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PROBABILITY OF MORTALITY IN CASUARINA TWO YEARS AFTER THE FIRE AT THE PIEDMONT OF THE TLALOC VOLCANO, STATE OF MEXICO, 2017

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ABSTRACT

In 2017, at the foot of the Tlaloc volcano, occurred the largest forest fire in the State of Mexico (2500 ha), with surface and crown (canopy) phases, on plantations of various species and various types of vegetation. Studies on the effects of fires on trees serve to define mortality and whether or not restoration will be required in an affected area. The hypothesis was: the greater the intensity and severity of the fire and the smaller the size of the trees, the greater the probability of mortality. The objective of the study was to establish the fire severity and dasometric variables that influence the probability of both mortality and resprouting in *Casuarina equisetifolia* L. plantations affected by fire. The study was conducted at the Experimental Forestry Station "Las Cruces" (Universidad Autónoma Chapingo, State of Mexico). In 2019, 442 trees (15 sites of 100 m^2) were sampled in 50 ha of plantations affected by the fire. Records were made on whether the trees were alive or dead, normal diameter, bark thickness, height, height at the base of the original crown, height of the fire scar on the trunk, height of crown scorch and presence of resprouting. The statistical analysis consisted of logistic regressions, using the Proc Logistic procedure of the SAS program. The average tree mortality was 63 %. The variable that was directly related ($p \leq 0.05$) to the probability of mortality was the height of the scar above the trunk. The dasometric variables inversely related ($p \leq 0.05$) with the probability of mortality were: height, normal diameter and bark thickness. For resprouting probability, there was an inverse relationship ($p \leq 0.05$) with normal diameter, bark thickness and height of scar on the trunk. It is concluded that casuarina is a fire sensitive species.

Keywords: *Casuarina equisetifolia* L., fire effects, fire, mortality, logistic regression, fire severity.

INTRODUCTION

In April 2017, a forest fire occurred on the slopes of the Tláloc volcano, State of Mexico, which was the most extensive of the year (2500 ha) in the federal entity (Probosque, 2017). The fire lasted for a week and was complex because it affected forest plantations of casuarina (*Casuarina equisetifolia* L.), white cedar (*Callitropsis lusitanica* (Mill.) D.P.Little), eucalyptus (*Eucalyptus camaldulensis* Dehnh.), pine (*Pinus pseudostrobus* Lindl) and others, in addition to various types of natural vegetation, such as scrub oak (*Quercus frutex* Trel.), oak forest (with species such as *Quercus deserticola* Trel, *Q.*

laeta Liebm., *Q. crassipes* Bonpl., *Q. rugosa* Née, *Q. laurina* Bonpl. and *Q. castanea* Née), pine forest (with species such as *P. leiophylla* Schltdl. & Cham., for example) oyamel forest (*Abies religiosa* (Kunth) Mirb.) and grassland, among others. Therefore, the forest fuel models were very diverse, including: grassland, undergrowth, shrubland and leaf litter. Likewise, the topography was very diverse, with slopes ranging from flat to greater than 100 %, on northern, southern, eastern or western exposures and with an abundance of gullies. Regarding weather, winds changed direction frequently and sometimes blew at more than 30 km h^{-1}; during the day, the temperature exceeded 30 °C, relative humidity was around 20 % (observations recorded with a portable meteorological kit) and the humidity of fine fuels reached 3 %. The fire had superficial and aerial phases in several areas (the latter in plantations of white cedar, casuarina, eucalyptus and pine; natural vegetation of oak, true fir forest and chaparro oak scrub). Some observations of surface fire behavior were made, recording flame lengths > 4 m and propagation rates > 40 m min^{-1}. Also, in crown fires, flame lengths of up to 15 m were recorded (Figure 1) (personal observations of the third author).

The Mario Avila Experimental Forestry Station ("Las Cruces"), of the Universidad Autónoma Chapingo, summarizes all of the above, since it is located within the area

Figure 1. A) Panoramic view of the 2017 fire at the piedmont of Tlaloc volcano; B) Intense surface phase of fire in the area; C) View of a crown fire in white cedar plantations. Pictures: Dante A. Rodríguez T.

affected by the fire and contains most of the planted species and types of vegetation mentioned above. *Casuarina equisetifolia* is a tree native to Australia and Papua, introduced in Mexico in the first quarter of the last century, for the successful fixation of dunes in Veracruz (Pennington and Sarukhán, 2005), as it has also had success in several countries because it fixes nitrogen and has social, economic and environmental importance (Rojas-Sandoval and Acevedo-Rodríguez, 2021), although it is currently considered invasive, for example, in the Natural Protected Area of Cozumel, where it reduces composition and alters structure in the native vegetation (Zaldívar-Cruz *et al.* , 2022). The species can thrive in a wide range of ecological conditions and has therefore been planted throughout Mexico, mainly in reforestation and dune fixation programs on the Gulf coast; it is also used to form windbreaks and as an ornamental plant. It is a monopodic tree up to 18 m tall and 65 cm in diameter; outer bark fissured, dark brown, with a thickness of 10 to 13 mm; the twigs that bear the leaves (scaly, triangular) are green, the twigs of growth, brown; dioecious species, sometimes monoecious, male flowers in whorls, the female in dense spikes; samaroid fruits, grouped in an ovoid cone that opens as a capsule (Pennington and Sarukhán, 2005).

