



Germination and seedling emergence of four endangered oak species

Germinación y emergencia de plántulas de cuatro especies de encino amenazadas

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ABSTRACT

Germination and emergence of the endangered cloud forest oak species *Quercus germana*, *Q. insignis*, *Q. sartorii* and *Q. xalapensis* were observed under different light conditions (sun *vs.* shade) in a secondary forest fragment (SFF) and in a greenhouse (GRE). Seed weight variability was evaluated for each species and its relationship to germination and emergence determined. After 60 days, a total of 62.17% of the acorns had germinated and 37.79% had emerged in both experiments. Germination was highest in *Q. sartorii* (71.83% ± 2.09%), followed by *Q. germana* (66.33% ± 2.06%), *Q. insignis* (60.83% ± 2.34%) and *Q. xalapensis* (53.50% ± 2.32%). In the GRE, *Q. insignis* germination was higher under sun (62.00% ± 4.73%) than shade (48.00% ± 5.12%), whereas its emergence was the lowest (37.66% ± 3.46%) compared to other species in both light environments. In the SFF, germination and emergence only differed among species; *Q. xalapensis* germination was lowest (47.00% ± 3.11%) and *Q. sartorii* emergence was highest (58.66% ± 3.35%), compared to the other species. Acorn weight did not influence germination or emergence in any species. The implications of this study are discussed, along with recommended propagation techniques for growing oaks for forest restoration in disturbed areas.

KEYWORDS: early seedling establishment, light environment, *Quercus*, seed mass, tropical montane cloud forest.

RESUMEN

La germinación y emergencia de encinos amenazados del bosque de niebla, *Quercus germana*, *Q. insignis*, *Q. sartorii* y *Q. xalapensis* fue evaluada bajo diferentes condiciones lumínicas (sol *vs.* sombra) en un fragmento de bosque secundario (SFF) y un invernadero (GRE). Para cada una de las especies, la variabilidad del peso de la semilla fue relacionada con la germinación y emergencia. Después de 60 días, en ambos experimentos, un total de 62.17% de las bellotas germinaron y 37.79% emergieron. La germinación fue mayor en *Q. sartorii* (71.83% ± 2.09%), seguido de *Q. germana* (66.33% ± 2.06%), *Q. insignis* (60.83% ± 2.34%) y *Q. xalapensis* (53.50% ± 2.32%). En el GRE, la germinación de *Q. insignis* fue mayor bajo el sol (62.00% ± 4.73%) que bajo la sombra (48.00% ± 5.12%), mientras que su emergencia fue la más baja (37.66% ± 3.46%) comparada con otras especies en ambos ambientes lumínicos. En el SFF, la germinación y emergencia solo fueron diferentes entre especies; *Q. xalapensis* registró la germinación más baja (47.00% ± 3.11%) y *Q. sartorii* la emergencia más alta (58.66% ± 3.35%) comparada con el resto de las especies. El peso de la bellota no influyó en la germinación y emergencia de las especies. Se discuten las implicaciones de este estudio, así como recomendaciones sobre técnicas de propagación para la producción de encinos para restaurar bosques en áreas perturbadas.

PALABRAS CLAVE: establecimiento temprano de plántulas, ambiente lumínico, *Quercus*, peso de semilla, bosque de niebla.

INTRODUCTION

Tropical montane cloud forests (TMCF) are a group of mountain communities characterized by the frequent presence of cloud and normally high levels of relative air humid-

ity (Hamilton, Juvik, & Scatena, 1995). Their physiognomy, structure and composition depend on factors such as latitude, elevation, wind and precipitation patterns, as well as evolutionary history, all of which lead to the high beta

diversity reported for this forest type (Bubb, May, Miles, & Sayer, 2004). Worldwide, TMCF cover a mere 0.14% of the land surface (Scatena, Bruijnzeel, Bubb, & Das, 2010) and are considered one of the most endangered ecosystems because of their limited distribution and the high rates of deforestation to which they are subjected (Toledo-Aceves, Meave, González-Espinosa, & Ramírez-Marcial, 2011).

