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TURKISH HAZEL (*Corylus Colurna* L.) IN BOSNIA AND HERZEGOVINA AND MONTENEGRO: A REVIEW OF DISTRIBUTION, AUTECOLOGY, PRODUCTIVITY, SILVICULTURE, AND RESPONSE TO CLIMATE CHANGE

SUMMARY

Due to climate change, the distribution range of major tree species in Europe is expected to decrease, creating opportunities for the utilization of rare and neglected species that are more resilient to climate extremes. Turkish hazel (*Corylus colurna* L.) is one such species with potential for forest restoration in degraded areas, though its ecology remains under-researched. This review synthesizes current knowledge on its distribution, autecology, growth, silviculture, and climate change response.

Distribution: Hot-spot small isolated populations of Turkish hazel in Bosnia and Herzegovina are found on Mt Prenj, Mt Velež, around Nevesinje, while in Montenegro they are located on Mt Njegoš near Nikšić, in the localities of Somina, Piva Komarnica, and the Klauderske forests near Berane.

Autecology: The Turkish hazel (*Corylus colurna*) in Bosnia and Herzegovina and Montenegro occupies limestone areas, often highly karstified, with soil found in pockets. These areas have a distinctly mixed tree composition, indicating mesoxerothermic climatic conditions in mountainous regions.

Growth and Wood Use: The species culminates in growth by age 40, reaching up to 35 m in height and 100+ cm in diameter, with a lifespan exceeding 200 years. Wood is widely used especially for carpentry and furniture.

Silviculture: Shade-tolerant on fertile sites and light-demanding on rocky soils, Turkish hazel is less competitive than other broadleaves. Regular silvicultural treatments are required to ensure adequate light and growth. It is well-suited for urban environments and showing good tolerance to city pollution.

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Climate Change Response: Resistant to drought, temperature extremes, windthrow, and snow damage, Turkish hazel is a promising tree species for shaping climate-smart forests.

Keywords: Turkish hazel, *Corylus colurna* L., distribution, autecology, silviculture, climate change

INTRODUCTION

Climate-induced changes in forest ecosystem structure and species composition, particularly from recurring droughts, significantly alter interspecific competition, reduce biodiversity and stand stability, impair carbon sequestration, and result in long-term economic losses (Alfaro *et al*., 2014; Schelhaas *et al*., 2015; Kunz *et al.,* 2018). A major consequence of these climate extremes is the large-scale dieback of forests dominated by commercially valuable species, such as beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) Karst.), which are highly sensitive to such disturbances and are projected to experience substantial range contractions in the future (Hanewinkel *et al*., 2013; Walentowski, 2017; Buras & Menzel, 2018).

In response, the establishment of mixed forests with higher species diversity, including rare native and drought-tolerant exotic species, is increasingly advocated as a strategy to reduce the risks of climate-induced forest decline (Kölling, 2013; Vitali *et al*., 2017; Koch *et al*., 2022; Višnjić *et al*., 2024). One such candidate is Turkish hazel (*Corylus colurna* L.), a rare native species whose western distribution limit lies in Bosnia and Herzegovina and Montenegro. Owing to its tolerance to drought and soil moisture deficits, as well as its resistance to both high and low temperatures, wind, and snow damage, Turkish hazel shows considerable potential for use in climate-adapted forestry (Alexandrov, 1995; Richter, 2013, 2019; Šeho *et al*., 2018, 2023; Sandholz, *et al*., 2024). In addition to its ecological resilience, the species produces high-quality timber and supports forest biodiversity, traits that are particularly valuable when considering the integration of non-dominant or underutilized species into managed stands (Kölling, 2013, Richter, 2013, 2019; Temel *et al.,* 2017; Šeho, *et al.,* 2023).

Turkish hazel Typically inhabiting gorges, canyons, and steep slopes, the species prefers limestone rendzinas and brown soils, where it plays a stabilizing role and provides habitat for various organisms. Its edaphic and climatic preferences vary regionally, highlighting its adaptability to diverse site conditions.

In Bosnia and Herzegovina, it is primarily located on limestone substrates in Herzegovina near Mostar, Konjic, Gacko, Nevesinje and Rujište, with smaller populations reported around Rogatica, Srebrenica, and Višegrad (Fukarek, 1956, 1963b; Beus, 1970, 1982). In Montenegro, the species grows in the regions of Piva, Cetinje, Nikšić, and Berane (Petrović, 1934; Fukarek, 1956, 1963b; Horvat *et al*., 1974; Marković, 2021). In Bosnia and Herzegovina and Montenegro, Turkish hazel grows as single trees or in smaller isolated populations in the southeastern part of the Dinarides. This species serves as a pioneer tree on shallow limestone soils, screes, and rocky outcrops, where the absence of competing tree species allows it to establish and dominate. The climatic conditions of its habitats are thermo-mesophilic, and it is found mixed among tree species such as *Fagus sylvatica*, *Acer pseudoplatanus*, *Fraxinus excelsior*, *Ostrya carpinifolia*, *Carpinus orientalis*, *Tilia cordata*, *Acer optusatum* and *Acer monspessulanum* (pers. comm. Vojniković, 2025).

