International Journal of Biodiversity and Conservation Vol. 2 (5), pp. 105-113, May, 2010
Available online http://www.academicjournals.org/ijbc
ISSN 2141 – 243x © 2010 Academic Journals

Full Length Research Paper

Enrichment planting of an understory palm: Effect of micro-environmental factors on seedling establishment, growth, and survival

Hayley A. Kilroy[1, 2]* and David L. Gorchov[2]

[1]Department of Botany, Pearson Hall, 700 E. High St., Miami University, Oxford, OH 45056, USA.
[2]Department of Ecology and Evolutionary Biology, Kansas Biological Survey, Higuchi Hall, University of Kansas, 2101 Constant Ave., Lawrence, KS 66047, United States of America.

Accepted 4 February, 2010

Although extraction of non-timber forest products (NTFPs) is considered an ecologically sustainable source of income, NTFP populations are vulnerable to depletion. The community of Alta Cima in the El Cielo Biosphere Reserve in Tamaulipas, Mexico, has conducted enrichment plantings of *Chamaedorea radicalis*, an important NTFP in northeastern Mexico, in forest areas near the village to supplement wild populations and increase the sustainability of harvesting. To gain an understanding of planting methods that will maximize the value of enrichment plantings, we assessed microsite environmental conditions to determine which factors aid establishment, growth, and survival of seedlings. We assessed two methods of seed planting. In 2006 and 2007, we measured seedlings in areas planted with seeds and seedling transplants in 2003 and measured several micro-environmental parameters. Sites with fewer overhead foliage layers had higher seedling establishment, growth, and one-year survival (seedling transplants only). Seedlings located at farther distances from saplings or trees had longer leaves (seedlings planted as seed) or a greater number of leaves (seedling transplants). Seedling transplants had higher survival to four years, but the labor costs of planting seedling transplants were five times greater per surviving seedling. These results suggest that the best management practice of *C. radicalis* enrichment plantings is direct seeding in areas with high light availability.

Key words: *Chamaedorea radicalis,* enrichment planting, non-timber forest products, El cielo Biosphere Reserve, Tamaulipas.

INTRODUCTION

The harvest of non-timber forest products (NTFPs) from wild or conserved forests has been promoted in recent years as a way to provide communities with a source of income while having minimal effects on forest ecosystems. NTFPs from tropical forest can provide economic value to the forest, adding incentive for conserving and protecting the forest (Marshall et al., 2003).

The palm *Chamaedorea radicalis,* a wind-pollinated, dioecious, tropical understudy palm (Berry and Gorchov, 2004), is a NTFP whose leaves are harvested and sold internationally for use in floral arrangements (Hernandéz et al., 2005). Harvesting *C. radicalis* leaves is the principle source of income for many people in northeastern Mexico, such as in the ejidos of El Cielo Biosphere Reserve, in Tamaulipas, Mexico (Peterson, 2001). There, *C. radicalis* is the only product permitted to be commercially extracted from the protected forest. As a NTFP, *C. radicalis* can potentially provide a sustainable source of income to communities within the reserve, as well as provide economic incentive to conserve the forest. However, *C. radicalis* is considered vulnerable in Mexico, and over harvesting and livestock browsing threaten the viability of wild *C. radicalis* populations and therefore a sustainable income for palm collectors (Endress et al., 2004; Hodel, 1992; Berry et al., 2008).

Cultivation may be one way to combat threats to NTFP

*Corresponding author. E-mail: hkilroy@ku.edu. Tel: (785)760-4452.

Abbreviation: NTFP, Non-timber forest product; **YFEL,** Youngest fully-expanded leaf.

Table 1. Categories for estimating percent cover.

Category	Percent
1	0
2	< 1
3	1-4
4	5-24
5	25-49
6	50-74
7	75-94
8	95-98
9	99-100

populations. In recent years, *Chamaedorea* palms have been cultivated in understory plantations in which the understory may be removed for light availability (Trauernicht et al., 2006; Jeremy Ash, pers. comm.). Cultivation of NTFPs in general has been recommended as a part of larger forest management approaches, in order to increase the net value of forest managed primarily for timber, provide income in years when timber is not harvested, or as part of a reforestation method that will restore biodiversity of degraded lands while maintaining a source of income (Ashton et. al., 2001; Lamb et. al., 2005). However, one method of NTFP management that has been given very little attention is the practice of supplementing wild populations with enrichment plantings.

The community of Alta Cima within the El Cielo Biosphere Reserve has conducted enrichment plantings of *C. radicalis* in areas that were depleted of the palm. Between 2003 and 2005, palms were planted on approximately 5 ha near Alta Cima. Apart from digging to plant seeds and seedlings, the forest was left undisturbed. Some of the local harvesters (*palmilleros*) of Alta Cima spoke to us of the many benefits they would gain from supplementing wild populations with enrichment plantings, such as alleviating the need to travel long distances to harvest. Enrichment plantings might also speed the return of *C. radicalis* populations to areas that have been previously disturbed, and decrease the isolation of populations near villages, a pattern observed by (Jones and Gorchov, 2000).

