultana and Khan (2000) reported about 382 species of birds from the oak forests of Kumaun Himalaya, India. Many oaks are keystone species without which the complex web of the ecosystem cannot be completed. Their presence has been related to the quality and quantity of spring water. In the Indian Himalayas, oak forests are the basis of age-old subsistence agriculture (Bargali et al. 2013; Pande et al. 2012; Bargali et al. 2014).

Aboveground

Life on leaves

Oak leaves provide food to a wide variety of animals. Because of their wide range over diverse habitats and their plentiful and tasty leaves, oaks have become the target of many, many organisms (Singh et al. 2005). The oak leaf-blotch miner (*Cameraria agrifoliella* Braun.) and live oak ribbed case-maker (*Bucculatrix albertellia* Busck) are two common moths that feed on the leaves of American oaks. *Tortrix* sp., *Dasychira* sp., *Medasina albidaria* Walker, and others, feed on Himalayan oaks when they are young. In both cases the early caterpillar stage is a green larva that feeds exclusively on the softer tissues such as palisade and spongy parenchyma that are confined between the two epidermal layers of a leaf blade. Oak moths cause more damage to oak leaves than other organisms. Often larvae appear in such great number that they can defoliate a tree. *Phycita*, *Acrobasis*, *Cryptoblaus*, and *Endotricha* are the names of some other moth genera whose larvae can appear in sufficiently large numbers to seriously damage the tree canopy.

1/ The *Quercus rysophylla* Weath. caterpillar in Mexico.

In the Chinese and Indian Himalayas silk worms have been raised on oaks for centuries; apparently the caterpillars have a preference for their leaves.

Fungi, particularly mildews, grow vigorously when tender new leaves are subjected to humid conditions; they can cover entire leaf surfaces in a white powder. The main feeding body of these fungi remains inside the leaf tissue, digesting it continuously, while the conidia at the surface are dispersed to other vulnerable leaves.

In addition, there are many mammals that make oaks an integral part of their diet: deer, cattle, sheep, monkeys, langurs and agoutis are some of them. New oak leaves are vulnerable to browsing by deer. In mature oak, branches are high beyond the reach of the tallest deer, but saplings and seedling are severely browsed. This in turn poses a threat to oak regeneration. In regions where the forest is regularly used for browsing by cattle, oaks fail to regenerate (Singh et al. 2005; Bargali et al. 2013) as severely browsed saplings and seedlings cannot replace mature trees when they die. All the Himalayan oaks are regarded as good fodder species and are thus heavily lopped for stall-feeding of cattle, particularly in winters when little green fodder is available. Humans also use oak leaves in different ways. In the Himalayas, for example, leaves are harvested for cattle fodder and for raising silkworms, and leaf litter is used to manure crops.

Life on acorns

Acorns provide a major portion of the food supply of a vast array of wildlife: Hanuman langur (*Semnopithecus entellus* Dufresne), red giant flying squirrel (*Petaurista petaurista* Link), mule deer (*Odocoileus hemionus* Rafinesque), acorn woodpecker (*Melanerpes formicivorus* Swainson), turkey (*Meleagris gallopavo* L.), and wild pig (*Sus scrofa* L.) It has been estimated that acorns constituted up to half the diet of most tribes of California Native Americans (Pavlik et al. 1991). Acorns of all species of oak may be stored and eaten (Koenig and Haydock 1999). A list of organisms that feed on acorns is given in Table 1. There are numerous weevil species[1] that infest acorns of Himalayan oaks (Kalia 1988; Bora 1989). The two most common and important are *Sitophilus glandium* and *Dicranognathus nebulosus*, which mainly infest acorns of *Q. leucotrichophora* A. Camus. Kaushal et al. (1993) reported that 83.7% of *Q. leucotrichophora* acorns and 5.6% of *Q. floribunda* Lindl. ex A. Camus acorns were infested by these acorn weevils in Nainital, India. *D. nebulosus* attack acorns both on the tree and on the ground, whereas *S. glandium* infest only those on the ground. The weevil bores a long cylindrical hole into the acorn where it lays an egg and then passes to the next acorn for a repeat performance. After some time, worm-like larvae hatch that feed on the acorn. The larvae eventually shove their way out of the acorn for the next stage of life.

2/ Mule deer enjoying *Quercus grisea* Liebm. acorns in Texas.

1. The common name "weevil" refers to a group of insects spread across seven different families in the super family *Curculionoideae*.

