Harvest of the Palm *Chamaedorea radicalis*, Its Effects on Leaf Production, and Implications for Sustainable Management

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Abstract: *Few studies have integrated local management strategies with ecological experiments to assess the harvest and management of nontimber forest products, even though nontimber forest resources are primarily managed by local communities. To understand the harvest and management of leaves from the understory palm* Chamaedorea radicalis *Mart. in the El Cielo Biosphere Reserve, Mexico, we documented local management practices and used this information to conduct an experiment to examine the effect of several leaf-harvest regimes on leaf production, length, and yield. We interviewed palm harvesters to document harvest and management strategies and collected data on the number of leaves sold by 12 harvesters over 32 months to estimate the number of leaves harvested per year in the community of Alta Cima. In January 1999, we established 10 study plots (50 palms/plot;* $n = 500$*) to conduct our harvest experiment. Plots were divided into subplots of 10 palms each, and treatments were randomly assigned to subplots. The treatments were as follows: control, 1×/year, 2×/year, and 4×/year harvest, and a modified 4×/year harvest, during which one leaf at most was removed each time. Leaf production, length, and yield were recorded through August 2001. Palm harvesting was intense, with an average of 4000 leaves harvested per collector per month. Harvest resulted in a modest increase in leaf production; however, leaves produced in the harvest treatments were significantly shorter than those in the control. This reduction in leaf length led to a 41–68% decline in yield after 2 years because many leaves produced were too short to be marketable. This response suggests that leaf harvesting is not a stable source of income for communities in El Cielo. Because we tailored our experimental treatments to approximate current harvest practices and potentially acceptable alternatives, our results were directly relevant to communities and interpretable within the local context.*

Key Words: El Cielo Biosphere Reserve, leaf harvest, Mexico, nontimber forest products, palm leaves, sustainable management, Tamaulipas

Efectos de la Cosecha de Hojas de Palma (*Chamaedorea radicalis*) sobre la Producción de Hojas e Implicaciones para un Manejo Sustentable

Resumen: *Pocos estudios han integrado estrategias locales de manejo con experimentos ecológicos para evaluar la cosecha y el manejo de productos forestales no maderables, aun cuando son manejados primariamente por comunidades locales. Para comprender la cosecha y manejo de hojas de la palma de sotobosque* Chamaedorea radicalis *Mart en la Reserva de la Biosfera El Cielo, México, documentamos prácticas locales de manejo y utilizamos esta información para realizar un experimento examinando el efecto de varios regímenes de cosecha de hojas sobre la producción, la longitud y el rendimiento de hojas. Entrevistamos a cosechadores*

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de palma para documentar las estrategias de cosecha y manejo, y registramos el número de hojas vendidas por 12 cosechadores a lo largo de 32 meses para estimar el número de hojas cosechadas por año en la comunidad de Alta Cima. En enero de 1999 establecimos 10 parcelas (50 palmas/parcela, n = *500) para realizar nuestro experimento de cosecha. Dividimos a las parcelas en subparcelas de 10 palmas cada una, y asignamos tratamientos a las subparcelas aleatoriamente. Los tratamientos fueron control, 1 cosecha/año, 2 cosechas/año, 4 cosechas/año y 4 cosechas/año modificada, en la que se removía cuando mucho una hoja en cada tiempo de cosecha. Registramos la producción, longitud y rendimiento de hojas hasta agosto de 2001. La cosecha de palmas fue intensa, con un promedio de 4000 hojas cosechadas/recolector/mes. La cosecha resultó en un leve incremento de la producción de hojas; sin embargo, la longitud de las hojas producidas en los tratamientos de cosecha fue significativamente menor que la del control. Después de 2 años, esta reducción en la longitud de las hojas condujo a una declinación de 41 – 68% en el rendimiento porque muchas hojas producidas eran demasiado cortas para ser comercializadas. Esta respuesta sugiere que la cosecha de hojas no es una fuente estable de ingresos para comunidades en El Cielo.*

Palabras Clave: hojas de palma, manejo sustentable, México cosecha de hojas, productos forestales no maderables, Reserva de la Biosfera El Cielo, Tamaulipas

Introduction

Over the last two decades, interest in the extraction of nontimber forest products (NTFPs) as a form of sustainable development has resulted in numerous publications and workshops, in addition to the creation of many NTFP-based development projects. Nontimber forest product extraction has been promoted because it is assumed to have fewer impacts on forest communities and ecosystem processes than other land uses and provides communities with a source of income (Nepstad & Schwartzman 1992; Hartshorn 1995; Putz et al. 2001). However, harvest of NTFPs can also result in overexploitation and extirpation (Peters 1999). NTFP research has focused on a wide range of issues, including (1) economics and marketing (Plotkin & Famolare 1992; Wollenberg & Ingles 1998; Pattanayak & Sills 2001), (2) importance (or lack thereof) to community development and biodiversity conservation (Dove 1993; Salafsky et al. 1993; Arnold & Ruiz Pérez 2001), (3) harvest and management (Boot & Gullison 1995; Velásquez Runk 1998), and (4) effects of extraction on NTFP demography and population dynamics (Pinard 1993; Anderson 1998; Zuidema 2000).