Oaks (genus *Quercus*) are an important component of TMCF, since they are dominant canopy species of high importance values and can generate microenvironments that are suitable for the establishment of other species (Kapelle, 2006). Mexico has the highest richness of oaks in the world, with approximately 160 species (109 endemic species; Valencia, 2004; Valencia & Gual-Díaz, 2014). Of these, 38 have been reported in the TMCF of Mexico and 33 of these are at some degree of risk (González-Espinosa, Meave, Lorea-Hernández, Ibarra-Manríquez, & Newton, 2011).

Despite the risk of extinction of the oak populations that dominate TMCF canopies, little is known about their regeneration ecology (Valencia & Gual-Díaz, 2014). While they are considered intermediate or late successional species, some species have been reported to successfully regenerate in open areas and thus demonstrate potential for use in ecological restoration programs (López-Barrera, Manson, González-Espinosa, & Newton, 2006; Ramírez-Marcial, Camacho-Cruz, González-Espinosa, & López-Barrera, 2006). However, for other oak species, different limiting factors that affect regeneration have been documented in open areas and difficulties have been reported in terms of their conservation (Quintana-Ascencio, González-Espinosa, & Ramírez-Marcial, 1992; Ortega-Pieck, López-Barrera, Ramírez-Marcial, & García-Franco, 2011; Montes-Hernández and López-Barrera, 2013).

Several studies have analyzed early establishment in oaks and compared different habitats, including: a) forest successional stages (Li and Ma, 2003; Gómez, 2004; González-Rodríguez, Barrio, & Villar, 2012), b) light gradients within the forest (Gómez-Aparicio *et al.*, 2008; Pérez-Ramos, Gómez-Aparicio, Villar, García, & Marañón, 2010), c) open sites *vs.* closed canopy forest

(Negi, Negi, & Singh, 1996; Fan, Guo, Wang, & Duan, 2014) and different light environments under greenhouse and laboratory conditions (Khan and Shankar, 2001; Quero, Villar, Marañón, Zamora, & Poorter, 2007). Temperature, light and humidity have been identified as the most important factors for the germination and emergence of oak seedlings (Ashton and Larson, 1996; Puer-ta-Piñero, Gómez, & Valladares, 2007).

Other factors have been identified that affect germination and emergence in oaks, including maternal origin (González-Rodríguez *et al.*, 2012), seed size (Tripathi and Khan, 1990), insect damage (Branco, Branco, Merouani, & Almeida, 2001; Yi and Zhang, 2008) and substrate characteristics (López-Barrera and González-Espinosa, 2001; Li and Ma, 2003; Flores-Cano, Badano, & Flores, 2012). These studies have demonstrated that the responses of the oaks to the evaluated factors are species specific; however, most of the study has been conducted with oaks of the temperate zone in forests dominated by a few species and little information is available about the effect of the light environment and seed quality on germination and emergence in the oak species that coexist in TMCF (Camacho-Cruz, González-Espinosa, Wolf, & De Jong, 2000).

OBJECTIVE

The objective of this study was to evaluate and compare the germination and emergence of four endangered oak species in TMCF (*Quercus germana*, *Q. insignis*, *Q. sartorii* and *Q. xalapensis*) in two experiments carried out in (1) a secondary forest fragment (SFF) and (2) a greenhouse (GRE), each featuring two light environment treatments (sun *vs.* shade). Acorn weight variability was also evaluated for each species and examined in the context of germination and emergence.

MATERIALS AND METHODS

Study species

Species were selected based on seed availability and the following criteria: 1) species were co-dominants of the TMCF canopy, 2) species were included on the red list of



Mexican tropical montane tree species (González-Espinosa *et al.*, 2011), 3) species were white or red oaks, and 4) seed weight and size were highly variable between species. *Quercus germana* (Schlttdl. & Cham.) and *Quercus insignis* (M. Martens & Galeotti) belong to the *Quercus* section (white oaks) and are classified as critically endangered species. *Quercus sartorii* (Liebm.) belongs to the *Lobatae* section (red oaks). It is classified as an endangered species but there is no information about its regeneration ecology. *Quercus xalapensis* (Bonpl.) is also a red oak and is classified as a critically endangered species. *Quercus germana* and *Q. sartorii* are endemic to Mexico, while *Q. insignis* and *Q. xalapensis* occur in Mexico and Central America (González-Espinosa *et al.*, 2011).

