


CONSERVATION SCIENCE IN MEXICO'S NORTHWEST

ECOSYSTEM STATUS AND TRENDS IN THE GULF OF CALIFORNIA




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LIVING AT THE EDGE: THE BLUE FAN PALM DESERT OASES OF NORTHERN BAJA CALIFORNIA

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Plant species living at the limits of their distribution are likely to be particularly affected by climate change, and it is in these areas where significant plant variation, adaptation and migration usually occur. Information on the current processes that control the ecological dynamics of relict palm populations at the limit of their northwestern distribution in America is poorly known. We provide summarized information on what we know about the ecology of blue fan palm oases in the northern deserts of Baja California, and on the underlying mechanisms driving palm establishment and distribution in these highly fluctuating ecosystems. Since such riparian ecosystems provide vital ecological services for human and nonhuman life, the identification of these processes is critical to preserve biodiversity and water availability in the Central Desert in the face of ongoing environmental change.

1. INTRODUCTION

Plants living at the edge of any habitat are elements for the formulation of multiple questions for ecological investigations such as, why limits occur where they do? and how do marginal plant communities respond to them? Several disciplines such as, biogeography, demography, macroecology, reproductive biology, physiology and genetics should be integrated to provide adequate answers to these questions recognizing that ultimately, margins management depend on the manner of human perception on the nature of variation of plant populations. Marginal areas have experienced climatic changes in the past and, therefore, species living in these areas may be pre-adapted to such changes making them relevant in the study of species responses to fluctuating environments. In a scenario of a warmer world it is highly probable that changing climatic conditions will have a marked effect on plant geographical distributions, their responses to environmental alterations, particularly in marginal areas that withstand human exploitation. Thus, current interests in climate change have prompted different research projects into plants living at the margins (Crawford 2008).

Boundaries provide an interesting opportunity for observing limits to plant species survival, in the sense that these are not merely controlled by the impact of average probability of adverse climatic conditions, but also by the competition from other species and by the frequency of extreme events, such as drought, flooding, and freezing, which have been occurring for decades, centuries, or even millions of years ago, creating complicated patterns of distribution (Crawford 2008). At a more local scale, individuals at the margins of populations may be exposed to special spatial features influenced by their relationships with their neighbors which include a variety of factors such as pollen dispersal, seed production, gene flow and the availability of potential sites for establishment. Many of the adaptations that allow plants to live at the margins have evolved as means of overcoming limited access to resources; and one of the most common solutions is to reduce the energy demand or what is known as the *Montgomery effect* (Montgomery 1912), which states that in areas of low environmental potential, ecological advantage is conferred by low growth rates. Plant species in marginal habitats with fluctuating environments frequently show a high degree of polymorphism and provide a number of distinct ecotypes, described as a *balanced polymorphism,* that confer immediate fitness by increasing the ecological tolerance of the species as a whole (Crawford 1997). Examples of this phenomenon are visible in places where the constant risks of disturbance and environmental stress maintain a pronounced degree of polymorphism in plant populations (Crawford 2008).

Demographic limits to plant distribution include those factors that adversely affect recruitment or increase mortality. Demographic factors influencing plant distributions are not the property of species or populations, but are instead a function of habitat and location (Antonovics *et al.* 2001). The principles of *Island Biogeography* (MacArthur and Wilson 1967), that relate species numbers on islands to an equilibrium, clearly illustrate the necessity to consider the nature of the habitat and how it modifies recruitment and mortality rates, particularly at population margins where opportunities of recruitment and the hazards of extinction are different from core locations in demography studies. Between the factors that influence recruitment and mortality, the soil seed bank has its own demographic dimension, with embryos that lie dormant in the soil until there is an opportunity for them to germinate. Disturbance is included in demography since it affects both recruitment and mortality, and can have negative effects as it can destroy plant biomass and/or positive effects by providing new spaces for colonization or by aiding diversity through limiting the extent to which any species can permanently dominate a habitat. In this sense, plants that can withstand frequent and severe physical disturbances (*ruderals*) are expected to have been selected for an optimal set of characteristics including, size, growth pattern, resource storage, and reproductive strategies.