Planting practices have been haphazard so far, though interest in continuing enrichment plantings remains high. To maximize the value of enrichment plantings, it would be beneficial to determine the best practices of planting *C. radicalis* seeds and seedlings. One aim of this study is to assess which microsite conditions promote seedling establishment, growth, and survival of palms; with the purpose of providing information to the community of Alta Cima on the most ideal locations within a forest for future enrichment plantings. Another aim is to compare the survival and costs associated with practices of planting seeds and seedlings to determine which practice is preferable.

METHODS

Study site

This study was conducted in an early successional forest stand near the village of Alta Cima, in the El Cielo Biosphere Reserve in Tamaulipas, Mexico. In this area, approximately 40,000 seeds and 7,000 seedling transplants which had been raised in nursery conditions for a few years were planted in May 2003 (Johnson Bridgewater, pers. comm.). In May 2006 and June 2007 with the help of local field assistants, we counted and measured 252 seedlings originating from seed and 121 seedling transplants along seven transects.

Field Methods

We set up four parallel 50 x 2 m belt transects in the area where *C. radicalis* was planted as seed in 2003. Locations for the beginning of the transects were selected semi-randomly, with some attempt to maximize the spacing between them in order to appropriately capture a representative sampling of seedlings and their microsite conditions. In the area where *C. radicalis* seedlings were transplanted in 2003, we set up three parallel 2 m transects of length 30, 20 and 15 m. These transects were shorter than 50 m due to limitations imposed by the smaller area in which seedling transplants had been planted. Each seedling along the transect was tagged and numbered. For each seedling, we recorded the number of leaves, number of dead leaves, length of the youngest fully-expanded leaf (YFEL), and number of leaflets on each leaf (transplants only) in both 2006 and 2007.

"In 2006 we measured variables characterizing the forest structure, light environment and topography of seedling microhabitats. While some of these variables, e.g. canopy openness, may vary over time at each site, the 2006 measurements should correlate with values experienced by seedings during the 2003-2007 period."

Six topographical variables were used. The number of leaf layers, humus depth, and soil depth were measured at 10 cm from the seedling in each cardinal direction are totaled for all four points. "Leaf layers" was measured as the number of leaves that intersected a chaining pin pushed into the ground. Humus depth was measured with a ruler, and soil depth was measured as the distance a rod of 4 mm diameter could be pushed into the ground (Svenning, 2001). The percent cover of three ground cover categories (exposed rock, leaf litter, bare soil, and in a very few cases large roots, trunks, or logs) was estimated within a 25 cm radius around each seedling, using percent cover categories similar to Daubenmire's (1959) method of visual cover estimation (Table 1). We also measured aspect, but because little variation was present, it was not included in the analyses. The forest structure/light environment variables were distances to the nearest sapling (diameter at breast height < 10 cm and height >2 m) and tree, canopy openness, number of strata, and an estimation of plant cover of less than 0.5 m in height within a 25 cm radius around each seedling. Canopy openness was measured as the sum of four readings of a concave spherical densiometer taken facing each cardinal direction directly over a seedling or sampling point, using the wedge-shaped modification of Strickler (1959), which uses 17 points per reading instead of 96 (Cook et al., 1995). The number of strata were the number of well-developed foliage layers was estimated in each of four height ranges: 0.5 - 2, 2 - 5, 5 - 10, and >10 m, similar to the method used by Svenning (2001), but modified for the appropriate canopy height of the forest.

Points every 3 m along all transects were deemed as suitable or non-suitable for planting by a field assistant who had been involved in the planting in 2003. At suitable points, all of the same measurements on micro-environmental factors were taken, and at unsuitable points, only the cover categories were recorded.

Comparison of planting sites

To determine which cover categories influenced whether or not a location was determined to be 'suitable' or 'not suitable' during planting, we qualitatively compared the frequency distributions of the four cover categories for both types of locations.

We used SAS 9.1 (SAS Institute Inc.; Cary, NC) for all statistical analyses. To determine the factors associated with successful seedling establishment, we used stepwise logistic regression (SAS PROC LOGISTIC) to determine the micro-environmental factors that distinguished 'suitable' points along the transects of seed plantings from the locations where a seedling was present along those transects. 'Suitable' points were used as a stand-in for locations where seeds were planted, since the exact locations of seed plantings were unknown. In all regressions, some variables were not included in the model because of strong correlations with included variables. When strong correlations occurred, the best predictor of the correlated variables was left in the model. The independent variables in this and all other stepwise regressions were standardized with a mean of 0 and a standard deviation of 1, and p = 0.25 was used to enter or leave model.

Seedlings planted as seed

Stepwise linear regression, with SAS PROC REG, tested the effects of micro-environmental factors on the 2006 seedling size. Although both the number of leaves and the length of the YFEL were measured, only the length of YFEL was analyzed for seedlings planted as seed since there was little variation in the number of leaves.

In both 2006 and 2007, we measured the number of leaves and the length of the YFEL. The change in both of these measurements from 2006 - 2007 was used as measures of seedling growth. Although leaves of *C. radicalis* don't grow once they have expanded, one or more fully-expanded leaves could be produced in a one year interval, and in each year we measured the youngest fully-expanded leaf. Length in the YFEL is a good measure of size, so change in the length of the current YFEL over one year can indicate positive or negative growth. We performed stepwise linear regressions to test the effects of micro-environmental factors on the growth in length of the YFEL and in the growth in number of leaves from 2006 - 2007, and stepwise logistic regression to test the effects of micro-environmental factors on survival from 2006 - 2007.

