SPECIES	DISTRIBUTION	THREATS
Globally threatened		
Quercus alpestris Boiss.	Sierra de las Nieves	Overgrazing, loss of habitat, erosion
Quercus alnifolia Poech	Troodos Mountains, Cyprus	Fire, overgrazing, felling, human development
Quercus aucheri Jaub. & Spach	Aegean region and Anatolia (Turkey)	Small isolated populations
Quercus ilex L. subsp. *ballota* (Desf.) Samp.	Portugal and Spain	Fire, over grazing, loss of habitat
Quercus pontica K. Koch	Georgia and Turkey	Overgrazing
Quercus robur L. subsp. *imeretina* (Steven ex Woronow) Menitsky	Georgia and Russia	Felling and loss of habitat
Quercus vulcanica Boiss. & Heldr. ex Kotschy	Isparta province (Turkey)	Few isolated populations
Least concern		
Quercus brantii Lindl.	Turkey	
Quercus cerris L.	Central, East and Southeast Europe, Turkey	
Quercsu coccifera L.	Mediterranean region	
Quercus dalechampii Ten.	Central, East and Southeast Europe	
Quercus frainetto Ten.	Southern and Central Italy, Balkan Peninsula, Northwest Turkey	
Quercus ilex L.	Mediterranean region	
Quercus infectoria Oliv.	Greece	
Quercus ithaburensis Decne.	Southeastern Italy to Eastern Mediterranean	
Quercus libani Oliv.	Turkey	
Quercus petraea (Matt.) Liebl.	Europe	
Quercus petraea (Matt.) Liebl. subsp. *huguetiana* Franco & G. López	Southern France and North Spain	
Quercus robur L.	Europe	
Quercus pubescens Willd.	Eastern, Central and Southern Europe, Northern Turkey	
Quercus suber L.	Western Mediterranean Basin	

Table 1/ List of threatened species according to the IUCN (Oldfield and Eastwood, 2007).

Endangered Oak Resources in Europe and Around the Mediterranean Basin: Marginal Populations and Minor Species

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ABSTRACT

Oaks are common species in Europe and around the Mediterranean Basin where they are a major component of forest ecosystems and economy. According to Govaerts and Frodin (1998) this region hosts 29 species and 44 taxa. We will first try to establish a tentative list of species. "Try" because oaks form a complex of species that does not fit the classical definition of a species. We will then look at the different threats that exist at both population and species level, reviewing climate change, new emergent diseases, human impact (forestry practices, overgrazing, fire, housing, and so forth), endemism, etc. We will focus on climate change and the risk of introduction of *Ceratocystis fagacearum* (Bretz) Hunt. Oaks from warm and dry climates are key species for the future because they have a high adaptation potential due to high genetic diversity, high gene flow within and between species and large genetic diversity. Today, several marginal populations and rare species like *Quercus crenata* Lam. or *Q. sicula* Borzi are endangered. We will propose different strategies for adaptation and conservation of these valuable and noble trees.

Keywords: European oaks, *Quercus,* taxonomy, biodiversity, genetic resources, threat

Introduction

In Europe, oaks are a major forest component from the Mediterranean Basin to southern Scandinavia and from Ireland to the Ural Mountains. Even if Europe doesn't host the high diversity of oaks found in North America and Southeast Asia, there is nevertheless important diversity. Oaks are a major component of many different ecosystems: plain forest, riparian forest, Mediterranean scrublands, calcareous plateaus. Today, oaks in Europe are subject to different threats. The aim of this paper is to list European oak diversity and then to review the main threats facing it.

Oaks in Europe and around the Mediterranean Basin

How many species?

We have established the European oaks list from two sources: the *World Checklist and Bibliography of Fagales* (Govaerts and Frodin, 1998) that can be consulted on the Kew Garden website http://apps.kew.org/wcsp/home.do and Cristofolini and Crema, 2005. According to this source, Europe hosts 29 species divided into 44 taxa. 11 species belong to section *Cerris* and 18 species to section *Quercus*.

1/ *Quercus crenata*, France (1999).

This list is not satisfactory because the definition of a species that is used is based only on morphological criteria. Oaks form a complex of species with intense gene flow between species and therefore clear-cut divisions between species are difficult to establish. This remark can be illustrated with two examples

First, the natural ranges of *Quercus ilex* L. and *Q. rotundifolia* Lam. overlap widely. In this overlapping zone, we can observe a gradient from pure *Quercus ilex* L. to pure *Q. rotundifolia* Lam. Lumaret et al. (2002) observed a discrepancy between morphology and molecular variations. The authors explain that morphological variation is an adaptive response to climate not a taxonomical differentiation between two species

The second example is *Q. crenata* Lam. This species is accepted as a species since 2005 (Cristofolini and Crema, 2005) but the status of this taxon is not clear. The hybrid origin of this taxon (*Q. cerris* L. × *Q. suber* L.) is well established (Conte et al., 2009) but the hybrid status is not clear because it may be a fixed hybrid or it may represent the offspring of current hybridization between the two parental species or both (Cristofolini and Crema, 2005). If it is a fixed hybrid, it must be considered a species and therefore maintained in this list, if not, it must be removed.

