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REPORT

Pillar of strength: Columnar cactus as a key factor in Yoreme heritage and wildland preservation

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Abstract The persistence of traditional cultures and modes of land use within rapidly changing, globalized societies is a central issue in understanding ecological and cultural change in the Anthropocene. Located in the heart of the Green Revolution, the Yoreme (Mayo) people of the Mayo Valley in Mexico still obtain a significant proportion of their sustenance from wild ecosystems in the midst of this intensive technological and agricultural development. They live in and around the thornscrub dominated by pitaya (*Stenocereus thurberi* (Engelm.) Buxb.). In this study, we hypothesize that pitaya supports Yoreme heritage and sustenance amidst anthropogenic changes to the landscape, and we asked three specific questions: What is the land-use status of the *S. thurberi* habitat? What are its potential uses? Does *S. thurberi* provide economic value? To address these questions, we conducted interviews, vegetation surveys, and land-use analysis based on geographic information systems. We found that (a) land conversion of the pitaya-rich thornscrub is occurring at a precipitous rate, (b) local producers preserve and adapt their traditions, and (c) *S. thurberi* supports Yoreme heritage while providing economic benefit. The resulting land-use projections along with the cultural value of pitaya products shows the importance of conserving land and promoting sustainable projects instead of clearing land for other uses. If habitat shrinking continues at the current rate, it is likely that both Yoreme livelihoods and continued cultural practices will suffer.

Keywords Ethnobotany · Land-use change · Pitaya · Sonora, Mexico · *Stenocereus thurberi* · Yoreme

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INTRODUCTION

The persistence of traditional cultures and modes of land use within rapidly changing, globalized societies is a central issue in understanding ecological and cultural change in the Anthropocene. Human-induced land-use changes, often referred to as the human footprint, affect biodiversity and ecosystem services (Sanderson et al. 2002; Butchart et al. 2010; Romanelli et al. 2015). These changes are noteworthy in Mexico, especially in southern Sonora and northern Sinaloa, where land development is widespread and often occurs side by side with ancestral traditions, practices, and surviving natural ecosystems (González-Abraham et al. 2015). One region where the interaction between traditional and modern systems is particularly strong is in the ancestral territory of the Yoreme people (Yetman and Van Devender 2002; Semotiuk et al. 2015). The Yoreme (often referred to as the Mayo) live in and around the transition zone from the Sonoran Desert into the Sinaloan thornscrub (Moctezuma Zamarrón and López Aceves 2007; Arizona-Sonora Desert Museum 2016). Here, the mechanized and large-scale farming operations of the Green Revolution are widespread (Nabhan 2012), while, at the same time, there persists a strong culture of plant and ecosystem use based on traditional knowledge and management practices in the region (Yetman and Van Devender 2002).

One peculiarity in the region is the contrast between the irrigated grain farms and the neighboring *pitaya*-dominated thornscrub. The pitaya (*Stenocereus thurberi* (Engelm.) Buxb., Cactaceae, also known as *pitaya dulce* to distinguish it from other columnar cacti as the one with especially sweet (*dulce*) fruits), or organ pipe cactus in English, is a dominant element in large remnant patches of native vegetation that sharply delineate the edges of cultivated grain fields.

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This candelabriform cactus branches profusely from the base, sending its arms up above the thornscrub canopy (Molina-Freaner et al. 1998; Búrquez et al. 1999). Along the ribs of these arms, white-funnelform flowers and, subsequently, spiny fruits form. The spines easily fall away from mature, red fruits that are of variable sizes usually between that of a golf and tennis ball (4–7 cm). The term *cereus* in its Latin name *Stenocereus* refers to the wax-taper form of the plant (Anderson 2001). The fruits of many species of the genus *Stenocereus* have been harvested in areas from the south to the north of Mexico (Pimienta-Barrios and Nobel 1994). The peculiar contrast of pitaya thornscrub alongside large-scale agriculture leads us to hypothesize the former presence of widespread ancestral stands of *S. thurberi* thornscrub on what are now large agricultural plots. The current patches of *S. thurberi* seem to be remnants of this larger matrix. It seems interesting to analyze the benefit and complementarity of both food production systems.