Recently, there has been an increased emphasis on experimental approaches to assessing NTFP extraction (Flores & Ashton 2000; Zuidema 2000; Ticktin et al. 2002). While this has greatly increased the robustness of NTFP research, it has also resulted in studies that have ignored site-specific factors and mechanisms that affect NTFP extraction, such as local harvest and management strategies. Because NTFPs are primarily used, managed, and conserved by local communities, an understanding of their harvest and management strategies is essential to evaluating NTFP extraction (Anderson 1998; Castillo & Toledo 2000). Thus, ecological studies that do not consider the local context may generate inaccurate or incomplete assessments of the value of NTFPs for sustainable development. Despite the importance of integrating local management strategies with ecological experiments, only a handful of studies have taken this approach (Joyal 1996; Kainer et al. 1998; Velásquez Runk 1998; Svenning & Macia 2002; Ticktin et al. 2002).

Leaves from the understory palm, *Chamaedorea radicalis* Mart. (palmilla or palma camedor) are harvested in the mountains of northeastern Mexico for sale as cut foliage in the United States and are an important source of income for many rural residents. *C. radicalis* is one of several *Chamaedorea* species found in Mexico and Central America that are currently used by the floriculture industry. In 1999 over 2000 tons of *Chamaedorea* leaves were exported from Mexico, generating around $20 million (CEC 2002). Many of the floricultural species are listed as threatened or vulnerable, including *C. radicalis* (FAO 1997).

Within the El Cielo Biosphere Reserve (hereafter El Cielo), Tamaulipas, Mexico, *C. radicalis* leaves are the only forest resource that inhabitants of El Cielo are allowed to harvest for commercial purposes, and they are the principal source of income for most communities (Jiménez Pérez et al. 1999). This has resulted in intense leaf-harvesting within El Cielo, and palm collectors (palmilleros) are concerned that overharvesting has reduced palm abundance and leaf yield, threatening their primary source of income (Peterson 2001). To understand the harvest and management of *C. radicalis* in El Cielo, we (1) collaborated with local palmilleros to document palm management strategies and (2) used this information to design an experiment to examine the effect of several harvest regimes on leaf production, length, and yield. From these data, we assessed palm resource management within El Cielo.

Other palm species respond to defoliation in a variety of ways, some of which affect leaf production and harvest. In general, leaf removal has little or no effect on palm survival (Ratsirarson et al. 1996; Zuidema 2000; Endress et al. 2004) or leaf production (O'Brien & Kinnaird

1996; Ratsirarson et al. 1996), though there are exceptions (Zuidema 2000). In some cases, defoliation actually increased leaf production rates over the short term (Mendoza et al. 1987; Oyama & Mendoza 1990; O'Brien & Kinnaird 1996; Anten & Ackerly 2001). However, leaf harvest can result in the production of shorter leaves (O'Brien & Kinnaird 1996; Ratsirarson et al. 1996). If leaf harvest reduced *C. radicalis* leaf lengths below 40 cm (minimum length for salable leaves), palmilleros in El Cielo would be unable to sell leaves, resulting in reduced income.

Methods

Study Site

We conducted our research in the communities of Alta Cima and San José, located in the El Cielo Biosphere Reserve, Tamaulipas, Mexico (22°55′–23°30′N and 99°02′–99°30′W). El Cielo extends over 144,530 ha of the Sierra de Guatemala mountain range. El Cielo is managed by the Tamaulipas Secretary for Urban Development and Ecology (SEDUE; Sirur 2001). The region is characterized by rugged karst limestone outcroppings, and 98% of El Cielo has slopes of >20%. Precipitation averages 2500 mm/year in nearby Rancho del Cielo (1100 m), with an average temperature of 13.8° C (Puig & Bracho 1987).

Alta Cima (population, 250; area, 1152 ha) and San José (population, 75; area, 1500 ha) are both ejidos, which are legally recognized, communally held and managed lands. Within El Cielo, logging or other types of forest conversion are prohibited, and *C. radicalis* is the primary source of income for 92% of families in the two communities (Peterson 2001). These communities have harvested *C. radicalis* leaves for nearly 40 years, but it was not until the creation of El Cielo in 1985 that harvest of *C. radicalis* became their main livelihood activity (Medellín & Contreras 1994). Thus, palms in the ejidos have been subjected to continuous harvest for over 17 years.

