Ethnobotany, trade and population dynamics of *Cycas circinalis* L., and *Cycas swamyi* Singh & Radha in the Western Ghats of southern India

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In loving memory of Ravi Uncle

and Swetambari

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ABSTRACT

Harvest of Non Timber Forest Products (NTFPs) has been frequently studied as a means to conserve forests and provide income to user communities, often with the assumption that harvest has relatively little ecological impact. *Cycas circinalis* L. and *Cycas swamyi* Singh & Radha are such NTFPs extensively harvested from the Western Ghats, South India. They are harvested for bark, leaves, seeds and male cones by indigenous people for medicinal, food and ornamental purposes, while commercially harvested for the medicinal and floricultural industries. Although indigenous people have a long association with *Cycas* spp, harvest for sale in informal regional markets has been uncontrolled over the past 15years. *Cycas circinalis* is now regionally listed as 'critically endangered' and internationally listed as an 'endangered' species. In an attempt to understand the uses and responses of these species to harvest pressures, this study aims to document the trade, ethnobotany, life history, and population dynamics of *Cycas* spp. My study shows there is a large scale trade of leaves and pith and peak leaf sales occurs shortly after new leaf production in cycad habitats. The pith of *C. circinalis* and *C. swamyi* are collected for the herbal medicinal industry however, they are adulterants and don't provide the necessary constituents of the herbal drug, *vidari*. Demographical studies confirm that harvested populations are on a decline as the projected population growth rate over the long term λ, was <1 for all harvested populations. *Cycas* spp have ancient lineages from the Jurassic age, being long-lived and slow-growing, and this coupled with intensive extraction reduces the chances for populations to rapidly withstand the induced stress of harvest. The effects of harvest can be further compounded by other disturbances such as fire, habitat loss and climate change. Sustainable harvest practices for seed harvested populations and the discontinuation of leaf and pith harvest

are imperative to conserve the last few populations of *C. circinalis* and *C. swamyi* in the Western Ghats.

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CHAPTER 1

Dissertation Introduction

Humans were hunters and gatherers long before they adopted agriculture and commercial timber extraction. They survived on wild plants, what we currently call “Non-Timber Forest Products” (NTFPs). Even now, in the age of agriculture, NTFPs form the backbone of a subsistence and local commercial economy for many forest dwelling communities (Hiremath, 2004). This is especially true in the tropics, where 90% of forests lie outside of protected areas (WWF, 2002) which is used by millions of forest-dependent peoples who live in and around these forest areas. For example, in India, about 75-80% of the forest export income comes particularly from the export of NTFPs (Tewari, 1994) contributing up to 40 per cent of the household income in some parts (Chopra 1997). The estimated market value of herbal medicine alone (a large proportion of which is collected from the wild) is about US $ 14 billion (CBD, 2001).The FAO estimates that 80 percent of the populations of developing countries use NTFPs (FAO, 1997). NTFPs are important to rural house- holds in terms of their contribution to health, food, energy, and other aspects of rural welfare (Mahapatra, Albers, & Robinson, 2005).

Long-term economic benefits from sustainable NTFP extraction have been proposed to prevent forests from being put to more destructive land uses such as logging, mining or ranching, and help lower rates of tropical deforestation (Panayotou & Ashton, 1992). However, harvesting NTFPs as a means to conserve biological resources is debatable. Several authors have claimed that promoting NTFP harvesting does not necessarily lead to forest conservation (Chediack, 2008), because the extraction of NTFPs can cause significant ecological impacts (Cunningham, 2001; Kusters, 2009; Ticktin, 2004). Other times, the harvest of NTFPs is assumed to have little or no ecological impact. Yet, continuous harvest may affect the physiology and vital rates of individuals and change demographic and genetic patterns of populations (Ticktin, 2004). The removal of a plant product from a forest may also adversely affect dependent animal populations, the effects of which could then reverberate through forest ecosystems as some of the affected species could be significant pollinators or fruit dispersers (Terborgh 1998) altering community and ecosystem level processes. Unfortunately, the lack of data limits our understanding of the ecological implications of harvest on a larger scale and at a regional approach (Ticktin, 2004).

Hence, monitoring and evaluating the ecological effects of NTFP harvesting has increasingly been suggested as an essential strategy to mitigate negative impacts (P. Hall & Bawa, 2009; Setty, Bawa, Ticktin, & Gowda, 2008; T. Ticktin, 2004).

The ecological effects of NTFP harvest are specific and can vary according to the ecosystem, region and management practices adopted (B. a. Endress, Gorchov, & Berry, 2006). The harvest of NTFP can have different impacts on the individuals and plant populations exploited, depending on the plant life-history, the part of the plant harvested, and the intensity and time of harvesting, as well as environmental and management conditions (Ticktin 2004). At the individual level, the exploitation of vegetative parts might negatively affect the particular part being extracted (Delvaux, Sinsin, & Van Damme, 2010) as the normal development of other organs is harmed by redirecting nutrients to repair damaged parts (Cunningham, 2001b). Additionally, the harvest of vegetative parts can affect survival (P. Hall & Bawa, 2009). To give a few examples, harvest of leaves can effect annual survival and growth (B. A. Endress, Gorchov, & Noble, 2004; Martinez-Ramos, Anten, & Ackerly, 2009) with direct consequences for how long it takes organisms to achieve reproductive size as well as how many years they are expected to live. The harvest of roots can affect survival (Ticktin, 2004), while the harvest of flowers has direct consequences on reproduction (Schmidt & Ticktin, 2012). At the population level, harvesting affects the size of populations (C. M. Shackleton, Guthrie, & Main, 2005; Tamara Ticktin, Nantel, Ramirez, & Johns, 2002) and can cause modifications in age structure of populations (Peres et al., 2003). Since populations interact with each other, this can them affect community and ecosystem level processes.

In the Western Ghats of South India, a biodiversity hotspot (Bawa et al., 2007), many NTFPs are heavily harvested, yet very little is known about the quantities extracted, the nature of the trade, or of the ecological impacts. Species of the genus *Cycas* (*C. circinalis* L. and *C. swamyi* Singh & Radha) represent important NTFPs harvested from the Western Ghats by indigenous communities as well as commercial harvesters for lucrative market sale. In the case of commercial harvest, it is customarily executed in bulk for the cones, leaves, pith and seed for food, medicinal and floricultural purposes. *Cycas circinalis* is included in the negative list of exports notified by the Government of India Notification 2 (RE-98) dt. 13-04-1998, 1997-2002 (Ravikumar & Ved, 2000). It is also listed as “endangered” by the IUCN Red-list (A. Varghese, Krishnamurthy, Ganesan, & Manu, 2010). The Foundation for the Revitalization of

Local Health Traditions (FRLHT) estimated a reduction in *C. circinalis* populations of > 80% and >50% in Karnataka and Tamil Nadu. Plant products are collected *en masse* often lopping whole plants. For example in Thattekaru Tamil Nadu, a total of 30 *C. circinalis* plants were lopped in a single visit (Krishnamurthy, 2006). Harvest effort is relatively low as most cycad populations are found in clumps (Norstog & Nicholls, 1997) minimizing the amount of time spent looking for the plant. The legalities of harvest vary over the range of *Cycas* spp; albeit, most harvest is done illegally. On the other hand indigenous people harvest the leaves, seeds and bark of *C. circinalis* for cultural, food and medicinal purposes. It is evident that pressure from harvest is immense, however, little is known about the quantity, rate and seasonality of harvest of these plant products.

The genus *Cycas* belongs to the order Cycadales. Cycads have ancient lineages from the Jurassic age, being long-lived and slow-growing plants (Watkinson & Powell, 1997) with a very gradual stem development. This coupled with intensive extraction reduces the chances for populations to rapidly revive themselves after the induced stress of harvest, often responding in very diverse ways. For example, studies show that even a 5% annual adult harvest of *Encephalortus cycadifolius* and *Encephalortus villosus* in South Africa caused the population to decline (Raimondo & Donaldson, 2003), clearly limiting harvest of adult plants while for *Cycas arnhemica*, harvest affected the recruitment of seedlings (Griffiths, Schult, & Gorman, 2005) probably due to the plant compensatory growth responses to re-grow the plant part harvested (Martinez-Ramos et al., 2009). In the Mexican cycad, *Dioon edule*, contribution to sexual reproduction was higher in disturbed populations while contribution to adult persistence was higher in relatively conserved populations (Octavio-aguilar, González-astorga, & Vovides, 2008). In the case of *Cycas* spp. in the Western Ghats, a preliminary study conducted on *C. circinalis* in the Nilgiri Hills shows higher number of individuals in the smaller stage classes with a low population of adults (Krishnamurthy et al., 2013; Varghese A and T. Ticktin, 2007).

Approximately 82% of all cycads are listed by the IUCN as threatened, largely because of deforestation and trade in wild plants (IUCN, 2003). *Cycas* spp. are listed in the Appendix II of CITES. However, *Cycas* species in India are understudied with little available information limited to morphology and anatomy. During the past few decades, research has shown that cycads have evolved symbiotic interactions with nitrogen fixing cyanobacteria, arbuscular mycorrhizae, bird and mammal dispersal agents, and with various insect pollinators (IUCN, 2003), none of which is known about the *Cycas* spp. in India. As part of my doctoral dissertation, I am interested in the worm's-eye view of the use, status and functioning of *Cycas* species in the Western Ghats. For this I have obtained the necessary data to ensure effective conservation through research on ethnobotany, trade, life history and population dynamics.

The aim of this study is to identify and compare the levels and patterns of different uses and trade of *C. circinalis* and *C. swamyi*, determine the impacts of these uses on the wild populations and test potential strategies for restoration.

Specifically, my research questions are:

1. Which are the main regional markets that sell plant products of *Cycas* spp.? What other wild-harvested NTFPs from the Western Ghats are sold in these markets?
2. What are the prices of buying and selling, quantities of harvest, trade trajectory, and methods and patterns of extraction of *Cycas* spp?
3. What are the different ethnobotanical uses, methods of harvest and management, quantities and patterns of extraction of the different plant products of *Cycas* spp used for subsistence by local indigenous communities?
4. What effects do leaf/pith and seed harvest have on the population dynamics of *Cycas* spp?
5. Do *C. circinalis* and *C. swamyi* populations respond differently to leaf/pith harvest? If so, why?

This dissertation is divided into five chapters. Chapters 2, 3 and 4 present the results of my reseerch. Chapter examines trade of *C. circinalis* and *C swamyi*, Chapter 3 presents the analyses from the population modeling of *C. circinalis* and *C. swamyi* and Chapter 5 documents the ethnobotanical uses of *C. circinalis*.

In Chapter 2, I present the results of my interviews conducted in informal flower and medicinal markets in southern India. I draw on data of two years of interviews conducted in the flower markets and one year of interviews conducted in the medicinal markets. I assess the trends in markets supply and sales. The main research questions for both the markets are: 1) How many leaves and how much pith is sold on a bi-monthly and monthly basis and does this vary seasonally? 2) How many vendors sell *Cycas* products and what are the different types of vendors present in the markets? 3) Who are the main consumers? 4) Where does the supply come from?

In Chapter 3, I examine the effects of harvesting cycad seeds, pith and leaves on the population dynamics of *C. circinalis* and *C. swamyi*. For this study I use Integral Projection Models to analyze the specific impacts of harvest on survival, growth and reproduction of these two species. I draw on data over three locations and 10 populations of *C. circinalis* and *C. swamyi.* The questions I address are: 1) What are the population dynamics of *C. circinalis* and *C. swamyi* populations? 2) What are the effects of seed and pith harvest on long-term population growth rates?

In Chapter 4, I list the different ethnobotanical uses of *C. circinalis* in different indigenous villages of the Western Ghats. Additionally, I document some of the Traditional Ecological Knowledge (TEK) of these communities for the sustainable use of *C. circinalis* in comparison with commercial harvesting and its impacts. The specific research questions are 1) What are the different uses of *C. circinalis* in different indigenous communities of the Southern Western Ghats? 2) How are these uses associated to present trends of commercial harvest?

Finally, in chapter 5, I conclude this dissertation by presenting my main findings on the ethnobotany of cycads and the impacts of commercial harvesting on population dynamics. I also present complementary research that is being developed in south India, discuss the limitations of my work and provide suggestions for future research.

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CHAPTER 2

How modern and traditional practices affect wild plants: quantifying the sale of cycad leaf and pith in local markets of southern India

Vandana Krishnamurthy & Tamara Ticktin

Abstract

The sale of Non-timber Forest Products (NTFPs) provides multiple livelihood benefits to local communities and regional economies. The informal market structure in populated areas provides a setting for the trade of forest products with a variety of uses and their study can provide key insights on patterns and volumes of harvest. However, informal markets remain understudied. In this paper, we assess the trade of two NTFPs from the Western Ghats of southern India. *Cycas circinalis* and *Cycas swamyi* are cycads reported to be overharvested for sale in the ornamental cut-flower and medicinal industry. The leaves are used as fillers in floral bouquets and the pith is used as an adulterant in Ayurveda and Siddha systems of medicine. *C. circinalis* is listed as "endangered" in the 2013 IUCN Red List of threatened species. To assess the pressures from local markets, we ask: 1) what is the quantum of leaves (*C. circinalis* and *C. swamyi*) and pith (*C. circinalis*) inflow and outflow and how does this vary over time? 2) Who are the vendors involved in the trade and the main consumers of these products? Where is the supply of leaf and pith harvest coming from? We conducted bi-monthly and monthly market visits to three important urban/semi-urban markets where the leaves and the pith of these plants are sold. Our results show that harvest is strongly seasonal in the leaf markets. In 2011 and 2012, 35650 and 39600 leaves were harvested respectively to supply the Bangalore market. Inflow of leaves, price and season were significantly positively correlated with the outflow. Leaf inflow strongly followed the Hindu cultural calendar. In the pith markets, monthly inflow ranged from 2 – 45 tons through the one year of study in both markets. Outflow was dependent on the stocks available, and the demand from the Ayurvedic/Siddha industry. Given that leaf harvest involves complete defoliation and that pith harvest involves lopping the entire plant, the scale of harvest documented could jeopardize the remaining populations of these slow-growing and long-lived cycads.

Keywords: ntfp, informal markets, harvest, livelihoods, medicinal plant, floriculture

Introduction

Non Timber Forest Products (NTFPs) constitute an important source of livelihoods for people in most human-dominated forest landscapes in tropical countries (Shaanker *et al.* 2004). Many people across the developing world trade in a diverse range of NTFPs daily, which are marketed primarily in local and regional domestic markets (Scherr, 2004). Some of the NTFPs traded in these markets include building materials, indigenous foodstuffs, medicines, craft items, resins, honey, oils etc. At least one-fourth of the world's poor depend partly or fully on forest products for subsistence (World Bank, 2002), and significant sources of cash income (Mahapatra *et al.* 2005; Shackleton *et al.* 2007; Davidar *et al.* 2008; Howell *et al.* 2010).

Informal local markets located in rural areas account for the bulk of all NTFP sale (Arnold *et al.* 1994; Arnold 1998). However, local markets tend to be relatively poorly acknowledged, under-appreciated and often neglected (Shackleton *et al.* 2007). Most studies concentrate on products procured for export markets, but rarely focus on its contribution to rural income and employment or the quantities and people involved in the trade (Arnold, 1998). This sort of information is essential to reiterate the view that a wide number of people from developing countries depend on NTFPs to sustain their livelihoods. Quantifying the trade in NTFPs includes expensive data gathering costs for most countries as the extent of products used and people involved in the trade is extremely variable (Vantomme, 2003). Apart from this, the seasonal and sporadic production of many products, extremely localized production or consumption, dispersed production sources, adulterants, the secrecy of the trade, the lack of dedicated infrastructure, and the cultural roots, are some of the reasons that these markets remain understudied (Fereday *et al.* 1997).

India is known for its vast dependence on forest derived products. In areas where dense human populations live in close proximity to biodiversity-rich forests, extraction is widespread and contributes significantly to household incomes ((Kothari 1995; Rai and Uhl 2004; Bawa *et al.* 2007). Of the 15,000 flowering plant species in India, nearly 3000 species (20%) yield NTFPs. However, only about 126 species (0.8%) have been commercially developed (Maithani, 1994) while the rest are not documented or quantified. In certain areas, NTFPs have been known to contribute up to 40% of the household income (Mahapatra & Shackleton, 2011; Tewari, 1994). Government records show that minor forest products contribute about 50 % of the Indian government forest revenue and 70 % of forest-based product exports (ICCF, 2005). This is an income equivalent of US$ 2.7 billion per year (Chauhan 2008).

Ayurveda, Siddha, Unani are some of the most common traditional and alternative systems of medicine in India (Nagori et al. 2011). These systems utilize different herbal preparations to cure a range of different illnesses, although other mainstream forms of medicine such as Allopathy and Homeopathy are dominant. It is estimated that there are approximately 6000 plant species that are used in these systems of medicine as well as many traditional and folk medicines (Rajshekharan 2002). The market for Ayurvedic medicines is estimated to be expanding at 20% annually in India (Subrat *et al.* 2002). There are over 1.5 million practitioners in traditional medicinal systems using medicinal plants in preventive, promotional and curative applications with over 7800 medicinal drug-manufacturing units in India, which consume about 2000 tons of herbs annually (Verma & Singh, 2008). Although there has been some successful cultivation of wild plants for mainstream medicine production, a significant portion of the plants are harvested from forests and sold at local markets (Dubey *et al.* 2004).

Unlike agricultural systems in India, where there is an elaborate system of price fixation administered through the government to protect producers, the markets in NTFP trade are mostly determined by the leaseholders or local traders. Rural NTFP businesses mostly function in an informal microeconomic setting and suffer from limited or no access to larger markets or end use value chains (Mahapatra & Shackleton, 2011).The natural product trade in Indian states is strongly established through village markets and is an integral part of the household economy with rural people buying or selling forest products as part of their daily activities *(Mahapatra et al.* 2005). It is clear that there is a huge national market for wild harvested medicinal plants; however, there is very little information on particular plants and quantities extracted along with regions of extraction. Local markets play an important role in understanding the dynamics of the quantities of wild harvested plants and the people involved in the market chain. This serves as a basal understanding of interventions in rural development, associated livelihood dynamics and conservation of resources in forested regions. This type of data is vital to avert over extraction and subsequent extinction of particular plants. Since more than 70% of NTFP collection and sale occurs in the tribal belt of the country (Mitchell *et al.* 2003), markets are prime regions for conservation studies. Here we use a case study of the trade in cycad parts to understand the dynamics of NTFP markets in India.

Cycas circinalis L. and *Cycas swamyi* Singh & Radha are cycad species that are endemic to the Western Ghats in southern India. The young leaves of this species are used as food by indigenous and local communities, and the mature leaves are harvested for local cultural celebrations and commercially for sale in the cut flower industry (Krishnamurthy *et al.* 2013). The pith and male cone are collected for their medicinal value, while the seeds are used as food and medicine (Varghese and Ticktin 2007; Krishnamurthy *et al.* 2013). Widespread harvest of cycads is reported to occur for *C. circinalis* and *C. swamyi*, (Krishnamurthy *et al.* 2013), which is thought to be responsible for the observed decline in populations of these two species. The two largest threats are the sale of the leaves for the cut flower markets and pith for medicinal value in metropolitan markets of India. *C. circinalis* is listed as "endangered" and *C. swamyi* is listed as "data deficient" according to the 2013 IUCN Red List of Threatened Species. The harvest of plant products from adult cycads may have serious consequences for wild populations, since cycads are extremely slow growing, and replacing adult individuals may take many decades (IUCN, 2003). However, there is little information on the trade patterns and the quantification from local markets. Local markets can be very informative about the age of the individual, harvesting methodology and extent of harvest of a specific plant part and the prevalence of certain size classes may reflect what is available in the wild or what is preferentially targeted by harvesters (Botha *et al.* 2004; Williams *et al.* 2007).
This study aims to quantify the trade of *C. circinalis* and *C. swamyi* leaves and pith in the local markets of southern India. The data are collected from local floral markets where the leaves are sold to florists and local herbal markets where the pith is sold to industries involved in preparing herbal medicine formulations. The main research questions for both the markets were: 1) How many leaves and how much pith is sold on a bi-monthly and monthly basis and does this vary seasonally? 2) How many vendors sell *Cycas* products and what are the different types of vendors present in the markets? 3) Who are the main consumers? 4) Where does the supply come from?

Study species and study site

Study species

Cycads are ancient, long-lived, dioecious woody plants with palm-like appearance found growing in Africa, Central and South America, South-east Asia, India and Australasia (Jones, 2002). The world cycad flora has 335 species and subspecies, which represent a small fraction of the earth's plant diversity (Calonje, Stanberg, & Stevenson, 2012). Cycads have global conservation significance as the destruction and alteration of natural habitat and selective removal of plants and plant products from the wild in massive numbers have significantly reduced population size (IUCN, 2003). The 2011 IUCN Red List of Threatened Plants cites that 79% of all cycads are threatened with extinction (Varghese et al. 2010). In Asia, collection of plants for horticulture, harvest for ornamental use and cultural/medicinal value are important causes for decline. Most cycads are harvested and sold in local markets (IUCN, 2003).
Cycas circinalis is endemic to the Western Ghats, a mountain range on the western coast of India. It is found in the states of Kerala, Karnataka, Tamil Nadu, and Maharashtra. *Cycas circinalis* is facultatively deciduous in extremely dry times. It appears to be an adaptable species with colonies extending from rocky hill outcrops down to coastal habitats at sea level. It is arborescent, growing up to 8 m tall, with leaves that are 1.5-2.5 m long. It is usually found in fairly dense, seasonally dry scrubby woodlands in hilly areas (Lindstrom and Hill 2007).

Cycas swamyi is similar to *C. circinalis* but differs with a shorter apical spine on the megasporophyll and shorter and narrower leaves. The *C. swamyi* populations also show distinct suckering growth habit, probably due to disturbance. *C.swamyi* is restricted to the Hassan district in Karnataka state, common on flat sandstone or on quartzite-dominated areas. This species forms extensive colonies (Lindstrom and Hill 2007).

The Western Ghats comprises the major portion of the Western Ghats and Sri Lanka Hotspot and one of 34 global biodiversity hotspots for conservation. It covers an area of 180,000 square kilometers, which is less than 6 percent of the land area of India. However, the Western Ghats contains more than 30 percent of all plant, fish, herpetofauna, bird, and mammal species found in India. It also has a high proportion of endemic species. Because it is a largely montane area it receives between 2,000 and 8,000 millimeters of annual rainfall within a short span of three to four months. (Bawa *et al.* 2007).