Seedling transplants

Both measurements of seedling size, number of leaves and the length of the YFEL in 2006, were used for seedling transplants. We performed two stepwise linear regressions to test the effects of micro-environmental factors on each measurement of seedling size. Since the only significant variable in the model for the length of YFEL was rock cover, a one-way ANOVA was done with rock cover categories 1 and 2 as "absent" and rock cover categories 3 - 9 as "present" (Table 1), with length YFEL as the dependent variable.

Change in the number of leaves, change in the length of the current YFEL, and survival of seedling transplants from 2006 - 2007 were analyzed as described for seedlings planted as seed.

Comparison of planting methods

To determine whether planting seeds or seedlings was more cost-effective, we divided the total cost of planting by the estimated number of survivors separately for seeds and seedlings. To estimate the number of survivors we multiplied the area planted (from a map drawn from compass bearings and segment distances) by the density of seedlings found in transects. The initial numbers of seeds and seedlings planted in 2003, as well as descriptions of the planting processes and associated costs, were provided by Johnson Bridgewater of Wild Share International and Eduardo Padrón Serrano of Alta Cima. Using these values for the number of individuals planted in 2003, we calculated percent survival to 2006 and 2007.

RESULTS

Planting sites

Of the four cover variables, rock cover was the best predictor of whether or not a point along transect was determined to be suitable for planting (Figure 1). The majority of sites with low (<5%) rock cover were suitable for planting (31 out of 37 sites), whereas only 3 out of 28 sites with high (>24%) rock cover were suitable for planting. Of the 18 sites with intermediate rock cover (5-24%), 9 were suitable and 9 were unsuitable. Among these 18 sites, there were no apparent differences between suitable and unsuitable sites with regard to cover of leaf litter, plant cover, or bare ground. Therefore, it appears that solely the presence or absence of rock influenced whether a planter would select a site for planting a seed or transplant.

Predictors of establishment

"Stepwise logistic regression of sites suitable for planting, a stand-in for locations"where seeds were planted in 2003, vs. sites where a seedling was growing in 2006 generated a model with eight predictors significant at the threshold of $p < 0.25$. However, only one of these predictors was significant at $p < 0.05$; the number of foliage layers above 10 m ($\chi^2 = 13.5075$, $DF = 1$, $p = 0.0002$); Sites with seedlings had fewer foliage layers >10 m above them (mean = 0.2) than 'suitable' sites (mean = 0.6) (Figure 2), indicating that foliage layers in the highest height category influenced seedling establishment. Seeds may have been planted in shadier sites, but were not found to be growing in shadier sites three years later.

Growth and survival of seedlings planted as seed

Four micro-environmental parameters were significant predictors of seedling size (length YFEL) in 2006: layers of leaf litter distance to nearest sapling, humus depth, and distance to nearest tree, according to a stepwise linear regression (Table 2, R^2=0.1334, $p < 0.0001$). All four significant variables were positively correlated with

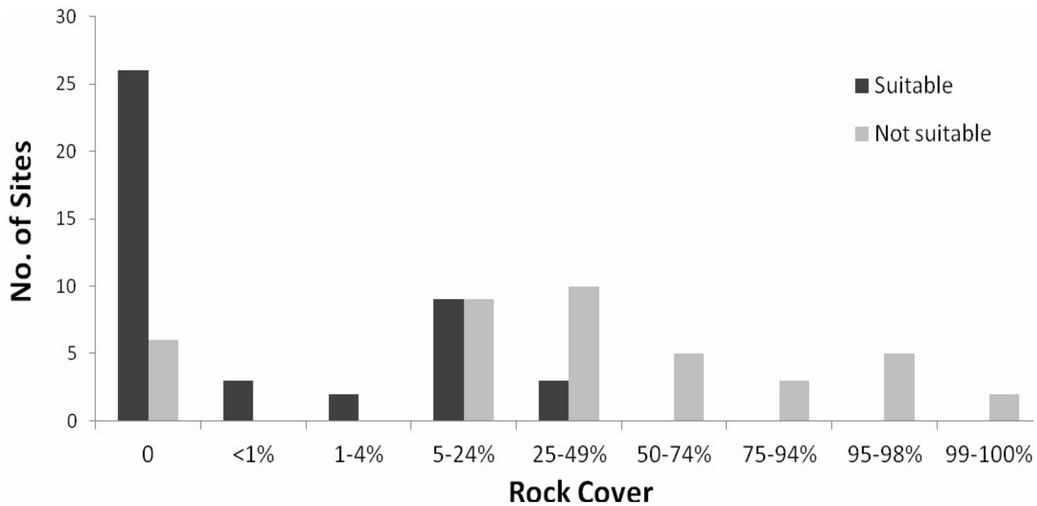

Figure 1. Frequency distributions of rock cover classes of regular points along all transect of locations determined to be ‘suitable’ or ‘unsuitable’ for planting a seed or seedling.