Small, isolated populations in Bosnia and Herzegovina and Montenegro are of great importance for the future spread of the species. Numerous studies highlight the restoration potential of Turkish hazel and its strong adaptability to climate change. Populations from Bosnia and Herzegovina and Montenegro may serve as a nucleus for assisted migration and use in forest restoration efforts in areas affected by climate extremes (Vitali *et al.*, 2017; Koch *et al.,* 2022), the development of climate-smart forests (Šeho *et a*l., 2018; Sandholz, *et al*., 2024), and the establishment of green climate islands in cities (Roloff & Grundmann, 2008; Gillner *et al*., 2015; Višnjić & Ivojević, 2023). The aim of this publication is to synthesize and present comprehensive knowledge on Turkish hazel, specifically focusing on its distribution, ecological characteristics, and silvicultural potential and competitive interactions in mixed stands in Bosnia and Herzegovina and Montenegro, as well as its role in mixed forests under climate change pressures. This species could play an important role in mitigating climate change and enhancing the resilience of forests affected by climatic extremes. Currently, Turkish hazel is not cultivated in forest nurseries in Bosnia and Herzegovina and Montenegro and this paper will shed further light on seed production, nursery propagation of Turkish hazel seedlings.

MATERIAL AND METHODS

This review paper has been prepared based on the existing literature, including digital libraries, scientific databases, professional publications, reports, theses, project documents, national forest inventories, and unpublished maps related to Turkish hazel (*Corylus colurna* L.). Field surveys were carried out in areas of the natural distribution of Turkish hazel in Bosnia and Herzegovina and Montenegro, to colect data on its occurrence, site conditions, and association with other tree species.

Based on previous studies and field data, a distribution map of Turkish hazel in Bosnia and Herzegovina and Montenegro was created using ArcGIS software. The same color was used across the map, with darker shades indicating a higher frequency of occurrence. Key habitats, along with their geographic coordinates, are shown in a table. These data were taken from national forest inventories (NFI, 2006–2009; NFI, 2013), stand-level inventories in Bosnia Herzegovina and Montenegro, and the own field surveys. An overview of the Tukish hazel productivity, wood quality and uses, silvicultural characteristics, and response to climate change is provided based on the available literature and field survey findings.

RESULTS AND DISCUSSION

Distribution

Turkish hazel has a broad native range spanning Asia Minor, the Caucasus, and the Balkan Peninsula. According to the Euro+Med (2006+), it is present in Albania, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Greece, North Macedonia, Romania, the Russian Federation (Caucasus), Serbia (including Kosovo), and both the European and Asian parts of Turkey (Fig. 1). Some authors extend this range to include Iran, Afghanistan, and even the Himalayan region (Schmukcer, 1942; Šilić, 2005; Brus, 2012), suggesting a significant ecological amplitude.

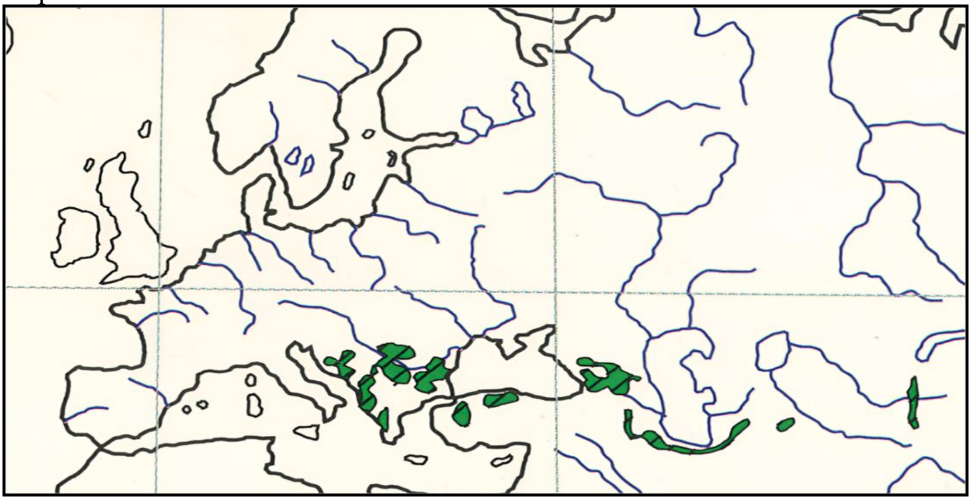

Figure 1. Distribution map of Turkish Hazel (*Corylus colurna* L.) (Brus, 2012)

Bosnia and Herzegovina marks the westernmost extent of Turkish hazel's natural range, where the species predominantly occurs in Herzegovina on limestone substrates. Major populations are found near Mostar, Konjic, Mount Čabulja, Crna Gora near Nevesinje, Mount Velež, Gacko, Bjelašnica, Rujište, and the Rakitnica valley near Umoljani (Fukarek, 1956). Smaller, more scattered populations are reported in Bosnia around Rogatica, Srebrenica, Višegrad, and Foča, as well as within Sutjeska National Park (Fukarek, 1956, 1963a, 1963b). Additional occurrences were documented by Beus (1970, 1982) on Mount Igman and in the vicinity of Prača.