Study site

The adult leaves of *C. circinalis* and *C. swamyi* are harvested in bulk for floral decorations from the wild, and transported to the city where florists buy the leaves to line bouquets or other floral decorations. The main floral market for the sale of *C. circinalis* and *C. swamyi* leaves is Bangalore, Karnataka (Figure 1). Bangalore is one of the main urban centers of southern India. It is well connected with other major cities and towns in the region. Karnataka is the biggest floricultural market in all of India. Most of the sales happen in three markets, viz., KR Market, Yeswanthapur and Shivajinagara in Bangalore City (Choudhary 2000). Approximately 250000 million retailers and flower vendors are engaged in the flower trade in Bangalore City (GOK, 2000). The Krishna Rajendra market (K. R. Market) was selected for this study, as it is the biggest market and the first point of entry into Bangalore. K. R. Market is the central point for cycad leaf deposition and is also the place from where middle men transport leaves and flowers to other smaller markets.

The pith of *C. circinalis* also called as Vidari is known to be used in Ayurveda and Siddha systems of medicine (Mitra, 2007). There is a lot of confusion around the original plant species under this trade name. While its authentic source is *Pueraria tuberosa* (Willd.)DC. and its substitute is *Ipomoea mauritiana* Jacq., market samples are rarely derived from these two. *Cycas circinalis* pith has crept into the raw drug market under the trade name of *Vidari* because of the similarity of its appearance to the raw form from *P. tuberosa* and *I. mauritiana*. However, research has shown that *C. circinalis* does not qualify as a source of this drug as per Ayurvedic descriptions (Venkatasubramanian, K, & Venugopal, 2009), and is therefore a fraud. Nevertheless, harvest of *Cycas* species continues for the pith.

The pith is sold predominantly in Madurai and Chennai in the *naattu maranda kade's* or local herbal medicinal shops (Fig 1). The *nattu maranda kade's* in Madurai and Chennai are traditional markets that play an important cultural role. Madurai is the third largest city and the second largest municipal corporation in the state of Tamil Nadu. The city of Madurai rises from the plains of the Vaigai river valley. It is one the oldest cities in the world and its history covers two and a half millennia and during much of that time it has been an important cultural and political center (Reynolds, 1987). Madurai is built around the Meenakshi Amman Temple, which acted as the geographic and ritual center of the ancient city of Madurai. The Madurai Meenakshi Amman temple built in 1623 CE served as an important worship site for many communities. It became a nodal point in Madurai district and southern India for trade and culture. The study was conducted in the local medicinal shops that are found all around the temple. Raw drugs are sold in these markets to treat many everyday ailments like coughs and colds as well as illnesses like diabetes and high/low blood pressure.

Chennai, (formerly Madras) is the capital city of the state of Tamil Nadu and the biggest industrial and commercial center, as well as a major cultural, economic and educational center in south India. The *naattu maranda kade's* in Chennai are found in the northern part on one single street called Nainappan Naicken Street. *Naatu maranda kade's* in Chennai are the main regional green drugs market for South India. Regional markets cover a very large area and support several market places (Cunningham, 2001a) and include a designated street for the sale of raw drugs. Apart from raw drugs, the street al.so has a number or surgical and chemical stores. Although only 10 to 15 vendors sell raw drugs on this street, this market is the most important hub in all of south India for the sale of raw materials for the Ayurvedic, Siddha and Unani medicinal systems.

Methods

Data collection

A preliminary visit to all major markets in south India was conducted in June 2009. Study for the leaf markets (in Bangalore) was conducted over two consecutive years between January 2011 and December 2012. Study of pith markets (in Chennai and Madurai) was conducted from May 2012 to April 2013.

Market structure

We conducted an initial survey of the number and type of vendors, products, schedules, and infrastructure in Chennai, Madurai and Bangalore to understand the extent of the market and to document the different types of vendors present at the markets. A pilot study showed that there was one main vendor and several sub-vendors in the market.

Quantum of trade

Open ended semi-structured interviews were conducted monthly with cycad vendors in the markets to document the mechanism and process behind the trade of cycad leaves in Bangalore. Pilot studies showed that there is one main vendor and several sub-vendors in the market. The primary vendor was chosen as our main participant and interviews were conducted every two weeks. Three other sub-vendors were selected for monthly interviews. Interviews were designed to obtain data on quantities of harvest, quantities sold, price, earnings and type of clientele. The length of the leaves was measured to understand the size of the leaves being harvested. Interviews also included information on the sites of harvest. Open, semi-structured interviews were conducted with three regular customers who owned their own established florist stores, on leaf market prices, sale periods and client base. In addition to this, the other species of leaves present in the market were also noted to understand florist trends. Data collected was classified into seasons. The seasons were, Spring (March 23 – May 22), Summer (May 23 – July 22), Monsoon (July 23 – September 22), Autumn (September 23 – November 22) and Winter (November 23 – March 22) following the Hindu calendar months Vasanta, Grisma, Varsha, Sarad, and Hemanta respectively.

In Chennai and Madurai, four vendors were chosen for half yearly interviews and one specific vendor was chosen in each market for regular monthly data collection. Pilot studies in 2009 showed that amongst the vendors selling pith, there was one major vendor with a larger store and larger customer base. This major vendor was chosen as our main participant for weekly interviews and the three other vendors were interviewed every six months. Similar interviews were conducted for pith trade as well.

Data analyses

A multiple regression with a Poisson error distribution, (where the response variable was outflow and the independent variables were inflow (supply), price, year and season) was used to identify predictors of outflow (sale) of leaves and pith. The data from the three markets were linked to ecological data collected earlier to draw a relationship between quantum of leaves/stems harvested and number of harvested trees. All analyses were conducted in R version 3.0.1 (R Core Team, 2013).

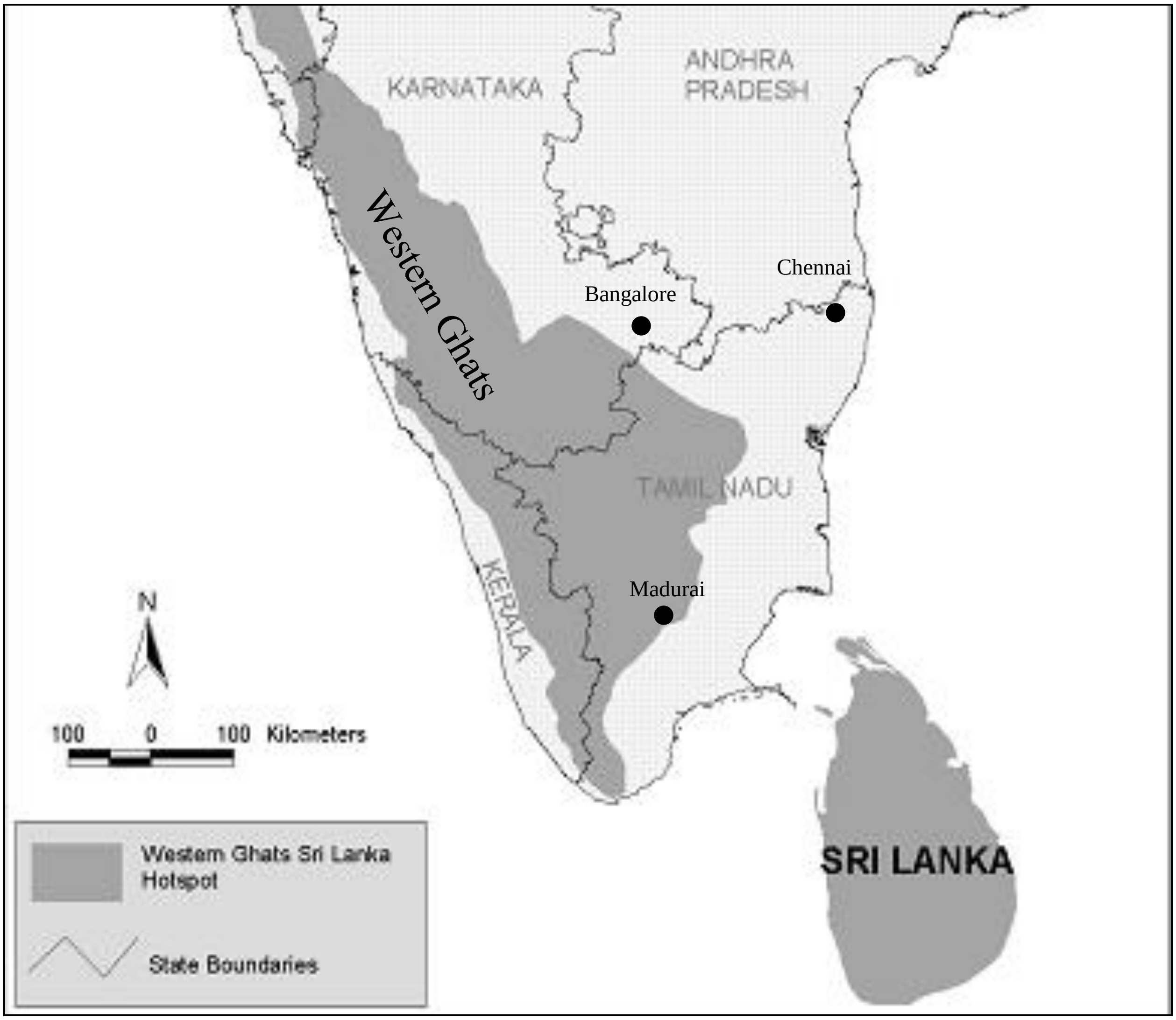

Figure 1. Map of southern India with the market sites: Bangalore, Madurai and Chennai

Results

Leaf harvest - Bangalore

Market description and structure

K. R. Market predominantly sold flowers and related products. According to preliminary surveys, the market had 100 – 150 traders-cum-commission agents operating in flower trade as against 50 – 60 in the 1960s. From our observations, there were three distinct types of vendors at these markets – Permanent, seasonal (or travelling), and itinerant according to the classification by Cunningham (2001). The permanent vendors are people who are present all through the year. They own furniture specifically made for regular sales and have staff who receive payments every day. The seasonal or travelling vendors are found only at specific times of the year, typically during the flowering season of specific flowers like *Jasmine*. The itinerant traders are not regular or seasonal, but visit the markets very irregularly.

The market was active only between 3:00 am and 9:00 am, beyond which the street resumes its activities as a shopping avenue. According to long time vendors, K. R. Market was largely dominated with culturally important flowers in the past. It is only in the last 20 years, vendors have adopted modern cut-flowers. The flowers prominent in these markets were roses (*Rosa* spp), followed by *Gladiolus* spp., *Asters* spp, jasmine (*Jasminum sambac* (L.) Aiton and *Jasminum augustifolium* Willd.) kanakambara (*Crossandra infundibuliformis* (L.) Nees), marigold (*Tagetes erecta* L.), *Chrysanthemum* spp, tuberose (*Polianthus tuberosa* L.), ferns (*Asparagus racemosus* Willd.), kanagale (*Nerium oleander* L.), various orchids and *Anthurium* spp. Sales were usually in bulk either small bunches, (12 flowers with stems or sold loose) or large bunches (80 – 100 flowers with stems/loose).

According to flower vendors, commercial flowers are grown on the edges of Bangalore city. Many flowers are transported to Bangalore from other states like Tamil Nadu and Kerala. Ooty is an important hill town from where unusual species like orchids and lilies are sourced. A small flower vendor earns anywhere between Rs.3,000-4,000 ($49.12 - $ 65.49) and a major vendor between Rs.20, 000-40,000 ($327.44 - $654.88) on a daily basis.

The people driving this industry are local vendors from different ethnic origins. The vendors can be described as small-scale, informal, commercial operators who fulfill fluctuating demands for wild-harvested products. Ornamental flowers in different varieties and colors were the predominant produce on sale. While there are many native flowers like *Jasminum* sp., *C.*

infundibiluformis, and *N. oleander*, most other species are exotic. *Cycas circinalis*, *C. swamyi*, and *Caryota urens* were the native filler plants used. There was a distinct divide in the market between ornamental cut flowers and religious flowers by the kind of flowers being sold. The religious flower market was larger with more diversity and higher sales.

Of the ~150 vendors, 10 specifically sold leaves used as backgrounds and fillers (Image 1). The market had a specific corner which is designated only for the sale of leaf fillers. *C. circinalis* and *C.swamyi* leaves were the dominant fillers sold. The other leaves available in the markets for florist use were, fish tail palm (*C. urens* L.), *Cycas revoluta* Thunb., asparagus ferns (*A. racemosus*), babys breath (*Gypsophila paniculata* L.) and bamboo palm (*Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf.) (Image 1). All 10 vendors were present through the two years of data collection. Other flower vendors also carried *C. circinalis* leaves, but in very small quantities (2 – 5 bundles).

Image1. Vendors selling filler leaves at the Bangalore markets

Quantum of inflow and outflow

According to our main participant, sales of *Cycas* leaves started in 1996 by his father because of the shift in trends of flower decoration and the expansion of the horticulture industry. The demand for *Cycas* leaves came from florists, especially for larger flower decorations. At the time these leaves were rare. The main regions of harvest were Arsikere and Melkote. Earlier, *C. swamyi* was the main species being harvested. The cost of the leaves being sold then was Rs 5 ($0.08) per bundle at 50 paise ($0.008) per leaf. At that time, each bundle consisted of 10 leaves and an average inflow was 30 bundles daily. *Cycas* leaves were used because of their ornamental appearance and the ease of harvest, as most harvesting sites in forests are open and on the sides of main highways.

Cycas circinalis was the main species that was sold during the study period. *Cycas swamyi* was present however, in very small amounts and supply was very irregular. This was reported to be because of the lack of harvestable leaves in Melkote and Arsikere. Each bundle consisted of 6 leaves and was sold at Rs 15 – 20 ($0.25 – $0.33) a bundle at the rate of Rs 2.5 – 3.3 ($0.04 - $0.05) per leaf for *C. circinalis* and *C. swamyi*. The vendors wire money to the harvesters before the produce is delivered. The order is placed over the phone and subsequently the required quantities are transported by truck. The consignment is delivered early in the morning before the markets are active. The market chain consists of the harvester, vendor, florist and consumer. If the leaves are transported to other cities from Bangalore, the vendor in the Bangalore market becomes the middle man who then transports it to the respective vendors in other cities.

The average leaf size of *C. circinalis* in the market was 75.3±5.8 (range 65-90 cm). The average leaf size of *C. swamyi* was 42.7±3.7cm (range 33 – 48 cm). Most often the petiole is cut off during harvest and the leaves are cut into two and the leaflets further trimmed as ornamentation by florists.

Interviews with the vendors indicated that the cycad leaves were used purely for decorative purposes. The clients who purchase the leaves are florists with established shops/kiosks in the city. K. R. Market is also a central market from where leaves are purchased in bulk to be transported to towns in Tamil Nadu. The leaves are utilized for marriage and ceremonial decorations as well as gifting purposes. The trade names are “palm leaf” or “cycas”. They are preferred over the common bamboo palm leaf (*D. lutescens*) because of their longer shelf-life, darker color, ease of access to harvest sites and cheaper price.

The numbers of leaf bundles sold every two weeks varied from 70 to 500 bundles for *C. circinalis* in the first year and 50 – 600 bundles in the second year (Fig 2). The price for *C. circinalis* ranged from Rs 15 – 20 ($0.25 - $0.33) (Fig 3). For *C. swamyi*, the number of leaf bundles sold ranged from 1 – 55 bundles for the first year and 4 - 30 bundles in the second year

(Fig 4). Usually, *C. swamyi* was sold at the same price as *C. circinalis* and ranged from Rs 15 – 20 (Fig 5). The average inflow of leaf bundles every month for *C. circinalis* was 289.4±141.6 and 16.6±10.9 bundles for *C. swamyi* (Table 1).

For *C. circinalis*, inflow, price, season and year were significant predictors of outflow (Table 2). For *C. swamyi*, inflow and season was positively correlated with outflow; however price did not vary with different levels of outflow (Table 3). For both species, outflow was significantly lower in summer and monsoon seasons for both years. This period is referred to as *Aashada masa* which is an inauspicious time for any ceremonial practices. The greatest outflow occurred during the wedding season (November to March). The average number of *C. circinalis* leaf bundles sold during the wedding season, from November 25th - December 20th was 350±114.01 bundles in the first year and 370±44.72 in the second year. For *C. swamyi*, the average number of bundles in the wedding season of the first year was 41±11.40 and 20.8±2.77 in the second year. Price varied in different seasons and was significantly positively correlated with outflow (Table 2 & 3). The lull in sales during the *Aashada masa* resulted in an average earning of Rs 216 ($3.6) as opposed to Rs 3716 ($61.93) in the wedding season for C. circinalis. *C. swamyi* sales also increased in the wedding season. The earnings from *C. swamyi* sales would fetch the vendor an average of Rs 294 ($ 4.9) while only Rs 16.85 ($0.28) during Aashada masa.

For *C. circinalis*, the total inflow of leaves in year 1 from our main participant was 7130 bundles, which equates to leaves from 356.5 adult trees in the wild, assuming that each tree produces approximately 120 leaves in a year in one whorl (Lindstrom and Hill 2007). The total inflow in year 2 was 7920 bundles which equates to leaves from 396 adult trees. The average number of leaves produced in a year for *C. swamyi* is 60 leaves as it has been recorded to produce leaves only once a year (Krishnamurthy, unpublished). The total inflow of leaves was 455 (45.5 trees) bundles in the first year and 407 (40.7 trees) bundles in the second year. The above estimates are based on the assumption that these plants produce the estimated number of leaves in a whorl despite the effects of harvest, and if all the leaves on a tree are harvested.

Table 1. Inflow (number of bundles), price (Rs), earnings (Rs) and harvested trees for *C. circinalis* and *C. swamyi*. (This data was collected from one vendor who was the main participant in the study).

Leaf measurements	***Cycas circinalis***		***Cycas swamyi***	
	Year 1	**Year 2**	**Year 1**	**Year 2**
Range of bundles inflow	60 - 500	50 – 600	1 to 55	4 to 30
Average monthly inflow	274.3±127	308.8±155.8	17.5±14	15.7±6.7
Average annual inflow during the wedding season (November – March)	350±114	370±44.7	41±11.4	20.8±2.7
Total annual inflow of leaves	7130	7920	455	407
Price Range (Rs)	15 - 20	15 - 20	15 - 20	15 - 20
Earnings (Rs)	47955	1,12,025	4278	4120
Estimated no of trees defoliated	356.5	396	27.3	24.42

Table 2. Outflow of *C. circinalis* leaves from the Bangalore floral markets, as a function of inflow, price, season and year (N = 52).

Deviance Residuals:

Min	1Q	Median	3Q	Max
-9.028	-3.800	-1.404	2.211	14.167

Coefficients	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.303e+03	4.879e+01	26.716	< 2e-16 ***
Inflow	3.507e03	1.141e04	30.752	< 2e-16 ***
Price	3.650e02	6.030e03	6.054	1.41e -09 ***
Season-Autumn	3.705e-01	5.215e-02	7.103	1.22e-12 ***
Season-Monsoon	2.007e-01	5.346e02	3.754	0.000174 ***
Season-Spring	-7.260e-02	5.195e-02	-1.397	0.162292
Season-Winter	3.586e-01	4.703e-02	7.626	2.42e-14 ***
Year	6.495e-01	2.426e-02	26.777	< 2e-16 ***

Significance p>: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 0.99
Null deviance: 6535.8 on 51 degrees of freedom
Residual deviance: 1278.9 on 44 degrees of freedom
AIC: 1632.4
Number of Fisher Scoring iterations: 5
(Dispersion parameter for Poisson family taken to be 1)

Table 3. Outflow of *C. swamyi* leaves from the Bangalore floral markets, as a function of inflow, price, season and year (N = 52).