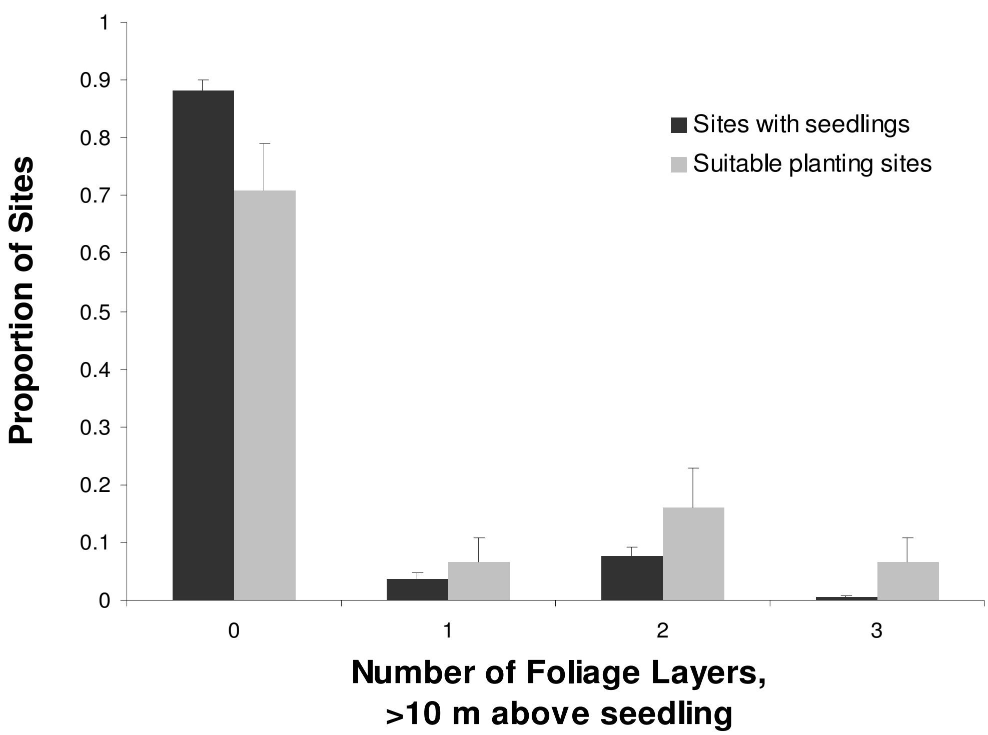

Figure 2. Number of foliage layers >10 m above seedling locations and suitable planting sites. Bars represent standard error.

length YFEL. Layer of leaf litter were the best predictor of the length of the youngest fully expanded leaf.

Stepwise linear regression of the growth in length YFEL from 2006 to 2007 generated a model with two predictors significant at the threshold of p = 0.25 (R^2 = 0.0296, p = 0.0459); Only one predictor was significant at p < 0.05: the number of foliage layers greater than 10 m above seedlings, which negatively correlated with growth in length of YFEL, although it wasn’t a strong predictor. Stepwise linear regression of the growth in the number of leaves from 2006 to 2007 generated a model with two predictors significant at the threshold of p = 0.25: distance to the nearest tree and the number of foliage layers above 2 m in height (R^2 = 0.0305, p = 0.0417). Both factors negatively correlated with the growth in number of leaves; however, neither variable was

Table 2. Significant micro-environmental predictors of the length of the youngest fully expanded leaf in 2006 of seedlings planted as seed, as determined by a stepwise linear regression. Variables included: distance to nearest sapling (which was log transformed to normalize the distribution), distance to nearest tree, leaf layers, humus depth, plant cover, foliage layers between 0.5 and 2 m, and foliage layers >2 m.

Step	Variable	Partial R^2	Model R^2	p
1	Leaf layers	0.0603	0.0603	0.0001
2	log(distance to sapling)	0.0273	0.0876	0.0078
3	Humus depth	0.0259	0.1135	0.0087
4	Distance to tree	0.0199	0.1334	0.0159

Table 3. Significant microenvironmental predictors of the growth of the number of leaves of transplants from 2006 to 2007, as determined by a stepwise linear regression. Variables included: distance to sapling (log transformed), distance to tree, leaf layers, humus depth, plant cover, rock cover, and canopy openness.

Step	Variable	Partial R^2	Model R^2	p
1	Humus depth	0.0594	0.0594	0.0110
2	Canopy openness	0.0326	0.0920	0.0549

significant at $p < 0.05$.

Stepwise logistic regression of survival from 2006 - 2007 generated a model with two predictors significant at the threshold of $p < 0.25$; bare ground and distance to nearest tree, though neither was significant at $p < 0.05$ (Wald $\chi^2 = 4.7217$, $DF = 2$, $p = 0.0943$).

Growth and survival of transplanted seedlings

Number of leaves in 2006, one measure of seedling size, was best predicted by canopy openness and distance to sapling, according to a stepwise linear regression ($R^2 = 0.08$, $p = 0.0095$). Both variables were positively correlated with number of leaves; however, only canopy openness was significant at $p < 0.05$.