In Montenegro, Turkish hazel has been recorded near Košarice (Cetinje), Čeklići and Cuce in the Katunska nahija region, as well as in Ostrog, Dubovik (between Njegoš and Cetinje), and at Čeovski Lisac and Pusti Lisac west of Nikšić (Fukarek, 1963b). Blečić (1958) reported its presence in the Piva and Tara canyons at elevations between 1000 and 1200 m, and in the regions of Vojnik and Vasojevići. More recent data from Marković (2021) indicate a broader distribution, including localities such as Kazanci, Čarađe, Javljen, Somina, Oputne Rudine, Njegoš, Zla Gora, Širakača, Bratogošt, Pješivci, Ubaljska Planina on Mount Orjen, Duga, Šišman on Golija, and the Komarnica Canyon. Additional isolated occurrences have been documented in Donja Dobrilovina, Gradac near Mojkovac, Kaludar near Petnjica, and Dapsići. Local forest inventory data confirm broader presence in the Kaludar forests, Somina, and Zla Gora (Njegoš).

In Serbia, Turkish hazel primarily occurs on limestone substrates in the eastern and southeastern parts of the country (Petrović, 1934; Fukarek, 1956; Jovanović, 1997; Tomić, 2004; Tomić & Rakonjac, 2017). In North Macedonia, the species grows in the Vardar Valley occurring on silicate, limestone, and eruptive substrates at elevations of 800–1300 m (Fukarek, 1956). In Bulgaria, Turkish hazel occurs up to 1400 m a.s.l., and in Turkey, it can reach elevations of 2000 m (Arslan, 2023).

Table 1. Hotspot isolated populations of Turkish hazel in Bosnia and Herzegovina and Montenegro

Country	Location	Coordinates	Elev.	T °C	Tveg °C	R (mm)	Rveg (mm)	Assoc. Species
Bosnia and Herzegovina	Zijemlje	18°2'35.25"E 43°22'59.01"N	1076	8,19	14,8	1130	478	*F.sylvatica, A.pseudoplatanus, A.monspessulanum, F.excelsior, O.carpinifolia*
Bosnia and Herzegovina	Rabina, Nevesinje	18°2'48.23"E 43°15'31.83"N	1069	9,84	15,4	1119	460	*A. pseudoplatanus, F.excelsior*
Bosnia and Herzegovina	Nedavić, Kalinovik	18°20'40.81"E 43°27'13.23"N	1155	8,47	14,2	1029	465	*F. sylvatica*
Bosnia and Herzegovina	Prenj, Konjic	19°31′56″E 43°33′59"N	1063	8,7	12,8	1063	463	*F. sylvatica, F.excelsior, A.campestre, Acer obtusatum T.platiphyllos, O.carpinifolia*
Montenegro	Kaludarske šume, Berane	19°53'50.39"E 42°48'10.36"N	1169	8,31	12,2	961	466	*F. sylvatica, F. ornus, Q. cerris, C. betulus*
Montenegro	Somina	18°39'43.47"E 42°59'9.44"N	1168	8,47	13,9	1092	460	*F. excelsior, A.alba, T.cordata, P.avium*
Montenegro	Zla gora, Nikšić	18°40'31.74"E 42°58'43.23"N	1230	9,02	14,2	1107	466	*A. alba, F. sylvatica, F.ornus, P. avium, A.pseudoplatanus*
Montenegro	Piva Komarnica	19° 15′00.41″ 43° 10′00.00″	1093	8,1	12,4	1089	480	*F. sylvatica, A.pseudoplatanus, O.carpinifolia, T.cordata*

Sources: The Second National Forest Inventory of Bosnia and Herzegovina (NFI 2006-2009), the First National Forest Inventory of Montenegro (NFI 2013), forest stand inventory data, and field surveys. Climatic variables were derived using the easyclimate R package (Cruz-Alonso et al., 2023). Elev. = Elevation; T = Mean annual temperature; Tveg = Mean temperature during the vegetation period; R = Mean annual precipitation; Rveg = Mean precipitation during the vegetation period.