Deviance Residuals:

Min	1Q	Median	3Q	Max
-2.6477	-1.0605	-0.1505	0.9145	2.5435

Coefficients:	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-292.4999	203.5542	-1.437	0.150729
Inflow	0.0247	0.0047	5.256	1.47e-07 ***
Price	-0.0173	0.0239	0.724	0.469071
Season-Autumn	0.8350	0.2226	3.751	0.000176 ***
Season-Monsoon	0.1763	0.2385	0.739	0.459772
Season-Spring	0.7087	0.2093	3.385	0.000711 ***
Season-Winter	0.9187	0.1967	4.672	2.99e-06 ***
Year	0.1461	0.1011	1.445	0.148526

Significance p> 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 0.99
Null deviance: 212.904 on 51 degrees of freedom
Residual deviance: 78.541 on 44 degrees of freedom
AIC: 288.97
(Dispersion parameter for Poisson family taken to be 1)

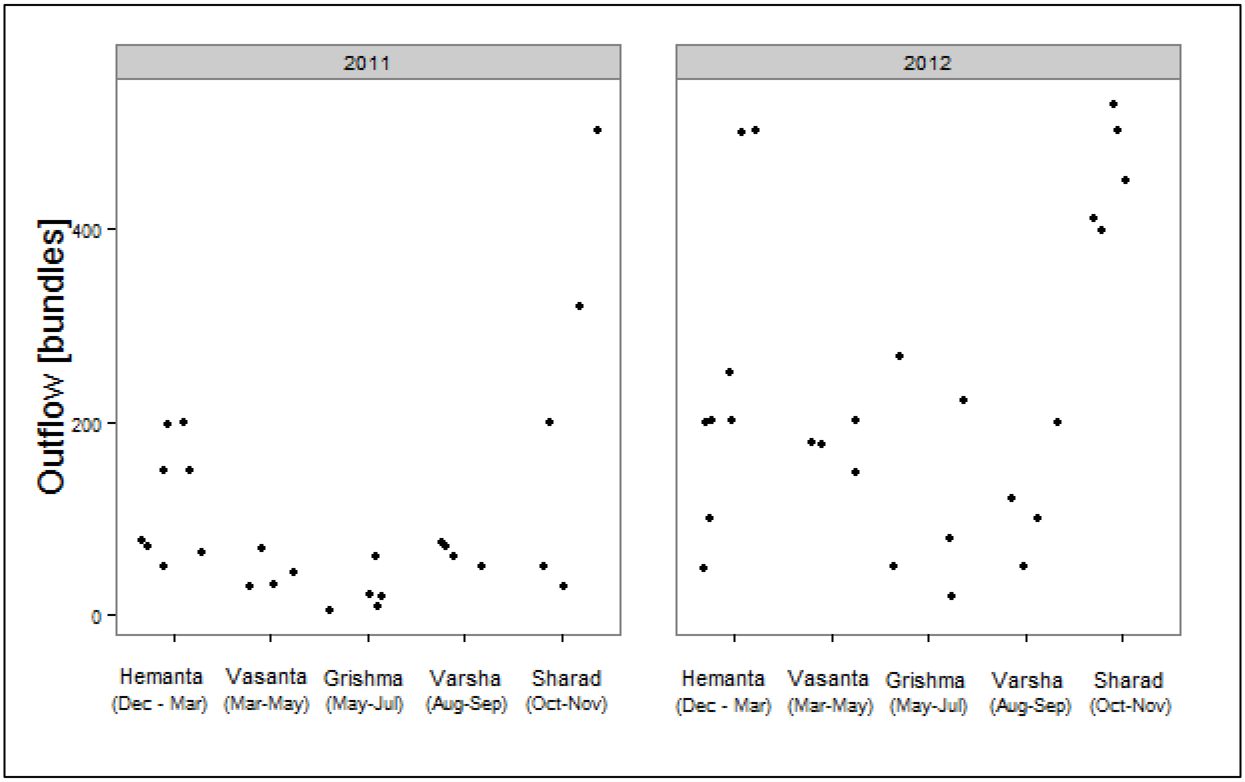

Figure 2. Ouflow of *C. circinalis* leaves (bundles) in different seasons by year

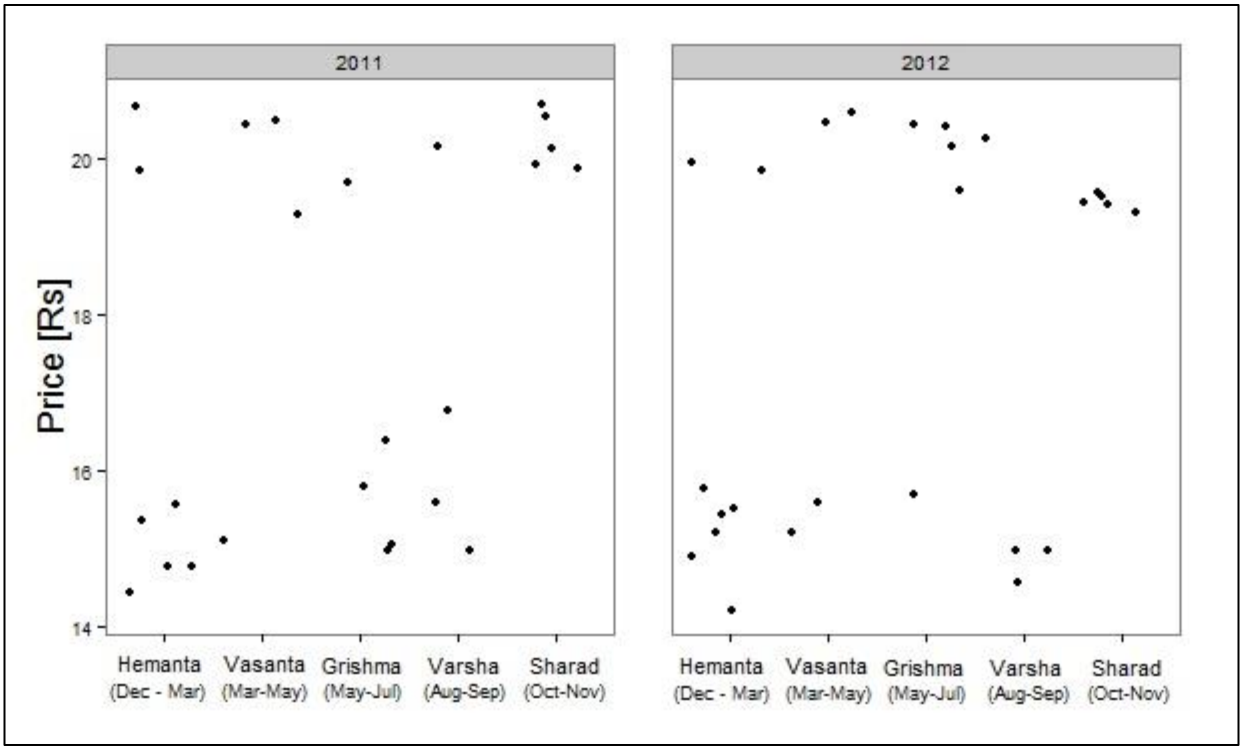

Figure 3. Price (Rs) of *C. circinalis* leaf bundles in different seasons and years

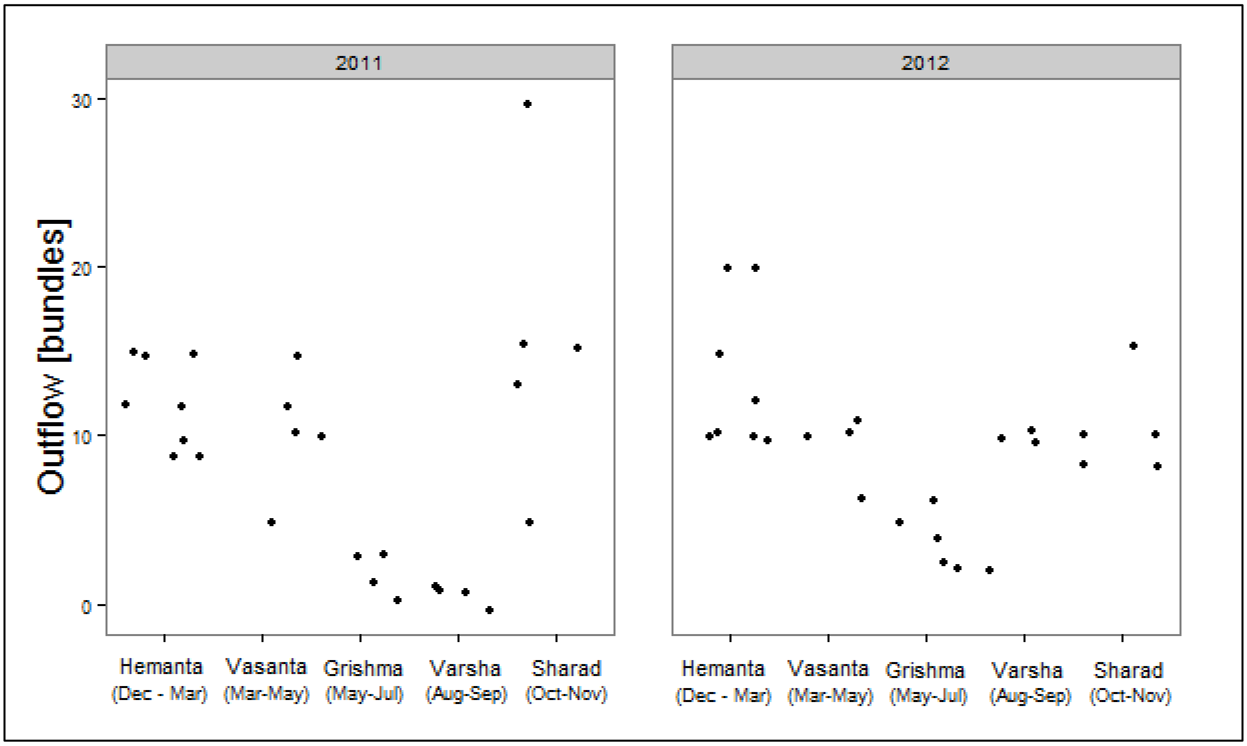

Figure 4. Outflow (bundles) in different seasons and years for *C. swamyi*

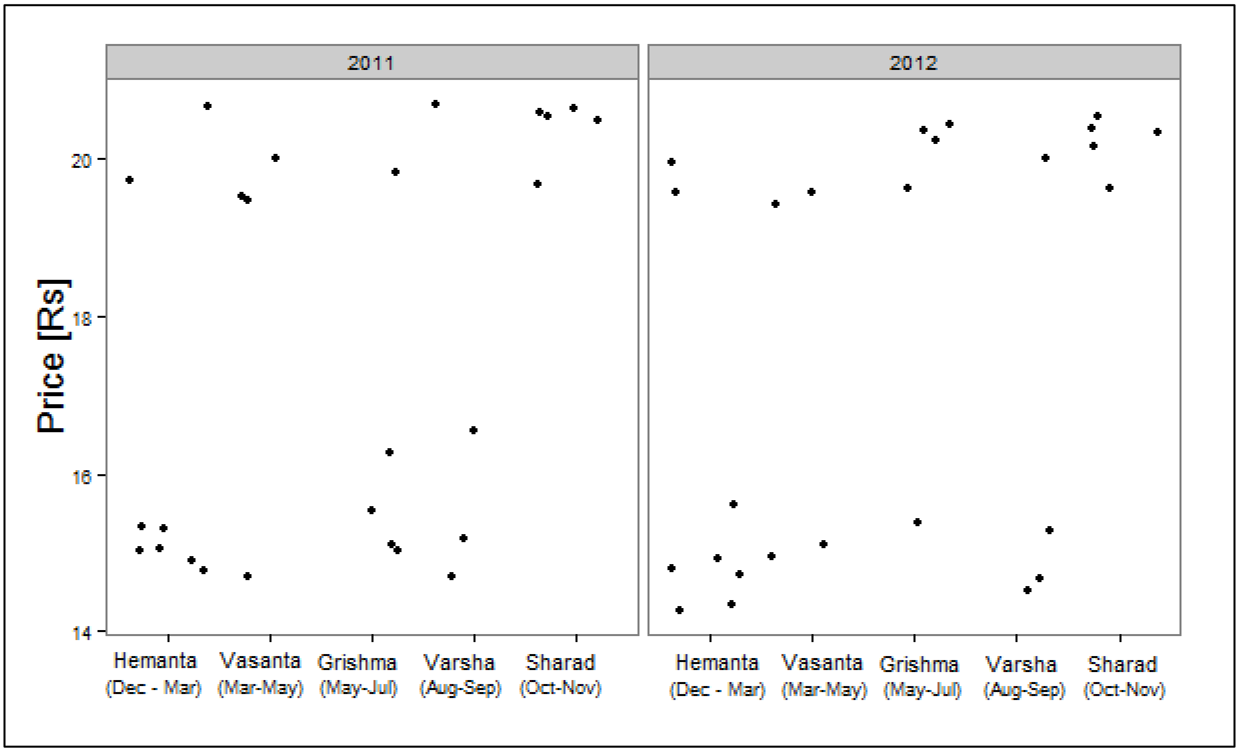

Figure 5. Price (Rs) of leaf bundles of *C. swamyi* in different seasons and years

Sites of harvest

According to the vendors, the cycad leaves are harvested and transported from the forests of Tamil Nadu, Karnataka and Kerala. They reported that *C. circinalis* comes predominantly from Tamil Nadu and Kerala. In Tamil Nadu, the leaves are sourced from the Nilgiri Hills and surrounding areas. The vendors were unsure about the exact location of leaf harvest in Kerala with the possibility of Nilambur as a potential site. For *C. swamyi*, the leaves come from Karnataka. In Karnataka, the leaves are harvested from Arsikere, Melkote and Hassan districts. The vendors believed that the reduction and low quantities of inflow for *C. swamyi* was because of lack of trees and leaves.

Consumer perspectives

Interviews with the florists showed that the florists prefer cycad leaves because of the long shelf life and stiff and leathery texture of the leaves (Image 2). Each florist buys an average of 7 – 10 bundles in a visit. They visit the market once in three to five days. Each leaf of *Cycas* stays fresh in the floral decoration for 5 – 7 days (Image 2). Their first preference is *Cycas* leaves, but when the leaves are not available, they modify their floral arrangements with the bamboo, fish tail palm and *Cycas revoluta* leaves. At the market each leaf cost ~ Rs 2.5 ($0.041). The florists sell each leaf for Rs 5 ($0.08), double the cost that they paid at the market.

Image 2. Using of *C. circinalis* leaves in floral bouquets

Pith harvest – Madurai and Chennai

Market description and structure

The market surrounds the main temple area. This is a central market in the Madurai district and includes many different products ranging from everyday home requirements to medicine and garments. The market focused on providing commodities for daily living as well as travelers and temple goers. The *naatu maranda kade's* in this market were spread out and didn't have a defined area for sales. The shops were small with permanent sellers (Image 3). Interviews with permanent vendors indicated that the leaves, flowers, stems, roots and tubers are collected in the nearby forests by villagers and sold to traders for a price that varies with season when it is harvested (price can rise in the rainy season). Apart from regular clients who prepare their own home remedies, many Ayurveda and Siddha healers purchase raw drugs in bulk for different herbal preparations. The vendors selling the raw form of the pith primarily sold raw drugs for medicinal and cosmetic use (Image 4).

Image 3. Pith vendor at a *nattu maranda kade* in Madurai

Image 4. *C. circinalis* dried pith being sold in a *nattu maranda kade*

The market is generally populated and sales are mostly made in bulk. Each shop is equipped with a large backroom or warehouse where they store large quantities of produce that can sometimes measure up in several hundred tons. Unlike Bangalore markets, the Chennai and Madurai markets are built for permanent sales. The shops open by 9:00 am and close by 9:00 pm. The vendors that sold pith also sold other raw plant materials and prepared pastes and powders for used in *kashayams* (home-brewed Indian ayurvedic drink). Medicines, brooms, spices, herbs and tubers were some of the common wild harvested produce.

The markets in Chennai and Madurai are very variable. These are older markets and the types of vendors, produce, and consumers are very diverse. While the Bangalore markets are made for bulk perishable products, the pith markets can store produce for long periods of time. In Madurai many of the consumers were people who prefer home remedies for everyday ailments, while Chennai was primarily stocked raw materials for large scale industrial use.

Quantum of inflow and outflow

Madurai had a very low frequency in the inflow of pith (Fig 6a). This was reported to be due to the declining supply from local forest areas. Moreover, the vendors have been able to source pith from Orissa, a state in the east coast of India. According to the vendors, the supplies as well as the regular client base have reduced in the last 10 years owing to the reduction of pith inflow. Nevertheless, our main participant always had pith available at all times. The average inflow of pith every month was 4.8±3.6 (range 2-12 tons) and the average outflow was 1.75±1.8 (range 1-5 tons) over the one year study period. The sale was very irregular. While some months didn’t have any outflow, the highest monthly sale was 5 tons over the one year period (Fig 6b).

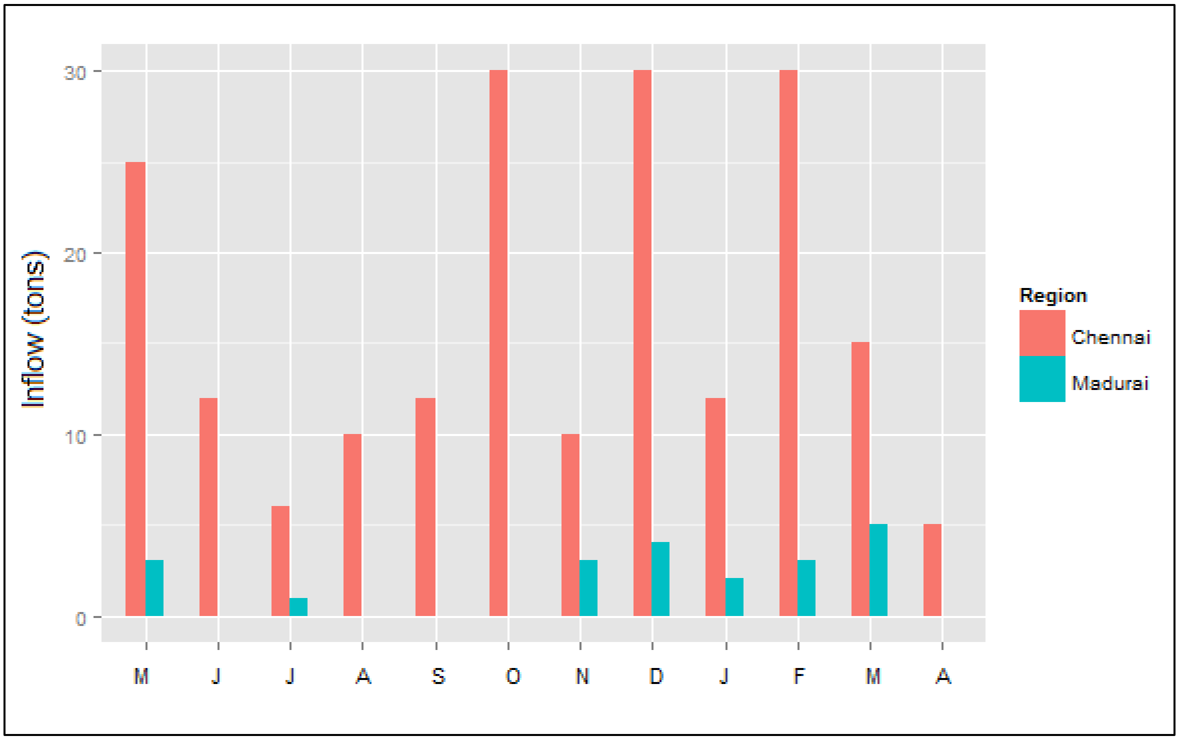

Figure 6a. Comparison of *C. circinalis* pith inflow in Chennai and Madurai between May 2012 and April 2013

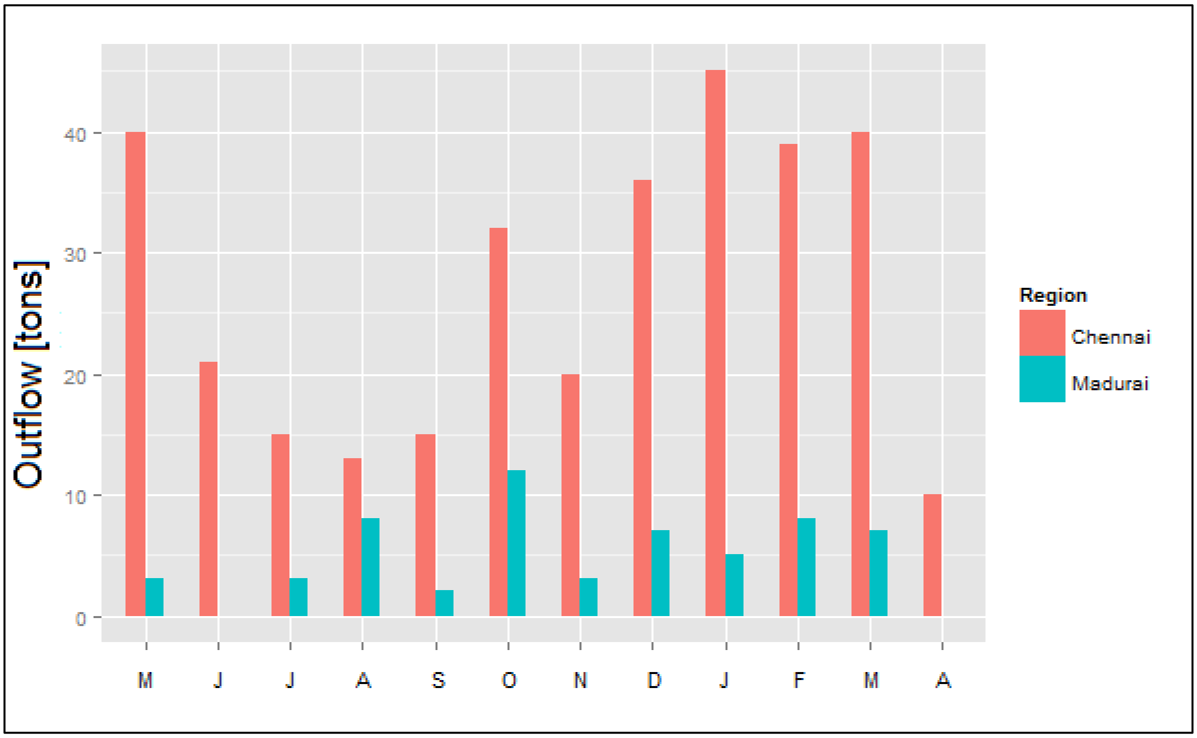

Figure 6b. Comparison of *C. circinalis* pith outflow in Chennai and Madurai between May 2012 and April 2013

The pith was purchased by Ayurveda and Siddha healers from south India. Price, month and inflow were not significant predictors of outflow. Price ranged from Rs 30 – 32 per ton. The total earnings from pith sale in Madurai were Rs 640 ($10.66, range Rs 0 - 160).

The inflow and outflow in Chennai was much higher than Madurai (Fig 6a & 6b). The average amount of pith inflow was 27.2±12.7tons (range 10-45 tons) and the average outflow was 16.47±9.6 per month (range 5-30 tons). Sales varied over time and price ranged from Rs 35 – Rs 45 per ton. Bulk purchases were made from the Ayurveda and Siddha pharmacies. Inflow was significantly correlated with outflow (Table 4) but did not vary with price and season of harvest. The earnings from the pith were Rs 7644.6 ($127.41, range Rs 200 - 1260) in one year. For pith harvest, interviews with indigenous communities in forest sites suggests that a tree of height 5 feet can provide approximately 25 – 50 kgs of pith (Krishnamurthy, unpublished), which means that thousands of trees are cut to supply pith in tons to the herbal markets. This equates to a total of 1052 trees harvested for Madurai markets and 5514 trees for the Chennai markets (if yield was 50 kg/tree) in one year. This is true if we assume that all plants harvested are 5 feet in height.

Table 4. Outflow of cycad pith from the Chennai herbal markets related to inflow (N = 12).

Coefficients:	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.84898	0.20985	8.811	< 2e-16 ***
Inflow	0.03218	0.00622	5.175	2.28e-07 ***

Significance p>: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 0.99
Null deviance: 60.484 on 11 degrees of freedom
Residual deviance: 32.075 on 10 degrees of freedom
AIC: 89.891
Number of Fisher Scoring iterations: 4
(Dispersion parameter for Poisson family taken to be 1)

Sites of harvest

In Madurai, permanent vendors mentioned the Alagar Hills in Madurai district for commonly used herbal preparations like Amla (*Phyllanthus emblica* L.) juice, 'keezhanelli' (*Phyllanthus amarus* L.) powder or *Aloe vera* paste. The Dindigul forest range was mentioned more frequently as an important site of *C. circinalis* pith harvest, according to these vendors. Our main participant informed us that the *Cycas* pith sold in Madurai was originally harvested from the Dindigal forest range ~90 km from Madurai. The pith harvest and slicing takes place at the site of harvest and the pieces get transported to the market. He reported that in the last decade, there has been low harvest from the Dindigal forest range, probably due to diminishing resources or lack of harvesters. Vendors reported that the produce now being sold to the medicinal industry comes from Orissa, which is ~ 1800 km from Madurai.

Our main participant in Chennai expressed that the *Cycas* pith found in the Chennai markets were known to be harvested in different forest sites in south India in Tamil Nadu, Karnataka and Kerala. The vendors could not provide information on the specific sites of harvest, which is probably because of the fear of illegal harvest of *Cycas* pith or because they were sincerely unfamiliar of the sites of harvest. However, similar to the scenario in Madurai, vendors did mention that all of the supply now comes from Orissa.

