AGROBIODIVERSITY IN AN OASIS ARCHIPELAGO

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Oases on Mexico's Baja California peninsula harbor farms and gardens which largely feature crops first introduced by Jesuit missionaries (1697–1768). These spring-fed agricultural landscapes are currently managed as diverse agroecosystems with original heritage food crop species as well as newer crop and livestock introductions. These isolated landscapes are relict sanctuaries for unique desert crop varieties and farming systems that may be important for in situ conservation of agrobiodiversity and crop resources. Historical records in 1774 describe twenty-one original perennial crop species introductions in cultivation on the peninsula just after the Jesuit expulsion. This research expands rapid-assessment surveys conducted in nine mission oasis sites on the peninsula in 2010 through in-depth surveys of Mission era and total perennial crop species richness and relative frequency in twelve Jesuit mission oases. In all, 241 large field-gardens were surveyed with eighty-nine total perennial crop species cultivated in the mission oases. Species-area and rank-abundance relationships were calculated to determine patterns of inter and intra-oasis agrobiodiversity. A high persistence of Mission era species indicates that these oases serve as agrobiodiversity refugia, or protected source areas for heritage perennial crop species. The cultural and agricultural islands of the oases should be considered as an archipelago of interconnected sites for the long-term resilience of the region's farming and food systems.

Key words: *Baja California Peninsula, Oases, Agrobiodiversity, Mission era species;* In situ *conservation*

Los oasis de la península de Baja California, México tienen predios agrícolas y huertas que presentan cultivos foraneos introducidos por primera vez por los misioneros jesuitas entre 1697 a 1768. Estos entornos agrícolas irigados por manantiales son manejados comunmente como diversos agroecosistemas con especies de cultivos y ganado originales y nuevos especies introducidos ultimamente. Estos oasis, como aislados parajes, sostienen cultivos de especies y sistemas agrícolas únicos—importante para la conservación in situ de la agrobiodiversidad y los recursos de cultivos utilizables en un futuro bajo posibles condiciones de altas temperaturas y sequia. Los registros históricos que datan de 1774 describen veintiuna especies originales de cultivos perennes en la peninsula justo después de la expulsion de los jesuitas. Esta investigación amplía estudios de evaluación rápida realizados en nueve oasis-misiones en la península en 2010 por estudios en profundidad de riqueza y frequencia relativa de especies de cultivos perennes total y de la época misioneral en doce oasis-misiones. En total, estudiamos 241 huertas en los doce oasis con ochenta y nueve especies de cultivos perennes. Calculamos relaciones entre especies y superficie y rango de abundancia para determinar patrones de agrobiodiversidad dentro y entre los oasis. Alta persistencia de especies de la época misional indican que estos oasis sirven como reservorios para la agrobiodiversidad o fuentes protegidas de especies de cultivos perennes originales. Estos oasis deben de considerarse como un archipiélago de sitios interconectados para la resilencia a largo plazo de los sistemas alimenticios y agrícolas de la región.

Key words: *La Península de Baja California, Oasis, Agrobiodiversidad, Especies de la Epoca Misional; Conservación In situ*

Introduction

The oases of the Baja California peninsula, Mexico, harbor farming systems with crops first introduced by Jesuit missionaries during their political, economic, and ecclesiastical dominance from 1697–1768. The oases represent

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geographies of historic dissemination and hold assemblages of heirloom perennial crop species with origins in six of seven continents. The first Jesuit missionaries to the peninsula documented their agricultural introductions in detail, and these historic documents along with records from subsequent Franciscan and Dominican missionaries provide a benchmark by which to measure the persistence and/or loss of perennial crop species. Few other locations in the world have such complete historical records of the earliest agricultural transformations occurring with contact between hunter-gatherers and agricultural societies. Using original ethnohistorical manuscripts combined with thorough field-garden surveys and farmer interviews, we have attempted to measure modern species richness and characterize species persistence within and among the oases of the peninsula.

Studies in agricultural oases in Egypt, Oman, and on the Baja California peninsula show that oases, harboring complex species assemblages, provide unique sites for formal and informal *in situ* crop and traditional knowledge conservation (Hammer et al. 2009; Geubauer et al. 2007; Nabhan 2007; Nabhan et al. 2010; Routson 2012). *In situ* conservation maintains agricultural species within the biocultural systems in which they evolved and, especially applicable to oases agroecosystems, allows for continuing the adaptation of plants and animals within a social context (Brush 2000; Altieri and Merrick 1987; Nabhan 2007). Traditional oasis agricultural systems support complex agroecosystems with higher levels of native biodiversity than surrounding environments or small household gardens (Nabhan et al. 1982; Pimentel et al. 1992; Thrupp 2000). The agrobiodiversity within these systems—diverse crop and livestock species, crop wild relatives other associated wild biodiversity, and traditional knowledge, are resources for the future of humanity and natural systems in the face of environmental degradation, climate variability and extreme events, crop disease outbreaks, and a growing world population (Frese et al. 2012; Hammer and Teklu 2008; Lenné 2011; Ortiz 2011). These ''islands'' of agricultural diversity exist in broader landscapes where agriculture cannot be practiced, urban development has consumed agricultural production, or the systems have changed to large-scale crop monocultures. Oases, or other isolated pockets in the geographies of historical dispersal, however might only hold small representations of genetic diversity for each species, bottlenecked as many populations are through fragmentation, vicariance, or long-distance dispersal mechanisms. Associated farming and food processing knowledges and practices are equally fragmented and vulnerable to disappearance.

We participated in a collaborative initial investigation into the historical and contemporary dynamics of the species composition, farming systems, and farming communities of the Baja California peninsula oases (Cariño et al. 2013; Nabhan et al. 2010). Using historical records, farmer interviews, agricultural species inventories, and species-area and rank-abundance graphs, we characterize patterns of perennial crop species persistence in the oases. We refine a model of the archipelago of oases as a series of connected *refugia* to conserve agrobiodiversity on the Baja California peninsula first proposed by our team in 2010 (Nabhan et al. 2010). We build upon the rapid-assessment methodology of this previous work through in-depth studies of twelve of fifteen Jesuit mission oases, including surveys of every field garden within each oasis and extended interviews with farmers and oasis residents to understand the full complexity of oasis farming systems.

Social and Ecological Context of the Baja California Oases

The isolation of the peninsula and the oases create agricultural landscapes with unique environmental and social potential for *in situ* conservation. The Baja California peninsula forms a splinter off the southwestern edge of the North American continent, reaching a length of approximately 1,300 kilometers and varying in width from 30 to 240 kilometers between the Pacific Ocean and the Gulf of California (Davis 2006). A series of mountain ranges forms the spine of the peninsula, uplifted and eroded remnants of a geology that predates the formation of the peninsula and others formed from subsequent volcanic activity (Aschmann 1967). The peninsula transitions from a temperate northern region to extreme aridity in its central deserts to the dry, tropical cape. The northern reaches receive more winter rainfall, and the south receives the tailspin of summer tropical cyclones (Adams and Comrie 1997; Comrie and Glenn 1998; Minnich et al. 2000). Climate also transitions west to east, with fog and colder temperatures along the western margin of the peninsula, and higher temperatures and lower humidity along the gulf coast. Annual rainfall on the peninsula varies between 100–300mm (León de la Luz and Cadena 2006).

Although the peninsula has no perennial rivers, a series of springs and seeps along its length create small riparian environments, or oases. Using aerial images, Maya et al. (1997) identified 184 permanent and ephemeral oases in the state of Baja California Sur. The length and varied geography of the narrow peninsula creates an ''archipelago'' of these oasis environments, each differing in latitude and longitude, micro-climate, geology, soil types, hydrology, vegetation, and human influence. The agricultural oases we selected for this study all have perennial springs that support farming villages. They span the lower two-thirds of the peninsula and have vastly different environmental matrices, though they share many of the same agricultural species, farming systems, and traditional practices. These oases were nuclei for the hunter-gathering groups that inhabited the peninsula for thousands of years prior to the arrival of the Jesuit missionaries (Crosby 1994).

During their seventy years on the peninsula (1697–1768), Jesuit missionaries established eighteen missions on the Baja California peninsula to evangelize the native Pericú, Guaycura, and Cochimí tribes and enforce the ''*reducción*'' of the nomadic peoples to sedentary, agrarian lives (Cariño 1996). The rugged, arid geography of the peninsula limited the ecological niches in which agriculture could be successfully established (Crosby 1994). The missionaries concentrated their efforts within spring-fed oases where they developed terraced fields and *acequia* irrigation systems, and introduced domesticated crop and livestock species (Del Barco 1980; Clavijero 2007; Venegas 1757). Extreme aridity, plagues of locusts, destructive hurricane floods, and the almost complete decimation of native populations through disease and cultural disruption, diminished the long-term success of their evangelical objectives.

Despite the fact that these missionaries spent only a handful of decades on the peninsula, their efforts transformed the peninsula landscapes. Many of the original stone structures and crop species have persisted through the centuries.

These missionaries developed the oases into complex agroecological systems with stratified cropping structures, livestock and crop rotations, terraced fields, winding canals, and open spaces between hedgerows of mixed perennials where they planted annual vegetable and grain crops.

The crop repertoire within each oasis embodies cumulative geographies of agricultural and cultural dissemination from around the world. The Jesuit missionaries transported perennial crop species available in Spain at the time as well as those species they found in the landscapes of their New World conquests (Dunmire 2004; Nabhan 2012). These included figs, date palms, pomegranates, grapes, and olives species that originated in Central Asia, the Middle East, North Africa, and the Mediterranean region introduced by the Moors and earlier trade and conquest; citrus species transported along silk and spice routes from Asia, mango and coconut brought on ships directly across the Pacific, and several New World species introduced across the peninsula, as well as a few native to the peninsula (Mukherjee 1953; Ramón Laca 2003; Rivera et a1. 2012; Zizumbo-Villarreal 1996). The oases, spanning the lower two-thirds of the peninsula, have varied climates and microclimates to successfully support a broad range of these introduced food crop species, including tropical fruits such as breadfruit, mangosteen, and cherimoya in the central and southern oasis sites, and more temperate apple, pear, peach and quince species in the northern oases.