In this study, we calculate the rate of land-use change in the ancestral territory of the Yoreme people and examine possible social reasons as to why the change may have occurred, what uses these lands are turning into, and what potential botanical resources and uses are being lost. We hypothesize that *S. thurberi* supports Yoreme heritage and sustenance amidst anthropogenic changes to the landscape. The landscape changes affecting indigenous peoples around the world provide a strong rationale for investigating hypotheses along these lines (UN 2009). With these changes come changes in species available to cultures and many times these are vital for the stability of continued cultural practices (Garibaldi and Turner 2004). This study seeks to address this all too common happening around the globe to gain a glimpse of cultural resilience, supported by local flora, amidst outside pressures.

STUDY LOCATION

The Yoreme people settled along the banks of three main rivers, the Mayo, the Fuerte, and the Sinaloa ca. 1800 yBP, during the Mesoamerican Formative period (Berry 2001; Fig. 1). Their settlements took the form of scattered hamlets known as *rancherías* that depended on mixed hunter–gatherer and farming practices (Phillips 1989). Currently, the Yoreme still inhabit the area, which is now known for agricultural production from networks of irrigation canals (Banister 2011). Work is largely seasonal depending on harvest times in the fields and fishing seasons along the coast. Correspondingly, there are large gaps in conventional types of jobs. As a result, many people fill one of these gaps in May with the harvest of wild pitaya fruits. To the people of the *pitayal*, the birdsong of the *pipiski* or red cardinal (*Cardinalis cardinalis*; Russell and Monson 1998) signifies the start of the pitaya harvest (Consultant interview, pers. comm., January 26, 2015). These spiny fruits, botanically berries, are plucked off the tall columns with a long rod, often fashioned from an agave (*Agave* ssp.) scape, and collected into twenty-liter buckets. The yield depends on the weather conditions and pollination from bats (*Leptonycteris curasoae*), hummingbirds (*Cynanthus latirostris* and *Calypte costae*), and insects (Sahley 2001). The fruits' sweetness is highly dependent on rain. If there are a few heavy rains just before harvest, the fruits are less sweet than if there is no or little rain (Consultant interview, pers. comm., January 26, 2015).

The pitaya-dominated thornscrub lies in the heart of the ancestral land of the Yoreme (see the distribution map of Fig. 2). This site offers an ideal study area because of the visual prominence in the advancement of land development and the dependence local people have on seasonal work from *S. thurberi*. Seasonal rainfall in the area ranges from 200 to 400 mm with the heaviest rains in late summer around the month of August. Elevation from the coast slowly increases to about 100 m at the base of the Sierra Madre Occidental mountain range near the state line and then shoots to over 2000 m once inside the states of Chihuahua and Durango. Average annual temperatures range between 22 and 26 °C with summer highs often in the mid-40s and winter lows sometimes reaching a frost (INEGI 2003). With this low rainfall and high temperatures, farm crops must be heavily irrigated. The diversion of water around Sonora has been a major cause of contention historically and in recent years (Meyer 1996; Banister 2011; Radonic 2015). Interestingly, yields of *S. thurberi* are independent of irrigation and rely on seasonal rains.

MATERIALS AND METHODS

Interviews

Community members were interviewed about harvest, sale, and processing of *S. thurberi* fruits. Consultants for interviews were identified via the snowball method. For this, consultants could recommend others who were knowledgeable about pitaya and could potentially participate in interviews. These data were collected on field trips to southern Sonora and northern Sinaloa during January 7–31, 2015; May 10–August 28, 2015; and January 28–March 10, 2016 in Juchica and Sirebampo, Sonora. Seven adult consultants with three from Juchica and four from Sirebampo (four women and three men) were interviewed about land use and sale of pitaya.