The only significant predictor of length of the YFEL, another measure of seedling size, in 2006 was rock cover, according to stepwise linear regression ($R^2 = 0.0364$, $p = 0.0376$). To explore this relationship, we did a one-way ANOVA of length YFEL on rock cover presence/absence, with categories 1 and 2 (<1% cover) scored as "absent" and rock cover categories 3 - 9 (≥1%) scored as "present." Seedlings in plots with rock present had larger leaves, with a mean of 22.8 cm, than those in plots with rock absent, with a mean of 20.1 cm ($F = 4.03$, $p = 0.047$).

Stepwise linear regression of the growth in number of leaves from 2006 to 2007 generated a model with two predictors significant at the threshold $p = 0.25$: humus depth and canopy openness (Table 3; $R^2 = 0.0920$, $p = 0.0063$), although only humus depth was significant at $p < 0.05$. Seedlings with greater humus depth were likely to have greater growth in number of leaves (Figure 3). The only significant predictor of the growth in YFEL from 2006 to 2007 of transplants was foliage layers between 2 - 5 m in height above the seedling, according to a stepwise linear regression ($R^2 = 0.0783$, $p = 0.0034$). Seedlings with fewer foliage layers 2 - 5 m in height were likely to have greater growth in YFEL (Figure 4).

The only significant predictor of survival from 2006 - 2007 of transplants was foliage layers 2-5 m above the seedlings, according to stepwise logistic regression ($\chi^2 = 6.5016$, $DF = 1$, $p = 0.0108$). Seedlings with fewer foliage layers between 2 and 5 m above them were more likely to survive (Figure 5).

Comparison of planting methods

Approximately 14 kg of seeds (~42,000 seeds) and 6,588 seedling transplants were planted in 2003 (Johnson Bridgwater, pers. comm.). Assuming a similar average density of seedlings across the planting areas as we measured in the transects, 9,054 seedlings planted as seed and 1,996 seedling transplants were present in 2007 (Table 4). Therefore, approximately 21.6% of seeds planted germinated and survived from 2003 to 2007. Approximately 30.3% of seedling transplants survived from 2003 to 2007. These numbers must be interpreted with caution; as the seedlings which were transplanted in 2003 were kept in nursery conditions for several years, and were root-bound when transplanted. It is likely that transplantation of seedlings with healthy rootstock would yield vastly different results; however, we were unable to include such a comparison in this study. Planters were paid \$300 for directly sowing 1.70 hectares and paid \$360 for planting transplants in 0.24 hectares. Therefore,

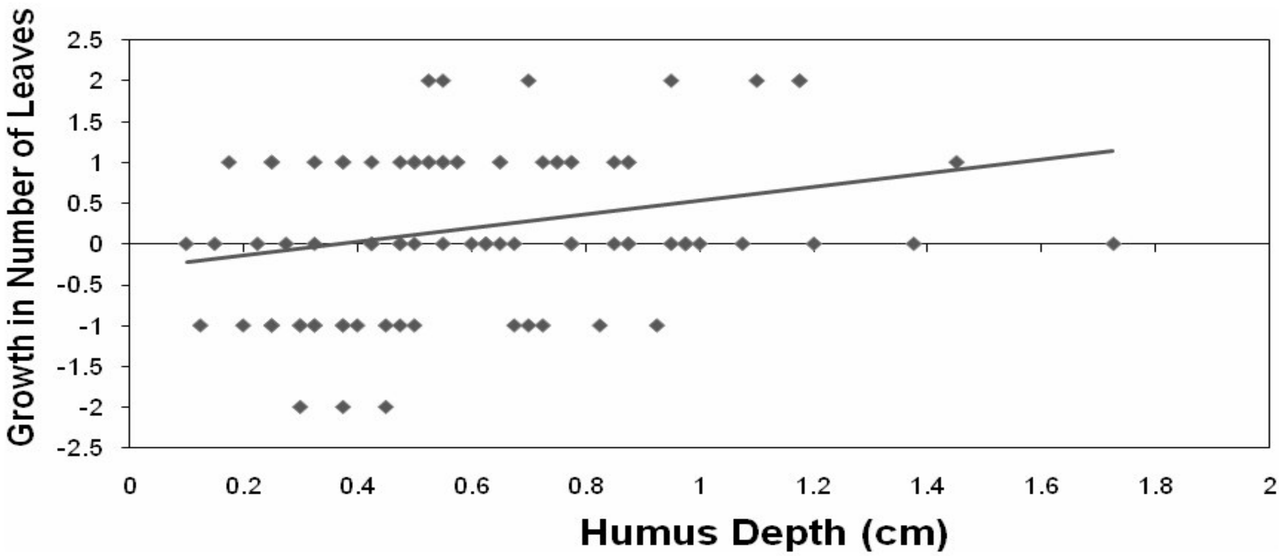

Figure 3. Seedling growth from 2006 - 2007 of transplants, quantified as change in the number of leaves, versus humus depth. Each point represents one seedling.

