

**ECOLOGY AND CONTROL OF RHODODENDRON
(*Rhododendron ponticum* L.) IN TURKISH EASTERN BEECH
(*Fagus orientalis* Lipsky) FORESTS**

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ABSTRACT

Purple-flowered rhododendron (*Rhododendron ponticum* L.) and yellow-flowered rhododendron (*R. flavum* Don.) are two dominant shrub species of the eastern beech (*Fagus orientalis* L.) understories in the eastern and western Black Sea Region (BSR), respectively. These invasive woody species significantly reduce beech growth and can preclude tree regeneration. The ecological consequence is an aging beech overstory with little or no regeneration to replace the mature trees. Great rhododendron (*R. maximum* L.) has been increasing in the forests of the Southern Appalachians of the United States, reducing tree regeneration and growth. The BSR and Southern Appalachians bear noteworthy similarities in climate, topography, and the forest flora. Purple-flowered and great rhododendrons also show important similarities in their ecology and the forest vegetation problems they can cause. Current rhododendron-dominated and threatened BSR forests may provide an advanced ecological picture of the forests of the Southern Appalachians in which great rhododendron now thrives. Therefore, new information gained on the ecology and effective and cost-efficient control of purple-flowered rhododendron may significantly improve forest management practices, not only for the current rhododendron-invaded BSR ecosystem, but also for other parts of the world.

This dissertation consists of five separate yet related chapters. The first gives relevant literature reviewed for the dissertation. The second chapter focuses on various environmental and disturbance factors that may have shaped the current purple-flowered rhododendron-dominated beech forests of the BSR of Turkey. Chapter 3 assesses the effects of various manual and herbicidal woody control techniques on purple-flowered and yellow-flowered rhododendron in two field experiments in the BSR. The fourth chapter relates a study of uptake and translocation behavior of triclopyr ester and imazapyr in great rhododendron. This information is used to determine the optimum herbicide-surfactant combinations for the greatest active ingredient uptake and root translocation in great

rhododendron. The last chapter is a synthesis of the information gained in all of these different experiments.

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CHAPTER 1: LITERATURE REVIEW

Ecology of Eastern Beech

Distribution

Beech (*Fagus* spp.) is a temperate deciduous tree genus occurring in cooler, mesic zones of the Northern Hemisphere, although its distribution extends to the montane belt of tropical regimes (Peters et al. 1995). The east-to-west distribution of eastern beech (*Fagus orientalis* Lipsky.) begins at 26°30' E in eastern Europe in the mountains near the Bulgarian-Turkish border (Figure 1, Atalay 1992). Its distribution expands eastward through the Northern Anatolian Mountains in the BSR of Turkey to 42°33' E. Eastern beech's distribution further curves to the north along the coastline of the Black Sea until it nears the Crimean Peninsula. The northern aspects of the Northern Anatolian Mountain belt in the BSR and the Istranca Mountains in Thrace contain the main distribution of eastern beech. However, isolated patches of the species can be found on the northern aspects of the Saphane and Murat Mountains in the northeastern Aegean Region as well as in the Amanos Mountains in the eastern Mediterranean Region to the south. The southernmost boundary of eastern beech's range is reached at 36°40' N (Atalay 1992).

Although eastern beech's coverage of 614,615 ha in Turkey may seem low in view of the total forested area of Turkey (11.4 million ha), its total standing volume of 154 million m³ makes up almost 20% of the forest standing wood volume of the country (Turkish Forestry 1989). Of beech's area coverage, 81% falls into the productive class, with an annual yield increment of 6.6 m³/ha (Turkish Forestry 1989).

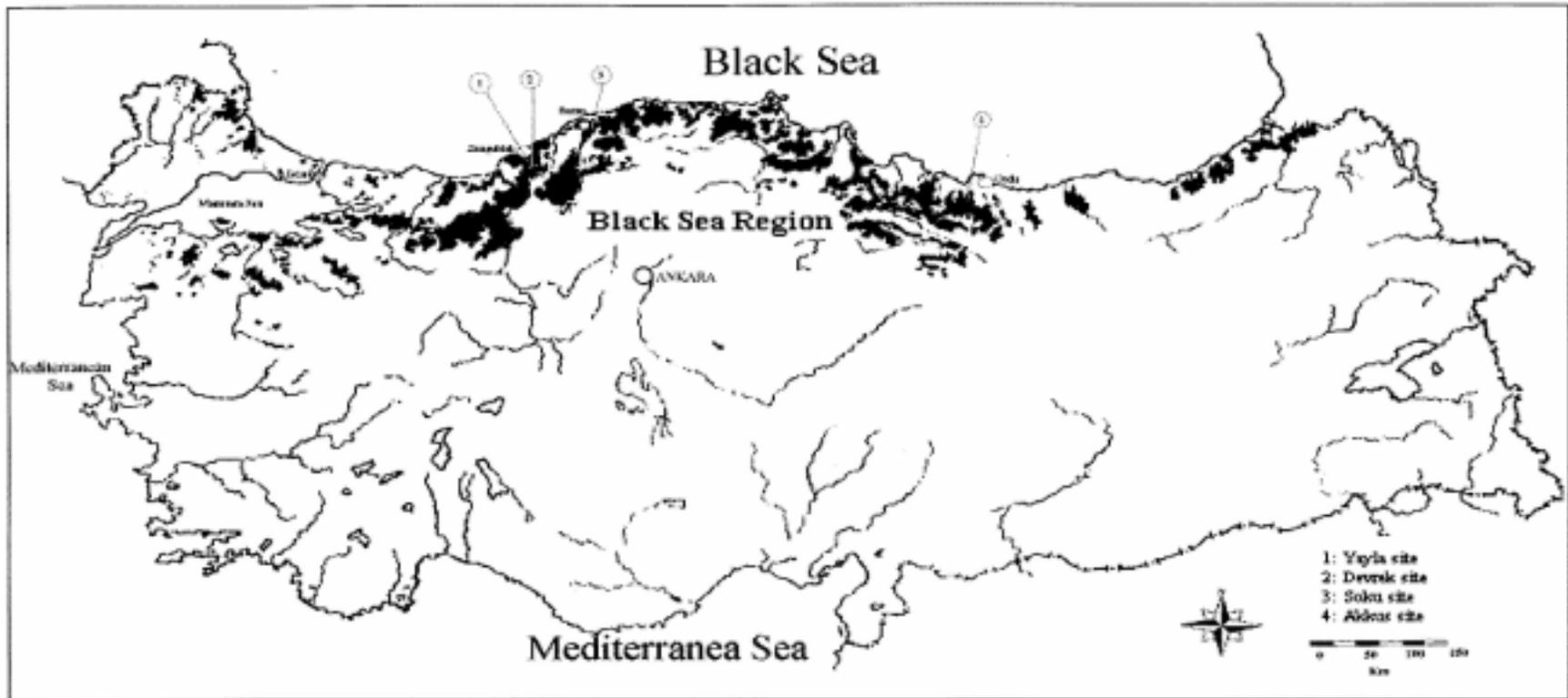


Figure 1. General distribution range of eastern beech and locations of experimental data collection sites of eastern beech and purple-flowered rhododendron in the Marmara and Black Sea Regions of Turkey.

Climate of the Black Sea Region

Though the climate of the BSR, where eastern beech and purple-flowered rhododendron have their optimum growth, has generally been described as “humid, perhumid, and oceanic” (Suner 1978, Peters 1997), Bottema et al. (1995) divided the region’s climate into two different sections, based on the previous accounts of Akman and Ketenoglu (1986) and Mayer and Aksoy (1986). The “Euxinian Climate Belt” typically prevails over the northern exposures or aspects of the Northern Anatolian Mountains of the BSR (Figure 1, Bottema et al. 1995). The mean annual daylight temperature ranges between 6 and 14°C in this belt, whereas the maximum and minimum temperatures are widely differentiated, being 40 and -20°C, respectively (Atalay 1992). The Euxinian climate consists of cold, snowy winters with a typical January temperature ranging between 4 and 6°C, and cool/mild and rainy summers with a typical July temperature varying between 21 and 24°C (Çepel 1978, Turkish Forest Research Institute 1986, Atalay 1992). The annual precipitation often exceeds 700 mm for the western BSR, whereas it rises to 1300 mm in the eastern parts of the region (Bottema et al. 1995).

The southern slopes of the Northern Anatolian Mountain belt form the beginning of another climatic zone, the “Sub-Euxinian Belt” (Bottema et al. 1995). This climatic zone prevails over an ecotone between the cold, deciduous flora of the northern aspects and the Central Anatolian Region characterized by the continental steppe vegetation. The Northern Anatolian Mountains control most of the variation in climate between these two extremes by cutting off the moisture-loaded air masses from the Black Sea, hence lowering both mean annual precipitation (400-650 mm) and temperature (2-10°C) for the Sub-Euxinian Belt (Bottema et al. 1995).

“Fohn events” play a significant role in the climate of the eastern BSR forest (Atalay 1992). A fohn event materializes as a cold air front proceeds from the summits of the Northern Anatolian Mountains toward the Black Sea and its temperature elevates to 24-30°C due to air compression. This results in unusually warm temperatures in wintertime, generally between November and April, for the landscape lying along the Black Sea. Furthermore, the sky over the eastern beech distribution range is covered by clouds for almost 60% of the year. As a rule of thumb, the sky is open during the morning hours and cloudy towards afternoon (Atalay 1992).

Topography throughout Eastern Beech's Distribution

The close link between topography and climate of a given locale is reflected well by wide variation in both microclimatic and floristic conditions among aspects (Smith 1992). That the northern aspects of mountains in the Northern Hemisphere receive considerably less amounts of solar energy than the southern aspects is a well-understood fact among plant scientists (Atay 1990, Smith 1992). Therefore, reduced solar energy and, in turn, evapotranspiration, confer relatively more mesic and cooler microclimatic regimes on northern slopes than on southern slopes (Atay 1990, Lipp and Nielsen 1997). These microclimatic differences make the patterns of plant communities different between northern and southern aspects (Atay 1990, Smith 1992).

Heterogeneity in surface geometry results in climate changes over short distances, resulting in great variability in vegetation (Atay 1990; Smith 1992). This physiographic heterogeneity of frequently broken, dissected, and rough geomorphology within short distances has conferred optimum growing conditions for many different species on both the central-southern Appalachians (Smith 1992) and the Northern Anatolian Mountains of the BSR, fostering diversity (Atalay 1992).

Slope steepness is another important factor that determines the total amount of solar energy received by mountain aspects (Smith 1992). Southern aspects, for example, acquire the greatest illumination from the sun when their slope steepness matches the angle of the sun from the zenith. When the slope steepness equals or is greater than this angle, incident solar radiation reaches its lowest level for northern slopes (Smith 1992).

Atalay (1992) concluded that aspect is the most important topographic factor for eastern beech compared to other factors, including the direction of mountain belt and elevation. The Northern Anatolian Mountain Belt, which runs parallel to the Black Sea, forms a major barrier to moisture-carrying air currents emanating from the sea. Steepness of these slopes is reported to be greater than 20%, and this causes a sudden rise of these air fronts over the steep northern slopes of this mountain belt. This results in significant drops in temperature, subsequently causing the rapid condensation of vapor in the clouds into precipitation (i.e., orographic precipitation). Forms of precipitation are rain, drizzle, and fog. In fact, the latter two are considered the major sources of summer precipitation for elevations

greater than 500 m, where slopes and peaks of mountains are covered by clouds (Atalay 1992).

Perry (1994) also demonstrated the profound effects of such mountain formations on regional climate and flora. Lowlands of the Venezuelan Andes receive precipitation greater than 600 mm/year and harbor diverse broad-leaved vegetation. The higher elevations of these mountains (> 2500 m) nourish even more diverse flora due to increased precipitation. Drizzles coming from clouds covering the mountain slopes account for most of the precipitation; in fact, the forest that has formed at these high elevations is termed “cloud forest” (Perry 1994).

Steepness of slopes of eastern beech sites has resulted in a high rate of soil erosion unless the soil is covered by vegetation (Atalay 1992). With its dense coverage both above and below ground, rhododendron reduces the speed of raindrops, providing rain a slow transition from the canopy to the soil. As result, the erosion rate is reduced (Saatçioğlu 1957).

Elevational Distribution of Eastern Beech

Eastern beech is confined to an elevational belt in the Northern Anatolian Mountains (Alemdag 1963, Turkish Research Institute 1985). Beech forests generally begin at 250-600 m above sea level, although this limit may be as low as 80 m above sea level in Akçakoca, in the western BSR. The uppermost elevation does not exceed 1300 m in this region, whereas this limit drops down in the mid-BSR and then climbs back up to 1800-1900 m in the eastern BSR. The optimum elevational distribution for eastern beech varies between 700 and 1200 m (Alemdag 1963; Turkish Research Institute 1985; Atalay 1992), and total standing volume per ha increases with elevation (Alemdag 1963).

The low-lying lands (<500-600 m above sea level) in the western BSR are occupied by hornbeam (*Carpinus* spp.), chestnut (*Castanea sativa*), linden (*Tilia tomentosa*), and some Turkish red pine (TRP) (*Pinus brutia*). Higher elevations (800-1600 m) are characterized by eastern beech, fir (*Abies bornmulleriana*), and Austrian pine (*P. nigra*). At elevations greater than 1400-1500 m, eastern beech starts disappearing, leaving fir (the dominant), Austrian pine, and Scots pine (*P. sylvestris*) (Atalay 1992).

In the middle BSR, intensive human settlement has disturbed forests dramatically, causing the timberline to recede to elevations greater than 1000 m (Atalay 1992). The optimum distribution for eastern beech occurs at 1000-1200 m elevations around Akkus-Ordu in this region. Towards the interior Central Anatolian Region, lower slopes are occupied by oak (*Quercus* spp.)-eastern beech mixed forests, succeeded by eastern beech-Scots pine forests at higher elevations. Similar to the western BSR, the latter tree association may be found on southern slopes at high elevations. TRP may also be found at low altitudes (< 600 m) on southern slopes in this region. It is not uncommon to find eastern beech and TRP growing at the same elevations yet at different aspects, and meet in the middle BSR (Atalay 1992).

The eastern BSR has more undulating topography, thus harboring greater diversity of tree species (Atalay 1992). As part of this diverse habitat, eastern beech forests range at 500 to 1200-m elevations with various other deciduous tree species. The low- to mid- NE and SW slopes (i.e., 450-700 m) of the Northern Anatolian Mountains are occupied by chestnut, eastern beech, and alder (*Alnus* spp.) mixed forests. As elevations increase (between 1200 and 1500 m), mixed deciduous forests are succeeded by mixed deciduous-coniferous forests, constituted mainly by eastern beech and spruce (*Picea orientalis*) (Atalay 1992).

Soil Requirements of Eastern Beech

The genus of beech can generally grow on a wide variety of soils (Peters 1997). The Northern Anatolian Mountain belt contains diverse parent materials, which include siliceous, crystalline, and clayey schists, quartzites, granites, flysch with interchanging sandstone, siltstone, marl, and clayey limestone (Atalay 1992). Undulating and steep slopes on this mountain belt have prevented soils from being well developed. The parent materials are postulated to have formed during the Paleozoic era. The soils of the County of Zonguldak, for example, have the typical lithology of the “Permo-carboniferous” period (Atalay 1992). Hsieh (1989) reported similar soil and parent material characteristics for Taiwan beech (*F. hayatae* Palib. *Ex* Hayata) with interspaced combinations of sandstone, shale, and claystone sedimentary materials.

The strongly to slightly acidic nature of beech soils (pH = 4.5-6.0) (Hausenbuiller 1978) is attributed to the leaching effects of high precipitation in the region (Atalay 1992).

Beech is, however, known to be able to withstand greater soil acidity (pH = 3.2-4.2) in Taiwan (Hsieh 1989).

With a complex mineralogy and high organic matter content (> 5%), soils on which eastern beech grow can also support a wide variety of other flora (Atalay 1992). The texture of these soils ranges between sandy and loamy clay (Atalay 1992; Peters 1997).

Shade Tolerance

The survival of plant seedlings is determined by the quality, intensity, and ratio of direct to diffuse light in the forest. Radiation, including the visible (0.4-0.7 μm) and the infrared (0.7-10.0 μm) sections of the light energy spectrum, is critical for plant survival (Smith et al. 1997). Differences in tree species composition and seral stage for a stand largely influence the quality and quantity of light available on the forest floor (Smith et al. 1997). For instance, a deciduous forest canopy comprised of typical late-successional tree species (i.e., beech and maple) permits only 1-5% of the total light available in the open to reach the forest floor. This figure can be reduced to 0.5% by an evergreen canopy. Duration of leaves in the canopy during the year is another significant factor regulating light conditions in the understories of forests (Canham et al. 1990, Smith et al. 1997). Light available on the forest floor under a fully leafed-out canopy may vary between 1 and 5% of total light in the open, yet this figure may increase up to 50-80 % without a heavy canopy (Canham et al. 1990, Smith et al. 1997). Topographic factors such as slope steepness, aspect, and latitude also regulate the amount of light that reaches the forest floor (Smith 1992, Smith et al. 1997).

Fine-scale natural (e.g., individual tree falls, blown-outs, ice-storms, etc.) and anthropogenic disturbances (e.g., partial harvests) that create small gaps in the forest canopy are important regeneration mechanisms found throughout the world's forests, including those in the BSR (Saatçioğlu 1957, Atay 1990), eastern North America (Runkle and Yetter 1987, Beaudet and Messier 1998), and Taiwan (Hsieh 1989). These small openings in the canopy play an important role in the regeneration of temperate deciduous forests by modifying resource availability and microclimatic conditions (Collins et al. 1985, Beaudet and Messier 1998). Variability in tree species' shade tolerance levels strongly influences the relative

position of these species in the future forest canopy (Bazzaz 1979, Beaudet and Messier 1998).

Strong shade tolerance is a common characteristic of *Fagus* spp. in various parts of the world (Çepel 1978, Atay 1990, Peters 1997). The low light compensation point of beech explains its great shade tolerance (1-1.25% of daylight in the open) (Turkish Forest Research Institute 1986, Peters 1997). By comparison, juveniles of maple, oak, and birch require at least 2, 4, and 11% relative light, respectively, to compensate for their carbon loss through respiration (Peters 1997). Beech can maintain a stock of advance regeneration in shady conditions for many years, which gives it a competitive advantage (Canham 1988, Beaudet and Messier 1998). Juveniles of eastern beech, European beech (*F. sylvatica* L.), Japanese beech (*F. crenata*), and American beech (*F. grandifolia* Ehrh.) may thrive under shade as long as 10, 30, 40, and 70 years, respectively (Turkish Forest Research Institute 1986, Peters 1997). However, a dense woody cover in the understory may preclude regeneration of beech (i.e., ≤ 1 seedling/100 m²), as was the case with Taiwanese beech (*F. hayatae*) and dwarf bamboo (*Yushina niitakayamensis*) (Peters 1997). The preliminary results from the data collected from two western BSR rhododendron-beech forest sites also consistently showed that beech seedling density was significantly reduced or prevented by established rhododendron cover. The light available under the rhododendron canopy ranged between 0.2% and 0.6% of that in the open throughout the two sites, falling far short of the aforementioned available light levels for beech.

The juveniles of shade-intolerant tree species growing under the overstory can generally take advantage of small incremental increases in the amount of light available under the canopy and undergo continuous height growth to uphold a dominant position in the future canopy (Runkle and Yetter 1987, Beaudet and Messier 1998). Their pursuit of light lasts for many years (Walters et al. 1993, Beaudet and Messier 1998), and the cost of sustained height growth in shade is increased mortality (Kobe et al. 1995, Beaudet and Messier 1998). Increased resource allocation to above-ground tissues for height growth at the expense of roots and defense mechanisms, which determine the longevity of trees, result in increased mortality for less shade-tolerant trees growing under shady conditions (Beaudet and Messier 1998).

Shade-tolerant tree species find an optimum in the middle of this dilemma by putting more energy into lateral growth than height growth. By doing so, shade-tolerant trees can both capture greater light in the diffuse form and decrease leaf “shelf-shading” (Beaudet and Messier 1998). Beech’s morphological plasticity in this regard is widely recognized (Canham 1988, Peters 1997). The great plasticity of beech in leaf display and branching as well as growth rate afford this late-successional species a high seedling survival rate without compromising a great deal in the amount of light required for growth in shade (Canham 1988, Peters 1997). Beech’s “horizontal and monolayered” crown architecture, for instance, provides an efficient harvest of light for photosynthesis in shade (Beaudet and Messier 1998).

Sexual Reproduction

For many tree species, sexual regeneration not only passes the genetic fingerprints of individual parent trees along to their offspring, but also allows genetic recombination in offspring (Smith et al. 1997). Recombination of different genes in offspring can increase the fitness of these newcomers in a changing environment. An ample seed supply is indispensable to successful natural regeneration, which is in turn dependent upon the minimum age of trees to bear seed. The risk of failure, however, is a reality of natural regeneration. Drought, nutrient stress, and other adverse environmental and site conditions, as well as unexpected insect attacks, may result in seed production failure in trees. In a recent study, Thurston et al. (1992) found that the densities of first- and second-year seedlings of American beech in the northern hardwood forests of the United States were largely affected by seed availability, existence of advance seedling bank, and sprouts. Physical factors of sites that were clearcut had weak influences on the seedling density of beech (Thurston et al. 1992).

Predation of fallen seed by forest fauna (e.g., mice) may also contribute to unsuccessful natural regeneration (Smith et al. 1997). For example, a thick litter and humus layer accumulated on the mineral soil commonly makes eastern beech seed conspicuous to rodents that forage on these seeds, and an expensive natural regeneration effort by foresters may result in a total failure (Çetintas 1997, pers. comm.).

Eastern beech is a wind-pollinated, monoecious tree species. Seed production for this tree species occurs once every 3 to 5 years in Turkey. Mast seed production for European

beech occurs once every 5 to 6 years in France and every 8 to 12 years in Germany. These figures may vary, however, with differences in site, altitude, and aspect (Suner 1978, Turkish Forest Research Institute 1986, Atay 1990, Atalay 1992, Peters 1997). Diameter at breast height (dbh), occurrence of a preceding dry summer, and high precipitation during growing season, as well as appearance of rich, short, and fat buds on trees in the current year are used to predict an occurrence of a mast year for beech (Atay 1990, Turkish Forest Research Institute 1986, Kamitani 1986, Peters 1997). The minimum age for seed production also varies according to light availability. In open conditions, mast seeding occurs between the ages of 30 and 50, or it can be delayed to age 60 under a closed canopy (Atay 1990, Peters 1997).

During mast years, dissemination occurs mainly between September and November (Suner 1978, Turkish Forest Research Institute 1986, Atalay 1992, Peters 1997). In terms of seed germination, winter chilling is a major prerequisite for successful germination. A dense stand of rhododendron in the understory, reducing solar radiation available on the forest floor, can thus be considered a major impediment to seed germination for eastern beech in the BSR (Zedaker 1999, pers. comm.). The aforementioned requirements for successful beech regeneration prevent untimely beech seed germinations in exceptionally warm periods in winter, thereby reducing losses to early frosts (Heide 1993). Origin of parent tree was reported to be a determining factor in abundance of seed produced in *F. crenata* (Kamitani 1986). Sprouts produce greater quantities of seed than those of seedling origins when dbh is held constant (Kamitani 1986).

Beech seed is large and can be dispersed by birds and mammals. Rare occurrences of mast years present regeneration problems for beech, especially if the understory and herbaceous layers are crowded by many woody (e.g., dwarf bamboo [Hsieh 1989] and rhododendron) and herbaceous species. Therefore, planting is a widely chosen regeneration method for beech, along with natural regeneration (Çetintas 1997, pers. comm.).

Vegetative Reproduction

Vegetative propagation is a plant reproduction trait that has been traditionally taken advantage of for various purposes throughout anthropogenic history (Smith et al. 1997). For example, beech was managed for its sprouts for use as war and cultivation instruments by the

Romans in Eurasia in the beginning of the first millenium (Peters 1997). Many hardwoods of resprouting capability have been solely managed for similar reasons in the recent past throughout Europe (Peters 1997). In fact, the fundamental emergence of silvicultural terms in European forestry such as the “low-forest, coppice, and coppice-with-standard system” regeneration methods, reflect the need for vegetative production (Smith et al. 1997).

As mentioned in the previous section, regeneration through generative reproduction carries risks for the following reasons: capriciousness in environmental conditions and its effects on “safe” site conditions for adequate seed germination and seedling development, and susceptibility of fallen seeds to rodents and other damage (Smith et al. 1997). The ability to sprout allows perennial plants to avert the aforementioned risks prior to regeneration (Peterson and Jones 1997, Smith et al. 1997). Vegetative reproduction additionally confers competitive advantages on plant species besides protection from the aforementioned dangers. Vegetative sprouts, whether from stumps or roots, rise from a pre-established root system left from a parent perennial plant, hence gaining an immediate resource foraging capability, while their plant competitors whose reproduction is primarily dependent upon generative regeneration expend significant energy to establish their own root systems (Oliver and Larson 1990, Çolak 1997). Reoccupation of cut-over loblolly pine sites by fast-growing hardwood sprouts (e.g., sweetgum [*Liquidambar styraciflua* L.]) exemplifies this advantage of hardwoods in competition (Oliver and Larson 1990).

Vegetative reproduction becomes a common regeneration method for plants as environmental conditions become stressful (Held 1983, Peterson and Jones 1997); most perennial plants that live in environmentally stressed sites (e.g., resource-limited, frequently disturbed, overshaded, and boreal conditions) often utilize the vegetative reproduction mode (Peters 1997, Peterson and Jones 1997). The vegetative mode of reproduction is also often used by woody species of mesic and “unstable” ecosystems (Peterson and Jones 1997). Peters (1997) and Peterson and Jones (1997) reported that in stressed environments of dry and cool climates, vegetative production contributes to total production more than sexual reproduction does in beech. The harsh climate of higher altitudes such as the cool montane zones of the European Alps and the North Anatolian Mountains brings frequent failure of trees in generative regeneration. Hence, eastern beech may largely rely on sprout banks for successful recruitment in the harsh climate of the North Anatolian Mountains (Peters 1997).

However, generative production can make up from 4 to 99% of the total number of seedlings for American beech (Peterson and Jones 1997).

Both eastern beech and purple-flowered rhododendron grow in a mesic, cool, and highly disturbed ecosystem, and shade is a significant factor throughout their life histories (Atalay 1992; Çolak 1997). Heavy human and natural disturbances, and the combination of both, form a highly disturbed environment for trees in the BSR (Atalay 1992). Heavy downpours in conjunction with a few topographic and site factors, including shallow soil columns due to ongoing erosion on the steep slopes over many years, contribute significantly to disturbance in this region (Atalay 1992). In this highly disturbed and stressed (i.e., shaded) environment, vegetative reproduction is many times the only successful recruitment strategy for both eastern beech and rhododendron. Existence of an advance seedling bank consisting of sprouts in these environments ensures the future of the forest for these woody species (Oliver and Larson 1990, Ohkubo et al. 1996, Peters 1997, Peterson and Jones 1997). Dense understory vegetation arises as a major impediment to seed germination. Hence, regeneration through sprouting remains as the only viable recruitment strategy for beech in highly competitive environments (e.g., dwarf bamboo [*Sasa nipponica*] in Asia and *R. ponticum* in the BSR) (Peters 1997).