Consumer perspectives

We interviewed three consumers who were purchasing pith for industries. All three were unaware of the specific plant that is used as *Vidari*. They mentioned that the produce is bought, cleaned, powdered and packed to then be sold to pharmacies and Ayurvedic and Siddha practitioners. They also mentioned that it was a popular drug with high sales on a regular basis.

Discussion

High quantum of inflow and outflow of leaf and pith

Our study from the three main markets showed that the quantity of cycad plant material being harvested from native habitats was very high. For the leaf harvest, according to vendors, the trade inflow increased by ten-fold from the 1990s. Likewise, the price has increased by three times since its introduction.

Data on volume, size and price of wild plants sold in informal markets can inform the magnitude of resource depletion, plant demographics, sustainability of harvesting and scale of cultivation required to substitute wild collected stocks (Williams *et al.* 2007). Information on leaf numbers and leaf size is important as it facilitates an assessment of the impact of harvesting on cycad populations. The life-history stages affected by harvesting may be evident while analyzing the leaf lengths and the prevalence of certain size classes may reflect what is available in the wild or what is preferentially targeted by harvesters (Botha *et al.* 2004). The size range of the leaves being harvested was from 65 – 90 cm for *C. circinalis* and 33 – 48 cm for *C. swamyi* (excluding the petiole). Data collected from harvest sites (Krishnamurthy, unpublished) shows that the leaves of this size can belong to any category from seedling to adult individuals as the leaf length does not increase with size and seedlings can sometimes produce leaves that are approximately 150 cm long. This puts all the different size classes at risk, including seedlings which are vulnerable life history stages in cycads (Griffiths *et al.* 2005).

The inflow of *C. circinalis* leaves was much higher than for *C. swamyi* leaves, which appears to be due to a lack of harvestable leaves and not the reduction in demand. The vendors in the market have observed the reduction in supply quantities of *C. swamyi* leaves over the last decade and also mentioned the reduction in leaf sizes. Forest rangers and local communities in *C. swamyi* forest sites believe that the reduction in population size is because of intense harvest pressures over the last 15 years (Krishnamurthy., pers. comm).

For *C. circinalis*, season, inflow, price and year were all significant predictors of the outflow of cycad leaves. The trends in sale of cycad leaves followed the Hindu cultural calendar. Leaf sales were very high in autumn and winter from mid-October to early March. November is the prime month for weddings. During this season flowers are almost always bought in bulk to decorate wedding halls. The outflow of leaves showed a significant drop between late summer and wet monsoon seasons for both years. In south India, according to the Hindu calendar, there is a season called *Aashada masa* or *Aadi masam,* which falls between early June and August. According to astrology, this period is the time when the Sun takes a southward turn in the zodiac. This period also happens to be the hottest period in India before which the season changes to the wet monsoons and it is believed that it is an inauspicious month when marriages don't occur because if the newlywed bride were to become pregnant, the child would be born in April or May which is peak summer and not suitable for the health of the baby or the mother. The beliefs associated with *Ashada* have no scriptural backing and they are not mentioned in Hindu holy texts. No marriages occur during this period, and hence the use of decorative flowers is at a minimum, and as a consequence market dynamics in the cut flower industry are affected. However, vendors are equipped to deal with this slump either by taking on other day jobs or selling different products.

According to our main participant, the inflow quantities depended on remaining stocks from the previous day, neighboring vendors prices, the cultural calendar or, if bulk sales were made for transport to other cities. Most often product quality, quantity, the demand from consumers, seasonality, cost of related products, and competition can reflect on prices of products in the market (Montoya *et al.* 2008; Phelps *et al.* 2014; Cousins *et al.* 2011). Customer requirements also play a very important role in cycad outflow and therefore, the entire market chain gets impacted to suit the growing trends in sales. Weddings are typically huge celebrations in Bangalore city and the higher earnings in 2012 could be attributed to higher sales or a higher number of weddings in that year.

Trade of pith is a lot more complex than the leaf harvest. The trade name *Vidari* is used for four different species and therefore creates some confusion in the markets in terms of the specific species being harvested. Traditional vendors have been trading *Vidari* for many years. However, recent evidence (Venkatasubramanian, and Venugopal 2009; Mitra 2007) shows that the original *Vidari* plants, *Pueraria tuberosa* and *Ipomeae mauritiana* are not what is being sold in the markets. It has been reported that presently *C. circinalis* is the most prominent source of *Vidari* in local herbal shops. Description of the plant from our main participants in Madurai and Chennai indicated that the plant was *C. circinalis*. *P. tuberosa* can be easily identified by the presence of papery flake like tubers and *I. mauritiana* by the presence of its concentric rings of vascular bundles and *C. circinalis* by its leaf scars and absence of vessel elements (Mitra, 2007). Though both *P. tuberosa* and *I. mauritiana* are available in plenty throughout India, it is unclear how *C. circinalis* came to being sold as Vidari. Demand, supply and regional availability could be some of the reasons for substitution and adulteration with other species that may or may not resemble *Vidari* in terms of morphology, properties or actions (Venkatasubramanian and Venugopal 2009). While the inflow in Madurai was low and almost vanishing, the Chennai markets flourished with *Vidari*, likely due to the regular customer base from the Ayurveda and Siddha pharmacies. Sales are regular and harvest will continue as long as Ayurveda and Siddha systems thrive and the demand for this product is high. To add to further uncertainty about the source of *Vidari*, the plant products from Orissa might be of a different species which is either the original source (*Pueraria tuberosa* or *Ipomoea mauritiana*) or the local plant *Cycas pectinata* Buch.-Ham. (Singh and Singh 2011).

Information on harvesters and harvesting patterns was difficult to gather from the vendors. As most pith is sold in green raw drug stores, it is usually amongst thousands of other herbs that are wild harvested. Many of these herbs are allowed to be sold legally in areas preserved for medicinal plant harvest, but the legalities behind the trade of some other herbs are questionable. *C. circinalis* and *C. swamyi* are not on the list of legally harvested NTFPs in Karnataka, Kerala or Tamil Nadu (its endemic range) because of their “endangered” and “data deficient” status respectively (IUCN 2013). *Cycas swamyi* was earlier known as *Cycas circinalis*. In 2007, it was renamed as *Cycas swamyi* due to its morphological differences (Lindstrom & Hill, 2007) and therefore under the “data deficient” status.

Similar for the leaf market, it was challenging to get information on harvest patterns and frequency from the vendors at the market. However, our results indicate that for a regular supply of leaves to the market, the forests are combed and hundreds of trees defoliated throughout the year. Repeated defoliation implies the loss of photosynthetic output which can be recovered only when the next whorl of leaves are produced. Defoliation could have varied effects that lead to important consequences for population viability. Frequent defoliation has been shown to decrease reproductive output in other plant species (Endress, Gorchov, and Berry 2006; Gaoue *et al.* 2013; Ticktin & Shackleton 2011). It can also affect growth (Ticktin 2004), survival (Anten & Ackerly 2009) and reduce plant size (Law and Salick 2005). In the cycads and some palms, leaf harvest can decrease adult plant persistence (Octavio-aguilar et al., 2008; Raimondo & Donaldson, 2003) and increase mortality (Endress *et al.* 2006). Varghese and Ticktin (2007), showed that *C. circinalis* leaf harvested populations had a lower proportion of seedling and saplings than unharvested populations, affecting plant population size.

One critical factor that can greatly alter the impacts of leaf harvest is the timing of harvest. *C. circinalis* and *C.swamyi* leaves which are produced in flushes that senesce and shed naturally (Lindstrom & Hill, 2007); 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. In this case however, the peak in harvest (October/November) corresponds with the time when leaves are still young for both species. New leaf production occurs in September and May for *C. circinalis* in Kerala (which produce leaves twice per year) and in May for *C. swamyi* (which produces leaves once per year) (Krishnmaurthy unpublished).

The harvest of pith involves lopping the entire stem of the plant to gather the central pith and our results suggest that hundreds of adult cycads are lopped annually for harvest. Harvest of adults in other cycad species reduces the number of reproductive stems, resulting in low coning frequencies, decreasing the production of new individuals and hence population size (Octavio-Aguilar *et al.* 2008; Álvarez-Yépiz *et al.* 2011). This is compounded by the fact that sexual reproduction in cycads is often sporadic and not all mature individuals reproduce every year

(Clark & Clark, 1987; Tang, 1990; Watkinson & Powell, 1997). Young adult and adult harvest for pith may have serious consequences for wild populations since cycads are very slow growing and replacing adult individuals may take decades (Octavio-Aguilar *et al.* 2008; Raimondo and Donaldson 2003; IUCN 2003). In Melkote, historical stem harvest for pith has encouraged the re-sprouting of vegetative shoots or offsets (Krishnamurthy., unpublished), but the growth of these offsets is extremely slow and it would take tens of years to become reproductive stems. In addition to this, it needs to be stated that this study was conducted with only three vendors. It is unclear how many more vendors trade in cycad leaf and pith and the total quantities of leaf and pith harvest remain uncertain.

The vendors in the leaf markets informed us that the *C. circinalis* leaves available in the market came from Tamil Nadu and Kerala. In a previous study (Krishnamurthy *et al.* 2013) we estimated that the total population size of *C. circinalis* in Tamil Nadu was ≤ 1300 individuals and populations in Kerala was ≤ 1000 individuals. In the Nilgiri Biosphere Reserve, part of the Western Ghats mountain range, Varghese and Ticktin(2007), documented that the leaf harvest occurred only in Tamil Nadu and not Kerala. However, vendors at the Bangalore market were very certain that the leaves were being supplied from Kerala, which could imply that the harvesters moved from Tamil Nadu to Kerala between 2007 and 2011, possibly because of low yields in leaves and a higher demand from the booming markets. These findings are consistent with information from the pith markets on depleted populations. Dindigul was reported to be the main harvest site for *C. circinalis* pith in the past but there was no supply from Dindigul during the study period. Our main participant specified this as being one of the main reasons for the low inflow.

Varghese and Ticktin (2007) previously documented the trade of cycad pith in Virudhnagar (20 kms from Madurai). Their study showed that 200 – 300 tons of pith was being traded annually. A visit to the Virudhnagar markets during this study showed no presence of pith. Information from the vendors there revealed that the lack of pith stocks was because of absence of resource from adjoining forests and the entry of pith supplies from east India. Similarly in Chennai, our main participant mentioned Tamil Nadu and Kerala as sites of harvest for pith in south India; however, they were wary about this information.

Permanent vendors trade in leaf and pith for profits

Karnataka is one of the biggest producers of commercial ornamental flowers (Thippaiah, 2005) 2005). The area under the production of traditional and modern flowers has increased from 0.004 million hectares in 1978-79 to 0.021 million hectares in 1999-2000 valued at Rs 2500 million ($41.75 million) (Thippaiah, 2005). With newer methods of propagation through the support of horticultural research institutions and universities, newer plant varieties get added to the floriculture industry. As the trade in commercially cultivated floriculture crops grows the pressure on non-cultivated plants such as *C. circinalis* and *C. swamyi* will increase. Cycad leaves entered the market first in 1996. Subsequently, there has been a consistent inflow of leaves on a daily basis as the demand from the cut-flower industry has considerably increased over the years. The vendors that traded cycad leaves in the Bangalore markets were permanent and the same vendors were regularly seen at the markets.

The number of vendors in the market between years stayed consistent; however the quantity of produce increased in the second year for *C. circinalis.* The system of regular inflow is well established by the harvester - vendor communication channel. This link is based on trust and there is a small chance of error as the association has existed over a decade.

Our main vendors in Chennai earned 11 times more than the vendor in Madurai. The lowest earning from the vendor in the Chennai markets was Rs 200, which was higher than the highest earning (Rs 160) for the vendor in the Madurai market. This was because of the consistent customer base in Chennai.

Florists and Ayurveda/Siddha pharmacists are regular consumers

The cut-flower arrangement is the single reason for the large inflow of cycad leaves from forest sites. The use of these leaves is non-essential, and can certainly be substituted with a plant which is cultivated for this specific purpose. Cycads are cultivated for landscape purposes, however, they are very slow-growing (Whitelock, 2002) and to grow monocultures of *C. circinalis* and *C. swamyi* for harvest purposes would take too much time and investment. Interviews with the florists indicated that their preference for cycad leaves was primarily for its long shelf-life. There are several cultivated fillers such as *Asparagus racemosus* Willd., *Gypsophila paniculata L.* and *Dypsis lutescens* that were popularly used. These species can be substitutes for the cycad leaves. Florists play an intermediate role in the process. The consumers that buy these bouquets as gifts should be made aware of the impact of buying bouquets with cycad leaves. Although substitutes are available, wild harvest of cycads have been continual. Other research has shown that the price of substitutable goods will likely change with the influx of a competing product (Bulte and Damania 2005; Phelps *et al.* 2014), however, during the study there was no drastic increase in sale or quantity of the substitutes.

All of the pith stocks in Madurai and Chennai were purchased by pharmacies of the Ayurveda and Siddha medicine systems for *Vidari*. *Vidari* is used as an aphrodisiac, cardiotonic, demulcent, diuretic, refrigerant, galactogogue and tonic to treat consumption, emaciation, enteric fever and spermatorrhoea (Chopra *et al.* 1992). The pith is generally dried, powdered and sold by pharmacies and doctors. The pharmacists regularly purchase the pith, however they were unaware about the plant species that was harvested and the specific origin of *Vidari*. The inflow is largely determined by prior orders made by the Ayurvedic and Siddha pharmacists.

For these two species, indigenous communities do harvest plant material from the forests of the Western Ghats. However, the commercial harvesters are most often outsiders and do not belong to the indigenous communities that live around *Cycas* sites (Krishnamurthy *et al.* 2013), which makes it challenging in locating the harvesters for potentially instituting sustainable harvesting practices. The potential role of NTFP in forest conservation has been promoted through the long-term financial returns from sustainable NTFP harvest (Leisher *et al.* 2012) and their role as safety nets for indigenous communities (C. Shackleton & Shackleton, 2004). However, in the case of *C. circinalis* and *C. swamyi*, harvest was done purely for commercial profits. It is important to institute marketing and management practices that minimize the ecological impacts while at the same time provide revenues (Varghese and Ticktin 2008). We are uncertain about the total number of vendors that trade in cycad leaf and pith, which is a bigger cause for concern because the quantity of pith and leaf being harvested could be much higher that what we have estimated in this study.

In many states in India, there is control over forest products and their sale with the intention of improving market efficiencies, participation and returns for the producers and local traders (Mahapatra & Shackleton, 2011) through land tenure systems. Unfortunately, in the case of *C. circinalis* and *C. swamyi*, there are no tenure systems available and most forested areas are open to encroachment even though cycad habitats are located around indigenous villages (Krishnamurthy *et al.* 2013).

Conclusions

NTFP activities can neither be researched nor promoted in isolation from the context of the livelihoods affected by them (Ruiz-pérez *et al.* 2004). Intervention plans need to understand the nested relationship between local and regional conditions that link NTFP-based economies with general regional development. In India, forest conservation through participatory models, such as joint forest management and community-based conservation in which NTFP extraction constitutes an attractive economic incentive for local people, had gained much impetus over the years (Shahabuddin & Prasad, 2004). However, most bulk sales with profit making intentions occur illegally as with the case of *C. circinalis* and *C. swamyi*. As evident by the quantities of produce harvested on a daily and monthly basis, the people involved in the market chain are driven by commercial sales for profit. Sustainable harvest and the return of income back to the communities who manage the forest for NTFPs are concepts unknown of from this kind of harvest.

Establishing partnerships can enhance the transparency of this trade. The involvement of the Forest Department, indigenous communities and local NGOs is important to prevent intensive extraction of the cycads. Markets play a crucial role in the provision of income to local communities. Therefore critical to understand the dynamics of informal markets to make important management decisions (Shackleton *et al.* 2007). There is a need to improve the overall understanding of the informal economy's demand for local wild-harvested species. Effective legal regulations are imperative since the harvest of these products have highest pressures from commercial market sales. Additionally, awareness amongst the user community is imperative to protect these wild plants from decline.

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CHAPTER 3

Integral Projection Models for slow growing cycads: Effects of harvest on populations of *Cycas circinalis* and *Cycas swamyi* in the Western Ghats of Southern India

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Abstract

The cycads, *C. circinalis* L., and *C. swamyi* Singh & Radha are endemic to the Western Ghats of southern India. Demographic studies were conducted between 2010 and 2013 in three sites within the Western Ghats mountain range which are over harvested for seeds, leaves and pith. Integral Projection Models (IPMs) were used to examine the population dynamics of these species over different harvest types. IPMs showed that the long-term population growth rate, λ was below 1 in all harvest types, indicating population decline over the long-term. The seed harvested populations had low seed germination and seedling recruitment with low adult mortality. Elasticity was highest for seedlings, indicating that even a small change in seedling vital rate could have an impact on the population growth rate of C. *circinalis.* On the other hand, the leaf/historical pith harvested sites showed a low number of adult individuals, lack of reproduction and very minimal growth between years. Seed harvest simulations showed that harvest up to 95% was acceptable, below which the λ value dropped, indicating that if a small portion of seeds are left behind, the population cold thrive. In the leaf/historical pith harvested sites, any harvest is detrimental to the *C. swamyi* populations. Our results highlight the importance of protecting these multi-use plants which could go extinct if harvest rates continue at the same rates.

Introduction

Cycads are the oldest living seed plants and have survived three mass extinction events in the earth's history (Schneider, Wink, Sporer, & Lounibos, 2002). They are presently facing a major extinction crisis because of habitat destruction, illegal trade and removal of plants from the wild for propagation (IUCN, 2003). In response to the worldwide threats to cycad conservation, all cycad species are listed in either Appendix I or II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The cycad trade includes a range of products: leaves for the cut flower market, seeds for propagation and medicinal use, and whole stems used as feature plants for landscaping and collections (Griffiths et al., 2005; IUCN, 2003; Whitelock, 2002).Cycads are long-lived, perennial plants (Whitelock, 2002) that usually occur in small, isolated populations in groves (J. Hall & Walter, 2013). Sexual reproduction is often sporadic and not all mature individuals reproduce every year (Álvarez-Yépiz et al., 2011; Clark & Clark, 1987; Tang, 1990; Watkinson, AR & Powell, 1997) and very little is known about seed dispersal mechanisms (Snow & Walter, 2007). These life history characteristics, combined with the added impacts of harvest and habitat destruction further challenge cycad persistence (Raimondo & Donaldson, 2003).

In India's Western Ghats, *Cycas circinalis* L. *and Cycas swamyi* Singh & Radha are used extensively. The young leaves of these species are used as food by indigenous and local communities, and the mature leaves are harvested for local cultural celebrations and commercially for sale in the cut flower industry. The pith and male cone are collected for their medicinal value, while the seeds are used as food and medicine (Krishnamurthy et al., 2013; Anita Varghese & Ticktin, 2007). Widespread harvest of cycads is reported to occur for *C. circinalis* and *C. swamyi*, (Krishnamurthy et al., 2013), and is thought to be responsible for observed declines in populations of these two species. *C. circinalis* is listed as "endangered" and *C. swamyi* is listed as "data deficient" according to the 2013 IUCN Red List of Threatened Species. By far, the heaviest harvest pressures are due to the sale of the leaves for the cut flower markets and pith for medicinal value in metropolitan markets of India (Chap 1).

The harvest of plant products from adult cycads may have serious consequences for wild populations, since cycads are extremely slow growing, and replacing adult individuals may take many decades (IUCN, 2003). A previous study on *C. circinalis* revealed small population sizes, and lower numbers of seedlings and adult individuals in sites with high levels of harvest (Krishnamurthy et al., 2013). Demographic studies of other cycads have showed that whole plant harvest of the adults can result in rapid population decline (Raimondo & Donaldson, 2003) particularly a reduction in seedling abundance (Griffiths et al., 2005). Continual leaf harvest can lower reproduction (Octavio-aguilar et al., 2008) and reduce growth (Lázaro-Zermeño, González-Espinosa, Mendoza, Martínez-Ramos, & Quintana-Ascencio, 2011) but in sites affected by fire it can result in greater leaf production (Negrón-ortiz, Gorchov, Journal, & Jul, 2000). Rare species of cycads found in niche habitats affected by land conversion suffered low fecundity, recruitment and extinction probabilities over the short-term (Álvarez-Yépiz et al., 2011).

To date, cycad population dynamics have been studied using matrix population models (Álvarez-Yépiz et al., 2011; Octavio-aguilar et al., 2008; Raimondo & Donaldson, 2003). These models combine stage specific measures of growth, reproduction and survival to project population change through time (Caswell 2001). They integrate multiple vital rates into one measure of projected long-term population growth (λ) and are powerful tools for assessing the net consequences of different kinds of management (Crone et al. 2013). However, they can be difficult to parameterize accurately for species that are very slow growing (like cycads) and for those with small population sizes(Ramula, Rees, & Buckley, 2009). In these cases, Integral Projection Models (IPMs) may be more appropriate. IPMs are extensions of matrix models that can incorporate stage, age and continuous states to yield similar analyses of population dynamics (Easterling, Ellner & Dixon 2000; Ellner and Rees 2006).

In this study we use IPMs to ask: 1) What are the population dynamics of *C. circinalis* and *C. swamyi* populations? 2) What are the effects of seed and pith harvest on long-term population growth rates?

Methods

Study species and area

C. circinalis is endemic to the Western Ghats, a mountain range on the western coast of India. It is found in the states of Kerala, Karnataka, Tamil Nadu, and Maharashtra. It typically occurs in fairly dense, seasonally dry scrubby woodlands in hilly areas (Lindstrom and Hill 2007). *C. circinalis* is facultatively deciduous in extremely dry times. It appears to be an adaptable species which can inhabit different habitats with colonies extending from rocky hill outcrops down to coastal habitats at sea level. It is arborescent, growing up to 8m tall, with leaves that are 1.5-2.5 m long. There are a total of 12 populations found in three different states of southern India (A. Varghese et al., 2010).

Cycas swamyi was regarded within the scope of *C. circinalis* until 2008 when it was differentiated based on its morphological differences in leaf sizes and reproductive appendages. *Cycas swamyi* differs with a shorter apical spine on the megasporophyll and shorter and narrower leaves (Singh & Radha, 2008). The *C. swamyi* populations also show distinct suckering growth habit, possibly due to disturbance. *C. swamyi* is restricted to Melkote in the Nagamangala and Narayana Durga Reserve Forest in Pandavapura region of Karnataka state. It is commonly found over open, sunny, and rocky terrains (Singh & Radha, 2008). There are approximately 5 different populations of *C. swamyi* found only in Melkote.