Distribution

For oaks we observe a classical gradient of biodiversity from the Mediterranean region to northern Europe. In the north we find only 2 species (*Q. robur* L. and *Q. petraea* (Matt.) Liebl.); in the intermediate zone 5 species (*Q. petraea*, *Q. robur*, *Q. pubescens* Willd., *Q. pyrenaica* Willd. and *Q. cerris* L.) and all of the 29 species and 44 taxa are found in the south of Europe which is a key region for oaks

Threat levels

Biodiversity has three levels: ecosystemic, specific and genetic. In this section we will look at examples of threat for oaks at each of these levels.

Ecosystemic

An ecosystem can disappear through destruction or degradation. In Europe, some forest ecosystems have dramatically regressed: temperate broad-leaved forest (75%), Mediterranean forest (78%), riparian forest (90%) (Halkka and Lappalainen, 2001). In these forests, oaks are frequently dominant

Specific

Several oaks species are endangered. Oldfield and Eastwood (2007) have recorded 7 oak taxa threatened throughout Europe and 14 taxa of least concern (Table 1). However, this list is not satisfactory because: (i) the nomenclature needs to be updated; (ii) several endangered species are missing (*Q. aucheri* Jaub. & Spach., *Q. brantii* Lindl., *Q. canariensis* Willd., *Q. crenata* Lam. and *Q. sicula* Borzi ex Lojac.) and, (iii) there is no clear distinction between the different risk categories. IUCN has identified different threats: loss of habitat, overgrazing and felling, endemism, fire, etc. In this paper, we have retained only three examples of threat: climate change, pathological problems and endemism.

Genetic

The two mains threats on the genetic level are 1) genetic drift and 2) genetic transfer.

1. Genetic drift

Is the change in the frequency of a gene variant or allele in a population due to random sampling between generations. Genetic drift may cause gene variants to disappear completely and thereby reduce genetic variation. Marginal populations are at high risk because many of them are disappearing, they have very often less than 2,000 breeding individuals and are isolated. Genetic drift could impoverish diversity because gene flow could not compensate for this loss due to this isolation. Marginal populations are concentrated on the outer edges of natural ranges. Southern margins host thermophilic and drought resistant populations that have high adaptation potential regarding current climatic change. The genetic resources of these populations could be very useful for boosting adaptation of populations in central Europe.

2. Genetic transfer

Foresters resort to planting because of lack of natural regeneration or in their eagerness to increase productivity. Most often though genetic resources used for this regeneration are not local. This exogenous source of genetic material is the main disturbance of genetic diversity (Lesur, 1999). Lesur has studied genetic resources in the 600 compartments of the national forest of Compiègne (France) with cpDNA markers. She found that since the 70s, the provenance of most plantations has a very distant geographical origin. About 20%

of the regeneration comes from eastern Europe. This study reveals that genetic transfer is a major disturbance for the distribution of genetic diversity. Nevertheless we must not consider these plantations only from a negative point of view. They could increase local genetic diversity and therefore enhance oak adaptability to current climate change. On the other hand, they raise a major problem for conserving the genetics resources of sessile and pedunculate oaks that would also represent a loss of adaptive capacity.

Origin of risk: global changes

Human impact: housing, fire, overgrazing, plantation

These threats are often cited as major concerns for oaks, although for the most part without clear studies to corroborate such claims. They are well documented only at forest level. There is a tendency in Europe to artificialize lands through, for example, urbanization. In France 1,380,000 ha were urbanized between 1982-2003 (Pointerau and Coulon, 2009). Forest fires concern mainly the Mediterranean region, with from 0.19% (France) to 1.23% (Portugal) of the forest surface burnt each year.

Diseases

Hosts and pathogens have evolved together through continuous and reciprocal coadaptation that promotes fitness (Van Valen, 1973). It is an armed peace: in the long term, hosts and pathogens are in equilibrium. With the rapidity of modern transportation in the global market the arrival rate of new pathogens is greatly increased. Coevolution and adaptation on the other hand, need time – without it, these new pathogens can inflict severe damage to host species especially when they arrive in industrial quantities. Below we review one example of a probable past introduction and one example of a possible future introduction along with its potential risk

1. Powdery oak mildew

Erysiphe alphitoides (Griffon & Maubl.) U. Braun & S. Takam, *E. hypophylla* (Nevod.) U. Braun & J.H. Cunnington, *E. quercicola* Schwein., and related species. Powdery mildew is a major fungal disease of European oaks. A recent study (Mougou-Hamdane et al., 2010) shows that several species are involved in this epidemic: *Erysiphe alphitoides*, *E. hypophylla*, *E. quercicola*, etc. Probably the result of an introduction (Marçais et Desprez-Loustau, 2007), the disease, appeared suddenly and spread to almost all of Europe in the early 20th century. It was particularly severe on *Q. robur* and foresters were afraid that powdery mildew would decimate indigenous oaks (Mougou et al., 2008). Pyrenean oak is very sensitive to this pathogen and, since the beginning of this epidemic, populations of Pyrenean oak have declined (Mougnou-Hadane et al., 2010).