Fig. 1 Yoreme ancestral territory estimated from current municipalities with Yoreme villages (Amarillas Valenzuela 2010; CDI 2010)

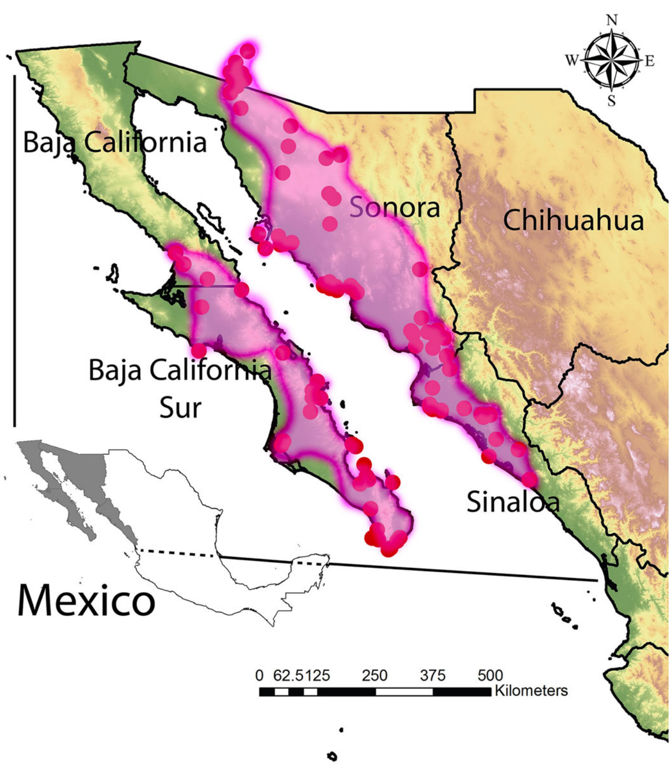

Fig. 2 Distribution of *S. thurberi*. The distribution follows low elevations around the coast of the Gulf of California and across the Sonoran Desert up into southern Arizona. Each point is a collection record taken from the GBIF Database (GBIF 2016)

Interviews took the form of one-on-one conversations while the investigator wrote notes in a field book. All interviews were conducted in Spanish with prior-informed consent and with pre-approval from the University of California, Riverside, Institutional Review Board (HS-14-103, HS-13-036) and followed the International Society of Ethnobiology Code of Ethics (International Society of Ethnobiology 2006).

Vegetation surveys

Vegetation surveys of the pitaya-dominated thornscrub were conducted using the vegetation cover survey method of Martin et al. (1997). This method is designed to measure vegetation in and around sites selected for nesting or other uses. We sought to measure the vegetation cover of *S. thurberi* at frequently used points of harvest identified by local consultants. This method measures vegetation cover at selected sites by sampling a central plot and three peripheral plots 50 meters away from the central plot and separated by 120° from each other. The angle of the first peripheral plot was randomly chosen by dropping either a spinning arrow or a pencil on the ground to randomly assign the direction of the plot. Each survey plot was 11.3 m in radius around its central point, corresponding to 401.1 m^2 (approximately one tenth of an acre). All individual plants of *S. thurberi* were counted within each plot and categorized as mature (over head height and with multiple branches), intermediate (greater than one meter) or immature (less than one meter).

In each of three actively harvested sites, we marked four circular survey plots as described above. In addition to counting plants in harvested areas, we also repeated the procedure at three randomly selected sites to compare species density in sites selected by traditional harvesters with randomly selected sites. Randomly selected sites were assigned by generating a random assortment of longitude and latitude coordinate pairs. All pairs that landed inside the pitaya thicket near Sirebampo, Sonora (N26°38′24.37″, W109°14′13.14″) were included, while those that landed outside, on a zone such as a road or waterway, were not surveyed. All herbarium specimens collected during vegetation surveys were collected under the appropriate collection permit (SEMARNAT, permit number FAUT-0265) and deposited in the University of Sonora Herbarium (USON24030 and USON24031).

Because plant density is a frequency count, we tested the difference between harvest sites and randomly selected sites by means of a X^2 test using a log-linear model with the number of plants at each plot as a dependent variable and harvest type (harvested vs. randomly selected) as a predictor. The analysis was done using the R programing language for statistical computing (R Core Team 2013).