Regarding the fire ecology of the species, it has been observed that individuals > 8 cm in normal diameter succumb to fire, and that individuals smaller than this diameter survive and resprout from the base, starting from the root crown. It is considered that in sites affected by fire, or outside of them, casuarina can regenerate by seed one or two years after the fire; such seed is transported by wind, animals or water currents (Snyder, 1992).

It is necessary to study fire ecology and the effects of fires in national plantations, with species such as casuarina. As far as could be investigated, this topic has not been addressed in the country with the species of interest despite the extent of this exotic often affected by fire. In fact, globally, conifers have been more studied in this regard than hardwood species (Cansler *et al*., 2020), such as *Casuarina*. It was hypothesized that the probability of tree mortality is inversely related to tree dimensions (diameter and height) and positively related to the level of fire severity (height of the scar on the trunk). The objective of the study was to establish the fire severity and dasometric variables that influence the probability of mortality and resprouting in *Casuarina equisetifolia* L. plantations affected by fire. Research questions include: Is there a direct or indirect relationship between the probability of mortality and the different explanatory variables considered, and is there a critical size at which mortality and resprouting increase?

MATERIALS AND METHODS

Study area

Las Cruces Experimental Forest Station is located between parallels 19.45° and 19.47° N and meridians 98.83° and 98.80° W, between 2480 and 2640 m altitude; it has 325.75 ha for conservation and restoration, and its main objectives are teaching and research. The *C. equisetifolia* plantations affected during the fire were established for restoration purposes. Within Las Cruces there are mixed plantations of *Eucalyptus* and *Casuarina* with an area of 102 ha; those of the latter species cover about 50 ha and it is estimated that half of them were affected by the aforementioned fire. This fire occurred during the peak of the 2017 fire season in April.

Field sampling

In the months of September, October and November 2019, stratified random sampling was carried out by qualitatively locating areas with different levels of severity (mortality), by fire, of *C. equisetifolia*. There were 15 sites of 100 m^2. The sample was 1500 m^2, which corresponds to a sampling intensity of 0.3%, considered representative in forest inventories (Romahn-de la Vega and Ramírez-Maldonado, 2010). Likewise, based on the number of trees per site of this sample and applying the formula referred to by Torres-Rojo and Magaña-Torres (2001), for estimating sample size in stratified random sampling, considering a value of E = 4 (maximum desired variation in number of trees per site), as well as two strata of density (< 30 trees/site and ≥ 30 trees/site), a sample of 12 was obtained, so that of the present study (15) is appropriate. A total of 442 sample trees were obtained.

Each tree was recorded as to whether it was alive or dead, as well as dasometric variables and fire severity. Among the first are: normal diameter (cm) with a diametric tape, bark thickness (mm) with a bark meter, total height (m) and height to the lowest branch (m), with clinometer or 2 m-length wooden ruler, according to height, crown diameter (m) and distance between trees (m), the last two with a tape measure. From the latter, the following were obtained: height of lethal scorch on the crown (m), height to live foliage (m) and height of burn scar on the trunk (m) with a wooded ruler, and it was also recorded whether there were resprouts at the base of the trunk, on the trunk or on the crown.

As an example of the variability of dimensions captured during sampling, trees were recorded with heights from 2 to 20 m (mean = 9.1 m), normal diameter from 2 to 30 cm (mean = 13.4 cm), bark thickness from 0.2 to 1.2 cm (mean = 0.5 cm) and scar height above the trunk from 0 to 16 m (mean = 3.5 m).

Statistical analysis

The logistic procedure (PROC LOGISTIC) of the SAS program (v. 9.0 for microcomputers) was used to obtain the probability of mortality and resprouting using logistic models based on tree dasometric and fire severity variables. The model has the following general expression (Hosmer *et al*., 2013):

$$Pm = \frac{1}{1 + e^{-(\alpha_1 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n)}}$$

Pm = probability of mortality, e = base of natural logarithms (= 2.7182), α_1 = constant (intercept), β_1, ... β_n = constants associated with the independent variables, X_1,... X_n= independent variables (fire scar height, total height, tree diameter, etc.).