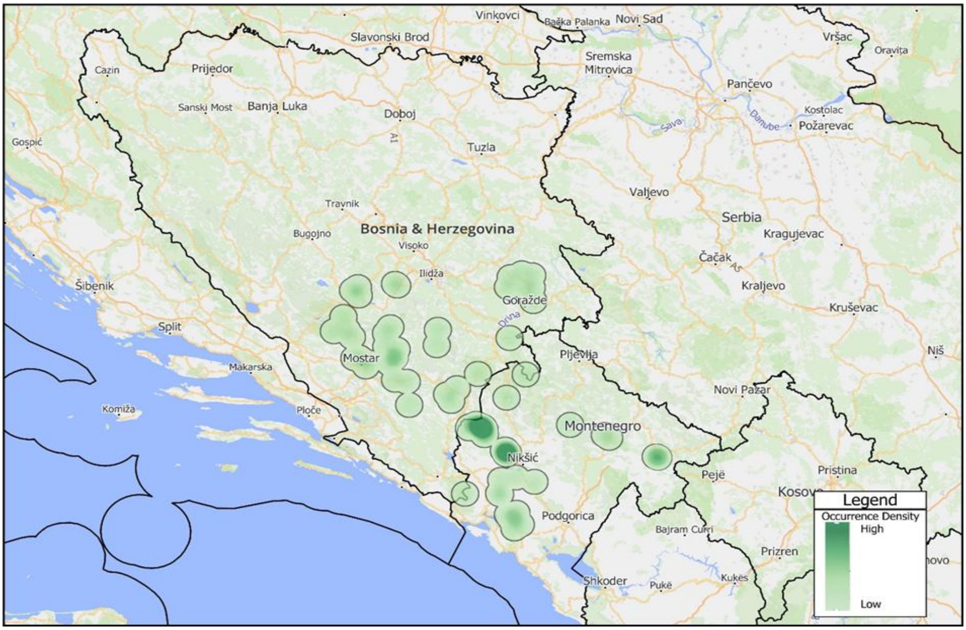

Figure 2. Spatial distribution of Turkish hazel in Bosnia and Herzegovina and Montenegro based on literature sources (Fukarek, 1956, 1963b; Blečić 1958; Vojniković *et al.*, 2017; Šilić *et al.*, 1985; Marković, 2021), unpublished maps by Fukarek, P., NFI BiH (2006-2009); NFI Montenegro, (2013), autors field survey and local inventory data (PGŠ, 2017, 2018, 2024). Darker green shades indicate areas with higher occurrence of the species

Autecology

Turkish hazel typically grows in gorges, canyons, deep valleys, and broad, sheltered basins with pronounced relief. Its elevational range varies by region: from 380 to 2000 m a.s.l. in Turkey (Arslan, 2023); 700–1350 m in Serbia (Jovanović, 1997; Tomić, 2004; Tomić & Rakonjac, 2017); 250–1700 m in Bosnia and Herzegovina (Fukarek, 1956); 100–1400 m in Bulgaria (Šeho *et al*. 2018), and predominantly 930–1530 m in Montenegro. At lower elevations (250–400 m), higher precipitation is needed (Arslan, 2023). While in Turkey the species avoids sun-exposed slopes, in Bosnia and Herzegovina it also grows on warm, southern aspects (Fukarek, 1963b). In Montenegro's Piva Canyon, it inhabits fragmented limestone terrain with deep sinkholes (Blečić, 1958; Fukarek, 1963b).

According to Academician Beus (pers. comm.), Turkish hazel in Bosnia and Herzegovina grows exclusively on pure limestone, avoiding saccharoid dolomites and limestone moraines. Šilić *et al.* (1985) confirmed this by describing the subassociation *Rhamno–Abietetum colurnetosum* on bare Mesozoic limestone on Velež. Šilić (2005) also identified Turkish hazel as a strict limestone specialist. On steep slopes, soils are often shallow and mixed with deluvial material and rock fragments (Jovanović, 1997). Although it is occasionally found on silicate substrates (Fukarek, 1956; Jovanović, 1997), limestone remains its primary bedrock (Arslan, 2023). According to Brus (2012), Turkish hazel thrives best on deep, fresh limestone soils but can also tolerate sandy and alluvial substrates, as well as drought-prone and nutrient-poor sites. However, it avoids extremely compacted, excessively dry, or overly wet soils. On fertile soils, it is shade-tolerant; on poor, dry soils, it behaves as a light-demanding species.

Oberdorfer (1994) placed Turkish hazel within the order *Quercetalia pubescentis*. Due to their distinct floristic composition, *Corylus colurna* forests in Serbia were classified by Horvat *et al.* (1974) as a separate suballiance, *Fago-Colurnenion* Borhidi 63. Jovanović (1997) later renamed this suballiance *Corylo colurnae–Fagenion moesiacum* (B. Jov. 1979; see Jovanović 1997). Fukarek (1956) considered Turkish hazel part of the montane element, occurring within *Querceto–Carpinetum* or *Querceto–Ostryetum* communities, though it has largely disappeared from the lower layers of beech forests.

In Montenegro, the *Colurno–Ostryetum carpinifoliae* community was described in the Piva Canyon on Mount Vojnik, between Jasenovo Polje and Veliki Javork, below the beech–fir belt (Blečić, 1958; Fukarek, 1963b; Horvat *et al.,* 1974). This forest, despite being dominated by *Fagus sylvatica* and assigned to the *Aremonio–Fagion* alliance, shows thermophilous features due to species from the *Orno–Ostryon* alliance. Blečić (1958) documented 38 woody species in this community, including *Acer platanoides*, *A. pseudoplatanus*, *A. campestre*, *Prunus avium*, *Betula pendula*, *Populus tremula*, *Tilia cordata*, *Salix caprea*, *Sorbus torminalis*, *Rhamnus fallax*, *Lonicera alpigena*, *Ribes grossularia*, *Daphne mezereum*, *Sorbus aucuparia*, *Rosa pendulina*, and *Ribes alpinum*.

In Bosnia and Herzegovina, Turkish hazel occurs in several subassociations such as *Seslerio–Ostryetum colurentosum* on Velež and in Sutjeska, and *Rhamno–Abietetum colurnetosum* on Velež (Lipovačka Ljut, Pavlovača, Gvozda slopes, Runjevi Gradac, Jelova Glava) (Fabijanić & Fukarek, 1969; Šilić *et al*., 1985; Barudanović *et al.,* 2015). The latter occurs between 1080 and 1460 m a.s.l. on northeast-facing slopes (5–25°) with shallow soils over Mesozoic limestone. Associated species include *Abies alba*, *Sorbus aria* ssp. *umbellata*, *Rhamnus fallax*, *Lonicera alpigena*, and *Ribes alpinum* ssp. *palidigenum*.

