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Conservation status and effects of harvest on an endemic multi-purpose cycad, *Cycas circinalis* L., Western Ghats, India

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Abstract: *Cycas circinalis* belongs to the cycads, which are among the world's most threatened plant groups. In the Western Ghats of India, this species is subject to heavy harvest pressures from commercial trade and local-level retailing. To identify the effects of these threats, we assessed the status of 37 *C. circinalis* populations across 13 sites in the Western Ghats, identified effects of seed, leaf and pith harvest on population structure of the species and documented phenology patterns in relation to harvest. Most populations were small, and harvest had a significant impact on the population structure. Populations subject to pith harvest entirely lacked individuals > 50 cm tall. Leaf-harvested populations had low levels of seedling and adult individuals. The timing and level of leaf production differed significantly across sites, suggesting variation in resilience to harvest with environmental conditions. Our results highlight the importance of protecting the remaining populations of this multi-purpose species.

Resumen: *Cycas circinalis* pertenece al grupo de las cícadas, plantas que figuran entre los principales grupos de plantas más amenazadas. En los Gates Occidentales de la India, esta especie está sujeta a fuertes presiones de cosecha para el comercio de gran escala y la venta al por menor a nivel local. Para identificar los efectos de estas amenazas, evaluamos el estado de 37 poblaciones de *C. circinalis* en 13 sitios en los Gates Occidentales, identificamos los efectos la cosecha de semillas, hojas y médula sobre la estructura poblacional de la especie, y documentamos los patrones fenológicos relacionados con la cosecha. La mayoría de las poblaciones fueron pequeñas y la cosecha tuvo un impacto significativo en la estructura poblacional. Las poblaciones sujetas a la cosecha de médula carecieron completamente de individuos > 50 cm de altura. Las poblaciones en las que se cosechan hojas tuvieron proporciones bajas de plántulas e individuos adultos. El momento y el nivel de producción de hojas difirieron significativamente entre los sitios, lo que sugiere una variación en la resiliencia a la cosecha de acuerdo con las condiciones ambientales. Nuestros resultados resaltan la importancia de proteger las poblaciones remanentes de esta especie de usos múltiples.

Resumo: A *Cycas circinalis* pertence às cicadáceas, plantas que estão entre os grupos mais ameaçadas do mundo. Nos Gates Ocidentais da Índia, esta espécie está sujeita a pressões de

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abate para o comércio em grande escala e do comércio local de retalho. Para identificar os efeitos dessas ameaças, avaliámos a situação de 37 populações de *C. circinalis* em 13 locais nos Gates Ocidentais, identificámos os efeitos da colheita de sementes, de folhas, e medula sobre a estrutura de população da espécie e documentaram-se os padrões da fenologia relacionados com a colheita. A maioria das populações eram pequenas e a colheita teve um impacto significativo na estrutura da população. Às populações sujeitas a colheita de medula faltavam-lhes inteiramente indivíduos com altura > 50 cm. As populações sujeitas à apanha de folha apresentavam baixos níveis de plântulas e de indivíduos adultos. O momento e o nível de produção de folhas diferiram significativamente entre os locais, sugerindo variações na resiliência à colheita com as condições ambientais. Os nossos resultados destacam a importância de proteção das populações remanescentes desta espécie multiusos.

Key words: Leaf harvest, medicinal plant, non-timber forest product (NTFP), population structure, seed harvest, South India.

Introduction

The cycads (family Cycadaceae) are one of the world's most threatened plant groups. Originating 300 million years ago during the Carboniferous period, cycads are the oldest extant group of seed plants (Donaldson 2003). Many species have a restricted distribution with small population sizes, making them especially vulnerable to extinction (Donaldson 2003). Along with habitat destruction and modification, their harvest from the wild is one of the main threats to cycad species. Cycads are harvested for subsistence and commercial purposes, including for horticultural, ornamental, medicinal and food uses (Thieret 1958). Detailed ecological studies of the impacts of harvest on cycad populations are still rare, though research to date has illustrated some of the different effects that harvest may have on cycad species. For example, Raimondo & Donaldson (2003) showed that even a 5 % annual harvest of *Encephalortus cycadifolius* (Jacq.) Lehm and *Encephalortus villosus* Lem. adults in South Africa can cause population decline, highlighting the importance of adult plants for population persistence. In Australia, harvesting of whole plants and fire severely reduce seedling abundance of *Cycas arnhemica* (Griffiths *et al.* 2005). In the Mexican cycad *Dioon edule* Lindl., adult plant decapitation led to low sexual reproduction in disturbed populations and reduced adult survival in relatively conserved populations (Octavio-Aguilar *et al.* 2008).

Nine species of cycad are currently recognized within India, of which six are endemic (Lindstrom & Hill 2007; Singh & Radha 2008). The species *Cycas circinalis* L., endemic to South India, is an important multiuse plant for indigenous (*adivasi*) communities in India's Western Ghats, a biodiversity hotspot (Myers *et al.* 2000). *Cycas circinalis* is harvested throughout this region. The young leaves of this species are used as food by indigenous and local communities, and the mature leaves are sold to the floriculture industry. The pith and male cone are collected for their medicinal value, while the seeds are used as food and medicine (Varghese & Ticktin 2008). *C. circinalis*' endemic status combined with the fact that it is listed as 'Endangered' on the IUCN Red List (Varghese *et al.* 2010) and critically endangered (in the states of Karnataka and Tamil Nadu) or vulnerable (in Kerala) by the Foundation for Revitalisation of Local Health Traditions (Ravikumar & Ved 2000), make it of special conservation concern. However, almost no information is available on the ecology, conservation status and threats to cycads within India (Lindstrom & Hill 2007).