Root sprouts often form from “adventitious buds” following a wound or cut on the roots of certain hardwood species (Smith et al. 1997). These sprouts actually originate from the cambium tissues of roots. Regeneration via root sprouts or suckers is common for sweetgum, blackgum (*Nyssa sylvatica* Marsh.), black locust (*Robinia pseudoacacia* L.), sassafras (*Sassafras albidum* (Nutt.) Nees), and American and eastern beech (Jones and Raynal 1987, Jones and Raynal 1988, Oliver and Larson 1990, Smith et al. 1997). The fact that the lower portions of the boles of certain species (e.g., eastern beech) contain rot gives an advantage to stems formed from root suckers over those from stump sprouts (Oliver and Larson 1990).

Connected roots of ramets provide beech with tolerance to resource limitations in stressed environments (Peterson and Jones 1997). This morphological integration provides translocation of necessary growth regulators within the connected plant web (Peterson and Jones 1997). The period in which morphological links form between ramets may vary from several years to decades (Peterson and Jones 1997). In Asian beech, long maintenance of the

morphological links between ramets was speculated to ensure a period of shade in which ramets can discover a spot with greater resource availability to rise into the canopy (Hara 1987, Peterson and Jones 1997).

Most early successional hardwood tree species that produce root sprouts depend upon disturbance for sprout production (Jones and Raynal 1988). Sweetgum and poplar, for example, require physical damage to trees in order to eliminate apical dominance, allowing root suckers to emerge (i.e., disconnecting the above-ground part from the root), or they require heat treatment of roots or a combination (Jones and Raynal 1988). However, apical dominance was found to have weak influence on root suckering of American beech, which enhances regeneration under a shaded canopy in the absence of a disturbance (Jones and Raynal 1988). Studies on American beech root suckering indicate that form of root damage, season of damage, exposure of the root, and diameter of parent tree affect the formation, number, and longevity of root suckers (Jones and Raynal 1987, 1988). Cutting resulted in a greater number of root suckers, although a majority of them succumbed to self-thinning within three years. While scouring off the cambium initially caused fewer sprouts on beech than cutting did, survival of sprouts three years after treatment was greater than that of sprouts in the cutting treatment. Exposing roots also enhanced root suckering. Damaging the root during the spring stimulated the survival of a greater number of root sprouts three years after treatment, compared with summer and autumn treatments. Therefore, spring was suggested as an appropriate time for treatment in order to stimulate regeneration from root suckering, while autumn was recommended as a treatment time if less beech was desired in the next regeneration (Jones and Raynal 1987).

Rhododendron is reported to possess various modes of clonal development, including layering (e.g., *R. ponticum*, Gritten 1995), ligno-tuber (e.g., *R. ponticum*, Çolak 1997), root suckering (e.g., *R. ponticum*, Çolak 1997), and stolons (e.g., *R. flammeum*, *R. nudiflorum*, Foote and Jones 1989). Root grafting is a common clonal development demonstrated by rhododendron in the BSR ecosystem, in which different ramets are connected into a common web (personal observation). Root grafting has perhaps resulted as an adaptation to frequently disturbed soils (i.e., erosion and local mudslides) (Keeley 1988) or against upheavals by wind (Graham and Bormann 1966), as reported for other woody species (Peterson and Jones 1997).

Preemption of site resources and, hence, competitiveness of eastern beech against oak species in mixed forests in northern and northwestern Turkey following a disturbance such as cutting (Atay 1990), indicates an immediate foraging ability of beech ramets through old root systems. Ramet seedlings linked to each other can tolerate stressful environmental conditions (Peterson and Jones 1997).

Regeneration Techniques Used for Beech

Shelterwood is the most common method of beech regeneration in Turkey (Atay 1990). The shelterwood method theoretically consists of four consecutive cuttings: preparatory, seed or establishment, light, and removal (Atay 1990). The aim of preparatory cutting, as implied in its title, is to prepare both the site (e.g., modification of microclimate) and the stand (i.e., encouragement of seed trees) for natural regeneration for the next 8 to 10 years. By removing trees of unwanted phenotypes, a quasi-genetic selection is performed with the cutting to ensure that the oncoming regeneration is of seed trees that were selected for specific phenotypes. The approximate number of seed trees left on the site is around 150/ha, with canopy closure reduced to 70%. However, excessive cutting in beech stands in the BSR has left a canopy closure that eliminates the necessity for the preparatory cutting (Seçkin 1997, pers. comm.).

The seed cutting is intended to enhance light conditions on the forest floor for the seedlings to come while preserving a protective shelter against frost and direct sunlight, and to create a new age class. The severity of the cutting is determined such that the development of unwanted forest flora is discouraged (Atay 1990). The seed cutting removes 25-38% of the standing wood volume, or half to two-thirds of the trees (Suner 1978). This may, however, enhance rhododendron in the understory. Extensive herbaceous/woody weed control is carried out during the seed cutting, followed by litter raking on regeneration bands. Litter raking is perceived by Turkish foresters as a “must” to ensure that a sufficient quantity of seedlings come onto the site (Atay 1990). Soil disturbance is not an unusual exercise following litter raking in beech forests.

Successive light cuttings as a continuation of the seed cutting ensure desired development of beech seedlings on the site with gradual exposure to sunlight. New beech seedlings are vulnerable to external physical pressures in the first year of their lives.

Therefore, the first light cutting is generally performed following the second year, preferably during the winter over snow so as not to damage seedlings by bole extraction. Subsequent cuttings are repeated within the next two to four years. Ten years after the seed cutting, successful natural regeneration should be achieved following the removal cuttings. Saatçioğlu (1970) reported that up to 35 seedlings/m² could be established using this shelterwood method at the end of the 10th year after the seed cutting. However, five seedlings/m² was reported to be a sufficient quantity for a successful regeneration.

Ecology of Rhododendron

Since purple-flowered rhododendron and eastern beech coexist over extensive areas, most environmental factors under which rhododendron grows (i.e., climate, topography, soil, and so on) are very similar to those mentioned for eastern beech.

Taxonomical Nomenclature

As the largest genus of the *Ericaceae* family, *Rhododendron* includes 1200 species distributed mainly throughout Northeast Asia and Eurasia, western Europe, and eastern North America (Neary et al. 1980, Rotherham 1983, Clinton and Vose 1996, Çolak 1997). *Rhododendron*'s nomenclature has come from the Greek: “rhodo” means rose, and “dendron” denotes “tree;” in combination, “rosetree” (Genaust 1976 in Çolak 1997). The Turkish common name of this shrub is very similar to the Greek version: “forestrose”.

Distribution of Purple- and Yellow-Flowered Rhododendron

Purple-flowered rhododendron (*R. ponticum*) grows mainly in the UK, Ireland, Bulgaria, Turkey, the Caucasus, and Lebanon, although southeastern Spain, middle and southern Portugal, Belgium, and France include some areas with this shrub species. Among the aforementioned locales, the UK, Ireland, and the BSR of northern Turkey make up most of purple-flowered rhododendron's distribution (Varol 1970, Robinson et al. 1980, Eyüboğlu and Karadeniz 1987, Eyüboğlu and Karadeniz 1987, Clay et al. 1992, Çolak 1997).

Purple-flowered rhododendron grows in dense stands throughout the BSR and occurs at elevations up to 2100 m on the Northern Anatolian Mountains. Yellow-flowered rhododendron (*R. flavum*) rises to greater elevations before the subalpine zone begins, where

coniferous forests begin to take over (Çolak 1997). Yellow-flowered rhododendron's natural range is smaller than that of purple-flowered rhododendron and most of its distribution is in the eastern BSR (Saatçioğlu 1957; Atalay 1992; Çolak 1997).

Origin of Rhododendron in Turkey

Purple- and yellow-flowered rhododendrons are both native species of northern Turkey (Çolak 1997). However, there have not been many records on rhododendron presence or its development in the BSR except one from the ancient Greek writer-traveler Xenophon from 405 B.C. Xenophon compiled his experiences and impressions about an area encompassing the BSR in his book called "Anabasis" while accompanying the Greek army on its campaign against the Persian army. Occasionally, his accounts indicated the composition of the surrounding vegetation (Brownson 1980) as follows:

"...After accomplishing the ascent the Greeks took up quarters in numerous villages, which contained provisions in abundance. Now for the most part there was nothing here which they really found strange; but the swarms of bees in the neighborhood were numerous, and the soldiers who ate of the honey all went off their heads, and suffered from vomiting and diarrhea, and On the next day, however, no one had died, and at approximately the same hour as they had eaten the honey, they began to come to their senses..."

(Brownson 1980, p. 341)

A type of honey called forestrose honey is commonly known and consumed in the rural BSR. The honey is produced by bees that forage on rhododendron pollens, and thus it is a specialty of the region. A bitter taste is characteristic of this honey, and when it is consumed in large quantities, it causes a temporary abdominal illness. The symptoms of the illness are identical to those given in Xenophon's accounts above. Although natural range and local distribution cannot be derived from these accounts, it is likely that this species has been present in the BSR for at least more than one millenium.

Aspect

Rhododendron generally prefers cool, mesic, and protected sites of northerly mountain aspects and riverbanks where high illumination, wind, and drought are not prominent factors (Lipscomb and Nilsen 1990, Thomson et al.1993, Baker 1994, Çolak 1997, Lipp and Nilsen 1997), as on the northern slopes of the Southern Appalachian Mountains, USA (Lipscomb

and Nilsen 1990, Lipp and Nilsen 1997), the Northern Anatolian Mountains of Turkey (Saatçioğlu 1957, Varol 1970, Eyüboğlu and Karadeniz 1987, Turkish Forest Research Institute 1985, Çolak 1997, Peters 1997), the montane and subalpine south-central mountains of British Columbia, Canada (Coats et al. 1991) and the northern slopes of the northwestern French Alps (Pornon and Doche 1995).

However, tolerance levels to environmental stresses may vary across different species of this woody genus. Although purple-flowered rhododendron tends to avoid sites with soil moisture shortages (Cross 1981, Çolak 1997), yellow-flowered rhododendron can tolerate drought better (Saatçioğlu 1957, Çolak 1997). Therefore, yellow-flowered rhododendron can extend to the southern aspects of the Northern Anatolian Mountain belt in the eastern BSR (Çolak 1997).

Light and Shade Tolerance

The ability to tolerate dense shade gives rhododendron a great advantage over its competitors (Saatçioğlu 1957, Tabbush and Williamson 1987, Gritten 1995, Clinton and Vose 1996, Çolak 1997). Almost closed canopy conditions (i.e., 90% of full closure) do not prevent this woody understory species from growing where many of its plant competitors succumb to insufficient light (Saatçioğlu 1957, Clinton and Vose 1996, Çolak 1997). Only a few plant species can thrive on the forest floor, including *Arbutus unedo*, *Ilex aquifolium*, *Taxus baccata*, and *Hedera helix*, when grown under the dark shade of rhododendron (Cross 1981, Çolak 1997, pers. obs.).

Annual duration of leaves in the forest canopy is a significant factor regulating light conditions in the understory (Canham et al. 1990, Smith et al. 1997). Light available on the forest floor under a fully leafed-out canopy may vary between 1 and 5% of total light in the open, yet this figure may increase up to 50-80% without leaves (Canham et al. 1990, Smith et al. 1997). From this perspective, it is obvious that an evergreen canopy is an important competitive factor (Perry 1994).

The high shade tolerance of rhododendron is linked to its very low light compensation point and low metabolic rate (Cross 1981). For example, purple-flowered rhododendron continued its growth under a dense mixed Austrian pine-eastern beech canopy, which permitted only 0.5-0.6% of light to reach the understory (Çolak 1997). The highly

illuminated conditions of open land (i.e., 100% relative light), on the other hand, depressed this woody shrub's growth significantly, with morphological deformities on the leaves and buds (Çolak 1997). Çolak (1997) attributed this antagonistic light effect to the higher temperatures found in the open (i.e., 4-7°C higher), which probably resulted in excessive transpiration. Furthermore, rhododendron is among plant species that can increase their leaf area to capture greater diffuse radiation as density of shade increases; denser overstory canopy with relative light availability diminishing from 39% to 10% brought about an increase in leaf area in rhododendron (Cross 1975, 1981).

Lipscomb and Nilsen (1990) elaborated on the physiological mechanisms behind rhododendron's preference for mesic northern aspects and its aversion to direct exposure to sunlight. They found that the high solar energy available on southern slopes or in the open reduces quantum yield, "photosynthesis per mole of chlorophyll," and water use efficiency. The great quantities of direct solar energy accelerated disintegration of leaf chlorophyll and leaf abscission under these conditions (Nilsen and Bao 1987). Leaf curling was postulated to be developed by this species as a stress avoidance strategy to protect its large leaves from direct sunlight, especially during the winter (Lipscomb and Nilsen 1990).

In addition, Lipscomb and Nilsen (1990) found that transpiration and dry conditions, both of which require rapid and unimpeded flow of water in the plant xylem, as well as frequent exposure of the xylem conduits to winter freeze-thaw cycles, may result in air cavities in the xylem conduits. This impedes the flow of water in the xylem, causing a condition called "embolism" (Lipscomb and Nilsen 1990). Xylem embolism is a common physiological phenomenon, especially for broadleaf plant species with small-diameter vessels (Tyree and Sperry 1989 in Lipscomb and Nielsen 1990) such as rhododendron (Lipscomb and Nilsen 1990). Therefore, low light conditions of understories on mesic and northern aspects provide physiologically "safe" sites for rhododendron (Lipp and Nilsen 1997).

However, high shade tolerance should not devalue the importance of light for rhododendron. It is common for rhododendron to grow long and slender stems under circumstances where light is scarce (Çolak 1997). An abundance of light (i.e., between 10 and 30% relative light) is also essential for inflorescence formation for rhododendron (Çolak 1997). Seed production and dissemination therefore take place predominantly in illuminated

thickets, which grow in ecotones between the heavily shaded understory and the open (Çolak 1997, pers. obs.).

Light is also essential to rhododendron for seed germination (Çolak 1997). In a germination experiment, low and high temperatures did not substitute for light for maximum seed germination. Seed germination also varied between seed-origin and sprout-origin rhododendrons, with a greater abundance of germinants from the sprout-origin plants (Çolak 1997). Çolak (1997) attributed this to an established root system that nourished sprouts better than the still-developing root system of seed-origin stems.

Flowering, Seeding, and Generative Reproduction

Purple-flowered rhododendron flowers after age 12 (Robinson 1980). Flowering mainly occurs between April and August in most of the BSR, although towards the western BSR it may extend into September (Çolak 1997). Pollination occurs via “entomogamy.” The bush possesses strikingly colorful inflorescence to attract insects to its flowers (Çolak 1997). In the inflorescence, tetrads of pollens line a sticky filament, by which insects foraging on these flowers remove some of the pollen on their bodies. Pollination occurs when the insects visit other bushes.

Following pollination, rhododendron seed ripens between August and December (Cross 1981; Çolak 1997). Seed is disseminated after February or March (Cross 1981). The average weight of a seed varies from 0.02 to 0.19 mg, depending upon location (Çolak 1997). An inflorescence can disseminate as many as 5,000 seeds. The total number of seed disseminated may reach one million for an individual 2-m high thicket (Cross 1981). This figure varies between 163,500 and 1,250,500 in the BSR (Çolak 1997).

Disturbances may substantially affect the fertility of thickets. Shade and early frosts reportedly lower seed bearing significantly. Seed production of thickets of sprout origin and those not damaged by a recent fire is greater than that of thickets of seed origins and those that have been burned (Çolak 1997).

Seed is primarily disseminated to distances of 10 to 1,000 m via wind (Shaw 1984, Çolak 1997). Animals also play a significant role in seed dissemination (Çolak 1997). Peccaries (*Tayassu* spp.) in the BSR and sheep (*Ovis* spp.) and deer (*Cervus* spp.) in the UK

have been reported as an important component of the rhododendron community and aid substantially in seed dissemination (Cross 1975, 1981; Çolak 1997).

Seed germination lasts five to six days if conditions are suitable for germination (Cross 1981). Light is indispensable for seed germination, and germination was found to decline drastically under low light conditions (i.e., 2% relative light) (Cross 1981). Çolak (1997) classified purple-flowered rhododendron under the plants that needed light for germination. Germinants of rhododendron tend to be clumped, and clumps are typically associated with "loose boulders, rock outcrops, and breaks in slope" (Cross 1981). Bare soil conditions are not generally suitable for successful seed germination. A seedbed covered by 1 cm-deep bryophyte cover (e.g., mosses, liverworts) is essential for germination of rhododendron (Cross 1981). The blanket of bryophytes over rhododendron seed retains higher moisture on the soil surface by reducing evaporation, as well as reducing the impact of raindrops on soil and hence, soil erosion (Cross 1981).

Root System of Rhododendron

Çolak (1997) stated that an extensive root mat, distributed mainly in the first 2 to 15 cm of soil, characterizes the root system of purple-flowered rhododendron in the BSR. Fine secondary roots mainly make up this root system (Çolak 1997). This characteristic root system gives rhododendron several potential advantages, including competitive ability and soil moisture retention (Saatçioğlu 1957, Çolak 1997). Rhododendron may also preclude other plant roots by exhausting soil oxygen -- an indirect competitive effect on surrounding rival species (Çolak 1997).

Mycorrhizae are essential for the survival and growth of rhododendron roots as a symbiont, and they enhance mineral and water acquisition significantly (Robinson 1980, Read 1984, Baker 1994, Çolak 1997). Hence, the competitiveness of rhododendron is increased by mycorrhizae. Purple-flowered rhododendron benefits from "endo-ericoid" mycorrhizae, especially in mineral-poor environments (Çolak 1997). Mycorrhizae also protect rhododendron from growth-inhibiting chemicals produced by rhododendron (Read 1984).

Vegetative Reproduction

Vegetative reproduction may be the most effective means of propagation for rhododendron (Saatcioglu 1957, Baker 1994, Çolak 1997). Whether this shrub species can carry on vegetative propagation via stem or root sprouts is a contentious point among rhododendron researchers (Çolak 1997). Çolak (1997) stated that stem sprouts in a woody plant originate primarily from “adventitious” buds following a disturbance, whereas root suckers result from “preventive” buds. The preventive buds are placed on “lignotumors” that are a form of storage for carbon and nutrients (Çolak 1997). Çolak (1997) also reported, according to Harder and Ark (1965), that the preventive buds are activated under special circumstances, and they are common features of beech and oaks with an extended viability that may last as long as 100 years. Other researchers insisted that rhododendron sprouts chiefly originate from “layers” of stems that are buried under litter and organic layers on the mineral soil (Shaw 1984). Çolak (1997) concluded in their research on purple-flowered rhododendron in the BSR that sprouts might stem from both types of “adventitious” buds on stems and “preventive” buds on roots.

Emerging new sprouts, which are connected to the main thicket by these layers or buried stems, are continuously nourished by the roots of the main thicket. Therefore, the tolerance of new sprouts against negative environmental conditions is enhanced (Baker 1994).

Allelopathy

Ericaceous plants (e.g., *Calluna* and *Rhododendron* spp.) are known to synthesize organic acids that are allelopathic to other plants and animals (i.e., compounds that inhibit growth of other plants) (Cross 1981, Read 1984). The basis of the organic acids is phenolic (aromatic) and hydroxyalkanoic (aliphatic) complexes, which are highly lipophilic in nature (Read 1984). Increased allelopathic discharge into the soil, soil acidity, and poor base status of the soil eliminate plant competitors for Ericaceous plants. Synergistic association of these family members with mycorrhizal fungi not only protects them from toxic organic compounds, but also aids in extraction of otherwise unavailable resources in the soil (Read 1984). This woody species also synthesizes a chemical compound known as “androtxin,” which makes it unpalatable to animals (Cross 1981).

Çolak (1997) extracted organic compounds that were synthesized by various rhododendron organs and tested these extracts on spruce and pine seedlings. They found that the extracts damaged epidermis cells on the roots of the seedlings. Read (1984) explained the allelopathic effects of organic acids on other plants at the cellular level by saying that enrichment of the soil medium with free hydrogen ions disrupts the cellular integrity of the roots of surrounding plants.

Disturbance: The Essence of Change in Forests

Disturbance is defined as “any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment” (Helms 1998). This definition captures two essences of disturbance from the perspective of forest development: one is the disruption of an existing structure in assemblages of varying scales between plant and plant or plant and environment, and the second is the release of resources for succeeding vegetation (Oliver and Larson 1990, Helms 1998). Competitive traits of different plant species (i.e., fast colonization and growth vs. slow colonization and growth) determine dominant species following the disturbance (Oliver and Larson 1990).

The composition and structure of many temperate forests are significantly dependent upon various physical, climatic, and biological disturbances (White 1979, Oliver 1981, Stewart and Rose 1990). The scale, frequency, and intensity of a disturbance regime in a forest ecosystem affects its future vegetation structure and dynamics (Runkle and Yetter 1987, Oliver and Larson 1990, Clinton et al. 1994).

There are differences in scale, frequency, and intensity between natural and human-induced disturbances (Oliver and Larson 1990). A general rule of thumb is that the less frequent a disturbance, the greater magnitude it carries (Oliver and Larson 1990). Human-induced disturbances are generally confined to the period of an average human life (i.e., 60-70 years) and tend to be less destructive. However, occurrences of natural fire, for example, may take place at much longer intervals (e.g., 300-400 years or longer), since lengthy and unlikely natural processes (e.g., large fuel accumulation on the forest floor or lightning strikes) are required in combination for ignition. The level of destruction of such a fire can be expected to reach immense scales. Long-term implications of human disturbances are not

uncommon, though; the present management policy of fire exclusion has changed floristic and animal species composition in many ecosystems throughout the world, since fire exclusion has eliminated habitats of many pyrogenic species (Oliver and Larson 1990, Kirwan 1999).

The composition, structure, and dynamics of plant communities, including those of beech and/or rhododendron, have long been influenced by humans and fire (Lemee 1982, Nowacki and Abrams 1994, Diaci 1996, Diaci 1996, Kirwan 1999, Nielson 1997, Peters 1997, Sharma and Rikhari 1997, Wiser et al. 1997). These two disturbance agents have often mingled with each other; therefore, many times ecologists assess these together.

Development of Beech Forests under Anthropogenic Pressure

Beech has been used for a variety of products by many civilizations (Peters 1997). People of the prehistoric era benefited from beech nuts for both themselves and their domestic animals, and made cultivation and warfare tools and script tablets from its wood. The Central European beech forests had been devastated for charcoal and glass production until the turn of the first millenium (Peters 1997).

In Northern Anatolia, beech wood was used for a variety of purposes, including home construction and embroidery framing, during the Ottoman Empire (1299-1923) (Kutluk 1948). Although many of the main posts in home foundations had been made out of beech, its lower strength for external force and decay resistance in moisture -- an important requirement for industry -- resulted in less use of beech compared to pine, oak, chestnut, and ash (Kutluk 1948).

The development of beech forests through time has differed between eastern North America and Europe-Eurasia (Peters 1997). Varying natural (i.e., glacial) and anthropogenic disturbance effects on vegetation and differences in values of beech wood in the two continents' markets have mostly accounted for the divergent patterns in species composition and management between their forests.

Prior to 1500, North American forests were molded by Native American tribes, mostly via fire (Kirwan 1999). Anthropogenic stress on the region's flora continued with the first European settlers, who benefited from the forests (Kirwan 1999). The region's forest flora was radically disturbed by extensive fires and intensive logging for railroad construction

during the period between 1880 and 1930 (Marquis and Johnson 1989, Gilliam et al. 1995). The current forests in the region are therefore the second generation of this pre-industrial vegetation (Gilliam et al. 1995). However, these forests still include numerous hardwood tree species, including American beech, with a rich diversity of woody species such as great rhododendron (*R. maximum*) (Peters 1997).

There is not an abundance of information to shed light on the past forest composition of the BSR except for accounts of a few ancient Greek and Ottoman travelers, one of whom was Xenophon. The following paragraph gives some description of the flora at around 405 BC as the Greek army was marching through an area close to Sinop, a city in the middle to eastern BSR:

“After this they marched into the country of the Taochians five stages, thirty parasangs; and their provisions were running low, for the Taochians dwelt in strongholds, and in these strongholds they kept all their provisions stored away. Now when the Greeks arrived at one of them which contained no town nor houses, but was only a place where men and women and a great number of cattle were gathered... There is this one way of approach which you see, but when one tries to go along by this way, they roll down stones from this overhanging rock... Now as much as a plethrum of that distance is covered with tall, scattered pine trees, and if men should stand behind them, what harm could they suffer either from the flying stones...” (Brownson 1980, p.325)

A few speculations may be derived from the preceding paragraph to understand the vegetation composition and possible disturbances under which vegetation existed at the time. It is clear that the human population constituted an important component of the forest ecosystem, and it is not wrong to expect some level of influence from this human component on the floristic component of the ecosystem. “A great number of cattle” indicates that grazing was probably a major influence on the flora. The human presence and animal husbandry may also support part of Neuman’s (1991) postulation that the period preceding the beginning of the cold era (0 CE) had been warmer and moister so that human colonies and their domestic animals could continue their existence.

The greatest devastation of forest flora, however, probably did not occur before the Ottoman Empire became a regional power around the 15th century (Turkish Forestry 1989). Most of warfare (e.g., warships) as well as life’s other utilities (e.g., homes, bridges, energy for home and industry) were then primarily dependent on wood, and therefore forests were

strategically important at the time. With a wide land coverage that extended from the Arab Peninsula in the South to Austria in the Northwest, to North Africa in the West, the empire relied mostly on the BSR forests, along with those of the Taurus Mountains in the Mediterranean Region (Turkish Forestry 1989). The BSR must have been preferred due to its rich wood content and convenient sea shipment from the region to the palace in Istanbul via cargo ships through the Black and Marmara Seas, which are connected. At the time, most of the imperial domains lacked forestland. Thus, the BSR forests had to meet the heavy wood demand not only from Anatolia, but also from the other forested parts of the Ottoman-ruled area, including the Arabian Peninsula, the Middle East, and North Africa (Turkish Forestry 1989). The Sultan's 1761 decree on transportation of large volumes of sawlogs along with terpenoid material and pitch from the Anatolia to Suez and Cidde, the Arab Peninsula for shipbuilding, clearly exemplifies the continuous wood flow from Anatolia and other imperial provinces (Kutluk 1948).

Numerous historical decrees of the Ottoman Sultans dated from 1487 to 1923 indicated that only domestic wood consumption of the palace and Istanbul with its surroundings had already put an immense demand on forests of the Marmara -- the geographic region in which Istanbul is situated -- and the BSR (Kutluk 1948). For instance, from a few decrees of the Sultans in Kutlu (1948), it is easily inferred that the Ottoman Sultans paid special attention to the trade city harbors lining the Black Sea coast, including Bartın and Amasra, near the present study's experimental and observational research plots. These trade cities apparently maintained a continuous flow of resources from the BSR to the palace and elsewhere (Kutluk 1948).