In the Perućica Primeval Forest, *Corylus colurna* is found in the *Seslerio–Ostryetum colurnetosum* subassociation between 720 and 1000 m a.s.l., mostly on southern to southeastern exposures (Fukarek, 1963a, 1963b). The community is floristically heterogeneous, combining elements from *Quercetalia pubescentis* (e.g., *Cornus mas*, *Acer monspessulanum*, *Sorbus torminalis*), *Fagetalia* (e.g., *Fagus sylvatica*, *Acer pseudoplatanus*), *Calamagrostio-Abietion*, and meadow types such as *Festuco-Brometea* and *Brachypodio-Chrysopogonetalia*. This diversity reflects highly variable light and moisture conditions. Though rare in the Sutjeska area, mature individuals are found above Suha, on lower slopes of Volujak, below Beškita, and along the Perućica stream. Reports of Turkish hazel in the subassociation *Quercetum frainetto hercegovinicum colurnetosum* (Fabjanić & Fukarek, 1969; Barudanović *et al*., 2015) in the Neretva Valley are uncertain due to the site's low elevation and thermophilic character, as is its classification within *Aceri obtusati-Fagetum colurentosum*.

In conclusion, Turkish hazel is most commonly found in beech and thermophilous broadleaf forests such as those dominated by downy oak, hop-hornbeam, field maple, and wild service tree - and does not form pure stands. It displays pioneer traits, tolerates a wide range of conditions, and contributes to soil improvement through its leaf litter, making it suitable for afforestation of degraded karst landscapes. It typically grows as scattered individuals or in small groups; larger natural populations of 20-100 individuals are rare, though some stands may contain up to 300 trees (Fukarek, 1956).

Growth and Productivity of Turkish hasel

Turkish hazel (*Corylus colurna* L.) is a long-living species, typically reaching up to 200 years of age (Alexandrov, 1995; Schmidt, 2003), with exceptional specimens living significantly longer. In Bosnia and Herzegovina, near Rogatica, one tree was estimated to be around 460 years old (Mirković, 2011), while in Turkey, individuals over 620 years have been documented (Genç, *et.al.*1998). On favorable sites, it can reach heights of up to 35 m (Genç, *et al*. 1998), while on shallow or dry soils it grows up to 25 m, and in semi-arid areas near steppe zones, only 10–15 m (Richter, 2019). Height increment culminates between 20 and 40 years of age. On fresh, nutrient-rich soils, its growth is comparable to that of hop-hornbeam (*Ostrya carpinifolia*) (Šeho *et al.,* 2017), and it reaches harvest maturity earlier than sessile oak (*Quercus petraea*), enabling relatively fast production of high-quality timber (Richter, 2019).

According to the first National Forest Inventory (NFI, 2013), Turkish hazel in Montenegro covers an area of 631.19 ha. It achieves an average growing stock of 68.2 m³/ha and a current volume increment of 1.4 m³/ha.

Growth performance is highly site-dependent. In Lich (Hesse), on fertile soils under a dense canopy, sycamore maple, Norway maple, and wild cherry surpass Turkish hazel in height increment, while beech and sessile oak grow more slowly. However, on higher elevations and nutrient-poor, shallow soils, Turkish hazel performs comparably to sycamore maple and wild cherry (Richter, 2019). In Romania's Oravita primeval reserve, it maintains similar height growth to ash, sycamore maple, cherry, and wild service tree on warm, dry microsites, reaching top heights of around 20 m. On a trial plot in southern Germany (Heilbronn), established on high-quality vineyard loam, 16-year-old Turkish hazel showed greater height growth than wild cherry, with average increments between 75 and 87 cm and a maximum of 140 cm (Schölch, 2011; Šeho, 2016).

Since Turkish hazel typically appears as individual trees or small groups in mixed stands, its stocking proportion within its native range is generally low. In Romanian mixed forests, it reaches an average height of 22 m and a volume of 87 m³/ha, with a form factor of 0.5 (De Avila & Albrecht, 2017). The highest volume recorded for Turkish hazel is in the Oravita Nature Reserve, where it accounted for 214 m^3/ha out of a total stand volume of 406 m^3/ha (Neumann, 2015). Other associated species included silver lime, hornbeam, and ash.

Figure 3. Turkish hazel tree (h-20m, dbh-50cm) with fir, beech, sycamore, and small-leaved lime. Mount Njegoš, Montenegro (Photo: Ašanin D.).

Figure 4. A 29-year-old Turkish hazel (h-19m, dbh-35cm), a solitary tree in the park of the Faculty of Forestry Sarajevo (Photo: Višnjić Ć.).

Wood Quality and Uses

Due to past overexploitation in its native range, Turkish hazel timber is now rarely available on the commercial market (Richter, 2012). Logs are classified based on intended use. The wood is highly valued for its distinctive coloration and decorative appeal, with approximately half of the cross-section composed of yellowish-reddish sapwood and reddish-brown heartwood (Šeho *et al*., 2018). It is elastic, moderately hard, and diffuse-porous, exhibiting properties similar to sycamore maple. Though prone to cracking if dried too quickly, it remains dimensionally stable after proper drying and tolerates fluctuations in air humidity without deforming (Mittendorf, 2016; Šeho, 2018). Its wood density is approximately 0.63 g/cm^3 (Wagenführ, 2000).