The models were selected when: they were significant in all their explanatory variables, the confidence interval of each of them did not contain the value 1 (which would imply that the odds ratio or probability of occurrence between the probability of non-occurrence was equal to 1), relevant concordance of at least 40 %. Likewise, the Hosmer-Lemeshow goodness-of-fit test (Hosmer *et al*., 2013) was performed, with the null hypothesis that the data do not fit a logistic distribution. Therefore, non-significant results ($p > 0.05$) in the test were adequate to consider the model tested as robust. This type of regression was used because the independent variable is binomial (mortality or regrowth), inference is obtained on the relevance and performance of each variable considered, whether it is a positive or negative relationship and provides well-calibrated probabilities (Hosmer *et al*., 2013).

RESULTS AND DISCUSSION

Mortality probability

A mortality rate of 63% was found in casuarinas two years after the forest fire (Figure 2). Significances of the intercept, variables, confidence intervals for each variable, concordance and goodness-of-fit test of the significant models for the present study are provided (Table 1). The models found and their trends are as follows:

Probability of mortality (Pm) with respect to height (A, m):

$$Pm = \frac{1}{1 + e^{-(1.7762-0.1321A)}} \quad (1)$$

The trend indicates that the higher the tree height, the lower the probability of mortality (Figure 3A). In other words, a 5 m tall individual is more likely to die than a 20 m tall individual.

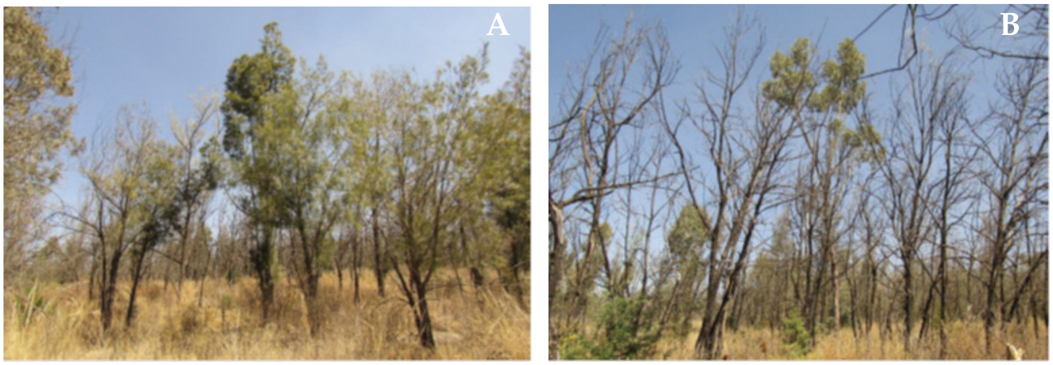

Figure 2. A) Area of moderate severity, with survival of casuarinas; B) zone of high severity, with almost total mortality of casuarinas. In the latter, note in the background that the eucalyptus survived the fire. Pictures: M. Magdalena Hernández R. and Ana L. Leyva V.

Table 1. Significance, confidence interval, concordance and goodness-of-fit test for mortality probability models.

Model	Variables	*p* intercept	*p* variable	IC (95%)	C (%)	*p* BA
1	A	< 0.0001	< 0.0001	0.831 – 0.924	64.0	> 0.05
2	DN	< 0.0001	< 0.0001	0.880 – 0.939	67.2	> 0.05
3	GC	< 0.0001	0.0298	0.159 – 0.910	48.0	> 0.05
4	ACT	0.0004	< 0.0001	1.354 – 1.733	71.6	> 0.05
5	A	< 0.0001	< 0.0001	0.591 – 0.719	88.5	> 0.05
	ACT		< 0.0001	2.051 – 3.334		
6	GC	0.0012	< 0.0001	0.002 – 0.039	82.6	> 0.05
	ACT		< 0.0001	1.775 – 2.663		
7	A	< 0.0001	0.0236	0.764 – 0.981	92.2	> 0.05
	DN		< 0.0001	0.705 – 0.832		
	ACT		< 0.0001	2.581 – 4.752		

IC: confidence interval; C: concordance; BA: goodness-of-fit test; A: total height; DN: normal diameter; GC: bark thickness; ACT: height of the burn scar over the trunk.