Species Description

C. radicalis is a long-lived, dioecious, understory palm found in mountainous regions of northeastern Mexico. Within El Cielo, *C. radicalis* is found in a number of forest communities, including seasonal tropical forest (200–800 m), mixed mesophyll (800–1400 m), and pine-oak forest (>1400 m; Mora-Olivo et al. 1997; Jones & Gorchov 2000). The palm usually appears stemless (but has an underground stem), although some individuals have a well-developed stem 3–4 m high (Hodel 1992). We recognize four general life-history stages for *C. radicalis*: seeds, seedlings (bifid leaves), juveniles (3–9 leaflets on youngest leaf, nonreproductive), and adults (>10 leaflets and able to produce flowers; Endress et al. 2004). Male and female palms are morphologically similar, with the exception of their flowers (Berry & Gorchov 2004).

The harvest of *C. radicalis* leaves is restricted to adult palms. Suitable leaves are pinnately compound leaves ≥40 cm in length (from base to tip of rachis), with minimal insect or fungal damage.

Palm Harvest and Management

Participant observation and open-ended interviews with palmilleros provided insight into palm resource management. We accompanied and assisted palmilleros throughout the harvest process, from collecting leaves to sorting and processing them for sale. Open-ended interviews were conducted with 18 palmilleros (10 from Alta Cima, 8 from San José) and covered topics such as the technique(s), frequency, and pattern of harvest.

Between January 1999 and December 2001, 12 palmilleros from Alta Cima (34% of collectors in the town) recorded the number of leaves they sold each week in order to estimate the total number of leaves harvested and sold in Alta Cima. We estimated the number of leaves harvested per collector per month, and multiplied this by the number of palmilleros in Alta Cima. To incorporate the number of leaves harvested that are discarded prior to sale (because they were unsuitable), we added 1.3% to the value calculated above (Endress 2002).

Effect of Harvest on Leaf Ecology

We used information from the interviews to design our experiment to approximate current harvest patterns. In January 1999, we established 10 plots within Cañón del Diablo near Alta Cima. Plots were located on mid-level and upper hillside slopes (elevation ranged from 1039 to 1120 m), where *C. radicalis* is abundant (for additional plot description, see Endress 2002). Plot size varied from 53 to 290 m^2. Each plot contained 50 adult palms with leaves of marketable size ($n = 500$). Prior to December 1998, palms in our plots were exposed to leaf harvest; many palms showed evidence of past harvest (cut rachises), but there was no significant difference in the mean number of cut rachises per palm among treatments (df = 4,392, $F = 1.22$, $p = 0.486$).

The plots were divided into five subplots of 10 palms each, and one of five leaf-harvest treatments was randomly assigned to each subplot (split-plot design; $n =$ 100 palms/treatment). The treatments were (1) control, no leaf removal; (2) 1×/year, all marketable leaves removed once per year (August); (3), 2×/year, all marketable leaves removed twice per year (August and February); (4), 4×/year, all marketable leaves removed four times per year (February, May, August, and November), and (5), 4×/year modified, same as (4), but at most one leaf per palm was removed each harvest, and for a leaf to be harvested, the palm had to have at least two leaves (prevented 100% defoliation).

The 4×/year treatment approximated the current harvest regime in El Cielo. The 4×/year modified treatment was similar in harvest frequency, but restricted the number of leaves harvested per palm per visit. The other treatments (1×/year and 2×/year) were designed to test a range of harvest frequencies that palmilleros thought could plausibly be implemented.

In January 1999, all palms were permanently tagged, and the following data were recorded for each individual: number of leaves, number of leaflets on each leaf, leaf length, and inflorescence or fruit production. When new leaves emerged, they were marked to monitor leaf production. Palms were surveyed monthly through August 2001. At each census we recorded survival, number of new leaves, leaf length and number of leaflets, and inflorescence or fruit production. The harvest treatments were initiated in May 1999 and continued through August 2001.

Our study used treatments based on the frequency of visits to the site and local harvest selection criteria (leaf length and condition), not on the number or proportion of leaves removed per palm, and are thus fundamentally different from other palm defoliation studies (Oyama & Mendoza 1990; O'Brien & Kinnaird 1996; Ratsirarson et al. 1996; Zuidema 2000; Anten & Ackerly 2001). In our study, therefore, within a given treatment, the number of leaves removed per palm depended on the number of marketable leaves present, as occurs during actual harvest.