The Ottoman Empire had one of the world's largest warship fleets, along with a considerable number of trade ships. Thus, quality sawlogs were probably always in high demand for ship construction and its fringe industries. Many imperial decrees given by the Sultans involved logging and transportation of sawlogs of pine, chestnut, elm, walnut, oak, hazel, and ash trees for the shipping industry (Kutluk 1948). According to the Ottoman archival documents, Scots pine and Austrian pine comprised a significant proportion of the BSR forests. In fact, in a document dated 1917, pine, oak, beech, fir, and hornbeam were reported to be the five most abundant species in decreasing order in the Ottoman forests (Kutluk 1948).

Pines were apparently regarded as the most valuable species in these documents, owing to the wide array of uses of these species (Kutluk 1948). Pine apparently made up the majority of wood volume used for ship construction, home construction and home improvement, tool making, charcoal production, and extraction of chemical byproducts (i.e., terpens, pitches) to prevent wood from decaying, among others (Kutluk 1948). The Ottoman archives also indicate the significant land area of pine species in the BSR forests. For instance, an imperial decree indicated a large coverage of pine forests around Kastamonu and Safranbolu in the western BSR, and asked the region's governor to arrange for exportation of pitch from these forests. In addition, there are several imperial decrees aimed at preserving large numbers of hectares of pine forests to use for future ship construction. From these decrees, it is understood that pines were the major components of the BSR forests, either in pure stands or mixed with hardwood species. In addition, Evliya Celebi's accounts of the large volume of pine boards being stored in the BSR harbor cities waiting to be shipped to Istanbul or elsewhere support this premise. All this information indicates that pines were excessively and probably selectively logged over other tree species. Major cuttings performed on hardwood species also implicate a significantly greater species-rich forest in the region at the time. From this information, it may be speculated that today's beech-dominated forests in the BSR used to have much greater species diversity, with pine species making up the majority of the composition. Furthermore, the present invasion by conifers (e.g., Scots pine and fir) of the region's agricultural fields that are recently being abandoned by villagers for socio-economic reasons (Atalay 1992) may also be taken as indicative of the predominance of pines in these forests years ago.

The concerns over extinction of the region's forest resources date back to the Ottoman term around the late 1500s. In an archival document, the Sultan prohibited the trade of wood in 1593 as part of an effort to protect a sustainable stock of wood volume in forests in view of the growing demand for sawlogs (Kutluk 1948). To serve the same purpose, construction of extra bathhouses was forbidden, since they consumed great volumes of fuelwood. Toward the end of the 19th century, the growing concern about a wood famine intensified and triggered several rehabilitation efforts administered by the palace. Invitation of French foresters and the founding of the first forestry school occurred in parallel to these concerns over forest decline (Kutluk 1948).

Effects of Fire on Beech Growth and Distribution

Fire is probably the most important disturbance agent governing the composition, structure, and dynamics of forests in the northern temperate ecosystem (Oliver and Larson 1990). The Native Americans imprinted their signature on the surrounding vegetation via fire in much of the American continent, including the southern Appalachians (Baker 1994), the southern coastal plain (Kirwan 1999), the Gulf Coastal Region (Delcourt and Delcourt 1977), Argentina (Dezzotti 1996) to the south, Pennsylvania (Nowacki and Abrams 1994; Latham et al. 1996), and northern lower Michigan forests to the north (Palik and Pregitzer 1992). The easy and effective use of fire to clear lands resulted in the native tribes' using fire extensively for hunting, gathering, traveling, warfare, improved pasture, and growing fruit-bearing vegetation such as blueberries (Dezzotti 1996, Latham et al. 1996, Kirwan 1999). The use of fire was continued by European settlers between 1880 and 1930 (Marquis and Johnson 1989, Dezzotti 1996), accompanied by extensive logging for railroad construction in the eastern United States during the same period (Marquis and Johnson 1989, Gilliam et al. 1995). From that time to the present, the establishment of national parks and reservations, abandonment of agricultural lands, and conservation and preservation policies have diminished fire occurrences significantly in these forest ecosystems (Dezzotti 1996).

The ecology and distribution of many tree species are closely linked to frequent fires (Smith et al. 1997). For example, fires are required by pines with serotinous cones (e.g., jack pine [*P. banksiana* Lamb.], lodgepole pine [*P. contorta* Dougl. Ex. Loud.], and sand pine [*P. clausa* (chapm. Ex Engelm.) Vasey ex Sarg]). A "top-down" fire that consumes the canopy, bares the soil, and opens the serotinous cones is essential for regeneration of fire-maintained tree species. Cherry (*Prunus* spp.) and several shrub species such as *Ribes* spp. can safely preserve themselves in the seed bank in the soil, awaiting a disturbance to bring them back onto the ground for germination. Fire is also needed by these species to eliminate the hard coat on their seeds. Angiosperm trees and shrubs (e.g., great rhododendron, Baker 1994) and several other conifers (e.g., pitch pine, [*P. rigida* Mill.]) are able to reproduce via sprouting after fires of low intensity. Light-seeded species such as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), sweetgum, and yellow-poplar (*Liriodendron tulipifera*) are not very resistant

to fires, but they become established on the bare ground cleared from vegetation by fire (Smith et al. 1997).

Divergent compositional development occurs in forests whether or not fire is a prominent factor. In the northern states of Pennsylvania and Michigan, recurrent fires have increased the proportional contribution of bigtooth aspen (*Populus grandidentata* Michx.), eastern white pine (*P. strobus* L.), yellow-poplar, and northern red oak (*Q. rubra* L.) to the overall forest composition, while those of red maple (*Acer rubrum* L.), birch (*Betula alleghaniensis* Britton), American beech, and eastern hemlock (*Tsuga canadensis* L.) were depressed by fires (Palik and Pregitzer 1992, Nowacki and Abrams 1994).

The fire exclusion policies of recent forest managers, together with continuing human-induced disturbances, have made significant compositional and structural changes in forest ecosystems (Delcourt and Delcourt 1977). Recent exclusion of fire from the Gulf Coastal forests in North America, for example, has encouraged invasion of American hornbeam (*Carpinus caroliniana* Walt.), flowering dogwood (*Cornus florida* L.), and eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch.) into sites dominated by longleaf pine (Quarterman and Keever 1962). The proposed magnolia-beech (*Magnolia grandiflora* L.-*Fagus grandifolia* Ehrh.) climax forest of the Gulf Coast Region has also been converted to a mixed hardwood forest, partly due to intensive logging (Delcourt and Delcourt 1977). Enhanced competition by less shade-tolerant understory trees as opposed to shade-tolerant beech (Peters 1997) and magnolia due to increased light availability in these forests might have partly contributed to this conversion. The recent exclusion of fire, changes in land use to logging and cultivation, and the complex web of roads serving as fire-breaks have also changed the trajectory of forest succession in this region (Delcourt and Delcourt 1977). The lessened occurrence of fire in the Pocono barrens of Pennsylvania has also promoted the invasion of red maple, which had been held in check by frequent fires throughout time (Latham et al. 1996).

Throughout the South Atlantic and Gulf Coastal Plains, the patchy distribution of American beech, a fire-intolerant species, has overlapped with the land areas that are naturally sheltered from fire (Kirwan 1999). These sheltered areas included “mesic islands, swamp borders, river banks, hydric soil” (Kirwan 1999).

Recent fire exclusion policies have proportionally increased American beech in eastern North America (Kirwan 1999). For example, American beech has risen to a codominant position in the canopy in the southern mixed hardwood forests due to lack of fire (Quarterman and Keever 1962). The recent invasions of the Pocono barrens of Pennsylvania and upland pine-oak communities by fire-sensitive species, including red maple and American beech, were also attributed to the long-term exclusion of fire in forests (Latham et al. 1996).

The fire intolerance of southern beech has also been noted. In the Argentinean Andes, dry northern aspects that were typically burned were soon dominated by an *Austrocedrus chilensis* community after burning ceased. Shade cast by the conifers and less fire eventually led to a beech community in the region (*Nothofagus dombeyi*) (Dezzotti 1996).

In New Zealand, frequent anthropogenic fires have resulted in reductions of fire-intolerant Canterbury mountain beech (*Nothofagus solandri* var. *cliffortioides*) (Wiser et al. 1997). Fifteen-year results of a fire study from the region concluded that mountain beech could not tolerate fire, and although it could sprout following fire, most of the stems were killed within the first five years (Wiser et al. 1997). Fire also allowed fire-tolerant species to take over the burned sites, leading to the exclusion of beech seedlings (Wiser et al. 1997).

Humans and fire in conjunction have also put major pressures on European forest ecosystems (Lemee 1982, Peters 1997). A successional retrogression of a heath oak-beech community in Fontainebleau, France, to birches has been tied to frequent fires (Lemee 1982). Similarly, the recent spread of European beech into the Danish Scots pine plantations in Europe was attributed to removal of fire from these forests (Peters 1997).

Anthropogenic disturbances in conjunction with fires have also greatly influenced forest composition and structure in the BSR over time. The description by Xenophon of large numbers of people and their cattle in the middle to eastern BSR around 405 B.C. probably implies the clearing of forests for grazing and hunting. Fire probably continued to be a tool for land clearing during the Ottoman period. Several of the Ottoman archival decrees, as compiled by Kutluk (1948), reported frequent arson by shepherds in the BSR forests and asked provincial governors to prosecute these arsonists. Moreover, accounts of large areas of pine forests and pine wood use in daily life by the imperial decrees and the pyrophytic character of pines for regeneration also support the premise that fire was a

prominent disturbance agent at the time. In fact, an imperial decree dated 1815 ordered the administrative transfer of the forests of Divrigi, a large town situated between Zonguldak and Bartın cities where the research plots of the present project are located, to a neighboring province due to a recent devastation of Divrigi's forests, probably by a large fire (Kutluk 1948). All these accounts imply that fire played a significant role in the region's forests at the time.

The Rising Population of Rhododendron in Conjunction with Anthropogenic Disturbances and Fires

When the rhododendron ecology literature is reviewed carefully, one may find it logical to classify disturbances according to their spatiotemporal patterns to understand the type of responses they inflict on rhododendron populations. A regime in which disturbances occur infrequently at low intensity, in contrast with repeated disturbances in an agricultural field by cultivation, seems to stimulate rhododendron population growth (Cross 1981, Radosevich and Holt 1984, Shaw 1984, Rotherham 1990, Thomson et al. 1993, Baker 1994). As evidence of this, excessive but spatially dispersed logging activities in the southern Appalachian forests after 1900 promoted the spread of great rhododendron in the region (Baker 1994, Philips and Murdy 1985). Gaps increase rhododendron populations (McGee and Smith 1967, Baker 1994, Philips and Murdy 1985). Tree blowdowns have also been recognized as an important disturbance agent of the Pocono ecosystem in Pennsylvania in which rhododendron was a significant component. Strong winds have overturned a preponderance of trees growing in this ecosystem and initiated a regeneration process in plant species (Latham et al. 1996). Recession of American chestnut (*Castanea dendata*) by 40% from the overstory in the Southeast (McGinty 1972, Baker 1994) due to an epidemic chestnut blight (*Cryphonectria parasitica*) contributed significantly to creation of gaps in the overstory and to rhododendron invasion of these gaps (Baker 1994, Philips and Murdy 1985).

Similarly, humans played a direct role in the spread of purple-flowered rhododendron in the UK and Ireland at the beginning of the 18th century by promotion of this exotic species for aesthetic reasons (Cross 1981, Gritten 1995). The woody weed's spread has been stimulated by long-lasting human disturbances in southwest Ireland (Cross 1981). Extensive disturbances made by the British Army during the early 1940's expedited the spread of

rhododendron on the sand dunes of Winterton, Norfolk, UK (Cross 1975, Fuller and Boorman 1977). Following this period, rhododendron populations on the sand dunes made an exponential increase between 1953 and 1973 (Fuller and Boorman 1977). Heavy clearing by loggers and increased use by “artisans” for trading in the Killarney oakwoods of southwest Ireland during the 18th and 19th centuries have also given rise to the population explosion of rhododendron (Cross 1981).

Grazing, regardless of whether it is human-induced, is another major disturbance that may promote or depress the proliferation of rhododendron on a given site (Cross 1981). Low-intensity deer and sheep grazing in North Wales, UK, promoted rhododendron establishment by providing reduced competition from other plants (Cross 1981, Shaw 1984, Rotherham 1990, Thomson et al.1993). Another factor behind enhanced rhododendron establishment in low-intensity grazing areas includes the provision of “safe sites” (Cross 1981, Tabbush and Williamson 1987). Displacement of vegetation and perturbation of the soil by grazers, including deer, goat, sheep, cattle, and even birds, can create suitable conditions in the soil for bryophyte establishment, providing rhododendron seed with improved moisture and light conditions and protection from outside influences (Cross 1981, Tabbush and Williamson 1987).

High-intensity grazing with short return intervals nonetheless suppressed the population spread of rhododendron (Rotherham 1990, Thomson et al.1993, Baker 1994, Gritten 1995). Similar high-intensity grazing pressures were applied on rhododendron by native red deer (*Cervus elaphus* L.), domestic cattle, pig, goat, sheep, and recently, exotic sika deer (*C. nippon*) in the Killarney Oakwoods of southwest Ireland, hence preventing establishment of purple-flowered rhododendron populations (Cross 1981). Pornon and Doche (1995) observed that *R. ferrugineum* populations flourished only in the meadows of the northwestern Alps in France, where heavy grazing was not a significant perturbation. Grazing in conjunction with fire kept populations of great rhododendron low in the Southern Appalachians until the cessation of these disturbance agents around the 1920’s (Baker 1994, Philips and Murdy 1985, Clinton and Vose 1996).

Fire is another disturbance type whose effects on rhododendron spread are dependent upon its intensity and return interval. Çolak (1997) performed a burning trial, probably at low intensity, on purple-flowered rhododendron plots in the BSR, Turkey. One year after

application, results indicated that burning had suppressed rhododendron resprouting significantly. Following the second growing season after application, however, rhododendrons sprouted prolifically from buds placed on the “lignotuber” roots (Çolak 1997). Clearing of native vegetation cover and exposure of the mineral soil provided suitable conditions for moss settlement, and hence improved chances of successful rhododendron establishment (Cross 1981, Tabbush and Williamson 1987).

Frequent and widespread fires in the eastern USA between 1897 and 1917, along with other human-induced disturbances, prevented great rhododendron populations from spreading (McGee and Smith 1967, Phillips and Murdy 1985, Baker 1994). Rhododendron populations were probably confined within their natural boundaries, including riparian zones, mesic islands, river banks and other moisture-rich areas (Baker 1994). A North American rhododendron species (*R. canadense* (L.) Torr.) was also found growing only in an ecotone between a fire-maintained scrub oak community and a fire-protected swamp forest in the Pocono plateau of Pennsylvania (Latham et al. 1966). The fire suppression program put in effect in the eastern USA after the 1920's, therefore, seemed to remove the check on aggressive rhododendron populations, resulting in rapid expansion of this woody species (Monk et al. 1985, Phillips and Murdy 1985, Baker 1994, Nowacki and Abrams 1994).

Many evergreen shrubs that grow in cold, mesic climates, including rhododendron, typically contain high concentrations of organic acids in their leaves and wood (Read 1984; Latham et al. 1997). Lowered soil pH as a result of exudation of these organic acids into the soil, as well as the cold, mesic character of the weather, reduce the rate of decomposition in the soil, resulting in debris accumulation on the forest floor over time (Pritchett and Fisher 1987). Latham et al. (1996) recognized the flammability of leaves of evergreen vegetation living in stressed environments such as the mineral-poor Pocono barrens. The flammability of leaves and the thick biomass accumulation on the forest floor inevitably lead to fire, recycling a whole community by setting forest succession back.

Feasibility of Information Transfer between Different Regions of Rhododendron

Effects of the environment on development of certain traits used by plants to cope with their environment have long been recognized (Grime 1979). From this aspect, stressful environments determine the composition of a plant community by exerting a selective pressure on the species (Perry 1997, Peterson and Jones 1997). Evergreen leaves and vegetative reproduction are accepted as common adaptive traits among plants that grow in similar stressful environments (Perry 1997, Peterson and Jones 1997). The evergreen habit conserves nutrients. The smaller-sized leathery leaves and smaller leaf area/leaf weight ratio of evergreens as compared to deciduous trees also curtail excessive transpiration for these stress tolerators. With persistent leaves, evergreens can further take advantage of the small number of mild winter days with conditions for photosynthesis (Perry 1997). The different rhododendrons seem to have many of these competitive traits, probably owing to similar selective pressures placed on their environments.

Habitats of great rhododendron in the Southern Appalachians of the southeastern USA and purple-flowered rhododendron in the Black Sea Region of Turkey bear noteworthy resemblances to each other in many environmental aspects, including climate, topography, soil and the floristic composition. An ecophysiological resemblance between the American beech of the Southern Appalachians and the European and eastern beeches of the BSR -- the latter two are considered close relatives -- has also been previously noted (Peters 1997). All the functional and structural similarities between these two regions may therefore justify sound information transfer between them in factors that govern these ecosystems. This possible connection between the two ecosystems becomes more critical when understanding the mechanisms behind the invasive ecology of rhododendron, and from this information, development of effective forest vegetation management methods to control this invasive shrub are targeted. The ecology of this invasive shrub, however, needs to be well understood to achieve these objectives.

Manual Rhododendron Control

Rhododendron's great potential to produce root and stem suckers after a perturbation results in manual control's being ineffective against this invasive shrub (Saatçioğlu 1957, Varol 1970, Suner 1978, Robinson 1980, Eyüboğlu and Karadeniz 1987, Tabbush and

Williamson 1987, Palmer et al. 1988, Çolak 1999). Pieces of root and buried stems left in the soil after a manual cut, and rapid colonization of unattended sites by seed, guarantee revival of the pre-existing rhododendron population in short periods (Wood et al. 1967, Tabbush and Williamson 1987). Manual rhododendron removal (i.e., cutting and grubbing) can maintain shrub-free site-prepared plots for only one or at most two years (Saatçioğlu 1957). In a five-year period, 75% of cut sites reverted to rhododendron with added *Rubus* spp. invasion (Varol 1970). During the installation of the present study in the summer of 1997, rhododendrons that were cut 10 cm above ground level were observed to resprout as soon as 25 days after treatment (DAT) (personal observation 1997).

High cost is another prohibitive factor for manual control (Saatçioğlu 1957, Suner 1978, Eyüboğlu and Karadeniz 1987). Broadcast manual removal of one hectare of rhododendron required 2080-2540 labor hours in the BSR (Saatçioğlu 1957). In recent years, a cooperative woody control program between the Turkish and German Forest Services prescribed planting tall and large-diameter three-year-old eastern beech seedlings in spots where the shrub was manually removed (Kahveci 1997, pers. comm.). The fourfold costs of growing three-year-old seedlings with respect to one-year old seedlings has, however, arisen as a major impediment to this prescription (Eyüboğlu and Karadeniz 1987). In addition, the few advantages of manual control are already on the decline due to the unattractive cost of labor (Seçkin 1998, pers. comm.). Newton (1979) added to the already-mentioned disadvantages of manual control by reporting that obtaining qualified labor for the job at the desired time and place was becoming increasingly difficult. The high operational risks of manual vegetation control have forced many forest managers to consider other means of vegetation management (Newton 1979). In fact, forestry operations using sharp cutting tools have been ranked as the most risky job in the state of Oregon, USA. This high operational risk was reflected twice in the manager's budget, both as days lost to injuries and as high insurance rates (Newton 1979). Though environmentally friendly herbicides have been falsely accused of inducing environmental pollution and risk for human and wildlife health, manual removal of unwanted vegetation can in fact raise serious environmental concerns due to oil and gas leakage and fuel burned by chain saws used during the operations and the long degradation period of these waste materials (Johston and Nickerson 1991).

Mechanical control brings about concerns for long-term soil productivity (Childs et al. 1989). High traffic on forest soils by heavy equipment compacts the soil, reduces macroporosity and organic matter content, causes rutting and puddling of mesic or waterlogged soils, and increases the erosion rate (Childs et al. 1989). The overall result of these soil disturbances is reduced tree growth (Childs et al. 1989). Moreover, the discharge of environmental pollutants threatens the local flora and fauna (Johnston and Nickerson 1991). Besides its site-degrading effects, mechanical control does not grant the desired level of woody control. Chopped rhododendron root and stem pieces are widely distributed by the blades of bulldozers and, in fact, may enhance the proliferation of this aggressive shrub (Wood et al. 1967, Tabbush and Williamson 1987). The high cost associated with this control technique is another limiting factor; clearing purple-flowered rhododendron in bands 40-60 m apart by bulldozers costs US\$267 ha⁻¹ in the UK (1 British pound = 1.57 \$US, as of March 1999). Further passes within the next four years to prevent reinvasion of the bands by rhododendron added US\$126 to the previous figure, totaling US\$393 ha⁻¹ (Robinson 1980).

Chemical Rhododendron Control

History of Chemical Control in Turkey

The history of herbicide use in Turkish forestry is not long. Alpay (1969) first used herbicides against various herbaceous species growing in the rangelands of Mount Bolu, a part of the Northern Anatolian Mountain belt in the eastern BSR. He used NaCl, 2,4-D, 2,4,5-T, a combination of the latter two, and a standard solvent at various rates. Following Alpay, Varol (1970) used 2,4-D, 2,4,5-T, CS 301, CS 301/70, Tributon D, and a standard solvent at differing rates against rhododendron in six different forest stands in the region. Among the applications, 4% (v:v) 2,4,5-T mixed with diesel oil provided the most efficacious results, yet could not eradicate the shrub entirely. One year after treatment (YAT), 10% of the area sprayed was reinvaded by rhododendron. Moreover, 2-4% (v:v) 2,4-D in a water carrier could desiccate only the above-ground portions of the rhododendrons shorter than 50 cm (Varol 1970).

Foliar Chemical Rhododendron Control

Environmentally friendly herbicides, when used appropriately, provide the safest, most effective, and most cost-effective means to control unwanted vegetation in forestry applications (Ross and Lembi 1989, Johnson and Nickerson 1991). Negative impacts of the use of chemical compounds on human, wildlife, and water resources have been virtually eliminated by the recently developed environmentally friendly herbicides and integrated pest management practices, of which herbicidal control is a part (Johnson and Nickerson 1991; Zedaker 1997, pers. comm.).

Foliar herbicidal woody control is now a common and effective site preparation and release treatment used to increase initial tree growth in forest management practices in the USA. *Rhododendron* spp. have, however, proved difficult for many herbicides to control, with great recovery after a few growing seasons of application (Lawrie and Clay 1993). The hydrophobic nature of the waxy epicuticular layer on the adaxial leaf surfaces significantly precludes herbicide penetration into the leaf interior in rhododendron (Holloway 1970, Kitchen et al. 1980, Tabbush et al. 1987, Gritten 1995).

Imazapyr and triclopyr, two recently developed herbicides (Tabbush and Williamson 1987, Ezel et al. 1995), have displayed promising results for the long-term suppression of purple-flowered rhododendron (Tabbush et al. 1986, Tabbush and Williamson 1987, Clay et al. 1992, Lawrie and Clay 1993). Triclopyr ([3,5,6-trichloro-2-pyridinyl]oxy]acetic acid) is a synthetic auxin-type post-emergence herbicide that is effective for woody control (McCavish 1980, Lewer and Owen 1990, Forster 1998, Jackson et al. 1998). Its control amplitude covers a broad range of woody weeds (Lewer and Owen 1990, Jackson et al. 1998). Garlon 4 and Pathfinder are two oil-soluble commercial products of triclopyr formulated as a butoxyethyl ester, whereas Garlon 3A is formulated as a triethylamine salt and is water-soluble (Foster 1998, Jackson et al. 1998). Garlon 4 is used as a foliar or basal application due to its greater penetration of hydrophobic plant surfaces (i.e., leaves and bark) than Garlon 3A when these two are compared on a coequal active ingredient basis (Zedaker 1986, Forster 1998). On the other hand, Garlon 3A is used for stem injection or cut-stump applications (Lewis et al. 1984; Zedaker 1986; Cain 1995). Although triclopyr has been generally recognized as a readily translocated herbicide within woody plants (MacCavish

1980), a kerosene carrier built into the formulation was blamed for inhibiting translocation by damaging leaves and conducting tissues in plants (Jackson et al. 1998).

Triclopyr has been used to control purple-flowered rhododendron in the UK (McCavish 1980, Robinson 1980, Palmer et al. 1988, Lawrie and Clay 1993). McCavish (1980) had limited success controlling rhododendron with triclopyr ester applied at 1.44 kg ae ha⁻¹. Palmer et al. (1988) used triclopyr (Garlon 2) at 2-4 kg ae ha⁻¹ rates on the foliage of rhododendron with greater success than McCavish. They gained woody control that varied between 85 and 100% 6 months after treatment (MAT) (Palmer et al. 1988). Robinson (1980) tested glyphosate and triclopyr control on rhododendron foliage against 2,4,5-T. The last herbicide, when applied at 11.3 kg ae ha⁻¹, brought about 100% reduction in woody height and crown volume 1 YAT. Glyphosate and triclopyr reached an equivalent control with 2,4,5-T when they were applied at 3.6-5.4 kg ae ha⁻¹ and 3.6 kg ae ha⁻¹ rates, respectively. This study also concluded that the year-round photosynthesis ability of rhododendron made the application date factor less significant when compared to other woody species. However, the best application dates were suggested as mid-July to mid-September (Robinson 1980): 3.6 kg ae ha⁻¹ glyphosate conferred 100% woody control for both mid-July and mid-September application dates (Robinson 1980). Lawrie and Clay (1993) also applied triclopyr on rhododendron foliage in the UK at 0.075, 0.375, 1.5 kg ae ha⁻¹ rates with 82, 70, and 97% reductions, respectively, in fresh shoot weight 15 MAT.

Imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid) is a systemic herbicide that also has a broad spectrum of control on many herbaceous and woody weeds (Tucker et al. 1994, Nissen et al. 1995). It is readily translocated within plants to the main targets (i.e., roots for woody plants) and hardly degraded by plants to products that are no longer phytotoxic (Nissen et al. 1995). This herbicide, as its mode of action, arrests "acetohydroxyacid synthase" and prevents valine, leucine, and isoleucine -- fundamental amino acids for synthesis of protein and division of cells in the meristematic tissues of plants -- from forming. Exhaustion of proteins in plants takes time; therefore imazapyr, in contrast to triclopyr, displays efficacy results in an extended period (Tucker et al. 1994). Imazapyr is widely used in the southeastern USA for site preparation and conifer release (Ezel et al. 1995, Harrington et al. 1998).