Germination and emergence tests

This study was conducted in a secondary forest fragment, SFF (19° 27' 59.7" N and 96° 57' 09.1" W) and a greenhouse, GRE (19° 28' 00.6" N and 096° 57' 08.1" W) located in the municipality of Coatepec, in central Veracruz, Mexico (1250 m asl). The regional climate is tropical with a mean annual temperature of 17 °C - 20 °C (García, 1973) and mean annual rainfall of 1700 mm (Barradas *et al.*, 2010). The SFF is dominated by several arboreal species, including *Q. germana*, *Q. leiophylla*, *Alchornea latifolia*, *Clethra mexicana*, *Heliocarpus appendiculatus* and *Persea schiedeana*, among others. This site was TMCF but was then converted into a coffee plantation (1942) and subsequently abandoned 15 years ago (2000). Two light conditions were selected in the SFF: a 20 m x 20 m canopy gap (sun) and a 20 m x 20 m area with a closed canopy (shade). In the GRE, two light conditions were created: sun or open conditions (under a transparent plastic cover) and partial shade (created using a black shade cloth that blocked 30% of the light). In each treatment, Photosynthetically Active Radiation (PAR) was recorded once a month (November and December 2012) using the average of 30 readings taken over an hour with a ceptometer (Decagon LP-80) connected to an external sensor for calibration. This sensor was also useful for taking reference PAR readings in open conditions when measurements were taken

in the shade in SFF and in the GRE. To that end, the measurement units ($\text{mmol m}^{-2} \text{s}^{-1}$) were expressed as percentages of the values measured in open conditions. Air temperature and relative humidity were measured in each treatment using sensors (HOBO Pro Series Onset); readings were taken every 10 minutes during 60 days.

In October 2012, approximately 800 acorns were collected from ten trees of each species. Acorns of *Q. germana*, *Q. sartorii* and *Q. xalapensis* were collected from a TMCF fragment in Xalapa, Veracruz, while those of *Q. insignis* were collected from a TMCF fragment in Huatusco, Veracruz. Damaged seeds were discarded using the float method (Gribko & Jones, 1995). Each acorn was weighed, measured (length and width) and individually labeled to facilitate individual monitoring during the germination trials. Prior to the experiment, an adhesive label was used on each acorn for identification. This label was removed when the acorns were sown and replaced with a plastic label indicating the position of each acorn, but not attached to it.

Five acorns per species were sown in black polyethylene bags (20 cm x 25 cm; 7850 cm^3) filled with a substrate composed of sieved SFF soil and fine gravel (50:50) sterilized using the solar method. A total of 600 acorns were sown per species (a total of 2400 acorns in 480 bags). A total of 120 bags were randomly assigned to each light condition in the SFF (sun and shade) and GRE (sun and shade) experiments. The bags were rotated to minimize edge effects and watered to field capacity every seven days (600 ml). The number of acorns that germinated and emerged was recorded every 10 days for 60 days, after no further germination or emergence occurred. Germination was defined as the first visual appearance of the radicle, while development of the aerial shoot was taken to define an emergence event.

Statistical analysis

The Pearson correlation coefficient (r) was used to analyze the relationships among morphometric acorn characteristics. The variable of final germination had a binary response (germinated or non-germinated), for which rea-

son generalized linear models (logistic regression, link function, binomial family) were performed to determine the effects of the factors of species (*Q. germana*, *Q. insignis*, *Q. sartorii* and *Q. xalapensis*), light environment (sun and shade) and acorn weight, as well as the interactive effect of species and light environment on germination and emergence. *Quercus germana* was excluded from the emergence analysis because of the low emergence presented by the species. To compare the germination and emergence curves, a survival analysis was performed using the Log-rank statistic (Kaplan-Meier) to analyze the temporal behavior of the variables. Logistic regression analyses were performed using R studio environment (v.0.98.1091) while the survival analysis was performed with SPSS (v.15.0). Values presented in the text are means \pm 1 standard error (SE), unless indicated otherwise.