Land-use analysis

Land classification data were downloaded as digital vector files from the website of Mexico's National Institute of Statistics and Geography (Instituto Nacional de Estadística, Geografía, e Informática—INEGI) at www.inegi.org.mx. Data came in the form of shape files (*.shp) at a scale of 1:1 000 000 and 1:250 000 for the years 1996 and 2011, respectively. The land classifications were categorized into natural or induced land cover where the "natural" category included all areas with native vegetation and without farming, mining, or urbanization, while the "induced" category included all areas where the native vegetation cover has been lost such as farms, mines, or urban sites. The shape files were projected into ESRI World Cylindrical Equal Area projection, intersected with Mexican municipal boundaries, and the area of each polygon was calculated to determine the area of land-use change. The resulting areas were used to calculate the percent of land-use change using the rate equation $\text{Rate} = (1/A) \times dA/dt$, which can be approximated as a finite difference equation $\text{Rate} = \ln(A_1/A_0)/(t_1 - t_0)$. Further, predictive maps of land cover scenarios were created based on the 2011 land cover and the land conversion rates over the past 15 years. The analysis was done using ArcGIS software (ESRI, Redlands, California, U.S.A.) and Microsoft Excel (Seattle, Washington, U.S.A.) for map algebra operations. The full protocol is available as supplemental material (Protocol S1).

RESULTS

Stenocereus thurberi uses

To determine the potential role of *S. thurberi* in being a part of Yoreme life, culture, and sustenance, we examined the current harvest practices and uses of the fruit. The most apparent use is direct sale at local markets. People harvest fruit into twenty-liter buckets, carry them to the nearest highway, and transport them by bus to larger town centers such as Navojoa and Etchojoa. We further examined local value-added marketing strategies and the current value-added products made from this fruit. We present a list of products in Table 1 and representative photographs in Fig. 3. Historically, winemaking with pitaya was common with local Yoreme and other tribes such as the Comcáac (Seri), but the practice has been diminishing since the latter part of the twentieth century (Felger and Moser 1985; Yetman and Van Devender 2002), and it was not mentioned during our fieldwork.

Table 1 Pitaya uses for food and value-added products. Prices are given in value of 2016 Mexican pesos with the US dollar equivalent given in parenthesis and rounded to the nearest ten-cent unit. Some local vernacular of the region includes the popular *coyota*, which is a thin, round, fruit-filled pastry with a flaky crust. *Empanadas* are also a fruit-filled pastry, but with a thicker filling. Pitaya water is made by mashing fruit in a pitcher of water, and as the pulp settles the sugars and flavors dissolve to create a refreshing drink. Pitaya paste is the precursor ingredient for many items on the table including fillings and also dried fruit rolls and dehydrated pitaya. The fruit rolls are individual servings, while the dehydrated pitaya is sold by the gram in larger quantities

Product	Maximum price (MXN)	Minimum price (MXN)	Unit size
Coyotas	15 (90¢)	10 (60¢)	2 pastries
Marmalade	200 ($12.00)	100 ($6.00)	~400 ml
Candied fruit with chile	10 (60¢)	5 (30¢)	1 piece
Pitaya water	5 (30¢)	5 (30¢)	~200 ml
Dried fruit rolls	30 ($1.80)	20 ($1.20)	15 × 25 cm
Dehydrated pitaya	400 ($24.00)	400 ($24.00)	100 g
Pitaya sorbet	5	5	1 scoop
Empanadas	5	5	1 pastry
Nursery stock		20	1 starter plant
Milk shake	Not sold		
Pitaya with cream	Not sold		
Yogurt	Not sold		
Paste	Not sold		
Firewood	Not sold		
Roof and wall paneling	Not sold		

Stenocereus thurberi density

Because the pitaya harvest sites must be selected by the harvester, vegetation surveys were conducted to measure the density of *S. thurberi*. The mean density in human-selected harvest sites was 450.8 (SE $\pm$ 41.7) plants per hectare and the density in randomly selected sites (as described in the materials and methods) was 652.3 $\pm$ 75.7 plants per hectare (Fig. 4). The number of mature plants in harvest sites (280.4 $\pm$ 33.0) was lower than the number of mature plants in randomly selected sites (423.8 $\pm$ 64.8), and the difference was highly significant ($X^2 = 14.1$, *d.f.* 1, $P < 0.0001$). The same trend was maintained in intermediate and immature plants (81.0 $\pm$ 20.0 and 89.3 $\pm$ 39.6 in harvest sites vs. 118.4 $\pm$ 21.9 and 110.1 $\pm$ 11.0 in randomly selected sites), but the differences were non-significant.

Land-use change

In the 15-year period studied (1996–2011), the conversion of land from wild areas to developed agriculture or urban areas considered in our study had the highest rate in the area of the pitaya-dominated thornscrub (Figs. 5, 6). The rate of wildland loss reached over two and a half percent per year (Table 2).