There are a limited number of studies that have used imazapyr against rhododendron. In one of these studies, Lawrie and Clay (1993) applied imazapyr to rhododendron foliage at rates of 0.125, 0.25, and 0.5 kg ae ha⁻¹. These applications resulted in 67, 73, and 100% reductions in fresh shoot weight 15 MAT, respectively. In terms of crop tree safety, application of imazapyr at the rates of 0.2, 0.8, and 3.2 kg ai ha⁻¹ did not reduce the fresh shoot growth of two-year-old European beech 9 MAT (Lawrie and Clay 1989).

In terms of other herbicides used against rhododendron, applications of glyphosate at 0.45, 0.9, 1.8 kg, and 3.2 ae ha⁻¹ rates and methsulfuron-methyl at 3.8, 7.5, and 15 g ai ha⁻¹ did not result in as much woody dieback as did triclopyr and imazapyr (Tabbush and Williamson 1987, Lawrie and Clay 1993). An application of picloram at 5 kg ae/ha produced only limited control of great rhododendron in the eastern USA 2 YAT (Neary et al. 1980).

Cut-Stump Treatment

Coating the cambium of cut stem surfaces of woody plants with undiluted or water-diluted herbicides is a common application method that has been successfully used in the southeastern USA against prominent woody weeds (Zedaker et al. 1987, Zedaker 1988). This technique is particularly useful in uneven-aged Appalachian hardwood stands (Zedaker 1988). The cut-stump technique's low use rates (0.6-0.7 gal/100 ft² basal area) have made this technique more attractive to forest managers than the other herbicide techniques from the perspectives of environmental safety and cost-effectiveness (Zedaker 1988).

The cut-stump treatment is not an herbicidal technique that has been used widely on rhododendron. In one study in the UK, Roundup® was applied (36% ae) to the cambium of cut rhododendron stems at rates of 0, 25, 50, 75, and 100% (v:v) with water between May 1984 and March 1985 at two-month intervals. Evaluations in July 1985 showed that all these rates suppressed the shrub significantly with respect to resprouting in control plots (Tabbush and Williamson 1987).

The Leaf Cuticle

“Wettability” is a critical factor in herbicide absorption by plant foliage (Holloway 1970). Wettability is determined by the physicochemical features of the leaves and spray

droplets. The type and composition of chemical groups and characteristic topology of leaf surface control how wettable a given leaf surface is (Holloway 1970).

The first barrier to herbicide absorption by plant foliage such as rhododendron leaves is the cuticle layer (Holloway 1970, Kitchen et al. 1980, Hess 1985, Tabbush et al. 1987, Gritten 1995). The cuticle layer characteristically consists of an epicuticular layer on the leaf surface in which waxes of varying chemical composition are embedded, as well as pectin, cutin, and cellulose. The waxy epicuticular layer on the adaxial leaf surface is hydrophobic in nature, and the hydrophobicity originates from methyl terminals of functional chemical groups compactly positioned on the leaf surface. Different than the epicuticular layer, the pectin, cutin, and cellulose have a greater affinity for water (Holloway 1970).

The waxes on leaf surfaces are actually made up of long-chained aliphatic carbon polymers (i.e., C₂₀₋₃₅) (Holloway 1970). The most common wax groups found on leaf surfaces include alkanes, alkyl esters, secondary alcohols, primary alcohols, and fatty acids (Holloway 1970). The major alkane species identified in a rhododendron species (*R. fortunei* cv Admiral Piet Hein) growing in the UK, for example, include hentriacontane (43-55%), tritriacontane (11-26%), and nonacosane (13-20%) (Salasoo 1983). The nature, number of groups, and chain length of the waxes varies from plant to plant (Holloway 1970). In addition, chain lengths of hydrocarbons in alkanes in the epicuticular wax have been found to increase with increasing leaf age for many plant species such as *Eucalyptus globulus* (Salasoo 1983). However, no such trend was apparent between alkane composition and leaf age once rhododendron leaves had assumed their usual shape (Salasoo 1983).

The topology of the cuticle on leaf surfaces is another critical factor determining wettability (Holloway 1970). Formation of complex surfaces (solid/aqueous and air/aqueous) on leaf surfaces are directly related to the surface's topology. The characteristic cuticle topology of leaves is generally finalized towards the end of leaf development. The common types of leaf surface topology found among plants are termed "granular," "grooved," or "ridged" based on given appearances. Heterogeneity of topology, density, and distribution of veins and epidermal cells on leaves collectively determine the extent of wettability of the leaves by aqueous solutions. Trichomes -- superficial projections of the epidermal cells embedded within the cuticle -- also provide passages for aqueous solutions into the leaf interior and thus enhance the wettability of plant leaves. They are generally

most plentiful on the leaf midrib and veins (Holloway 1970).

The common measure of leaf wettability is the surface contact angle (Holloway 1970). The surface contact angle is the angle between spray droplet spread on the leaf and the leaf surface. After removing surface wax from leaves using chloroform, Holloway (1970) measured contact angles of leaves of different plant species. He identified the plant species with leaf contact angles greater than 90° as those in which wax plays a major part in hydrophobicity. In plant species with leaf contact angles less than 90° , leaf waxes are less important in determining hydrophobicity. Among the plant species studied, purple-flowered rhododendron did not have “prominent” hydrophobicity due to its low adaxial leaf surface contact angle (70°). Although its adaxial leaf wax content was high, the low contact angle for rhododendron was explained as the smoothness or lower roughness of the wax film covering the leaf surface. The smooth wax film did not increase the contact angle of spray droplets as much as it would have if the leaves had had a rougher surface (Holloway 1970). In the same study, some tree species such as *Eucalyptus globulus* had a higher adaxial leaf surface contact angle (170°), whereas *Acer pseudoplatanus* demonstrated a lower contact angle (44°) (Holloway 1970).

Surfactants

Surfactants (surface active agents) have recently been added extensively to herbicide spray solutions to substantially improve woody weed control in forest vegetation management (Hess 1994, Zedaker et al. 1994, Jackson et al. 1998). Most surfactant molecules contain nonpolar lipophilic and polar hydrophilic sites, hence they interact with both polar and nonpolar compounds (Hess 1994). Ethylene oxide forms the polar site for most nonionic surfactants. An important feature of nonionic surfactants is that their lipophilic sites interact with one another and constitute “micelles” at the periphery of droplets at concentrations commonly employed in weed management practices. The surfactant concentration at which the micelles are formed is termed the “critical micelle concentration”. Emulsification of nonpolar molecules, including herbicides, oils, and the epicuticular layer of the cuticle, is possible by these surfactant micelles. In fact, emulsifiable concentrate formulations of herbicides are drafted by amalgamation of such surfactants (Hess 1994).

Surfactants reduce the surface tension of spray deposition on leaves, resulting in greater transformation from the aqueous/air interface to the liquid/solid interface (Hess 1994). The result of the reduced surface tension of spray deposition is enhanced spray leaf retention, spreading, and penetration, which in turn enhance herbicide uptake by plants (Hess 1994; Jackson et al. 1995).

Conventional organosilicone and oil surfactants have achieved great herbicide activity enhancement against many prominent herbaceous and woody weeds (Hess 1994, Knoche 1994, Zedaker et al. 1994, Jackson et al. 1998). The boost in activity by conventional surfactants arises from the delayed drying time of spray droplets and enhanced cuticular penetration (Knoche 1994, Zedaker et al. 1994). Organosilicones improve activity by reducing the dynamic surface tension of spray formulations (Hess 1994, Knoche 1994, Jackson et al. 1998). The organosilicones are formulated by connecting an ethylene oxide (the hydrophilic portion) to a trisilicone spine (the lipophilic portion). Enhanced infiltration through stomatal pores due to reduced dynamic surface tension of spray formulations is the main benefit acquired by the use of organosilicones (Lawrie and Clay 1993, Knoche 1994, Jackson et al. 1998). Rapid spread and absorption (i.e., rainfastness) determine herbicide efficacy more significantly in regions with mesic climates, such as the BSR. However, one important disadvantage of the use of organosilicones for forest vegetation management is that most forest woody species do not have many stomata on their adaxial leaf surfaces (Jackson et al. 1998). For example, purple-flowered rhododendron has only 2-3% of its total leaf stomatal content on its adaxial leaf surface (Cross 1975, Lawrie and Clay 1993). Therefore, major herbicide leaf penetration enhancement by organosilicones is not realized by most forest vegetation sprays (Jackson et al. 1998). Moreover, hydrolysis of the trisiloxane moiety in formulation pH ranges other than 6-8, incompatibility of these surfactants with other type surfactants such as the kerosene surfactant that built in Garlon 4 (Forster 1998, Jackson et al. 1998), and high costs are limiting factors for extensive use of these surfactants in weed management (Murphy et al. 1991, Policello and Murphy 1993, Hess 1994, Knoche 1994).

Knoche (1994) reported that herbicide penetration by organosilicones through various openings on leaf surfaces other than stomas differs from one organosilicone to another. For instance, Silwet L-77 and Y-12301 are absorbed by plant leaves through stomatal pores, whereas Silwet L-7607 shows greater penetration through non-stomatal openings (Knoche

1994).

Zedaker et al. (1994) compared herbicide leaf uptake enhancement of an organosilicone surfactant (Silwet L-77) with that of several conventional surfactants. They also tested whether herbicide leaf uptake enhancement by surfactants differed between the adaxial and abaxial leaf surfaces of red maple, sweetgum, and red alder (*Alnus rubra*). Their results indicated that glyphosate uptake by the abaxial leaf surfaces of red maple and sweetgum were enhanced significantly by Silwet L-77. This organosilicone also enhanced the abaxial leaf uptake of Garlon 3A when compared to that of Garlon 4 not mixed with any surfactants. High rates of Garlon-organosilicone combinations depressed translocation out of the treated leaves, yet at lower rates, the antagonistic effects in translocation disappeared (Zedaker et al. 1994).

Organosilicone-based uptake enhancement of hydrophilic Garlon 3A, compared with that of lipophilic, non-added Garlon 4, has triggered subsequent research due to the potential environmental safety gains of using Garlon 3A instead of Garlon 4 without loss in efficacy (Jackson et al. 1998). In fact, 1% and 5% Garlon 3A added with 0.2% Silwet 408 surfactant achieved, on the average, equal herbicide absorption by sweetgum when compared with herbicide absorption by Garlon 4 applied at equal rates (Jackson et al. 1998). In Zedaker et al. (1994), abaxial herbicide uptake was significantly enhanced by the organosilicone when compared to that of the adaxial leaf surface. This result is particularly important for future research efforts on herbicide uptake and translocation in rhododendron. Holloway (1970) reported that hydrophobicity of the abaxial leaf surface of purple-flowered rhododendron is significantly lower (i.e. leaf contact angle 43°) than the hydrophobicity of its adaxial leaf surface (i.e. leaf contact angle 70°). Referring to Jackson et al. (1998), improved herbicide uptake and perhaps translocation, as well as fewer environmental hazard risks, may be gained by using hydrophilic formulations such as Garlon 3A rather than lipophilic formulations like Garlon 4.

Although herbicide translocation may generally be independent of its uptake performance, organosilicones may increase translocation in some plants (Knoche 1994). There have been several hypotheses put forward to explain possible translocation enhancements by surfactants. The first of these was that stomatal infiltration resulted in increased herbicide concentration in the vicinity of the vascular tissues that were responsible

for metabolite circulation within plants. Second, phytotoxic effects of organosilicone on leaf tissues might enhance accessibility of the tissues to herbicides, increasing herbicide deliverance to the phloem transport system. Third, enhanced spread by organosilicones might improve the chances of spray deposition to find more accessible passages into the leaf interior (e.g., via veins or trichomes). Greater spray droplet spread by these surfactants also reduced contact phytotoxic effects of organosilicones on leaf tissues on a per-unit-area basis (Knoche 1994).

Lawrie and Clay (1993) used a wide variety of surfactants with triclopyr and imazapyr against purple-flowered rhododendron. The surfactants used included a 1% (v:v) non-ionic alkyl phenol ethylene oxide condensate (Agral), a 2% (v:v) 1:1 (v:v) mixture of nonyl phenol ethylene oxide condensate, a primary alcohol ethylene oxide condensate (High Trees Mixture B), a 0.25% organosilicone surfactant (Silwet L-77), and a 1% rape seed oil, 95% oil plus emulsifier (Codacide). Triclopyr and imazapyr were applied at 0.375, 0.75, and 1.5 kg ae ha⁻¹ and 0.125, 0.250, 0.5 kg ae ha⁻¹, respectively. Fifteen MAT, rhododendron shoot fresh weight was reduced significantly by the 0.5 kg ae ha⁻¹ imazapyr and 1.5 kg ae ha⁻¹ triclopyr rate applications, with percent regrowth varying between 0 and 8%. Different surfactants did not make significant differences in rhododendron control at these high rates of herbicides. The greatest control for the lowest triclopyr rate application was achieved by Codacide, with only 15% regrowth 15 MAT when compared to the control level achieved by non-added triclopyr application. On the other hand, the lowest imazapyr rate application controlled the shrub the most when it was mixed with Agral and Mixture B. Only 9% and 11% regrowth occurred with these surfactants, respectively, compared with non-added imazapyr application woody control (Lawrie and Clay 1993).

Two types of oils are used for oil surfactants or carriers: refined mineral and vegetable or seed oil (Hess 1994). Mineral oils are incision products from petroleum refinement. Petroleum-based carriers had been widely used successfully with basal applications of herbicides in forest vegetation management (Bollig et al. 1994). The use of petroleum-based oils or kerosene in forest vegetation management has, however, recently diminished due to health considerations (Schneider 1991, Jackson et al. 1995). Therefore, many forest managers prefer vegetable oils (Schneider 1991, Hess 1994, Bollig et al. 1995). Schneider (1991) compared three petroleum-based solvents added to varying rates of triclopyr ester

(aromatic, aliphatic, and kerosene solvent) with a vegetable oil triclopyr ester in a basal application experiment on red maple, white oak (*Q. alba*), and Virginia pine (*P. virginiana*). His results revealed that the vegetable oil achieved the greatest herbicide uptake among all of the solvents used.

Triglycerides and methylated oils are the major vegetable oils used recently in forest vegetation management (Hess 1994). In triglycerides, glycerol forms the main frame, with fatty acids of differing types attached to the carbon of the glycerol spine via ester bonds. Methylated oils are hydrated version of triglycerides. Triglycerides are put in reaction with water and the fatty acid parts of them are cut from the spine. The resulting molecules are methyl esters of triclycerides or methylated vegetable or seed oils. These oil derivatives have been found to perform better with herbicides for plant absorption than triclycerides (Hess 1994).

Methylated seed oils have been successfully used as carriers with foliar- or basal-applied herbicides (Hess 1994). They lower the dynamic surface tension of spray solutions and hence enhance wetting and spreading on target plant leaves. Methylated sunflower seed oil (Sun-It II) has significantly increased the efficacy of imazapyr against many herbaceous and woody weeds (Minogue et al. 1994). Six WAT, 50% (v:v) Sun-It II-carried Chopper EC and Arsenal AC, each applied at 0.75 lb ae/acre, more substantially damaged hardwood foliage than CWC Hygrade, JLB Plus Improved carriers of varying rates (Minogue et al. 1994). Similarly, 50% (v:v) Sun-It II-carried Chopper (4 gallons per acre) significantly enhanced control of yellow-poplar, mockernut hickory (*Carya tomentosa* (Poir) Nutt.) and an herbaceous weed species (Minogue 1996).

CHAPTER 2: SOIL AND SITE FACTORS INFLUENCING PURPLE-FLOWERED RHODODENDRON AND EASTERN BEECH FORESTS IN TURKEY

Abstract

Eastern beech is the major crop tree species growing in the Black Sea Region (BSR) forests of Turkey. The future of these forests is now in danger. Purple-flowered rhododendron currently dominates the understories of almost the entire eastern beech forest, reducing beech regeneration and growth significantly. Understanding the effects of environmental and disturbance factors on the distribution and growth of rhododendron and beech is the key to developing effective management prescriptions for sustaining these forests.

The effects of canopy light, topographic (aspect, elevation, slope), soil (moisture content, depth, texture, pH) and disturbance (anthropogenic and fire) variables on the establishment, abundance, and growth rate of rhododendron and beech were examined in two rhododendron-dominated beech forests in the western BSR. These forests differed in anthropogenic disturbance histories. Inventory data for the abovementioned variables were collected from both forests in fixed-radius plots placed in a 2-km line using a systematic point sampling design. The basal area, age, and growth rate of rhododendron stems and beech trees were also determined for each plot. Distance from the nearest village or road was measured for the effects of anthropogenic disturbance in forest. Fire effects were evaluated by measuring charcoal particule density in soil samples. Multiple regression and correlation analyses were used to evaluate the effects of these environmental and disturbance variables on the abundance and growth rate of rhododendron and beech. Interviews with the elderly residents of the nearby villages were also used to characterize past forest composition and major disturbances.

The current beech overstories were established prior to rhododendron establishment. Lack of correlation of charcoal density in soil samples with vegetation and original beech establishment suggested that fire may not be the major regenerative disturbance for these sites, at least in the past 100-200 years. However, density of charcoal, accounts of elderly villagers, and records from the Ottoman archives on past vegetation and disturbances

indicated that fire has probably been an influential component of these forests in the long term.

Anthropogenic disturbance was the most probable regenerative disturbance and shaped forest structure in these sites. Selective logging of pine and other hardwoods from once-mixed forests has probably resulted in pure beech forests. Rhododendron precluded beech regeneration and affected the long-term growth of beech. The structure of rhododendron populations suggests that it would continue to dominate these sites in the near future. Both indirect topographic and direct measurements of moisture availability on these sites indicated that soil moisture was the most important environmental factor shaping rhododendron and beech abundance and growth. Adequate soil aeration was also critical for rhododendron.

Introduction

Turkey's forests occupy 27% of the country's area; of this, only 52% (almost 13 million ha) is productive (i.e., forests with canopy closure $\geq 70\%$, Tüfekçioğlu 2000, pers. comm., Turkish Forest Service Forest Management Report 1997). The nation's wood production cannot satisfy its increasing wood demands (Tunçtaner et al. 1985). The demand for wood exceeds supply by >1 million m^3 , and the country spent more than \$150 million in 1999 for wood imports from abroad (TFS Management and Marketing Report 1999).

The BSR, located in northern Turkey, has the greatest forest area and standing volume in the country (Forestry in Turkey 1988, Figure 1). Eastern beech is a significant tree species for Turkish forestry, with a total area coverage of 615,000 ha and a standing volume of 154 million m^3 , making up almost 20% of the total standing wood volume (Atalay 1992). Beech has its widest distribution and optimum growth under the mesic, oceanic climate of the northern aspects of the Northern Anatolian Mountains that lie in the BSR (Saatçioğlu 1957, Varol 1970, Suner 1978, Eyüboğlu and Karadeniz 1987, Atalay 1992, Çolak 1997).

Purple-flowered rhododendron dominates almost the entire forest understory throughout the eastern beech distribution in the BSR. Tree regeneration and growth are almost entirely precluded by this shade-tolerant, invasive woody species, as evidenced by the aging beech overstory and lack of natural beech regeneration (Seçkin 2000, pers. comm.). The region's future forest resource is therefore under serious threat from rhododendron (Saatçioğlu 1957, Varol 1970, Suner 1978, Eyüboğlu and Karadeniz 1987, Atalay 1992,

Çolak 1997). Similarly, rhododendron species have become a serious forest vegetation management problem in other parts of the world, including Ireland, Scotland, England (Fuller and Boorman 1977, Cross 1975, Robinson 1980, Cross 1981, Shaw 1984, Tabbush and Williamson.1987, Clay et al. 1992, Lawrie and Clay 1993, Thomson et al.1993, Gritten 1995), the eastern United States (Baker 1994, Philips and Murdy 1985, Clinton and Vose 1996), and Canada (Coats et al. 1991).

Variation in topography (e.g., aspect, slope, elevation) and canopy dynamics (e.g., available solar irradiance in the understory) control environmental conditions and resource availability levels that are essential for plant regeneration and growth in a given forest community (Oliver and Larson 1990, Smith 1992, Perry 1994, Smith et al. 1997). The outcome of many interspecific interactions – including competition – is largely determined by the variation in these environmental factors (Runkle and Yetter 1987, Canham et al. 1990, Atalay 1992, Peters 1997, Beaudet and Messier 1998, Canham 1988). However, no study has quantitatively investigated the effects of topographic and available solar irradiance in the understory on abundance and growth of rhododendron and beech in the BSR.

Soil moisture content, particle size distribution, and pH are soil factors that influence vegetation development (Pritchett and Fisher 1987). However, the effects of soil physical characteristics (i.e., stoniness, depth, texture, moisture contents of soil horizons) and acidity on the abundance and long-term growth of beech and rhododendron have not been studied in the BSR.

The composition and structure of temperate forests have been shaped by various physical, climatic, and biological disturbances (White 1979, Oliver 1981, Stewart and Rose 1990). Anthropogenic pressure and fire have molded many beech and/or rhododendron communities throughout the world (Lemee 1982, Nowacki and Abrams 1994, Diaci 1996, Latham et al. 1996, Kirwan 1999, Nielson 1997, Peters 1997, Sharma and Rikhari 1997, Wisser et al. 1997). The BSR and other parts of Anatolia have been inhabited by numerous civilizations over several thousand years; hence, their forests have been severely disturbed. Although the first documentation of such anthropogenic disturbance in forests is found as far back as 405 B.C. in Xenophon's book of Anabasis (Brownson 1980, Aksoy 1999, pers. comm.), anthropogenic pressure on the BSR flora has intensified since the period of the Ottoman Empire (1299-1923) (Turkish Forestry 1989). Numerous Ottoman archival

documents indicate intensive utilization of the once species-rich BSR forests by both the Empire and the public (Kutluk 1948).

Imperial documents also reveal forest fires ignited by goat and cattle herders in the mountain villages, and the governors' demands that legal action be taken against the arsonists (Kutluk 1948). The archives also mention higher value and heavier consumption of conifers – especially *Pinus* spp. – as opposed to other tree species. This may lead to two conclusions about past disturbances. First, in the 18th and 19th centuries, pines probably made up a significant proportion of what today are pure beech forests in the region. The fire dependency of pine for regeneration (Neyisçi 1987) and the large presence of pine in the period's forests imply that fire had played a significant role in the formation of these forests. Second, isolated patches of Turkish red pine, a prominent pyrophyte in the fire-maintained Mediterranean flora of southern and western Turkey, are found today on southern slopes throughout the BSR (Neyisçi 1987, Atalay 1992). A few studies have correlated charcoal particules in soil with vegetation abundance (Kirwan 1999, Welch 1999). However, no study has been conducted to date to quantitatively study the effects of humans and fire on regeneration in the now rhododendron-dominated eastern beech forests of the BSR.

Tree ring studies have helped scientists understand the effects of both long-term climate change and short-term events (e.g., capricious climatic changes, fire, insect, and human disturbances) on tree growth over time (Klubica 1994, Nowacki and Abrams 1994, Bedeau et al. 1995). Studying tree ring chronologies of both eastern beech and rhododendron may not only reveal how rhododendron and beech originally became established, but also how various environmental and disturbance factors have affected the long-term growth of these two species.

The objectives of this study were to evaluate the effects of aspect, slope, elevation, percent incident light in the understory, soil moisture, depth, texture and acidity, and anthropogenic and fire disturbance factors that may have influenced the today's rhododendron dominated beech ecosystem. New knowledge from this study could improve management practices for the rhododendron-invaded beech ecosystem in the BSR.

Methodology

Site Selection

Two forest sites were selected within the Zonguldak Province of the western BSR for data collection. The degree of human influence on vegetation varied significantly on the two sites. Accounts of Turkish Forest Service forest engineers and workers who know the region well were relied upon for site selection.

The first site is situated on the boundary of the forest village of Kardesler, approximately 7 km southeast of the western Black Sea coastal city of Zonguldak. There are villages of various sizes in close proximity of the site and it thus has received a great degree of anthropogenic impact. Local residents have frequently harvested wood for heating and cooking. The site has predominantly eastern beech overstory with a fairly closed-in average yet variable canopy (Table 1). Purple-flowered rhododendron makes up virtually 100% of the understory. Administratively, the forests around Kardesler Village are managed by the Yayla Forest Management Chiefship of the Zonguldak Forest Management Directorate, which is further tied to the Zonguldak Regional Forest Management Directorate of the Turkish Forest Service.

Table 1. Mean and range (minimum, maximum) values of beech overstory, rhododendron understory, and regenerated beech seedling basal area and incident solar irradiance (light) available under the beech and rhododendron canopies in the Yayla and Devrek sampling sites in the western Black Sea Region of Turkey.

Site	Basal Area			Light	
	Beech Overstory	Rhododendron	Beech Seedlings	Beech	Rhododendron
	-----m ² /ha-----		---cm ² /ha---	-----% of open-----	
Yayla	20 (0-52)	2 (0-8)	48 (0-780)	12.7 (0.1-100.0)	0.6 (0.01-6.8)
Devrek	22 (5-40)	5 (0-14)	1 (0-20)	3.3 (0.2-37.2)	0.2 (0.02-1.6)

The second site selected was Devrek, similar but with minimal anthropogenic influence. A site containing pure mature eastern beech in the overstory and purple-flowered rhododendron in the understory, 5 km southeast of the Hacimusa Village, fit the criteria. Both beech and rhododendron demonstrated distributions that were more fully closed canopies in Devrek than those in Yayla. The Devrek Forest Management Directorate

managed this site, which is also administratively linked to the Zonguldak Regional Forest Management Directorate.

Mean annual temperature for this part of the BSR is 13.5°C (Atalay 1992). Maximum annual temperature averages 30°C. Minimum annual temperature ranges between –8 and 12°C. Annual precipitation averages 1291 mm, of which 18% occurs during summer. Relative humidity generally exceeds 70% (Atalay 1992).

Inventory data were collected from both sites using a systematic point sampling design (Figure 2). The inventory at the Yayla site started from a random point on the boundary of Kardesler Village and extended 2.0 km on a bearing of 150°. Six-meter fixed-radius circular sample plots were placed on the 2.0-km line every 200 meters. Ten 350-m parallel axes were placed through each of the sampling plots, perpendicular to the main axis. Additional circular six-meter radius sampling plots were installed on the parallel lines at 50-m intervals. If any of the plots or subplots fell in nonforested areas (i.e., cultivated land, barren area, or recently logged), the nearest recently undisturbed forested point to the sampling plot was selected on the same azimuth without interrupting the integrity of the sampling design. In cases where no such point existed within 50 meters, the point was excluded from the study. A similar sampling procedure was followed for the Devrek site. A total of 63 and 70 plots were used for the Yayla and Devrek sites, respectively.