The Mission era and more recently introduced species and farming systems comprise the agrobiodiversity that exists in the oases of the Baja California peninsula. After the Jesuit expulsion in 1768, Franciscan and Dominican missionaries assumed temporary control of the missions and settlers, ranchers, and miners from the mainland arrived on the peninsula. These people formed the basis of the new ranchero culture that adopted the agriculture of the mission oases on the peninsula. The physical geography and quantity of water and arable land limited the scale at which agriculture could be produced, however the products exceeded local demand and were exported in national and international markets (Lassépas 1859). While enhanced water extraction technologies and agricultural machinery has allowed mechanized, industrial agricultural production to be implemented in many of the oases, farmers still practice small-scale systems and cultivate many of the original perennial crop species.

Methods

Study Sites

To characterize oasis agrobiodiversity and persistence of Mission era species, we selected 12 of 15 agricultural oases on the Baja California peninsula inhabited by the Jesuits at the time of their expulsion in 1768 (Figures 1–2, Table 1). We excluded three, Santa Maria, Loreto, and San Jose del Cabo based on absence of original mission crops and/or agricultural systems. These 12 mission oasis sites all have persistent small-scale agriculture and records of historic agricultural introductions by Jesuit, Franciscan and Dominican missionaries. These missions were developed under the same religious institution during the Jesuit era (1698–1768) and were interconnected through the secularization of the missions (1833). This early institutional network among the oases ensures that a similar suite of

Figure 1. San Javier Oasis. This photo shows the ruggedness of the terrain, the small town and mission, and the oasis field-gardens, bordered by olive trees. The spring water can also be seen in the arroyo, upstream of the community.

agricultural crops was introduced to each and likely re-introduced following catastrophic events that occurred during the Mission era.

While the environmental matrix within which the oases occur varies greatly from dry temperate desert in the central mountains to subtropical hills on the cape, these mesic systems share many characteristics. Each oasis has one to several springs that emerge in a canyon or drainage, usually where erosion has exposed an impermeable layer of rock or consolidated sediment along which the subterranean water flowed. Most oases have a constructed dam or spring box to catch the water and divert it into a canal that transports the water along the banks of the water channel to downstream fields. The location and size of these fields depends on the topography of the canyons, however in general the field gardens lie close to or within the arroyos, and the villages are positioned slightly higher on the slopes. Soil types range from dense clays to almost pure sand—the geology of the peninsula cannot be easily generalized, and includes old basement sedimentary and metamorphic from before the split of the peninsula, unconsolidated alluvium, and ancient to very recent volcanic rock. Likewise, the topography ranges from deep, narrow canyons within the peninsula's mountains to the more gently rolling slopes of the southern tip. Rainfall is highly variable on both spatial and temporal scales; the oases receive from 109mm to 308mm, generally following a pattern of higher precipitation in the more southern latitudes, but this is also subject to coastal proximity and rainshadow effect. Climatic fluctuations are also variable, though all oases show about a 46° range between the minimum and maximum temperatures. The proximity of both

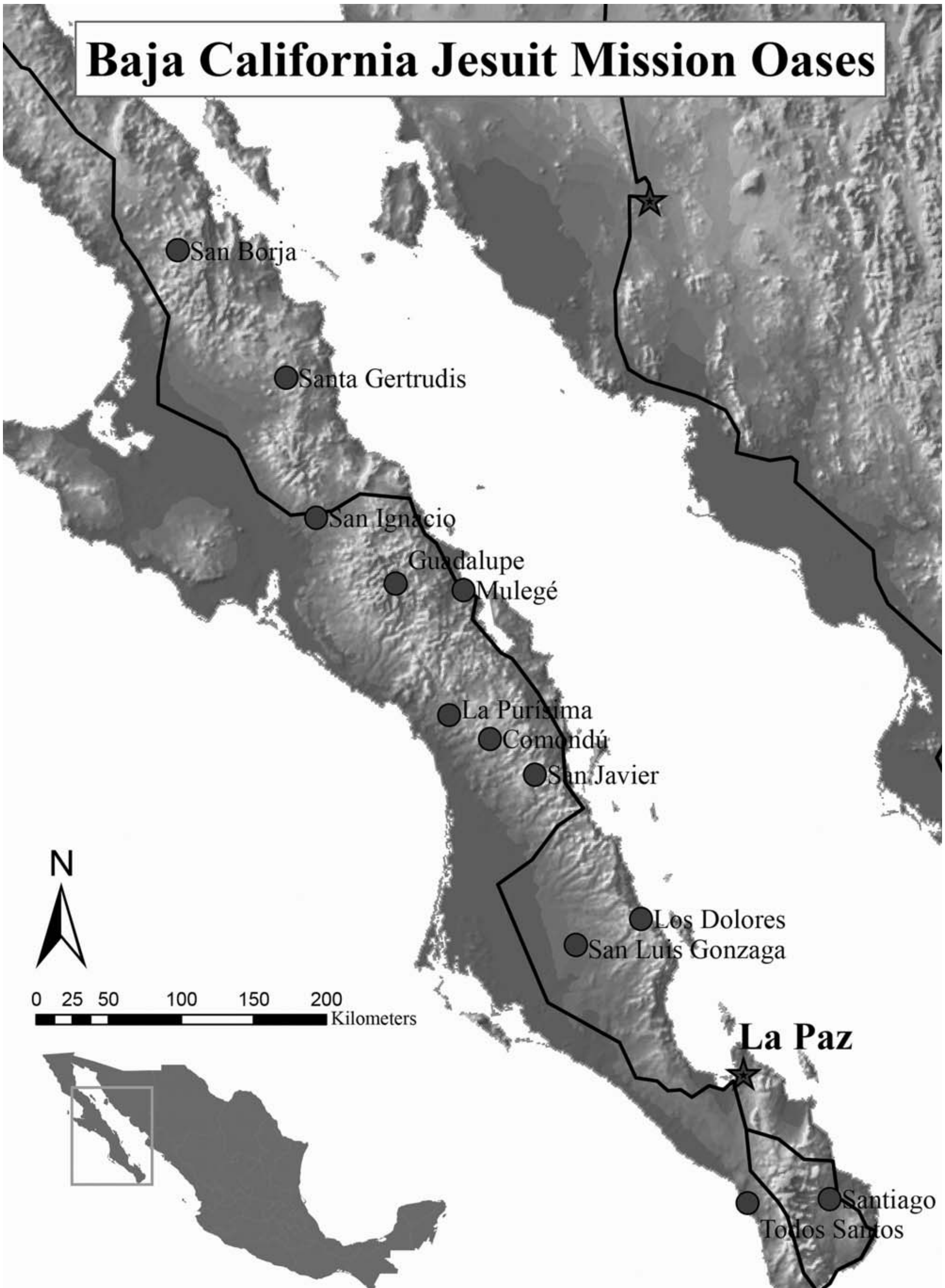

Figure 2. Twelve of 15 Jesuit mission oases of the Baja California Peninsula selected for this study.

Table 1. Physical data of the Jesuit Mission oases included in this study, listed north to south (climate data calculated from CONAGUA 2011).

Oasis	Oasis code	Lat/Long coordinates	Avg elev.	Temp. range	Annual precip.	Cultivated area	Field gardens
San Borja	SB	N28 44.657 W113 45.255	400m	——	——	6.29ha	2
Santa Gertrudis	SG	N28 03.081 W113 05.097	400m	0°C–42°C	109mm	9.47ha	12
San Ignacio	SI	N27 17.024 W112 53.912	120m	−1°C–45°C	145mm	25.68ha	25
Guadalupe	GU	N26 55.153 W112 24.353	700m	−5.5–46°C	239mm	0.50ha	3
Mulegé	MU	N26 53.118 W111 59.159	8m	−1.5–45°C	97mm	6.64ha	8
La Purísima	LP	N26 11.422 W112 04.371	100m	0°C–45°C	113mm	75.93ha	43
San Jose de Comondú	CU	N26 03.583 W111 49.330	280m	0°C–46°C	230mm	65.60ha	43
San Javier	SJ	N25 51.652 W111 32.521	420m	1°C–47°C	255mm	17.01ha	17
San Luis Gonzaga	LD	N25 03.333 W110 53.071	55m	1°C–45°C	249mm	13.97ha	3
Los Dolores	SLG	N24 54.490 W111 17.451	160m	0°C–46°C	191mm	4.60ha	1
Todos Santos	TS	N23 26.991 W110 13.531	41m	3°C–42°C	144mm	153.15ha	55
Santiago de los Coras	SC	N23 28.540 W109 43.041	120m	−2°C–44°C	308mm	45.80ha	29

water bodies to all of the oases has a tempering effect on the climate, however interior mountain oases such as San Borja, Santa Gertrudis, San Ignacio, Guadalupe, San Javier, Comondú, and San Luis Gonzaga tend to have slightly more extreme temperature trends more often than those closer to the coasts—Muelgé, La Purísima, Los Dolores, Todos Santos, and Santiago.

Within each mission oasis, we delimited the agricultural sites surrounding the Jesuit missions as the collective body of *huertas,* or agricultural plots within the original *acequia* or canal system, initiated by Jesuit missionaries. For the purposes of this study we define a *huerta* as a field-garden larger than 100 square meters, watered by the *acequia* or canal system or by a well, though not usually associated with a house. The primary purpose of the *huerta* is to grow food for domestic consumption and/or for market, and not to produce the assorted vegetables and culinary herbs for the kitchen. *Huertas* may also supply forage for livestock; farmers grow, harvest and transport the forage crops to animals, or rotate animals through the *huerta* between growing seasons. Most *huertas* have hedgerows or borders of perennial species, often times in tiered vegetation structure, and open, sunny areas between, to grow annual crops or rows of perennials, such as grapevines or nopal (*Opuntia* spp.).