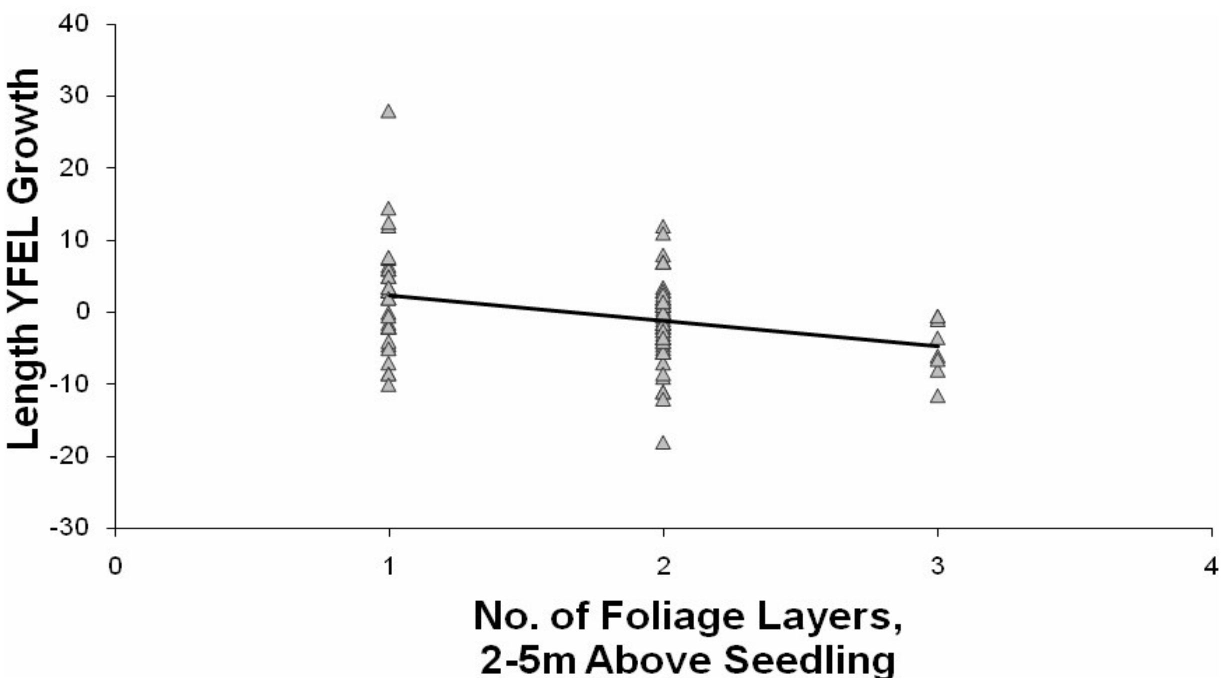

Figure 4. Seedling growth from 2006 - 2007 of transplants versus foliage layers between 2 - 5 m in height above the seedling. Growth was quantified as length of youngest fully expanded leaf (YFEL) in 2007 minus length YFEL in 2006. Each point represents one seedling.

solely considering the labor costs of planting, as of 2007, it cost $0.033 per surviving seedling planted as seed and $0.180 per surviving seedling transplant (Table 4). Additionally, seedling transplanting also has costs associated with growing seedlings in nursery conditions before transplanting, which were not quantified in this study.

DISCUSSION

Light availability

The majority of significant environmental predictors for all response variables were parameters that should correlate directly with light availability. Fewer overhead foliage

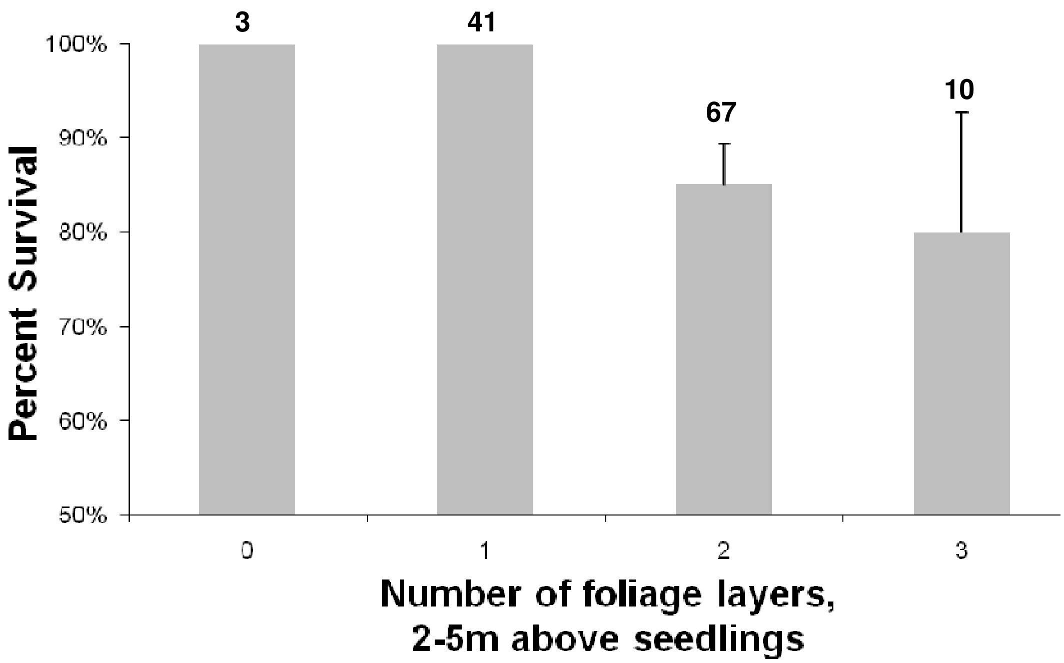

Figure 5. Percent survival from 2006 - 2007 of transplants based on the number of foliage layers 2 = 5 m above seedlings. Bars represent standard error (note: since all seedlings with 0 or 1 foliage layers survived, standard error is 0 for those categories). Sample sizes given above each bar.