2. PALM SPECIES OF NORTHAMERICA'S NORTHWEST: THE DISTRIBUTION LIMIT OF A RELICTUAL VEGETATION

During the Cretaceous and Tertiary periods, and also during post-glacial times a particular flora was widely distributed in North America, approximately up to 65 degrees of latitude (Sankey *et al.* 2001). Woodrat (*Neotoma*) middens that contain remains of plants, invertebrates, and vertebrates have been used as a tool for tracking climate/vegetation changes and for the reconstruction of the past environments and climates (Wells 1976, Betancourt *et al.* 1990). A particular study in Baja California documented past relative plant abundances and distributions that were different from the modern ones (Sankey *et al.* 2001). Apparently, soil development on boulder surfaces and a relatively more mesic climate in this Peninsula, allowed plants to expand into marginal habitats. As the climate gradually turned out dry and hot at the end of the Miocene (12 million years ago), the vegetation restricted to the riparian habitats (Betancourt *et al.* 1990, Sankey *et al.* 2001, Wehncke *et al.* 2012b).

In the Central Desert region of Baja California vegetation patches from an ancient paratropical flora (Peñalba and Van Devender 1998), are found today as isolated climatic relicts on mountain tops and along canyons that still conserve wet conditions. Dominated by the blue fan palm, *Brahea armata*, these remote oases depend on intermittent water courses, and consequently on highly variable climatic conditions. In turn, they provide particular microclimatic conditions that support contrasting biotic communities and offer fundamental ecological services (Wehncke *et al.* 2009, 2010, 2012a, 2012b).

These palms correspond to the group of the Coryphoids, one of the five monophyletic groups (subfamilies) of the family Arecaceae (Bjorholm *et al.* 2005). While most palm lineages are currently widespread in the tropical and subtropical regions of the world, in congruence with the traditional association of the family with warm and moist climates, the geographical pattern of coryphoid species richness still seems to reflect its ancestral history, exhibiting a strong bias toward Central and North America (Corner 1966, Bjorholm *et al.* 2005, 2006). According to Bjorholm *et al.* (2006), coryphoid species richness seems to be least strongly controlled by the modern environment, but instead influenced by historical and regional factors. The endemic blue fan palm seems well adapted to this fluctuating environment, coping well with extreme aridity, summer heat, high direct solar radiation, and freezing temperatures (-12ºC, www.floridata.com) with only minor foliage damage. Age estimates, using repeat photography methodology suggest a potential longevity that exceeds 500 years (Bullock and Heath 2006).

In the Central Desert, where many organisms live at or very near the threshold for surviving climatic extremes, the availability of oases with palm fruits arranged in patches and interspersed along canyons is critical for human and non-human subsistence (Wehncke *et al.* 2009, 2012b). Since palm oases are distributed as distinct patches in space and time, seed dispersal and post-dispersal seed predation processes both within and between oases are of great demographic importance (Wehncke *et al.* 2009). Likewise, because the seed dispersal syndrome of blue fan palms fruits seems to correspond to endo-zoochory probably performed by the now extinct Pleistocene mega-fauna (R. Felger, pers. comm.), their spatial distribution and ecological interactions with the present-day fauna are important elements in understanding the recruitment patterns of this species near the northern limit of the family's distribution in western North America (Wehncke *et al.* 2009, 2010). Commonly dominated by plants that live for decades and even centuries (Vasek 1980, Turner *et al.* 1995, 2003), the underlying mechanisms of desert vegetation dynamics are generally difficult to study (Whitford 2002).

3. ECOLOGICAL ASPECTS OF DESERT OASES ECOSYSTEMS

Spatial patterns in many desert plant populations and communities derive from the interplay of abiotic factors and of positive (facilitation) and negative (competition, predation, herbivory) biotic interactions (Callaway 1995, Miriti *et al.* 1998, 2001). Frugivory, seed dispersal, and seed predation processes may affect the resulting recruitment patterns and the ecological dynamics of plant populations (Jordano 1995, Herrera 1998, Thompson 2002). In addition to the biological processes, the physical structure of a system has its own spatial characteristics (Dungan *et al.* 2002), which influence palm population density and distribution (Wehncke *et al.* 2010). For example, flood regimes in rivers of arid regions determine groundwater conditions, therefore declines in flood intensity and frequency may change abiotic and biotic conditions within a floodplain, homogenize seed banks, and drive patch dynamics (Pickett and White 1985) producing well-defined vegetation patterns (Stromberg *et al.* 1996). The presence of surface attributes, rocks and soil properties are key elements in shaping water, nutrient, and seed fluxes that influence ecosystem structure