The impacts of plant harvest vary depending on the species being harvested, the part of the plant being removed and environmental conditions under which harvest occurs (Ticktin 2004). Leaf removal limits the photosynthetic capacity of plants and may, therefore, lead to reductions in leaf production, plant growth and reproduction, although sometimes leaf production may increase in response to partial defoliation over the short term (Pinard & Putz 1992; Ratsirarson *et al.* 1996). Compensatory leaf production comes at the expense of allocation to other energy demands, however, and so may not be sustained over the long term (Fong 1992). In addition, the effects of leaf harvest may vary according to leaf phenology and timing of harvest (Joyal 1996). Seed harvest may reduce population regeneration (Peres *et al.* 2003), although many studies have shown that populations can withstand high levels of fruit or seed removal without jeopardizing population persistence (Ticktin 2004). Pith harvest results in the death of adult plants and thus can reduce population viability by reducing the production of new individuals in cycad populations due to small numbers of adult plants and low coning frequencies (Octavio-Aguilar *et al.* 2008; Raimondo & Donaldson 2003). Understanding the extent and the effects of harvest on cycad populations is key to the conservation of this threatened group.

In view of this, the objectives of this study were to: (1) assess the current status (size and structure) of *C. circinalis* populations throughout the Western Ghats; (2) document current rates and extent of harvest; (3) assess the impacts of harvest on *C. circinalis* populations by comparing the size structure of populations subject to different types of harvest; and (4) compare the phenology of *C. circinalis* leaf production and reproduction, and the rate and timing of leaf harvest across sites with different environmental conditions.

Materials and methods

Study species and study site

C. circinalis is a cycad endemic to the Western Ghats and hilly regions of the southern peninsula of India, occurring in the states of Kerala, Karnataka, Tamil Nadu and southern Maharashtra. The epithet *circinalis*, (Latin for coiled), refers to the circinate pattern of leaflet unfolding. It is arborescent, growing up to 8 m high, sometimes branched, with old leaf bases usually prominent but sometimes weathering away to a more or less smooth skin. Leaves are 1.5 - 2.5 m long with leaflets in 90 - 120 pairs. These broad and long leaflets easily distinguish it from other Indian cycad species.

The plants are dioecious, distinguished by a non-pectinate megasporophyll and an attenuate microsporophyll apex. Megasporophylls, or seed cones, are brown, tomentose, 6 - 12 ovules are arranged in the upper half of a 15 - 30 cm long stalk, blade rhomboid, about 7 cm long, open at pollination and seed set. Male cones, or pollen cones, are solitary and cylindrically ovoid with 37 - 50 mm long microsporophylls. The pollen cones are 30 - 60 cm long, cylindric ovoid, prolonged into an upcurved subulate spine about 25 mm long. (Pant 1973). *C. circinalis* is facultatively deciduous in extremely dry times (Lindstrom & Hill 2007). Female plants in seed often shed their crown of leaves, possibly aiding in seed dispersal (Lindstrom & Hill 2007; Whitelock 2002).

The Western Ghats makes up the majority of the Western Ghats and Sri Lanka biodiversity hotspot (Mittermeier *et al.* 2004), one of 34 global biodiversity hotspots for conservation and one of two on the Indian subcontinent. Although it makes up less than 6 % of India's land area, the Western Ghats contains more than 30 % of all plant, fish, herpetofauna, bird and mammal species found in India and a high proportion of endemic species. It receives between 2,000 and 8,000 mm of annual rainfall during the monsoons, and, therefore, plays important hydrological and watershed functions. In addition to rich biodiversity, the Western Ghats is home to diverse social, religious and linguistic groups (Bawa *et al.* 2007). Our study took place in portions of the Western Ghats located in Tamil Nadu and Kerala. Vegetation types where *C. circinalis* is found include fairly dense, seasonally dry scrubby woodlands in hilly areas (Lindstrom & Hill 2007), where annual rainfall varies from 700 to 4500 mm (Table 1). *C. circinalis* is also found in moist deciduous and dry deciduous vegetation types (personal observation, V. Krishnamurthy).

To select sites for study, we conducted participatory resource mapping exercises in 2006 - 2007 to map the areas where *adivasi* people collect forest produce. Subsequent reconnaissance surveys helped to ground truth the information. Based on this information, we selected 13 sites where *C. circinalis* was present for this study. We determined the types and history of harvest at each site based on observations and focus-group discussions with local communities. We also located two sites (TSP & KMT) that had no harvest for at least five years prior to the survey. In each study site, all *C. circinalis* populations were located. This ranged from one to five populations per location, with a total of 37 populations overall (Fig. 1, Table 1).

Population size, structure and impacts of harvest

To assess the status of *C. circinalis,* we visually estimated the density of adult individuals in each study site after they were identified through the participatory resource mapping exercise. To assess population structure, we established one

Table 1. Location, harvest type and estimated population sizes of *C. circinalis* in study sites.