Table 4. Estimated and calculated values for comparing cost and survival of seeds and transplants. The estimated number planted in 2003 and the planting costs were obtained from persons involved in the planting. The area planted was measured, and seedling density and survival from 2006 - 2007 were measured in transects. From those measured values, the total number alive was extrapolated.

	Seeds	Transplants
Estimated number planted (2003)	42,000	6,588
Area planted (ha)	1.70	0.24
2006 Density of seedlings (per ha)	6,300	9,308
2006 Estimated number alive	10,740	2,215
2007 Density of seedlings (per ha)	5,311	8,386
2007 Estimated number alive	9,054	1,996
Survival (2006-2007)	84.3%	90.1%
Estimated survival (2003-2007)	21.6%	30.3%
Total planting costs	$300	$360
Cost per seedling surviving to 2007	$0.033	$0.180

layers were positively associated with seedling establishment, growth of YFEL from 2006 to 2007 of seedlings of both planting methods, and survival of seedling transplants from 2006 - 2007. Seedlings located at farther distances from the nearest sapling and/or tree had longer lengths of YFEL (in the case of seedlings planted as seed) or had a greater number of leaves (in the case of seedling transplants). Greater canopy openness, measured with a spherical densiometer, also correlated with a greater number of leaves of seedling transplants.

That greater light availability aids in seedling establishment, growth, and survival of *C. radicalis* is in accordance with the practice of some plantation managers who clear the understory to increase light (Trauernicht et al., 2006). Light limitation has been documented for other neo-tropical understory palms, as well. Two palms in Ecuador, *Chamaedorea linearis* and *Prestoea acuminata,* were found to occur most frequently where gap exposure was high (Svenning, 2001), and variation in the growth rate of the Mexican understory palm *Astrocaryum mexicanum* correlated with light availability (Sarukhán et al., 1984). De Steven (1989) found that, for the clonal palm *Oenocarpus mapora*, leaf production rates and flowering frequency increase under high light conditions, and attributed high growth rates of palms in some sites to disturbances causing canopy openings. Svenning (2002) found that for *Geonoma macrostychys,* an understory palm in Ecuador, greater crown illumination promoted growth, reproduction, survival, and recruitment. Higher illumination contributed to greater seedling size of *G. macrostychys,* although not establishement. Svenning (2002) also projected that light limitation of individuals has a strong effect on population growth rate.

Based on these results, successful enrichment planting of *Chamaedorea radicalis* should be directed on forest areas with relatively high light availability.

Although our measurements of canopy openness using a spherical densitometer significantly correlated with some measures of seedling growth, the distance to the nearest sapling or tree and the number of overhead foliage layers were also significant predictors of seedling establishment, growth, and survival. Distance to the nearest sapling or tree, and the number of overhead foliage layers, unlike canopy openness, may be measured without any special tools beyond a tape measure, and we therefore recommend these measures to the community of Alta Cima rather than using a spherical densiometer. An examination of our data's distribution leads us to recommend an initial practice of planting at least 3 m from the nearest tree and 1 m from the nearest sapling. The height ranges of foliage layers that were significant were between 2 and 5 m, and above 10 m. However, since all foliage layers above 2 m were highly correlated with one another, we recommend, considering the total number of foliage layers above 2 m, and recommend an initial practice of planting in areas with less than three overhead foliage layers above 2 m. We believe that using these measures to select planting sites will increase the success of enrichment plantings.

Comparison of planting methods

As of four years after planting, the labor cost of planting seedling transplants is over five times higher than planting seeds, when calculated per surviving seedling (Table 4). The advantage of the higher survival of transplanted seedlings was outweighed by the higher labor cost of this method. In addition to the planting costs quantified in this study, growing seedlings in a nursery requires obtaining planting bags and soil, preparing an appropriate nursery location, watering and weeding for 1 - 2 years, and transporting seedlings to the planting site via burros. An additional consideration in this case is that, due to a lack of reliable funding, the seedlings which were planted in 2003 were kept in nursery conditions for several years, and were root-bound when transplanted. Additionally, more seeds might need to be collected for this planting method, depending on the proportion of nursery-planted seeds that germinate, establish, and survive to transplant age.

There is also the risk of seedlings remaining in nursery conditions longer than intended, as happened in this case. Planting seeds is a short-term project that can be completed in less than a year, whereas planting transplants is a more expensive, multi-year endeavor. It is possible that seedlings grown in a nursery setting have a greater size and vigor than seeds planted in the forest; however, that was impossible to assess with this study since the seedling transplants were older, having been started in a nursery setting years before the seeds were planted in the forest. At the time of the 2007 census, seedling transplants were larger on average (3.0 leaves and length YFEL = 20.6 cm vs. 2.5 leaves and length YFEL = 12.3 cm for seedlings from seed), and had slightly higher survival from 2006 to 2007 (90.1 vs. 84.3%). It also might be possible that seedling transplanting when performed as intended, with seedlings remaining in nursery conditions for only 1 - 2 years, will yield greater benefits than are demonstrated here.