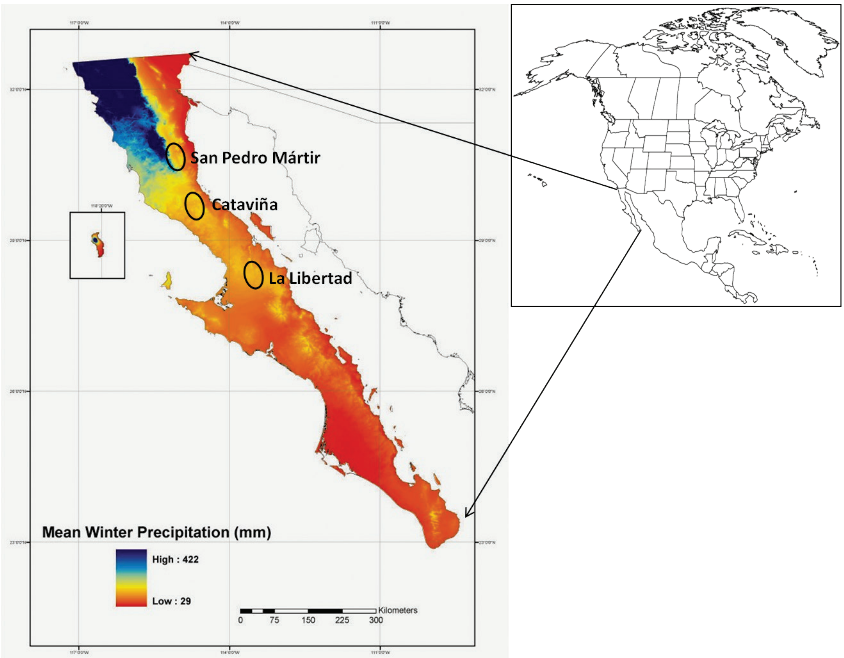

FIGURE 1. Location of study sites (San Pedro Mártir, Cataviña, and La Libertad) in northern Baja California, Mexico.

and dynamics (Poesen and Lavee 1994, Aguiar and Sala 1999, Maestre and Cortina 2002). Blue fan palm desert oases are probably one of such fluctuating environments in which seeds may be dispersed in two or more "phases", with different sets of dispersal agents involved on each one.

4. UNDERLYING ECOLOGICAL PROCESSESS AND PALM DISTRIBUTION PATTERNS

Here we summarized what is known about the ecological processes underlying the current distribution and structure of blue fan palm populations forming oases (Wehncke *et al.* 2009, 2010) in three mountain washes separated from each other approximately 200 km in a straight line (San Pedro Mártir [SPM]; Cataviña [CAT], and La Libertad [LL], see Figure 1). In each of these sites we established four plots of approximately 1ha in size (200 x 50 m) that constitute patches of vegetation along the canyons. We considered that each site represents a different population since the distances between plots were >30 m, but <3 km apart. Phytogeographically, the sites are found in two different subdivisions of the Sonoran Desert: the San Pedro Mártir site is located within Forrest Shreve's (1951) Lower Colorado Valley, while Cataviña and La Libertad are located within Shreve's Vizcaíno Region, also known as the Central Desert of Baja California. Sierra San Pedro Mártir is composed of large granite blocks that drop off sharply toward the eastern desert floor below. A number of east-flowing streams run along the escarpment fed by water collected as ice and rain in the higher elevations during the moist and cold winter months. Cataviña and La Libertad, are part of the Natural Protected Area Valle de los Cirios and are located on the Pacific slope of the Baja California ranges having a more tropical climate influence.

We used the actual spatial distribution of plants to explore the underlying processes that regulate plant populations and structure communities (*e.g.*, Greig-Smith and Chadwick 1965, Connell 1971, Janzen 1971, Wright and Howe 1987, Wehncke *et al.* 2010). We explored the importance of post-dispersal seed removal by vertebrates, recruitment, and distribution patterns of the blue fan palm in these canyons by evaluating (i) the levels of palm seed removal by vertebrates at two spatial scales and the initial fate of dispersed seeds, (ii) the spatial distribution and association of seedlings and adults at two spatial scales, (iii) seed removal levels and seedling densities based on density and distance to adult palm trees, and (iv) the age structure of the population (Wehncke *et al.* 2010). Although it is known that rodents and other seed-eating animals are abundant in deserts, we found that overall, levels of post-dispersal seed removal were low in all study sites (in 78% of cases, seeds were found intact, 7% corresponded to cases in which one half of the seeds was removed, and 15% to cases where both seeds were removed, N = 56). In general, postdispersal seed predation by vertebrates did not have a significant effect on blue fan palm establishment. However, small rodents and invertebrates were identified to be responsible for most of the blue fan palm seed removal/predation in this ecosystem (see Table 1). This is congruent with the absence of large vertebrates that could predate such hard seeds. Anachronistic traits still remain in blue fan palms, such as the spines along the petiole of the leaves representing defenses against non-existent browsers as well as, fruits and seeds that accumulate below trees that seem also unfit to the living fauna. Janzen (1986) suggested that after the megafauna extinction, plant species would contract to monospecific stands, each surviving only where habitat conditions are suitable and where it is not exposed to resource competition from others.