The wood's structure, elasticity, and ease of processing make it highly versatile for timber applications. It is widely used in the furniture industry, for decorative veneers, and for turning. It is also suitable for interior paneling, doors, stairs, and parquet flooring. Its ornamental value makes it desirable for artistic products such as bowls, tool handles, and musical instruments, and it is frequently used for high-end interior finishes. In specialized applications, it can be used for precision components like tool parts and sporting goods (Zeidler, 2012). On high-quality sites, Turkish hazel allows for the faster production of valuable timber compared to oak. However, disadvantages include the frequent presence of ingrown branches and irregular, wavy grain (Ruhm, 2013). Due to its rarity and superior quality, the wood commands premium prices and is often used for exclusive products. According to Fukarek (1956), along with yew, Turkish hazel was highly valued by the Austrian imperial court in the 19th century.

Silvicultural Characteristics

Seedling Production

Turkish hazel (*Corylus colurna* L.) begins fruiting at 10–12 years of age, with abundant seed years occurring every 2–4 years. Flowering occurs in March and April, before leaf emergence, and fruits mature from August to October. The nut is a single-seeded fruit, 17–20 mm long and 12–18 mm wide, flattened and smaller than that of common hazel (*C. avellana*), typically appearing in clusters of 2–8 (commonly 5–6), each enclosed in a deeply serrated involucre, two to three times longer than the nut (Alexandrov, 1995; Popović *et al*., 2022). Harvest is optimal when the fruit pods turns yellow-green and the pericarp light brown (Ninić-Todorović, 2012). After harvesting, fruit pods should be removed. Approximately 600 nuts make up a kilogram, and the 1,000-seed weight ranges from 953 to 1819 g (Šeho *et al.*, 2016; Kruessman, 1997). Seed viability varies widely by provenance, ranging from 19% to 89% (Šeho *et al*., 2016).

Studies on seed dormancy in Turkish hazel are inconsistent. Hartman (1989) reported no embryonic dormancy, whereas Todorović (2000) attributed dormancy to an underdeveloped embryo. Aygun et al. (2009), on the other hand, identified seed coat dormancy resulting from chemical inhibitors. Dormancy is most likely caused by a deficiency of gibberellins, which are synthesized after seed maturation and dispersal during exposure to low winter temperatures (Ross & Bradbeer, 1971). Turkish hazel therefore exhibits physiological dormancy, and improper storage or drying can induce secondary dormancy (Šeho *et al.,* 2016). Germination typically takes 6 months to 2 years, highlighting the importance of appropriate stratification techniques.

Dormancy is best overcome by autumn sowing immediately after harvest. For spring sowing stratification is recommended. Nursery germination rates range from 40% to 75% (Alexandrov, 1995), with ~64% germination under optimal autumn conditions, compared to only ~14.2% after 120 days of cold-wet stratification at 4 °C (Mehlenbacher, 1994; Aygun *et al*., 2009; Ninić-Todorović *et al.*, 2012). Removing the seed coat can improve germination by up to 30% (Jansky *et al.,* 1988). Treatment with gibberellic acid (GA_3) also enhances germination; 75 ppm is considered optimal (Aygun *et al.*, 2009). A nursery germination rate of 74.17% can be achieved through warm–cold stratification combined with gibberellic acid treatment. Seeds are first kept for three weeks in a warm, moist stratification medium (sterilized sand) at 25–28 °C, followed by three weeks in a cold, moist stratification medium at 3 °C. After stratification, the seeds are soaked for 24 hours in a 150 ppm GA_3 solution, after which sowing is carried out (Gupta, 2015).

Nursery sowing is typically conducted in autumn, ideally in October immediately after seed collection, or in spring following stratification. Seedbeds (1-1.2 m wide) are sown in rows or broadcasted. Recommended row spacing is 25 cm, with 100-150 seeds per meter. After sowing, seeds are covered with 2-4 cm of sawdust or sand, followed by rolling, and a layering of peat (2 cm) and composted sawdust (1–2 cm) to retain winter moisture (personal comm. Macić, 2025). Seeds sown in autumn germinate earlier in spring (March–April) and are vulnerable to late spring frost; therefore, young seedlings should be protected by placing covers over the seedbeds after emergence (Mekić, 2018). For spring sowing, stratified seed is used, with late February being the optimal sowing time though this may vary depending on the condition of the seed after stratification. As stratified seeds germinate quickly, the emerging seedlings must also be protected from late frosts (Mekić, 2018).

One-year-old seedlings reach up to 20 cm, and two-year-old ones ~50 cm (Ninić-Todorović *et al.*, 2012). The latter are preferred for afforestation due to better establishment. Older seedlings with larger root systems are less suitable for transplanting (Šeho *et al.*, 2018), and container-grown stock may be used in weedy or urban sites.

Natural Regeneration

Natural regeneration occurs primarily from seed, rarely from vegetative sprouts. Small seedling clusters are found near parent trees, while larger regeneration areas are uncommon (Fukarek, 1956; Beus, 1970, 1982). Establishment improves on bare mineral soil or in the absence of competing vegetation (Richter, 2017). Seeds may remain dormant in the soil for up to two years (Mettendorf, 2016) and establish under canopy cover on deep soils or in rocky limestone outcrops (Beus, 1970, 1982).

Limiting factors include irregular seed years, low viability, large seed size, seed predation, and competition from herbaceous and woody species (Richter, 2017; De Avila & Albrecht, 2017). However, birds and rodents aid in seed dispersal, which explains the occurrence of isolated individuals in beech and oak forests (Fukarek, 1956; Beus, 1970).