If the acorn has not been completely consumed by the weevil's larva, the acorn moth (*Valentina glandulella* Riley) may lay eggs on what is left of the acorn embryo. The larvae will either stay inside the acorn throughout the winter season emerging only in spring but they may also die within the acorn and end up serving parasitic wasps that lay their eggs on the decaying larvae. If they remain alive they eat their way out and proceed to their next stage of development. At this point the acorn embryo dies and several saprophytes including snails, beetles, and mites feed on the acorn's rotting remains. Various fungus spores also enter the holes and grow inside. When all the soft material has been eaten and the acorn shell lies empty, many ants begin new colonies inside these snug, waterproof homes. Finally, the acorn's shell will be fragmented and broken down by soil bacteria and fungi, providing nutrients for the tree (Keator and Bazell 1998).

Some animals benefit oaks by dispersing their acorns. The most important among these are the rodents and birds that harvest acorns for food but bury them in caches for later use. Of all these, the jays (several genera in the family *Corvidae*) of the Northern Hemisphere (including Mexico and Central America) play one of the most precise and interesting roles in the life of an oak. Many species of jay make acorns the main staple of their diet. Scrub jays, such as the Western scrub jay (*Aphelocoma californica* Vigors) and others of Southwestern North America, may depend on the success of an acorn harvest for rearing their young. Troup (1921) described that in Shimla (India) jays stayed throughout the winter and by the time they left not many acorns remained on *Q. leucotrichophora*. The distribution of jay species and their diversification coincides closely with the distribution and diversification of oaks. The two areas of the world most noted for their great variety of oaks, Southeast Asia and Mexico, are also areas of high jay diversity.

Other animals, including cattle, langur, pigs, deer, wild turkeys, bear, monkey and woodpeckers may play a less positive role in the life of an oak tree. The life of an acorn woodpecker (*Melanerpes formicivorus* Swainson), for example, is intimately associated with oaks (Koenig and Haydock 1999). These birds have a unique method of storing acorns in trees that they transform into "storage trees" or granaries. Thus one can see old trees with their trunks riddled with thousands of carefully drilled holes each occupied by an acorn. Since the acorns are stored well above the ground and diligently pounded into the holes of the granary, they seldom fall out to germinate and grow into new trees.

Human beings throughout the world have found many uses for acorns. For example, *Q. leucotrichophora* acorns are used as a diuretic, to treat gonorrhea, as an astringent for indigestion, and to cure diarrhea especially in children.

The epiphyte community

A number of plants including lichens, bryophytes, pteridophytes, orchids, and some other flowering plants live on oak trunks and branches. Epiphytes favor oak bark because there is less competition (in relationship to the bark of other trees) for resource utilization, better light, and higher oxygen circulation for their roots. The density of epiphytes on oak depends on bark texture and chemistry, both of which vary from species to species. Most oaks, particularly of the White Oak group, have crevices, furrows and troughs providing a larger surface to support a great number of epiphytes.

In mountain climates oak trees often host luxuriant growth of a wide variety of epiphytic lichens. There are thousands of species that present a wondrous array of shapes: flattened and blade like (foliose), branched and twiggy (fruticose), or crust forming and

inseparable from the bark they cover (crustose). In a site-specific study Sah (1995) reported 13 species of lichens from trunks and branches of *Q. leucotrichophora*. However, assessments at a regional scale suggest that oak forests may support more than 100 species of lichen. Lichens do not harm their host in any way: in fact some of them are beneficial. Recent evidence suggests that some of the nitrogen that lichens fix, is shared with the host (Bates et al. 2011).

3/ *Aphelocoma californica*

Lichens are the first plants to colonize the fresh bark of young oak trees and when they die their decomposing bodies provide nutrients to the bryophytes that follow. Among the first new settlers are the leafy liverworts and mosses that form bright green cushions on the damp base of trees. Mosses grow as tufted bunches of leafy branches with a spongy texture. Leafy liverworts[2] also grow in the form of dense mats. Joshi (1993) reported a higher number of epiphytic bryophytes (17) on *Q. semecarpifolia* Sm. in comparison to other associated species (14 on *Aesculus indica* (Wall. ex Cambess.) Hook., and 15 on *Abies pindrow* (Royle ex D. Don) Royle) in a high-altitude forest (2,500-3,000 m/8,200-10,000 ft) in Western Himalaya. Tewari and Pant (1994)

4/ *Melanerpes formicivorus*

2. Bryophytes in the class *Hepatopsidae*.

reported about 85 species of epiphytic bryophytes associated with the Himalayan oaks *Q. leucotrichophora, Q. floribunda, Q. lanuginosa* D. Don[3], and *Q. semecarpifolia*. These bryophytes have no adverse effect on oak trees but when wet during the rainy season can weigh several kilograms. Such a great weight spread over a large oak tree adds to its burden and may cause it to keel over during an intensive windstorm.