Spatial variation in seed removal levels by rodents was significant at regional but not at local scales, and this agreed with our expectations that seed predator communities may diverge in accordance with regional climate and biogeography (Lawlor 1983). However, since we registered similar species compositions of seed removers

TABLE 1. Vertebrate blue fan palm seed predator species registered during the studied period, in northern oases of Baja California, Mexico. Study areas: San Pedro Mártir (SPM), Cataviña (CAT), and La Libertad (LL). Sizes of seed predators (total length in millimeters): *Reithrodontomys*: (135–154; 64–85), *Peromyscus*: (220–285; 117–156), *Neotoma*: (225–383; 95–185), *Dipodomys*: (234–259; 135–161), *Perognathus*: (110–115; 53–83), *Chaetodipus*: (136–182; 70–103), *Tamias*: (208–240; 71–120), *Ammospermophilus*: (210–240; 71–83), *Spermophilus*: (357–500; 145–200).

Family	Species	SPM	CAT	LL
Muridae	*Reithrodontomys megalotis*	x	x	x
	Peromyscus californicus	x		
	Peromyscus eremicus	x	x	x
	Peromyscus eva			x
	Peromyscus fraterculus	x	x	x
	Peromyscus maniculatus	x	x	x
	Peromyscus truei	x		
	Neotoma lepida	x	x	x
Heteromyidae	*Dipodomys agilis*	x	x	x
	Dipodomys merriami	x	x	x
	Perognathus longimembris	x	x	
	Chaetodipus arenarius	x	x	x
	Chaetodipus formosus	x	x	x
	Chaetodipus penicillatus	x		
	Chaetodipus rudinoris	x	x	x
	Chaetodipus spinatus	x	x	x
Sciuridae	*Tamias obscurus*	x	x	
	Ammospermophilus leucurus	x	x	x
	Spermophilus beecheyi		x	
	Spermophilus cf. atricapillus		x	x
Total species		**17**	**16**	**14**

at the three sites (see Table 1), we suggest that regional differences in postdispersal seed removal and seed fate might rather result from distinct removal activity and behavior at each site as a result of differences in the physical characteristics of the three canyons. This also agreed with other studies that suggest that spatial variation in seed predation may arise because some habitats, irrespective of seed availability, are more suitable for certain granivores than others (Hulme and Benkman 2002). The distinct geomorphologic characteristics of each of the studied canyons, as well as the distribution of the vegetation cover, have the potential to affect post-dispersal seed removal activity by rodents and/or birds. One of our study sites, Cataviña, was characterized by wide canyons with less coverage of understory plants and/or rocks, providing rodents with limited hiding places, thus making them more visible and susceptible to predation. Such effect has the potential to restrict rodent movement patterns, and consequently their seed removal activities. Cataviña also showed the lowest seed removal values (see Figure 2a), though most of the seeds removed disappeared or were considered dead. The fate of removed seeds was significantly different among the three study sites (see Figure 2b). Frequently fewer seeds are removed from open microhabitats (Myster and Pickett 1993, Hulme 1997), and this appears to occur when rodents are the principal granivores, since their abundance is positively associated with vegetation cover (Hulme 1993). Seeds were removed from 0.5 up to 20m from the stations at La Libertad and from 0.5 up to 13m at Cataviña, 1m being the most frequent removal distance at both canyons (see Figure 2b).

Seedlings tend to establish near adults and their densities decline with distance from the adult palm (see Figure 3a, b) a tendency which was significant in all sites. In contrast, seed survival showed no significant association with adult densities or distance to the nearest neighbor adult plant, showing no variation in differential survival attributable to distances to adults (Wehncke *et al.* 2010). Based on this and the overall low levels of blue fan palm seed removal by vertebrates found in all sites, it seems that current post-dispersal seed removal by vertebrates does not have a significant effect on the establishment of the blue fan palm. A similar pattern emerged when using a Spatial Analysis by Distance Indices methodology (Wehncke *et al.* 2010). The weak positive association between seedlings and adults at the whole 'patch' level simply indicates that establishment tends to occur in or near those places where adults have already established successfully. More important, however, was that the analysis showed a negative association between seedlings and adults at the individual tree ('within the patch') level, indicating that within places where growth is most successful seedlings established preferentially in relatively open spaces. Their apparent affinity at the scale of the whole patch is probably caused by their co-occurrence in particular patches where local conditions are more suitable, possibly related to water availability.