2. Oak wilt (*Ceratocystis fagacearum* (T. W. Bretz) J. Hunt)

Oak wilt is due to this fungus whose natural range extends from Texas to Wisconsin and from Arkansas to Pennsylvania (Juzwik et al., 2011). Due to low dispersal, the disease attacks are limited to small patches. European white oaks are very sensitive to this pathogen (Pinon et al., 2003). Moreover, in Europe *Scolytus intricatus* (Ratzeburg, 1837) could be a very efficient dispersal agent. The introduction of this fungus through the wood trade, could lead to a very serious epidemic.

Climate change

Thuillez (2003) and Thuillez et al., (2005) have modeled the climatic envelop of *Q. petraea* today and in the future using different climatic models. A global shift northward of several hundred kilometres (100 km = 63 mi) is predicted for the end of this century. It is probable that sessile oak will not be able to keep apace with this rate of change. Also predicted is the loss of all of the southern marginal populations that host very valuable genetic resources because they are very close to glacial refugia and have evolved in warm climates.

Origin of risk: population structure

Range (endemism)

Several European oaks have a narrow, natural range. These endemic species include, amongst others, *Q. alnifolia* Poech, *Q. crenata*, *Q. sicula*, *Q. vulcanica* Boiss. & Heldr. ex Kotschy. Due to endemism these species are very vulnerable for demographic and genetic reasons. *Q. vulcanica* forests cover 8,000 ha (Balaban & Yilgor, 1999) represented by 12 isolated populations in Turkey (Avci, 1996). These populations will not be able to expand because they are surrounded by hostile regions (urban zones, orchards, steppes, etc.) and if one population disappears, it could not be restored naturally. The population of *Q. crenata* is estimated at about 1,000 individuals in Italy, several dozen in France and just a few individuals in Slovenia and Croatia. (Conte et al., 2007)

Demography

Minimum viable population (MVP) is the critical limit of a species below which it can not reproduce in the wild (Schaffer, 1981). Current numbers of breeding individuals

2/ *Quercus vulcanica,* Turkey (2010).

3/ *Quercus faginea* (2008).

are very low for several oaks species (*Q. crenata*, *Q. sicula*, etc.). They could, under the MVP requirements, be considered as very vulnerable species.

Conservation efforts

Different conservation efforts that include oak populations and resources have been undertaken. The aim of NATURA 2000 is to assure the long-term survival of Europe's most valuable and most threatened species and habitats. This European policy concerns several ecosystems hosting oaks and different oak species. EUFORGEN is a European program to promote conservation of forest genetic resources, protecting the genetic resources eleven oak species in Conservation Units. Many initiatives for oak and oak ecosystem conservation have also been taken at national level (national parks, natural reserves, etc.). Several oaks species are protected in different countries, for example, *Q. crenata* in France, *Q. alnifolia* in Cyprus, *Q. vulcanica* in Turkey. In France the CRGF (Commission Ressources Génétiques Forestières) manages 20 Conservation Units of sessile oak. This program will be extended to other oak species. It is very difficult to establish a list of programs at regional level, but two examples exist in France under the auspices of the Espaces Naturels Sensibles organization that purchases valuable ecosystems. In Italy, different regions also have programs to protect *Q. crenata*.

Several conservation strategies must be developed for European oaks based on geographic distribution, ecological requirements, genetic structure and demographic parameters. Examples include:

- *Q. vulcanic*a: this species need to be assisted in its migration to the north; this can be accomplished through the creation of additional populations in the future potential natural range.

- *Q. crenata*: conservation strategy will depend on the taxonomical status of this species. If individuals are offspring of current hybridization between the two parental species the best strategy is to restore genetic contact between the two parental species. If it is a fixed hybrid, then seed orchards must be created with the resultant acorns used for planting new populations in order to promote intraspecific genetic diversity.

- *Q. petraea*: only marginal populations are threatened. These populations must be duplicated in safer zones (in consideration of future climate), in other words where there is no anthropomorphic risk such as urbanization, fire, etc.

- *Ceratocystis fagacearum*: there must be greater restrictions in the wood trade with the USA; areas surrounding points of entry for wood imports must be monitored several times a year in order to reduce the possibility of introduction.

Conclusion

Oaks are common in Europe and are very important for economical, ecological and sociological reasons. One would think that they are very well known but, surprisingly, this paper reveals a lack of basic knowledge of these species. Taxonomical and genetic work are urgently needed in order to correctly determine the number of taxa in Europe and the Mediterranean Basin in order to establish conservation and management strategies. The importance of threat is dependent on distribution and population size. Even common species like *Q. petraea* are threatened at the genetic resource level. Obviously minor oak species like *Q. sicula* are at high risk of becoming extinct

A major problem exists only in the northern zone. Genetic resources are threatened in two regions, the center and the south. Most oak species in the southern region are subject to threat at all three risk levels.

Photographers. Title page: Alexis Ducousso (*Quercus frainetto*). Photos 1, 3: Alexis Ducousso. Photo 2: Béatrice Chassé.

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