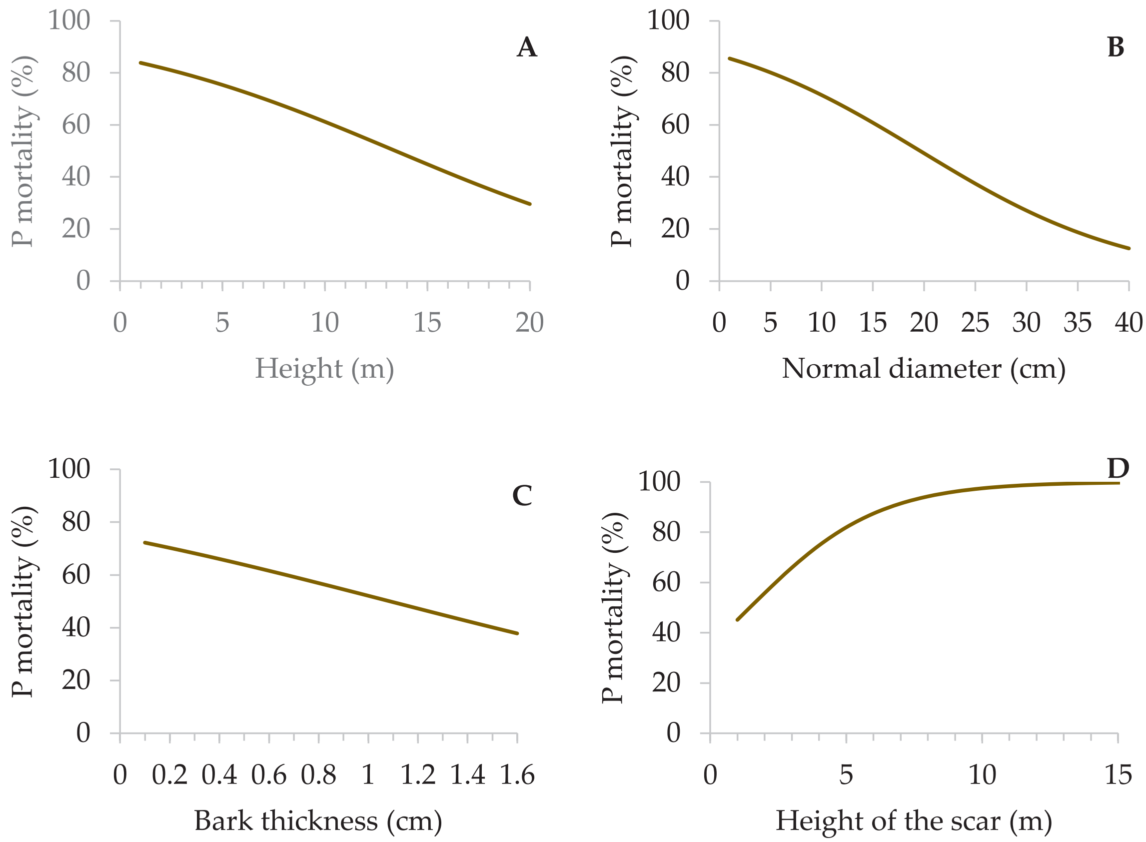

Figure 3. Effect of dasometric variables on the probability of mortality of *Casuarina equisetifolia*. A) height; B) normal diameter; C) bark thickness; D) height of the burn scar on the trunk.

It is clear that a tall, well-developed tree will have lower mortality in forest fires. This trend has been recorded in another relatively fire-sensitive species in the valley of Mexico, the oyamel, *Abies religiosa* (Kunth) Schltdl. & Cham. Six months after a canopy forest fire in southern Mexico City, around 2011, Temiño-Villota *et al*. (2016) obtained logistic models yielding mortality probabilities of 95 % and 38 % for trees with heights of 2 and 20 m, respectively. These probabilities are similar to those obtained for casuarina in the present work, with 82 and 30 %, respectively.

In contrast, in a superficial forest fire in Chiapas, in stands of the fire-adapted species *Pinus oocarpa* Schiede ex Schltdl., with high intensity and severity (1.5 m mean height of burn scar on the trunk) and with mortality of 48.8 %, the mortality probabilities for trees of 2 and 20 m, based on the logistic models of this work (Rodríguez-Trejo et *al*., 2019), were 80 and 7 %, indicating that in this fire-adapted species, although mortality of juveniles is also high, that of adult trees is significantly lower. In some cases, height is considered as the main attribute that allows tree survival, even more than bark thickness, as Rodríguez-Cubillo *et al*. (2021) report for tree species of the Brazilian savanna (cerrado).

Probability of mortality with respect to normal diameter (DN, cm):

$$Pm = \frac{1}{1 + e^{-(1.8706-0.0954DN)}} \quad (2)$$

As with the previous variable, the larger the normal diameter, the lower the probability of post-fire mortality. An individual with a DN of 5 cm is four times more likely to die than an individual with a DN of 40 cm (Figure 3B).