Land-use change purposes

We asked local consultants for what purposes land clearing was occurring. The responses varied over a range of uses including seeding of invasive buffel grass (*Cenchrus ciliaris* L. [=*Pennisetum ciliare* (L.) Link]), dryland agriculture, development subdivisions, aquaculture, and clearing for irrigated agriculture (Table 3). With the exception of irrigated agriculture and land subdivision, all other induced land uses were abandoned. These developments are driven largely by non-Yoreme investors such as regional realtors or industrial farm developers. The investments may or may not have paid during the term of their use, but it is sure that the recovery of *S. thurberi* stands, if it ever occurs, will take many decades.

Future projections

In order to gain perspective of human conversion of land, we projected current land-use change rates into the years 2030 and 2050 to show future scenarios of natural lands given the rate of land conversion over the last 15 years. These projections along with the 2011 percent cover of natural lands are displayed in Fig. 7.

DISCUSSION

Stenocereus thurberi supports the function of the thornscrub of the Yoreme ancestral territory as productive land. In the present study, we examined the interaction of people, *S. thurberi*, and land-use choices. This study offers three findings: (1) Land conversion of the pitaya-dominated thornscrub into other, induced and often non-renewable, land uses is occurring at a much higher rate than in other ecosystems of the region. (2) Local producers preserve and adapt traditions making value-added products from the native pitaya. (3) *S. thurberi* supports Yoreme heritage and provides economic benefits to traditional community members.

Interestingly, *S. thurberi* density in human-selected sites was lower than in randomly selected sites, suggesting that site selection is influenced by factors other than density of the resource, such as accessibility, quality of the fruit, or

Fig. 3 The usefulness of *S. thurberi* can be seen in its versatility. Photos show the species' use in value-added, marketed products. **a** Nursery stock of young *S. thurberi* for sale. **b**, **c** Coyotas made with *S. thurberi* fruit pulp. **d** Brick oven fired with *S. thurberi* firewood to bake pitaya coyotas. **e** Kitchen constructed with roofing and walling of *S. thurberi*

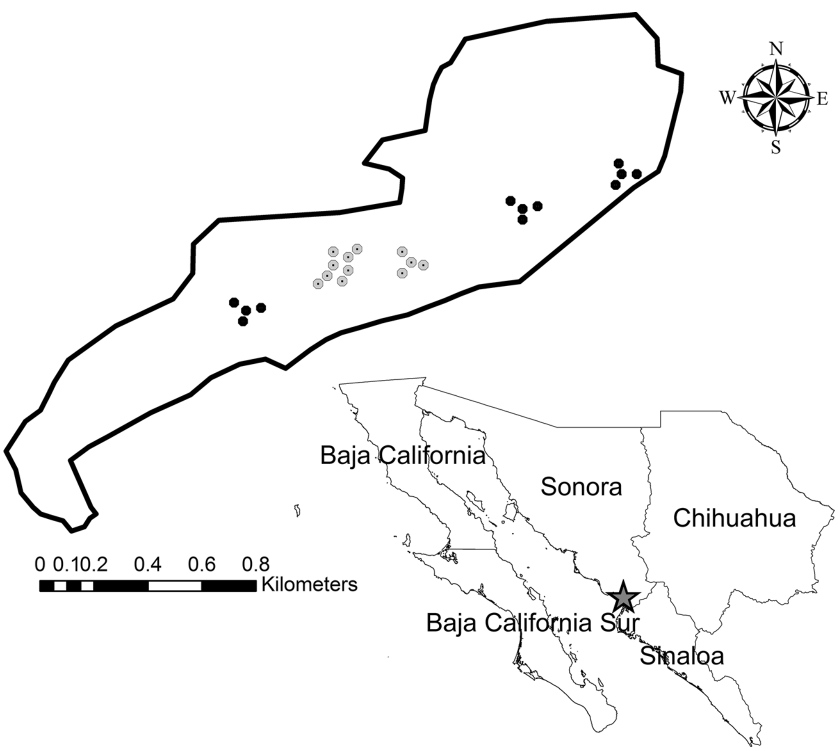

Fig. 4 This map shows vegetation survey plots of *S. thurberi* in human-selected sites (*gray*) and randomly selected sites (*black*). The boundary shows the main expanse of *S. thurberi* north of Sirebampo, Sonora