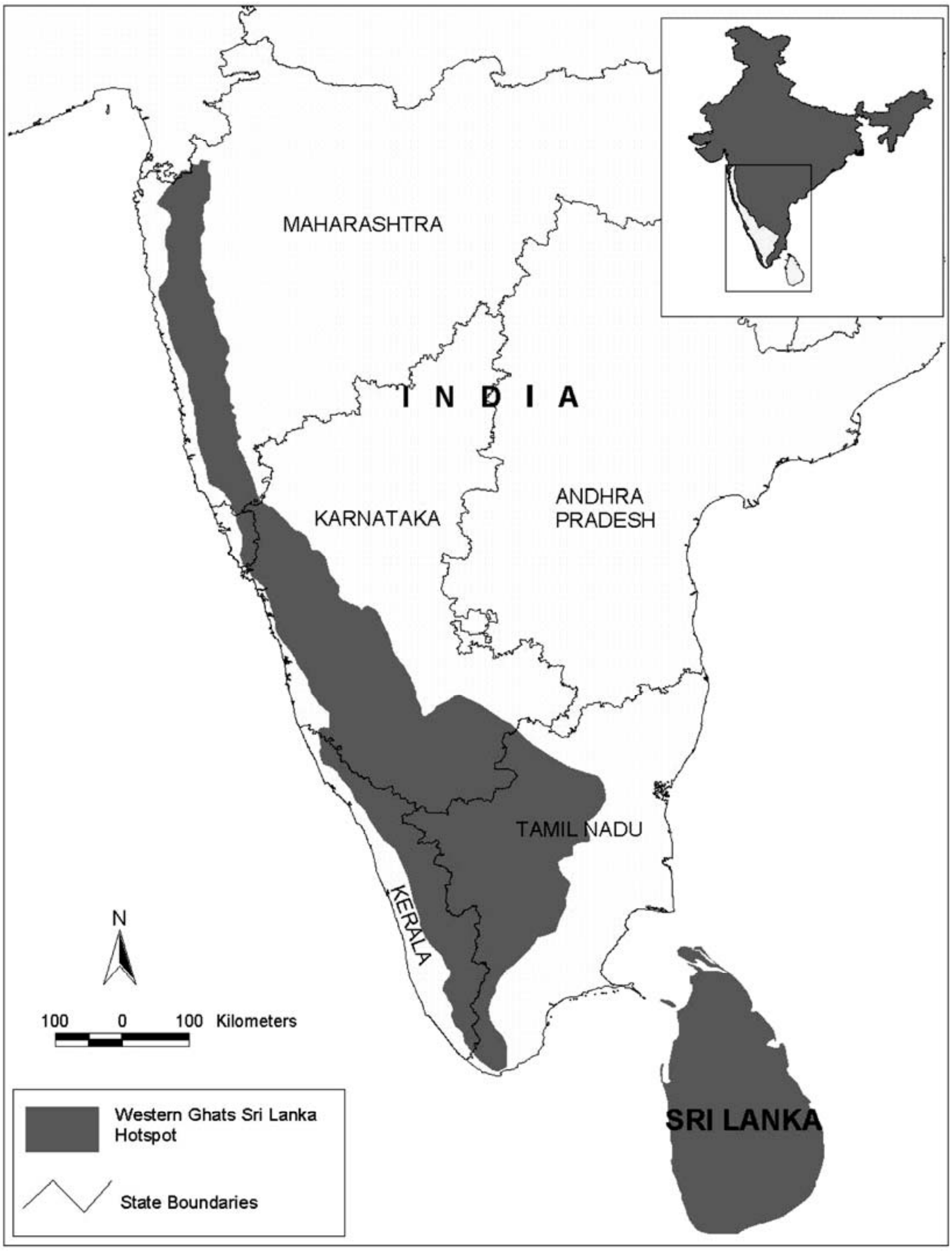
State	Site code	Altitude (m)	Rainfall (mm)	Type of harvester	Proximity to harvester village (km)	No. of populations monitored	Harvest type in census plot[1]	Estimated number of adults across all populations in site
Tamil Nadu	VLC*	1012	1500	Local and Hired	4.5	3	Heavy leaf[2], local[3] seed	> 300
Tamil Nadu	MRK	876	1500	Local and Hired	3.5	1	Heavy leaf, local seed	< 200
Tamil Nadu	KDM*	505	1500	Local and Hired	8	2	Heavy leaf, local seed	< 200
Tamil Nadu	TKR	442	1500	Local and Hired	2.5	3	Pith[4]	< 200
Tamil Nadu	KLR	642	1500	Local and Hired	4.5	1	Pith	< 200
Tamil Nadu	GDG	571	1500	Local and Hired	2	1	Heavy leaf, local seed	< 100
Tamil Nadu	TSP	740	800-4500	Local	1	5	Low/no harvest[5]	> 200
Tamil Nadu	KMT	300 - 400	800	Local	2-8	5	No harvest	
Tamil Nadu	STK*	582	700	Local and Hired	2	1	Heavy leaf, local seed	< 100
Kerala	APK*	100	3000	Local	0.5	1	Heavy seed[6], local leaf, male cone	> 300
Kerala	VNP	200	3000	Local	1	2	Heavy seed, local leaf	< 200
Kerala	PJK	585	3000	Local	0	1	Heavy seed, local leaf	< 200
Kerala	SVY	1100	4,500	Local	5	4	Heavy seed	> 300

Rainfall data: Source- Keystone Foundation.