A total of 37 palms were removed from the experiment because they either (1) regressed to the juvenile stage (youngest leaf with 3–9 leaflets, hence not marketable) prior to the initiation of harvest treatments ($n = 16$), or (2) were browsed by cattle ($n = 21$). This resulted in the following sample sizes for each treatment: control; $n = 81$; 1×/year harvest, n = 96; 2×/year harvest, n = 96; 4×/year modified harvest, n = 94; and 4×/year harvest, n = 96.

We documented the leaf phenology of adult *C. radicalis* individuals by analyzing patterns of initiation, growth, and senescence of leaves produced by palms in the control treatment. Leaf initiation was determined by the presence of a visible spear leaf during our monthly censuses. We examined the time it took leaves to fully expand for leaves produced in May 1999 (the beginning of the first growing season; $n = 24$) and September 1999 (the end of the first growing season; $n = 23$), and differences in expansion rates were analyzed via a two-tailed t test. Precipitation was measured daily with a rain gauge placed in a clearing in Alta Cima, and summed monthly. The correlation of monthly precipitation and monthly leaf initiation was tested with the product-moment coefficient.

Annual leaf production rates among the treatments were determined for 2 years (year 1: June 1999–May 2000; year 2: June 2000–May 2001) and included all leaves initiated during that time. Palms that died during the study ($n = 66$) were removed from analysis. June 1999 was used as the start date because we only wanted to include leaves produced after initiation of treatments. Differences in annual leaf production among treatments were analyzed with repeated-measures analysis of covariance (ANCOVA). The model included three main effects: treatment, plot, and time, with size (number of leaflets on youngest fully expanded leaf in May 1999) as a covariate. The treatment × plot mean square error was used as the error term for the F tests for treatment effects (Potvan 2001). Statistical analyses were conducted in SAS (PROC GLM; SAS Institute 2000).

We used a repeated-measures ANCOVA to examine the effect of harvest on leaf length. For this analysis we tested for mean differences between (1) the length of the youngest fully expanded leaf prior to the first harvest (May 1999), (2) the first leaf produced following the first harvest (after May 1999), and (3) the first leaf produced 1 year after the treatments began (after May 2000). Model parameters were identical to the ANCOVA used to test differences in leaf production, and, again, analyses were restricted to palms that survived during the study period.

To evaluate the effect of the harvest on leaf yield, we recorded the number of leaves harvested per palm in the treatments over the first year (May 1999–February 2000) and the second year (May 2000–February 2001). The frequency distribution of yield data followed the Poisson distribution. Therefore, a repeated-measures generalized linear model following a Poisson distribution (PROC GENMOD) was used to test for differences in leaf yield among harvest treatments. Parameters in this model included treatment, plot, and time, with size as a covariate. We also compared mean leaf yields from this analysis with those of an analysis restricted to palms that survived through February 2001, to examine the relative contribution of mortality to observed differences in leaf yield.

Data on leaf yields were then integrated with data on the density of adults to estimate the income generated by each harvest treatment on a per-hectare basis. Previously, we estimated an average density of 1171 adult palms/ha in Cañón del Diablo (Endress et al. 2004). Therefore, we multiplied the mean number of leaves harvested (and 95% confidence interval) by the current stock of palms producing marketable leaves (1171) to estimate the mean number of leaves harvested per hectare per treatment. We then multiplied the mean number of leaves by the leaf price to estimate the income generated per hectare in U.S. dollars (using a conversion rate of US$1 = Mex$9).

Results

Leaf Phenology

Leaf initiation in *C. radicalis* varied seasonally and was positively correlated with precipitation ($r = 0.45$; Fig. 1).

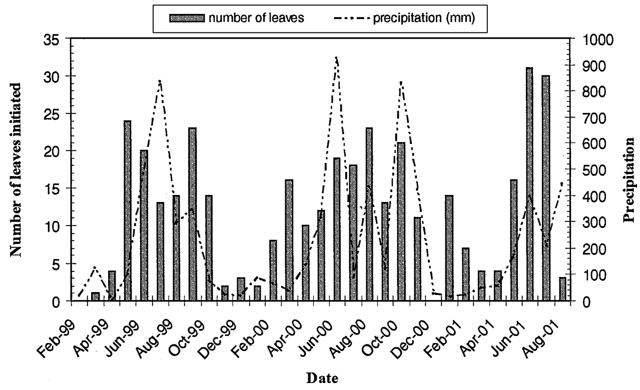

Figure 1. Number of new leaves produced each month on C. radicalis *adults in the control treatment* (n = *81*) *between February 1999 and August 2001, and precipitation from Alta Cima.*