Artificial Regeneration by Sowing and Planting

Practical silvicultural experience with Turkish hazel is limited in its native range and primarily based on trials in Western Europe (Richter, 2012, 2013, 2017; Ruhm, 2013; De Avila & Albrecht, 2017; Šeho *et al*., 2017, 2018). Regeneration is achieved either by direct sowing or planting nursery stock. Sowing is performed in strips or patches in canopy gaps or open sites following weed removal and soil preparation, and is effective even on shallow, rocky substrates with limited competition (Richter, 2012).

For afforestation, 1+0 and 2+0 seedlings (50–80 cm) are commonly used (Richter, 2025), while larger seedlings (>120 cm) are planted in urban environments (Šeho *et al.,* 2017; Višnjić & Ivojević, 2023). Transplants (1+1, 1+2) are avoided due to damaged taproots (Richter, 2025). Planting is done in early spring, before bud swelling, with soil moisture being critical for survival (Pauls, 2006; Richter, 2017). Roots may be dipped in alginates or superabsorbents to enhance water retention (Višnjić, 2006).

Turkish hazel is planted either as individual trees or in groupings (“nests”) (Ruhm, 2013; Višnjić, 2024). In mixed plantations, spacing of 5×1.5 m (with wild cherry) or 5×2.5 m (with lime) is common. In forest gaps, close spacing (2×1 m or 2×2 m) is used, while abandoned farmland allows for wider spacing (3×3 to 7×7 m) (Richter, 2013; Šeho *et al.*, 2018). In degraded forests, it is planted in nests of 13-24 seedlings (1×1.5 m spacing), with 15 m between nests, yielding 577-1066 seedlings/ha (Richter, 2014). Wild cherry and sycamore maple may be interplanted.

For urban planting, a 7–8 m spacing along streets and paths is recommended (Višnjić & Ivojević, 2023). Protection against wildlife is necessary, using fencing or tree shelters, which also reduce competition and rodent damage (Richter, 2012, 2013). Drought sensitivity in early years requires additional care.

Tending and Thinning

Turkish hazel in younger development phases tolerates shade on fertile soils but requires light on poorer sites (De Avila & Albrecht, 2017). Even when shaded, it maintains upright growth without phototropic bending. In dense thickets especially with hornbeam, lime, or cherry it self-prunes effectively (Mettendorf, 2016; Richter, 2017). However, genetic forking is observed in some individuals. Negative selection to remove poorly formed, shrub-like, or damaged individuals improves stand quality (Mekić, 2018). On open sites, self-pruning is limited (Alexandrov, 1995), necessitating formative pruning to produce quality stems. In plantations with spacing >3×3 m, pruning should begin when trees reach 2 m height, targeting branches <3 cm thick (ideally ~1 cm), to allow wound closure within one season. Pruning is best performed in June-July. Forked stems should be corrected by removing the weaker shoot (Pintarić, 1992).

To produce high-value timber, thinning and branch pruning are critical (Richter, 2013). The goal is to promote future crop trees at 12–15 m spacing with ~8 m of clear stem (Richter, 2017). Turkish hazel shows rapid juvenile growth and reaches polewood stage by age 10. In Austria, 10-year-old plantations average 7.5 m in height and 6.8 cm dbh (Šeho *et al.*, 2018), while in England, 9-year-old stands reached 4.31 m and 8.76 cm dbh (Willoughby *et al.,* 2007). Growth is faster in open stands and slower in shade. On fertile sites, it competes poorly in mature mixed stands, necessitating the removal of vigorous competitors (Richter, 2016; Temel *et al*., 2017). Early identification and release of future crop trees is essential (Pintarić, 1992; Mekić, 2018). While the species tolerates lateral shade, the upper crown must remain exposed, which requires the removal of overtopping competitors.

Harvesting

Harvesting strategies depend on management objectives. The rotation period is typically around 100 years but may be shorter on fertile sites. Turkish hazel outpaces beech in early growth stages and reaches harvest maturity earlier than oak (Ghimeey, 1980; Richter, 2019). Trees are harvested individually upon reaching target diameter, regardless of the development stage of associated species.

Response to Climate Change

Climate change significantly impacts forest ecosystems, with monocultures being especially vulnerable. Establishing mixed forests that include rare, native tree species adapted to changing ecological conditions can mitigate the risk of forest decline (Bolte *et al*., 2009; Lindner, 2000; Kölling, 2013; Vitali *et al.,* 2017; Koch *et al.,* 2022; Višnjić *et al*., 2025). Turkish hazel (*Corylus colurna* L.) is increasingly considered for introduction into climate-affected areas due to its adaptability (Alfaro *et al*., 2014; Šeho *et al*., 2023; Sandholz *et al*., 2024). According to German criteria for the introduction of non-native species (Kölling, 2008), it ranks highly, as it grows faster than sessile oak, produces valuable timber, has low water requirements, tolerates both drought and frost, and shows resistance to pests, pathogens, snow breakage, and windthrow. Its leaf litter decomposes well, and it is not considered invasive. Richter (2019) also notes that Turkish hazel can endure prolonged drought, withstand low temperatures, and is thus well-suited to areas threatened by climate extremes. With proper silvicultural measures, it can enhance the stability of mixed stands and support long-term timber production even under increasingly variable climatic conditions (Sandholz *et al.,* 2024).