* Phenology studies were undertaken
1 VLC, MRK, KDM were also subject to pith harvest in the past, but not within the study plots
2 'Heavy leaf' refers to commercial leaf harvest for floriculture industry combined with local leaf harvest for food and rituals
3 'Local' refers to use for subsistence only by local communities
4 Pith-harvested populations were also previously harvested for leaves and seeds
5 No leaf or seed harvest within the past five years at least and no known history of pith harvest
6 'Heavy seed' refers to commercial seed harvest for medicine combined with local seed harvest for food.

20 x 20 m plot within each population at each site (depending in the size of the *C. circinalis* population). This plot size and approach was appropriate because of the very patchy nature of *C. circinalis* populations. In each plot, all *C. circinalis* plants of all sizes were counted and tagged. Girth (measured below the leaf whorl), stem height, number of whole leaves, number of cut leaves, number of leaf scars, number of branches and reproductive status were recorded for each individual. We assessed the population size structure in 12 of the 13 study sites; the site STK was included only in the leaf phenology study.

To assess the impacts of harvest on population size structure, we divided all individuals within a site into 6 size classes based on stem height (cm):



Source: Political boundaries from Environmental Systems Research Institute, Inc.- Digital Chart of the World. (Bawa *et al.* (2007).

Fig. 1. Locations of *C. circinalis* sites along the Western Ghats, India.

< 50, ≥ 50 - <100, ≥ 100 - < 150, ≥ 150 - < 200, ≥ 200 < 250 and ≥ 250. The first class includes seedlings and saplings. Individuals become reproductive when they attain a height of around 150 cm. Individuals from different populations within a site were summed as opposed to averaged given the low density of *C. circinalis* individuals per population. We compared population size structures between harvest types using log-linear analysis.

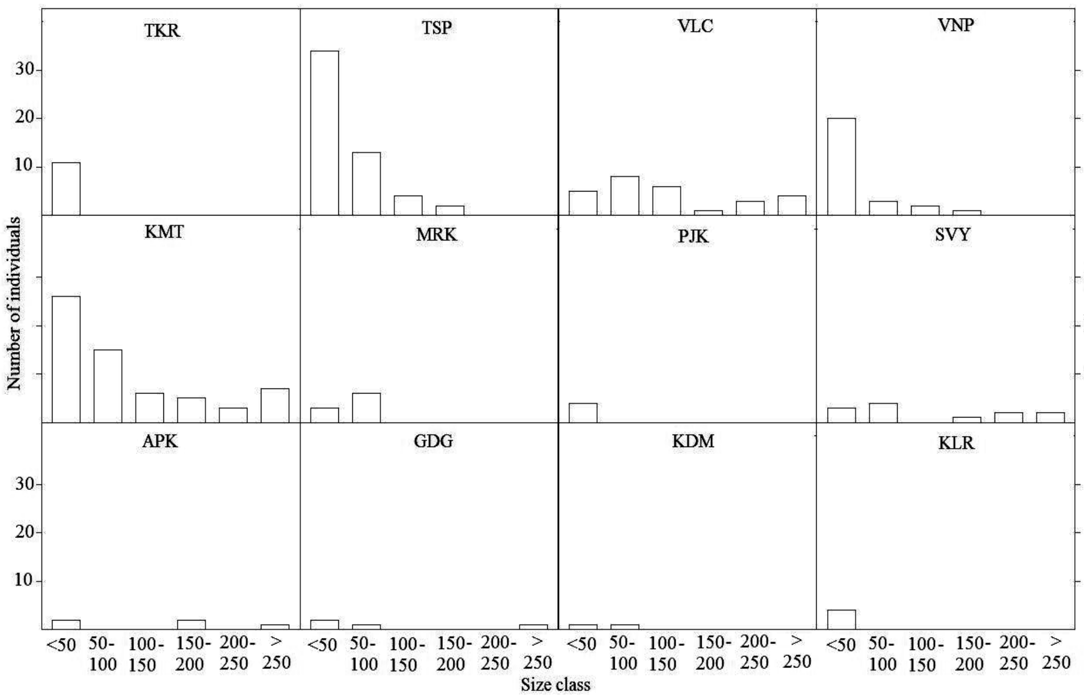


Fig. 2. Population structure of *C. circinalis* by site across the Western Ghats. Size classes represent height categories (cm).

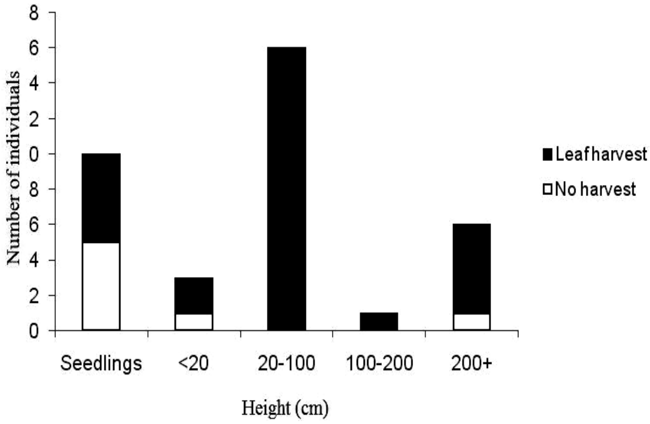


Fig. 3. Size-specific rates of leaf harvest of *C. circinalis* individuals.

