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RESPONSE OF *ARBUTUS ARIZONICA* (ARIZONA MADRONE) TO FIRE IN SOUTHEASTERN ARIZONA

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ABSTRACT—I investigated the response to fire of *Arbutus arizonica,* an important but little-studied tree species of fire-prone Madrean pine-oak communities of the southwestern United States and northern Mexico. *Arbutus arizonica* exhibited a marked ability to tolerate both moderate-severity and high-severity fire. Although all individuals were top-killed by high-severity fire, the shoots of nearly half of the trees survived moderate-severity fire, and most top-killed trees in both types of fire resprouted. Tree response to fire appeared to be governed by fire severity and tree size. Top-survival and epicormic resprouting after top-kill were both higher after moderate-severity than high-severity fire and increased with tree size. Levels of root crown resprouting, however, exhibited the opposite pattern. The results of this study suggest that *A. arizonica* has a capacity, similar to that found for sympatric *Quercus* species, to persist in a fire-prone environment.

RESUMEN—Investigué la reacción al fuego de *Arbutus arizonica,* una importante pero poco estudiada especie de madroño que se halla en las comunidades propensas a fuegos en las áreas del sudoeste de los Estados Unidos y del norte de México. *Arbutus arizonica* exhibió una marcada habilidad para tolerar fuegos tanto de severidad moderada como altamente severos. A pesar de que la parte afuera de la tierra de todos los individuos murió por un fuego de alta severidad, los retoños de casi la mitad de los árboles sobrevivieron fuegos moderadamente severos, y la mayoría de los árboles con sus partes superiores muertas en ambos tipos de fuegos brotaron nuevamente. La reacción de los árboles al fuego parece estar dictaminada por la severidad del fuego y el tamaño del árbol. Tanto la supervivencia de las partes superiores como el retoño epicórmico después de la muerte de las partes superiores fueron más altos después de los fuegos moderados que de los severos, e incrementaron con el tamaño del árbol. Sin embargo, los niveles de retoños de la corona de las raíces exhibieron el patrón contrario. Los resultados de éste estudio sugieren que *A. arizonica* tiene una capacidad, similar a la que se halla en especies simpátricas como *Quercus,* para sobrevivir en un medio ambiente propenso a fuego.

Arbutus arizonica (Arizona madrone) occurs in the mountains of southern Arizona and New Mexico and south into the Sierra Madre Occidental of Mexico (Standley, 1924; Kearney and Peebles, 1960). Although it is rarely locally abundant, *A. arizonica* is a distinctive component of Madrean pine-oak communities and the only *Arbutus* species in this community type in the United States (Whittaker and Niering, 1965; Brown, 1982; Niering and Lowe, 1984; Barton, 1994, 2002; Park, 2001).

During presettlement times, surface fires burned frequently in Madrean pine-oak forests (Fulé and Covington, 1996; Swetnam et al., 1999, 2001). Starting in the late 1800s in the United States and more than 50 years later in Mexico, livestock grazing and active fire suppression drastically reduced fire frequency in many of these ecosystems (Fulé and Covington, 1996; Swetnam et al., 1999, 2001). The resulting increase in fuel load has given rise recently to a spate of high-severity crown fires—fires that are probably out of the range of natural variation for Madrean pine-oak forests (Swetnam et al., 1999, 2001; Fulé et al., 2000; Barton, 2002).

Although knowledge of the responses to fire of the abundant pines and oaks of these communities has increased over the past decade (e.g., Barton, 1993, 1999, 2002; Fulé and Covington, 1996; Fulé et al., 1997, 2000; Park, 2001; Rodriguez-Trejo and Fulé, 2003), little is

known about the response of *A. arizonica* to fire. In fact, the United States Department of Agriculture Forest Service Fire Effects Website (Pavek, 1993), a clearinghouse for fire ecology information on North American tree species, cites mainly anecdotal information regarding the fire ecology of *A. arizonica* and calls for research to fill this gap (see also Bennett and Kunzmann, 1992). In this paper, I report on the response of *A. arizonica* to 2 levels of fire severity in the Chiricahua Mountains in southeastern Arizona.

METHODS—Two sets of data were used to assess the response of *A. arizonica* to fire. First, as part of studies of pines and oaks from 1990 to 2000, I recorded post-fire data on *A. arizonica* in 7 burns that exhibited a wide range of fire severity in the Chiricahua and Animas mountains. For each individual ≥10 cm diameter at breast height (dbh) encountered along transects in these burns, I recorded whether the tree was top-killed by fire, and if it was, whether it had resprouted. Stems within 1 m of each other were considered members of one genetic individual (i.e., genet), and were not sampled separately. Details of the methods can be found in Barton (1999, 2002).