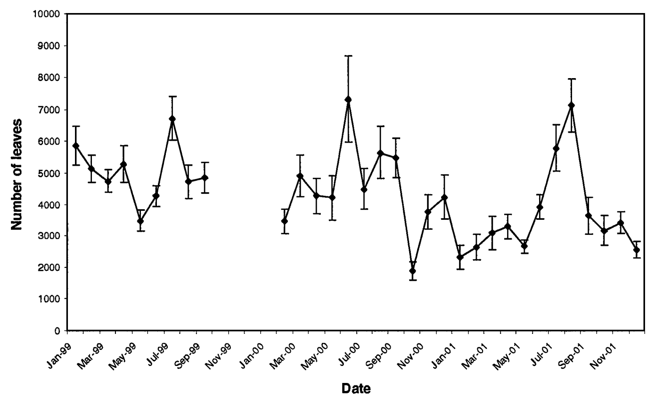

Figure 2. Mean number of C. radicalis *leaves (±SE) sold by 12 palmilleros each month in Alta Cima.*

Those leaves that initiated early in the growing season on average reached their final length after 7.6 months, significantly faster than leaves initiated late in the growing season (mean = 10.9 months; df = 45, $t = 5.39$, $p < 0.001$). Leaves were long-lived, with 91.5% living past one year and 44.7% living at least 24 months. The oldest leaves observed were 28 months old and were still alive in August 2001.

Palm Harvest and Management

The harvest of *C. radicalis* in the two communities occurs year-round, with palmilleros spending 3–5 days per week harvesting leaves. Ejido members have usufruct rights to palm resources, meaning that, although the community collectively owns palm resources, individuals within the community can harvest in any location at any time on ejido land. Palmilleros from surrounding communities are prohibited from harvesting within the ejidos.

Palmilleros travel 1–3 hours away from villages to reach dense stands of *C. radicalis,* and they visit the same location every 3–4 months. Usually 1–2 leaves per palm are collected, and harvest occasionally results in complete defoliation. Palmilleros generally do not harvest leaves that are not fully expanded, however, or the youngest leaf on a palm when no spear leaf is present. Palmilleros indicated that if these leaves are harvested, subsequent leaves will be shorter, and the palm will have an increased probability of dying. None of the pallimeros interviewed were aware of unharvested populations in their ejido or within El Cielo. Also, they reported that only a small proportion of palms, those located in inaccessible areas such as rock outcrops, are never harvested.

Once leaves have been harvested, they are sorted and bundled for sale. A small proportion of leaves harvested are discarded (1.3%) prior to sale for various reasons, including missing leaflets, yellowish color, or obvious fungal or insect damage. Marketable leaves are then bound into bundles of 25 and sold on a weekly basis to the middleman. During this study, the price per bundle of 25 leaves remained constant at Mex$2.50/bundle (US$0.28). The leaves are then transported to a processing facility in Ciudad Victoria, where approximately 25% of all leaves entering the facility are discarded because of insect or fungal damage (L. Trejo, unpublished data). From Ciudad Victoria, leaves are transported overland to the United States.

In Alta Cima, the 12 palmilleros sold an average of 48,053 leaves per month, resulting in a total of 1,537,700 leaves sold over 32 months, generating approximately US$17,086 (Fig. 2). This data excluded four months (October 1999–January 2000) when palmilleros were unable to harvest because of an expired harvest permit. From these data, we estimated the total number of leaves harvested by the 35 palmilleros in Alta Cima during this time as 4,484,950 leaves, generating around US$49,832. Accounting for leaves thrown out prior to sale, we estimated that Alta Cima palmilleros harvested just over 4.5 million leaves during the study.

Data on weekly sales of leaves were unavailable for San José; interviews suggested, however, that San José palmilleros harvest nearly twice as many palm leaves per harvest day as those in Alta Cima. In Alta Cima, palmilleros reported that they collect 16–20 bundles on an average day, and 24–30 on a good day, whereas in San José palmilleros collect 30–40 bundles on an average day and 50–60 on a good day.

Many palmilleros interviewed expressed concern about leaf quantity and quality. Palmilleros in Alta Cima were more concerned about palm resources than palmilleros in San José, and palmilleros from both communities indicated that San José had more productive palms than Alta Cima. Limited palm resources have resulted in leaf poaching by palmilleros of other ejidos, which has caused some tension among villages.

Table 1. Mean annual *Chamaedorea radicalis* leaf production rates per palm (+SE) in the harvest treatments for year 1 (June 1999–May 2000) and year 2 (June 2000–May 2001).