Oak trees also support a large number of pteridophytes, mostly ferns. Khullar (1981) reported that the pteridophytes form an important component of the Himalayan flora with both ground and epiphytic ferns. He also suggested that the nature of tree bark, altitude, and forest composition play important roles in the distribution and frequency of epiphytic ferns. In the Himalayan region Tewari (1995) reported 12 epiphytic fern species on *Q. leucotrichophora* and *Q. floribunda* and 4 on *Q. semecarpifolia*. Indeed, the highest species diversity was observed on tree trunks with rough-textured bark (as is the case for the three oaks mentioned above) that provide large surfaces accompanied by high humidity and heavy moss cover. When it rains these epiphytes also benefit from stemflow that provides them with extra nutrients (Tewari 1995). In general, the frequency of epiphytic ferns declines with increasing elevation (Khullar 1981), possibly because of low temperature accompanied by high wind velocity. At high elevation (2,500-3,000 m/8,200-10,000 ft), *Q. semecarpifolia* appeared to be a good host for some epiphytic ferns like *Araiostegia pseudocystopteris* (Kunze) Copel., *Polypodiodes microrhizoma* (C.B. Clarke ex Baker) Ching, *Lepisorus kashyapii* Mehra[4], and *Drynaria mollis* Bedd.

Some parasitic flowering plants, most commonly mistletoes (*Loranthus* spp.) of which there are 1,200 species, also grow as epiphytes on oak trees. These mistletoes are semi-parasites i.e., they still photosynthesize, but have lost the ability to absorb water

5/ *Loranthus* sp in *Quercus cordifolia* in Mexico.

3. Considered a synonym of *Q. lanata* Sm.

4. The accepted name for this species is *Lepisorus mehrae* Fraser-Jenk.

and minerals from the soils. Most have taken to the air, perched high in the crowns and branches of trees, and their roots have been converted into massive sucking organs (haustoria) that pierce and penetrate the bark. Inside the tree the haustoria fan out into the tree's conducting tissues to suck water and minerals. Some of these haustoria are so large that they cause a conspicuous swelling of the branch. Mistletoes with conspicuous tubular flowers and tasty nectar attract a variety of birds in different regions of the world (humming birds in America, sunbirds in tropical Africa and Asia, and honeyeaters in tropical Australia and Southern Asia). Other mistletoes, especially those that infest oaks in Temperate North America and Europe (*Phoradendron* spp. and *Viscum album* L.), do not have conspicuous flowers. A few parasites on a healthy oak tree do little damage, but on old or weakened oaks, flourishing mistletoe can further weaken the tree and lead eventually to death. Semi-parasites have expanded in the Himalayas due to of the lopping of branches that creates easily penetrable cut surfaces and allows for greater light penetration in the understory that in turn encourages the growth of semi-parasites.

Galls and associated life

Galls are unusual deformations and outgrowths of plants that are caused by a wide variety of organisms including bacteria, virus, fungi, and insects. Oaks are common hosts to gall-forming insects (Ronquist and Liljeblad 2001); indeed they harbor more kinds of galls than all other plants combined (a list of common oak galls is given in Table 2.). One highly specialized group of insects, the cynipid wasps (family *Cynipidae*) are responsible for the majority of oak galls. The gall is produced by the oak in a complex reaction to the saliva produced by the feeding larva. About 82% (roughly 1,300 species) of cynipids use oaks for their home (Ronquist and Liljeblad 2001; Zargaran et al. 2012). Many species are host-specific but not all, and some are often restricted to one particular part of the tree at one particular time of the year. Galls can be found on every conceivable part of an oak, even on roots and acorns. White Oaks host the greatest number of gall species, with *Q. douglasii* Hook. & Arn. harboring the most lavish diversity of them all (Keator and Bazell 1998). Not much has been studied on the galls associated with Himalayan oaks.