Based on the present work and the sources cited in the previous paragraph, the probability of mortality for trees with 2 and 30 cm of normal diameter was: 84 and 27 % for casuarina, 84 and 76 % for oyamel and 83 and 4 % for *P. oocarpa*. Another species relatively sensitive to fire in semi-arid environments, *Juniperus deppeana* Steud. also showed higher probability of mortality at smaller diameters (Rodríguez-Trejo and Pausas, 2019). In general, trees with larger diameters tend to have thicker bark that protects them by insulating the vascular cambium from the heat of fire (Scott *et al*., 2014). The probability of mortality for oyamel trees with large diameters, 30 cm, markedly exceeded that of casuarina, while that of pine was very low, showing adaptation to fire and that it tends to have a thicker bark (mean of 11.5 mm for this pine, according to Rodríguez Trejo *et al*. (2019), compared to 5 mm for casuarina). Again, a greater sensitivity to fire is observed for the latter, compared to pine.

Mortality probability with respect to bark thickness (GC, cm):

$$Pm = \frac{1}{1 + e^{-(1.0506-0.968GC)}} \quad (3)$$

The greater the bark thickness, the lower the probability of mortality (Figure 3C). A tree with a bark thickness of 0.5 cm is almost twice as likely to die as a tree with a bark thickness of 1.6 cm.

Bark thickness is directly related to normal diameter and the thermal insulation capacity of the bark is a function of the square of the bark thickness (Peterson and Ryan, 1986). Likewise, variability in bark thickness is partly explained by variability in fire regimes, as frequent surface fires select trees towards thick bark (Pausas, 2017). Hence the clear tendency in casuarina to reduce the probability of mortality with greater bark thickness. For example, with 2 mm, the probability of mortality reaches 70 %, but is reduced to 47 % with 12 mm. On the other hand, Madrigal *et al.* (2019) found that the critical bark thickness for *Pinus pinea* L., under which the heat flow rate allows reaching lethal cambium temperatures quickly, is 20 mm. It should be noted that other bark properties also influence its insulation capacity, such as its moisture content, surface structure, and density; however, the property that most influences insulation, is bark thickness, as Wei *et al.* (2019) found for *Quercus mongolica* Fisch. ex. Turcz.

Probability of mortality with respect to the height of the burn scar above the trunk (ACT):

$$Pm = \frac{1}{1 + e^{-(-0.6217+0.4264ACT)}} \quad (4)$$

In this case, the trend indicates that the higher the scar height, the higher the probability of tree mortality (Figure 3D). In the relatively fire-sensitive species *Juniperus deppeana*, the same trend was observed (Rodríguez-Trejo and Pausas, 2019).

Mortality probability as a function of total height and burn scar height above the trunk:

$$Pm = \frac{1}{1 + e^{-(2.0022-0.4283A+0.9612ACT)}} \quad (5)$$

Two years after the fire, the probability of mortality of the studied species increases as the height of the scar left by the fire on the trunk increases. Likewise, this tendency is more pronounced as the height of the tree decreases; for trees 5 m tall, the probability of mortality increases significantly even for low values of trunk scar height; for trees 10 m tall, the ratio is almost linear, while for trees 15 m tall, the probability of mortality is low with small values of trunk scar, but it increases strongly from 3.5 m of trunk scar height onwards (Figure 4A).

Mortality probability as a function of bark thickness and height of burn scar on the trunk:

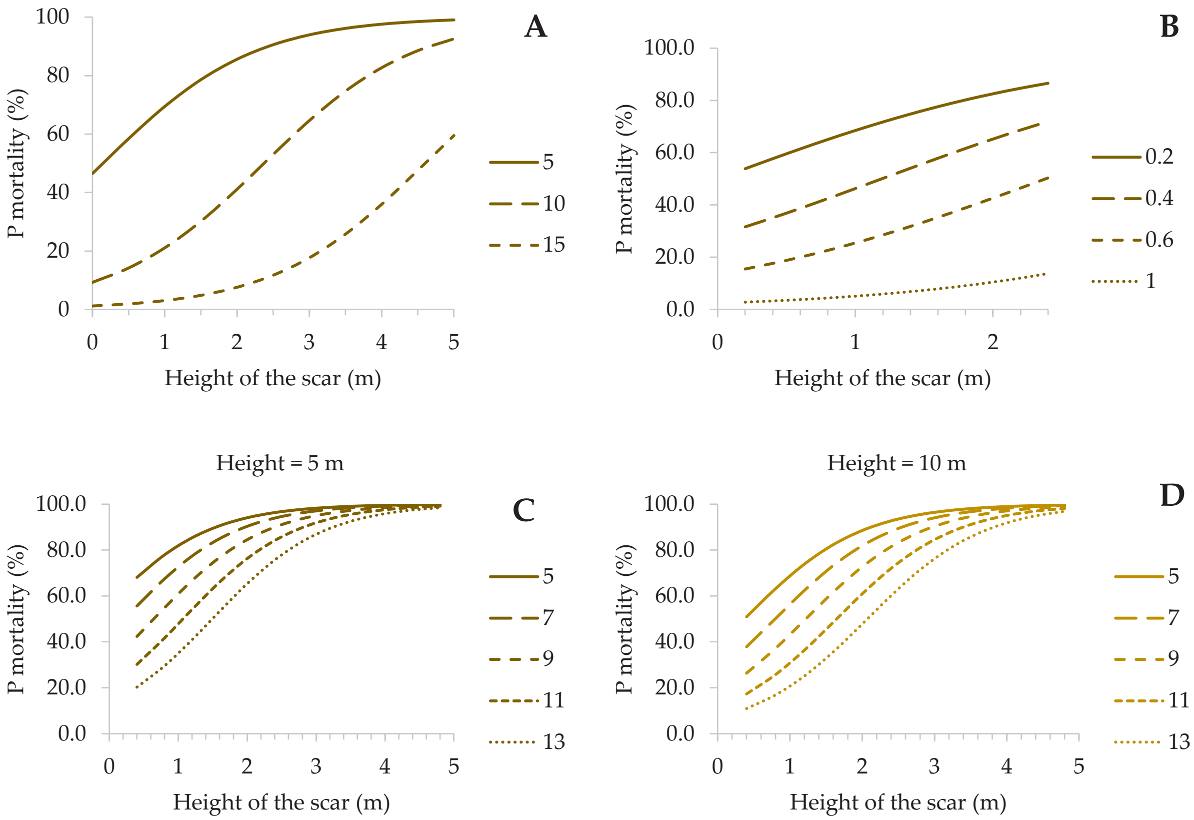

Figure 4. Mortality probability for *C.equisetifolia* with respect to interactions between A) total height and the height of the burn scar on the trunk; B) bark thickness and height of the burn scar on the trunk; C) total height, height of the burn scar on the trunk and normal diameter.

$$Pm = \frac{1}{1 + e^{-(0.924 - 4.6246GC + 0.7766ACT)}} \quad (6)$$

The thinner the bark and the higher the height of the scar, the higher the probability of mortality. Thin bark thicknesses (e.g., 0.2 cm) exhibit high mortality probabilities (as much as 50 %) even with trunk scar heights of only 0.1 m, while thick bark, 1 cm, slightly exceeds 10 % mortality probability even with trunk scar heights of 2. 5 m (Figure 4B).

Probability of mortality from total height, normal diameter and height of burn scar on the trunk:

$$Pm = \frac{1}{1 + e^{-(2.3139 - 0.1446A - 0.2665DN + 1.2533ACT)}} \quad (7)$$

The probability of mortality increases as the height of the scar increases over the trunk; similarly, it increases as the diameter is reduced. Such increases in the first variable are higher in smaller trees (e.g., 5 m tall), with respect to taller trees, 10 m tall, as an example (Figure 4C, left and right plots, respectively).

The fire scar on the trunk is directly related to the flame length of the surface fire, i.e. the intensity of the fire (energy release) and the more intense it is, the greater the severity and mortality (Scott *et al*., 2014). Based on the average trunk scar height of the burned casuarina plantation, 3.5 m, which denotes a high fire intensity, with flame lengths of at least this dimension (because the wind tends the flame and this is longer than the burn scar remaining on the trunk of the trees), the probability of mortality for this average trunk scar height reaches 70%, very similar to the average mortality (63%) found in this research.

Probability of resprouting

Of the 442 trees sampled, only 12 % showed resprout of some kind (55 trees); of these, 49 % showed basal resprout, 27 % crown resprout and 24 % epicormic resprout. The probability of resprout, two years after the fire, was calculated in general, including the three types of resprout. Significances of the intercept, variables, confidence intervals for each variable, concordance and goodness-of-fit test of the significant models for the present study are provided (Table 2). The following three models were significant.

Table 2. Significance, confidence interval, concordance and goodness-of-fit test for resprouting probability models.

Model	Variables	*p* intercept	*p* variable	IC (95%)	C (%)	*p* BA
8	DN	0.0353	< 0.0001	0.850 - 0.942	65.7	> 0.05
9	GC	0.0103	0.0019	0.027 - 0.442	57.4	> 0.05
10	ACT	< 0.0001	0.0026	0.706 - 00929	69.7	> 0.05

IC: confidence interval; C: concordance; BA: goodness-of-fit test; DN: normal diameter; GC: bark thickness; ACT: height of the burn scar over the trunk.