Historical Inventories

We used several sources to establish the extent of the original crop introductions to the peninsula during the Jesuit Mission era. In particular, we scrutinized the published works of Jesuit and Franciscan missionaries from the peninsula. We also conducted research at the archives of the Arizona State Museum, the Mexican federal *Archivo General de la Nación* (AGN) in Mexico City and state *Archivo Histórico de Baja California Sur Pablo L. Martínez* (AHPLM) at La Paz. We used historical registries, writings, and drawings of the Jesuit missionaries Del Barco (1980), Baegert (1979), and Venegas (1757) as primary sources for inventories of agricultural species and practices introduced during the Jesuit era, however these records are incomplete and not sufficient for reconstructing an agricultural baseline. The writings of Clavijero (2007) during this same time period also give information about the agriculture of the Baja California peninsula missions, though this missionary never visited the peninsula and his works provide only a partial description. Crosby (1994) provides the most comprehensive collection of agricultural data from Jesuit missionary writings as well as descriptions of agriculture in the missions today. Vernon (2002) has also collected primary Jesuit agricultural data and described the current condition of mission agriculture on the peninsula. Inventories and descriptions of Franciscan missionary Palóu written in 1772, collected and translated in Engelhardt (1908) are the first original writings that treat all of the Baja California peninsula missions together and describe the condition of the fields after the Jesuit expulsion. We used a series of Dominican records collected and complied in 1774 as our baseline for Mission era crop introductions. A thorough review of these in the *Archivo General de la Nación* (AGN) enabled us to complete a partial list developed during our first survey of peninsula agriculture (Nabhan et al. 2010). These writings provide the earliest comprehensive inventories and descriptions of annual and perennial crops, area in cultivation, and amount harvested in the missions. Most of the fruit trees recorded in these inventories are mature, and thus would have been planted during the Jesuit administration of the peninsula, six years earlier. These records also verify the Jesuit's critical role in introducing agricultural techniques, systems, and crops to the missions.

Oasis Garden Surveys

At each mission oasis, we attempted to survey every *huerta* within the original irrigation systems, though in a few cases, this was not possible. We utilized guides who introduced us to farmers, pointed out the boundaries of the *huertas*, clarified questions on some varieties and species, and served as a connection to the community. We obtained approval through the University of Arizona Human Subjects Protection Program for all methods included in this research (IRB00001751; FWA00004218; Project# 09-0552-02). We collected Global Positioning System (GPS) points for at least two field corners to assist in the delineation of field shape and area using GIS (Geographic Information Systems) technology and aerial photographs. We took GPS points at the mission, springs, wells, and dams in each oasis.

We limited our investigations to cultivated perennial food crop species to characterize current species richness and compare our results with historical inventories. We selected perennials because of their longevity and the likelihood that the species we encountered would be comparable with the species and in some cases the varieties described in the historical records. Many of these are clonally reproduced, and if the original trees are not still living, the genetic material vegetatively propagated from them would likely be similar or identical. The few studies we have of Mission figs and Mission grapes show an extraordinarily high level of genetic similarity among parent populations in the Old World and widely dispersed clonal materials still growing in American regions (This et al. 2006; Aradhya et al. 2010). The only case of possible divergence over the last three centuries in this region—noted in a recent study of Mission olives—may in fact be evidence of somatic clonal mutations or hybridization with a parent that is no longer present (Soleri et al. 2010).

We recorded scientific names and local names for all perennial food crop species and made photo collections and descriptions based on standards of the International Plant Genetic Resources Institute. For each collection, we recorded site descriptions, tree or plant and fruit characteristics, and GPS points. We collected specific and varietal names from the historic documents, oasis farmers, and Mexican and American horticultural scientists for the perennial food crops in archaic and contemporary Spanish and the corollary English and scientific (Latin) names. For perennial crops that we could not identify in the field, we collected samples for herbarium identification or sent photos to horticulturalists or species experts. We consulted horticulturalists and botanists from the Baja California peninsula, Mexico City, Spain, and the United States for different agricultural species identifications. Some species still remain in question since the identities of several of the historic crops are difficult to reconstruct with absolute confidence and we could not accurately identify some of the nopal, agave, and citrus species.

Agrobiodiversity Analyses

We combined field data with geo-referenced digital maps of the oases produced from SPOT (*Satellite Pour l'Observation de la Terre*) composite aerial photograph images and aerial photography with a resolution of two meters

(WGS84, UTM Zone 12) to calculate the area of each garden. We calculated species-area relationships for the oases using number of species and total area in cultivation for each, and fit a power curve to the data following the Arrhenius power curve calculation ($S = cA^z$, where S = number of species, A = area, c = constant, and z = slope of the species-area curve in log-log space). Both c (constant) and z (slope) are determined from the data by transforming the equation logarithmically ($\log S = \log c + z \log A$), which linearizes the relation (Dengler 2009). We then used these coefficients in the original equation to develop a descriptive model or curve of the oasis species-area relationship. We tested individual significance of the species-area relation (total number of perennial crop species and total area in cultivation) for each oasis to the curve using Pearson residuals. We generated calculation sets, one to compare total perennial crop diversity and one with only historic, Mission era crop species.

To determine trends in oasis agricultural diversity, we calculated rank-abundance relationships for seven oases using species presence/absence and frequency of occurrence in each garden to characterize the total perennial crop diversity within oases. The rank abundance graphs for the oases show both overall species richness (x axis) and number of gardens (y axis) and demonstrate the frequency of each crop appearing in the oasis gardens. Oases with fewer than ten gardens (SB, GU, MU, LD, SLG; Table 1) were excluded from the analyses. The species with highest relative frequency (number of times species occurred/ number of gardens in the oasis) were assigned a number 1, and consecutive numbers given to consecutive decreasing values of species relative frequency. Graphs of these relative frequencies represent the distribution of perennial crop species within the oases. The species with the most representation are given the highest scores, while species with low representation lie closer to the x axis. The graphs with the steepest rate of descent are those where only a few species have the most representation in the gardens. The graphs with shallow declines are those where a higher number of species are represented throughout more of the gardens. The sites with the most even descent imply that these oases have the greatest long-term potential of retaining agrobiodiversity because the diversity is more evenly distributed throughout the gardens. We used these data to analyze oasis agricultural diversity, trends and persistence of historic crops.

Oasis Farming Systems and Practices, Political Ecology, and Cultural Practices

We selected farmers in each oasis to answer interview questions based on farmer availability, knowledge, and willingness to participate. We conducted one to 15 farmer interviews per oasis to gather further information on agricultural practices, including history of the garden, information on perennial plant management, irrigation timing and methods, fertilizer inputs, field design, annual crop inventories and cultivation, and livestock management. We also conducted interviews with farmers as well as supplemental interviews with produce buyers, extension agents and town authorities related to oasis political ecology, including questions about distance to markets and source areas for seed, fertilizer, and mechanical needs, primary revenues from the agricultural lands and a description of economic chains, and how land tenure, tourism, demography, and water governance of the oasis affected the persistence of perennial crops. Our third set of interviews addressed cultural foodways practices, and symbolic significances associated with heritage crops in the oases. We asked about processing techniques and histories of the different perennial species in the oases, and also questions related to the significance of each species, and its use during religious rites and celebrations, holidays, and daily life. We used the responses to these questions to understand individual and community knowledge repertoires related to the perennial food crop species. In all, we conducted 79 individual and group farmer interviews related to farming practices, 83 interviews on oasis political ecology, and 90 interviews related to cultural practices. We acquired human subjects approval from the University of Arizona, and all methodology followed these institutional standards. We took hand-written notes and translated all interviews, then analyzed them in relation to the agrobiodiversity persistence at each oasis.

Results

Historical Inventories

We found mention of 21 perennial crop introductions to the Baja California missions in the historical documents of Jesuit, Franciscan and Dominican priests, and compiled by later authors (De Mora et al. 1774; Engelhardt 1908; Baegert 1979; Del Barco 1980; Crosby 1994; Del Rio 2003) (Table 2).

Oasis Garden Surveys

Within 241 oasis *huertas* surveyed in the 2010–2011 study, we recorded a total of 89 species of perennial food crops, belonging to 64 genera and 36 families (Table 3). All 21 species of mission crops noted in the 1774 inventories were found in the 2010/2011 surveys. In some cases, however, these Mission era introductions were not associated with the same oases as noted in historical documents. This indicates that the crops were introduced and then lost and reintroduced to the peninsula in other locations, or propagated and dispersed to another oasis, and then lost in the original location (Table 4). The genera with the most species represented were *Citrus* (13+ species and distinct hybrids), *Prunus* (5 species), *Annona* (4 species), and *Morus* (3 species). Among the families, Rutaceae (16 genera), Rosaceae (10 genera), Moraceae (6 genera), Anacardiaceae (4 genera), and Anonaceae (4 genera) had the highest number of genera represented. Only three species were found in all 12 of the surveyed oases: sweet orange, date palm, and guava. Eight species were found in 11 of 12 oases: the three previously mentioned and sour lime, fig, mango, pomegranate, and grape. The next most frequently encountered species (found in ten of 12 oases) were papaya, sweet lime, banana, olive, and nopal. This last species is problematic, since some of the individuals were clearly *Opuntia* ×*ficus-indica* and others may be a distinct *Opuntia* species. Nearly one third (31 species) of the total species were documented in one of 12 oases.

Oasis Todos Santos had the highest number of perennial food crop species (78/89) and families (35/36) recorded and also the highest number of mission species (21/21) (Tables 3 & 4). Santiago de los Coras, also in the southern peninsula had the second highest number of species (48/89), families (24/35),

Table 2. Crops introduced to the Baja California Peninsula oases by 1774 as recorded by Jesuit, Franciscan, and Dominican missionaries, updated from Nabhan et al. 2010. Updated information identified in bold.