Šeho *et al.* (2023) report that Turkish hazel has a broad climatic tolerance, surviving temperatures from –38°C to +40°C, and naturally occurring in habitats with annual mean temperatures between 5°C and 13°C and annual precipitation ranging from 480 to 1300 mm. Although it prefers a continental climate, it can also grow in Mediterranean regions under semi-arid conditions. Temel *et al*. (2017), who classified 18 Turkish populations based on climatic conditions, found that it thrives in areas with a mean annual temperature of 8.83°C (ranging from 6.9°C to 11°C) and annual precipitation between 477 and 952 mm. Only three populations were found in semi-arid climates, while the majority occurred in more humid environments where most precipitation falls during the growing season (Temel *et al*. 2017).

In Bosnia and Herzegovina, Turkish hazel is typically found at higher elevations above 900 m a.s.l., where conditions are more humid and average annual temperatures remain below 10°C (Fukarek, 1956; Beus, 1970, 1982). However, Šeho *et al.* (2019) wrongly reported that the "Konjic" provenance, located at 1300 m a.s.l., grows under a mean annual temperature of 12.7°C, data derived from a meteorological station in the town of Konjic (267 m a.s.l.;

FHZBiH, 2025). At the actual site, the temperature is significantly lower, below 8°C.

While numerous studies highlight the significant potential of Turkish hazel for utilization beyond its natural distribution range under climate-stressed conditions (Kölling, 2008; Richter, 2013, 2019, 2025; Šeho *et al*., 2019, 2023; Sandholz *et al*., 2024), Temel *et al.* emphasize that climate change poses a considerable threat to *Corylus colurna* within its native range in Turkey. The species' response rate to changing climate remains unknown and likely depends on its genetic variability, migration capacity, and phenotypic plasticity (Alfaro *et al.*, 2014).

According to St. Clair & Howe (2011), species with disjunct distributions, such as Turkish hazel, are particularly vulnerable to climate change and often require ex situ conservation efforts.

Since the first documentation of its distribution in Bosnia and Herzegovina (Fukarek, 1956) and subsequent studies by Beus (1970, 1982), the range of Turkish hazel has contracted, now limited to a few enclaves with scattered individuals or small groups. This decline is largely attributed to poor regeneration capacity, strong competition from other species (notably beech, fir, and sycamore maple), lack of silvicultural interventions, unselective logging, dieback of senescent trees, and increasingly frequent wildfires, many of which are linked to climate change. Although Turkish hazel grows faster than sessile oak (Richter, 2017), its drought tolerance is likely lower, reducing its ability to compete in oak forests or among other native species on dry sites.

In urban environments, Turkish hazel performs exceptionally well. Due to its biological traits, adaptability to city climates, strong cooling potential, and tolerance to pollution, it is expected to play an important role in future urban green infrastructure under climate change (Höstler, 1993; Arslan, 2005; Roloff & Grundmann, 2008; Popek *et al*., 2013; Gillner *et al.,* 2015; Višnjić & Ivojević, 2023). However, these positive results are likely supported by intensive management practices in urban greenery, and such success may not be directly transferable to forest ecosystems (Kölling, 2013).

To improve understanding of the species' biology, ecology, and climate resilience, more research is needed in its natural range-particularly focused on habitat characteristics, interspecific interactions, light requirements during growth, and natural regeneration dynamics.

CONCLUSION

At the western boundary of its natural distribution, Turkish hazel occurs in Bosnia and Herzegovina and Montenegro primarily in canyons, gorges, and on steep limestone slopes. It is most commonly found at elevations between 1000 and 1300 m, though isolated individuals may occur at lower elevations on shallow limestone soils under open canopies, where competition from beech and other species is minimal. The mean annual temperature in these habitats typically ranges from 8 to 9 °C, with annual precipitation between 1000 and 1200 mm.

Turkish hazel usually occurs as solitary trees or in small groups, although local populations exceeding 300 individuals have been recorded.

In both countries, the species is most frequently associated with beech and thermophilous deciduous forests, co-occurring with downy oak, hop-hornbeam, field maple, narrow-leaved ash, and wild service tree. At higher elevations and in canopy gaps, it may also be found alongside fir, sycamore maple, small-leaved lime, aspen, and ash.

Current evidence indicates that Turkish hazel is unlikely to play a more dominant role in mixed forests without targeted silvicultural interventions aimed at promoting its growth and reducing competition. Although its share in forest stands can be increased through plantation establishment, the production of high-quality timber requires intensive management-including protection from weeds and browsing, tending of young trees, pruning, and thinning-which significantly raises production costs. This brings into question the economic viability of investing in Turkish hazel for timber production, especially when alternative climate-resilient species such as fir, beech, oak, wild service tree, or noble hardwoods may offer similar benefits at lower cost.

Despite its promising adaptive traits, the species' response to climate change remains poorly understood, even within its native range. The apparent contraction of its distribution highlights the urgency of conservation measures, including assisted migration, to preserve and expand genetically diverse populations. Future efforts should prioritize ecological, silvicultural, and structural research on natural populations to better understand the species' habitat requirements, regeneration potential, and suitability for introduction into forest ecosystems beyond its current range-particularly in regions facing increasing climate stress.

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