Cycas circinalis and *Cycas swamyi* are endemic to the Western Ghats. The Western Ghats comprises the major portion of the Western Ghats and Sri Lanka Hotspot, which is one of 34 global biodiversity hotspots for conservation (Bawa et al. 2007). It covers an area of 180,000 square kilometers which is less than 6 percent of the land area of India. However, the Western Ghats contains more than 30 percent of all plant, fish, herpetofauna, bird, and mammal species found in India. It also has a high proportion of endemic species. Because it is a largely montane area it receives between 2,000 and 8,000 millimeters of annual rainfall within a short span of three to four months. (Bawa et al 2007).

To assess the dynamics and understand the effects of harvest on *C. circinalis*, we selected seven stands that we were able to obtain permits to study in the state of Kerala (Table 1). These were found in two sites: Nilambur and Silent Valley. All stands were commercially harvested for their seeds. It was impossible to find populations in Kerala not harvested for their seeds. Each individual can produce between 10 – 80 seeds per reproducing female tree (Lindstrom & Hill, 2007) and during the seeding season all of the seeds are harvested and sold locally. The seeds are leached by placing them in running water, dried and steam cooked or made into a flour (Chap 3).

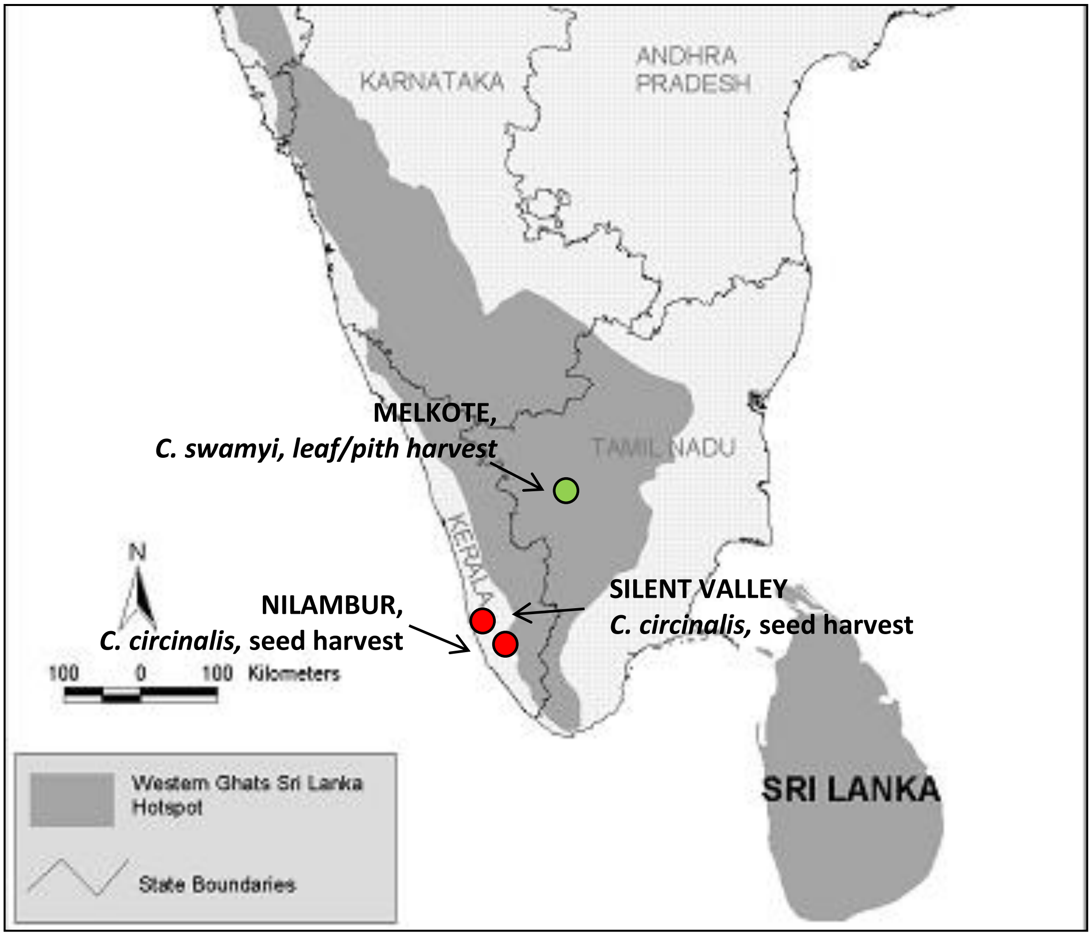


Figure 2: Map of South India showing study sites for leaf/pith harvested - *C. swamyi* in Melkote and seed harvested - *C. circinalis* in Nilambur and Silent Valley.

To assess the dynamics of *C. swamyi* populations we studied 3 stands in the Melkote Temple Wildlife Sanctuary area in the state of Karnataka. The leaves have been harvested periodically over the last 15 years but were not harvested during the study period. On the other hand,the pith was harvested once for commercial purposes about 10 years ago, but has not been harvested ever since. The pith was harvested for the Ayurvedic and Siddha traditional mainstream medicine systems with the trade name, *vidari*. However, recent studies (Venkatasubramanian et al., 2009) show that *C. circinalis* is used as an adulterant in Ayurvedic and Siddha preparations. The pith is harvested by lopping the tree and scooping the central part of the stem. It is then dried and cut into cubes and transported to markets in southern India. *Cycas swamyi* leaves are harvested for the cut-flower industry in Bangalore (Krishnamurthy., Chapter 1). Leaf harvest involves removing all leaves. *Cycas circinalis* populations are also heavily harvested for their leaves in Tamil Nadu state but we were unable to obtain permits to monitor them.

Pollination of both species is thought to be by weevils (Krishnamurthy, personal observation), however there is no published information to support this. Seed dispersal, although anecdotal, indicates that bats could be potential dispersers (Krishnamurthy, personal observation). None of the cycads we sampled were grazed.

Study design and data collection

For each of the 10 stands, we established plots that included all the individuals in the clump. Cycads are grove forming plants and most new saplings fall below the mother tree as seed-dispersal relationships with mega-fauna are rare or extinct in contemporary ecosystems (J. A. Hall, Walter, Bergstrom, & Machin, 2004). Plot size varied with plant density and ranged from 20x20 and 50x50 sq meters. Plots were established and measurements taken in April 2011 and repeated in September of that year and once more in April and September of 2012 and 2013. We tagged each individual in each plot and we measured height, girth, number of leaves, and length of the longest and the shortest leaf, new seedlings and basal suckers. We used the height as an indicator of plant size, as height correlates with survival, growth, and reproduction in most cycads (Whitelock, 2002). When there were more than three stems of similar heights, each stem was measured and averaged. For reproductive individuals we recorded dimensions of male and female cones, number of seeds, dimensions of seeds and the number and measurements of basal suckers. The total number of individuals monitored was 337 (Table 1). In addition to this, we conducted interviews with local communities on the amount of seed, leaf and leaf/pith harvested in the sites.

Analysis of effects on population dynamics

We use Integral Projection Models (IPMs, Easterling, Ellner and Dixon 2000) to assess the dynamics of *C. circinalis* and *C. swamyi* populations and to investigate the impacts of harvesting on the projected population growth rates (λ). Integral Projection Models project population growth rates based on vital rates that are modeled as a continuous function of plant size, and therefore allow for variation among individuals of a given size (Easterling et al., 2000; Ellner & Rees, 2006). Given that number of individuals in each census (2011-2012 & 2012-2013) was small (Table 1) and vital rates were similar across stands and years, we pooled population data from stands and years within each site. Therefore we built an IPM each for *C. circinalis* populations at Silent Valley and at Nilambur, and one IPM for *C. swamyi*.

The fundamental building blocks of IPMs are regression models that relate the state of an individual (e.g., size, age) to its vital rates (Easterling et al., 2000). Integral Projection Models track the distribution of individuals *n* between census times (e.g., year *t* and year *t+1*) by projecting from models that define the underlying vital rates (e.g., survival, growth, reproduction) as a function of the continuous state variables. We built regression models for survival, growth and fecundity as a function of starting size (height). To model survival and fecundity, we used binomial GLMs and for growth we used a LM with Gaussian error structure (**Appendix A 1**).

The regression models were then fit into a kernel *K*. The kernel describes how the size (*z*) distribution of individuals at time *t*, *nt(z),* changes over one time step. Time step length is chosen to reflect the life cycle or census interval. Here we choose 1 year. The integral of *nt(z)* over a size interval *I, (*$\int$*Int(z) dz)* represents the number of individuals in that interval. The kernel, *K(z',z)*,maps this size distribution at time *t* to a size distribution at time *t+1* (one time step later) by describing how individuals survive, change in state (e.g. grow or shrink), and reproduce:

$$n_{t+1}(z') = \int_{\Omega}^{x} K(z', z) n_t(z) dz \tag{1}$$

where *z*' indicates size at *t+1* and Ω denotes the possible range of individual sizes. The integral in eqn. (1) performs a sum over all possible ways (survival, growth, reproduction) of changing from size *z* at time *t* to size *z'* at time *t+1*.

Since cycads are dioecious, we developed a single sex, female-based model of population dynamics. The ratio of male to females was 50% and there was no difference in rates of survival, growth and fecundity between sexes. Since seedlings didn't have a defined stem we modeled seedlings separately as a discrete class.

Following Zuidema *et al* (2010), we used a demographic kernel with four sections as the basis of our IPM,

$$\begin{bmatrix} k_{ss} & k_{cs} \\ k_{sc} & k_{cc} \end{bmatrix}$$

The left column of the kernel represents the behavior of seedlings. The upper left-hand quadrant, *kss*, represents seedling survival and growth. The lower left-hand quadrant, *ksc*, represents the growth of seedlings into individuals with a defined stem, which would occur when a seedling reaches >1 cm in height. The left column of the kernel is determined by the product of the survival and growth functions for seedlings. The probability of an individual from the continuous class becoming a seedling in size was defined to be zero. The upper right-hand quadrant, *kcs*, represents the production of new seedlings by individuals with defined stem through sexual reproduction and is determined by the fertility function which was calculated as the product of 1) the survival function of individuals with a stem, 2) the probability of a female seeding function, 3) the number of seeds per fruiting female, and 4) the number of new female seedlings per seeding adult. We assumed the number of new female seedlings to be half of the total number of new seedlings. The lower right-hand quadrant, *kcc*, represents the survival and growth of adults as well as the production of new individuals though seeds. This is determined by the product of the survival and growth functions for adults plus the size-dependent fecundity function.

To generate our IPMs, we numerically integrated the demographic kernel using the midpoint rule (Zuidema et al., 2010). For each IPM, we calculated asymptotic population growth rate λ, the dominant eigenvalue of the matrix, elasticity values and Life Table Response Experiments (LTREs), using the *popbio* package in R (R Core Team, n.d.). Lambda values provide an estimate of the expected annual rate of population growth, where $\lambda>1$ indicates that the population is growing and $\lambda<1$ indicates that the population could decline over the long term. Lambda values are more sensitive to changes in vital rates with higher elasticity values. Life table response experiment (LTRE) analyses decompose treatment effects on lambda into contributions from differences in the parameters that determine that variable (Caswell, 2010). To identify which vital rates contributed most to differences in population growth rates across sites and species, we carried out fixed one-way LTREs. We designated the sites with the higher lambda value (λh) as the reference matrix, so that positive contributions represented differences in vital rates that contributed to the higher population growth rates and negative contributions represented differences in vital rates that contributed to the lower population growth rates.

Simulating harvest levels

We assessed the effects of seed harvest and pith harvest using simulations. Since our *C. circinalis* populations were harvested for close to 100% of their seeds, we simulated decreasing seed harvest by increasing the number of new seedlings in our models. From previous studies (A Varghese & Ticktin, 2006), 80% of *C. circinalis* seeds are known to successfully germinate in cycad habitats. Using this, we simulated harvest levels of 100%, 75%, 50%, 25% and 0%. Zero percent harvest coincided with 80% germination in the simulations.

C. swamyi populations have been harvested once for pith approximately 10 years ago, but not during our study period. Since pith harvest involves the removal of adult stems, we simulated the effects of harvest by increasing mortality of adult individuals taller than 120cm (the size targeted by harvesters). We simulated harvest levels of 100%, 75%, 50%, 25% and 0%.

Results

Cycad demography

Survival rates in populations of all sites were high (Figure 3- **Figure 5**). For individuals with stem, 2% of *C. swamyi* individuals died in the first year and none in the second year. For *C. circinalis* at Nilambur, 1.7% of the individuals died in the first year and 2.6% of individuals died in the second year. *C. circinalis* at Silent Valley did not have any adult mortality through the study period. For seedlings with no stems mortality rates were higher. The seedling mortality for *C. swamyi* for the first year was 6% and 27% in the second year. For *C. circinalis* at Nilambur, 11.76% of seedlings died in the first year and 17.24% of seedlings died in the second year, while for *C. circinalis* at Silent Valley, 20% of seedlings died in the first year and second year.

Patterns of growth varied across sites and the two species (Figure 3- **Figure 5**). *C. circinalis* individuals showed positive growth between years (**Figure 5**). Most *C. swamyi* individuals did not grow, while some showed a small increase in height between years (Figure 3).

Seed production varied across sites (Figure 4 and Figure 5). There was no seed production in *C. swamyi* populations (leaf and pith harvest) over the two year period. From our data, the minimum height of a reproductive adult was 130 cm. We found 9 males and 10 female plants in Silent Valley, and 12 male plants and 14 female plants in Nilambur. Mean seed production in the first year for *C. circinalis* (Nilambur) was 36 ±17 and 36± 19 in the second year. For *C. circinalis* (Silent Valley) the mean seed production was 68.5±30.5 in the first year and 48.9±34.7 in the second year. There were 7 new seedlings in the first year and 3 new seedlings in the second year for *C. circinalis* in Nilambur. For *C. circinalis* in Silent Valley, 6 new seedlings were found in the first year and 5 new seedlings in the second year.

For *C. swamyi*, cut stems indicated evidence of historical pith harvest. These stems have basal suckers that arise from the base of the cut stump. Eight individuals had basal suckers on them with an average of 11.4±15 (range 1 – 44) suckers per individual with a mean height of 5.6±4.6 cm and mean girth of 6.4±5.6 cm.

Both the seed harvested sites had a high number of juveniles and young adults but fewer seedlings, while Melkote had a large number of large individuals (Figure 6).

Integration models showed that the finite rate of population increase, λ for the seed harvested *C. circinalis* sites: Silent Valley and Nilambur were 0.9305 and 0.9513 respectively, while for *C. swamyi* (previous leaf/pith harvest) the λ value was 0.988, indicating a population decline for all three sites over the long term.

Elasticity and LTREs

The elasticity of seedling stasis was dominant for both *C. circinalis* sites (Figure 7). For Silent valley, growth of seedlings also had high values. For the *C. swamyi* populations, the elasticity was dominated by the survival of non-reproductive individuals in the 60 – 100 cm size class. The projected population growth rate, λ was less sensitive to projected changes in fecundity and growth.

The LTREs showed that the biggest contributions to the higher λ observed in *C. swamyi* populations as compared to *C. circinalis* (Silent Valley) were due to higher survival of young adults and the shrinkage of adult individuals (Figure 8). The biggest contributions to the higher λ in *C. swamyi* as compared to *C. circinalis* (Nilambur) were from shrinkage or retrogression of adult individuals (Figure 9) and the biggest contributions to the higher λ in Silent Valley as compared to Nilambur were from higher fecundity and growth in Nilambur (Figure 10).

Simulating harvest

Simulations of fruit harvest show λ >1 for harvesting intensities up till 95%. The Silent valley populations had higher λ values and were able to tolerate higher rates of harvest than the Nilambur population (Figure 11). For *C. swamyi*, λ values remained stable up through harvest of about 10% of stems, after which it declined quickly. However, λ remained <1 over all harvesting intensities for this species (Figure 12).

Discussion

Our results show that *C. circinalis* populations subject to seed harvest and *C. swamyi* populations subject to recent leaf and historical pith harvest appear to be in decline. The use of IPMs proved especially valuable for understanding the effects of seed harvest and leaf/pith harvest as the effects of harvest on the populations were non-linear.

Dynamics of C. circinalis populations and effects of seed harvest

The low λ values for both *C. circinalis* sites indicate that populations are expected to decline over the long term. Although our simulations show that populations can withstand high rates of seed harvest (up to 95%), the near 100% harvest of seeds observed in our populations is clearly not sustainable. Other woody species can tolerate a harvest of 80–90 % of fruit (Ticktin 2004), for example fruits of Uppage (*Garcinia gummi-gutta*) can be harvested up to of 90% (Rai, 2003) without impacting the population projected growth rate. However, heavy long-term harvest of some species can lead to decline (Peres et al., 2003).

The low elasticity of reproduction is consistent with studies of other long-lived woody species (Franco & Silvertown, 2004). All the individuals that produced seeds in the first year produced again the second year. However, it is unclear if, over the longer term reproduction is irregular as in other cycad species (IUCN, 2003). Although nearly 100% of seeds are harvested, seedlings occur probably due to seeds that fall to the ground before harvest or from those that are dropped along the way.

Other kinds of human activity may also contribute to declining populations. For example, trampling of seedlings could occur as harvesters build temporary shelters within the forests. In some places fire is the an important positive factor in seedling recruitment (Negrón-ortiz et al., 2000) . Although fire does occur regularly in the seed harvested sites, it was not recorded during the study period but could potentially play a role in the survival and recruitment of young individuals.

Even though survival of adults typically has highest elasticity for long-lived species (Franco & Silvertown, 2004), we found that in both the seed harvested populations the dominant elasticity values were from seedling stasis. This may be a product of the very high rates of fruit harvest.

Dynamics of C. swamyi populations and effects of leaf and pith harvest

The *C. swamyi* populations that were heavily harvested recently for leaves and pith had a higher projected population growth rates than the seed harvested sites. The scrubland habitat in which *C. swamyi* grows is usually accompanied with low levels of rainfall and open canopy, which presents a poorer environment than the moisture rich habitats for *C. circinalis*. However, the higher λ value was due to higher survival and retrogression. Plants undergo retrogression or shrinkage because it aids in demographic buffering, increases survival and is related to maintenance–reproduction trade-offs (Salguero-Gómez & Casper, 2010). In this case, shrinkage could help in the survival of the population against the pressure of the environment and harvest by going into a period of dormancy with a low investment in fitness and consequently delaying senescence.

The large number of basal suckers observed was seen mainly on pith harvested individuals (whole stem harvested) and appears to allow for survival after harvest. However, it is not clear how fast these suckers grow, as in the 10 years since pith harvest the biggest basal sucker that was found was only 13 cm in height and 15 cm in girth. Many other species reproduce vegetatively especially after disturbance (Mandle & Ticktin, 2011).

Our results show that, unlike the harvesting of seeds, the harvest of even low proportions of adult stems for their medicinal value can have deleterious effects on population persistence. Raimondo and Donaldson (2003) in their study on South African cycads showed that even a 5% adult harvest on an annual basis can result in negative population growth. During the study period, there was no record of reproduction in this site. Investment in reproductive structures is costly, especially in dioecious plants, where females may incur a higher cost of reproduction, which can be measurable in terms of a lower vegetative growth rate and reduced survival (Obeso, 2002). The lack of reproduction could be a result of consistent and heavy leaf harvest (100 % of leaves harvested on all individuals each year), that depletes the stored resources. Although we are unable to test the effects of leaf harvest directly, frequent defoliation has been shown to decrease reproductive output in other plant species (Gaoue et al., 2013; Tamara Ticktin & Shackleton, 2011). In *Chameodora radicalis*, experimental leaf harvest increased adult mortality, reduced fecundity, and reduced the projection population growth rate λ. This study also showed that females produced fruits only 3 years after harvest was completely stopped (B. a. Endress et al., 2006). Leaf harvest can also affect growth (Ticktin 2004), survival (Anten & Ackerly 2009) and reduce plant size (Law and Salick 2005). In the cycads and some palms, leaf harvest can and increase mortality (Endress et al 2006) and decrease adult plant persistence (Octavio-aguilar et al., 2008; Raimondo & Donaldson, 2003) as it is seen to occur in *C. swamyi* populations.

Implications for Conservation

The high harvest rates of *C. circinalis* suggest that there is scope for this species to be harvested sustainably. Current and historical seed harvest by communities for subsistence has possibly had little impact on populations. However, current commercial harvest pressure of nearly 100% of seeds is clearly unfavorable to the long term survival of these plants. Harvesters can be made aware about the low regeneration rates and to leave behind a small proportion of the seeds to allow for the regeneration of individuals in seed harvested sites. The complete harvest of individuals also possibly affects fauna that may feed on and disperse these species, such as bats. There is a need to understand important processes like pollination and seed dispersal on which information is lacking for the Indian cycads and critical to ensure effective conservation.

Pith and leaf harvest of *C. swamyi*, at least at their current rates, do not appear to be sustainable. While the open habitats of *C. swamyi* are not difficult for harvesters to access (in contrast to those of *C. circinalis*), it is unlikely that harvesting lower levels of pith and leaves is financially rewarding to harvesters. The current small populations (due to decrease of adults resulting from pith harvest) and reported smaller size and low productivity of leaves have meant that these populations are currently not worth harvesting as is seen with the declining leaf trade in these areas (Chap 1). This may mean that populations could have a chance to recuperate, at least for a few years. On the other hand, these effect of past harvest 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, Lavorel, Araújo, Sykes, & Prentice, 2005). Conservation and management plans need to be enforced for the long term persistence of these plants.

Table 1: *C. circinalis* and *C. swamyi study sites, study populations and projected long-term population growth rates (λ).*

Site	**Species**	**No of individuals censused/ year**	**No of stands**	**Forest type**	**Rainfall (mm)**	**Canopy**	**Other disturbance**	**Protection status**	**λ**
Silent Valley	***C. circinalis***	235	4	Moist Evergreen	9,569.6	Partially open - closed	Fire*, Plantations**	National Park	0.93
Nilambur	***C. circinalis***	232	3	Moist Deciduous - Dense Evergreen	2500–5000	Partially open - closed	Fire*	Reserve Forest	0.951
Melkote	***C. swamyi***	207	3	Dryland Scrub	690 - 750	Open	Grazing***, Fire*, Plantations**	Sanctuary	0.988

*Fire: Common but not during the study period

**Plantation: Monocultures of *Coffea Arabica*, *Eucalyptus citriodora*, *Areca catechu*, banana and agricultural lands

***Grazing: Cycads are found growing in lands that were used as grazing lands by adjoining local communities

Table 2. Best fit models of the probability of survival, rate of growth, probability of flowering obtained from linear and generalized linear models with size (height) at time (*t*) as the response variable.