Rates of leaf harvest

The proportion of leaves harvested per individual was calculated by dividing the number of cut leaves observed by the total number of leaves. The proportion of individuals harvested for their leaves was also calculated for each size class, based on the evidence of cut leaves. At the time of the survey (2006), two of the sites sampled (MRK and VLC) had been harvested for their most recent whorl of leaves and, therefore, rates and patterns of leaf removal were calculated for these sites only. The other sites sampled are also harvested for their leaves consistently but did not have the most recent whorl harvested.

Leaf phenology and rates of leaf production at select sites

We selected four leaf-harvested *C. circinalis* sites (KDM, APK, STK and VLC) for a more detailed study of phenology and the rates and timing of leaf production and harvest. The sites represent varying environmental conditions and intensities of leaf harvest (Table 1).

At each of these locations, we randomly selected between five and seven adult individuals for study. Focal plants were at least 5 m apart. We monitored a total of 33 stems on 22 individuals between February 2007 and September 2008. Monthly measurements included the number of leaves produced and harvested, plant height and girth, and the presence of reproductive structures. All sites have a history of seed harvest in addition to leaf harvest. However, during the study period, no seed harvest was observed at the sites. In addition, seed harvest is not expected to affect the factors measured. In some months, the sites were inaccessible due to weather or wildlife.

We used correlation analysis to test for associations between rates of leaf production and leaf harvest. We used analysis of covariance (ANCOVA) to test for differences in leaf production among sites, with plant size (maximum leaf number) as a covariate. In this phenology study, the maximum number of leaves present was used as an indicator of plant size because measures of plant height were unreliable due to landslides and multiple-stemmed individuals. Leaf production was cube-root transformed to improve normality, and plants that had no leaves for the duration of the study were omitted.

Results

In total we located 13 sites and 37 *C. circinalis* populations, spread across 14,800 km^2 of the Western Ghats. Based on interviews with local communities and on evidence of harvest in the plots, we determined that, of the 37 populations we located, eight were subjected to heavy commercial seed harvest (with some local leaf harvest), eight to heavy commercial leaf harvest (with some local seed harvest) and four to commercial pith harvest (harvested previously for leaves and seeds) (Table 1). Seventeen populations had no or very low levels of current harvest. In total, we monitored 374 *C. circinalis* individuals.

C. circinalis *population size and structure*

C. circinalis population size structure and density varied greatly across sites (Fig. 2, Table 1). Most populations were very small and more than half (7 out of 13 populations) showed a near or total lack of individuals in the larger size classes.

Rates of harvest

The 2006 population surveys revealed very high levels of leaf harvest at the individual level (proportion of leaves harvested per individual) and at the population level (proportion of individuals harvested per population). Ninety-two percent of all *C. circinalis* individuals > 20 cm height (those with a visible stem) were harvested for their leaves. All individuals in the 20 - 200 cm height range were harvested (Fig. 3). An average of 91.3 % of all leaves (median = 100 % of leaves) were removed from harvested individuals. Only those leaves damaged by insects were left. Only the smallest and the largest individuals appear to have escaped harvest. Some of the very large individuals escaped harvest as it is very difficult to access their high leaves.

These rates are similar to those recorded between 2007 and 2008 at four other sites with leaf harvest. On average 86.6 % of leaves per whorl were removed from harvested individuals, ranging from 72.3 % at VLC to 89.8 % at APK. Across the three sites where harvest occurred included in the 2007 - 2008 phenology study, 86.3 % of cycad stems with leaves were harvested for their leaves, with a total of 46.2 % of leaves harvested over the course of the study. No leaves were harvested from any plant in STK during the study period. This may be due to the small size of the plants at the site or to inaccessibility of the sites. KDM and VLC had the highest rates of leaf harvest. At these sites, more leaves were harvested during the study period than new leaves produced. Only 35.3 % of the leaves produced were harvested from APK over the course of the study.

In APK, leaf harvest occurred primarily in March, prior to the major flush of new leaves in May (Fig. 4). Harvest of leaves at KDM occurred primarily in December, a few months before a new flush of leaves began emerging. However, VLC did not have a primary period of harvest. Instead, individual plants were harvested throughout the year. Across all sites, we found a significant positive correlation between the number of leaves produced and the number of leaves harvested ($R = 0.7230$, $P < 0.001$). No cone, seed or pith harvest was observed during the study period at these sites.

Impacts of harvest on population structure

Log-linear analyses revealed that population structure was dependent on harvest type ($\chi^2 = 97.15$, df = 18, $P < 0.001$; Fig. 5). Unharvested populations showed a reverse J curve, with many individuals in the smaller size classes. Populations subject to commercial seed harvest also showed a reverse J curve but had lower numbers of individuals in the larger size classes. Populations subject to heavy leaf harvest exhibited a flattish curve, with reduced numbers in the seedling/ sapling category and low densities of adults compared to the unharvested populations. Populations subjected to pith harvest entirely lacked individuals > 50 cm tall.