Oak leaves are host to several species of gall. One of the most common is the silk button gall of *Neuroterus numismatis* Olivier with which the underside of oak leaves is frequently studded. The galls are tiny flat discs with a central depression. They are fixed to the leaf by only a filmy stalk which makes it easy for them to be detached. Another leaf gall is the spangle gall produced by *N. quercusbaccarum* L. This galls is larger than the previous ones and is purplish brown with a concave center. Two other gall wasps are the cherry gall wasp *Dryophanta scutellaris* L. and the hop gall or artichoke gall wasp *Andricus fecundator* Hartig. Both of these species exhibit an alternation of generations in their reproduction (as is the case with most of these species). In contrast to the minute galls of the first two species mention above are the large, conspicuous apple galls that occur on many members of the White Oak group. Midges (*Bainidiplosis championi* Mani) form galls on *Q. floribunda* trees.

The hedgehog galls of the Eastern white oak (*Q. alba* L.) form on leaves when the female wasp *Acraspis erinacei* Beutenmüller lays her eggs on the young leaves in spring. These green, spine-encrusted galls are round to oblong and develop on both sides of the leaves. There are also several jumping galls (*Neurotarus saltatorius* Edwards) in different parts of the United States. California's magnificent valley oaks (*Q. lobata* Née)

6/ ***Neuroterus saltatorius*** **Edwards**
7/ ***Andricus quercuscalifornicus*** **Bassett in** ***Quercus lobata*** **Née.**
8/ ***Disholcaspis plumbella*** **L. in** ***Quercus berberidifolia*** **Liebm.**
9/ ***Heteroecus dasydactyli*** **Ashmead in** ***Quercus chrysolepis*** **Liebm.**

are host to one of them. Appearing on the leaves, these tiny, glossy brown, spherical galls generally occur in large numbers. Unlike most galls they complete their development on the ground as they fall off the leaves. The galls "jump" about each time the larva inside flips its body.

None of these galls present a serious problem to the mature oak that has learned to live with them for a long time, but when too numerous on young saplings they can diminish their strength.

Although known in Southern Europe for several hundred years, the Knopper gall wasp *(Andricus guercuscalicis* Burgsdorff) was first reported in England in the second half of the 20th century. During summer the galls of the asexual generation appear on the developing acorns of *Q. robur* L. and can grow to such an extent that they cover the entire acorn, sometimes resulting in as much as 90% acorn mortality. The galls of the sexual generation develop in spring on the male inflorescences of *Q. cerris* L., a species not indigenous to England.

All of these galls provide food for a wide variety of other animals, mostly predacious insects. The acorn woodpecker supplements its diet of oil-rich acorns with protein-rich wasp grubs. Galls may host filbert worms (*Cydia latiferreana* Walsingham) and other wasps, some of which parasitize the host wasp, while others eat the food stores of the gall itself. Galls produced on *Q. serrata* Murray are a good source of tannin (16-21%).

Belowground life

Soils under oaks sustain a large number and great variety of organisms. These range in size from visible creatures, such as slugs, snails, millipedes, woodlice, and larger insects, to microscopic life, such as bacteria, fungi and algae. Bacteria are among the most abundant of the soil denizens and they are crucial in the chain of life as their function is to break down organic substances. Fungi of many types are important soil inhabitants and include numerous molds and mildews besides the mycelia of larger fungi such as mushrooms. Molds feed on decaying organic matter, absorbing and recycling the proteins and carbohydrates in plants and animal residues. When they die they are metabolized by bacteria, liberating accumulated nitrogen and other important components that can be used by other organisms. Some fungus hyphae show symbiotic association with oak roots (mycorrhizal association). This symbiosis increases the absorption surface of roots and is vital in the capture of certain soil nutrients that the trees would not otherwise be able to absorb. Pande (unpublished data) reported 40 genera and 102 species of sporocarp-forming fungi in the oak forests of the Indian Central Himalayan region. Of these, 40 species are known to have mycorrhizal associations with oak trees. *Phoma hibernica* Grimes, M. O'Connor & Cummins, and *Cladosporium cladosporioides* (Fresen.) G.A. de Vries are two of the common pioneer species that initiate succession on leaf litter in Himalayan oak forests.

Among the microarthropods found in Himalayan oak-forest litter *Acarina* is the dominant genus, contributing 60-73% of the total litter fauna population (Singh and Singh 1992). Most numerous of the arthropods are the *Acarinae* or mites. They live predominantly on decaying vegetable matter but some also on decaying animal matter, including animal droppings. They thus perform a useful service in recycling the debris that falls to the ground. In Himalayan oak forests the most numerous (30% of the total population) soil microinsects belong to the genus *Collembola*, commonly known

as springtails (Singh and Singh 1992). These have elongated, segmented bodies with prominent antennae and are useful recycling agents as they feed on both plant and animal residues.