The three blue fan palm populations studied showed marked regional differences in adult densities and distributions (adult densities: AD, and nearest-neighbor distance: NND, were used as measures of adult distributions and were found to be significantly different among sites, but not significant among plots nested within

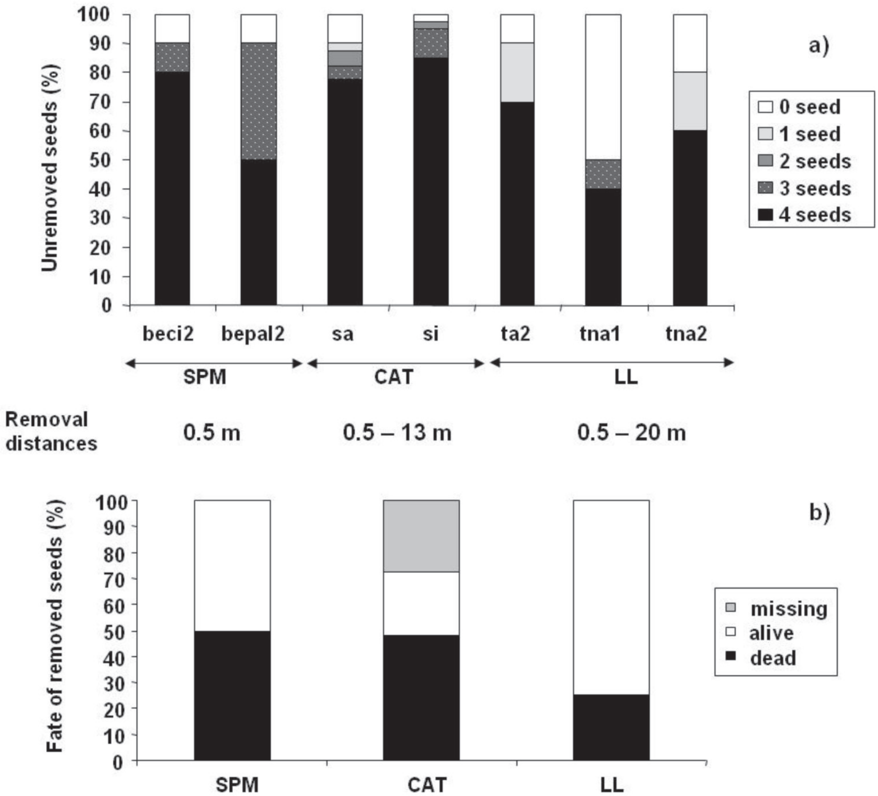

FIGURE 2. Patterns of seed removal: (a) percentages of cases with zero, one, two, three, and four seeds left at each site and plots within sites. San Pedro Mártir (SPM) included beci2 and bepal2 plots, Cataviña (CAT) included San Antonio (sa) and Santa Inez (si) plots, and La Libertad (LL) included ta2, tna1, and tna2 plots; (b) range of distances (meters) of blue fan palm seed removal by vertebrates (using the method of colored threads) and percentage of cases in which removed seeds were missing, dead or alive in each site.

sites (see Wehncke *et al.* 2010). Cataviña had the lowest AD and the highest NNDs measured from randomly placed points; La Libertad represented the intermediate case; and San Pedro Mártir showed the highest ADs and the most aggregated adult palm distribution (see Figure 3a, b). In contrast with adult distributions, seedling densities were only marginally different among populations or sites, but markedly different among plots within sites (Wehncke *et al.* 2010). This may reflect a more local dependence of seedling establishment on the different canyon physiography at each site. In arid and semiarid climates, and particularly in desert blue fan palm oases, where precipitation can be flashy (sudden, erratic, intense, and of short duration),