Name in English	Name in Spanish	Missions (where noted)	Source
Annona: custard apple	*Chirimoya*	San José de Comondú, San Javier	De Mora et al. 1774
Avocado	***Aguacate***	**La Purísima, San José de Comondú**	**De Mora et al. 1774**
Banana	*Plátano*	San José de Comondú, San Javier	De Mora et al. 1774; Crosby 1994; Del Barco 1980
Century plant	*Maguey*	Santiago	Del Barco 1980
Citrus: citron	***Cidra***	**La Purísima**	**De Mora et al. 1774**
Citrus: lime	*Limón*	**La Purísima**, San José de Comondú, San Javier, **San Ignacio**	De Mora 1774; Crosby 1994; Del Barco 1980
Citrus: sweet lime	***Lima***	**La Purísima, San José de Comondú**	**De Mora et al. 1774**
Citrus: orange	*Naranja, naranjo*	**La Purísima**, Todos Santos, San José de Comondú, San Javier	De Mora et al. 1774, Crosby 1994; Del Barco 1980
Coconut	*Coco*	Loreto	Zizumbo-Villareal 1996; Crosby 1994
Date palm	*Dátil, palma*	**Loreto, La Purísima**, San José de Comondú, San Javier	De Mora et al. 1774; Aschmann 1967
Fig	*Higo*	**Loreto, Santa Gertrudis,** Todos Santos, San José de Comondú, San Javier, **Guadalupe, San Ignacio, San Borja, Santa Maria**	De Mora et al. 1774; Crosby 1994; Del Barco 1980
Grape	*Uva, parra, zepa, cepa*	**La Purísima, Santa Gertrudis**, San José de Comondú, San Javier, **Guadalupe, San Ignacio**, Todos Santos, **San Borja, Santa Maria, San José del Cabo**	De Mora et al. 1774; Crosby 1994; Del Barco 1980
Guava	***Guayabo***	**La Purísima, San José de Comondú**	**De Mora et al. 1774**
Olive	*Olivo, aceituna*	**La Purísima, Santa Gertrudis,** San José de Comondú, San Javier, **Guadalupe, San Ignacio**	De Mora et al. 1774; Crosby 1994; Del Barco 1980
Passion fruit	***Granada china, granadilla***	**Santiago?**	**Del Barco 1980**
Peach	*Durazno*	**La Purísima**, Santa Gertrudis, **San José de Comondú**	De Mora et al. 1774; Del Barco 1980
Pomegranate	*Granado*	**Loreto, Santa Gertrudis**, San José de Comondú, San Javier, **Guadalupe, San Ignacio**, Todos Santos, **San Borja**	De Mora et al. 1774; Crosby 1994; Del Barco 1980
Prickly pear	***Nopal, tuna***	**La Purísima, San Javier**	**Del Barco 1980**
Sapote, yellow	*Zapote (amarillo)*	**La Purísima**, San José de Comondú, San Javier	De Mora et al. 1774
Sugar cane	*Caña de azucar*	Todos Santos, San Ignacio, San José de Comondú	De Mora et al. 1774; Crosby 1994
Tamarind	***Tamarindo***	**Loreto**	**De Mora et al. 1774**

Table 3. Total perennial food crop species found in 2010/2011 oasis *huerta* surveys.

English name	Spanish name	Scientific name	Family
Ackee	*Ackee*	*Blighia sapida* K.D. Koenig	Sapindaceae
Allspice	*Pimienta*	*Pimenta dioica* (L.) Merr.	Myrtaceae
Annona: custard apple, cherimoya, anona	*Anona*	*Annona reticulata* L.	Annonaceae
Annona: custard apple, cherimoya	*Chirimoya*	*Annona cherimola* Mill.	Annonaceae
Annona: soursop	*Anona, guanabana*	*Annona muricata* L.	Annonaceae
Annona: sugar apple	*Anona*	*Annona squamosa* L.	Annonaceae
Apple	*Manzano*	*Malus domestica* Borkh.	Rosaceae
Apricot	*Chabacano, albaricoque, alberichigo*	*Prunus armeniaca* L.	Rosaceae
Asparagus	*Esparragos*	*Asparagus officinalis* L.	Asparagaceae
Avocado	*Aguacate*	*Persea americana* Mill.	Lauraceae
Banana, plantain	*Plátano*	*Musa* ×*paradisiaca* L.	Musaceae
Blackberry	*Mora, zarsamora*	*Rubus* sp.	Rosaceae
Breadfruit	*Árbol de pan*	*Artocarpus altilis* (Parkinson) Fosberg	Moraceae
Cashew	*Castaña de cajú*	*Anacardium occidentale* L.	Anacardiaceae
Century plant	*Maguey, mescal*	*Agave* spp.	Asparagaceae
Cherry	*Cereza*	*Prunus avium* (L.) L.	Rosaceae
Cherry, native	*Capulín o cereza*	*Prunus serotina* Ehrh. var. *virens* (Wooton & Standl.) McVaugh	Rosaceae
Cherry, tropical (Brazilian, Surinam)	*Cereza braziliano*	*Eugenia uniflora* L.	Myrtaceae
Chiltepín	*Chiltepín*	*Capsicum annuum* L. var. *glabriusculum* (Dunal) Heiser & Pickersgill	Solanaceae
Chive	*Cebollín*	*Allium schoenoprasum* L.	Amaryllidaceae
Cinnamon	*Canela*	*Cinnamomum verum* J. Presl	Lauraceae
Citrus: calamondin	*Tanjerina, naranjito*	×*Citrofortunella microcarpa* (Bunge) Wijnands	Rutaceae
Citrus: citron	*Cidra*	*Citrus medica* L.	Rutaceae
Citrus: grapefruit	*Toronja*	*Citrus paradisi* Macfad	Rutaceae
Citrus: rough lemon	*Limón base de injertos*	*Citrus jambhiri* Lush	Rutaceae
Citrus: sweet lemon	*Limón real*	*Citrus* hybrid	Rutaceae
Citrus: sour lime (large)	*Limón Americana*	*Citrus limon* (L.) Burm. F.	Rutaceae
Citrus: sour lime (small)	*Limón*	*Citrus* ×*aurantifolia* (Christm.) Swingle	Rutaceae
Citrus: sweet lime	*Lima dulce chichona*	*Citrus limettioides* Tanaka	Rutaceae
Citrus: lime-orange	*Naranja lima*	*Citrus* sp.	Rutaceae
Citrus: mandarin	*Mandarina*	*Citrus reticulata* Blanco	Rutaceae
Citrus: sour orange	*Naranja amarga*	*Citrus aurantium* L.	Rutaceae
Citrus: sweet orange	*Naranja dulce*	*Citrus sinensis* L. (Osbeck)	Rutaceae
Citrus: pummelo	*Pomelo/toronja*	*Citrus maxima* (Burm.) Merr.	Rutaceae

Table 3. Continued.

English name	Spanish name	Scientific name	Family
Clove	*Pomarosa*	*Syzygium aromaticum* (L.) Merr. & L. M. Perry	Myrtaceae
Cacao	*Cacao*	*Theobroma cacao* L.	Malvaceae
Coconut	*Coco*	*Cocos nucifera* L.	Arecaceae
Coffee	*Café*	*Coffea arabica* L.	Rubiaceae
Date palm	*Dátil*	*Phoenix dactylifera* L.	Arecaceae
Fig	*Higo*	*Ficus carica* L.	Moraceae
Ginger	*Jinjibra*	*Zingiber officinale* Roscoe	Zingiberaceae
Grape, mission	*uva misionera*	*Vitis vinifera* (Roxb.) Benth.	Vitaceae
Guamúchil	*Guamúchil*	*Pithecellobium dulce*	Fabaceae
Guava	*Guayaba*	*Psidium guajava* L.	Myrtaceae
Guava, pineapple	*Guayabo de piña*	*Acca sellowiana* (O. Berg) Burret	Myrtaceae
Guava, strawberry	*Guayaba de fresa*	*Psidium cattleianum* Sabine	Myrtaceae
Hibiscus, sorrel	*Jamaica*	*Hibiscus sabdariffa* L.	Malvaceae
Jackfruit	*Yaca*	*Artocarpus heterophyllus* Lam.	Moraceae
Jujube	*Jujube*	*Ziziphus mauritiana* Lam.	Rhamnaceae
Kumquat	*Naranja china*	*Fortunella margarita* (Lour.) Swingle	Rutaceae
Lemon grass	*Té limón*	*Cymbopogon citratus* (DC.) Stapf	Poaceae
Loquat	*Níspero*	*Eriobotrya japonica* (Thunb.) Lindl.	Rosaceae
Lychee	*Litchi*	*Litchi chinensis* Maiden & Betche	Sapindaceae
Macadamia nut	*Macademia*	*Macadamia integrifolia*	Proteaceae
Mamey sapote	*Mamey*	*Pouteria sapota* (Jacq.) H. E. Moore & Stearn	Sapotaceae
Mango	*Mango*	*Mangifera indica* L.	Anacardiaceae
Mangosteen	*Mangostin*	*Garcinia mangostana* L.	Clusiaceae
Moringa	*Moringa*	*Moringa oleifera* Lam.	Moringaceae
Mulberry, black	*Mora negra*	*Morus nigra* L.	Moraceae
Mulberry, red	*Mora roja*	*Morus rubra* L.	Moraceae
Mulberry, white	*Mora blanca*	*Morus alba* L.	Moraceae
Olive	*Olivo misionero*	*Olea europaea* L.	Oleaceae
Papaya	*Papaya*	*Carica papaya* L.	Caricaceae
Passion fruit	*Granadilla*	*Passiflora ligularis* Juss.	Passifloraceae
Peach	*Durazno*	*Prunus persica* (L.) Batsch	Rosaceae
Pear	*Pera*	*Pyrus communis* L.	Rosaceae
Pecan	*Pecan*	*Carya illinoinensis* (Wangenh.) K. Koch	Juglandaceae
Pineapple	*Piña*	*Ananas comosus* (L.) Merr.	Bromeliaceae
Plum	*Chabacano*	*Prunus domestica* L.	Rosaceae

Table 3. Continued.

English name	Spanish name	Scientific name	Family
Plum, Spanish, red mombin	*Ciruela roja/amarilla*	*Spondias purpurea* L.	Anacardiaceae
Plum, Spanish, yellow mombin	*Ciruela anaranjada*	*Spondias mombin* L.	Anacardiaceae
Pomegranate	*Granada*	*Punica granatum* L.	Lythraceae
Prickly pear	*Nopal, tuna*	*Opuntia ficus-indica* (L.) Mill.	Cactaceae
Prickly pear, false	*Nopalillo*	*Nopalea cochenillifera* (L.) Salm-Dyck	Cactaceae
Quince	*Membrillo*	*Cydonia oblonga* Mill.	Rosaceae
Rosemary	*Romero*	*Rosmarinus officinalis* L.	Lamiaceae
Rue	*Ruda*	*Ruta graveolens* L.	Rutaceae
Sapodilla	*Chico sapote*	*Manilkara zapota* (L.) P. Royen	Sapotaceae
Sapote: black	*Zapote negro/prieto*	*Diospyros digyna* Jacq.	Ebenaceae
Sapote: white/yellow	*Zapote amarillo*	*Casimiroa edulis* Llave & Lex.	Rutaceae
Spearmint	*Yerbabuena*	*Mentha spicata* L.	Lamiaceae
Star fruit	*Carambola*	*Averrhoa carambola* L.	Oxalidaceae
Sugar cane	*Caña de azúcar*	*Saccharum officinarum* L.	Poaceae
Tamarind	*Tamarindo*	*Tamarindus indica* L.	Fabaceae
Tepeguaje	*Tepeguaje*	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae
Uvalama	*Uvalma*	*Bumelia peninsularis* Brandegee	Sapotaceae
Vanilla	*Vanilla*	*Vanilla planifolia* Andrews	Orchidaceae
Walnut	*Nogal*	*Juglans regia* L.	Juglandaceae
Yuca/cassava	*Yuca*	*Manihot esculenta* Crantz	Euphorbiaceae

Table 4. Presence/absence data for perennial food crop species in 2010–2011 oases surveys. *Mission era crop introduction.