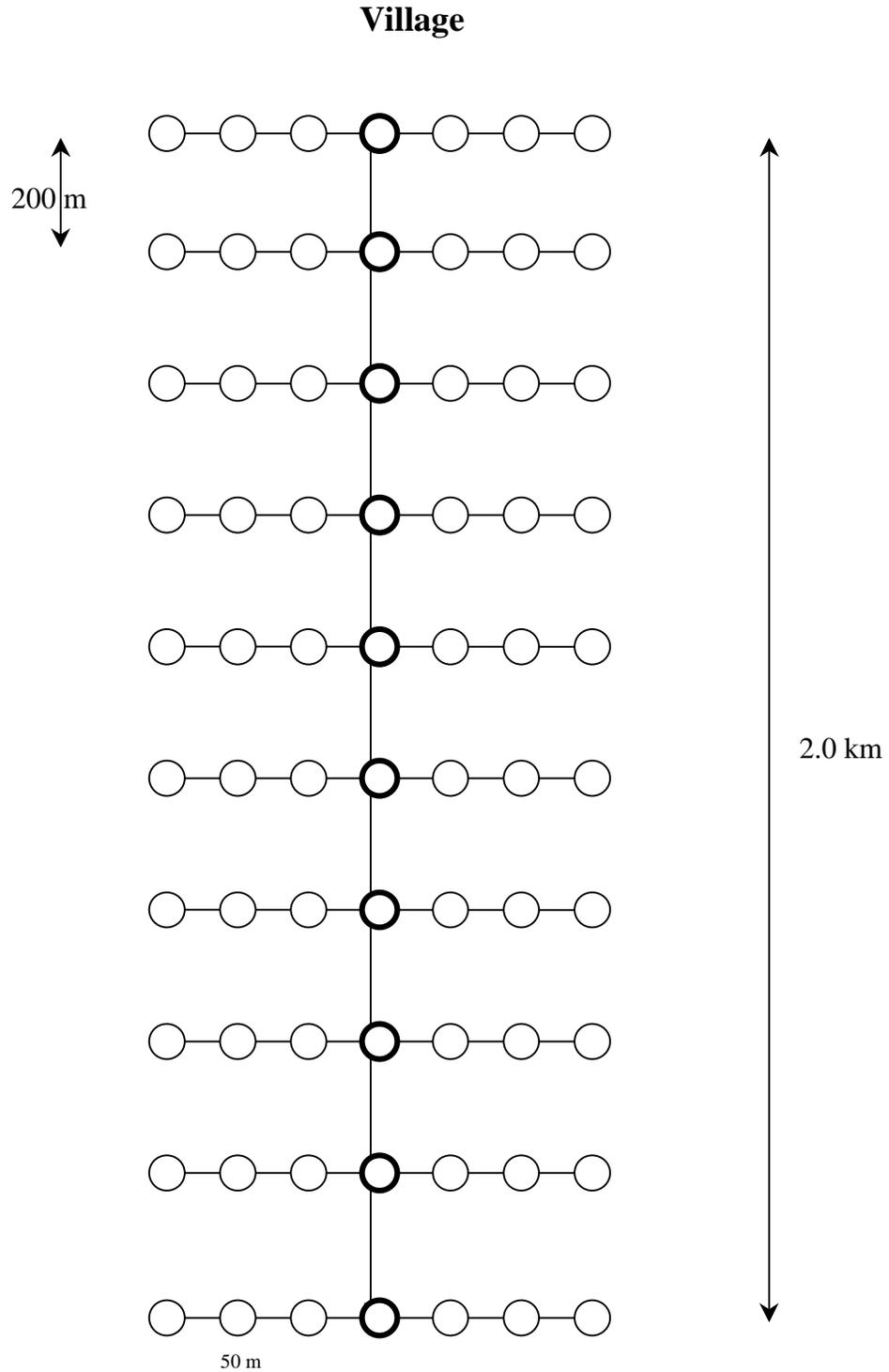


Figure 2. Systematic sampling design used in the Yayla and Devrek eastern beech-rhododendron forests in the western Black Sea Region of Turkey. Village was only for the Yayla forest.

Data Collection and Processing

Various environmental and floristic variables were measured and recorded at each of the sampling points. Beech basal area (BA) per ha was measured in both sites using a 2.4-m² basal area factor (BAF) prism during the summer of 1998. Basal areas of beech overstory and seedlings at both sites are given in Table 1. Beech seedlings were absent except in a few plots; thus, no statistical analysis was done for the variables of this table.

Tree core samples at breast height were extracted from each tree counted by the prism. Due to time limitations, however, only trees with a dbh greater than 10 cm were sampled at Yayla. The cores were treated with a broad-spectrum fungicide (Banrot[®], Sierra Crop Protection Company, Milpitas, CA, USA), shaved and sanded. The ages and annual ring widths of each tree core were determined using an Addo[®] ring dater mounted on a dissecting microscope. Samples that were excessively stained by fungus were eliminated from the dating procedure. From the annual ring widths, mean annual diameter growth for total lifespan of each beech tree was calculated.

Groundline diameter (gld) to the nearest mm was tallied by species for each woody plant in both Yayla and Devrek except for recent sprouts. From these data, total rhododendron basal area (RBA) was calculated per ha. A random subsample of rhododendron stem disks was cut from 0-5 cm above the groundline in each plot (3-5 stem disks/plot) to construct a rhododendron ring chronology. The ages and widths of annual rings on these disks were later determined on the Addo ring dater. The mean annual diameter growth rates for total life span of the disks were also calculated.

Aspect, percent slope, elevation, and percent incident solar irradiance under both beech and beech plus rhododendron canopies at each plot were measured on both sites using a hand compass, clinometer, altimeter, and Li-Cor[®] light meter, respectively. The slope and irradiance readings were replicated three times within each 6-m sampling plot. Prior to the canopy irradiance readings, a reference reading had been made in the open. The reference readings were repeated whenever the sky conditions changed to make sure both reference and canopy readings were in the same order of solar irradiance intensity (i.e., clear versus cloudy).

To characterize human disturbance effects on vegetation structure in the sampled area, distance of each sampling plot to the nearest “human footprint” (i.e., major settlement or

road) was determined. To determine if fire had occurred in the recent past, soil samples were extracted from three random points within each woody plot using a soil probe 38 cm long and 2 cm in diameter. Soil samples from 12 and 48 plots were processed for Yayla and Devrek, respectively, for charcoal particle density using the procedure developed by Kirwan (1999). Generally, charcoal particles are more frequently found in shallow depths of forest soils (Welch 1999). These soil samples were standardized to minimum and maximum soil depths for each forest. Percent charcoal density per plot was determined on three soil subsamples using a 1x1 mm grid system on a transparent sheet placed on the microscopic slide. When the midpoint or near midpoint of a charcoal particle intersected with a grid intersection, the particle counted. Percent counts from the three subsamples were later averaged.

To investigate the effects of soil physical and acidity factors on rhododendron and beech abundance and growth, 62 soil pits 1.5 m wide were excavated to the C horizon at the Yayla site during the summer of 1999. Depths of A and B horizons as well as total soil depth were recorded for these pits. Percent stoniness was also estimated by eye. Additional 0.5- to 1-kg soil samples were taken from different soil horizons of these soil pits and immediately stored in plastic ziploc bags for soil moisture content and physical analysis. However, soil sampling occurred during a month-long dry period. A heavy downpour during the later phase of the sampling disqualified some of the soil samples for soil moisture content analysis. All the soil samples had been stored in a refrigerator until they were analyzed. Gravimetric soil moisture content (%), soil particle size distribution, and acidity analyses were carried out by soil horizons at the Zonguldak Forest Soils Research Laboratory, and then values by horizon were averaged for the whole soil column.

Stepwise multiple regressions were used to compare basal area and mean annual diameter growth rates of beech and rhododendron (dependent variables) at Yayla with various independent environmental variables (degree distances from the northern and northeaster (NE) aspects, elevation, percent slope, percent solar radiation available in the understory, depth and percent sand, silt, and clay content, acidity of the A-, B-horizons and the whole column of the soil) and disturbance variables (distance from the Kardesler Village and the nearest forest road for anthropogenic disturbance) using the Proc Reg procedure of the Statistical Analysis System (SAS Institute Inc., 1989). Due to small sample size, percent

soil moisture content and soil charcoal density were not included in the multiple regression analysis. The effects of these variables as well as the rest of the variables on vegetation were analyzed, however, with correlation analysis. Degree distances from the N and NE aspects, elevation, percent slope, percent solar radiation available in the understory, depth of soil penetrable by the soil auger, distance to the nearest road, and percent soil charcoal density were used for Devrek for multiple regression analysis.

Twenty-seven interviews were conducted with elderly local residents within the jurisdiction of the Zonguldak Regional Forestry Directory, including the Zonguldak Central and Yayla Chiefships and Devrek Forestry Directory. In these interviews, questions were asked involving the past composition and major disturbances that occurred in nearby forests. To create unbiased conditions for the residents interviewed, the names and addresses of individuals were not asked. Prior to each interview, the person was specifically told that the interviews were conducted only for research purposes and that the specific answers of individuals would not be disclosed to any third party.

Results

Beech and Rhododendron Populations

Beech made up approximately 94 and 95% of total tree BA at Devrek and Yayla, respectively. European aspen (*Populus tremula* L., 4%), European and Eastern hornbeam (0.7%), European chestnut (0.3%), and oaks (0.1%) made up the rest of the total basal area at Devrek. Oaks (1.7%), fir (1.5%), chestnut (1%), hornbeam (0.6%), and Austrian pine composed the rest of the total tree basal area at Yayla.

The Yayla beech population showed a greater variation in basal area than did the Devrek beech population. Mean and range values of percent incident light available under the beech canopy suggested that the beech canopy was more open at Yayla than at Devrek. The Devrek site had, on average, twice as much rhododendron basal area than did the Yayla site. Percent incident light reaching the forest floor was dramatically reduced by the rhododendron canopy. The closure of rhododendron canopy was greater in Devrek than in Yayla (Table 1). Basal area of beech advance regeneration was substantially low at Yayla (Table 1). Beech regeneration was almost nonexistent for the Devrek site. Seedlings were observed to occur mostly in patches where rhododendron was disturbed.

Groundline diameter and age class distribution of rhododendron across the entire sampling area of both of the Yayla and Devrek sites approximated an uneven-aged stand structure (Figure 3). Minimum, mean, and maximum ages for the Yayla population were 3, 13, and 57, respectively: minimum, mean, and maximum ages for the entire population were 6, 16 and 48 years, respectively. Both gld and age class distributions in the two sites suggested little or no recent rhododendron regeneration, and this trend was a little more pronounced for the Devrek site. A significant positive linear relationship was found between the gld and ages of rhododendron (Figure 4).

The beech population at Yayla similarly demonstrated an unbalanced uneven-aged stand by dbh and age class distribution (Figure 5). Beech showed a little more regular distribution of age classes when compared to their dbh class distribution: the mean age for the Yayla beech population was 60 years, and a little more than 97% of the whole population was in the 0-100 year age class.

On the other hand, the beech trees of the Devrek site had a bell-shaped curve for both dbh and age class distributions (Figure 5); only 2% of the total number of beech trees belonged to the 0-10 cm dbh class. The ages of the Devrek beech trees averaged 107 years, with only 50% of the whole population included in the 0-100 year age class. The low regeneration observed for rhododendron in Devrek was also apparent for beech for this site. An abrupt descent was also noted in the upper end of the age class distribution of beech growing in Devrek. Unlike rhododendron, a weak relationship was found between dbh and age for beech in both the Yayla and Devrek sites (Figure 4). The dbh-age correlation was especially feeble in Yayla.

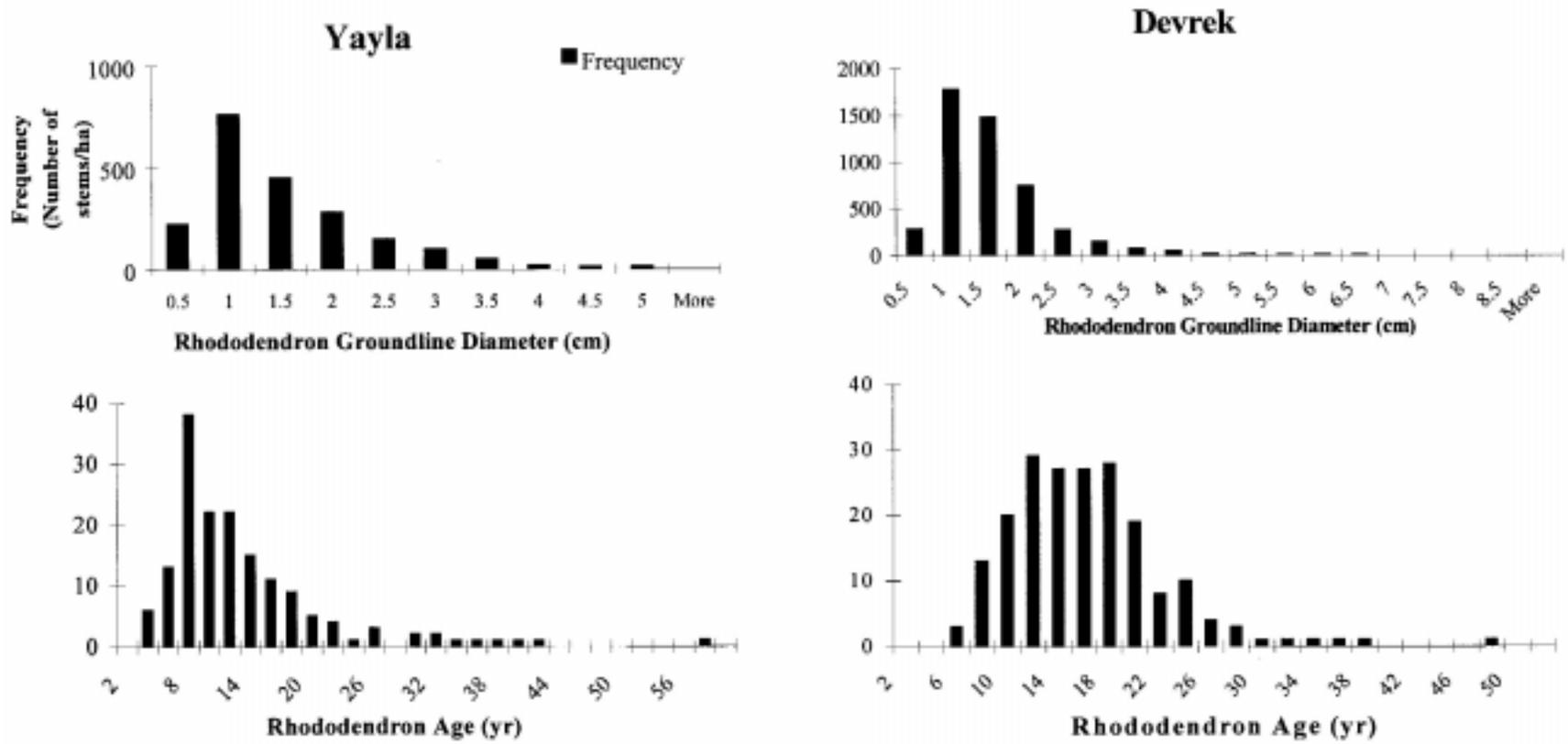


Figure 3. Frequency distributions of rhododendron diameter (above) and age (below) in the Yayla and Devrek sampling sites in the western Black Sea Region of Turkey.

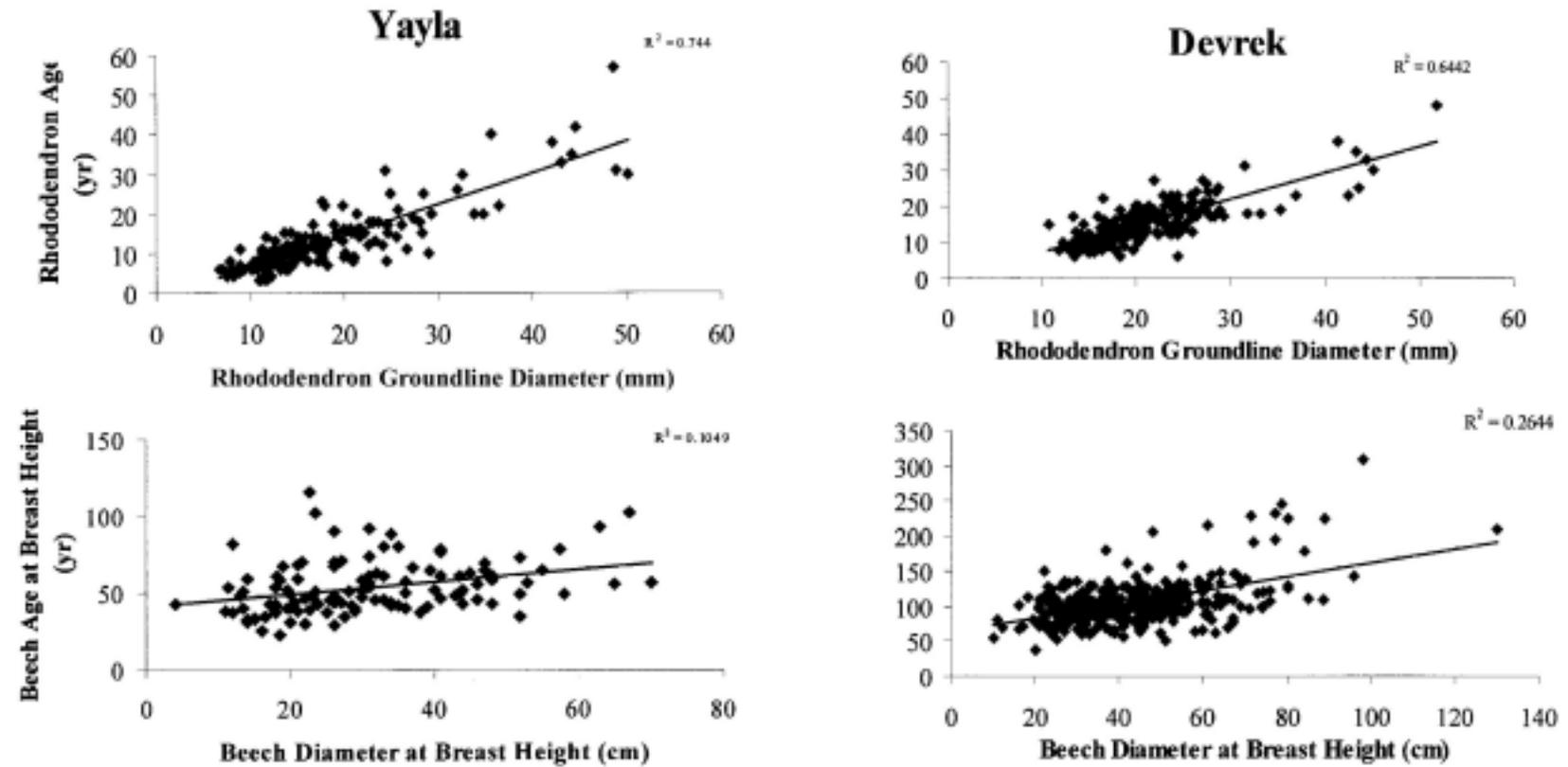


Figure 4. Relationship between diameter and age for rhododendron stems (above) and beech trees (below) in the Yayla and Devrek sampling sites in the western Black Sea Region of Turkey.

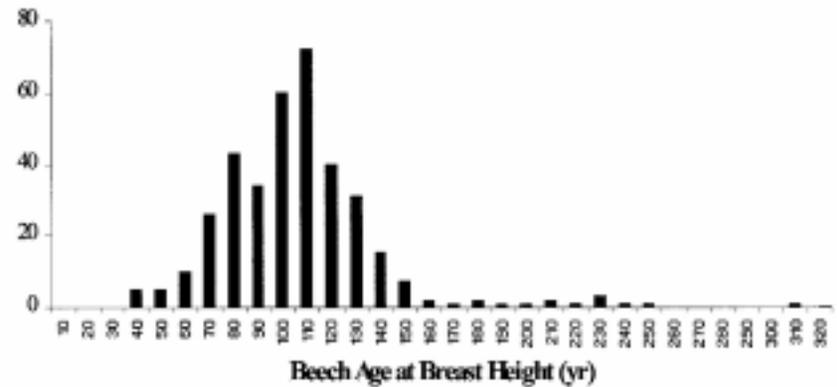
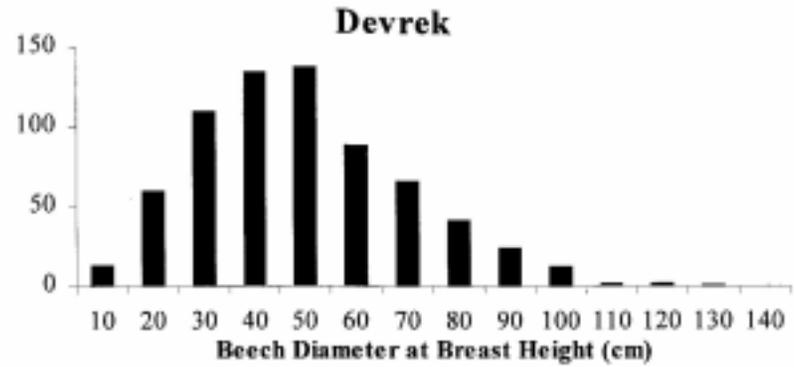
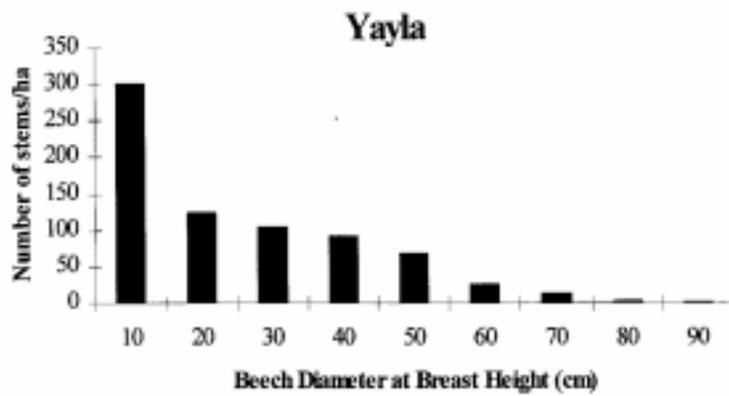


Figure 5. Frequency distribution of beech diameter at breast height (above) and age (below) in the Yayla and Devrek sampling sites in the western Black Sea Region of Turkey.

*Trees of <10 cm dbh were not included.

Rhododendron and Beech vs. Environmental Variables in Yayla

Stepwise multiple regression analysis from the Yayla site selected distance from the village, degree distance from NE, and soil B-horizon sand content variables for rhododendron basal area (RBA) with an r^2 value of 0.22 (Table 2). RBA increased significantly as distance from the village and percent sand content in the soil increased. RBA decreased as degree distance from NE aspect increased. The multiple regression relating mean diameter growth rate of rhododendron against various environmental variables selected no variable. Due to the small sample size, the relation of soil charcoal density with RBA was assessed by only correlation and plot analyses. A positive correlation ($r = 0.33$) was found between mean soil charcoal density and RBA.

A two-variable model explained 26% of the total variation of beech basal area (BcBA, Table 3). BcBA decreased significantly as distance from the village increased (Table 3). The second variable (percent sand content in the soil) had a significant, negative effect on BcBA.

A four-variable model explained 36% of the variation of mean diameter growth rate of beech (BG, Table 3). There was a significant increase in BG as distance from the village increased, with an intermediate positive correlation (Table 3). Increasing RBA reduced BG significantly (Table 3). Increasing slope also had a negative effect on BG, yet this effect was not significant. As total soil depth increased, beech growth tended to increase, yet not significantly.

Table 2. Stepwise regression of rhododendron basal area (RBA) on various environmental and disturbance variables from the Yayla sampling site in the western Black Sea Region of Turkey.

Independent Variable	R^2	Parameter Estimate	Significance Level (p)	Correlation with RBA
Village distance		0.1743	0.0289	0.3051
Degree distance from NE	0.22	-0.0112	0.0122	-0.1513
Soil B horizon sand content		0.0527	0.0459	0.2298

Table 3. Stepwise regression of beech basal area (BcBA) and mean annual dbh growth (BG) on various environmental and disturbance variables from the Yayla sampling site in the western Black Sea Region of Turkey.

Dependent Variable	Independent Variable	R²	Parameter Estimate	Significance Level (p)	Correlation with Dep. Var.
BcBA	Distance to village	0.26	2.0010	0.0019	0.4353
	Soil sand content		-0.5868	0.0289	-0.3371
BG	Distance to village	0.36	1.0863	0.0486	0.3362
	RBA		-1.1382	0.0480	-0.3064
	Slope		-0.0863	0.0962	-0.3456
	Total soil depth		0.0892	0.0631	0.2258

Relationship among Environmental and Disturbance Variables in Yayla

As percent slope increased at Yayla, the depth of the soil A horizon decreased substantially ($r = -0.40$), stone content increased ($r = 0.30$), and soil moisture decreased ($r = -0.28$). Mean soil moisture content increased with decreasing distance from the NE aspect ($r = -0.29$). Mean charcoal density in the soil samples increased when aspect departed from NE ($r = -0.26$) and when distance to the village decreased ($r = -0.28$).

Rhododendron and Beech vs. Environmental and Disturbance Variables in Devrek

The multiple regression using data from the Devrek sampling site produced a two-variable model that explained 22% of the variation in RBA (Table 4). RBA decreased significantly as one went away from the NE aspect (Table 4). Percent incident light available above rhododendron canopy had a negative effect on RBA, yet this effect was marginal. Slope made a positive yet nonsignificant effect on RBA.

A two-variable model explained 23% of the variation of the mean diameter growth rate of rhododendron (RG) at Devrek (Table 4). RG increased significantly when BcBA decreased. RG also tended to increase when soil charcoal density increased.

The multiple regression relating BcBA to the environmental variables collected from Devrek did not yield a significant variable. The multiple regression, however, selected three variables as significant for BG for the Devrek site (Table 4). These variables explained 28% of the variation of BG. Beech diameter growth rate decreased significantly as one went away

from the NE aspect. There was, however, a significant positive response from beech diameter growth rate as distance from the nearest road increased.

Table 4. Stepwise regression of rhododendron basal area (RBA) and mean rhododendron and beech annual diameter growth rate (RG and BG, respectively) on various environmental and disturbance variables from the Devrek sampling site in the western Black Sea Region of Turkey.

Dependent Variable	Independent Variable	R ²	Parameter Estimate	Significance Level (p)	Correlation with Dep. Var.
RBA	Degree distance from NE	0.22	-0.0159	0.0243	-0.2638
	Light in understory		-0.1329	0.0534	-0.1997
RG	Beech basal area	0.23	-0.0648	0.0092	-0.4169
	Soil charcoal		0.0356	0.1283	0.2440
BG	Degree distance from NE	0.28	-0.0334	0.0124	-0.2769
	Distance from road		0.0191	0.0037	0.3205
	Slope		0.0191	0.1047	0.0140

A three-variable model explained 29% of the variation in soil charcoal density (Table 5). Soil charcoal density increased significantly as aspect approached NE. An increase in penetrable soil depth had a significant negative effect on soil charcoal density.

Table 5. Stepwise regression of charcoal density with various environmental, disturbance, and rhododendron and beech basal area variables from the Devrek sampling site in the western Black Sea Region of Turkey.