***C. circinalis* – Silent Valley**	**Model Coefficient**	**SD**
Probability of surviving to t+1	2.45	0.0255
Seedling survival	0.325	
Mean growth function	4.59	1.02
Variance of growth	39.7	0.00138
Mean number of offspring	56	33.18
***C. circinalis* – Nilambur**	**Model Coefficient**	**SD**
Probability of surviving to t+1	0.9999	-
Seedling survival	0.746	-
Mean growth function	7.45	1.07
Variance of growth	4.05	0.078
Mean number of offspring	36.37	17.84
C. swamyi	**Model Coefficient**	**SD**
Probability of surviving to t+1	2.86	0.027
Seedling survival	0.99	0.01
Mean growth function	1.86	0.985
Variance of growth	1.31	0.0194
Mean number of offspring	0	0

Table 3: Observation rates of seedling stasis and growth over a 2 year period (to individuals with a measurable stem)

Site	**Seedling stasis**	**Seedling growth**
C. circinalis – Nilambur	0.746	0.111
C. circinalis – Silent Valley	0.325	0.475
C. swamyi	0.758	0.10

Figure 3: Growth and survival of *C. swamyi* populations as a function of size (height in cm) at time *t* and *t+1*. Populations were previously subject to pith and leaf harvest.

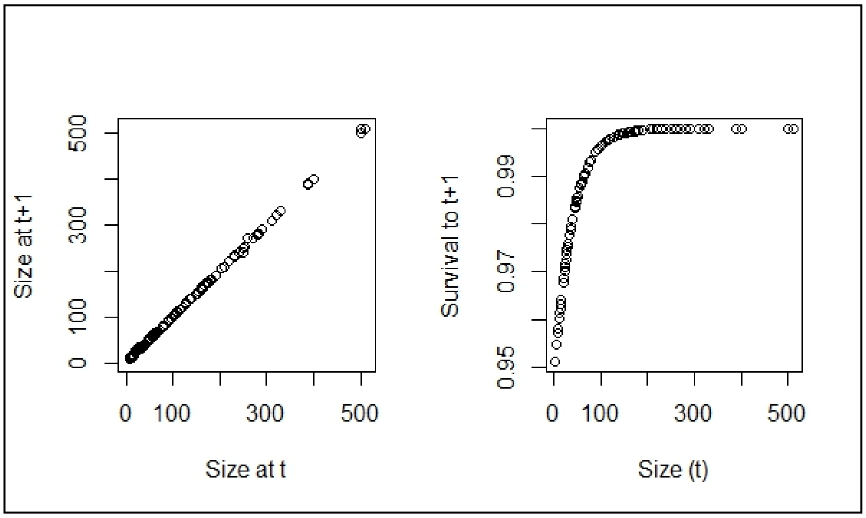


Figure 4: Growth, survival and seed production of *C. circinalis* populations at Silent Valley as a function of size at time *t* and *t+1*. Populations were subject to seed harvest.

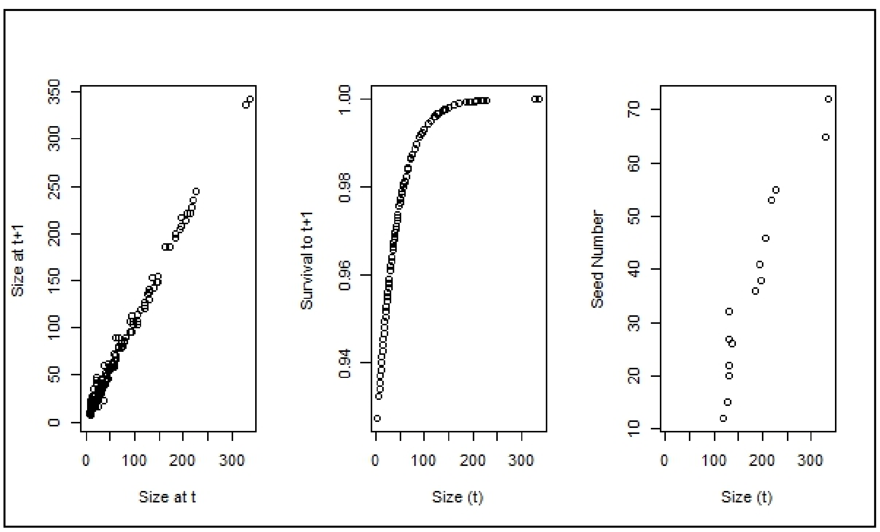


Figure 5: Growth, survival and seed production of *C. circinalis* populations in Nilambur at time *t* and *t+1*. Populations were previously subject to seed harvest.

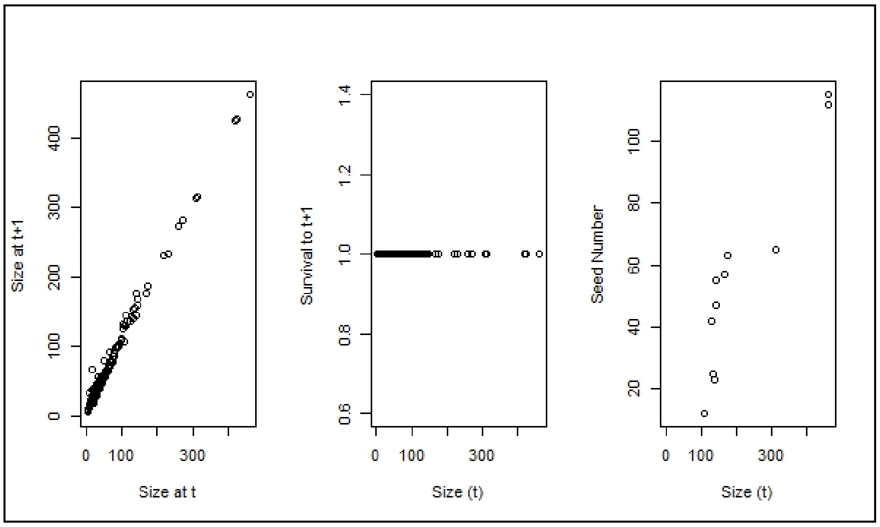
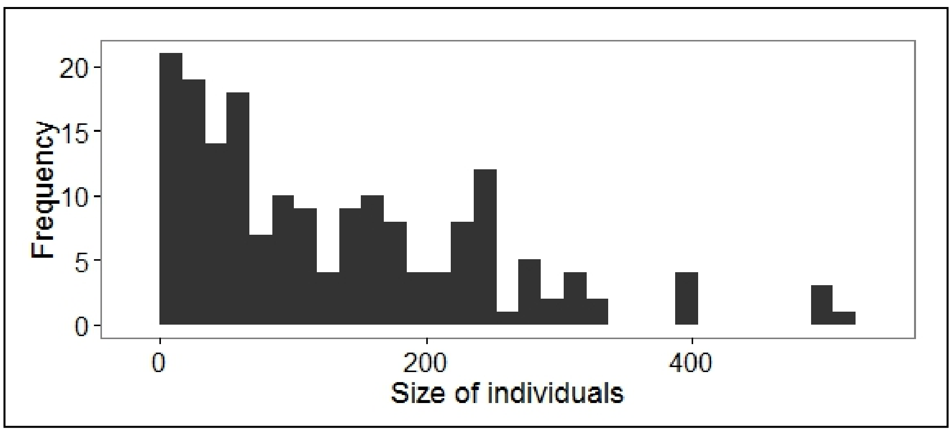
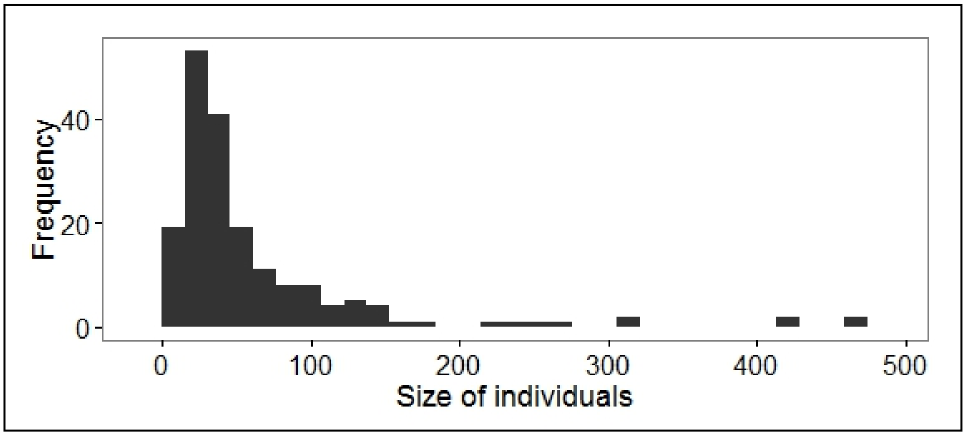


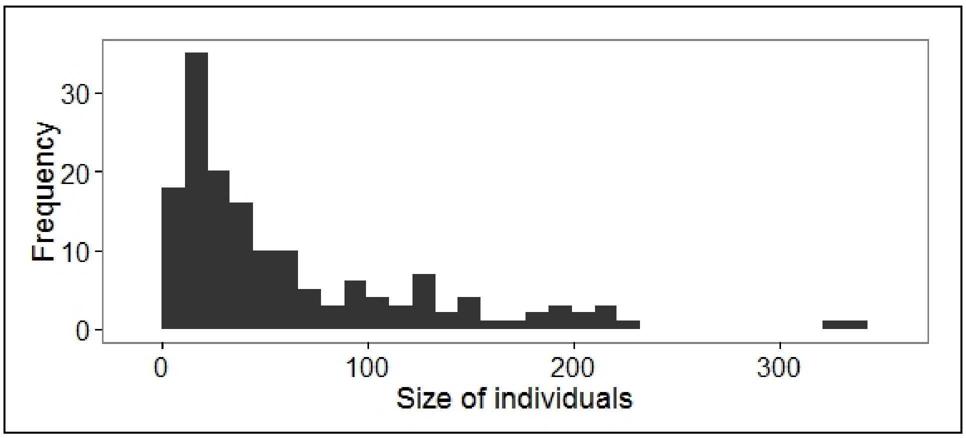
Figure 6: Size distribution of individuals for a) *C. swamyi*, Melkote , b) *C. circinalis*, Silent Valley, and c) *C. circinalis*, Nilambur measured in cm



a)

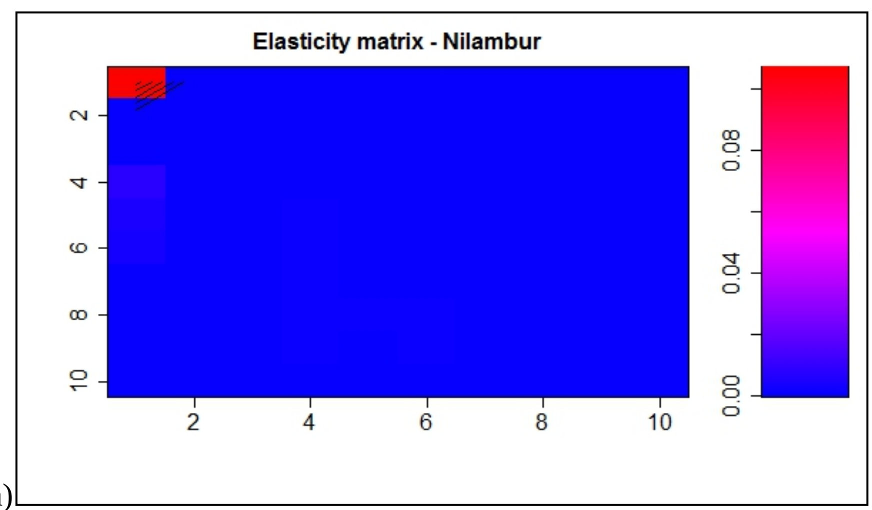


b)

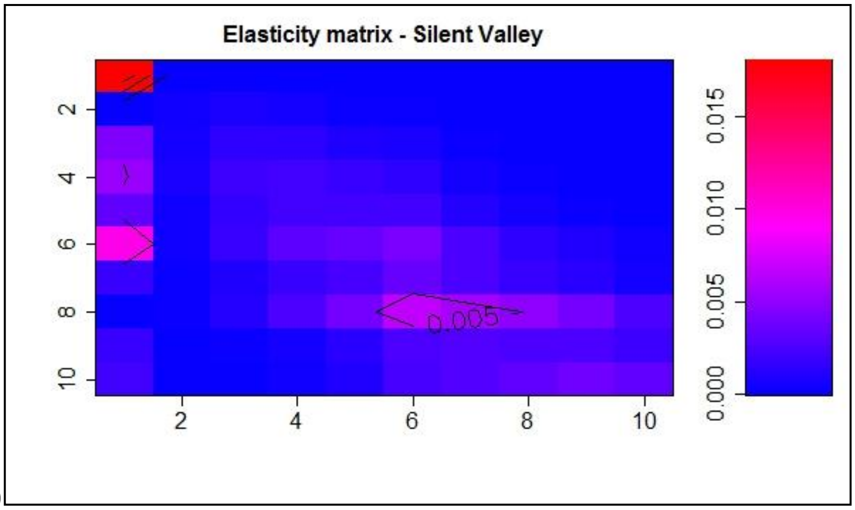


c)

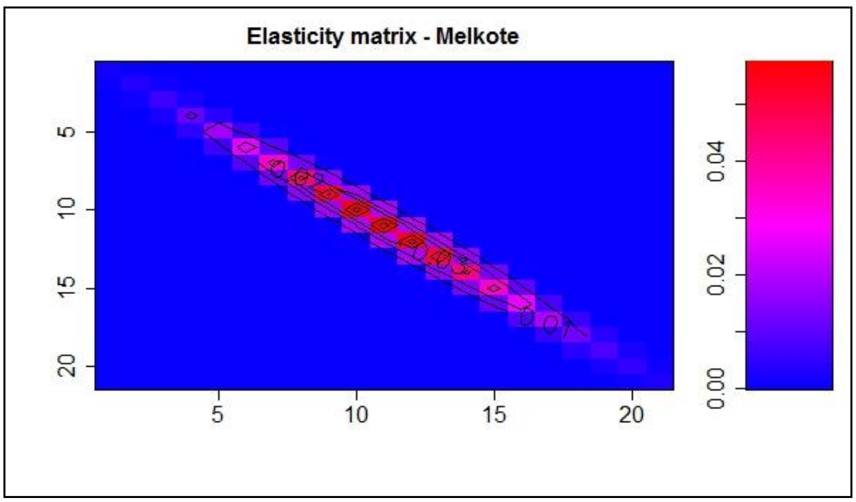
Figure 7: Elasticity matrices of *C. circinalis* Silent Valley (seed harvest) and Nilambur (seed harvest) and *C. swamyi* (previous pith and leaf harvest). All matrices had 200 rows and 200 coloumns. The elasticity matrix is a portion of the big matrix.



a)


Elasticity matrix - Silent Valley
2
4
6
8
10
2
4
6
8
10
0.005
0.000
0.005
0.010
0.015

b)


Elasticity matrix - Melkote
5
10
15
20
5
10
15
20
0.00
0.02
0.04

c)

Figure 8: LTRE effects comparing *C. swamyi* (past pith and leaf harvest) in Melkote and *C. circinalis* (seed harvest) in Silent Valley. (λ Melkote = 0.988 and λ Silent Valley = 0.933). Line colour: green – retrogression, blue – growth, red – survival and black – fecundity.

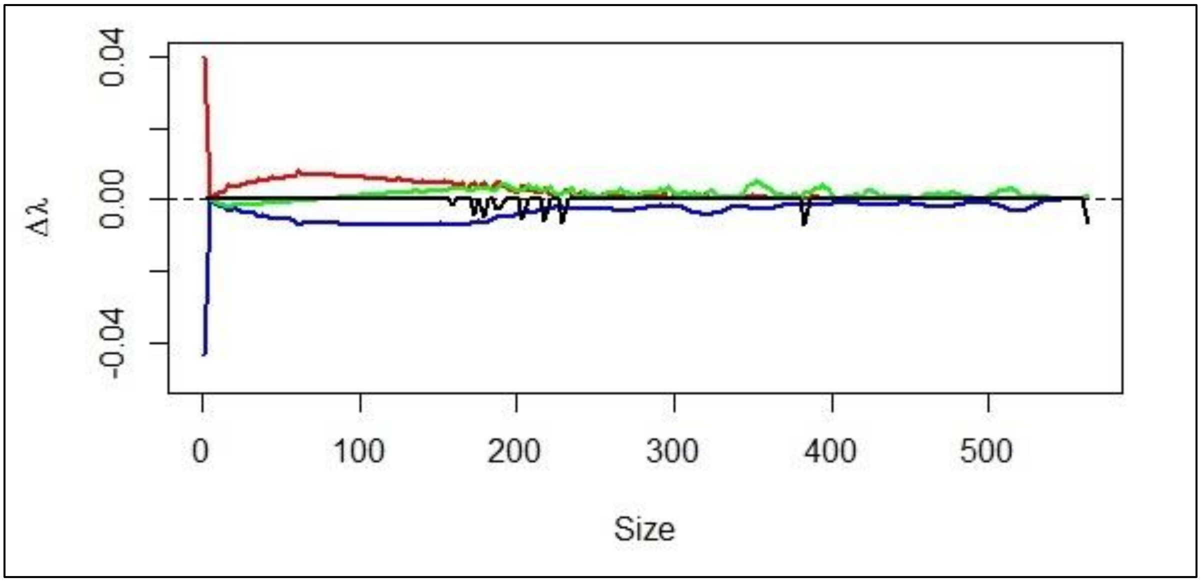


Figure 9: Life Table Response Experiments effects comparing *C. swamyi* (past pith and leaf harvest) in Melkote and *C. circinalis* (seed harvest) in Nilambur. (λ Melkote = 0.988 and λ Nilambur = 0.951). Line colour: green – retrogression, blue – growth, red – survival and black – fecundity.

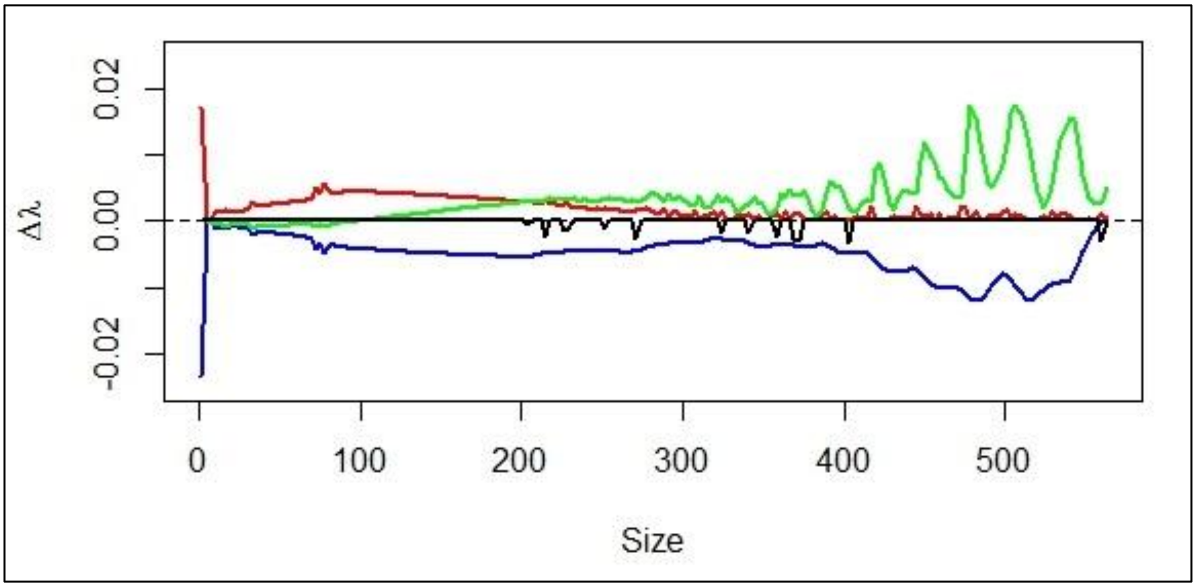


Figure 10: Life Table Response Experiments effects comparing *C. circinalis* (seed harvest) in Nilambur and *C. circinalis* (seed harvest) in Silent Valley. (λ Nilambur = 0.951 and λ Silent Valley = 0.933). Line colour: green – retrogression, blue – growth, red – survival and black – fecundity.