Crop	Oasis Code												N (%)
	SB	SG	SI	GU	MU	LP	CU	SJ	LD	SLG	TS	SC	
Ackee											x		1 (8.3)
Allspice											x		1 (8.3)
Annona: custard apple; annona*							x		x		x	x	4 (33.3)
Annona: custard apple; cherimoya							x						1 (8.3)
Annona: soursop											x	x	2 (16.7)
Annona: sugar apple											x	x	2 (16.7)
Apple	x	x	x			x	x	x			x	x	8 (66.7)
Apricot		x											1 (8.3)
Asparagus											x		1 (8.3)
Avocado*	x	x	x				x	x	x		x	x	8 (66.7)
Banana, plantain*	x	x	x		x	x	x	x	x		x	x	10 (83.3)
Blackberry											x		1 (8.3)
Breadfruit											x		1 (8.3)
Cashew											x		1 (8.3)
Century plant*		x	x		x			x	x		x	x	7 (58.3)
Cherry			x								x		2 (16.7)
Cherry, native											x		1 (8.3)
Cherry, tropical (Brazilian, Surinam)											x	x	2 (16.7)
Chiltepín			x		x	x	x	x			x	x	7 (58.3)
Chive						x					x		2 (16.7)
Cinnamon											x		1 (8.3)
Citrus: calamondin					x		x	x			x	x	5 (41.7)
Citrus: citron*											x		1 (8.3)
Citrus: grapefruit		x	x		x		x	x	x		x	x	8 (66.7)
Citrus: rough lemon					x		x				x		3 (25.0)
Citrus: lemon sweet		x	x		x	x	x	x	x		x		8 (66.7)
Citrus: sour lime (large)			x		x	x	x	x	x		x	x	8 (66.7)
Citrus: sour lime (small)*	x	x	x	x	x	x	x	x	x		x	x	11 (91.7)
Citrus: sweet lime*	x	x	x	x	x		x	x	x		x	x	11 (91.7)
Citrus: lime-orange	x		x	x	x	x	x	x			x	x	9 (75.0)
Citrus: mandarin	x		x		x		x	x	x		x	x	8 (66.7)
Citrus: sour orange		x	x		x	x	x	x	x		x	x	9 (75.0)
Citrus: sweet orange*	x	x	x	x	x	x	x	x	x	x	x	x	12 (100)
Citrus: pummelo			x	x	x	x	x	x	x		x	x	9 (75.0)

Table 4. Continued.

Crop	Oasis Code												N (%)
	SB	SG	SI	GU	MU	LP	CU	SJ	LD	SLG	TS	SC	
Clove											x		1 (8.3)
Cacao											x		1 (8.3)
Coconut*			x		x		x		x		x	x	6 (50.0)
Coffee											x	x	2 (16.7)
Date palm*	x	x	x	x	x	x	x	x	x	x	x	x	12 (100)
Fig*	x	x	x	x	x	x	x	x	x		x	x	11 (91.7)
Ginger											x		1 (8.3)
Grape*	x	x	x	x	x	x	x	x	x		x	x	11 (91.7)
Guamuchíl			x		x	x	x	x	x		x	x	8 (66.7)
Guava*	x	x	x	x	x	x	x	x	x	x	x	x	12 (100)
Guava, pineapple											x		1 (8.3)
Guava, strawberry											x		1 (8.3)
Hibiscus						x					x	x	3 (25.0)
Jackfruit					x						x		2(16.7)
Jujube												x	1 (8.3)
Kumquat												x	1 (8.3)
Lemon grass										x	x		2 (16.7)
Loquat							x				x		2 (16.7)
Lychee											x	x	2 (16.7)
Macadamia nut								x			x		2 (16.7)
Mamey sapote											x		1 (8.3)
Mango	x	x	x	x	x	x	x	x	x		x	x	11 (91.7)
Mangosteen											x		1 (8.3)
Moringa											x		1 (8.3)
Mulberry, black		x	x				x						3 (25.0)
Mulberry, red			x			x	x						3 (25.0)
Mulberry, white			x		x								2 (16.7)
Olive*	x	x	x	x	x	x	x	x			x	x	10 (83.3)
Papaya	x	x	x		x	x	x	x	x		x	x	10 (83.3)
Passion fruit*											x	x	2 (16.7)
Peach*	x	x	x		x		x	x	x		x	x	9 (75.0)
Pear			x					x			x	x	4 (33.3)
Pecan											x		1 (8.3)
Pineapple											x		1 (8.3)

Table 4. Continued.

Crop	SB	SG	SI	GU	MU	LP	CU	SJ	LD	SLG	TS	SC	N (%)
	Oasis Code												
Plum					x						x	x	3 (25.0)
Plum, Spanish, red mombin					x	x	x	x	x		x	x	7 (58.3)
Plum, Spanish, yellow mombin							x					x	2 (16.7)
Pomegranate*	x	x	x	x	x	x	x	x	x		x	x	11 (91.7)
Prickly pear*	x	x	x	x	x	x	x	x		x	x	x	11 (91.7)
Prickly pear, false			x		x	x	x	x			x	x	7 (58.3)
Quince	x												1 (8.3)
Rosemary		x	x				x				x		4 (33.3)
Rue												x	1 (8.3)
Sapodilla					x		x				x		3 (25.0)
Sapote: black											x	x	2 (16.7)
Sapote: white/yellow*		x	x	x	x	x	x	x			x	x	9 (75.0)
Spearmint		x						x			x		3 (25.0)
Star fruit											x		1 (8.3)
Sugar cane*			x				x	x			x	x	5 (41.7)
Tamarind*		x	x		x		x	x	x		x	x	8 (66.7)
Tepeguaje		x			x	x	x	x			x	x	7 (58.3)
Uvalama						x							1 (8.3)
Vanilla											x		1 (8.3)
Walnut											x		1 (8.3)
Yuca/cassava											x		1 (8.3)
N of species[1]	19	27	37	14	36	28	42	36	25	5	78	48	
Percent of species[2]	21	30	42	16	40	32	47	41	28	06	88	54	
N of ME species[3]	13	16	18	11	16	11	18	17	15	4	21	19	
Percent of species[4]	61	76	86	52	76	52	86	81	71	19	100	91	

1. Number of perennial food crop species found in each oasis.
2. Percent of total number (N=89) of perennial crop species found in all oases.
3. Number of Mission Era (ME) food crop species found in each oasis.
4. Percent of total number (N=21) of Mission era crop introductions.

and mission species (19/21). San José/San Miguel de Comondú and San Ignacio both had 18 of 21 mission species; San Javier 17 of 21, and Mulegé and Santa Gertrudis 16 of 21 mission species. All oases contained mission perennial crop species, and all had over ten mission species except San Luis Gonzaga, with the fewest species (5), families (5), and mission species (4). Two species found in the *huertas* actively planted and harvested as food crops are native to the peninsula: native cherry and uvalama (Wiggins 1980). Several species are native to continental Mexico and/or Central America and the Caribbean, among them allspice, custard apple-annona, soursop, sugar apple, avocado, agave, chiltepín, guava, mamey sapote, papaya, Spanish plum/red mombin, prickly pear, false prickly pear, sapodilla, black sapote, white sapote, tepeguaje, and vanilla (Dunmire 2004; Janick and Paull 2008; GRIN Database, accessed in August 2013; USDA Plants Database, accessed August 2013).

The 12 oases under consideration in this study are situated along the lower two-thirds of the Baja California peninsula, and differ in latitude, longitude, and their proximity to the Gulf of California and the Pacific Ocean. This produces a gradient of climatic, topographic, and other physical factors that inform the type of perennial crop species that can survive in the oases. While the natural mesic environment of the oasis as well as human alterations and constructions can create micro-climates, the data show slight differences in the species found in the northernmost and southernmost oases. A visual scan of the presence/absence data (Table 4) combined with farmer interview questions related to crop selection reveal that perennial species that thrive best in cooler climates or require chill hours, such as pears, quinces, pomegranates, grapes and olives were found more often in the northern oases than in the southern oases. Tropical introductions such as cherimoya, soursop, and breadfruit were found in higher frequency in the southernmost oases. This did not seem to hold true for tropical crops such as mangos, sugarcane and avocados, which were distributed throughout the oasis archipelago. Soil type also limited the species: coconuts were found mostly in the oases close to the coast, and in the oasis of La Purísima, farmers said that the soil was not suited to olive trees.

Species-Area Relationships

Our findings confirm that agricultural species within oasis gardens tend to follow the classic species-area power curve used for wild species in natural habitats, with the number of domesticated perennial crop species increasing with area in cultivation. Total perennial crop diversity and Mission era crop diversity differ with respect to species accumulation with increasing area when each are plotted out on a log-log scale (Total species/area slope (z) = 0.316; Mission era species/area slope = 0.137, Figures 3a and 4a). Slope (z) values for Total species are comparable to those observed for island-archipelago communities (0.25–0.35; Rosenzweig 1995), whereas slope values for Mission era species alone falls within the range of slopes observed for species on continents or subdivisions (0.12–0.18; Rosenzweig 1995). The reasoning for this is simple: the Mission era species were introduced three centuries ago and 1) are presumably the perennial crop species the Jesuits found to be most adapted to the peninsula climate and oasis environments; 2) were dispersed among all of the mission oases in this study during the Mission era; and 3) are more deeply woven into the cultural fabric of the peninsula oases.