Phenology of leaf production & reproduction

Twenty-four percent of the observed stems (8 out of 33 stems) in the phenology study did not produce any leaves during the study period, including four stems that had no leaves for the duration of the study. We observed reproduction only at the APK site. Of seven individuals moni-

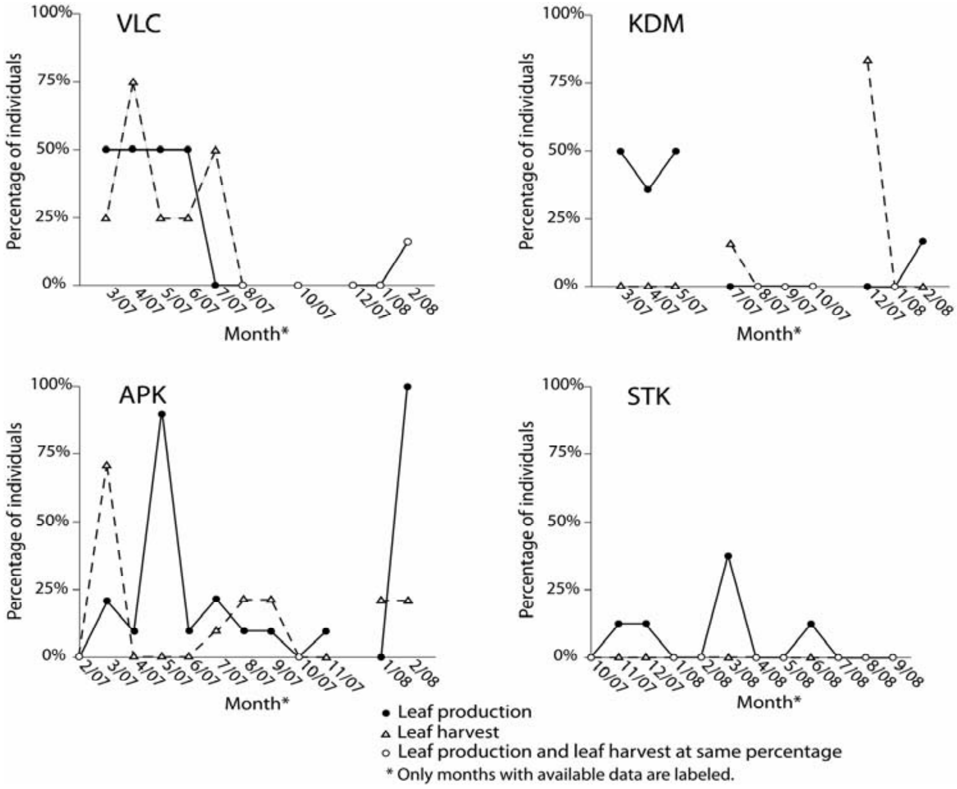


Fig. 4. Phenology of *C. circinalis* leaf production and leaf harvest across four sites in the Western Ghats.