Fig. 5 Contrasting land uses become apparent when one observes fields side by side. Just outside Agiabampo, Sonora (near the border with Sinaloa), grain fields and stands of *S. thurberi* meet. **a** Stands of *S. thurberi*. **b**, **c** Contrasting lines between fields of *S. thurberi* and grain fields

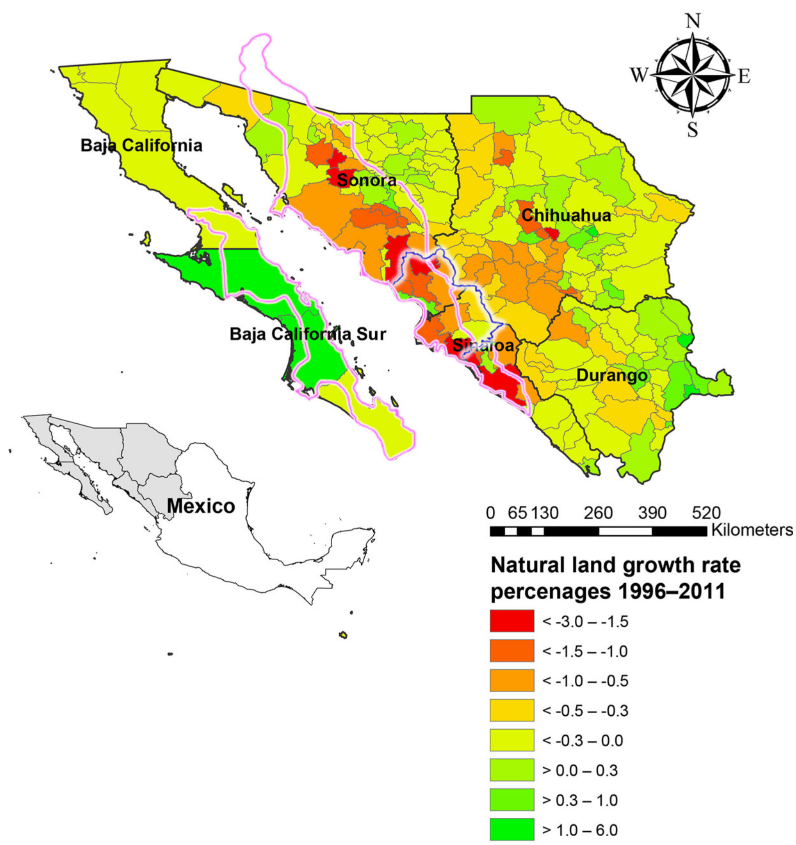

Fig. 6 Many of the highest land conversion rates in northwestern Mexico are occurring in the ancestral land of the Yoreme and the habitat for the pitaya-dominated thornscrub. The *radiant blue outline* shows the ancestral Yoreme territory and the *pink outline* shows the distribution of *S. thurberi* as per GBIF database records

Table 2 Land conversion rates of municipalities in the distribution range of *S. thurberi*. These municipalities lie in and around the Yoreme ancestral territory

State	Municipality	Undeveloped land loss rate (% loss per year)
Sonora	Quiriego	1.93
Sonora	Cajeme	1.74
Sonora	Etchojoa	1.32
Sonora	Navojoa	1.31
Sinaloa	Guasave	2.61
Sinaloa	Angostura	1.73
Sinaloa	Culiacán	1.61
Sinaloa	Ahome	1.45
Sinaloa	Salvador Alvarado	1.38

Table 3 Land conversion purposes

Use	Status	Note
Community pasture	Abandoned	Overgrazed non-native grass
Chiltepín (*Capsicum annuum* var. *glabriusculum*) plantation	Never completed	No secondary pitaya growth
Dryland garbanzo	Abandoned	Construction of road blocked drain water
Vacation lots	Under construction	No cacti left on lots
Shrimp aquaculture	Abandoned	Chose least ecological impact area
Irrigated agriculture	Active wheat crops	Production with irrigation

cultural traditions. Although harvested sites have similar recruitment as randomly selected sites (indicated by the non-significant differences in immature and intermediate plants), traditional harvesters seem to actively search for more open sites within the thornscrub, with less dense formations of mature pitayas, possibly because these sites allow for easier movement during harvest operations. In any case and at a larger scale, pitaya patches are dwindling rapidly in all areas.