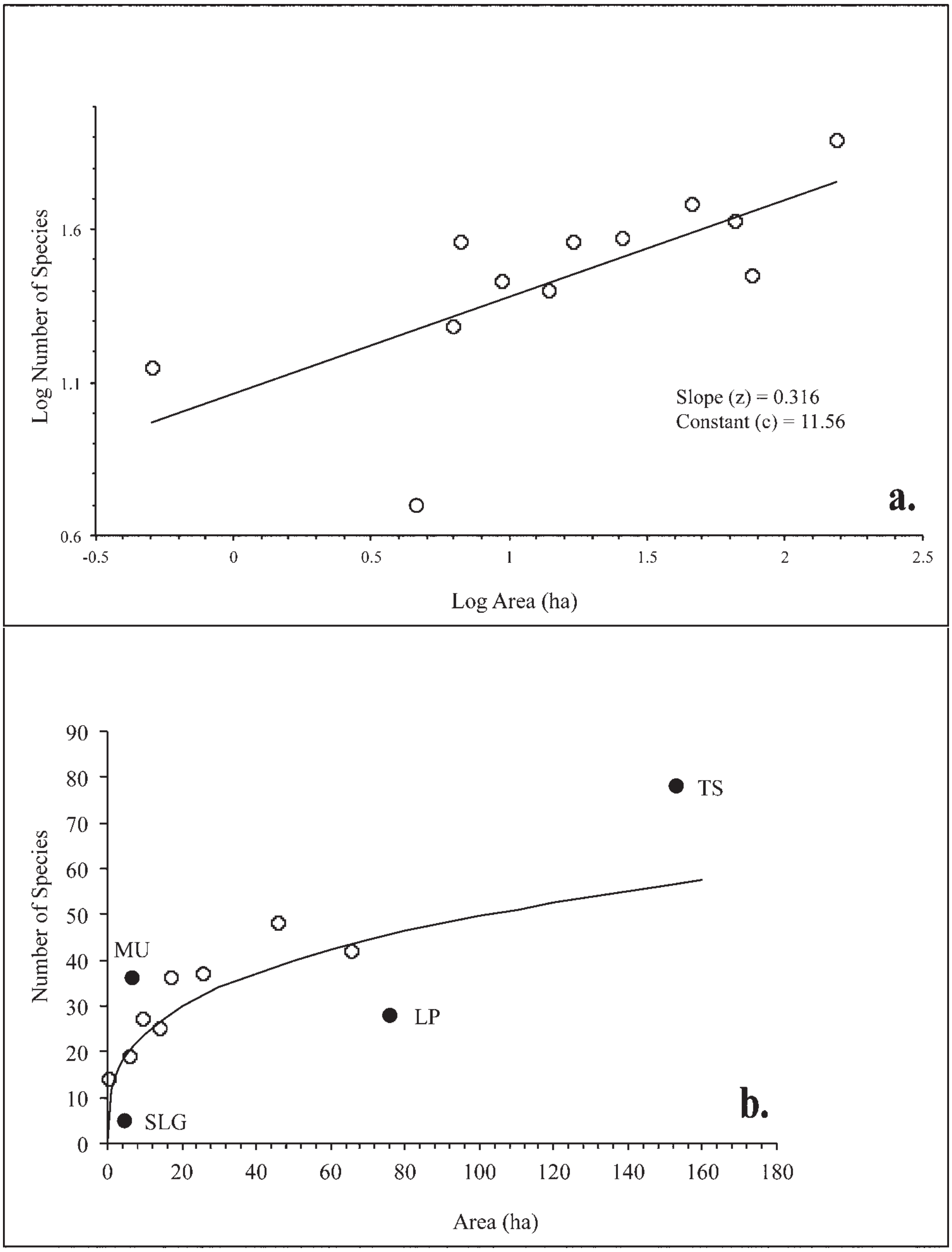

Figure 3. Total perennial food species-area relationship (LogSpecies: LogArea) (a); and curve (Species:Area) (b). In Figure 3b, the black dots are those oases that do not demonstrate a significant relationship to the curve. Mulegé and Todos Santos are above the curve, and San Luis Gonzaga and La Purísima are below the curve.

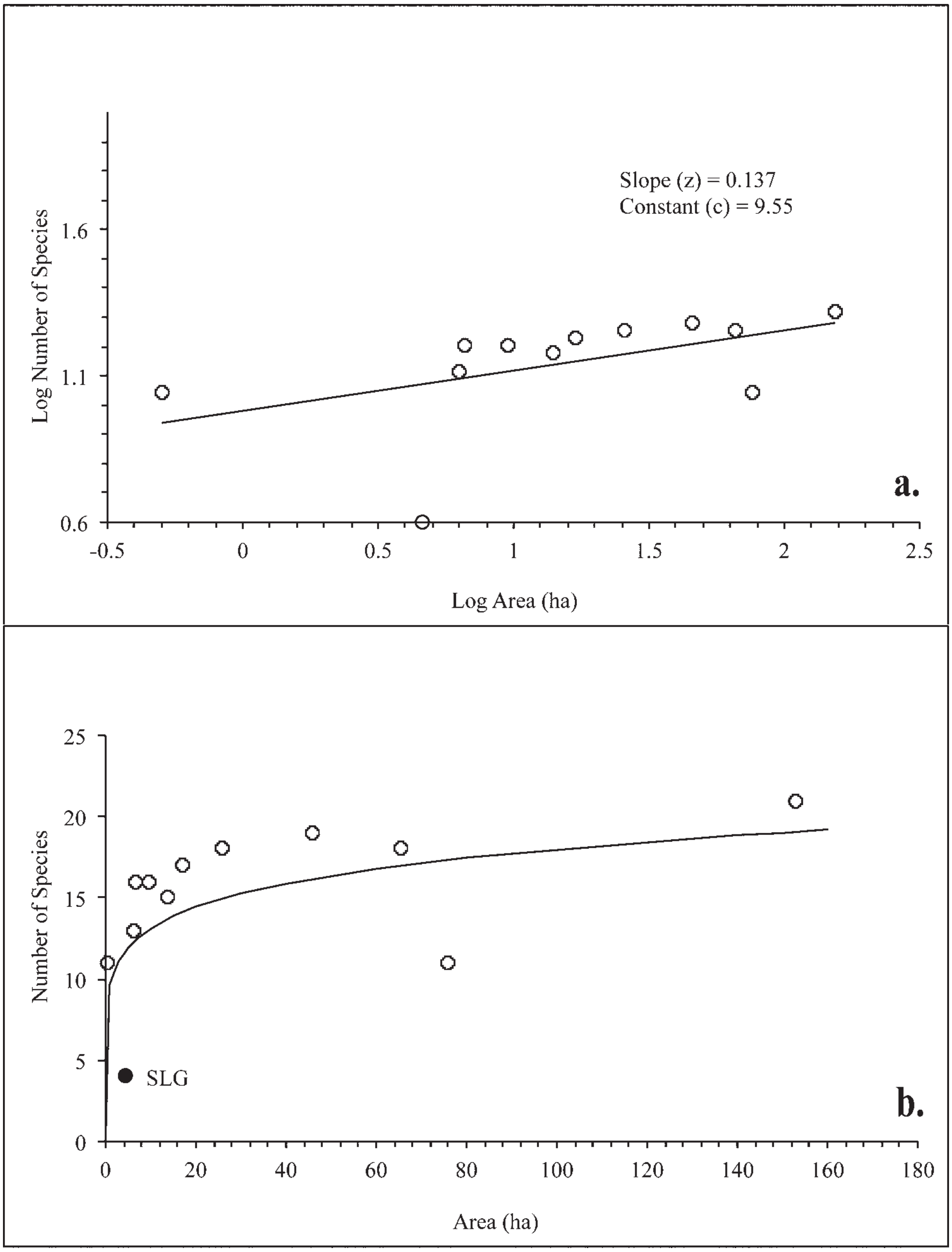

Figure 4. Mission era food species-area relationship (LogSpecies: LogArea) (a) and curve (Species: Area) (b). In figure 4b, San Luis Gonzaga, which shows no significant relationship to the curve, is shown as a black dot.

The slope also demonstrates the number of species shared among the sample plots. Plots that share many of the same species will have a more shallow slope than plots that share few species, which have slopes of higher values (Collins, Vázquez, and Sanders 2002). In the Mission era Species graph (Figure 4a), the slope

Table 5. Statistical results for oasis total perennial crop species-area curve. Results that show no significance are bolded ($p < .05$).

Oasis	Area in cultivation	Number of species	Predicted value	Pearson residual	P value
SB	6.29	19	20.7	−0.37	0.3556
SG	9.47	27	23.5	0.71	0.2382
SI	25.68	37	32.3	0.83	0.2032
GU	0.50	14	9.3	1.53	0.0624
MU	**6.64**	**36**	**21.0**	**3.26**	**0.0006**
LP	**75.93**	**28**	**45.5**	**−2.59**	**0.0048**
CU	65.60	42	43.4	−0.22	0.4141
SJ	17.01	36	28.3	1.44	0.0750
LD	13.97	25	26.6	−0.32	0.3763
SLG	**4.60**	**5**	**18.7**	**−3.17**	**0.0008**
TS	**153.15**	**78**	**56.8**	**2.81**	**0.0024**
SC	45.80	48	38.8	1.48	0.0690

of the line is shallower, indicating that all of the oases share many of the mission crops, and the sites in the Total Species graph (Figure 3a) share fewer species (as would be expected). Also in the Total Species slope, the number of species continues to increase with area at a higher rate than the Mission era Species slope, indicating that levels of mission crops reach saturation quickly in the oases, and larger oases do not hold many more mission species than smaller oases.

Applying this information to oasis agrobiodiversity conservation, we suggest that a reduction in area for ''island,'' or total species (Figures 3a and 3b) lowers the diversity more than a reduction of area does for ''mainland'' or mission species (Figures 4a and 4b). This indicates that ''losing'' one or more of the oases will result in a greater loss of newer species introductions than in a loss of the mission species. Again, because many of the newer species introductions are limited to a single garden or oasis, they are more vulnerable to social and environmental stochasticity. These data show that to preserve the total perennial crop diversity and the associated farming systems and knowledge, the oases should be considered as interdependent and interconnected sites, where some oases may serve as source areas for those ''sink areas'' more vulnerable to species loss.

Table 6. Statistical results for oasis Mission era species-area relationship. Results that show no significance are bolded ($p < .05$).