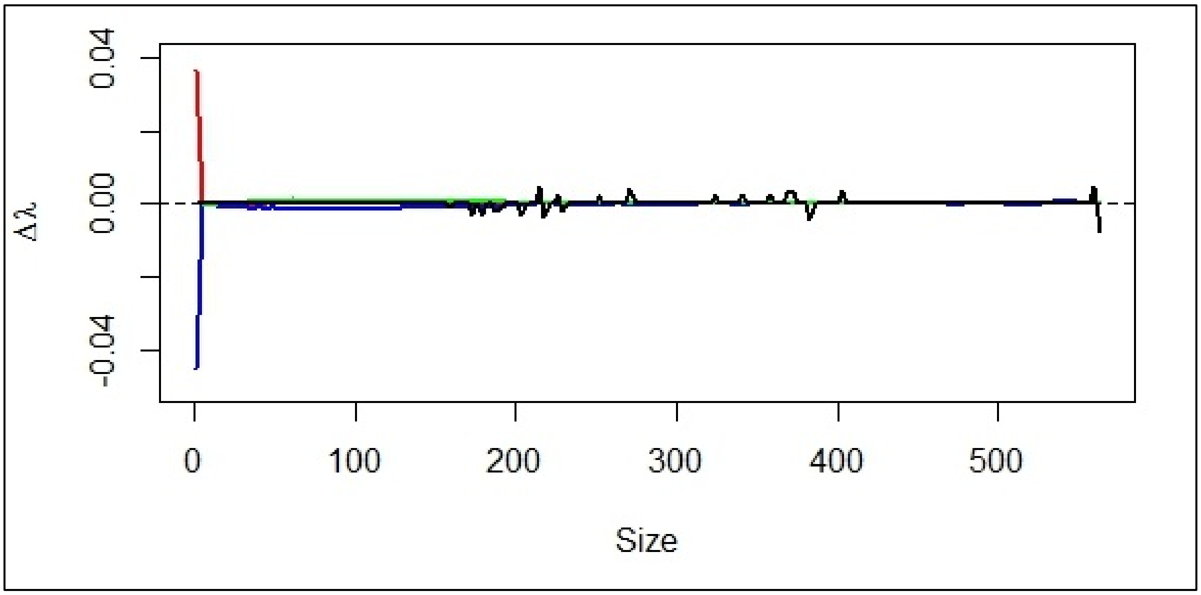


Figure 11: Simulated effects of seed harvest on *C. circinalis* population growth rates

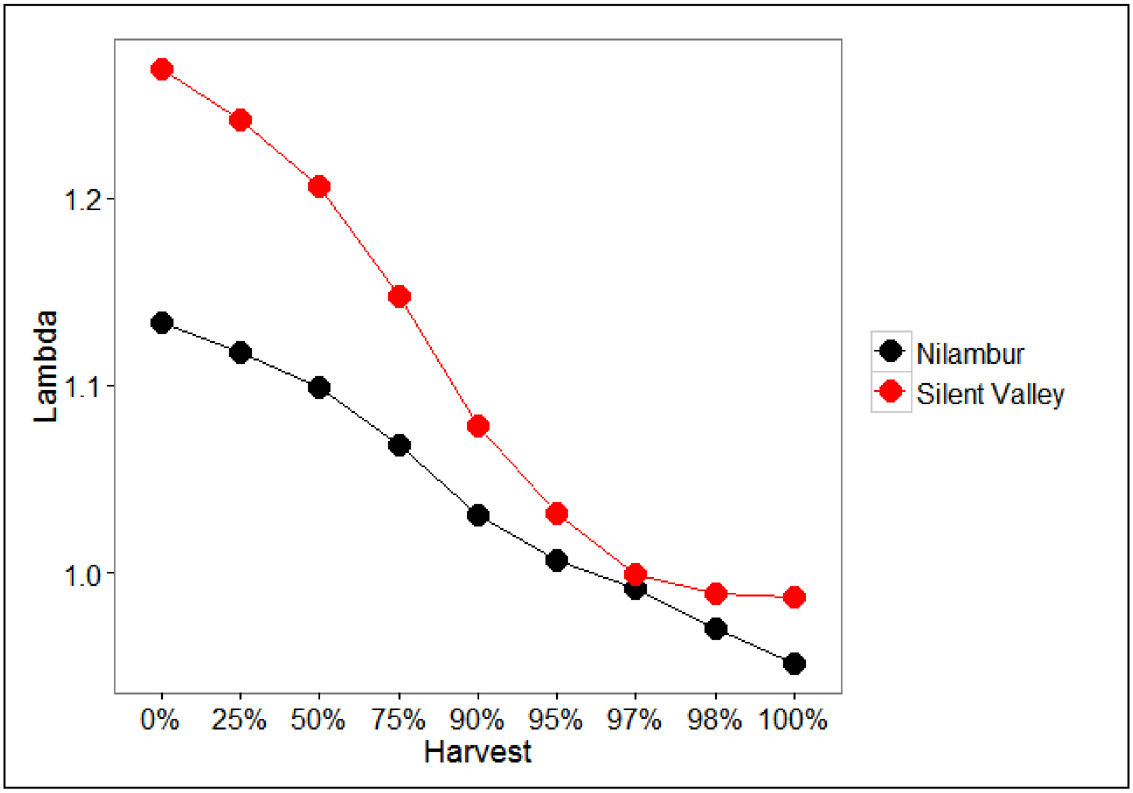
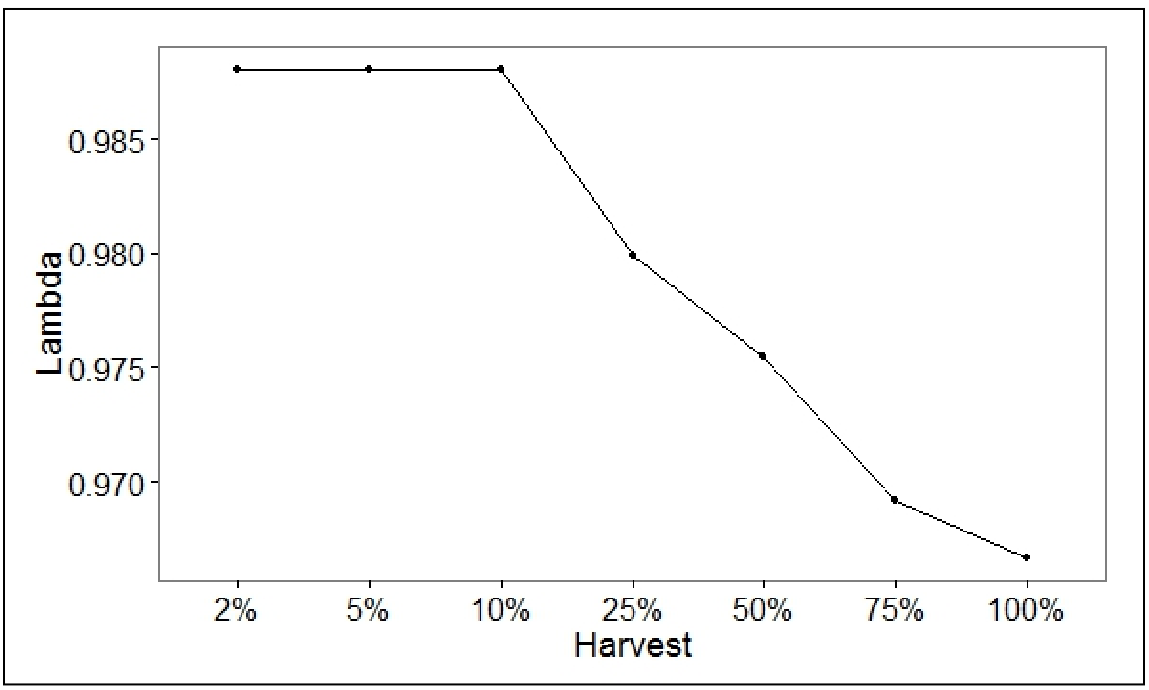


Figure 12: Simulated effects of pith harvest on *C. swamyi* population growth rates



Appendix A 1: Specifications of variables tested with linear and generalized linear mixed effects models (LMM and GLMM) for their effects on C. *circinalis* and *C. swamyi* vital rates. For all models, size (height) at time (t) was the only explanatory variable.

Model	**Form (R package)**	**Response variable**
Survival	Binomial GLM	Plant survived from time *t* to *t*+1(1,0)
Size at *t* + 1 of surviving individuals	LM	Plant size at *t* + 1
Probability of coning at time *t*	Binomial LM	Plant that coned at time *t*
Probability of producing a seedling	Binomial LM	Plant that produced seeds

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CHAPTER 4

An ethnobotanical documentation of the traditional uses of *Cycas circinalis* L.in the Western Ghats of Southern India

Vandana Krishnamurthy and Tamara Ticktin

Abstract

The Western Ghats is an important biodiversity hotspot with rich plant and cultural diversity. *Cycas circinalis* L., is an endemic cycad found in the southern part of the Western Ghats utilized by different indigenous communities for food, medicinal and ornamental purposes. In this study we document the different uses of this plant and the Traditional Ecological Knowledge (TEK) associated with *C. circinalis* use. We interviewed 22 individuals in 5 villages located in the states of Kerala and Tamil Nadu. Semi-structured interviews were conducted to understand patterns, quantities, methods of harvest and use and TEK of *C. circinalis*. The male cones are used as agricultural insect repellants, the leaves are used for food and decoration, the bark is used for medicine and the seeds are used to make different food preparations. The indigenous communities in Tamil Nadu have maintained *C. circinalis* populations by sustainably harvesting plant parts over generations. However, market pressures threaten the survival of *C. circinalis* populations, especially in Kerala where indigenous communities harvest seeds in bulk for local sales. We compare quantities and methods of harvest between sites to suggest limits to harvest for the long term persistence of *C. circinalis* populations.

Introduction

Historical records reveal a rich tapestry of interactions between cycads and humans all over the world. The usage dates back as far as the mid – late Holocene where archaeological records from this time identify the use of cycads as a potential food source (Asmussen, 2009). Cycads had a wide distribution during the Mesozoic and are amongst the most primitive living seed-plants (Schneider et al., 2002) and even now millions of people depend on these plants for subsistence (IUCN, 2003). There are a number of publications that focus on the use of cycads, one of the earlier ones is Thieret (1958) which discusses a range of uses of cycads from food to medicine and fiber. Cycads are used for medicine (S. R. Cousins, Williams, & Witkowski, 2012;

Osborne et al., 1994), magic (IUCN, 2003), food (M Bonta, Pinot, Graham, Haynes, & Sandoval, 2006; Thieret, 1958), decoration (Krishnamurthy et al., 2013) and cultural value (Bonta et al. 2006; Farrera and Vovides 2006).

Indigenous people possess unique knowledge of plant resources on which they depend for food, medicine, and general utility, including tremendous botanical expertise. They are major custodians of knowledge on endemic biodiversity with which they have been intricately involved (Omonhinmin, 2014). Indigenous communities provide alternative knowledge and perspectives based on their own locally developed practices of resource use (Berkes, Colding, & Folke, 2000). This Traditional Ecological Knowledge (TEK) is an integral part of local culture where knowledge, practices, and beliefs are handed down through generations about the relationship between living beings and the environment (Berkes et al., 2000). This knowledge informs the traditional management of natural resources and can provide insight into sustainable resource use (Ticktin, Whitehead, & Fraiola, 2006). Various studies have demonstrated that traditional methods for harvesting wild plant resources can effectively maintain and increase population sizes (Velasquez- Runk 1998; Martinez-Ballest´e et al. 2002; Ticktin & Johns 2002).

In India, the Western Ghats is an important mountain range with a large number of plants that have ethnobotanical importance. It has remarkable biological richness and high endemism inherent in its inclusion in the 34 biological hotspots of the world. There are nearly 7,000 plant species (Pushpangadan, Seeni, & Jacob, 1994) of which 30% are endemic and approximately 450 species are threatened (Krishnan, Decruse, & Radha, 2011).

The indigenous people of the Western Ghats have strong cultural, spiritual and linguistic traditions intertwined with their environment. These indigenous communities account for 5% of the area population in the Western Ghats and include more than 40 indigenous groups (Bawa et al. 2007). Some prominent tribes of this region are the Todas, Hallak Vokkals, Kuttanayakas, Kuruchiyans and Kurumba. They have small populations and often live in geographical concentrations, often distinct from one another. The communities living in Western Ghats have different ethnic and religious backgrounds and some of them, like the Todas are among the most ancient peoples of South Asia (The Swallows, 2010). Traditionally they are hunter-gatherers dependent on forests for their existence by harvesting different Non-Timber Forest Products (NTFPs) in a sustainable manner. However, even though they live in resource rich areas, these communities are amongst the poorest populations in India and their knowledge systems are at threat. Poor policies, impact of secondary education systems, material poverty and the influence of urban lifestyles are some of the reasons which have resulted in the erosion of their knowledge systems. This in turn has an impact on their culture, food and overall lifestyle (Nath & Sharma, 2007).

In this paper, we describe the ethnobotany of *Cycas circinalis* L., an endangered (A. Varghese et al., 2010) arborescent cycad used extensively by traditional communities in Western Ghats of southern India for cultural, medicinal and consumption purposes. However, over the last two decades, commercial harvest of *C. circinalis* for the cut-flower markets and the harvest of pith for the Ayurveda and Siddha medicinal industry has resulted in large scale harvest of wild populations (Krishnamurthy et al., 2013).

Varghese and Ticktin (2007) have documented the use of *C circinalis* in the Nilgiri Biosphere Reserve in the Western Ghats. In this study, we develop on their study by extending the documentation to other parts of the Western Ghats. The specific research questions are 1) What are the different uses of *C. circinalis* in different indigenous communities of the Southern Western Ghats? 2) How are these associated with present trends of commercial harvest?

Study species and study site

Study species

Cycads are ancient, long-lived, dioecious woody plants with palm-like appearance found growing in Africa, Central and South America, South-east Asia, India and Australasia (Jones, 2002). The world cycad flora has 335 species and subspecies which represent a small fraction of the earth's plant diversity (Calonje et al., 2012). Cycads have global conservation significance as the destruction and alteration of natural habitat and selective removal of plants and plant products from the wild in massive numbers have significantly reduced population size (IUCN, 2003). The 2011 IUCN Red List of Threatened Plants cites that 79% of all cycads are threatened with extinction (IUCN 2011). In Asia, collection of plants for horticulture, harvest for ornamental use and cultural/medicinal value are important causes for decline. Most cycads are harvested and sold in local markets (IUCN, 2003).

Cycas circinalis is endemic to the Western Ghats, a mountain range on the western coast of India. It is found in the states of Kerala, Karnataka, Tamil Nadu, and Maharashtra. It typically occurs in fairly dense, seasonally dry scrubby woodlands in hilly areas. *C. circinalis* is facultatively deciduous in extremely dry times. It appears to be an adaptable species with colonies extending from rocky hill outcrops down to coastal habitats at sea level. It is arborescent, growing up to 8 m tall, with leaves that are 1.5-2.5 m long (Lindstrom and Hill 2007).

Study site

To document the ethnobotanical uses and the TEK of *C. circinalis* we selected five indigenous villages in the Southern Western Ghats where people have been using *C. circinalis* over generations. We focused on the states of Tamil Nadu and Kerala. The sites Silent Valley and Appankapu were located in Kerala. Top Slip, Vellaricombei and Gudagur were located in Tamil Nadu (Figure 13). The people interviewed belonged to four different indigenous communities – the Kurumbas, Irulas, Kadars, and Kattu Naickens (Table 4).

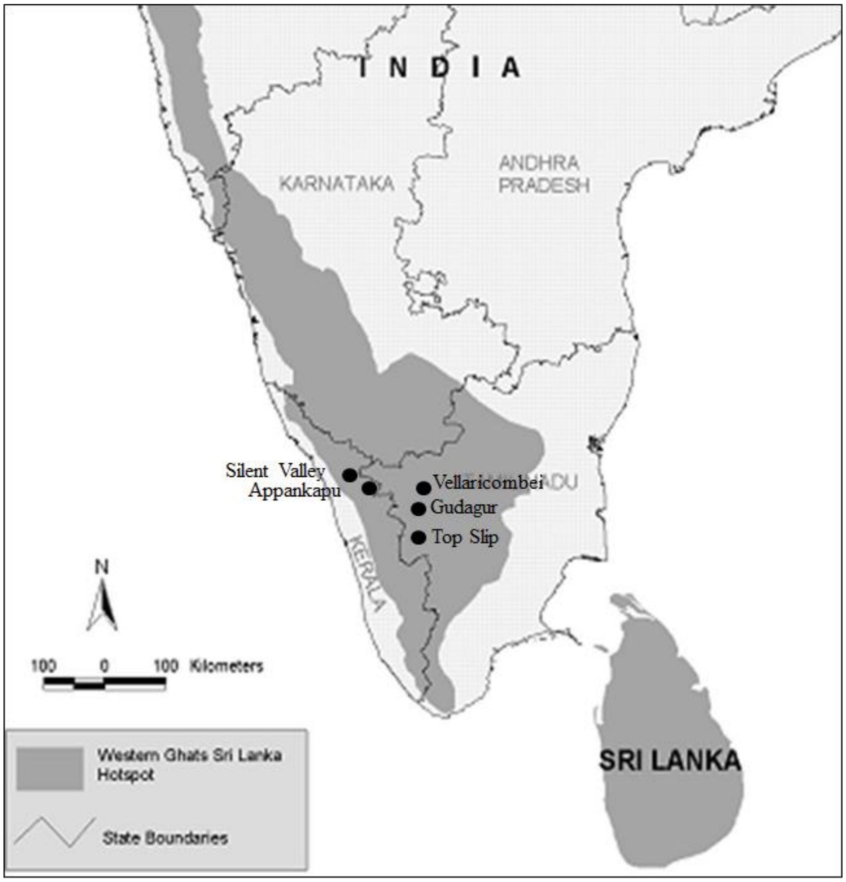

Figure 13: Map of southern India with the ethnobotany field sites: Silent Valley, Appankapu, Vellaricombei, Gudagur and Top Slip

Indigenous people

The Kurumbas are forest-dwelling people of the Nilgiris district of the Western Ghats, who practice shifting cultivation, collection of forest produce and small game for their survival and livelihoods (Banu & Thamizoli, 1998). They are known for their skill in honey collection and alchemy. Some people undertake seasonal agriculture or depend on wage labour. They collect forest produce during fruiting/honey yielding season and sometimes travel across borders to sell the NTFPs in markets (Nath & Sharma, 2007).

Irulas live in low altitude regions of the Western Ghats. Irula communities are forest dwelling, but the 1976 Forest Protection Bill ended the traditional livelihood of the Irulas, who sold firewood, wax, and honey collected from the forests, forcing many communities to move into villages. In more populated areas such as villages, the Irulas are known to be expert snake and rat-catchers. (Terjesen, 2007). The Irula community we worked with for this study is one of the few forest dwelling communities in the Western Ghats.

The Kattunaickens get their name from the word *kadu* meaning forest and *naicken* meaning leader. The primary occupation of this community is based on hunting and gathering, especially honey and is one of the most important honey collecting communities in the region. Till today, these Kattunaickens live with very few assets in small bamboo huts, around which they grow a little ginger, coffee, pepper, tapioca and yam, but are generally not cultivators. They collect NTFP during the season, but not in large quantities (Nath & Sharma, 2007).

The Kadars are a small tribe of southern India residing along the hilly border between Cochin in the state of Kerala and Coimbatore in the state of Tamil Nadu. The Kadars live in the forests and do not practice agriculture, building shelters thatched with leaves and shifting location as their employment requires. They have long served as specialized collectors of honey, wax, sago, cardamom, ginger, and umbrella sticks for trade with merchants from the plains. Many Kadar men work as labourers (Rajendran & Henry, 1994).

Historically, the relationship between tribal communities in India and forests was characterized by co-existence and these communities were considered integral to the survival and sustainability of the ecological system (Gadgil, Berkes, & Folke, 1993). This symbiotic relationship resulted in customary rights over forest produce. However, these rights were not recognized by the government while consolidating state forests during the colonial period as well as in independent India (Bhullar, 2006). The resulting insecurity of tenure and the threat of eviction led to the alienation of tribal communities from their ancestral forest lands. This historical injustice was perpetuated by the Wildlife (Protection) Act 1972 and the Forest Conservation Act 1980, which identified environmental protection and recognition of the rights of tribal communities as mutually irreconcilable objectives (Bose, 2010). In response to resulting tribal agitations and unrest, the Forest Rights Act was constituted in 2006 to ‘undo the historical injustice suffered by tribal communities’. The purpose of the Act is to recognize the rights of forest-dwelling communities and to encourage their participation in the conservation and management of forests and wildlife. However, the act has not been constituted effectively in many states and there has been a lot of debate over the specific rules and amendments of the Act (Bhullar, 2006). The communities we interviewed have been harvesting NTFPs by virtue of their location within core forest area; however, they have faced serious consequences in loss of tenural rights on their lands. The Forest Rights Act is believed to return land ownership and rights of these communities.

Table 4: Indigenous groups interviewed in Tamil Nadu and Kerala to document ethnobotanical uses of *C. circinalis*

Community	**Village**	**State**	**No. of participants**
Irula	Gudugur	Tamil Nadu	4 (3 men, 1 woman)
Irulas	Silent Valley	Kerala	3 (2 men, 1 woman)
Kurumba	Vellaricombei	Tamil Nadu	7 (4 men, 3 women)
Kattunaicken	Appankapu	Kerala	5 (2 men, 3 women)
Kadar	Top Slip	Tamil Nadu	3 (All men)

Methods

The location of cycad habitats were identified by creating Participatory Rural Appraisal maps with the Kurumbas, Irulas, Kadars, and Kattunaickens local communities that live in and around the *Cycas* sites. Villages were selected based on their use of *C. circinalis* over generations. A total of 22 individuals with 8 women and 14 men were interviewed across all villages. In these, 5 of the respondents were below the age of 30. The oldest individual was aged at 72 years.

Twenty two semi-structured ethnographic interviews with open-ended questions were conducted with the indigenous and commercial harvesters of *C. circinalis*. The study was done in July – September 2011. Indigenous harvesters were chosen for interviews based on individuals that regularly harvest *Cycas* plant products. Interviews focused on uses, local names, harvest quantities and techniques, traditional management and processing of *C. circinalis* seeds (to remove neurotoxins) and young leaves. The use of *C. circinalis* in these areas is ancient and indigenous communities have learned how to prepare and process it by knowledge transmission over generations.

Commercial harvesters (indigenous communities in Kerala) were located by information gathered at the regional markets or on site while collecting data. They were interviewed on methods and patterns of mature leaf harvest, seed harvest and pith harvest. Interviews were conducted in Tamil and Malayalam by VK.

Results & Discussion

Our interviews revealed that the local name for *C. circinalis* in Kerala was *eentha Panna* (language: Malayalam) and in Tamil Nadu local names were *eentha panai*, *madana kama raja* and *salaparai* (language: Tamil). Plants were found growing in natural forests, teak plantations and backyards in the villages. Top Slip, Silent Valley and Appankapu villages were located on the fringes of the forest, whereas Vellaricombei and Gudagur villages were found inside forest boundaries.

Uses

The harvest of these plants for domestic use was restricted to villages around the wild habitats of *C. circinalis*. The interviews showed that different parts of the plant were utilized for different purposes and there was a clear distinction between the uses in Kerala and Tamil Nadu. The seed was the main part of the plant harvested in both states. The mature cone and bark was used only by few individuals. These are described in more detail below.

Seeds

The use of cycad seeds as a source of food starch is popular in cycad habitats all over the world. The toxicity of cycads have long been known (Whiting, 1962). It is remarkable how different cultures have independently developed the technology to prepare food from cycads which contain several powerful toxins. All communities that consume the seeds, properly process them to remove the cycanogenic glucosides, cycasin and neocycasin (Barceloux, 2009). For example, aboriginal people living in northern Australia consume seeds of *Cycas angulata* R. Br. after treating the seeds by leaching and aging (Beck, 1992). Traditionally, seeds were the primary diet for many communities in Honduras where seeds of *Dioon mejiae* Standl. & L.O. supplements maize-bean diets for an estimated 33,000 indigenous and mestizo Hondurans (Bonta et al. 2006).

In our study, the seeds were consumed as food in both Tamil Nadu and Kerala with different methods of processing seeds to remove the toxic content. In Tamil Nadu, the Kurumba and Irula communities leave the seeds in running water for 1-2 weeks to allow toxins to leach out. They then soak the seeds in water for a day after which it is washed approximately 7 – 10 times, until the water does not appear turbulent. Seeds are then ground into dough which is made into '*idli*', a moist steam-cooked dish popular in southern India. *C. circinalis* seeds are collected very rarely and the indigenous communities do not depend on the plant as part of their daily diet.