Resprouting probability (Pr) as a function of normal diameter:

$$Pr = \frac{1}{1 + e^{-(-0.6483-0.1112DN)}} \quad (8)$$

The probability of resprouting is greater in juveniles than in adults, since the probability of resprouting is reduced as the diameter increases (Figure 5A).

Although there was resprouting in casuarina and it was possible to model it, it is not an intense resprouting, as it occurs in fire-tolerant species. An example of the latter is *Quercus crassifolia*, for which based on the logistic model of Juárez-Bravo *et al.* (2012), for the referred oak, a year and a half after a high intensity and severity, mixed fire, the

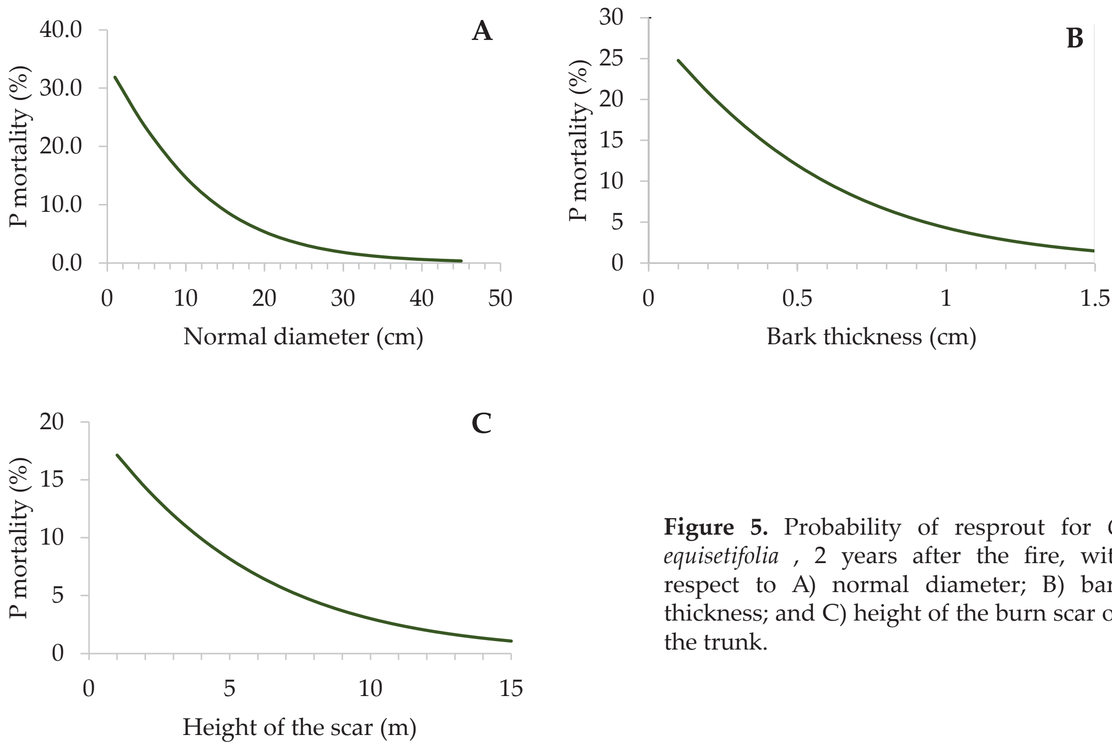

Figure 5. Probability of resprout for *C. equisetifolia* , 2 years after the fire, with respect to A) normal diameter; B) bark thickness; and C) height of the burn scar on the trunk.

probability of resprouting is high, for example 92 % for normal diameters of 13. 4 cm and a lethal crown height of 4.5 m; while for casuarina, considering both a similar fire intensity and the same diameter, the probability of resprouting is only 8 %. In the same study area of the present work, Herrera-Ramos *et al.* (2022) report that after a severe fire in plantations of *Eucalyptus camaldulensis* Dehnh, 100 % of the eucalyptus trees showed resprouting, which shows one of the reasons why eucalyptus is considered fire-adapted (Gibson and Hislop, 2021).

Probability of resprouting as a function of bark thickness:

$$Pr = \frac{1}{1 + e^{-(-0.8894-2.2148GC)}} \quad (9)$$

The greater the bark thickness, the lower the probability of resprouting (Figure 5B).