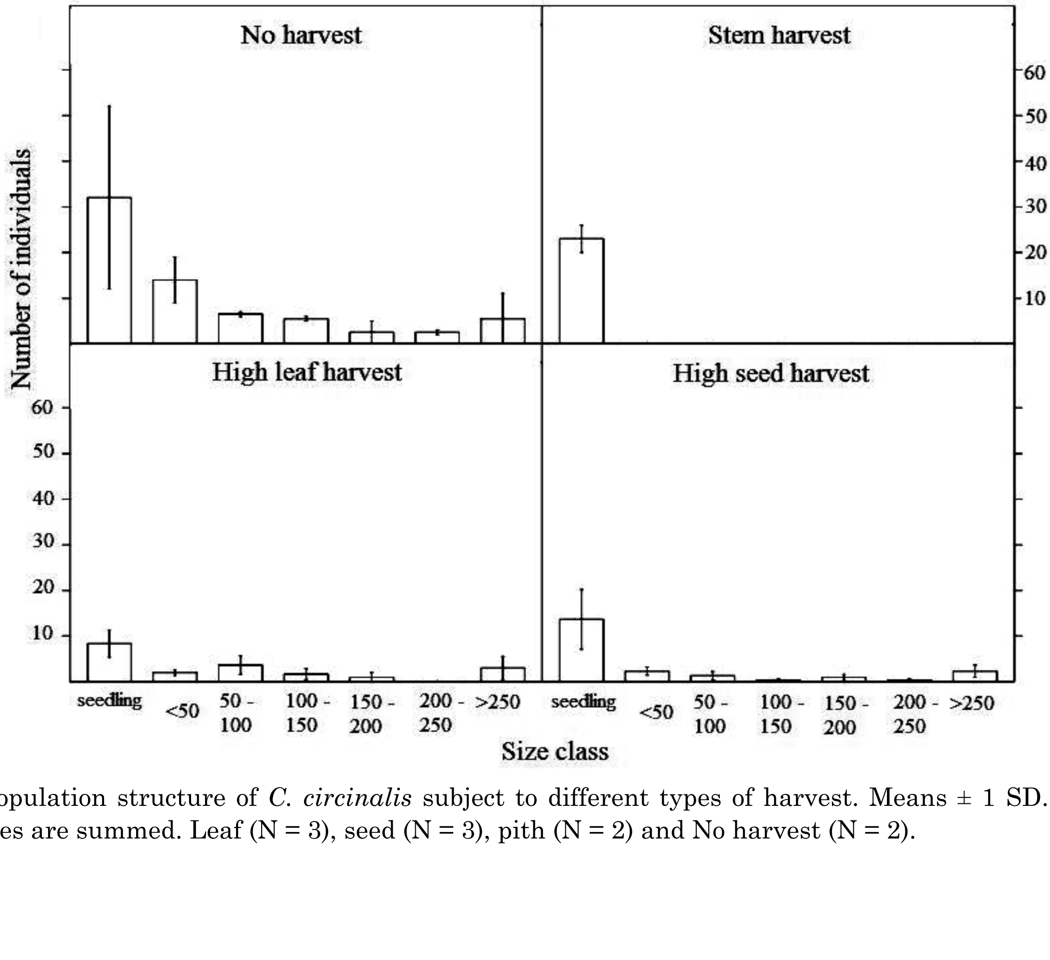


Fig. 5. Population structure of *C. circinalis* subject to different types of harvest. Means ± 1 SD. Populations within sites are summed. Leaf (N = 3), seed (N = 3), pith (N = 2) and No harvest (N = 2).

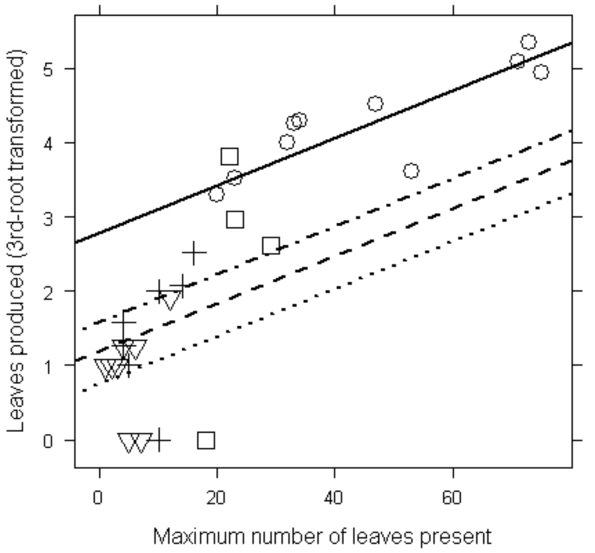


Fig. 6. Rates of *C. circinalis* leaf production are significantly higher (P = 0.0005) at Kerala site (solid line) than at other sites (dashed lines).

tored, one individual produced seeds and two produced pollen cones.

Differences in the timing of leaf production among the four sites appear to be related to environmental differences (Table 1). Plants at KDM and VLC, which receive similar amounts of precipitation, produced a single flush of leaves during the summer months. APK, in contrast, has a longer monsoon season and receives approximately three times the amount of precipitation. Plants at this site continued producing leaves throughout the year after a primary flush in May. The pattern is less clear in STK, where individual plants produced leaves only once per year, but leaf production did not occur synchronously across the population.

Across all four sites, stems with a greater number of leaves produced more leaves during the study period (Fig. 6, P < 0.001, F = 90.12, d.f. = 1,24). Stems of *C. circinalis* at the Kerala site produced more leaves than those stems of a comparable size at the three other sites (preplanned contrast, P = 0.0005, t = -3.087). The other three sites were not significantly different from each other. Omitting STK, which had smaller plants and lower levels of harvest, did not affect the results. In this analysis, leaf production rates for each stem were considered independent. When leaf production was summed across stems for each plant, the effect of site on leaf production was marginally significant (P = 0.059, F = 60.54, d.f. = 3,16).

Discussion

Status of C. circinalis *in the Western ghats*

Our surveys suggest that the status of *C. circinalis* populations in the Tamil Nadu portion of the Western Ghats - except the KMT site with no harvest - appears to be poor as most populations have few individuals and lack adult plants. While we do not have historical data on the populations we monitored, *C. circinalis* traders and harvesters reported that many populations have disappeared (personal communication to A. Varghese), and the Foundation for the Revitalisation of Local Health Traditions has estimated a reduction in *C. circinalis* populations of > 50 % in Tamil Nadu (Ravikumar & Ved 2000). Our results indicate that this decline is likely to continue. In Kerala, the status of *C. circinalis* may be better than suggested by our results as this species is also found growing in home gardens, rubber and teak plantations and along roads.

Effects of harvest on C. circinalis *populations*

Our analyses of population structure suggest that the decline in *C. circinalis* populations is strongly related to harvest, specifically the harvest of pith. The populations subjected to pith harvest showed a near-total lack of adult individuals. Other cycads have tolerated annual harvest of less than 5 % of adults (Raimondo & Donaldson 2003). This is likely very low compared to the current rates of pith harvest in Tamil Nadu, where pith harvesters tend to harvest all individuals > 50 cm height in a population.