Independent Variable	R ²	Parameter Estimate	Significance Level (p)	Correlation with Soil Charcoal
Degree Distance from NE	0.29	-0.0559	0.0163	-0.1402
Soil depth		-0.6412	0.0332	-0.3701
Plot no.		0.8496	0.0608	0.3309

Results of Interviews with Elderly Village Residents

All interviewees agreed on the fact that the forests of the 1940s and 1950s had more standing volume and a more closed forest canopy than the forests of today. The interviewees from the Zonguldak Central and Yayla chiefships indicated that beech was a dominant tree species then, but was mixed with chestnut (*Castanea sativa*) and hornbeam (*Carpinus betulus*, *C. orientalis*). Rhododendron was also prominent in the understories of the beech-

chestnut forests, and no significant change was noted in rhododendron abundance between the 1940s and the present time.

The interviewed villagers also indicated that populations of forest villages were heavily dependent upon the surrounding forest for their various needs. Large volumes of quality timbers were illegally extracted from the forest for home construction. Heating and cooking were also exclusively dependent upon fuelwood. Many chestnut trees were cut down for small ship and boat making. “Diseases” have also killed a great number of chestnut trees since then. Large volumes of quality beech trees were also selectively logged, especially for boat paddle making. The city of Zonguldak, which is only 7 km from the Yayla sampling site, has had very rich coal reserves.

Therefore, this area has supplied almost the entire coal demand of the country. Both the government-owned Turkish Coal Production Institute and the public extracted substantial amounts of beech from this forest during the 1940s and 1950s for coal mines and railroad construction. The Turkish Petroleum Institute also did significant damage in this forest in search of rich oil reserves. No large or prominent forest fires were reported by the interviewed people except two brush fires in Goktepe and Kanlibogaz in 1966 and 1993, respectively, each of which burned about 50 ha of forestland.

The interviewees from the Devrek Forest chiefship reported that pine (probably Austrian pine) used to make up a significant portion of the area (30-50%) of mixed beech forests during the late 1950s. Pines were selectively logged for home construction. Beeches were mostly cut down for fuelwood. Rhododendrons seemed to be confined to northern aspects and shallow soils around riverbanks. Rhododendron populations have recently expanded out of these areas to slopes and ridges. Only two specific fires, one in 1966 (30 ha) and the other in 1977, were reported. However, fire was frequently used by locals to make clearings from the forest for homebuilding and cultivation.

Discussion

Severe anthropogenic pressure has obviously shaped the existing forest in Yayla. The Yayla area has many villages of different sizes. Residents of these villages have been exclusively dependent upon the surrounding forests for home construction, heating, and cooking for years. Also, the Yayla site is situated near a road that had served the population

of Zonguldak City for years as the only major connection to the South. This site had thus been open to human pressure for years. The significant decline in beech basal area as one approached Kardesler Village, which bordered the sampling area, showed the increasing intensity of the village's pressure on the forest (Table 3). The forests of the Yayla chiefship received impacts not only from local wood consumption, but also from coal mines and railroad construction, for which large volumes of beech were extracted.

Although the age-class distribution of the Yayla beech population suggested a more balanced uneven-aged structure, this may be misleading (Figure 5). Trees of small dbh (i.e., < 10 cm) were not cored during field sampling due to their great number and the limited time given for coring. One may logically argue that had trees of small dbh been included in the age class distribution, the age distribution would probably have suggested a more irregular uneven-aged structure with an emphasis on younger stems. Using tree diameter for evaluating tree age may, however, result in erroneous conclusions (Smith et al. 1997). As a shade-tolerant species, beech would probably fall into the category of trees that are sensitive to this weak dbh-age correlation. In fact, there was a low correlation between age and dbh for beech on both sites (Figure 4). The lower dbh-age correlation of beech on the Yayla site than on the Devrek site suggested that disturbance further complicated this relationship.

Abrupt descents in the upper ends of the age class distributions of beech populations in both Yayla and Devrek might indicate high-grading (Figure 5). This may also appear in the dbh class distribution of the Devrek beech population. Larger-diameter and/or older beeches might have been selectively cut off these sites, leading to less representation of upper dbh and/or age classes. The selective cutting of quality beech trees for the boat industry, as indicated in the interviews, and intermediate selection cuttings in mature beech forests every 10 years by the Forest Service, may explain this (Çetintaş 2000, pers. comm.).

Unlike beech, a strong correlation was found in rhododendron between gld and age, suggesting that gld could be used as a good estimator of age for this shrub (Figure 4). Rhododendron is known to live as long as 100 years (Çolak 1997). Both the gld and age class distribution of rhododendron in Yayla suggested that this shrub had probably regenerated long after beech (Figure 3). The large proportion of stems in smaller gld classes suggested that rhododendron will most likely continue to dominate both Yayla and Devrek sites in the future. This result confirmed previous reports on the invasive strategy of rhododendron;

that is, upon establishment, population growth of rhododendron could increase exponentially (Monk et al. 1985, Baker 1994, Dobbs 1995, Hedman and Van Lear 1995). The old structure of rhododendron populations in both sites showed a good resemblance to that of the Southern Appalachian riparian regions of the U.S. that are dominated by great rhododendron. Baker (1994) reported that the rhododendron-dominated riparian ecosystem of Wine Spring Creek demonstrated an inverse-J diameter class distribution.

Rhododendron is known to proliferate vigorously after a disturbance such as cutting, as has been previously reported (Cross 1981, Shaw 1984, Eyüboğlu and Karadeniz 1987, Rotherham 1990, Thomson et al. 1993, Baker 1994, Çolak 1997). Therefore, one can argue that disturbances should have aggravated the abundance of rhododendron in Yayla. However, disturbances vary in scale, frequency, and intensity, and thus the consequences of their impact on a forest ecosystem (Runkle and Yetter 1987, Oliver and Larson 1990). This has been particularly demonstrated in the UK, where rhododendron populations grew in places that were grazed at different intensities (Cross 1981). Low-intensity deer and sheep grazing in North Wales, UK, promoted rhododendron establishment by providing reduced competition from other plants and “safe sites” (Cross 1981, Shaw 1984, Rotherham 1990, Thomson et al. 1993). From this information and the significantly less rhododendron basal area towards the village (Table 2), it may be said that the high intensity of anthropogenic pressure at short-term intervals depressed rather than stimulated the rhododendron population in Yayla.

Similarly to Yayla, rhododendron came in significantly later than beech had done in Devrek. The absence of a human settlement near the site probably lessened anthropogenic pressure in this forest substantially as compared to the Yayla site. As the only possible anthropogenic disturbance indicator, distance to the nearest road made no significant effect on the abundance of rhododendron and beech in Devrek (Table 3).

Apparently, the older beech overstory above rhododendron in Devrek indicated that a large-scale fire was very unlikely as a regenerative disturbance in the recent past, because beech is easily “stem-girdled” by fire (Smith et al. 1997). Additionally, the lack of significant correlation of the vegetation variables used for multiple regression with charcoal density may not suggest a large-scale fire as the major regenerative disturbance, at least for the past 100 to 200 years.

However, the great density of soil samples with charcoal particles on the Devrek site was noteworthy. This indicated that fire probably had been a significant component of this ecosystem in a larger temporal scale. Direct evidence of frequent occurrences of fire in the region also existed in the Ottoman archives. A specific imperial decree dated 1815 ordered the administrative transfer of the forests of Divrigi, a large town close to both Zonguldak and Devrek, to a neighboring province due to a recent devastation of Divrigi's forests, probably by a large fire (Kutluk 1948). Several other imperial decrees were prompted by frequent arson in the region's forests by herdsmen and directed provincial governors to prosecute these arsonists (Kutluk 1948). Furthermore, law has prohibited clearing the present state's forests for any reason. Interviews from the Devrek Forest Directory, however, indicated that fire had been a common tool for the local villagers to make openings from the surrounding forest for homebuilding and cultivation. Fire had apparently eased land acquisition for these locals. Furthermore, the presumed reduced rate of occurrence of fire in these forests in recent years may be tied to the long fire suppression policy of the Turkish Forest Service. Increasing charcoal density in Yayla as one approaches the village may also be evidence for greater human effects on the frequency of fire.

Historical accounts of the composition of BSR forests also reinforced the fact that fire has shaped the region's forest composition. Kutluk (1948) found Ottoman archival documents suggesting that pine, a well-known fire-dependent tree species, comprised a significant proportion of the BSR forests at the time (Kutluk 1948). In fact, an imperial document dated 1917 reported pine as the most abundant tree species in the BSR forests, followed by oak, beech, fir, and hornbeam in descending order (Kutluk 1948). Another imperial decree also indicated large coverage of pine forests around Kastamonu and Safranbolu (areas within or adjacent to Zonguldak province) for production of large quantities of pitch from these forests. Elderly villagers interviewed in Devrek also reported that pine made up 30-50% of total forests in this area during the late 1950s.

The Ottoman Empire had one of the world's largest warship fleets at the time, along with a considerable number of trade ships. Thus, quality sawlogs of conifers had probably always been in high demand for ship construction and its fringe industries. Many imperial decrees given by the Sultans involved logging and transportation of sawlogs of conifers along with other tree species for the shipping industry (Kutluk 1948). Interviews from the

Devrek area also accounted for selective pine logging for home construction. Furthermore, the present invasion by conifers of the region's agricultural fields that have recently been abandoned by villagers for socioeconomic reasons (Atalay 1992, pers. obsvs. 1998 and 1999) might also be taken as indication of the predominance of pines in these forests years ago. This information suggests that the current pure beech- and rhododendron-dominated BSR ecosystem is not a natural consequence, but a remnant of once species-rich forests. The current fire suppression policy of the Turkish Forest Service might have contributed to this.

Rhododendron generally prefers cool, mesic, and protected sites of northerly mountain aspects throughout the world's forests (Saatçioğlu 1957, Varol 1970, Eyüboğlu and Karadeniz 1987, Lipscomb and Nilsen 1990, Thomson et al. 1993, Baker 1994, Pornon and Doche 1995, Çolak 1997, Lipp and Nilsen 1997, Peters 1997), and riverbanks where high illumination, wind, and drought are not prominent factors (Lipscomb and Nilsen 1990, Thomson et al. 1993, Baker 1994, Çolak 1997, Lipp and Nilsen 1997). Aspect was the most significant environmental factor governing the distribution of rhododendron basal area on both the Yayla and Devrek sites (Tables 2 and 4). Rhododendron abundance significantly increased as one approached the NE aspect, where available moisture was most abundant, agreeing with the findings of previous studies on this woody species (Tables 2 and 4).

Rhododendron abundance also decreased as solar irradiance increased in the present study (Table 4). The negative solar irradiance effects on rhododendron were attributed to accelerated disintegration of leaf chlorophyll and leaf abscission and reduced photosynthesis (Nilsen and Bao 1987, Lipscomb and Nilsen 1990). Greater transpirational demand under high solar irradiance and temperatures may also increase embolism, impeding the flow of water in the xylem (Lipscomb and Nilsen 1990). Xylem embolism is a common physiological phenomenon, especially for broadleaf plant species with small-diameter vessels such as rhododendron (Lipscomb and Nilsen 1990).

The significant positive relationship between percent sand content in the B horizon and rhododendron basal area indicated that although moisture was an essential factor for rhododendron, adequate aeration was also required (Table 2). Increasing rhododendron basal area with increasing slope in Devrek (correlation: 0.33) may also substantiate this premise, although slope was not a significant topographic variable selected by regression analysis. Greater stone presence in soils with greater slopes probably enhanced drainage in these soils.

Thomson et al. (1993) previously reported a similar yet significant relationship between slope and this rhododendron species in the UK.

Significant negative effects of percent sand content in the soil on beech basal area in Yayla, as well as the significant decrease in mean diameter growth rate of beech with degree distance from the NE aspect in Devrek, indicated that moisture was a more critical factor for beech than for rhododendron (Tables 3 and 4). The negative effect of slope and positive influence of total soil depth on mean diameter growth rate of beech also suggested similar trends in this respect (Table 3).

Kirwan (1999) reported that American beech was almost absent on the well-drained sandy soils of the Delmarva Peninsula of the southeastern coastal plain of the U.S. He explained this with a fire-protection strategy for beech rather than a requirement for soil moisture. He found a significant negative correlation between soil charcoal density and beech abundance. A negative trend ($r = -0.20$) between soil charcoal density and beech basal area for the Devrek site may parallel Kirwan's findings. These results indicate that a requirement for moisture and fire protection might play roles in conjunction for eastern beech.

The scarcity of beech seedlings on both sites illustrated the negative effects of rhododendron on beech regeneration. The greater beech regeneration in Yayla may be explained by anthropogenic disturbances that locally eliminated rhododendron competition (Table 1). The significant negative relationship between mean diameter growth of beech and rhododendron basal area at Yayla and Devrek suggested that abundance of rhododendron not only almost precluded beech regeneration on these sites, but also reduced the growth of mature beech trees in the overstory substantially.

Conclusion

The current beech overstories in the BSR were established prior to the establishment of rhododendron, which can grow as old as 100 years. The lack of correlation of charcoal density in soil samples with vegetation and original beech establishment suggested that fire might not be the major regenerative disturbance for these sites, at least in the past 100-200 years. However, soil charcoal density, accounts of elderly villagers, and records from the Ottoman archives on past vegetation and disturbances indicated that fire had probably been

an influential component of these forests in the long term. Anthropogenic disturbance was the most probable regenerative disturbance, and shaped forest structure in these sites at varying degrees. Selective logging of pine from once mixed pine-hardwood forests has resulted in pure beech forests in this region. Rhododendron obviously prevented tree regeneration and has affected the long-term growth of beech. The structure of rhododendron populations in these sites suggested that this woody species will most likely continue to dominate these sites in near future. Both indirect topographic and direct measurements on moisture availability on these sites indicated that soil moisture was the most important environmental factor shaping rhododendron and beech abundance and growth. Adequate soil aeration may also be critical for rhododendron.

CHAPTER 3: CONTROL OF RHODODENDRON INVADING THE EASTERN BEECH ECOSYSTEM IN THE BLACK SEA REGION OF TURKEY

Abstract

Rhododendron ponticum L. and *R. flavum* Don. are dominant in the understories of the eastern beech forests of the eastern and western Black Sea Region, respectively. Tree growth and regeneration are largely reduced, if not precluded, by rhododendron. The continuity of the region's forests is thus seriously endangered, and effective woody control techniques are being sought.

Various manual and herbicidal woody control techniques were employed using permanent plots in two different beech sites with *R. ponticum* and *R. flavum* during the summer of 1997. Garlon[®] 4 and Arsenal[®] 250 SL herbicides were used at two rates for foliar spraying, whereas Garlon 3A and Pathfinder II were employed for herbicidal cut-stump applications. Three-year-old beech seedlings were planted in the *R. ponticum* site during the 1998 winter. Treatments were assessed for rhododendron control efficacy, tree seedling growth response, and cost efficiency 2 years after treatment (YAT).

Overall, rhododendron control and cost efficiency were significantly greater with herbicides than with the manual treatment. Seedling growth increased dramatically when rhododendron was controlled, regardless of technique used. Foliar herbicidal technique provided excellent rhododendron control and cost efficiency. Foliar-applied Arsenal SL controlled rhododendron significantly more than Garlon 4. Grubbing also provided good rhododendron control and cost efficiency, yet showed great potential of sprout crown production. Cut-stump herbicidal spray was intermediate in its efficacy technique. Cutting had the least rhododendron control and cost efficiency among all of the treatments. Increasing the rate of herbicides did not generally enhance efficacy. Therefore, the use of low rates of Arsenal SL and Garlon 4 is recommended for effective, long-term, and cost-efficient rhododendron control. Reducing rates further may provide the same level of control at less cost.

Introduction

The negative effects of woody weeds on tree regeneration and growth, and the persistence of these effects throughout the rotation, have been well documented (Bacon and Zedaker 1987, Miller et al. 1991, Liu and Burkhart 1994). *Rhododendron* has long been considered a decorative woody shrub species and hence has been planted for aesthetic reasons (Tabbush and Williamson 1987, Gritten 1995). This shrub is now, however, blamed for significant forest vegetation management problems throughout the world, including the eastern U.S. (Philips and Murdy 1985, Baker 1994, Clinton and Vose 1996), Canada (Coats et al. 1991), the UK and Ireland (Robinson 1980, Cross 1975, Cross 1981, Tabbush and Williamson 1987, Clay et al. 1992, Lawrie and Clay 1993; Gritten 1995), and the Black Sea Region (BSR) of Turkey (Saatçioğlu 1957, Atalay 1992, Varol 1970, Suner 1978, Eyüboğlu and Karadeniz 1987, Çolak 1997).

Rhododendron ponticum L. and *R. flavum* Don. are two dominant shrub species of the eastern beech understories in the eastern and western BSR, respectively. Growth of beech seedlings is significantly reduced, if tree regeneration is not precluded entirely, by this invasive woody species. The ecological consequence is an aging beech overstory with little or no regeneration to replace the mature trees. The region's future forest resources are therefore under serious threat from rhododendron (Saatçioğlu 1958, Varol 1970, Suner 1978, Eyüboğlu and Karadeniz 1987, Atalay 1992, Çolak 1997). Local floristic diversity in rhododendron-invaded sites is likely to be extirpated in the near future (Robinson 1980, Eyüboğlu and Karadeniz 1987). Immediate, effective woody weed control is therefore warranted to sustain beech forests in the region and to help restore the region's plant diversity. Information gained on effective control of these BSR rhododendron species will likely benefit foresters in other parts of the world where this shrub is already or is becoming a serious forest vegetation problem.

Many manual and mechanical woody control techniques are costly and ineffective against rhododendron (Saatçioğlu 1957, Varol 1970, Suner 1978, Robinson 1980, Eyüboğlu and Karadeniz 1987, Palmer et al. 1988, Çolak 1997). Foliar herbicidal woody control is a common and effective alternative woody control technique that can substantially improve tree regeneration and subsequent seedling growth, although many foliar-applied herbicides have been used against rhododendron with results that have not been promising (Varol 1970,

Neary et al. 1980, Lawrie and Clay 1993). For example, 10% of rhododendron area sprayed with 4% (v:v) 2,4,5-T in diesel oil was reinvaded by the shrub 1 YAT. A formulation of 2-4% (v:v) 2,4-D could not desiccate above-ground rhododendron taller than 50 cm (Varol 1970). Due to the hydrophobic nature of the waxy epicuticular layer on the adaxial leaf surfaces, insufficient herbicide uptake and translocation within rhododendron has been reported to be a major cause of ineffective control (Holloway 1970, Kitchen et al. 1980, Tabbush et al. 1986, Gritten 1995). Foliar-applied imazapyr and triclopyr have demonstrated great success for the long-term suppression of *R. ponticum* in the UK (Tabbush et al. 1986, Clay et al. 1992, Lawrie and Clay 1993). However, these studies were mostly conducted on pot-grown plants with very limited field applications. The field applications were also made on only relatively short (≥ 1 m) and sparsely populated (clumps 2 m apart) rhododendrons. Therefore, no data are available on the effects of these herbicides on the natural stands of *R. ponticum* in the BSR, where the shrub had grown to great heights (≥ 2 m and in some cases up to 5 m), groundline diameters (≥ 9 cm), and densities (48,000 plants/ha), and subsequent growth of tree seedlings. Furthermore, to date no data are available on the effects of herbicides on *R. flavum*, the common rhododendron species of the western BSR.

Cut-stump herbicide spray is another common form of herbicidal woody control that has been successfully used to manage hardwood stands in the southeastern U.S. against many prominent woody weeds (Zedaker 1986 and 1988, Zedaker et al. 1987). Environmental safety and cost efficiency due to low chemical volume discharge often make cut-stump applications preferable to other herbicidal woody control methods (Zedaker 1988). This technique has demonstrated some success for rhododendron control in the UK (Tabbush and Williamson 1987, Palmer et al. 1988). However, to date, no efficacy or cost-efficiency data are available for this technique on rhododendron growing in the BSR.

The objectives of the present study are to assess the effects of various manual and herbicidal woody control techniques on *R. ponticum* and *R. flavum* in the eastern and western Black Sea Region of Turkey, respectively, to develop an efficacious, long-term and cost-efficient woody control prescription.

Methodology

Site Selection

Two different sites were selected for this study, one in the eastern and the other in the western BSR of Turkey. The western Black Sea Region (WBSR) site is within the jurisdictional boundaries of the Sökü Forest Management Chiefship, 40 km south of Bartın City. The chiefship is also jurisdictionally part of the Bartın Forest Management Directorate. The eastern Black Sea Region (EBSR) site is within the jurisdictional boundaries of the Üçyol Forest Management Chiefship of the Akkus Forest Management Directorate. This site sits on the climatic and floristic boundary between the middle and eastern BSR (Seçkin 1999, pers. comm.).

Experimental plots were selected from mature eastern beech stands that had continuous rhododendron understories. All plots in the two sites had northerly aspects with azimuths ranging between 310-360 and 0-045°. The primary rhododendron species of the WBSR and EBSR were purple-flowered (*R. ponticum* L.) and yellow-flowered (*R. flavum* Don.), rhododendron, respectively.

The soil textures of the A and B horizons are loam and clay loam, respectively, for the WBSR site (Zonguldak Forest Service Soil Laboratory 1997). Soil pH for the A horizon is between 5.1 and 6.8 (moderately acid to slightly acid) (Hausenbuiller 1978). Organic matter content for this soil horizon ranges between 7.7% and 14.6%. Soil pH for the B horizon ranges between 5.5 and 6.9, and organic matter content of this horizon is between 1.0% and 2.9% (Zonguldak Forest Service Laboratory 1997). According to USDA soil taxonomy, these soils would be classified as lithic hapludalfs (Soil Survey Staff 1992). The general soil texture for the EBSR site was sandy loam (Duran 2000, pers. comm.)

Experimental Treatments

Two manual and two herbicidal rhododendron control techniques were used for this experiment (Table 6). The manual woody control treatments were hand-cutting and hand-grubbing for *R. ponticum*, but only hand-cutting for *R. flavum* on the EBSR site. For hand-cutting, individual rhododendron stems were cut approximately 10 cm above ground during the 1997 summer. For grubbing, stems were hand-uprooted from the uphill direction. The herbicidal woody control treatments were foliar and cut-stump spray of triclopyr and

imazapyr herbicides for both rhododendron species. For the foliar applications, triclopyr as Garlon[®] 4 - ([3,5,6- trichloro-2-pyridinyl)oxy]acetic acid), butoxyethylester, 500 g a.e./l, was applied at 2.5 and 5% (v:v) rates in water carrier. A 2.5% solution (v:v) X-77[®] -- a nonionic standard surfactant – was added to both the low- and high-rate Garlon 4 formulations. Arsenal[®] 250 SL, an isopropylamine salt of imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid) (250 g a.e./l) in water carrier was also used at the 5 and 10% rates for foliar application. A solution of 0.25% (v:v) X-77 was added to the Arsenal formulations.

Table 6. Manual and herbicidal woody control treatments applied on *R. ponticum* and *R. flavum* in the western and eastern Black Sea Region, respectively, with associated usage rates.

Treatment	Herbicide	Rate (kg ae/ha)
<i>Rhododendron ponticum:</i>		
Foliar	Garlon 4	5.1
	Garlon 4	2.6
	Arsenal	5.8
	Arsenal	3.0
Cut-stump	Garlon 3	9.8
	Garlon 3	5.4
	Pathfinder II	2.5
	Pathfinder II	1.3
Hand-cutting	-	-
Hand-grubbing	-	-
Check	-	-
<i>Rhododendron flavum:</i>		
Foliar	Garlon 4	5.1
	Garlon 4	2.3
	Arsenal	5.8
	Arsenal	3.0
Cut-wait-spray	Garlon 4	*
	Garlon 4	*
Hand-cutting	-	-
Check	-	-

* No herbicide usage data was available.

An 18-liter SP1[®] polyethylene plastic knapsack sprayer (Chemical Containers, Inc., Florida, USA) was used to spray foliar herbicides. Depending upon the height of the rhododendron canopy that was sprayed, a 1- or 2-m spray wand (B & G Spraying System[®], Co., Pennsylvania, USA) carrying a 5500 adjustable conejet nozzle was used for foliar applications.

For the cut-stump treatment, pre-trained teams containing two cutters and one sprayer first hand-cut rhododendron stems approximately 10 cm above the ground and immediately sprayed premixed formulations onto the cut surfaces using 700-ml regular garden sprayers. A 375 g ae l⁻¹ Garlon[®] 3A, an amine triclopyr formulation, ([3,5,6-trichloro-2-pyridinyl)oxy]acetic acid), triethyl amine salt, and 94 g ae l⁻¹ Pathfinder[®] II, ([3,5,6-trichloro-2-pyridinyl)oxy]acetic acid), butoxyethylester, a ready-to-use formulation, were used with undiluted and 1:1 (v:v) water-diluted rates. For *R. flavum*, no cut-stump spray or grubbing was carried out due to the smaller woody diameters. A cut-wait-spray treatment – a synthesis between cut-stump and foliar spray – including 2.5 and 5% (v:v) Garlon 4 mixed with 1% (v:v) X-77 surfactant replaced the cut-stump treatment for this rhododendron species. For this treatment, stems were cut similarly to the cut-stump treatments during the 1997 summer and allowed to sprout. Emerging sprouts were foliar-sprayed in the late summer of 1998 using the knapsack sprayers and the same technique used for the foliar applications.

Experimental Design

A randomized complete block design with five blocks (replications) was used for the *R. ponticum* site, whereas a randomized incomplete block design with four blocks was employed for the *R. flavum* site. Treatments were randomly assigned to 32 x 32-m experimental plots in each block (Figure 6). Each square plot was further divided into six identical 4 m-wide treatment bands, which were buffered by two 6-m bands in both ends. Treatments were applied only in the three interior 4-m bands (treatment bands), which were separated by two 4-m bands (buffer bands). The buffer bands served to reduce the risk of soil erosion, a problem in the BSR on intermediate to steep slopes (Çolak 1997).