RESULTS

Light environment

Available PAR in the SFF was $78.56\% \pm 3.34\%$ and $6.54\% \pm 2.21\%$ in the sun and shade experimental treatments, respectively. In the GRE experiment, available PAR was $46.33\% \pm 4.36\%$ and $4.24\% \pm 0.35\%$ in the sun and shade conditions, respectively. In the SFF, relative humidity and temperature under sun conditions were $90.50\% \pm 0.16\%$ and $16.04\text{ }^\circ\text{C} \pm 0.04\text{ }^\circ\text{C}$ respectively. Under shade conditions, these values were $89.32\% \pm 0.12\%$ and $15.70\text{ }^\circ\text{C} \pm 0.04\text{ }^\circ\text{C}$, respectively.

In the GRE, relative humidity and temperature values under sun conditions were $88.01\% \pm 0.19\%$ and $16.91\text{ }^\circ\text{C}$

$\pm 0.05\text{ }^\circ\text{C}$, respectively. Under shade conditions, these values were $91.01\% \pm 0.13\%$ and $16.37\text{ }^\circ\text{C} \pm 0.04\text{ }^\circ\text{C}$, respectively.

Acorn characteristics

The morphometric characteristics of the acorns are presented in table 1. There was greater variation in the weight of white oak (*Q. insignis* and *Q. germana*) acorns compared to those of the red oaks (*Q. xalapensis* and *Q. sartorii*). The maximum values and range of variation in acorn width, length and weight were observed in *Q. insignis* (Table 1). Acorn weight was correlated significantly to acorn diameter in *Q. insignis* ($r = 0.572$, $P < 0.0001$), *Q. germana* ($r = 0.122$, $P = 0.003$), *Q. sartorii* ($r = 0.530$, $P < 0.0001$) and *Q. xalapensis* ($r = 0.572$, $P < 0.0001$). Acorn width/length ratio (\pm SD) was 0.85 ± 0.05 for *Q. sartorii*, with similar values in *Q. insignis* and *Q. germana* (0.83 ± 0.13) but lower values in *Q. xalapensis* (0.68 ± 0.06).

Germination

After 60 days, 62.17% of the acorns in both experiments had germinated. Germination was highest in *Q. sartorii* ($71.83\% \pm 2.09\%$), followed by *Q. germana* ($66.33\% \pm 2.06\%$), *Q. insignis* ($60.83\% \pm 2.34\%$) and *Q. xalapensis* ($53.50\% \pm 2.32\%$). The germination curves revealed significant differences among species (Log-rank = 18.38, df = 3, $P < 0.001$). In all species, acorn germination began within the first 10 days of the experiment. During this period, *Q. germana* had the highest number of germinated seeds (42.50%), followed

TABLE 1. Morphometric characteristics of *Quercus* species. Data obtained from 600 fresh acorns from 10 trees of each species.

Species	Acorn weight (g)			Acorn width (mm)			Acorn length (mm)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
<i>Q. insignis</i>	34.54	10.25	8.60 - 74.49	41.36	5.63	23.16 - 63.98	40.81	5.25	25.27 - 52.19
<i>Q. germana</i>	10.60	4.32	1.34 - 28.12	25.41	4.42	13.57 - 35.97	30.57	3.72	19.18 - 42.05
<i>Q. sartorii</i>	3.05	0.66	1.33 - 5.26	15.70	1.34	10.86 - 19.78	18.60	1.59	13.46 - 22.79
<i>Q. xalapensis</i>	2.77	0.90	0.47 - 5.29	14.21	1.71	9.09 - 19.37	20.88	2.33	11.37 - 26.30



by *Q. insignis* (29.17%), *Q. xalapensis* (24.17%) and *Q. sartorii* (14%; Fig. 1).

In the GRE experiment, overall acorn germination was $62.83\% \pm 1.66\%$ and was affected by species (Table 2), as well as by the interaction between species and light conditions. *Quercus insignis* germination was higher under sun than under shade conditions ($P < 0.05$; Table 3). In the SFF experiment, overall acorn germination was $63.42\% \pm 1.58\%$ and germination was affected by species (Table 2). Neither light environment nor acorn weight had a significant effect on germination. *Quercus xalapensis*

presented the lowest germination value compared to the other species ($P < 0.001$; Table 3).