	Year 1		*Year 2*	
Leaf-harvest treatment	*mean*	*SE*	*mean*	*SE*
Control	1.75	0.067	1.88	0.065
1×/year	1.88	0.071	2.19	0.077
2×/year	1.77	0.061	2.16	0.061
4×/year modified	1.83	0.077	1.99	0.081
4×/year	1.71	0.056	1.99	0.073

Effect of Harvest on Leaf Production, Length, and Yield

Leaf production differed significantly among harvest treatments (df = 4,36, $F = 3.87, p = 0.0102$; Table 1), with leaf removal increasing leaf production. For both years, palms in the 1×/year treatment produced the most leaves and the control treatment the fewest. Contrasts indicated that only the 1×/year and 2×/year treatments produced significantly more leaves than the control (df = 1, $F = 2.04, p = 0.0122$ and df = 1, $F = 1.82, p = 0.0177$, respectively). Initial plant size affected leaf production, with larger adults having greater leaf production than smaller palms (df = 36,311, $F = 1.70, p = 0.0094$). Significant differences in leaf production were found among plots, with mean leaf production rates varying from 1.47 to 2.12 leaves/palm in year 1, and from 1.68 to 2.36 leaves/palm in year 2 (df = 9,311, $F = 10.79, p < 0.0001$). Within subjects, there was a significant time effect, with increased leaf production in year 2 (df = 1,311, $F = 1.73, p = 0.0184$).

Prior to the initiation of the harvest treatments (May 1999), the overall mean leaf length of the youngest fully expanded leaf was 49.3 cm, with no significant difference in mean leaf lengths among treatments (analysis of variance, df = 4,392, $F = 0.68$, $p = 0.607$). However, leaf harvest significantly reduced leaf lengths ($p < 0.0001$; Table 2; Fig. 3). The control treatment produced the longest leaves, and after just 1 year of the experiment, the 1×/year, 2×/year, and 4×/year harvest treatments produced leaves averaging below the 40-cm threshold for marketable leaves.

Leaf yield varied significantly among treatments (df = 3, $\chi^2 = 10.42$, $p = 0.015$; Table 3, Fig. 4). During the first year of harvest, the mean number of leaves harvested per palm ranged from 1.06 (1×/year treatment) to 1.59 (4×/year treatment). Leaf yield decreased dramatically in the second year, with the highest yield in the 4×/year modified treatment (0.71 leaves/palm) and the lowest in the 1×/year treatment (0.55 leaves/palm). The 4×/year treatment had the largest decrease in yield between years (62%), followed by the 2×/year (54%), 1×/year (48%), and 4×/year modified (41%) treatments. Contrasts showed that only the 2×/year (df = 1, $\chi^2 = 4.25$, $p = 0.0392$) and 4×/year (df = 1, $\chi^2 = 10.04$, $p = 0.0015$) treatments had significantly higher yields than the 1×/year treatment. Results were similar when we restricted the analysis to surviving palms (Table 3), indicating that adult mortality was not the primary cause of lower yields.

Table 2. Repeated-measures analysis of covariance (ANCOVA) of *C. radicalis* leaf lengths among leaf harvest treatments in the El Cielo Biosphere Reserve, Mexico.

Source	*df*	*MS*	F	p > F
Between subjects				
treatment	4	1096.26	4.41	0.0053
plot	9	1619.65	7.04	<0.0001
size	36	1092.69	4.75	<0.0001
treatment × plot	36	248.77	1.08	0.3521
error	311	230.22		
Contrasts				
control vs. 1×/year	1	3089.30	13.42	0.0003
control vs. 2×/year	1	1372.78	5.96	0.0152
control vs. 4×/ year modified	1	3436.20	14.93	0.0001
control vs. 4×/year	1	1635.98	7.11	0.0081
Within subject				
time	2	3484.27	88.31	<0.0001
treatment × time	8	279.50	4.58	0.0002
plot × time	18	203.49	5.16	<0.0001
size × time	72	46.58	1.18	0.1564
treatment × plot × time	72	61.08	1.55	0.0038
error (time)	622	39.46		

Multiplying the per-adult leaf production and yield data by the density of adults within Cañon del Diablo, we estimated that 3100–3878 adult leaves/ha are produced annually. Because many leaves in the harvest treatments are smaller than marketable size, however, yield was only 1877–2816 leaves/ha in the first year and 974–1257 leaves/ha in the second year (ranges were obtained by

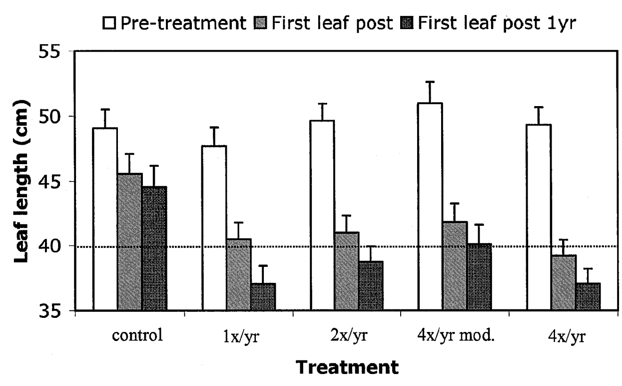

Figure 3. Mean leaf length (+SE) in each of the leaf harvest treatments (1) prior to treatment initiation, (2) the first leaf produced following treatment initiation, and (3) the first leaf produced 1 year after the experiment began (the dashed line = minimum size for marketable leaves).