Recommendations

For future enrichment plantings of *C. radicalis* in Alta Cima, we recommend direct sowing of seeds. Considering the patterns found in this study, it is our recommendation that seeds be planted at least 3 m from the nearest tree and 1 m from the nearest sapling, and in areas with less than three overhead foliage layers above 2 m.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the community of Alta Cima, especially E. Padrón Serrano and E. Barrones, who assisted with field research and shared their knowledge of the palmilla and the practices of palmilleros. Thanks to J. Bridgwater for providing data and support throughout the project. B. Endress, E. Berry, and J. Ash worked previously on *C. radicalis* in El Cielo and provided logistical assistance; additional thanks to B. Endress for his suggestion of this topic of study. Thanks to M. Hughes and N. Slade for their help with statistical analyses, and to M. H. H. Stevens, M. A. Vincent, and two anonymous reviewers for providing commentary on the manuscript. Funding was provided by the Miami University office for the advancement of research and scholarship (via the Undergraduate Summer Scholars Program, an Undergraduate Research Award, and the Hughes Internship Program), the Miami University College of Arts and Sciences (via the Dean's Scholar Program), the Miami University Honors and Scholars Program, and the Oklahoma City Zoo.

REFERENCES

Ashton MS, Mendelsohn R, Singhakumara BMP, Gunatilleke CVS, Gunatilleke IAUN, Evans A (2001). A financial analysis of rain forest silviculture in Southwestern Sri Lanka. For. Ecol. Manag. 154: 431-441.

Berry EJ, Gorchov DL (2004). Reproductive biology of the dioecious tropical understory palm *Chamaedorea radicalis* in a Mexican cloud forest: pollination vector, flowering phenology, and female fecundity. J. Trop. Ecol. 20: 369-376.

Berry EJ, Gorchov DL, Endress BA, Stevens MHH (2008). Source-sink dynamics within a plant population: The impact of substrate and herbivory on plant demography. Popul. Ecol. 50(1): 63-77.

Cook JG, Stutzman TW, Bowers CW, Brenner KA, Irwin LL (1995). Spherical densiometers produce biased estimates of forest canopy cover. Wildl. Soc. Bull. 23(4): 711-717.

Daubenmire R (1959). A canopy-coverage method of analysis of vegetation cover. Northwest Science 33(1): 43-64.

De Steven D (1989). Genet and ramet demography of *Oenocarpus mapora* ssp. *mapora*, a clonal palm of Panamanian tropical moist forest. J. Ecol. 77: 579-596.

Endress BA, Gorchov DL, and Noble RP (2004). Non-timber forest product extraction: Effects of harvest and browsing on an understory palm. Ecol. Appl. 14: 1139-1153.

Hernandéz LT, Ybarra EJ, Mendoza HV, Bortoni MJA, Encinia FB, Garcia GG (2005). Uso, manejo, y propogación de palmilla *Chamaedorea radicalis* Mart. (Arecaceae). *In* Historia natural El Cielo (G. Sanchez-Ramos, P. Reyes-Castillo, and R. Dirzo, editors). México pp. 638-649.

Hodel DR (1992). Chamaedorea palms: the species and their cultivation. Allen Press, Inc., Lawrence pp. 338.

Jones FA, Gorchov DL (2000). Patterns of abundance and human use of the vulnerable understory palm, *Chamaedorea radicalis* (Arecaceae), in a montane cloud forest, Tamaulipas, Mexico. SW Nat. 45(4): 421-430.

Lamb D, Erskine PD, Parrotta JA (2005). Restoration of degraded tropical forest landscapes. Science 310: 1628-1632.

Marshall E, Newton AC, and Schreckenberg K (2003). Commercialisation of non-timber forest products: first steps in analysing the factors influencing success. Int. Forest. Rev. 5(2): 128-137.

Peterson MB (2001). Resource use and livelihood strategies of two communities in the El Cielo Biosphere Reserve, Tamaulipas, Mexico. M.S. Thesis. Miami University, Ohio.

Sarukhán J, Martinez-Ramos M, Piñero D (1984). The analysis of demographic variability at the individual level and its populational consequences. *In* Perspectives on plant population ecology (R. Dirzo and J. Sarukhán, editors). Sinauer Associates, Sunderland, MA pp. 83-106.

Strickler GS (1959). Use of the densiometer to estimate density of forest canopy on permanent sample plots. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Research Note No. 180.

Svenning JC (2001). Environmental heterogeneity, recruitment limitation and the mesoscale distribution of palms in a tropical montane rain forest (Maquipucuna, Ecuador). J. Trop. Ecol. 17: 97-113.

Svenning JC (2002). Crown illumination limits the population growth rate of a neotropical understorey palm (*Geonoma macrostachys*, Arecaceae). Plant Ecol. 159: 185-199.

Trauernicht C, Ticktin T, Herrera GL (2006). Cultivation of non-timber forest products alters understory light availability in a humid tropical forest in Mexico. Biotropica 38(3): 428-436.