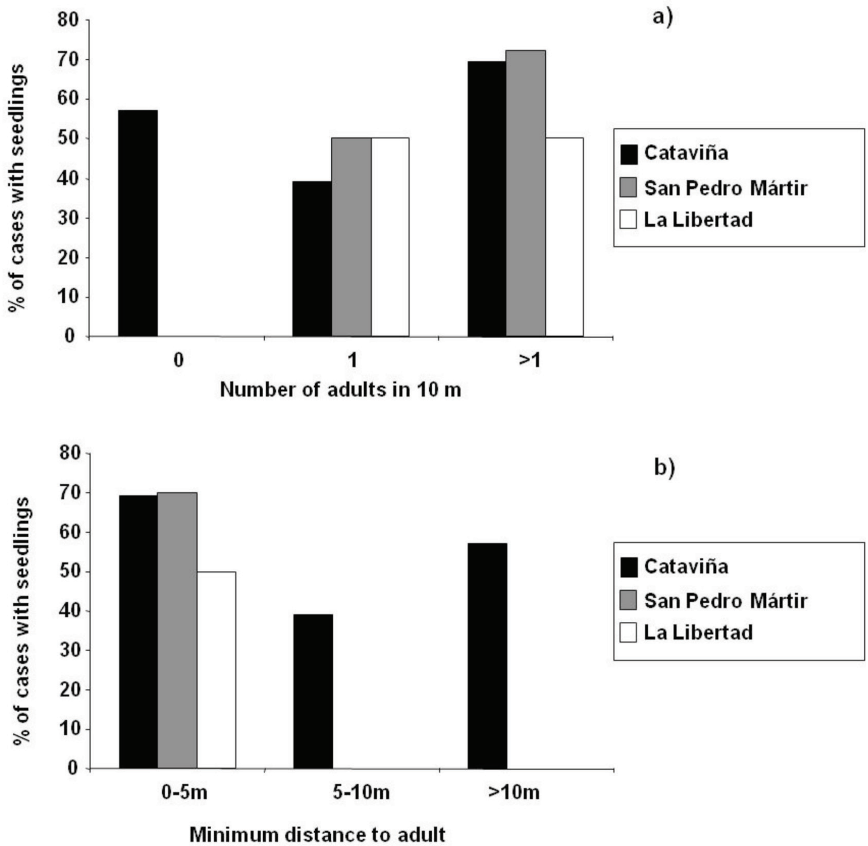

FIGURE 3. (a) Percentages of random points with seedlings (area: 0.0007ha), for each adult density category (AD: 0, 1, and >1 adults), and (b) at each nearest-neighbour distance category (NND: 0-5 m, 5-10 m, >10 m), in the sites of San Pedro Mártir, Cataviña, and La Libertad.

channels are susceptible to extensive erosion. Such disturbances often remove large amounts of streamside vegetation and sometimes entire adult palms, produce abrupt depositional changes, and disrupt community propagule banks (Wehncke unpubl. data, Briggs 1996).

The presence of nurse plants and/or nurse objects, as well as the canyon physiography at each site may have the potential to affect post-dispersal seed removal activity patterns by rodents, as well as to provide vital protection for palm seedling establishment from the extreme flood pulsing. Although the micro-environmental conditions prevailing in shaded microhabitats may be an important factor that enhances seed germination, nurse objects such as rocks and channel sand bars exert a

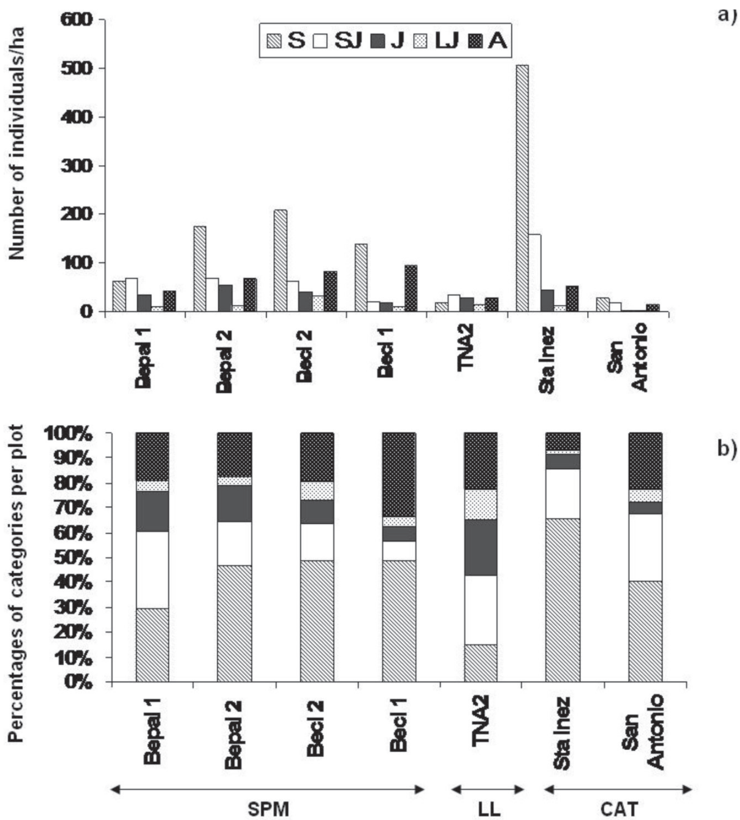

FIGURE 4. (a) Number of blue fan palm individuals per hectare at each age category, and (b) distribution of age categories (percentages of each category per plot) in study plots and sites. San Pedro Mártir (SPM): Bepal1, Bepal2, Beci2, Beci1 plots; La Libertad (LL): TNA2 plot; and Cataviña (CAT): Santa Inez and San Antonio plots.