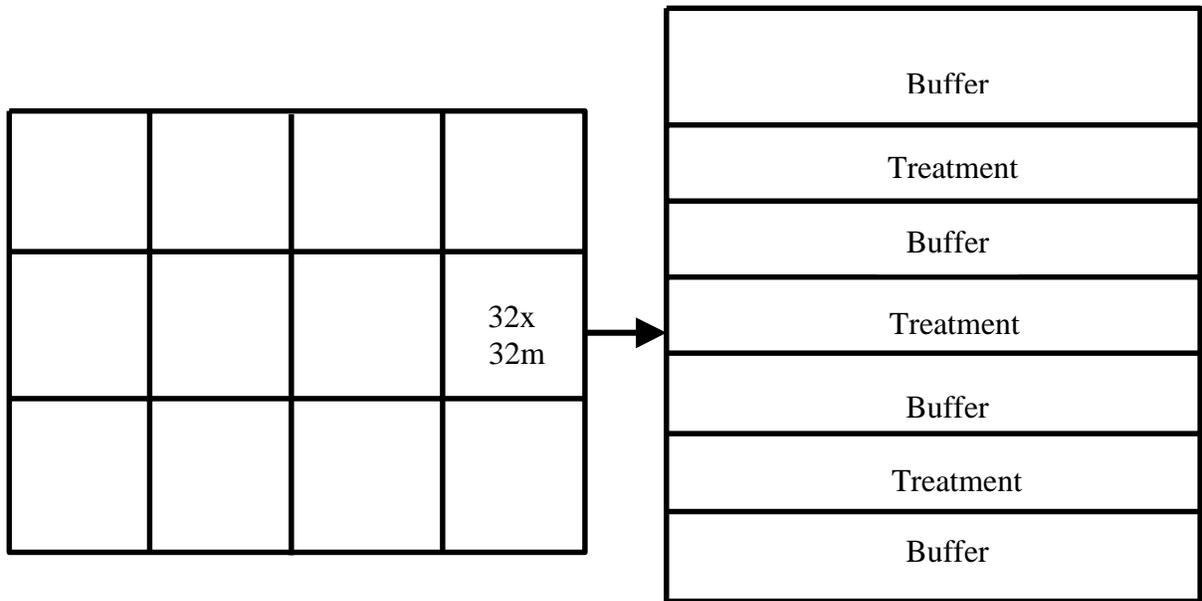


Figure 6. Scheme of randomized complete block design with permanent 32 x 32-m plots (left) and a detailed sectioning of the experimental plot block (right) used in Sökü and Akkuş sites in the Black Sea Region of Turkey.

Efficacy Assessment

Treatment effects were assessed in 1 x 10-m permanent subsampling plots randomly installed in each of the treatment bands for both rhododendron species during the summer of 1999. Groundline diameters (gld) of the treated stems were recorded to the nearest 0.1 mm in these 10-m² subsampling plots. From these data, percent reduction in stump basal area (SBA) per treatment band was calculated as follows:

$$\frac{(\text{Total live stump basal area} - \text{total dead stump basal area})}{\text{Total live stump basal area}}$$

For cost-efficiency analysis, total labor hours and chemical consumption (if any) of each treatment were recorded. Cost-efficiency of a given treatment per treatment band was calculated as follows:

$$\frac{\text{Cost of chemical (herbicide and surfactant, if any used) + labor cost}}{\text{Percent reduction in SBA}}$$

The 1999 labor rate of the Turkish Forest Service for vegetation control was approximately \$8 per 12-hr workday, and this rate was used for the labor part of the cost-efficiency calculations.

Tree Growth Response Assessment

Three-year-old eastern beech seedlings grown in regional nurseries were planted within the treatment bands 1.5 m apart in the WBSR site in the winter of 1998. Groundline diameter was recorded for each beech seedling to the nearest 0.1 mm using tree calipers. Height to live terminal bud was also measured on these seedlings to the nearest mm. Seedling mortality was very common under dense rhododendron coverage in the check plots, clearly due to intense woody competition. Zero gld and height were recorded for this competition-induced mortality. No beech seedlings were planted for the EBSR site.

Statistical Analysis

Due to the partial factorial structure of the design of the experiment used in this study, a series of orthogonal contrasts was used to determine significance of treatment effects on rhododendron SBA reduction. Effects of herbicide and rate were separately analyzed for foliar and cut-stump treatments using two-way analysis of variance. Tukey's least square means (LSM) were utilized to separate treatment means.

Results

Herbicidal woody control was significantly more effective than manual and no woody control in reducing the SBA of rhododendron 2 YAT: mean percent *R. ponticum* stump basal area (SBA) reduction was 32% greater with herbicides than with manual woody control treatments (Table 7). Herbicides also reduced SBA of *R. flavum* in the eastern BSR significantly more than the manual control treatment. Percent reduction in SBA was also substantially greater with manual woody control, compared with no woody control for both rhododendron species (Table 7). There was abundant rhododendron regrowth observed after the cutting treatment.

Mean beech seedling gld and height growth was significantly greater when *R. ponticum* was controlled than when it was not controlled at all. No large beech seedling growth

differences were found between woody control by herbicides and manual treatments (Table 7).

Foliar spraying was slightly more efficacious than grubbing in reducing BA of *R. ponticum* (Table 7). Mean percent woody SBA reduction was significantly greater with foliar spray or grubbing than with cut-stump and cutting. The cut-stump spray technique also reduced rhododendron SBA substantially more than cutting alone, which was the least successful woody control technique. Differences among foliar, cut-stump, grubbing, and cutting woody control techniques in beech seedling gld and height growth were small.

Table 7. Effects of manual (MWC), herbicidal (HWC), and no woody control (NWC) treatments with various application techniques on mean percent reduction in basal area of *R. ponticum* and *R. flavum* 2 YAT and on mean groundline diameter (gld) and height growth of four-year-old eastern beech seedlings in the *R. ponticum* site 1 YAT.

Treatment	Basal Area Reduction		Seedling Growth	
	<i>R. ponticum</i>	<i>R. flavum</i>	gld	Height
	-----%-----		mm	cm
HWC ¹	68.0 a ³	79.6 a	5.5 a	27.8 a
MWC ²	51.6 b	17.6 b	5.5 a	27.2 a
NWC	0.0 c	0.0 c	1.4 b	5.8 b
Foliar HWC	86.8 a	83.8 a	5.1 b	25.1 a
Grub MWC ⁴	85.9 a	-	5.6 ab	26.2 a
Cut-stump HWC ⁵	45.6 b	71.5 b	5.8 a	28.1 a
Cut MWC	17.4 c	17.6 c	5.5 ab	28.0 a
NWC	0.0 d	0.0 d	1.4 c	5.3 b

¹ Woody control differences were significant as a result of orthogonal contrast analysis, separately ($p < 0.05$).

² This treatment had only cutting for *R. flavum*.

³ Letters alongside numbers in the table are valid within a cell only. Treatments within the same cell with different letters are significantly different ($p < 0.05$).

⁴ No grubbing was carried out for *R. flavum*.

⁵ This treatment was cut-wait-spray for *R. flavum*.

Foliar spraying was also the most effective woody control technique for *R. flavum* (Table 7). Mean percent rhododendron SBA reduction was significantly greater (17%) with this technique than the cut-wait-spray technique. Cut-wait-spray still had substantially greater SBA control than did cutting alone. Mean percent SBA reduction by cutting was

significant when compared to that of no woody control at all for both *R. ponticum* and *R. flavum*.

Garlon 4 and Arsenal demonstrated different phytotoxicity patterns on rhododendron foliage. Garlon 4 acted very fast, with distinctive chlorosis on foliage occurring as early as 20 DAT. The majority of woody foliage sprayed with this herbicide was already defoliated 1 YAT. Defoliation occurred largely at the high rate rather than the low rate. Stems, however, began to sprout 1 YAT. Sprouts were consistently more abundant on the lower stems, tending to lessen toward the upper stem parts.

Arsenal-sprayed woody foliage did not show distinct defoliation within 1 YAT. However, bud damage, especially on apical buds, was apparent. Initially, chlorotic foliage turned reddish before brownout 2 YAT. Arsenal-sprayed stems demonstrated less sprouting than Garlon 4-sprayed stems both 1 and 2 YAT.

In terms of woody control, Arsenal reduced the mean SBA of *R. ponticum* and *R. flavum* significantly greater (15 and 38%, respectively) than Garlon 4. No significant rate or herbicide x rate interaction effects were found for foliar applications (Table 8).

Table 8. Effects of foliar Garlon 4, Arsenal SL, and different rates on mean percent basal area reduction of *R. ponticum* and *R. flavum* 2 YAT.

Treatment	Basal Area Reduced (%)	
	<i>R. ponticum</i> ¹	<i>R. flavum</i> ¹
Arsenal SL	93.6 a ²	97.7 a
Garlon 4	81.4 b	71.0 b
High rate	90.8 a	86.6 a
Low rate	84.2 a	82.0 a

¹ Herbicide main effect was significant ($p < 0.05$) with non-significant rate main and herbicide x rate interaction effects ($p > 0.05$).

² Letters alongside numbers in the table are valid within a cell only. Treatments within the same cell with different letters are significantly different ($p < 0.05$).

Garlon 3A in cut-stump treatments reduced mean percent SBA of *R. ponticum* more significantly (35%) than Pathfinder II (Table 9). Rates did not make large differences in herbicide efficacy for SBA. No significant interaction was found between the herbicide and rate main effects.

Table 9. Effects of Garlon 3A, Pathfinder II, and different rates of herbicidal cut-stump treatments on basal area of *R. ponticum*.

Treatment¹	Basal Area Reduction (%)
Garlon 3A	51.6 a ²
Pathfinder II	38.3 b
High-rate	45.5 a
Low-rate	44.0 a

¹ Herbicide main effect was significant ($p < 0.05$) with non-significant rate main and herbicide x rate interaction effects ($p > 0.05$).

² Letters alongside numbers in the table are valid within a cell only. Treatments within the same cell with different letters are significantly different ($p < 0.05$).

In terms of cost efficiency, controlling 1% woody SBA with the foliar spray technique cost 10 times less than the cut-stump spray technique (Table 10). The cut-stump technique's cost efficiency was approximately two times greater than that of cutting only. Cutting and grubbing were placed on the polar ends of the cost-efficiency spectrum. Achieving 1% control of woody SBA was substantially more costly (almost 30-fold) with cutting than with grubbing. Grubbing was, on average, also slightly more cost-efficient than foliar herbicidal control.

Foliar-applied Garlon 4 treatments were the most cost-efficient of all treatments (Table 10). The low-rate Garlon 4 treatment controlled 1% rhododendron SBA at less cost than grubbing. Although Arsenal was on average less cost-efficient than Garlon 4, its cost efficiency was in the same neighborhood with that of the Garlon 4 treatments when applied at the low rate.

Foliar treatments were even more cost-efficient in *R. flavum* than in *R. ponticum* (Table 10). The foliar-applied, low-rate Garlon 4 returned the greatest cost efficiency for this rhododendron species. Differences between the two foliar herbicides in cost efficiency were less for *R. flavum* than for *R. ponticum*.

Table 10. Cost efficiencies of manual and herbicidal treatments used to control *R. ponticum* and *R. flavum* in WBSR and EBSR sites, respectively.

Treatment ¹	Technique	Herbicide	Rate	Cost Efficiency (\$/%)	
				<i>R. ponticum</i>	<i>R. flavum</i>
Manual	Cutting	---	---	156.67	---
	Grubbing	---	---	5.98	---
Herbicidal	Cut-stump spray	Pathfinder II	Low	82.12	---
		Pathfinder II	High	78.93	---
		Garlon 3A	Low	49.63	---
		Garlon 3A	High	37.40	---
	Foliar spray	Arsenal SL	High	12.52	7.50
		Arsenal SL	Low	7.62	4.14
		Garlon 4	High	6.39	4.94
		Garlon 4	Low	5.20	3.05

¹ Unit costs of Arsenal SL, Garlon 4, Garlon 3A, Pathfinder II, and X-77 products were \$30, \$28.50, \$22.20, \$9.25, and \$6.34 per liter, respectively. Sources: Forestry Suppliers, Inc., USA, for Garlon 4, Garlon 3A, and Pathfinder II; TurkCyanamid, Turkey for Arsenal SL; Geiger, Inc., USA, for X-77.

Discussion

Manual control was ineffective in reducing rhododendron SBA when compared to herbicidal control, as has been reported before by numerous researchers (Saatçioğlu 1957, Varol 1970, Suner 1978, Robinson 1980, Eyüboğlu and Karadeniz 1987, Palmer et al. 1988, Çolak 1997). Manual control by cutting was also substantially more expensive than herbicidal control (Table 10). Abundant rhododendron regrowth observed after manual control suggested that herbicidal woody control would probably be even more undesirable for cost efficiency as time progresses. The recently declining quantity and quality of labor for this type of forestry operation in some areas of the BSR is another significant limitation of manual control (Çetintaş 2000, pers. comm.).

The great disparity between manual cutting and grubbing in both woody control efficacy and cost efficiency may be explained by characteristics of the root system of rhododendron and the degree of root damage conferred from these two techniques. Rhododendron generally grows roots in the first 27-30 cm of the soil column and hardly penetrates past the 45-cm depth (Çolak 1997). As a significant part of the root system, fine roots are mainly distributed in the litter, humus, and subsurface layers of soil. Growth of the root system is in one direction, most frequently uphill (Çolak 1997). Pulling stems from the

uphill direction, therefore, does not require a great effort. Hand-cutting stems in a dense rhododendron stand with sharp cutting tools was, on the other hand, operationally more difficult, time-consuming, and risky. In fact, there were a few cases during hand-cutting of *R. ponticum* in which workers were injured.

Grubbing removed the whole stem along with a significant part of the roots. This naturally reduced rhododendron SBA significantly greater than did cutting (Table 4). However, grubbing was difficult if not impossible for stems with gld values greater than 5 cm. Çetintaş (2000, pers. comm.) also confirmed this and stated that this gld cutting replaced grubbing in manual control of rhododendron in the boundaries of Zonguldak Regional Forestry Directory. Moreover, the great reproductive potential of root and stem parts left in the soil after grubbing may minimize long-term woody control. The sparsely distributed crowns after grubbing may not initially pose a significant threat for planted or naturally seeded tree seedlings. Fast-growing rhododendron crowns may, however, catch up with seedlings in the near future, probably reducing seedling growth. In addition, predation of fallen seed on the forest floor by forest fauna (e.g., mice) is an important factor for tree regeneration that may cause unsuccessful natural regeneration (Smith et al. 1997). Removing rhododendrons from the treatment bands by grubbing and other treatments involves cutting and piling the woody debris in the next buffer band. This may provide improved habitat for rodents and is a significant threat to planted and naturally seeded tree seedlings.

The great sprout production observed after cutting in the present study suggests that rhododendron populations will become dense again in the near future. As has been found by Varol (1970), 75% of the cut rhododendron sites in his study had reverted to rhododendron with added blackberry (*Rubus fruticosus* L.) invasion after five years (Varol 1970). A surge of blackberry invasion was seen in the cut and grubbed rhododendron plots in the present study as well. Çolak (1997) reported that dense herbaceous weeds could significantly reduce rhododendron establishment in the BSR. The lack of rhododendron encroachment in blackberry-dominated sites in the present study confirmed this. Forest managers can therefore capitalize on this competitive interaction and time unwanted vegetation control carefully for optimum and cost-efficient vegetation control. For example, herbaceous weed control might be delayed for regeneration areas that are potentially under threat by

rhododendron invasion, and both herbaceous and woody weed control might be carried out accordingly.

The incomplete rhododendron control and relatively greater cost of the cut-stump treatment probably stemmed from two factors: diameter distribution and density of rhododendron stands. The cut-stump technique is the most effective and cost-efficient woody control technique when woody glds and dbhs are greater than 30 cm (Zedaker 1986). The glds of rhododendrons in the Black Sea Region were far below this; mean glds were 1.4 and 1.5 cm for *R. flavum* and *R. ponticum*, respectively. The maximum gld did not exceed 9 cm for either of these rhododendron species. In addition, rhododendron densities, which exceeded 48,000 and 91,000 stems/ha for *R. ponticum* and *R. flavum*, respectively, resulted in great chemical consumption. Spraying the cambium of the cross-sectional area of such small cut stems with squirt bottles was rather difficult and resulted in great waste. These multiple factors probably make this application technique financially unattractive.

The foliar spray technique is the most attractive woody control technique from both efficacy and economic standpoints when woody weed densities exceed 8,000 stems/ha (Zedaker 1986). An efficacious herbicide application requires first placement of herbicide in effective amounts to point of entry on a targeted plant. The foliar technique most effectively fulfilled this requirement among all of the techniques used for this experiment and demonstrated great success for rhododendron control. This technique was also time-efficient and operationally easy. Only one person was needed for the most part to carry out foliar sprays. Use of a 2-meter wand with backpack sprayer was particularly useful for reaching tall rhododendron stems. One difficulty with foliar spray was limited mobility with the knapsack spray equipment in very tall and dense stands. Opening a walking path in these stands usually overcame this difficulty, yet at a greater operational cost. Grubbing was also favorable from both control efficacy and economic standpoints. The great reproductive potential that grubbed rhododendrons had demonstrated, however, suggested that grubbing would probably be outcompeted by foliar spraying in the long term.

The greater success of foliar spray in *R. flavum* than in *R. ponticum* might be explained by structural differences between stands of the two species. Heights of *R. ponticum* generally exceeded 2 m in the WBSR and in some cases reached up to 4-5 m. Foliar coverage was more difficult, resulting in greater chemical volume usage and application time, compared

with easier and time-efficient applications of *R. flavum* growing in relatively short stand heights (i.e., 1-1.5 m). Moreover, morphological differences in foliage probably contributed to the disparity in control efficacy and cost efficiency between these two woody species. *R. ponticum* has considerably glossy waxy adaxial foliage surfaces (Holloway 1970). The waxy epicuticular layer on the adaxial leaf surfaces confers significant hydrophobicity to the foliage of this rhododendron species and therefore presents a major barrier for herbicide uptake and translocation (Holloway 1970, Kitchen et al. 1980, Tabbush et al. 1986, Gritten 1995). On the other hand, *R. flavum* foliage had a non-waxy and hairy foliage appearance on the adaxial foliage surfaces with frequent venetation (pers. obs). Venetation and hairness are two morphological features on plant foliage that improve foliar wettability and efficacy of herbicides, along with absence of waxy leaf cuticle (Holloway 1970, Ross and Nembu 1985).

Substantially greater woody SBA control and sprout suppression with foliar-applied imazapyr, compared with foliar triclopyr ester in *R. ponticum* and *R. flavum*, confirmed the results of the previous studies in which these herbicides had been used (Clay et al. 1992, Lawrie and Clay 1993). For example, Clay et al. (1992) found that foliar application of imazapyr resulted in threefold greater regrowth suppression in *R. ponticum* in the UK 4 YAT than application of triclopyr ester. Enhanced long-term woody control by imazapyr, compared with triclopyr ester, in the present study was ascribed to the significantly greater mobility of imazapyr within rhododendron.

Conclusion

Significantly reduced survival and growth of beech seedlings indicate the necessity of rhododendron control for regenerating eastern beech forests. Foliar herbicidal techniques provide excellent woody control and cost efficiency. Specifically, the use of low rates of Arsenal SL and Garlon 4 is recommended for effective, long-term, and cost-efficient rhododendron control. Reducing rates further may provide the same level of woody control at less cost.

CHAPTER 4: HERBICIDE FOLIAR UPTAKE AND TRANSLOCATION IN GREAT RHODODENDRON

Abstract

Great rhododendron has become an abundant woody weed in the understories of eastern U.S. forests. It precludes tree regeneration and reduces tree growth significantly. Herbicides can be effective against this shrub. However, the waxy leaf cuticle may be a major obstacle to herbicide uptake and root translocation. Previous herbicide research in the UK has shown that triclopyr ester and imazapyr provided effective control on a Eurasian rhododendron species, *R. ponticum* L. Research on additives in many herbaceous and woody plant species have demonstrated that vegetable oil, organosilicone, and nonionic surfactants could circumvent the cuticle obstacle, enhancing efficacy by increasing herbicide uptake. This research was designed to measure uptake and describe translocation patterns of triclopyr ester and imazapyr in great rhododendron, and to determine the herbicide-surfactant combinations with the greatest active ingredient uptake and root translocation. Effects of the low- and high-rates of a conventional nonionic surfactant (Mixture B[®]), an organosilicone (Silwet 408[®]), and a methylated sunflower seed oil (Sun-It II[®]) on the uptake and translocation of the low- and high-rates of radiolabeled triclopyr ester (Garlon 4[®]) and imazapyr (Chopper[®]) were investigated in 15-month old great rhododendron.

Lipophilic triclopyr ester had significantly greater leaf uptake than imazapyr, yet lower translocation of the leaf-absorbed activity to roots of rhododendron. Surfactants had no significant effect on triclopyr ester rainfastness and translocation out of the treated leaf. Although imazapyr had generally poor rainfastness, its cuticular diffusion, foliar uptake, and root translocation were enhanced significantly by the addition of Sun-It II and Mixture B. Herbicide rate and surfactants did not influence translocation. Combinations of low-rate imazapyr with low-rate Sun-It II or Mixture B are recommended for use against great rhododendron.

Introduction

Rhododendron is a ubiquitous ornamental plant in many gardens throughout the world (Tabbush et al. 1987, Gritten 1995). However, this shrub has recently come under scrutiny worldwide for creating serious forest management problems. Many studies report limited regeneration, reduced tree growth, and excessive site preparation expenses for forested sites invaded by purple-flowered rhododendron in the UK (Cross 1975, Robinson 1980, Cross 1981, Tabbush et al. 1987, Clay et al. 1992) and in northern Turkey (Saatçioğlu 1957, Varol 1970, Suner 1978, Eyüboğlu and Karadeniz 1987, Atalay 1992, Çolak 1997), and by white-flowered rhododendron (*R. albiflorum* Hook.) in Canada (Coats et al. 1991). This invasive shrub has also been blamed for significant reductions in local plant diversity in its domain (Robinson 1980, Eyüboğlu and Karadeniz 1987).

Great rhododendron (*Rhododendron maximum* L.) is one of the most common woody understory species in eastern U.S. forests, with a wide range extending from Georgia to Canada (Lipp and Nielsen 1997). Regeneration and seedling growth of many important tree species such as oak, hickory, yellow-poplar, pine, and birch are often significantly reduced by rhododendron throughout its range (Philips and Murdy 1985, Clinton et al. 1994, Clinton and Vose 1996). Hardwood regeneration in North Carolina forests, for example, was reduced by 49% between the mid-1930s and late 1960s due to rhododendron encroachment (Philips and Murdy 1985).

Upon establishment, populations of this woody species can increase exponentially in as little as 15 years, and it becomes very difficult and expensive to control (Shaw 1984, Tabbush and Williamson 1987, Gritten 1995). The distribution of rhododendron in the Southern Appalachians, which was estimated as 2.5 million hectares during the mid-1980's, has been rapidly increasing (Dobbs 1995, Hedman and Van Lear 1995, Monk et al. 1995). Expanding rhododendron distribution has been predicted to cause major compositional and structural changes in "late-successional and old-growth riparian forests" of the Southern Appalachians in the early 21st century (Baker 1994, Hedman and Van Lear 1995). Since this aggressive woody competitor becomes very difficult and expensive to control, immediate attention is warranted to seek effective control methods.

Herbicidal weed control is a common and effective site preparation technique in forest management to increase crop growth (Bacon and Zedaker 1987). However, rhododendron is

difficult to control with many herbicides (Lawrie and Clay 1993). Imazapyr and triclopyr have demonstrated promising results for the long-term suppression of purple-flowered rhododendron, a Eurasian relative of great rhododendron, in the UK (Tabbush et al. 1986, Clay et al. 1992, Lawrie and Clay 1993). However, data are lacking on the effects of these herbicides on great rhododendron.

The hydrophobic nature of the waxy epicuticular layer on the leaf surfaces significantly precludes herbicide penetration into the leaf interior of rhododendron (Holloway 1970, Kitchen et al. 1980, Tabbush et al. 1987, Gritten 1995). However, with their low surface tension, lipophilicity, and non-ionic character, organosilicone surfactants can substantially improve wetting, spreading, and foliar uptake of herbicide sprays by enhancing leaf adhesion and retention of many weed species (Goddard and Padmanabhan 1992, Stevens 1993, Zedaker et al. 1994, Bollig et al. 1995, Jackson et al. 1998). Silwet L-77 enhanced leaf absorption of imazapyr on red maple and sweetgum when compared to leaf absorption of imazapyr alone (Zedaker et al. 1996). This organosilicone has also enhanced efficacy of imazapyr on purple-flowered rhododendron in the UK (Clay et al. 1992). Mixture B, a non-ionic surfactant consisting of oil-soluble and water-soluble groups, has enhanced the efficacy of triclopyr ester and imazapyr in purple-flowered rhododendron (Clipsham 1984, Tabbush et al. 1986, Lawrie and Clay 1993).

Recently, oil surfactants/carriers have also been utilized to enhance herbicide efficacy on woody weeds. Oil surfactants can improve spray adhesion and retention, reduce evaporation, and dissolve the waxy leaf cuticle (Clipsham 1984, Rhodenbaugh and Yeiser 1992, Schneider et al. 1992, Ramsey and Minogue 1995). Oil surfactants were found to enhance triclopyr (Schneider et al. 1992, Ramsey and Minogue 1995) and imazapyr efficacy (Minogue et al. 1994, Ramsey and Minogue 1995) against unwanted vegetation.

Few attempts have been made to study herbicidal entry into and movement within rhododendron (e.g., fosamine by Kitchen et al. [1980], hexazinone and glyphosate by Clipsham [1984]). The absorption and subsequent translocation of relatively new herbicides combined with modern surfactants in rhododendron is largely unknown.

The objectives of this study were to study the uptake and translocation behavior of triclopyr ester and imazapyr adjuvated by modern surfactants.

Methodology

Two hundred sixteen one-year-old great rhododendron seedlings from Musser Forests Nursery (Indiana, Pennsylvania, USA) were potted in 2.8-liter (15.24 cm x 15.24 cm) plastic containers in late October 1997 in a glasshouse in Blacksburg, Virginia, USA. The potting medium consisted of a 2:1 (v/v) mixture (pH = 4.2) of peat moss:natural acid heath soil (Lawrie and Clay 1993). The latter part consisted of a mixture of equal parts from both A and B horizons of a soil from a natural great rhododendron stand in the Fishburn School Forest near Blacksburg, Virginia. Seedlings were grown under an extended 16-hour photoperiod supplemented with high-pressure sodium vapor lighting ($150 \mu\text{mol m}^{-2}\text{s}^{-1}$) until treatments started. Seedlings were well-watered as needed. Fifteen ml of a 30:10:10 (N-P-K) (3000 ppm) aqueous soil fertilizer (Miracid[®]) were applied to each seedling once every two weeks prior to treatments. Temperature was sustained at 26°C in the greenhouse during the growth period of the seedlings. Treatments were applied to 15-month-old seedlings in the laboratory in late March 1998.

Nine replications of 24 treatments were randomly assigned to the 216 seedlings (Table 11). A randomized complete block design with nine replications in a factorial structure was utilized for the statistical design. Each block included 24 seedlings that grew in the same specific location and microenvironmental conditions in the greenhouse. Treatments were applied one block at a time. [¹⁴C]-Garlon 4[®] and [¹⁴C]-Chopper[®] applied at two rates were adjuvated with a methylated sunflower seed oil (Sun-It II[®], Cyanamid), nonionic surfactant moiety (High Trees Mixture B[®], Service Chemical), and organosilicone surfactant (Silwet 408[®], OSI Specialties Inc.) at varying combinations. Each treatment was then added up to 100% using deionized water.

Each seedling was first sprayed with cold formulations of its assigned treatment to deliver a spray volume of 15 gal/ac (141 L/ha). Following the cold formulations, the adaxial surface of a fully expanded leaf of each rhododendron was treated with 10 2.42- μL drops of C-14 radiolabeled herbicide plus surfactant solution. Each low- and high-rate Garlon 4-applied plant received 53 and 106 μg of active ingredient (ai), whereas the low- and high-rate imazapyr applications delivered 14 and 27 μg ai. Each treatment delivered 0.011 μCi (1 μCi = 37 GBq) of activity. One application standard was taken for each leaf application.