Emergence

After 60 days, 37.79% of the seedlings of all four species had emerged in both experiments. *Quercus sartorii* presented the highest degree of emergence ($56.16\% \pm 2.59\%$), followed by *Q. xalapensis* ($53.50\% \pm 2.32\%$), *Q. insignis* ($40.8\% \pm 2.27\%$) and *Q. germana* ($1.33\% \pm 0.45\%$). According to observations made at the end of the experiment, the low proportion of emergence in the latter species was the result of an apparent fungal attack on the germinated acorns. The emergence curves revealed significant differences among species (Log-rank = 301.90, df = 3, $P < 0.001$). In the first emergence count, *Q. xalapensis* had the highest value (24.33%), followed by *Q. insignis* (21.17%), *Q. sartorii* (11.17%) and *Q. germana* (0.83%; Fig. 1).

In the GRE experiment, overall emergence was $38.33\% \pm 2.13\%$ and differed among species. *Quercus insignis* was the species with the lowest emergence and differed ($P < 0.001$) from *Q. sartorii* and *Q. xalapensis*. In the SFF experiment, overall seedling emergence was $37.58\% \pm 1.96\%$ and differences were found between species only. Neither light environment nor acorn weight had a significant effect on emergence (Table 2). *Quercus sartorii* presented the highest emergence, compared to *Q. insignis* and *Q. xalapensis* ($P < 0.001$).

DISCUSSION

Acorn weight

Contrary to our expectations, intraspecific variability in acorn weight did not affect acorn germination or seedling emergence. Species with considerable intraspecific variation in seed size may present enhanced establishment in a heterogeneous environment (Quero *et al.*, 2007). Some studies have reported that heavier and larger acorns also present higher germination (Bonfil 1998; Purohit, Tamta, Nandi, Rikhari, & Palni, 2003), while others report no such correlation (Tilki & Alptekin 2005; Yi, Wang, Liu,

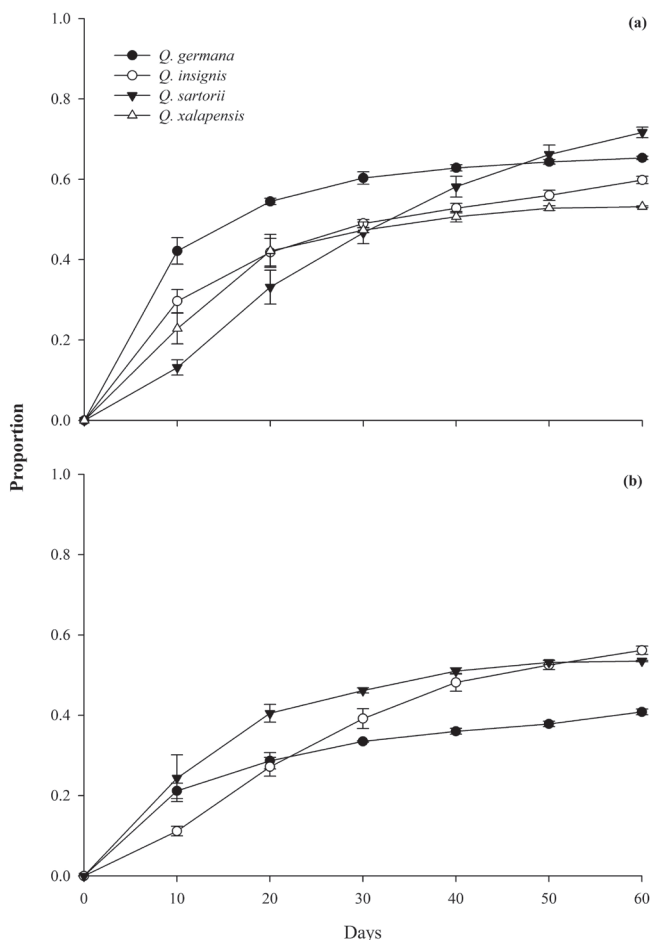


FIGURE 1. Proportion of a) germination and b) emergence in four *Quercus* species over a period of 60 days ($n=600$ acorns per species). Error bars indicate ± 1 standard error. *Quercus germana* was excluded from the emergence analysis because of the low emergence presented by this species.