In terms of leaf-harvested populations, given the very high rates of leaf harvest we documented, the lower seedling density and lack of individuals in the largest size classes relative to unharvested populations could be a result of reduced reproductive output and/or elevated mortality of older individuals due to consistent leaf harvest over time. The significant positive correlation between rates of leaf harvest and leaf production in the phenology study suggests that leaf harvest may increase rates of leaf production. It is possible that more frequent harvest is stimulating compensatory leaf production, as has been observed in other species, especially palms (Fong 1992; Joyal 1996). Alternately this relationship may simply reflect that harvesters collect more leaves from plants with higher rates of leaf production. Without unharvested control plants at each of our sites, we are currently unable to differentiate between these two possibilities. As with other species (Whitham *et al.* 1991), *C. circinalis* may be able to allocate the stored resources it holds in its stems to growth and reproduction after defoliation. This could allow for sustained rates of growth and reproduction - hence harvesters' observations that a new set of leaves emerge soon after they harvest a set of flushing leaves (personal communication to A. Varghese) - but not necessarily over high harvest intensities, nor over the long term (Fong 1992). While in some species, partial leaf harvest may allow for sustained growth and reproduction due to increased rates of photosynthesis in remaining leaves (Anten *et al.* 2003), the practice of harvesting almost all of the leaves on *Cycas* makes this unlikely. Other species are known to respond differently to leaf harvest. *Chamaedeora radicalis* Mart., an understory palm in Mexico, increased leaf production after harvest (Endress *et al.* 2004). However, the leaves were much shorter than those in unharvested populations. Leaf harvest of other species can also affect sexual and vegetative reproduction (Zuidema 2007), and these effects can vary across environmental contexts (Gaoue & Ticktin 2008).

The seed-harvested populations showed a reverse J size-class structure. and the proportion of seedlings was similar to that of unharvested populations, suggesting that good levels of regeneration occur despite commercial seed harvest. Heavy seed harvest has been shown to have little impact on population growth of other cycads (Raimondo & Donaldson 2003) and other tropical tree species in general (Ticktin 2004). However, humans are not the only consumers of *C. circinalis* seeds, and very heavy seed harvest could have an impact on the bats that are reported to disperse the seeds (personal communication with *adivasis* by V. Krishnamurthy). In addition, seed-harvested populations tended to have lower numbers of individuals in the adult size classes, indicating that survival in these populations may be reduced by other kinds of disturbances associated with people, such as fire. Similarly, the observed structure of the leaf-harvested populations may also be a result of high mortality due to other kinds of anthropogenic disturbances in addition to harvest. Longer-term studies are necessary for elucidating the factors contributing to the low *C. circinalis* densities we observed.

Interactions among harvest, phenology and climate

The impacts of harvest of *C. circinalis* leaves and, therefore, the potential for sustainability, may vary due to differences across sites in climate and in plant phenology. One critical factor that can greatly alter the impacts of leaf harvest is the time of harvest. *C. circinalis* leaves are produced in flushes which senesce and are shed naturally; therefore, harvest soon before the leaves are shed at the end of the natural lifespan of the leaves could have little impact as compared to harvest soon after leaf production. Since in KDM and APK leaf harvest primarily precedes leaf flush, harvest in these locations may be more sustainable than in VLC where harvest occurs both before and after leaf flushing.

Rates of leaf production per stem were significantly greater at the site with higher levels of precipitation (APK) compared to the other sites. With higher rates of leaf production coupled with the potential to produce leaves nearly year-round, the APK site may be able to support higher levels of leaf harvest than sites within Tamil Nadu. However, differences in leaf production between sites may also be due to differences in rates and time of leaf harvest. Because of high levels of harvest, we were not able to identify a sufficient number of comparable unharvested plants within each site and, therefore, could not differentiate between the effects of environmental conditions, such as precipitation, and the effects of leaf harvest intensity on leaf production. Based on our observations, rates of leaf production may also differ depending on whether new, young leaves or mature and fully expanded leaves are harvested. Our results point to the importance of more detailed phenological studies to better clarify these relationships.

Implications for conservation

Most *C. circinalis* populations are subject to different combinations and levels of leaf, pith and seed harvest, both by local communities and outside harvesters. Our results suggest that heavy harvest appears to be negatively impacting populations. These effects are likely compounded by habitat loss and potentially other factors such as climate change, which has already triggered species distribution shifts all over the world (Thuiller *et al.* 2005). Longer term studies for *C. circinalis* will provide more information on the plasticity and adaptability of this species.

Other species of cycads in India, viz., *Cycas beddomei* Dyer (Lindstrom & Hill 2007) and *Cycas spherica* Roxb., are also harvested in large quantities for medicinal purposes from the Eastern Ghats of India (personal observation, V. Krishnamurthy). Evaluations of these other cycad species are also necessary. This, along with studies in trade and *in situ* and *ex situ* experiments, will help these species to be effectively conserved.

An approach being initiated by Keystone Foundation is the establishment of "Cycad Conservation Centers," which integrate community-based monitoring, local propagation and conservation awareness within local communities. Outplanting within wild populations and in nurseries is needed to increase the feasibility of sustainable harvest in cultivation and preservation of this species in the wild. Research and conservation measures driven by local communities are vital to creating management plans for the sustainable use of this endemic species.

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