Table 11. Herbicides, surfactants, and rates (% v:v) used in the experiment of foliar uptake and translocation of great rhododendron.

Treatment	Herbicide	%	Surfactant	%
GA1-SU1	Garlon 4 ^a	5	Sun-It II	25
GA1-SU2	Garlon 4	5	Sun-It II	50
GA1-MB1	Garlon 4	5	Mixture B	1
GA1-MB2	Garlon 4	5	Mixture B	2
GA1-4081	Garlon 4	5	Silwet 408	0.25
GA1-4082	Garlon 4	5	Silwet 408	0.50
GA2-SU1	Garlon 4	10	Sun-It II	25
GA2-SU2	Garlon 4	10	Sun-It II	50
GA2-MB1	Garlon 4	10	Mixture B	1
GA2-MB2	Garlon 4	10	Mixture B	2
GA2-4081	Garlon 4	10	Silwet 408	0.25
GA2-4082	Garlon 4	10	Silwet 408	0.50
IM1-SU1	Chopper ^b	2.5	Sun-It II	25
IM1-SU2	Chopper	2.5	Sun-It II	50
IM1-MB1	Chopper	2.5	Mixture B	1
IM1-MB2	Chopper	2.5	Mixture B	2
IM1-4081	Chopper	2.5	Silwet 408	0.25
IM1-4082	Chopper	2.5	Silwet 408	0.50
IM2-SU1	Chopper	5	Sun-It II	25
IM2-SU2	Chopper	5	Sun-It II	50
IM2-MB1	Chopper	5	Mixture B	1
IM2-MB2	Chopper	5	Mixture B	2
IM2-4081	Chopper	5	Silwet 408	0.25
IM2-4082	Chopper	5	Silwet 408	0.50

Treated seedlings were cut at the root collar 72 hours after treatment (HAT). The adaxial surface of each treated leaf was washed with three 5-ml deionized waters, followed with a 5-ml funnel rinse, to determine unabsorbed chemical deposition on the leaf surface. Two-ml aliquots from these washes were placed in a 20-ml scintillation vial and mixed with Scintiverse II scintillation cocktail (Fisher Scientific, Pittsburgh, Pennsylvania, USA) for counting. Following the leaf washes, a pre-mixed solution of 5% cellulose acetate in acetone was applied on each of the treated leaves to isolate the leaf cuticle. After the solution had dried, the cellulose acetate was removed from the leaf surface and placed into a 20-ml vial for counting. All treated leaves were frozen after washing. Each plant was later separated

into treated leaf, other leaves, stem, and root to determine herbicide translocation within the plants. Plant parts other than the treated leaf were then oven-dried at 65°C for two weeks. The oven-dried samples were later ground and homogenized in a grinder. A subsample with weights varying between 0.15 and 0.25 g was taken from each homogenized sample for oxidization using a Harvey OX500 Biological Oxidizer (R. J. Harvey Instruments Corp., Hillsdale, New Jersey, USA). Radioactivity of each sample was counted using a Beckman LS 5000TA liquid scintillation counter (LSC) with a 5-min counting time (Beckman Instrument Co., Fullerton, Calif.). All counts were corrected for these efficiencies (subsampling, oxidizer, and LSC efficiency) and later adjusted for the subsampling. Uptake was calculated as the amount of herbicide not washed off the treated leaves. Translocation was determined as the percentage of the total amount of applied herbicide found in respective plant samples. Mean total recovery of all radio-treatments with respect to the application standards was 110.5%, with overruns most likely due to subsampling expansion. Analysis of variance (ANOVA) was used to test for the factorial main effects and interactions on percent results. Tukey's least square means (LSM) were used to separate treatment means using Statistical Analysis System (SAS Institute Inc., 1989).

Results

Qualitative Results

The visual symptomology of treatments on rhododendron leaves differed within herbicides and surfactants 72 HAT. Necrotic circular specks were common on the surfaces treated with triclopyr ester (Garlon 4), whereas the imazapyr (Chopper) applications generally showed much less, if any, leaf necrosis.

All the rhododendron leaves treated with Sun-It II exhibited a distinctly oily and luminous appearance throughout the experiment. The use of Mixture B and Silwet 408 surfactants resulted in varying degrees of leaf necrosis when applied with Garlon 4. The organosilicone drops spread to a substantially larger area than did the other surfactants once they were put on the leaf, and then disappeared swiftly.

Quantitative Results

Significant herbicide, surfactant, and surfactant-rate main and two- and three-way interaction effects were found for leaf-wash and treated-leaf recoveries in great rhododendron 72 HAT. Imazapyr lost significantly greater activity to leaf wash (tenfold) than did triclopyr ester (Table 12). Surfactant effects on leaf wash varied significantly between high and low herbicide rates for both of the herbicides. Leaf wash losses of herbicides were not rate-dependent. Surfactants did not differ for the leaf wash of triclopyr ester at the low rate. However, Silwet 408 and Sun-It II provided triclopyr ester with substantially greater (almost five- and threefold, respectively) leaf absorption than Mixture B at the high rate. The difference between the two former surfactants was not significant. Sun-It II enhanced the leaf absorption of imazapyr significantly more than the other two surfactants, with increasing differences from low to high herbicide rate. Leaf absorption with Sun-It II was 11 and 14 times greater than with Mixture B and Sun-It II, respectively, for the high-rate imazapyr application. Mixture B had an intermediate rank with significant differences from Silwet 408.

Reciprocal to its great leaf absorption, triclopyr ester had substantially greater (more than threefold) treated leaf accumulation than imazapyr (Table 13). Amounts of triclopyr ester found in the treated leaf were significantly greater (12%) with Sun-It II than with Silwet 408. No surfactant rate differences were found for leaf absorption and treated leaf accumulation of triclopyr ester. Imazapyr showed variable leaf wash loss and foliar uptake with different surfactants. Sun-It II elevated the poor leaf uptake of imazapyr into the range of triclopyr ester. The enhancement of imazapyr uptake by Sun-It II was significantly greater (by 8 and 11 times) than that by Mixture B and Silwet 408, respectively.

In contrast to the triclopyr ester treatments, an increased surfactant rate significantly improved leaf absorption and treated-leaf accumulation of imazapyr, except when applied with Sun-It II (Table 13). Increases of 12, 34, and 36% occurred in imazapyr absorption with Silwet 408, Sun-It II, and Mixture B, respectively, when the surfactant rate was doubled. Surfactant rate increases in the treated-leaf entrapment of imazapyr averaged 87 and 88% with Silwet 408 and Mixture B, respectively. No significant surfactant rate differences were found with Sun-It II in activity absorbed by the treated leaf.

Table 12. Percent of applied activity recovered from the leaf washes of great rhododendron 72 h after applications of the varying rates of radiolabelled triclopyr ester and imazapyr with different surfactants.

Herbicide ¹	Herbicide Rate	Surfactant	Leaf Wash Recovery (%)
Triclopyr ester	Low	Mixture B	3.6 a ²
		Sun-It II	3.2 a
		Silwet 408	3.1 a
		(Mean)	(3.3) B ³
	High	Mixture B	8.4 a
		Sun-It II	2.9 b
		Silwet 408	1.9 b
		(Mean)	(4.4) B
Imazapyr	Low	Silwet 408	65.9 a
		Mixture B	39.1 b
		Sun-It II	7.4 c
		(Mean)	(37.5) A
	High	Silwet 408	69.9 a
		Mixture B	54.1 b
		Sun-It II	5.0 c
		(Mean)	(43.0) A

¹ Herbicide x herbicide-rate x surfactant interaction was significant (p<0.05)

² Lower-case letters alongside numbers in the table are valid within a herbicide-rate cell only. Treatments within the same cell with different lower-case letters are significantly different (p < 0.05).

³ Upper-case letters alongside mean numbers in parentheses are for comparisons of herbicides at low and high rates and valid within the whole column. Treatments within the same column with different upper-case letters are significantly different (p < 0.05).

Table 13. Percent of applied activity recovered from the leaf washes and the treated leaves of great rhododendron 72 h after application of radiolabelled triclopyr ester and imazapyr with varying rates of different surfactants.

Herbicide ¹	Surfactant	Surfactant Rate	Leaf Wash Recovery	Treated Leaf Recovery
			-----%-----	
Triclopyr ester	Silwet 408	Low	2.6 a ²	76.3 a
		High	2.4 a	77.2 a
		Mean	(2.5) C ³	(76.8) B
	Mixture B	High	6.7 a	80.9 a
		Low	5.2 a	82.8 a
		Mean	(5.9) C	(81.9) AB
	Sun-It II	Low	3.1 a	86.4 a
		High	2.8 a	86.1 a
		Mean	(2.9) C	(86.3) A
Imazapyr	Silwet 408	Low	71.9 a	4.7 b
		High	64.0 b	8.8 a
		Mean	(68.0) A	(6.8) E
	Mixture B	Low	53.7 a	19.9 b
		High	39.4 b	37.5 a
		Mean	(46.6) B	(28.7) D
	Sun-It II	Low	7.1 a	58.4 a
		High	5.3 b	58.8 a
		Mean	(6.2) C	(58.6) C

¹ Herbicide x surfactant-rate x surfactant was significant (p < 0.05)

² Lower-case letters alongside numbers in the table are valid within herbicides only. Treatments within the same column with different lower-case letters are significantly different (p < 0.05)

³ Upper-case letters alongside mean numbers in parentheses are for comparisons of two herbicides and valid within the whole column. Treatments within the same column with different upper-case letters are significantly different (p < 0.05).

When the two herbicides were compared, the percent cuticular entrapment of triclopyr ester was significantly more than that of imazapyr (Table 14). Triclopyr ester entrapped was similar by the leaf cuticle between low and high herbicide rates whereas cuticular entrapment decreased significantly (20%) from low to high rate for imazapyr.

Table 14. Percent recovery of applied activity from the cuticle of the treated leaf of great rhododendron 72 h after applications of the varying rates of radiolabelled triclopyr ester and imazapyr.

Herbicide¹	Herbicide Rate	Cuticular Recovery (%)
Triclopyr ester	High	14.7 a ²
	Low	12.7 a
	Mean	(13.7) A ³
Imazapyr	Low	10.1 a
	High	8.0 b
	Mean	(9.1) B

¹Herbicide x herbicide interaction was significant ($p < 0.05$)

²Lower-case letters alongside numbers in the table are valid within a herbicide cell only. Treatments within the same cell with different lower-case letters are significantly different ($p < 0.05$).

³Upper-case letters alongside mean numbers in parentheses are for comparisons of two herbicides and valid within the whole column. Treatments within the same column with different upper-case letters are significantly different ($p < 0.05$).

The entrapment of herbicides by rhododendron leaf cuticle also varied by surfactants (Table 15). Significantly less triclopyr ester was trapped in the cuticle by Mixture B and Sun-It II (22 and 40%, respectively) than by Silwet 408. However, Mixture B reduced the cuticular diffusion of imazapyr significantly when compared to cuticular diffusion with Sun-It II and Silwet 408.

Table 15. Percent recovery of applied activity from leaf-cuticle, non-treated leaves, stems, and roots of great rhododendron 72 h after application of radiolabelled triclopyr ester and imazapyr with different surfactants.

Herbicide¹	Surfactant	Leaf Cuticle	Other Leaves	Stem	Root
Triclopyr ester	Silwet 408	17.6 a ²	4.0 a	5.5 a	3.6 a
	Mixture B	12.9 b	4.0 a	4.1 a	4.2 a
	Sun-It II	10.6 b	6.7 a	5.9 a	3.3 a
	Mean	(13.7) A ³	(4.9) B	(5.2) B	(3.7) B
Imazapyr	Mixture B	11.5 a	7.1 b	9.6 b	6.4 b
	Silwet 408	8.8 b	10.1 b	6.7 b	5.0 b
	Sun-It II	6.9 b	16.7 a	14.7 a	9.8 a
	Mean	(9.1) B	(11.3) A	(10.1) A	(7.1) A

¹ Herbicide x surfactant interaction was significant ($p < 0.05$)

² Lower-case letters alongside numbers in the table are valid within a herbicide cell only. Treatments within the same cell with different lower-case letters are significantly different ($p < 0.05$).

³ Upper-case letters alongside mean numbers in parentheses are for comparisons of two herbicides and valid within the whole column. Treatments within the same column with different upper-case letters are significantly different ($p < 0.05$).

Significant herbicide, surfactant, and herbicide x surfactant interaction effects were found in translocation out of the treated leaf of rhododendron (Table 15). Imazapyr translocation was significantly greater than triclopyr ester translocation. Amounts of imazapyr found translocated into other leaves, stems, and roots of rhododendron were 131, 94, and 92% greater, respectively, than amounts of triclopyr ester translocated into these plant parts. Surfactants did not make significant differences in translocation of triclopyr ester out of the treated leaf, whereas substantial differences were found among surfactants for translocation of imazapyr into other leaves, stems, and roots. Sun-It II consistently and significantly enhanced translocation of imazapyr from the treated leaf to other leaves, stems, and roots, compared with translocation into these plant parts with other surfactants.

Discussion

The rhododendron species of this experiment and that of Clay et al. (1992) in the UK were different, yet similar in their morphologies and the environmental conditions under which they grow. The rates of imazapyr and triclopyr both within the present experiment and across these two experiments also differed. These differences between the two experiments may not prevent comparison of their results, however. The greater imazapyr translocation in great rhododendron than that of triclopyr ester may explain the enhanced (almost threefold) regrowth suppression of purple-flowered rhododendron by this herbicide in the UK 4 YAT when compared to rhododendron control by triclopyr.

Imazapyr translocation is also great in the studies of herbaceous plants (Nissen et al. 1995). Root translocation in leafy spurge (*Euphorbia esula* L.) amounted to 17% of total activity applied eight DAT (Nissen et al. 1995). Also, imazapyr translocation to roots of alligatorweed (*Alternanthera philoxeroides* [Mart.] Griseb) varied among 2, 4, and 12% of total activity applied 1, 2, and 4 DAT (Tucker et al. 1994). These reports, coupled with the significant amounts of imazapyr still remaining in the treated leaves, other leaves, and stems of rhododendron in the present experiment, indicate that root translocation of this herbicide might increase to even greater levels given a greater length of time (i.e., > 72 hours).

The oil-based formulation of imazapyr (Minogue et al. 1996) could not improve its leaf absorption in rhododendron, which has lipophilic (oil-soluble) foliage due to great wax content in the cuticle (Holloway 1970), to the leaf absorption level of triclopyr ester. Reduced leaf absorption may present an efficacy problem for imazapyr in great rhododendron, since its typical climate is often rainy (Monk et al. 1995).

Oil-soluble (lipophilic) herbicides can penetrate lipophilic plant foliage to a greater extent than water-soluble (hydrophilic) herbicides (Bentson and Norris 1991, Jackson et al. 1998). Triclopyr ester is oil-soluble, and thus can diffuse through lipophilic foliage quickly (Ross and Lembi 1985, Forster 1998, Jackson et al. 1998). This was clearly demonstrated in great rhododendron in the present experiment. This herbicide has also been reported to have great rainfastness and foliar uptake efficacy for many woody plants, including red maple, sweetgum (Zedaker et al. 1994), and giant chinkapin (*Castanopsis chrysophylla* [Dougl.] A. DC.) (Bentson and Norris 1991). The localized necrosis commonly found on triclopyr ester-

sprayed foliage in the present experiment indicated contact phytotoxicity of this herbicide, which has also been reported for red maple (Jackson et al. 1995).

Limited movement of triclopyr ester has also been reported for various herbaceous plants, including barley (*Hordeum vulgare*, cv Igri), chickweed (*Stellaria media*), and wheat (*Triticum aestivum*, cv Norman) (Lewer and Owen 1990). The mean percent total triclopyr ester found in roots of great rhododendron of the present experiment matched that found in roots of barley (3.7 vs. 3.4%, respectively). Moreover, inhibited translocation with triclopyr ester was noted on northern red oak, red maple, and sweetgum (Forster 1998). Contact phytotoxicity of triclopyr ester resulted in the inhibition of active ingredient translocation out of the foliage of sprayed plants (Jackson et al. 1998). Significant rate-dependent antagonism between triclopyr ester and foliar uptake reported for some North American tree species was not found in the present study, probably due to species and application rate differences (1% vs. 10% for the studies of Jackson et al. [1998] and Bollig et al. [1995] vs. 10% for the present study).

The fact that there were no significant surfactant-caused changes in rainfastness, foliar uptake, and translocation of triclopyr ester in great rhododendron probably explains the unimproved efficacy of triclopyr adjuvated with 2% (v:v) Mixture B and 0.25% (v:v) Silwet L-77 on the control of purple-flowered rhododendron in the UK study one growing season after treatment when compared to efficacy results from the formulation with no surfactants (Lawrie and Clay 1993). The 2% (v:v) Mixture B did not improve triclopyr ester efficacy on purple-flowered rhododendron 4 YAT (Clay et al. 1992). Inhibited herbicide rainfastness with Mixture B at a high triclopyr ester rate is noteworthy for places where precipitation is very likely following spraying.

The greater cuticular resistance probably contributed to the inhibited efficacy of this surfactant for translocation with triclopyr ester. Poor cuticular diffusion of organosilicones (Silwet L-77 and Y-12301) was also reported for some herbaceous plants (e.g., bean, *Vicia alba*) sprayed with glyphosate (Stevens 1993). Similar findings were also reported for woody plants. Mixtures of 0.5% (v:v) Silwet L-77 and 0.05% (v:v) Silwet Y-6652 did not enhance the cuticular penetration of deoxyglucose (DOG) on adaxial leaf surfaces of “non-stomatous” *Eucalyptus botryoides* and *Citrus nobilis* (Zabkiewicz et al. 1988, Knoche 1994). On the other hand, Silwet L-7607 improved diffusion of DOG in eucalyptus significantly

more than the aforementioned organosilicones. Therefore, investigating foliar uptake and translocation effects of other organosilicones such as Silwet L-7607 on great rhododendron in future studies may be useful.

It has also been reported that organosilicone surfactants varied in foliar uptake enhancement with the herbicides to which they were added (Stevens 1993, Knoche 1994). This was confirmed in the present study by the significantly different foliar uptake and cuticular diffusion performances of Silwet 408 between triclopyr ester and imazapyr (Table 15). Organosilicones have been found to be antagonistic to translocation of several herbicides from the treated leaf, including glyphosate (Gaskin and Stevens 1993, Knoche 1994) and triclopyr ester, due to physicochemical incompatibility between organosilicones and other surfactants built into these herbicides (Zedaker et al. 1994, Jackson et al. 1998).

Significant enhancement of leaf uptake and translocation of imazapyr by Sun-It II over Mixture B and Silwet 408 in rhododendron in the present study is in line with previous results on the superior performance of this additive. It has been reported that Sun-It II can dissolve and solubilize the waxy leaf cuticle effectively, thereby enhancing herbicide uptake and translocation (Clipsham 1984, Rhodenbaugh and Yeiser 1992, Schneider et al. 1992, Ramsey and Minogue 1995). This was in fact substantiated by the great cuticular penetration by Sun-It II in the present experiment (Table 15). Although triclopyr ester translocation to rhododendron roots by the seed oil was not significantly different than root translocation by other surfactants 72 HAT, greater herbicide accumulation in the treated leaf and the greater activity that moved to the stem and leaves with Sun-It II may be taken as evidence that root translocation may be significantly enhanced given a longer time.

It was reported that the lipophilic and hydrophilic constituents embodied in Mixture B surfactant provided a more accessible pathway for herbicides into the leaf interior of purple-flowered rhododendron by dissolving the waxy cuticle (Tabbush et al. 1986). Mixture B, in fact, enhanced cuticular diffusion of triclopyr ester significantly more than Silwet 408 (Table 15). Cuticular dissolution of imazapyr, however, declined significantly with Mixture B in great rhododendron, suggesting the herbicide-specific performance of this additive. The inhibited cuticular diffusion, however, did not prevent this additive from providing imazapyr with as good translocation as did Silwet 408. Similarly, root translocation for imazapyr with Silwet 408 and Mixture B in great rhododendron probably explains the similar imazapyr

efficacy gained in purple-flowered rhododendron in the UK using these two surfactants (Clay et al. 1992).

The lack of significant surfactant-rate differences for herbicide translocation out of the treated leaf suggested that lower rates of surfactants might be as effective in rhododendron control as higher rates. This would certainly improve the cost efficiency of these treatments. Non-significant surfactant and herbicide rates of translocation out of the treated leaf also suggested that new combinations of these herbicides and surfactants should be investigated in rhododendron in future studies to further improve the cost efficiency of these treatments while maintaining woody control.

Conclusions

The oil-formulated triclopyr ester (Garlon 4) was able to circumvent the waxy leaf cuticle obstacle in great rhododendron at a much greater degree, due to its lipophilic character, than the salt-based and less lipophilic formulation of imazapyr (Chopper) 72 HAT. Increased contact phytotoxicity of triclopyr ester to leaves and conducting tissues, however, probably depressed translocation of this herbicide out of the treated leaves. Although foliar uptake of triclopyr ester varied by surfactants, no significant surfactant enhancement was found for the translocation of this herbicide.

Leaf absorption was generally poor with imazapyr (Chopper) in great rhododendron. However, this herbicide achieved substantially greater translocation out of the treated leaves, especially into the roots, with Sun-It II, when compared to translocation of triclopyr ester treatments. The enhanced herbicide uptake and translocation performed by Sun-It II was attributed to the ability of this surfactant to wet the foliage and to dissolve the wax and cuticle to a greater extent, and possibly by its physicochemical compatibility with imazapyr. Mixture B and Silwet 408 provided imazapyr with similar levels of translocation. However, with its greater translocation to stems, Mixture B is a good candidate for enhancing root translocation of imazapyr.

Increasing herbicide rate did not increase uptake or translocation for either herbicide. Higher surfactant rates, however, enhanced imazapyr leaf uptake. The combinations of the low-rate Chopper and the low-rate Sun-It II or low-rate Mixture B may provide enhanced herbicidal efficacy and cost efficiency of great rhododendron control.

CHAPTER 5: SYNTHESIS

The BSR has been inhabited by numerous civilizations over several thousand years; hence, the forests of this region have historically been severely disturbed. Although the first documentation of such anthropogenic disturbance in these forests is found as far back as 405 B.C. in Xenophon's book of *Anabasis*, anthropogenic pressure on the BSR flora has intensified since the period of the Ottoman Empire (1299-1923). Numerous Ottoman archival documents indicated heavy utilization of the once species-rich BSR forests by both the Empire and the public. Pines used to comprise a significant portion of the BSR forests, yet have probably been selectively extracted from the forest for ship and home construction. The present invasion by conifers of the region's agricultural fields that have recently been abandoned by villagers for socioeconomic reasons might confirm the significance of pines in these forests years ago. Therefore, the current pure beech- and rhododendron-dominated BSR ecosystem is probably not a natural consequence, but an outcome of human manipulation.

Periodic, severe anthropogenic pressure has resulted in frequent regeneration events in this region, leading to unbalanced uneven-aged structures. Populations of forest villages have been dependent upon the surrounding forests for home construction, heating, and cooking for years. This has apparently degraded the forests in the region. This anthropogenic degradation was significantly more intensive as one approached villages.

During the past 100-200 years, fire has obviously not been a major disturbance leading to the current pure beech forests. However, great densities of charcoal particles in soil samples probably reflect the frequent fires of more than 200 years ago reported in Ottoman archival documents, which correlates with an abundance of conifers during these years. Fire was also a common tool for the locals to make openings from the surrounding forest for homeseating and cultivation, as the accounts of the elderly villagers indicated. The increasing density of charcoal particles in the soil as one approaches Kardesler Village in Yayla may confirm this.

Extraction of conifers and beech from the region's forests gradually reduced the quantity and duration of canopy closure over the years. This has probably resulted in an increase in rhododendron abundance. Accounts by elderly villagers of the spread of rhododendron may confirm this. However, high levels of anthropogenic disturbance for

firewood may have depressed rhododendron abundance, as indicated by significant decreases in rhododendron basal area with decreasing distance from a village.

Soil moisture is certainly a very critical factor for both beech in the overstory and rhododendron in the understory. Northern aspects, specifically northeast aspects, suit the moisture requirements of these two species. However, adequate aeration is also important for rhododendron.

The current dense rhododendron cover significantly reduces not only tree regeneration, but also growth of beech overstory in the BSR forests. Beech apparently cannot regenerate unless rhododendron is controlled. Seedling survival and growth improves dramatically when rhododendron is controlled. Manual control of rhododendron is not an effective technique and is costly. Specifically, cutting and grubbing fail to reduce the great reproductive potential of rhododendron, and thus their efficacy is very short-term. Although grubbing may provide good rhododendron control and cost efficiency initially, the great reproductive potential of rhododendron will probably override the initial success of grubbing. Creation of nests for rodents in piles of grubbed rhododendrons may also reduce the survival of beech seedlings. Cut-stump herbicidal spray reduces rhododendron basal area, yet is not practical and cost-efficient when average woody gld is small and density is great. Cutting alone, grubbing, and cut-stump spraying create piles of brush that may enhance habitat conditions for rodents. Foliar herbicidal technique, on the other hand, is easy, practical, and provides excellent woody control and cost efficiency when compared with the other woody control techniques. Of foliar-applied herbicides, the efficacy of imazapyr (Arsenal SL) is significantly greater than that of triclopyr ester (Garlon 4). The enhanced long-term woody control by imazapyr, compared with triclopyr ester, is ascribed to the significantly greater mobility of imazapyr within rhododendron. Foliage, stem, and root translocation of imazapyr in rhododendron is significantly greater than that of triclopyr ester. Although imazapyr has generally poor rainfastness, foliar uptake and translocation can be enhanced significantly by addition of Sun-It II and by Mixture B to this herbicide. The oil-formulated triclopyr ester (Garlon 4) can circumvent the waxy leaf cuticle obstacle in rhododendron to a much greater degree, due to its lipophilic character, than the salt-based formulation of imazapyr. Increased contact phytotoxicity to conducting leaves and tissues from triclopyr ester, however, probably depresses translocation of this herbicide out of the treated leaves.

Different herbicide rates did not increase root translocation significantly based on percentage of total activity applied. However, total herbicide amount in roots increased with the higher rate.

These results have various important implications for forest management. Use of low rates of Arsenal SL or Garlon 4 with vegetable oils and Mixture B may provide effective, long-term, and cost-efficient rhododendron control. Reducing rates further may provide the same level of woody control at less cost, and this should be studied in the future. There was a great conformity between the results of the field experiment in Turkey and those of the herbicide uptake and translocation experiment in rhododendron in the USA, although the species used in these experiments varied. This indicates that sound transfer of information on the ecology and effective long-term control of rhododendron is possible among the BSR and other parts of the world where this woody weed is or is becoming a major forest vegetation management problem, including the Southern Appalachians.

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