significant protecting effect to palm seedlings from the extreme pulsing stream flow in these canyons. Preliminary demographic results showed that the highest number of seedlings occurred in a channel sand bar in Cataviña canyon (density individuals/ ha = 508, see Figure 4). Annual leaf production in individuals of up to 0.5 m tall also showed the highest values at this sand bar (mean = 6 ± 4.3 new leaves, N = 39, Wehncke unpubl. data). Additionally, in April 2007 we counted the total number of seedlings below a particular focal adult palm individual located at the limit of the sand bar. In the absence of water a seedling shadow of 370 seedlings extended up to 13 meters of distance from the adult tree, with a southwestern orientation following the direction of the stream. We observed that most of the seedling shadows below

FIGURE 5 (CLOCKWISE). (a) Seedling shadow on Cataviña sand bar, (b) Ongoing seed germination experiment in Cataviña sand bar, (c) Seed germination experiment in the laboratory.

trees (n = 20) had the same orientation in this plot. We visited the site again after eight months and found that all these seedlings disappeared or dried out. The next time we saw any seedling below the same focal tree again was in February 2009 (see Figure 5a).

In this desert ecosystem seeds can form part of the soil seed bank and apparently wait until adequate conditions allow them to germinate. In an ongoing germination experiment in October of 2008, 300 blue fan palm seeds distributed in three treatments were planted directly in the field on the sand bar of Cataviña (see Figure 5b). One hundred palm seeds were taken from diverse animal feces, 100 were planted with the whole fruits, and 100 without the fruit pulp corresponded to control seeds. After approximately four years of setting the experiment no germination has been registered. Likewise, germination experiments of blue fan palm seeds performed in the laboratory showed that from 120 seeds that were collected in September of 2006 and planted during the following days of collection only 4 (3.3%) germinated between July and August of 2008 (see Figure 5c).

Based on the previous observations on seedling emergence and the seed germination experiments performed in the laboratory, we could suggest that blue fan palm seeds tend to germinate after a two year period. However, based on the field germination experiments we could expect that this long-lived palm species may probably require a long time in the seed bank. Finally, we suggest that any protection against extreme solar radiation, mechanical damage, and flooding, and/or sand accumulation in such changing ecosystems might enhance palm seedling survival and determine seedling distribution patterns.

5. CANYON PHYSIOGRAPHY: A SIGNIFICANT PHYSICAL ASPECT IN CURRENT BLUE FAN PALM POPULATION STRUCTURE AND INTERACTIONS

It seems that the geomorphology of granite canyons and the associated water regime might be a significant factor on the palm population structure of these oases. In the San Pedro Mártir site—a deep narrow canyon with steep walls—adult palm density was the highest, while in the flat arroyo wash of Cataviña—an open sandy area with lots of available space and the formation of mid-channel bars that provide safe sites for seedling establishment—total palm seedling densities were the highest of the three sites (see Figure 4). Bar formations have important influences in the life cycle of many riparian plant species (Briggs 1996). Bars, generally composed of sand and/or gravel, are largely determined by the stream flow and influence the geometry strength of flow (Heede 1980). Overall, and judging by their population structure where all life-history categories were adequately represented within each site, the blue fan palm populations in the three oases seemed to be in a fairly good conservation state.