Of the larger fauna in the soil beneath an oak the most prevalent are the earthworms that plow through the decaying vegetable matter on which they largely feed. Other soil inhabitants include millipedes, woodlice, the larvae of numerous insects, slugs, snails, and ants. Some of them live on vegetable matter while some are carnivores. In general they are an important food source for larger and more advanced forms of animal life such as birds. Oli and Gupta (2000) reported 10 species of snails and 3 species of slugs from Central Himalayan oak forests. An oak forest in Central Himalaya supports far more belowground life than an adjacent pine forest, even when all other factors are similar.

Threats to oaks and the diversity they sustain

The economical and ecological value of oaks is generally higher than those of other woody species associated with oaks. There is a very strong relationship between oak forests and human activity and this poses a threat to *Quercus* species in different regions of the world. Pressures on oaks have increased due to the rapid increase and spread of population, increasing land value, the development of practices and machinery for clearing range land, channelizing streams, road building, and urban development. In the Indian Himalayan region, the subsistence economy is dependent on energy and nutrient input from forests. Chronic disturbance caused by biomass removal – lopping of trees for fuel wood and leaf fodder – is the dominant disturbance in these forests particularly in the vicinity of villages (Singh and Singh 1992). According to Singh and Rawat (2010) there are very few patches of intact oak forests left in the Himalayan region today and those that do remain intact are changing rapidly due to alien invasive species such as *Eupatorium adenophorum*, Hort. Berol. ex Kunth[5], *Lantana camara* L. and more aggressive species such as *Pinus roxburghii* Sarg. In many areas, where *Q. leucotrichophora* was the primary species it is giving way to *P. roxburghii* as a result of heavy lopping of the former. Heavy lopping also results in poor acorn production. Thadani (1997) reported that in areas of heavy lopping, acorn production was low, and many trees had almost no acorns. Zobel et al. (1995) and Zobel (1996) reported that in *Q. leucotrichophora* forests, one-year old twigs had lower starch levels in heavily disturbed forest stands in comparison to less disturbed stands. This indicates that sparse foliage of lopped trees may result in a deficiency of stored starch with no surplus available for acorn production.

Litter removal from the forest floor (used as fertilizer) changes the microclimate that acorns are exposed to once they fall, and this reduces acorn viability. The removal of litter from forests leads to a deficit of soil nutrients. Soil carbon and nitrogen are significantly lower in areas subject to human disturbance particularly where leaf litter is collected. Soil phosphorus is also lower in areas subject to heavy litter removal.

The nutritional richness of acorns makes them tempting targets for rodents and birds that hide them for times of scarcity. In the Central Himalayas as much as 90-100% of the acorn crop can be destroyed by mammal herbivory (Anonymous 1928). Troup (1921) reported the destruction of a promising acorn crop in Shimla by jays in 1916. Thadani (1997) reported that in the Kumaun region the 1997 crop was severely depleted by jays that came into the area in November and feasted on the unripe acorns. While the birds can

5. This is an unresolved name.

eat only a limited quantity of acorns, the intensive feeding activity causes an even greater amount to fall to the ground. In a poor seed year an entire crop can be destroyed this way thus restricting regeneration. Oak seeds are also attacked by a number of weevils that cause serious damage: Bora (1989) reports as much as 70-80% with *Q. leucotrichophora*. Weevil infestation is reported to be about 50% higher in disturbed *Q. leucotrichophora* stands than in the adjacent undisturbed stands (Upreti et al. 1985).

Fires are also a threat to oak forests. Fire can kill the stem outright or cause feathering along the stem from epicormic branching. Fire-damaged stems are especially susceptible to pathogens which weaken the tree and result in wind throw and breakage. The damage may immediately or eventually reduce the economic value of a tree. The most common fire damage is a basal wound caused by death of the cambium. As time goes by new cambium may eventually cover a wound. However, if decay is active and old cambium of the wound face is destroyed the growing cambium may curve inward and back on itself forming a wound that may remain open for many years. Subsequent fires may enlarge the wound until all that remains of the trunk is a thin partial ring of live wood at which point the tree may be too weak to face another stressful situation. Many of these wounds can also be infested with various insects, creating further damage.

Healthy forests and healthy trees contribute to many things that are lost due to disturbance: wildlife enhancement, watershed protection, recreation, and aesthetic value are among the most important.

Photographers. Title page: Guy Sternberg (*Acraspis erinacei* Beutenmüller). Photos 1-5: Béatrice Chassé. Photos 6, 8, 9: Ron Russo. Photo 7: Emily Griswold.

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