In Kerala, the processing of the seeds is done slightly differently. After seeds are harvested and sliced (

Image **1**), they are smoked and then leached by boiling several times. They are then dried and powdered into a flour to make pancakes and "*puttu*", a dry steam-cooked dish widely consumed in Kerala. The Irulas in Silent Valley mentioned that their grandparents had *puttu* made out of *C. circinalis* seeds on a daily basis. They believed that their grandparents they were a lot stronger and resistant to different infections. Rice according to them did not provide as much nutrition as the seeds of *C. circinalis*.

Image 1. Seeds of *C. circinalis* being cut into halves before drying and leaching in Silent Valley, Kerala

Leaves

The use of cycad leaves for ornamental purposes is another common practice amongst communities that live in cycad environments. Leaves are used to decorate shrines, altars, processional garments, tombs, church facades, temples and wedding halls (Mark Bonta 2012, Krishnamurthy., Chapter 1). In Mexico, the leaves of *Dioon* and some *Ceratozamia* species are commonly used as decoration during religious festivities (Lazaro-Zermeno et al 2011, Osborne and Vovides 2010; Pérez-Farrera and Vovides 2006) and *tiusinte* or *D. mejiae* leaves are used for a variety of Catholic celebrations in the Honduras community (Bonta et al. 2006).

We documented that the mature leaves were used for ornamentation in both states. In all Kerala sites people still follow the cultural practice of using *C. circinalis* leaves of decorating altars, temples and houses for ceremonial purposes. Traditionally, a house decorated with cycad leaves indicated a marriage celebration (Image 2). Sometimes a few hundred leaves are harvested to make decorative arches and *pandals* (decorative roofs). This trend of using *C. circinalis* leaves for wedding decorations is also followed in cities (Chap 1).

The tender immature leaves are eaten by the Kurumbas and Irulas in Tamil Nadu (

Image 3). The Kurumba community in Vellaricombei, remove the thin layer of skin on the tender leaves and make a stir-fry dish. The Irulas in Gudagur consume it without de-skinning the leaves. Occasionally, the stem of the leaves are also eaten by the Irulas after boiling to remove the outer fibrous layer as well as its toxic content.

Image 2. Mature leaves of *C. circinalis* to indicate a wedding in Appankapu, Kerala

Image 3. Tender shoots of *C. circinalis* eaten as a stir-fry dish in Vellaricombei, Tamil Nadu

Cone

The male cones were discussed by Kattunaicken participants in Appankapu to be used in Kerala by farmers to ward off agricultural pests (Image 4). The mature male cones tend to give off a strong odor which can travel several kilometers. This odor in the cycads is produced to attract pollinators (Terry, Walter, Moore, Roemer, & Hull, 2007). The farmers in Kerala have found that the odor of the mature cones when placed in a paddy field attracts pests to the *Cycas* cones that commonly devour the crop.

Image 4. Mature male cone of *C. circinalis* which is uses in agricultural pest control in Appankapu, Kerala

<u>Bark</u>

Cycads are used in indigenous systems of medicine in other cultures in India and the world. In China, the plant of *C. revoluta* is said to be a tonic. Its seeds are used to promote expectoration (Pant 1973) while in South Africa, ethnobotanical studies show the use of *Encephalartos* spp. bark for medicinal (Cousins et al 2011) and magical purposes (Donaldson 2003).

C. circinalis bark is used to make traditional medicines by the Irulas of Tamil Nadu. The bark is scraped off from the tree and boiled to make a concentrated decoction or *kashayam* (Image 5). This is administered to women who have just delivered, to cleanse their body and encourage lactation.

In other parts of India, in the state of Andhra Pradesh, male cones of *Cycas beddomei* known as *per ita* are known to have a cooling effect when dried and candied. The cones are also used to treat rheumatism and muscular pains (Pant 1973). Additionally, the pith is used in the diet of local communities to cure debility (Reddy, Reddy, Pattanaik, & Raju, 2006).

Image 5. Bark scraped off *Cycas* tree (left). *Kashayam* (decoction) made from the bark of *C.circinalis* used for medicinal purposes in Gudagur, Tamil Nadu (right)

Quantities harvested and seasons

In Tamil Nadu, participants did not rely on *C. circinalis* leaves and seeds for their daily sustenance. Although they traditionally have been harvesting cycad leaves and seeds, over the last few decades, their regular food rations are being purchased from the weekly markets in nearby towns. On regular forest visits, if new leaves have emerged or if the tree is in seeding, they harvest it. The harvest is made only for domestic use and not for sale in the markets and all recorded harvest during the study was done by male participants. When the plant is seeding, usually 2 – 3 kgs of seeds are harvested for domestic use. According to the participants, a fully grown female tree can produce approximately 6 kgs of seed. Additionally, harvest is done during times of famine and financial hardship, which is common in other cycad habitats in Mexico and Honduras (Bonta et al. 2006; Farrera and Vovides 2006; IUCN 2003). Consumption of *Dioon* species in Mexico enabled thousands of people to survive a major drought in 1951(Bonta et al. 2006). While harvesting tender leaves, leaves are harvested only from the center leaving an outer layer of leaves, allowing for photosynthesis. Mature leaf harvest in Tamil Nadu is practiced only for commercial use by harvesters who are not members of the indigenous communities.

In some communities, market pressures and income poverty push communities to practice unsustainable harvesting of NTFPs (Kumar et al., 2011). In Kerala, seeds are regularly consumed by indigenous people. All harvest is done by the indigenous communities. The average harvest in each visit is 15 kgs or all the seeds available during the seeding season, which takes place in July every year. The maximum quantity harvested in a single visit was 30 kgs. The customers who buy the seeds are residents from the village. Dried seeds are sold at Rs 30/kg ($0.50) which have a long shelf life and can be stored up to 6 months. In Silent Valley, the seeds were sold in small shops, while in Appankapu the seeds were sold more informally in people's houses. Sometimes, vendors from Silent Valley will transport the seeds to smaller villages within a 50 km radius for sale. Vendors who sold *C. circinalis* seeds also sold other NTFPs such as wild harvested honey, and dhupa resin from the *Canarium strictum* Roxb. tree.

Harvest methods and observations in trends over time

The importance of incorporating indigenous knowledge into ecological studies and resource management plans is being increasingly recognized (Mueller, Assanou, Dan Guimbo, &

Almedom, 2010; Souto & Ticktin, 2012; Ticktin et al., 2006) as they can provide valuable information on resource use as well as the development of valuable ecological and biodiversity indicators. In most tropical regions where 90% of the forests lie outside protected areas (Jenkins, 2004), these knowledge systems are being developed and adapted to manage forest resources.

In Tamil Nadu, the Kurumbas limit the quantities of harvest of *C. circinalis*. At the time of young leaf harvest for consumption in Vellaricombei, the Kurumbas always leave the outer layer of the new leaves and harvest only from the centre to aid in regeneration and as a method of ensuring resource availability over the long term, as practiced by other indigenous communities (Lariviere & Crawford, 2013). Vellaricombei participants expressed that they never harvest the young leaves from saplings and young adult individuals. They referred to the importance of protecting the large number of saplings available around the mother tree, which could become adult individuals in about 15 years, increasing the population size. The height of the *C. circinalis* trees was compared to a coconut tree. They recalled that in the past the trees were as tall as or taller than a coconut tree but now they were much shorter. Additionally, they mentioned that the clumped distribution with larger population sizes made it look almost like a plantation in the forest landscape. The seeding season was associated to the onset of the *Varsha* season which is at the end of summer and before the monsoon (rainy season) begins. According to them, it was hard to miss the flowering (coning) season as the smell would reach the villages. This coincided with the cold season or *Hemant*.

Participants in Gudagur and Vellaricombei have observed bats eat the outer fleshy layer of seeds and then drop the seeds to the floor. This is true in other cycads. Bats have been recorded to disperse seeds of *Cycas micronesica* in Guam. However, biomagnification studies have shown that people who ate the flying foxes that had consumed the sclerotesta of *C. micronesica*, tested positive for nuero-degenerative diseases such as ALS and Parkinsons. Cycad neurotoxins were known to be biomagnified within the flying foxes and further in the indigenous Chamorro people who consumed flying foxes during traditional feasts (Banack & Cox, 2003).

Kurumba people in Vellaricombei observed porcupines and deer feeding on the seeds. Irulas in Silent Valley stated that no wildlife visits the plant because the seeds if eaten raw have a very strong taste. One participant referred the taste similar to an ‘electric shock’. Thrips and weevils are known to be mutualistic pollinators of cycads in Australia and South Africa however this information is lacking in India as there are no studies on the plant-animal interactions of cycad species in India (Terry, 2008).

One of the main aspects that was emphasized by all participants was the dwindling numbers of *C. circinalis* individuals in natural habitats. Participants from Tamil Nadu indicated that the reduction in plants numbers was due to extensive harvesting by commercial harvesters from outside communities. They strongly believed that excessive leaf harvest has been detrimental to the *C. circinalis* plants and hence they are unable to grow naturally. In these sites, the participants estimated that the original *C. circinalis* population size in Vellaricombei was more than 3000 individuals, 1000 individuals in Gudagur and more than 5000 individuals in Top Slip. Our studies indicate that the total population size in Tamil Nadu is ≤ 1500 individuals, much lesser than what was claimed to be found in these sites (Krishnamurthy et al., 2013). This shows that the population has declined by approximately 80% of its initial size, which is evident from the large scale harvest of leaves for market sales in Chap 1.

In Kerala, participants also expressed a decline in the population size over years. They owed the reduction in population size to the intense harvest of seeds as well as the unpredictable rainfall and weather patterns. Participants also mentioned that *C. circinalis* was a very resilient plant and survives well even after a fire. They explained that it was the thick stem of the plant that protects it. This is known to be true in other cycads where fires positively affect leaf production and germination (Negron - Ortiz & Gorchov, 2000).

Not many studies have documented the impacts of harvesting cycads. Studies from South Africa and Australia showed that whole plant harvest of even 5% of adult cycads from the wild for landscaping can result in rapid population decline (Raimondo & Donaldson, 2003) particularly the reduction in seedling abundance (Griffiths et al., 2005). The continual leaf harvest is detrimental to long term survival of cycads as it can lower reproduction in adults (Octavio-aguilar et al., 2008) and reduce growth (Lázaro-Zermeño et al., 2011).

Excessive harvesting of seeds can affect the long-term population persistence of the *C. circinalis* populations (Chap 1). As part of another study (Chap 2), we conducted demography studies of *C. circinalis* in seed harvested sites in Kerala to understand the impacts of harvest on population dynamics. We found that recurrent seed harvest at the rates practiced (nearly 100% of seeds), would result in species decline over the long term. Simulating different levels of seed harvest showed that up to 95% seed harvest can take place without impacting the long term growth rates of the population. Therefore, if a small proportion of seeds were left behind, the population could be maintained over the long term which could economically benefit people as well as allow for population persistence.

Commercial Harvesters from outside of the communities

In Vellaricombei and Gudagur, the participants have observed outside harvesters arrive in large numbers during the wedding season in the month of November and May- June was a lean period due to the *Aashada Masam*, which concurs with our market studies in leaf markets. The leaves of *C. circinalis* and *Cycas swamyi* Singh & Radha., from Karnataka are reported to be overharvested for sale in the ornamental cut-flower industry (Chap 1). According to the participants, the harvesters cut all the healthy leaves and leave behind damaged leaves. Damaged leaves were those that had been eaten by the larvae of the Plains Cupid butterfly (*Chilades pandava*) that lays its eggs on the *C. circinalis* leaves. The harvesters only harvest the leaves and not the seeds; transport it to the closest town, Mettupalyam and Thirupur where vendors purchase it in bulk for sale in the big cities such as Bangalore and Chennai. Results from the market study conducted in 2011 and 2012, shows that intensive harvest coincides with the wedding season in Bangalore. In both years, 35650 and 39600 leaves were harvested respectively to supply the Bangalore market, known to originate from Tamil Nadu and Kerala populations (Chap 1). Subsequent demographic studies in high leaf harvest showed low growth and lack of reproduction of these species impacting slow-growing and long-lived cycads (Chap 2) clearly indicating the detrimental effect of harvest.

Conclusions

Cultural and social attributes of human communities can have substantial influence on biodiversity conservation and sustainable utilization of resources (Sam et al. 2006). We demonstrate how traditional use and market forces impact plant populations and the ways in which indigenous communities can be positive and negative agents in resource use.

The Kurumba and Irula communities depend largely on NTFPs for their sustenance and liveligoods. They harvest cycad seeds and leaves for domestic use in a sustainable manner. Yet, heavy commercial market pressure has severely reduced the population size of *C. circinalis* in these areas. In contrast, the people in Kerala depend on the sale of seeds in the market for annual income generation resulting in almost all seeds harvested for market sales.

In this context, there are two main factors that can contribute to better conservation by local communities. Firstly, indigenous knowledge systems on sustainable use of cycads, can serve as essential information which can feed into conservation action plans by the Tamil Nadu Forest Department. This knowledge is vital to indicate the impact that market sales have on cycad population decline. Secondly, the introduction of sustainable harvest limits in Kerala could help encourage seedling recruitment in high seed harvested sites. This could be achieved by sharing results from demographical studies on seed harvested cycad populations with the indigenous communities (Chap 2).

Conservation efforts are required to preserve the diversity of *C. circinalis* and the array of ethnobotanical applications and practices linked with the species. The rapid rate at which the existing traditional knowledge is becoming obsolete has to be checked to assure equitable resource availability for all, while conserving and improving natural resources.

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CHAPTER 5

Conclusions

Main findings

The dissertation focused on the harvest and population ecology of *Cycas circinalis* and *Cycas swamyi* in the Western Ghats of southern India. These species are overharvested for market sales in floriculture and medicinal markets. I used an ethnoecological approach to understand the harvest and management practices followed by the traditional communities in the Western Ghats as well as commercial harvesters from urban areas. *Cycas circinalis* is harvested for its seeds, pith, leaves, cones and bark by indigenous communities while commercial harvesters cut the leaves and the stem for the cut-flower and Ayurvedic medicinal industries respectively. I studied the market chain and supply and demand of these products to understand the quantum of produce that is being harvested. Using population models, I projected the long-term effects of these different harvesting practices on *C. circinalis* and *C. swamyi*.

I found that the harvest of *C. circinalis* and *C. swamyi* leaves for commercial sales is extremely high and the inflow (supply) and outflow (sale) strongly follows the Hindu cultural calendar. High sales peaked with the wedding season that occurs between mid-October and early March. The pith markets showed that large number of trees is being lopped to harvest the pith for the medicinal preparation, *vidari*. Unfortunately, *neither C. circinalis* nor *C. swamyi*, has the original chemical constituents of *vidari* which originally is extracted from the tubers of *Pueraria tuberosa* and *Ipomeae digitata*. *C. circinalis* and *C. swamyi* pith segments have crept into the medicinal markets as the dried form of the pith looks very similar to the dried tuber segments of *Pueraria tuberosa* and *Ipomoea digitata.* If harvest were to go on at the present rates, the population will risk extinction (Chapter 2).

Non-timber forest products (NTFP) are extensively extracted from Indian forests, and their role in rural and forest economies is immense (Shahabuddin & Prasad, 2004). However harvesting NTFPs for commercial gains can put plant populations into jeopardy as overharvesting leads to species decline. The intense harvest levels that I documented in the markets resulted in effects on survival, growth and reproduction of these two species. The long-term population growth rate (λ)

for all populations was below 1, indicating a decline in population size over the long term. Seed harvested populations had a lower λ than the leaf/historical pith harvested sites. In sites with seed harvest, I found low levels of seedling recruitment, while in sites with leaf and historical pith harvest, there was an absence of reproduction and minimal growth (Chapter 3).

While commercial harvest clearly affects the long-term population growth rate of *C. circinalis* and *C. swamyi*, traditional ecological knowledge systems of the indigenous communities can contribute to sustainably harvest plant resources ensuring regeneration over the long term (Chapter 4). In purely ecological terms, extraction can be considered sustainable if the harvest has no long-term deleterious effect on the reproduction and regeneration of populations being harvested in comparison to equivalent non-harvested natural populations, and if the harvest has no discernable adverse effect on other species in the community, or on ecosystem structure or functioning (Hall & Bawa, 2009; Shahabuddin & Prasad, 2004).

Management implications – harvest

Based on the results of my demography data, I make recommendations for the sustainable harvest of seeds, leaves and pith. The high harvest rates of *C. circinalis* suggest that there is scope for this species to be harvested sustainably. Current and historical seed harvest by communities for subsistence has possibly had little impact on populations. However, current commercial harvest pressure of nearly 100% of seeds is clearly unfavorable to the long term survival of these plants. Harvesters can be made aware about the low regeneration rates and to leave behind a small proportion of the seeds to allow for the regeneration of individuals in seed harvested sites.

Pith and leaf harvest of *C. swamyi*, at least at their current rates, do not appear to be sustainable. While the open habitats of *C. swamyi* are not difficult for harvesters to access (in contrast to those of *C. circinalis*), it is unlikely that harvesting lower levels of pith and leaves is financially rewarding to harvesters. The current small populations (due to decrease of adults resulting from pith harvest) and reported smaller size and low productivity of leaves have meant that these populations are currently not worth harvesting as is seen with the declining leaf trade in these areas (Chap 1). This may mean that populations could have a chance to recuperate, at least for a few years. On the other hand, these effect of past harvest 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). Conservation and management plans need to be enforced for the long term persistence of these plants.

Management implications – markets

Informal markets that sell NTFPs play an important role not only in local economies, but also in urban centers. However, the sale of *Cycas* spp. leaves and pith is not a requirement for dependent communities. In the floricultural markets, there are a variety of different leaf fillers being sold in the markets. All of the fillers, other that *C. circinalis* and *C. swamyi* are acquired from plantations that are set-up for this purpose. The markets and vendors in Bangalore are very resilient to change. If *C. circinalis* and *C. swamyi* discontinue their supply to these markets, the vendors will find other replacements. Therefore, I recommend the halt in supply of leaves from these two species. Additionally, bouquets for gifts are always based on trends set by the user communities. I recommend the initiation of urban awareness on the implications of using leaves from *C. circinalis* and *C. swamyi.*

On the other hand, for the pith markets I recommend sharing the results from these studies with vendors as well as Ayurveda and Siddha practitioners to highlight the importance of verifying that *vidari* originates from the original sources, *P. tuberosa* and *I. digitata*. This can also be achieved by spreading awareness in the user community about ensuring that the herbal medicine they are using is providing them with the required chemical constituents to treat the illness. This will help eradicating *C. circinalis* and *C. swamyi* pith fragments from the market altogether.

Contributions to scientific literature

This study is focused on resource use, ecology and indigenous knowledge which is critical not only for plant conservation, but for forest preservation as a whole. Although presently there are multiple studies on the impacts of harvesting NTFPs and population modeling as a statistical tool for conservation, there have been no studies that document the impacts of commercial harvest on cycads using Integral Projection Models (IPMs). This study focused an endangered cycad with small population size where using IPMs helped understand how slow-growing and long lived plans react to anthropogenic stresses over time.

Informal NTFP markets are a seriously understudied feature in NTFP use. Although we have global data on quantities of NTFP extraction, almost all documented material is restricted to export markets. Government records show that minor forest products contribute about 50 % of the Indian government forest revenue and 70 % of forest-based product exports (ICCF, 2005). This is an income equivalent of US$ 2.7 billion per year (Chauhan 2008) , but this information contributes to only 0.8% of what we know about NTFP use (Maithani, 1994). This study sheds light on the need for studying informal markets as it is a huge link between the harvest and use of NTFPs. Informal local markets located in rural areas account for the bulk of all NTFP sale (Arnold *et al.* 1994; Arnold 1998) and this information is essential to reiterate the view that a wide number of people from developing countries depend on NTFPs to sustain their livelihoods.

Traditional ecological knowledge has been reported to affect NTFP sustainability (Varghese & Ticktin, 2008) among communities across a landscape (Gaoue, Sack, & Ticktin, 2011; Varghese & Ticktin, 2008). My results contribute to this by illustrating how traditional ecological knowledge can enhance the sustainable use of resources but also how harvest can lead to unsustainable exploitation, even for a NTFP with high potential for sustainability such as *C. circinalis* and *C. swamyi*. This highlights the importance of conserving local ecological knowledge and emphasizes the need for adequate regulations for harvesting, where local ecological knowledge does not exist and/or economic pressures instigate unsustainable harvesting in spite of existing knowledge. Applied ecological research can help determine what parameters can be appropriate in establishing such harvesting regulations.

Limitations to this study

One of the major loopholes in this study is the lack of information from commercial leaf and pith harvesters. We were unable to contact harvesters to document the commercial harvest quantities and the harvest methods, which is critical to suggest sustainable levels of harvesting. Harvesters are elusive, even to the indigenous communities and possibly enter the forest in the early morning or late evening hours. A future Master's dissertation (Koulagi 2015, in preparation) will look into documenting leaf harvest with the harvesters in Melkote, Karnataka.

An important part of my study was to set up field experiments for germination studies. In this study, although intended, I was unable to study the germination rates of seeds from different sites because of complete harvest in seed harvested sites and lack of reproduction in leaf/historical pith harvested sites. With re-monitoring of *C. circinalis* and *C. swamyi*, I will have access to seeds and hope to conduct seedbank experiments as well as germination trials to understand if there are any bottlenecks in germination. Additionally, studies on pollination and seed dispersal are important aspects of cycad biology of which nothing is known in Indian cycads.

Future studies on the impacts of other disturbances such as fire, grazing, are needed to understand the ecosystem level responses to the growth of these plants. Longer term research looking at the trade-offs between plant survival, growth and reproduction informative in investigating the specific responses to disturbances.

The conflicts between local communities in protected areas and forest authorities were not directly discussed in the core of this dissertation, they were extremely important in shaping my research questions, field work and recommendations. By taking into account (i) local communities‘ management practices, (ii) the legislation related to protected areas, and (iii) the experiences and aims of protected areas managers, I wanted to produce scientific information that could inform management decisions and help the negotiation processes in these conflicts. To ensure that the results and recommendations I produced will actually be useful for the management of cycads and the Western Ghats, I plan to discuss my findings with different stakeholders in Kerala, Karnataka and Tamil Nadu.

Applied ecological studies can inform management practices, policy and decisions for conservation. For this to happen effectively, the results and applications of these studies need to be brought to multiple audiences, in a way that is appropriate for each context. Additionally, how these studies are conceived of and planned affects their potential to succeed in influencing management and policy. The receptivity of managers and local communities to apply research results is probably directly related to the amount of involvement these stakeholders have in the development of the study. The lack of involvement of managers in designing studies is thought to be one of the main reasons that the results of long-term research have failed to be directly applied in management of natural resources. Similarly, managers, policy makers and, especially, local communities must be involved in the research process if research-based recommendations are to be effectively incorporated into the sustainable management of natural resources.

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