Table 3. Mean leaf yield (leaves harvested/palm) of the harvest treatments during year 1 (May 1999–February 2000) and year 2 (May 2000–February 2001).*

	Including mortality			*Excluding mortality*		
	n	*mean yield*	*SE*	n	*mean yield*	*SE*
Year 1						
1×/year	96	1.06	0.09	81	1.05	0.01
2×/year	96	1.25	0.10	83	1.30	0.11
4×/year modified	94	1.21	0.10	77	1.36	0.11
4×/year	96	1.59	0.11	76	1.67	0.11
Year 2						
1×/year	96	0.55	0.07	81	0.64	0.08
2×/year	96	0.57	0.08	83	0.64	0.09
4×/year modified	94	0.71	0.09	77	0.87	0.11
4×/year	96	0.61	0.09	76	0.76	0.11

**Analyses with mortality included and analyses restricted to palms that survived through the study period are presented.*

multiplying 1771 by the extreme values among the treatments from Tables 1 and 3).

Incorporating the price of the leaves revealed that income generated per hectare from the treatments ranged from US$20.90 in the 1×/year treatment to $31.34 in the 4×/year treatment after 1 year (Fig. 4). As yield declined, so did revenue, with the 1×/year treatment generating the least and the 4×/year modified treatment generating the most in the second year of harvest.

Discussion

Although leaf initiation was correlated with precipitation, peak initiation generally preceded heavy rainfall months, suggesting that there is some seasonal cue other than soil moisture, such as solar irradiance, that triggers leaf initiation. Wright and van Schaik (1994) suggested that drought-tolerant trees in seasonal tropical forests generally expand their leaves in the season of maximum irradiance, not in the wet season; the same may be true for *C. radicalis*.

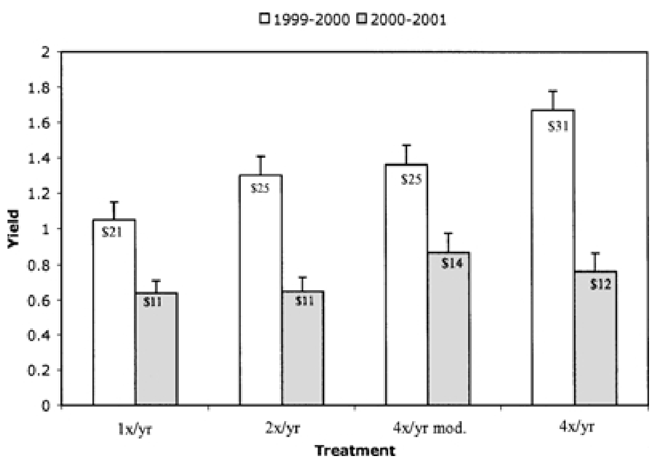

Figure 4. Mean number of Chamaedorea radicalis *leaves harvested per palm (+SE) between May 1999–February 2000 and May 2000–February 2000, and estimated mean income/hectare.*

Response to Harvest

All of our harvest treatments caused a modest increase in adult mortality and a slight decrease in fruit production, and transition-matrix models incorporating these effects project that harvested populations will grow significantly slower than unharvested populations (Endress et al. 2004). However, harvested populations would not decline (the finite rate of increase was not significantly lower than 1), suggesting that harvest should have only minimal ecological effects. This modest impact from harvesting appears to be primarily due to the production of shorter, unmarketable leaves, which effectively removes palms from the harvest pool. This respite may then allow them to recover from past harvest. It remains unclear how long it takes palms to produce marketable leaves again following harvest or whether there are differences among treatments in the rate of recovery.

Browsing by livestock appears to be a greater threat to *C. radicalis* populations than leaf harvest (Endress et al. 2004). Cattle, burro, and goats range freely in the communities, and all have been observed browsing *C. radicalis*. We found that a one-time brief exposure of a population to burro browse greatly increased the mortality of all life-history stages of *C. radicalis*, and we projected that populations subjected to annual browsing would decline (Endress et al. 2004).