The second and primary data set is from the 1994 Rattlesnake Fire in the Chiricahua Mountains, which burned 10,330 ha between 28 June and 24 July 1994, from about 2,400 m elevation in spruce-fir (*Picea-Abies*) forest down to about 1,800 m in Madrean oak (*Quercus*) woodland (unpubl. data, Coronado National Forest, United States Department of Agriculture, Forest Service). Within the fire boundaries, fire effects ranged widely from low-severity surface fire to high-severity crown fire. I carried out fieldwork in this burn in April 2003 in an approximately 25-ha area in Cave Creek Canyon (31°52′N, 109°15′W), where fire spread from the crest near Pine Park into lower elevation Madrean pine-oak (*Pinus-Quercus*) forest above the Herb Martyr campground. Prior to the fire, this area supported a mix of *Pinus engelmannii, P. leiophylla, Quercus hypoleucoides, Q. arizonica,* and lesser amounts of *A. arizonica* and other woody species. For detailed pre-fire and post-fire site descriptions, see Barton (1993, 1994, 1999, 2002).

I located *A. arizonica* individuals ≥10 cm dbh by walking transects perpendicular to the slope throughout the burned Madrean pine-oak forest. I recorded the following retrospective data for each *A. arizonica* encountered: 1) whether the tree was top-killed by fire; 2) if it was top-killed, whether it resprouted epicormically, from the root-crown, or not at all; and 3) the dbh of the stem. Individual stems within 1 m of each other were considered part of the same genet (33 of the 101 stems). The presence of underground connections between several such stems was verified by digging down to the roots or old root crowns. Data were recorded separately for each stem, including those in multiple-stemmed genets. In much of the burn, all canopy trees were top-killed; in some areas, however, fire severity was lower, and some of the numerically dominant pines and oaks survived. Accordingly, each *A. arizonica* recorded was identified as occurring in either a moderate-severity or high-severity burn site, based on the top-survival of pines and oaks in a surrounding 25-m radius. The retrospective approach used in this study has been shown to be an effective way to examine tree species responses to fire (Barton, 1999, 2002), but it has potential biases: some stems recorded as top-killed by the fire and not resprouted could have been dead before the fire, and top-surviving or resprouted stems might be more conspicuous and, therefore, more likely to be sampled than dead trees.

Statistical analyses of the Rattlesnake Fire data were carried out separately for genets ($n = 101$) and for stems ($n = 138$). A genet was considered to have top-survived or successfully resprouted if at least 1 stem exhibited that response. Logistic regressions were used to examine the influence of stem size (dbh) on top-survival and resprouting responses to fire. Logistic analyses were carried out for the stem data set, but not for the genet data set because multiple stem sizes occur for genets with more than 1 stem.

RESULTS—Nearly one-half of the shoots of *Arbutus arizonica* genets subjected to moderate-severity fire in the Rattlesnake burn survived, which was significantly different from the 100% top-kill for high-severity burn sites (Tables 1, 2). Most top-killed individuals resprouted after the fire (Table 1); percentages for this response did not differ between moderate-severity and high-severity burn areas (Table 2). Origin of resprouts contrasted strongly between the 2 fire areas: overwhelmingly epicormic after moderate-severity fire versus mainly from root crowns after high-severity fire (Tables 1, 2). Overall survival (individuals exhibiting either top-survival or resprouting after top-kill) was significantly higher for stems subjected to moderate-severity compared to high-severity fire (Tables 1, 2). The pattern of statistical results for top-survival, resprouting, and overall survival was similar for analyses of genets and stems (Tables 1, 2).

Response to fire was dependent on tree diameter. In moderate-severity burn sites, the probability of top-survival of stems increased

TABLE 1—Percentages for *Arbutus arizonica* for top-survival, resprouting after top-kill, epicormic sprouting (as a percentage of epicormic plus root crown sprouting), and overall survival (top-survival plus resprouting after top-kill). Data are for genets (for which each set of multiple adjacent stems presumably connected by roots are treated as 1 datum) and stems (for which each stem is treated as a datum) in moderate-severity and high-severity burn areas of the Rattlesnake Fire, Arizona, 1994.

Data source	Fire severity	Top-survival % (*n*)	Resprouting % (*n*)	Epicormic resprouting % (*n*)	Overall survival % (*n*)
Genets	Moderate	43.1 (51)	93.1 (29)	81.5 (27)	96.1 (51)
	High	00.0 (50)	82.0 (50)	31.7 (41)	82.0 (50)
	Total	21.8 (101)	86.1 (79)	51.5 (68)	89.1 (101)
Stems	Moderate	39.7 (73)	81.8 (44)	83.3 (36)	89.0 (73)
	High	00.0 (65)	73.9 (65)	35.4 (48)	73.9 (65)
	Total	21.0 (138)	77.1 (109)	56.0 (84)	81.9 (138)

(i.e., positive slope coefficient) significantly with tree dbh (Table 3). In contrast, the probability of a top-killed stem resprouting decreased with tree size after high-severity fire, but not after moderate-severity fire (Table 3). For both types of areas, the probability of a stem resprouting epicormically as opposed to basally from the root crown increased significantly with stem size (Table 3).