If habitat shrinking continues at the current rate, it is likely that both livelihoods and continued cultural practices will suffer. The loss of habitat signifies a loss in ecosystem services (Romanelli et al. 2015). Unfortunately, the growth of columnar cacti such as *S. thurberi* progresses at a slow rate with a long regeneration time (Drezner and Lazarus 2008). This slow regeneration time is hindered even more by rangelands being seeded with invasive grasses such as *C. ciliaris* (Van Devender et al. 1997; Búrquez and Martínez-Yrízar 2000). Even if cacti are spared during creation of rangelands, they have been shown to be driven to local extirpation as was the case with the columnar *etcho* cactus (*Pachycereus pecten-aboriginum* (Engelm. ex S.Watson) Britton & Rose) in sites north of our study area (Morales-Romero et al. 2012). This creates a troubling scenario where local cattle producers feel the need to create "productive" rangeland in a way that hinders the productivity of local vegetation. It is a complex interaction with no clear solution (Vasquez-León and Liverman 2004).

The main causes of land-use change can be understood in the context of Mexico's shifting land ownership policies. The most notable of these was the establishment of the *ejido* or communal land system established by President Lázaro Cárdenas (1934–1940). This system allowed farmers to use and manage land that could never legally be bought, sold, or leased. President Carlos Salinas de Gortari (1988–1994) modified the system to allow individual ejido members to sell their land, bringing a long wave of parcels changing ownership that opens the door for new investors with ideas on some new land use. Along with these changes, such as increased fencing, come impediments of access to resources that are still under communal ownership. This seems to be increasing the economic troubles of farmers and ranchers as opposed to helping them (Yetman 2000). With private investment and decreased overall economic ability, it is attractive for remaining ejido members to take advantage of anything that may provide a source of income. This, along with an increasing cattle market in Mexico (Peel et al. 2012; FIRA 2015), can be a large motivator driving land clearing for pasture, *chiltepín* plantations, or sale of land to developers and vacationers. As a result, larger investors currently accumulate parcels in the hopes of developing large tracts of land and, in this competitive environment, local producers of pitaya products take advantage of low-input and sustainable fruit production to the benefit of their family income and environment.

Unfortunately, the ideals of short-term profit often clash with the vision of long-term conservation. This, combined with the scarcity and cost of irrigation water in the area, gives a meager outlook for land clearing endeavors. Further, induced ecosystems such as non-native grasslands can prove very profitable one year and fail completely the next, or catch fire during drought, potentially leading to more native habitat loss. All the while, native thornscrub can survive and even maintain some productivity during dry years.

The productivity of *S. thurberi* takes many forms. The most predominant products in our study were value-added products from the fruit. Some studies have found that profits from harvest of wild plant products can be a highly volatile proposition (Arnold and Pérez 1998), but