Oasis	Area in cultivation	Number of species	Predicted values	Pearson residual	P values
SB	6.29	13	12.3	0.20	0.4206
SG	9.47	16	13.0	0.83	0.2035
SI	25.68	18	14.9	0.80	0.2127
GU	0.50	11	8.7	0.78	0.2172
MU	6.64	16	12.4	1.03	0.1525
LP	75.93	11	17.3	−1.52	0.0645
CU	65.60	18	17.0	0.25	0.4016
SJ	17.01	17	14.1	0.77	0.2199
LD	13.97	15	13.7	0.34	0.3652
SLG	**4.60**	**4**	**11.8**	**−2.27**	**0.0117**
TS	153.15	21	19.1	0.44	0.3294
SC	45.80	19	16.2	0.71	0.2396

Analyzing the oases individually against the two predictive species-area power curves (Total species and Mission era species), we see that the oases show more variation with respect to the total species diversity than with respect to the Mission era species (Figures 3b and 4b, Tables 5 and 6). In other words, while all perennial crop species in the oases tend to increase with area in cultivation, our data indicate that calculations of only the Mission era crops in the oases more closely align with the species-area power curve than calculations for the total perennial crop species. This can be seen in the number of oases that show significant relationships when we tested the individual fit of each oasis to the Total Perennial Species and Mission era descriptive power curves using Pearson residuals (Tables 5 and 6).

For the Total Species analysis, eight of the 12 oases demonstrate a significant relationship with the predictive species-area curve at the 95-percent confidence level (Figure 3b, Table 5). Four of the sites did not show significance with the predictive model–two above the curve, and two below. The sites that show no significance above the curve are Mulegé and Todos Santos. Tourist development in Mulegé has expanded on much of the arable land and the remaining few gardens are small, but maintain and a relatively high number of species; the ratio of total species to total area in cultivation is much higher than predicted by the curve. Todos Santos graphs much higher than the expected on the species-area curve because this oasis had by far the highest number of total perennial crop species with many exotics and recent crop introductions due to its tropical climate, high foreign population, and number of professional horticulturalists and nursery owners living in the oasis. The gentle topography of Todos Santos does not constrain arable land and the region has very productive springs. Indeed despite the 150 hectares in cultivation, excess spring water flows directly into the ocean. San Luis Gonzaga falls below its expected value because it has only one garden and five perennial crop species remaining due to land tenure disputes and a damaged dam and *acequia* system. La Purísima also lies below its expected value on the curve because of water issues—much of the spring water historically used in this oasis has been diverted to the upstream community of San Isidro, leaving many of the field gardens fallow. The spring water that does reach La Purísima is salty and intermittent, leading to a decline even in the number of untended crops that grow along the irrigation canal.

When the same calculations are applied only to species introduced during the Mission era (Figures 4b; Table 6), all oases except San Luis Gonzaga demonstrate significance with respect to the predictive species-area curve. All oases surveyed held some or all of the 21 Mission era species, and larger oases tended to hold more than smaller oases. While total species richness within the oases is influenced by many factors, including proximity to highways, urban development, tourism, agricultural market integration and other social, political, economic and environmental factors, these analyses indicate that such factors do not have as strong of an influence on mission species richness within oases, which tends to increase simply as area in cultivation increases.

Rank Abundance Relationships

We differentiate three general patterns in species distribution in the gardens: 1) oases that show relatively even descent lines (San Javier, Comondú and San

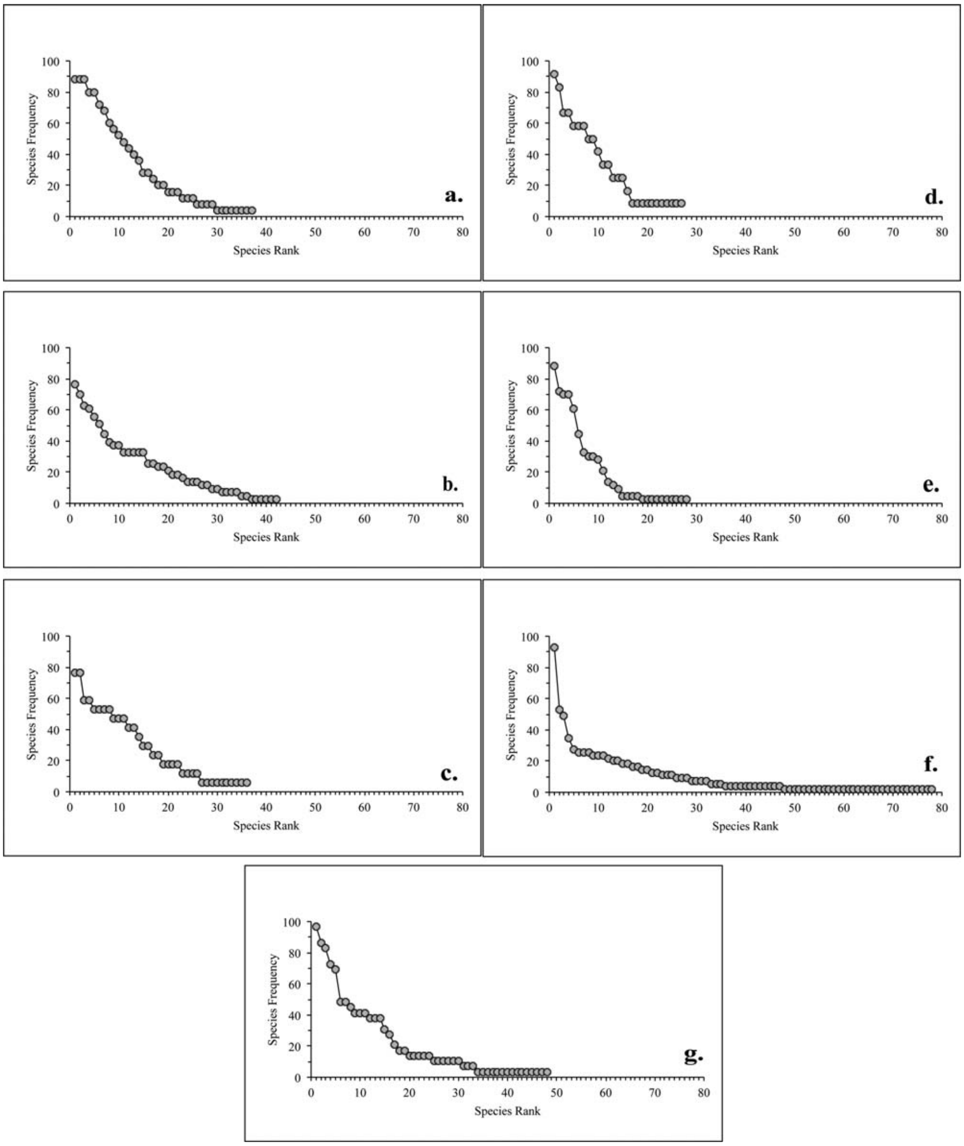

Figure 5. Rank-abundance curves for San Ignacio(a); Comondú (b), San Javier (c); Santa Gertrudis (d); La Purísima (e); Todos Santos (f); and Santiago (g).

Ignacio); 2) oases that show steep, short descent patterns (Santa Gertrudis and La Purísima) and 3) oases that show initial steep declines and then flatten out to include many other species (Santiago and Todos Santos) (Figures 5a–g).

The oases with the most even descent lines, and therefore the greatest long-term potential of retaining agrobiodiversity because the diversity is more evenly distributed in the gardens, are San Javier, Comondú and San Ignacio (Figures 5a–c). These oases will be more resilient in the face of environmental and social stochasticity because farmers tend to each cultivate a diversity of species and ''share'' the responsibility of species conservation. These are all mid-sized oases, ranking in the middle of the species-area curve, and they are also located in the middle of the peninsula—meaning central in latitude and at the midpoint between the Pacific and gulf coasts. All are somewhat accessible—neither too isolated, nor too integrated; both of these extremes tend to result in species and farming system disappearance (De Grenade 2013). These oases were located far from markets and agricultural resource centers, and had limited access to seed, fertilizers, and machinery, and thus had little industrial agricultural development. Their location distant from either coast tends to conserve traditional farming methods because the oases receive fewer foreign tourists and residents.

The oases with over all species and few species with highest representation in the gardens show short, steep declines (Santa Gertrudis and La Purísima, Figures 5d–e). These would be the most vulnerable to species loss because they have relatively few species to begin with, and few farmers, and many species are found in only a few of the gardens. These are the oases where conservation measures might have highest priority. Corroborating this finding, we noted one species fewer in Santa Gertrudis between our 2010 rapid surveys and the 2011 surveys (Nabhan et al. 2010).

Those oases with steep initial declines, but higher overall species diversity (Santiago and Todos Santos, Figures 5f–g) have few species with high frequency and many species with lower occurrence rates in the gardens. Both of these oases lie in the southern peninsula where arable land and water are abundant, supporting many gardens and high species diversity. Both towns have large populations, including many foreign residents that bring in new species, and strong agricultural economies based on a few export crops. These oases would also be vulnerable to losing single species, though the systems here are more robust in general because of the high species richness and high number of farmers and gardens.

Oasis Farming Systems and Practices

Based on our observations of the Baja California peninsula oases, we found that the oasis comprise an archipelago of unique agroecological landscapes developed for and through the specific geography of the oases and the peninsula. The landscape informs the design of the fields, especially in narrow canyons. The slope and track of the canal system also influences the location and extent of the arable land. Topography and soils give the gardens their slope and substrate, though terracing and soil development moderate these factors. In some of the ranch gardens, farmers had hauled soil in using mules to create gardens in the rocky canyon sides. These oasis gardens show structural diversity and an integrated native and domesticated animal and plant agricultural system both within and among the oases. They are also, in most cases, small-scale farming systems that utilize crop rotation, livestock integration, mixed annuals and perennials, and structural diversity or crop stratification. In many of the gardens, perennial fruit plants grow along the irrigation ditches and form hedgerows between fields, providing shade, windbreaks, and attraction for predatory species and pollinators. Open areas between yield forage crops, grains, legumes, vegetable crops, or are planted in rows of perennial fruit crops or vineyards.

Livestock, including cattle, burros, hair sheep and goats are grazed in the gardens during fallow periods, or tethered to tall trees in the huertas and fed grass and herbacious plants harvested by sickle. These mixed-method systems offer a defense against pest epidemics, drought, and floods and enable long-term viability of the farms and the farm families.