Seeds may escape from predation near seed sources due to the considerable homogenizing effect of the stream flow, but also due to significant levels of seed dispersal by vertebrates. Results from a study on the spatial association patterns between frugivorous birds and blue fan palms in two natural palm patches of Baja California and at different spatial scales showed that blue fan palms function as important sources of fruits, seeds and shelter for a great number of animals at the individual tree level and at the patch scale (Wehncke *et al.* 2009). Blue fan palms are important focus of resources for a great number of animals that use these oases as corridors, bringing seeds as they move and connecting isolated populations of palms. The vector which was probably responsible for relocating most viable seeds was the pulses of overland water flows which transported seeds downhill and eventually determined the pattern of adult distributions we currently see along drainage lines. Nevertheless, not all blue fan palms were distributed in this way; endozoochorous seed dispersal was evident in these canyons, especially at the peak of fruiting seasons. Since seed dispersal in desert canyons may be mainly governed by episodic events of winds and water flows through landforms and topography, the estimation of the qualitative and quantitative importance of palm seed dispersal by animals is relevant to start understanding 'multidirectional' (as opposed to 'unidirectional') forces of dispersal that may influence the occurrence and maintenance of this desert riparian ecosystem. Palms commonly seen growing from crevices on cliffs indicate that dispersal must also take place uphill. There is a diverse array of present-day blue fan palm seed dispersers that consume the thin and sweet mesocarp (Wehncke *et al.* 2009). Among them, ravens, jays, woodpeckers, pumas, lynxes, coyotes, foxes, skunks, bighorn sheep and mule deer have been observed to use canyons as sources of water and food, taking seeds in their movements from lowlands to uplands therefore connecting isolated palm populations. The importance of processes acting at small scales cannot be excluded, since significant beetle predation on seeds was detected below the palms (Wehncke *et al.* 2009).

Also during the flowering period, myriad of insect species visit palm flowers constituting what can be defined as several oases within oases, but also insect predators can be detrimental for palm populations. The interaction between the larva of an endemic moth, *Litoprosopus bajaensis*, and this endemic blue fan palm was documented in these oases, registering that palm populations were severely impacted by this larva, causing high damage to the inflorescences (Wehncke *et al.* 2012b). Again, Cataviña showed the highest reproductive success of palms and consequently, an important proportion of stems escaped from the herbivore predation. This study highlights the role of desert oases as resource patches and connectivity pathways for mobile insects, but also the effects of different water flow dynamics and water pulses in providing an opportunity window of escape from predation for host plant species living in desert environments.

6. FINAL REMARKS

In such fluctuating ecosystems there may be more than one kind of limitation to plant survival, *e.g.*, physiological, demographic, and/or reproductive, and therefore long-term records of demographic data are necessary to discern the causes of failure of populations to maintain their numbers. Marginal areas present a challenge to successful reproduction and thus, a wide range of different strategies have evolved to overcome disturbance through natural causes such as flooding and erosion, and many other aspects of environmental uncertainty. For example, in desert plants the maintenance of variation appears to be a common strategy for long-term survival. In many vegetation communities, anachronistic plants seem to be heading toward a long-term decline (Johnson 2009). Although several examples of plants with megafauna fruit syndromes in Central and North America show distributions restricted to lowlands and flood plains, reflecting their current reliance on gravity and water to move abrade large seeds (Janzen and Martin 1982, Barlow 2000), dominant blue fan palms seem to be very well adapted to this fluctuating ecosystem. These populations provide ecosystem structure, and act as the source of multiple interactions with the present-day fauna; therefore, changes in their distributions can be expected to have cascading effects on the entire ecosystem.

Such riparian ecosystems embedded in arid environments influence human and nonhuman life, providing fundamental ecosystem services, regulating water regimes, and acting as sources of biodiversity. The values of these functions to human society depend on a complex set of relationships between oases and the surrounding environment. The increase in population and the importance of water for human development will work against effective conservation of wetlands in deserts. Since measurements of the frequency or magnitude of such degradation have not been attempted to any significant degree, an important challenge for conservation in deserts is the understanding of their oases ecosystems dynamics. We expect that this baseline information will help in further investigations and encourage management actions to preserve these wonderful last water reservoirs.

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Exploring Mexico's northwest, the Baja California Peninsula, its surrounding oceans, its islands, its rugged mountains, and rich seamounds, one feels diminished by the vastness and the greatness of the landscape while consumed by a sense of curiosity and awe. In a great natural paradox, we see the region's harsh arid nature molded by water through deep time, and we feel that its unique lifeforms have been linked to this desert and sea for thousands of years, as they are now.

These landscapes of fantasy and adventure, this territory of surprising, often bizarre growth-forms and of immense natural beauty, has inspired a wide array of research for over two centuries and continues to inspire the search for a deeper knowledge on the functioning, trends, and conservation status of these ecosystems in both land and ocean.

This book offers a compilation of research efforts aimed at understanding this extraordinary region and preserving its complex richness. It is a synthesis of work done by some exceptional researchers, mostly from Mexico, who indefatigably explore, record, and analyze these deserts and these seas to understand their ecological processes and the role of humans in their ever-changing dynamics.

Elisabet V. Wehncke

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