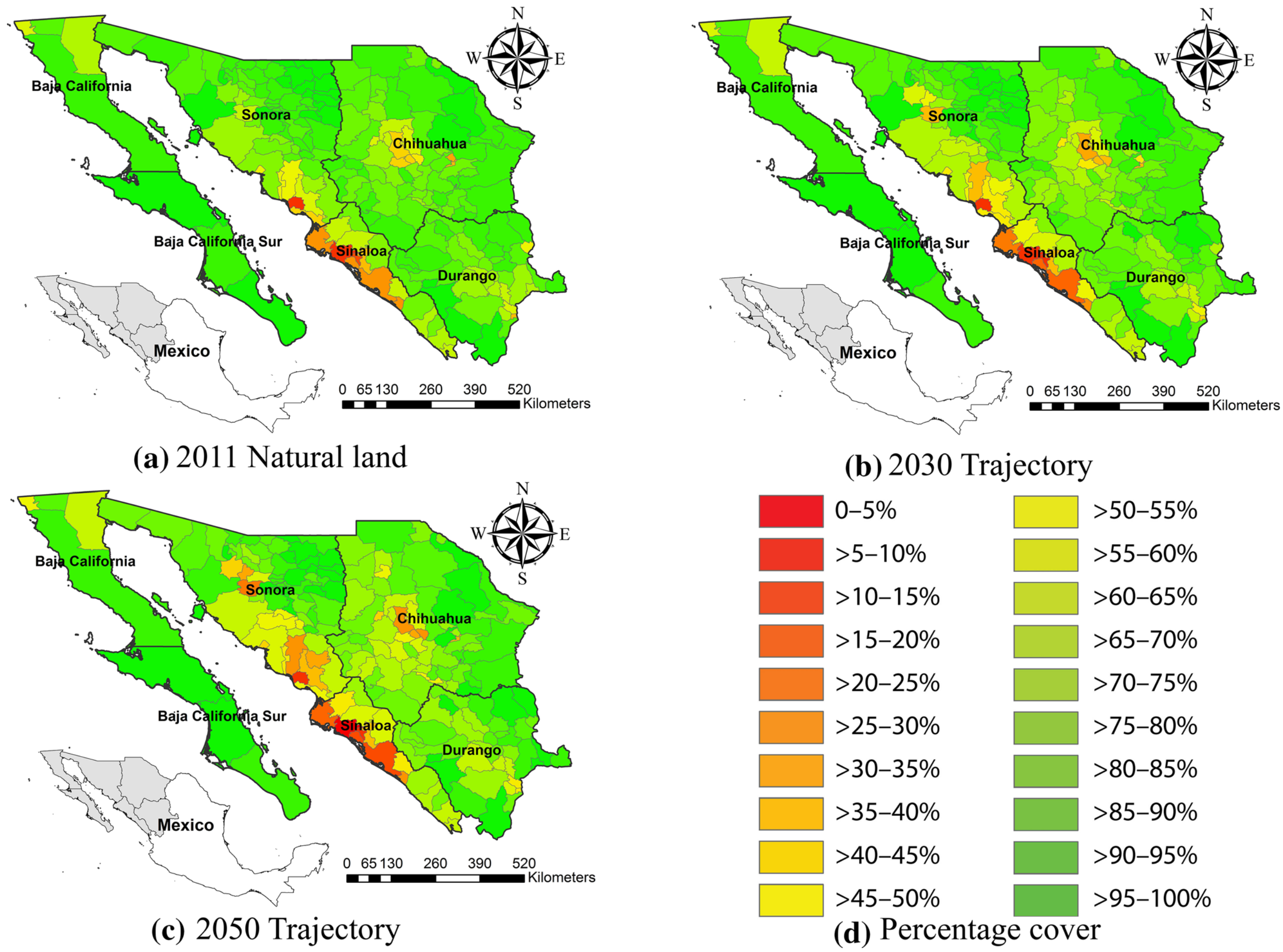

Fig. 7 Maps display the percent cover of natural lands per municipal area. The 2011 map displays the most up-to-date data on land cover, while the 2030 and 2050 maps show the projection of land cover trajectories based on land conversion rates for the last 15 years

others demonstrate that this challenging industry has the potential to give good profit margins (Belcher and Schreckenberg 2007; Tugume et al. 2016). Perhaps, the most assuring observation on local harvesters is not the promise of income, but that wild plant products provide a valuable safety net of food and basic necessities for economically disadvantaged families (Shackleton and Shackleton 2004). In and around the pitayal, families can taste and sell the sweet fruits of their labor without the need for high-cost inputs such as irrigation, pesticides and herbicides, tillage (expensive for annual crops such as wheat), and bank financing (usually not available to the Yoreme). It is, without a doubt, an extremely low-input crop (Mizrahi et al. 1997) that local villagers can and do benefit from.

Local villagers have been picking pitaya from time immemorial, but this is not to say that their traditions continue unchanged. Almost a century ago in 1932, Beals (1932) described shifts and changes in Yoreme culture. Later research showed preservation and evolution of Yoreme traditions (Valenzuela 1992). Our results suggest that culinary practices with pitaya fruits are adapted to current market demands. Further, these may lead to economically significant products available only if current cactus stands are preserved.

Taken together, we propose that stands of pitaya-rich thornscrub play a valuable role in Yoreme culture, heritage, and economics. Further, destruction of this valuable monetary and cultural resource shows little gain compared to the benefit it currently, and potentially, produces for local citizens and the region as a whole.

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