Top-survival and resprouting responses in the 7 burns other than the Rattlesnake fire were similar to those described above. Of 54 genets sampled in a wide range of fire severities, the stems of 12 (22.2%) individuals survived. Of the 42 top-killed genets, 29 (69.0%) resprouted.

TABLE 2—Chi-square results for *Arbutus arizonica* for the association between fire severity (moderate vs. high) and percentage of top-survival, resprouting after top-kill, epicormic sprouting (as percentage of epicormic plus root crown sprouting), and overall survival (top-survival plus resprouting after top-kill). Results are for separate analyses of genets (for which each set of multiple adjacent stems presumably connected by roots are treated as 1 datum) and stems (for which each stem is treated as a datum) in burn areas of the Rattlesnake Fire, Arizona, 1994. For each analysis, $df = 1$.

Data source	Top-survival	Re-sprouting	Epicormic resprouting	Overall survival
Genets	27.6***	1.9	16.1***	5.2*
Stems	30.3***	0.9	19.2***	5.4*

* $P < 0.05$
*** $P < 0.001$

DISCUSSION—*Arbutus arizonica* exhibited a marked ability to persist in the face of both moderate-severity and high-severity fire. Levels of top-survival of this species were lower than that found for sympatric *P. engelmannii* and *P. leiophylla* but comparable to that for *Quercus* species (Barton, 1999). Even in high-severity fire sites, where all woody plants were top-killed, *A. arizonica* demonstrated resilience by resprouting epicormically or from the root crown, at levels similar to that found for sympatric *Quercus* species (Barton, 1999, 2002). The marked resprouting after shoot damage found here is typical for other New World and Old World *Arbutus* species for which information is available (Wiedenfeld, 1975; Atzet and Wheeler, 1982; Gratani and Amadori, 1991). Fulé and Covington (1998), however, observed a lack of resprouting in Madrean *Arbutus* species after fire in the Sierra Madre.

Tree size and fire severity seem to govern the response of *A. arizonica* to fire. Top-survival was higher after moderate-severity fire and increased with tree size, patterns found also for epicormic resprouting. Both top-survival and epicormic resprouting depend on functional cambium; accordingly, the role of lower fire severity and larger tree size in these responses to fire probably hinge on higher levels of cambium survival after fire. *Arbutus arizonica,* in fact, exhibits a striking capacity to survive bark damage compared to sympatric tree species (e.g., *Pinus* and *Quercus*). Most top-surviving *A. arbutus* (93%) in the Rattlesnake fire exhibited large areas of missing bark, in many cases more than half of the bark at breast height. Interest-

TABLE 3—Logistic regression results for *Arbutus arizonica* for the relationships of top-survival, resprouting after top-kill, and type of resprouting (basal vs. epicormic) with tree size (diameter at breast height) in moderate-severity and high-severity burn areas of the Rattlesnake Fire, Arizona, 1994. Results are for the stem data set; the genet data set could not be analyzed because multiple-stemmed genets have more than 1 stem size. Top survival could not be analyzed for high-severity fire sites because all stems were top killed in those areas.

Fire severity	Tree response	*df*	Slope/*SE*[b]	*F*	*P*
Moderate	Top-survival	1, 71	0.08/0.03	6.5	0.001
	Resprouting	1, 42	0.08/0.06	1.5	0.23
	Resprouting type[a]	1, 54	0.33/0.14	10.4	0.002
High	Resprouting	1, 63	−0.08/0.03	9.7	0.003
	Resprouting type[a]	1, 46	0.09/0.04	4.4	0.04

[a] Basal resprouting coded as 0 and epicormic resprouting as 1; thus, a positive slope indicates an increase in the probability of epicormic resprouting with increasing tree size.

[b] Slope is the slope coefficient of the logistic regression; *SE* is the standard error of the slope.

ingly, resprouting capacity decreased for larger trees in high-severity burn sites, where most resprouting was from the root crown. This pattern, which has been found for many other species (e.g., Bellingham et al., 1994; Barton, unpubl. data), could be attributable to a decline in availability of latent buds in the root crown as the tree increases in age or size.

The results of this study suggest that *A. arizonica* has a capacity, similar to that found for sympatric *Quercus* species, to persist in a fire-prone environment. A more complete understanding of the response of this species to fire will require assessments in other mountain ranges, environments, and fire severities.

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