TABLE 2. Results of the logistic regression model applied to *Quercus* species germination and emergence as a function of light environment (sun *vs.* partial shade), species (*Q. germana*, *Q. insignis*, *Q. sartorii* and *Q. xalapensis*) and acorn weight (continuous variable) in two experiments: Secondary Forest Fragment (SFF) and Greenhouse (GRE).

Germination		d.f.	Wald	p
SFF	Light environment	1	2.24	0.133
	Species	3	49.6	< 0.001
	Acorn weight	1	1.01	0.314
	Light environment × Species	3	7.69	0.052
GRE	Light environment	1	0.35	0.550
	Species	3	17.49	< 0.001
	Acorn weight	1	0.16	0.681
	Light environment × Species	3	10.11	0.017
Emergence		d.f.	Wald	p
SFF	Light environment	1	1.6	0.205
	Species	2	14.49	< 0.001
	Acorn weight	1	0.1	0.751
	Light environment × Species	2	1.46	0.480
GRE	Light environment	1	0.07	0.789
	Species	2	32.07	< 0.001
	Acorn weight	1	0.82	0.362
	Light environment × Species	2	0.44	0.800

Guoqiang, & Zhang, 2014). These differences can be attributed to specific-species responses, variation in maternal origin, differences in provenance and intraspecific temporal and spatial variability in the range of seed size and weight (Tilki & Alptekin 2005; Koenig, Knops, Dickinson, & Zuckerberg, 2009; González-Rodríguez *et al.*, 2012). Methodological factors such as acorn storage prior to the experiment, dry *vs.* fresh acorn weight and exclusive consideration of extreme seed size categories may also affect comparability between results (Seiwa 2000; Khan & Shankar 2001; Quero *et al.*, 2007). There is a clear need for long-term studies that more accurately reflect the variation in seed weight for each species, covering years of high and low seed production in order to accurately determine the intra and interspecific effect of acorn weight on germination and seedling establishment.

Species differences

The results of this study demonstrate that some of the evaluated species differ in terms of their rates and final values of germination and emergence. The studied white oak species (*Q. germana* and *Q. insignis*) mostly germinated within the first 10 days, which was more quickly than the red oaks (*Q. sartorii* and *Q. xalapensis*). This concurs with other reports of white oaks, which have been documented to germinate faster than red oaks in response to greater attack and browsing by predators (Fox 1982). White oak acorns are consumed more than those of the red oaks due to the larger seed size, greater cotyledon content and lower tannin content of the former. Tannins function as inhibitory toxins that deter predatory attack (Weckerly, Sugg, & Semlitsch, 1989; Smallwood, Steele, & Faeth, 2001).

TABLE 3. Percentages of germination and emergence (± 1 S.E.) for each of four *Quercus* species in two experiments.

		<i>Q. germana</i>		<i>Q. insignis</i>		<i>Q. sartorii</i>		<i>Q. xalapensis</i>	
		Germination	Emergence	Germination	Emergence	Germination	Emergence	Germination	Emergence
SFF	Sun	66.66 \pm 4.42	44.66 \pm 4.03	68.66 \pm 4.14	54.66 \pm 4.97	66.00 \pm 3.85	44.00 \pm 4.42	66.66 \pm 3.50	44.00 \pm 4.22
	Shade	66.66 \pm 3.50	43.33 \pm 4.29	64.66 \pm 4.03	62.66 \pm 4.47	80.66 \pm 3.89	50.00 \pm 4.57	66.66 \pm 2.79	50.00 \pm 4.57
	Total	66.66 \pm 2.79	44.00 \pm 2.92	66.66 \pm 2.87	58.66 \pm 3.35	73.33 \pm 2.87	47.00 \pm 3.11	66.66 \pm 2.79	47.00 \pm 3.11
GRE	Sun	60.66 \pm 5.11	39.33 \pm 5.02	62.00 \pm 4.73	54.00 \pm 5.84	72.66 \pm 3.64	59.33 \pm 4.64	71.33 \pm 3.13	59.33 \pm 4.64
	Shade	71.33 \pm 3.13	36.00 \pm 4.83	48.00 \pm 5.12	53.33 \pm 5.45	68.00 \pm 4.94	60.66 \pm 4.64	71.33 \pm 3.13	60.66 \pm 4.64
	Total	66.00 \pm 3.05	37.66 \pm 3.46	55.00 \pm 3.57	53.66 \pm 3.96	70.33 \pm 3.06	60.00 \pm 3.25	66.00 \pm 3.05	60.00 \pm 3.25

1. Secondary Forest Fragment experiment (SFF): sun treatment (under a canopy gap) and shade treatment (under closed canopy). 2. Greenhouse experiment (GRE): sun treatment (under transparent plastic cover) and partial shade treatment (under a shade cloth that reduced light by 30%). *Quercus germana* was excluded from the emergence analysis because of the low emergence presented by this species.