Our results suggest that the selection process of NTFP harvesters, a neglected aspect of NTFP research, requires more attention by researchers. In situations where the quality or size of the product is important, selection criteria may be a critical component of NTFP management. Leaves are harvested for local or commercial purposes (e.g., roof thatch, basketry, floral arrangements) from a variety of palms, including *Chamaedorea* (Reining & Heinzman 1992; Endress et al. 2004), *Geonoma* (Flores & Ashton 2000; Zuidema 2000; Svenning & Macia 2002), and many other genera (O'Brien & Kinnaird 1996; Ratsirarson et al. 1996). However, in previous defoliation experiments (references above; Medoza et al. 1987; Oyama & Mendoza 1990; Anten & Ackerly 2001), defoliation treatments were based on a proportion of leaves removed per palm per year. This approach is appropriate when two critical assumptions hold: (1) harvest is uniform throughout the population and (2) harvest is fixed through time. Our research indicates that in cases where leaf size or quality are important, these assumptions are inappropriate because variation within populations dictates that some individuals will produce more valuable leaves than others. This results in variation in harvest intensity within a population, such that some individuals have more leaves removed than others. This, in concert with the response of individuals to defoliation, also results in temporal variation in harvest intensity (e.g., one year many leaves are removed, then next year fewer). Thus, studies that do not consider the spatial and temporal variation in harvest patterns may result in inaccurate assessments of the value of NTFPs for sustainable development or the effect of harvest on leaf production, yield, and population dynamics. This point underscores the need for long-term studies of the interactions between leaf production and spatiotemporal variation in harvesting throughout palm populations.

Palm Resource Management

Our results suggest that *C. radicalis* leaves are not a stable source of income for communities within El Cielo. The rapid loss of leaf yield is of particular concern because the communities are heavily dependent on *C. radicalis* as a source of income and have few available alternatives. All of the harvest regimes tested in our study resulted in a similar response, suggesting that less frequent harvesting will do little to ameliorate declining leaf yields, in addition to generating less revenue. Data from this study also suggest that palmilleros are currently harvesting nearly every available leaf, as they visit areas three or four times each year, whereas palms only produced approximately two leaves per year. This indicates that current harvest strategies are quite inefficient, with palmilleros covering large areas each day searching for leaves. Competition among palmilleros is strong, however, and palmilleros risk losing income if they do not repeatedly visit sites. The situation is particularly troubling in Alta Cima, which is three-fourths the size of San José, has twice as many palmilleros, and has three times as many residents (Peterson 2001). Intense leaf harvest, along with declining leaf yield and a low price for leaves, has resulted in illegal harvesting among communities and has limited the capacity of individual communities to develop resource-management plans for palms.

Assuming that yields from the second year are maintained, Alta Cima would need 1338–1727 ha of forest with *Chamaedorea* to sustain the present level of harvest (1,681,856 leaves/year). This is more area than the ejido of Alta Cima (1152 ha), further suggesting that there are not sufficient palm resources to meet current needs.

Several options exist to increase the sustainability of palm harvesting in El Cielo. Working with the palm buyer to base leaf prices on leaf quality, not quantity, would have beneficial results for palm populations and local communities, as fewer leaves would be harvested and palmilleros would receive increased revenue for premium leaves. The current system promotes the harvest of unmarketable leaves, resulting in increased pressure on palm populations and degradation of palm resources. Palmilleros are aware that many leaves they harvest may not make it to the marketplace; because the price of leaves is low, however, and they are heavily dependent on *C. radicalis*, many harvest these unmarketable leaves anyway to meet daily needs. Many palmilleros in Alta Cima and San José indicated that they would welcome sales based on leaf quality, feeling that they could earn more money and reduce their impact on *C. radicalis*.

Enrichment planting of *C. radicalis* would also increase the viability of palm harvesting, and Alta Cima and San José have been involved in palm propagation and enrichment plantings for several years, with over 50 ha having been reforested (Trejo 1992; Jiménez Pérez et al. 1999). Because *C. radicalis* is slow-growing however, it will take years for palms to produce marketable leaves, and because of slow leaf production and low yield, the scale of enrichment planting will have to be much greater to substantially benefit communities.

Most important, the underlying factors that result in palm-dependent communities within El Cielo must be addressed. A recent study (Peterson 2001) found that the policies of El Cielo greatly limited the ability of the communities to utilize their natural resources, and are the primary cause for intense palm harvesting in the reserve. Developing and supporting alternative livelihood activities, such as ecotourism and agroforestry, would likely reduce pressures on palm populations, diversify the resource base of communities, and strengthen local economies. Reserve management has supported small-scale development initiatives, but considerably more attention and effort is required to identify and solve natural resource problems within the reserve.

Our study highlighted the importance of understanding local harvest patterns and management strategies when evaluating NTFP extraction. Because we tailored our ecological studies to approximate current conditions, our results are directly relevant to communities and interpretable within the local context.

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