Probability of resprout as a function of the height of the burn scar above the trunk:

$$Pr = \frac{1}{1 + e^{-(-1.3655-0.2107ACT)}} \quad (10)$$

The results of the present study show that the higher the height of the scar above the trunk, the lower the probability of resprouting (Figure 5C). It has been said that as the crown of a fire tolerant species is more affected, it tends to resprout better (as long as it is not dead, obviously), because together with part of the crown, more auxins are eliminated, which, present in the buds, inhibit resprouting. Without this physiological limitation, and as there are buds that survive protected by their scales and bark, resprouting occurs. However, in the species studied this response is infrequent, of low probability and not numerous in the trees that show it. On the other hand, the greater resprouting in smaller and younger individuals denotes the greater vigor for vegetative propagation that Davies *et al*. (2017) refer to for young plants and branches. Most of the resprouts were basal (49 %) and were found mainly at the base of trees with dead trunks. Whether resprouting from the base or from buds on the trunk, they are key to tree recovery and ecosystem function. This type of resprouting is considered to be an adaptation to fire in forest ecosystems with high fire frequency, high intensity and on sites with relatively high productivity. These types of species are more resilient to crown fires (Pausas and Keeley, 2017).

However, *C. equisetifolia*, unlike other species that are clearly adapted to fire, although they share the tendency of greater resprouting when young, the higher levels of damage to the trunk or crown promote greater resprouting and, in addition, the proportion of individuals that resprout is much higher. The latter is the case of *Arbutus xalapensis* (89 % of individuals with post-fire resprouting) and *Quercus* spp. (76 %) in the Sierra Norte de Puebla (Gómez-Mendoza and Rodríguez-Trejo, 2021). According to the quantitative results of the present research, *Casuarina equisetifolia*, with thin bark and poor resprouting capacity, is a species that tends to be sensitive to fire, as Snyder (1992) had qualitatively classified it.

In the United States, the mortality of *Casuarina* in plantations has been evaluated. Snyder (1992) reports that in Florida, a forest fire in May killed 60 to 70 % of a *Casuarina* spp. plantation and notes that, through prescribed burning, 90 (almost without resprouting) to 100 % of the *C. equisetifolia* trees (with normal diameters of 13 to 20 cm) are killed. In the present study, mortality was 63%, similar to that of the first study, although lower than that of the second investigation.

While in Australia, within the genus *Casuarina*, there are species that benefit from fire (fire-adapted), there are also those that benefit from fire protection (fire-sensitive) (Bowman, 1998). However, adaptation to fire in several of the former is rather moderate, as is apparently the case of *C. equisetifolia.*

There is paleoecological evidence on how a moderate presence of fire can favor communities with species of the genus *Casuarina*, but when fires become more frequent, the community changes in favor of *Eucalyptus* species, which are more tolerant to fire. On Kangaroo Island, Australia, during the Holocene, there was little fire activity, as shown by evidence of few charcoal accumulations on the ground, which favored the presence of relatively fire-sensitive *C. stricta* Miq. forests. But about 5000 years ago precipitation decreased, fire frequency increased, and such forests were replaced by *Eucalyptus* forests (Kershaw *et al.*, 2002). There is also current evidence of a phenomenon similar to the above. Lunt (1998) notes that Australian forests unburned for many years, with *E. ovata* Labill., *E. viminalis* Labill. and E. *leucoxylon* F.Muell. were replaced by low forests or thickets of *C. littoralis* Salisb.

CONCLUSIONS

As a result of the high intensity and severity of the fire, mortality was high, 63%, in the casuarina plantations. The probability of mortality was inversely related to tree height, normal diameter and bark thickness, as individual dasometric variables or in different interactions between them, and directly related to the severity variable height of the fire scar on the trunk. In particular, the relevance of bark thickness as a means of thermal insulation to the vascular cambium is corroborated, since the species studied does not have a particularly thick bark. Resprouting was scarce (12 %) and the greatest potential for resprouting was evidenced in young individuals, since the probability of resprouting was inversely related to the variables normal diameter, bark thickness and height of the scar on the trunk. Although it was observed that the species shows some fire resistance (in larger individuals, with low fire severity), as well as some fire tolerance (minimal resprouting), it is rather a fire-sensitive species.

The high mortality in these plantations generated a large accumulation of forest fuels that need to be removed and managed (removed as firewood or logs, accommodated, dispersed, even eliminated by prescribed burning in areas of total mortality) in the affected areas, which for that reason currently have a greater danger of forest fire. Likewise, the areas affected by the fire at lower intensity and severity show that fire management in plantations with adult trees of the species studied should not only focus on fire prevention, but should also use fire (through prescribed burns) infrequently and at low intensity and severity, in order to reduce fire danger. The mortality probability models obtained have a potential utility to help determine a priori, based on the obtained dasonomic and fire severity variables, the areas that will present high mortality and therefore should be reforested or restored (including the removal or settlement of dead materials). It is also possible to determine which areas will have low mortality and which should not be reforested. This can be estimated almost immediately after the fire, using the models of this study.

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