In spite of the high germination values of *Q. germana*, in this study, emergence of this species was almost null. *Q. germana* seeds were exposed to the same biotic and abiotic conditions as the other species and experimental replicates within each treatment were randomly determined and were also rotated during the study period. The lack of emergence of *Q. germana* acorns could be attributed to the synergistic effect of several factors, such as insect and fungal damage to the endosperm and/or the plumule (Leiva & Fernández-Alés 2005). Acorn quality varies between species but also presents temporal and spatial intraspecific variation (Yu, Zhou, & Luo, 2003; González-Rodríguez *et al.*, 2012). While we did employ the float method to identify and discard damaged seeds, some of the apparently undamaged acorns may have been infested with larvae but with minimal levels of damage to the cotyledon at the beginning of the experiment. Higher cotyledon damage might have occurred during the course of the study but, due to the large seed reserves of *Q. germana*, its germination rate was unaffected. This pattern has been documented for other species with large acorn reserves (Xiao, Harris, & Zhang, 2007; Yi & Yang 2010). However, this insect damage may have exposed the *Q. germana* acorns to subsequent fungal attacks and thus early embryo and cotyledon rot and decay. Fungal attack has been reported as a factor in mortality during emer-

gence in some oak species (Yamazaki, Iwamoto, & Seiwa, 2009). It is therefore necessary to conduct further emergence trials for *Q. germana* that take these factors (fungal and insect damage) into account, in order to fully understand how variability in emergence is related to the maternal origin of the seeds and intraspecific temporal and spatial variation of insect-infected acorns (Yu *et al.*, 2003; González-Rodríguez *et al.*, 2012).

Light environments

In this study, *Q. insignis* was the only species affected by light, with higher germination presented under the sun condition. *Quercus insignis* seedlings are capable of establishment in open sites; however, seedling survival is higher under partial vegetation cover since mortality is increased in open sites due to herbivory by gophers as well as competition with exotic grasses and bracken (*Pteridium aquilinum*; Montes-Hernández & López-Barrera 2013; Avendaño-Yáñez, Sánchez-Velásquez, Meave, & Pineda-López, 2014)

CONCLUSIONS

We conclude that, in general, variation in the light environment and in acorn weight had no significant effect on germination or emergence in either experiment. These species can therefore be propagated in nurseries for the

purposes of introduction into degraded sites. It is necessary, however, to test whether this plasticity in the studied species continues into the following stages of regeneration, under both controlled and field conditions. Similarly, there are other factors that were not controlled in this experiment, such as differences in evapotranspiration rates in the two experiments, and this remains to be quantified in future studies.

Management implications

In this study, the germination and emergence values did not differ between the experiments conducted in the SFF and the GRE. This suggests that there is no need for a substantial investment in infrastructure in order to reproduce these species, but rather that the local inhabitants or owners of deteriorated forests could propagate them in sites close to their own homes. These sites could be equipped with moderate shading that would act to protect the seeds and seedlings from variations in temperature and humidity.

The oaks studied here are classified as endangered species, owing to the high rate of deforestation to which the TMCF is subjected and which has caused decreased populations. However, the germination and emergence values reported here for *Q. insignis*, *Q. sartorii* and *Q. xalapensis* are within the ranges published for other non-endangered species. While emergence failed in *Q. germana*, the germination was high and it is a species that has been successfully propagated in local nurseries (Carlos Iglesias, pers. comm.). Considering this, there are opportunities to reproduce these species in nurseries and to test their survival and growth under field conditions. Plantations including these species would have a two-fold objective: to encourage their reintroduction in order to increase populations and to restore the structure and function of TMCF, since such plantations can accelerate secondary succession and thus the recuperation of environmental interactions and the services these provide.

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