The systems integrate wild and introduced species in highly interactive, though not truly mutualistic relationships; date palms along with native California fan palms grow in the riparian eco-systems, providing food resources to temporary and permanent resident species, ecosystem structure for nesting and habitat sites, shade for understory species and organic matter that alters soil composition and moisture. Grapevines, pomegranate bushes and fig trees as understory introduced species also provide food and habitat resources as well as contribute to the agroecosystem structure and function. Rosenzweig (1995) noted in wild systems that the more species share a particular space, the more habitats they distinguish within the space; in oasis gardens, the more complex the garden structure, the more agriculture species likely to be found. Rosenzweig also notes that the highest levels of biodiversity are often correlated with intermediate disturbance. Within oasis gardens, our general observations show that the highest agrobiodiversity and biodiversity are often associated with traditional management systems where few if any mechanization is utilized in the garden. Small sections of fields are tilled by hand for annual crops and other sections left with perennial fruit trees and vines and forage crops. The fields with the lowest biodiversity are those almost abandoned and those converted to extreme industrial agricultural practices. When considered as an archipelago or interconnected system, the series of oases—with the range of industrial agricultural and small-scale agriculture sites, the combinations of irrigation systems, and the abandoned to heavily managed spaces—represent higher compositional, structural, and functional diversity than systems of only small-scale agriculture.

The farmers interviewed also gave us a range of agricultural perceptions and knowledges and utilized many different types of practices, from traditional to highly mechanized. These are elaborated in Routson (2012). In general, we found many shared techniques and methods described by farmers in all oases. The pool of agricultural knowledge in the oases is representative of a short agricultural history (three centuries) and a limited population of farmers connected through trade and intermittent travel to festivals,.The methods that survived over the isolation and distance may be simple techniques that were easy to remember and transfer orally or by demonstration.

As examples of specific traditional farming practices shared among the oases, most farmers pruned mission grapevine spurs to ''two buds'' in February, and did not prune fruit trees within the field gardens at all except to remove dead branches. In the southern commercial citrus and mango orchards in Santiago and Todos Santos, farmers pruned more rigorously in the spring, either before flowering (mangos) or following harvest (citrus). Most described similar methods reproducing perennial fruit trees and vines–either separating the young plants from the mother tree at or near the base and plant them in other locations, or taking the trimmings of the branches or vines and keeping them moist, in a mix of soil, sand and organic matter until roots sprout, and the cuttings become individual plants. Other methods utilized include air-rooting techniques of wrapping moist soil and organic material around a higher section of a branch and then parting the branch when roots sprout inside the soil ball, or bending a branch to the ground and pinning it to the moist earth until roots sprout, called *acodo*. Most gave importance to the stage of the moon, but many gave opposite recommendations (planting and pruning on the full moon or new moon) or simply could not remember. In general farmers did not practice grafting. Farmers also used seeds of perennial trees as a means of reproduction, especially if the seeds were large and did not require difficult processes or treatment for the seed to germinate. These techniques were all ones that could be easily transferred among farmers or through generations of farmers.

The knowledges described showed more variation among individual farmers than among oases, though many of the people interviewed had lived for three to five generations at the same oasis. Often traditional methods using hand and animal labor and mechanized cultivation methods were both utilized in the oases, though the oases with better access to highways tended to have more mechanized agricultural, more use of synthetic fertilizers, and greater orientation toward commercial production. We found that traditional farming methods were better preserved in some of the small and mid-sized, more isolated oases because limited land and/or water resources had made it not worth developing industrial agriculture within the oases, and limited access to the agricultural resource centers.

Oasis Political Ecology

Interviews related to our framework of oasis political ecology reveal that the agrobiodiversity in the oases is partially shaped by many factors, but determined absolutely by no single factor. We noted several driving factors, including the physical geography of the oasis, geographical isolation and access to markets, industrialization of agriculture, urban development, water quantity and quality limitations, proximity to cities, highways, airports, and ports, and area of arable land. Oases on either spectrum of geographic isolation—those too isolated or too urbanized, both demonstrated an absence of heritage crop species and traditional farming systems (De Grenade 2013). Otherwise, proximity to resource centers, highways, ports or airports, and the coast tended to increase the overall species richness, but not the frequency of occurrence. This finding is partially due to tourists, foreign residents, and those from the Mexican mainland with second homes on the peninsula, commercial agricultural production, and the immigrant laborers introducing more perennial crops species within individual field gardens, but these species have not had time to disperse within or among the oases. Land tenure type and conflicts over land ownership were most likely the cause of the low diversity in San Luis Gonzaga and to some degree in Comondú and Santa Gertrudis, whereas private property ownership was correlated with higher total perennial crop diversity in San Ignacio, Mulegé, Todos Santos, and Santiago de los Coras.

Problems in water access, quality, and quantity were the primary cause of low species diversity in La Purísima and noted by community members to have affected crop diversity in Mulegé. Water governance is the power management structure that most closely matches the scale of the oases, a form of governance internal to the oases. Higher levels of agrobiodiversity and vibrant agroecosystems exist where there is governance at the oasis scale, because the community has more control over its degree of autonomy and integration. Autonomy in oases requires self-governance; the degree of organization within the self-governing bodies allows them to negotiate the modes of connectivity, while maintaining solidarity. It is the relative autonomy of these oases that allows them to retain agrobiodiversity. This provides insights into governing oases more generally; if governance matches the ecological and agricultural scale, the integrity of the oasis can be maintained.

We discovered that the oasis agrobiodiversity is produced through both intentional and unintentional actions. It is a combination of that which is actively managed and cultivated and that which survives a historical moment, that which is planted and maintained, and that which grows or survives because of the natural mesic environment or the inefficiencies in the system. Species that were once in demand as export crops continue to thrive in the oases even after demand and commercial production has ceased, and similarly, species that once held important cultural roles now grow almost wild along irrigation ditches, self-propagating through clones or seeds dispersed through animals.

Oasis Cultural Practices

All oases surveyed demonstrated persistence of heritage Mission era species and intact cultural practices and food knowledges. Oral history and interview data revealed common perceptions of oasis and peninsula identities, pride in oasis culture, and memories of foodways, harvesting and food processing techniques and recipes, and descriptions of the importance of cultural events such as festivals in maintaining these practices. Refer to Routson (2012) and De Grenade and Nabhan (2013) for an expanded discussion of the Baja California oasis cultural ecology. One key finding is that as with the farming practices, most of the processes of preparing and processing these food resources are similar throughout the peninsula, with more variation among individuals than among the oases. This indicates that the peninsula landscape, or interconnected archipelago of oases, has undergone more independent cultural evolution than the individual oases, and that the oases operate together as a collective unit of agricultural and cultural practice and knowledge sites.

The degree of active cultural practices did vary among oases. Wine making, though the process was common knowledge in all oases surveyed, was only actively practiced in San Ignacio, Comondú, and La Purísima. This was partly connected to the presence of sufficient quantities of grape vines in these missions, for example the missions of Todos Santos and Santiago in the south of the peninsula were too tropical to produce grapes, though residents did speak of the practice of making wine from the wild grapes that grow in the mountains. The missions of San Javier, San Luis Gonzaga, Los Dolores, Guadalupe, and Mulegé, historically areas of grape production, did not have any sizeable grape vineyards. In a few cases, residents gave personal reasons for not producing wine, such as abstinence from alcohol or a lack of desire to undertake the rigorous process any longer.

Processing of sugarcane followed similar patterns. Sugar mills only existed in the oasis of Comondú, though residents in both La Purísima and San Ignacio had access to nearby mills. Otherwise, residents said that only a few remote ranches and smaller oases had mills and actively milled and processed sugarcane. Unlike grapes, which are limited by climate, sugarcane was historically grown in all oases, especially in Todos Santos, Santiago and Mulegé—three of the most urbanized oases that we surveyed, and all distinctly lacking in this traditional practice as well as in large cultivated areas of sugarcane. The practice of making dulces was more widespread and documented and described in all oases surveyed except San Luis Gonzaga and Guadalupe, both where the number of living fruit trees were few.

Importantly, the small and mid-sized, mid-peninsula oases (San Borja, Santa Gertrudis, San Ignacio, La Purísima, Comondú, and San Javier) that also showed the most potential for heritage crop persistence on the rank-abundance graphs and strong traditional farming practices, all showed a high retention of traditional food processing practices. These data indicate that active cultural practices are directly tied to the presence of crops within the oases and oasis gardens. The higher prevalence of crops within the oasis gardens offers community members more access and this in turn relates to the prevalence of the traditional foodways practices. Memories tended to be less tied to the actual trees—many of the agricultural changes within the oasis occurred since the construction of the transpeninsula highway in the 1970s, and residents are at most two generations removed from times when most of these practices were commonplace. Many of the techniques, recipes, and traditions are still held in living memory if not actively practiced. All of the oases tended to be connected by familial networks and pilgrimages for annual religious celebrations where families and oasis residents can ''re-source'' traditional practices in the same way that they can re-source agricultural species.

Discussion

We confirm that Baja California oases harbor Mission era and modern crop introductions (89 total perennial food crop species, with 21 Mission era species) and demonstrate a strong tendency to retain historically-introduced perennial food crop species over time. Compared to the agrobiodiversity of Sonoran oases first reported in this journal three decades ago by Nabhan et al. (1982), these oases on the other side of the Gulf of California remain far more biologically diverse and structurally complex. They show a diversity of structural, compositional, and functional complexity in their cultural management of the agricultural systems and integrated use of native and domesticated plant and animal species.

Our decision to focus on perennial species instead of varieties or land races, however, might be underestimating or possibly obscuring the broader range of genetic and cultural resources that these oases hold. Many of the oasis farmers we interviewed also distinguish annual crop varieties by color, size, ripening time, and flavor; of course, some perennial varieties are well-recognized clones of a single parent type, some distinct types reproduced by seed, others seedling types from heterogeneous species or progeny of cross pollination between varieties that have not been widely cloned or recognized. In addition, our surveys of crop species and varieties were not detailed enough to distinguish such unique selections as the original sweet orange, reproduced by seed from the mission times, from the standard grafted varieties, present now in many commercial orchards within oases.

We offer theses baseline ''snapshots'' of agrobiodiversity at particular places and times to encourage others to further document the genetic diversity represented in these heritage species. The relatively short cultivation history and the clonal propagation techniques do not facilitate varietal evolution or adaptation to the region; however this does not rule out the possibility for some small degree of genetic difference, or the development of different land races or distinct hybrids that are selected over time for environmental or cultural characteristics as Soleri et al. (2010) suggest for Mission olives in the nearby Catalina Islands off Alta California. These oases are likely to retain genetic material that while once common in other areas of the world which may have been lost in their source areas, just as some arcane forms of Medieval Iberian Spanish are still utilized here in a manner similar to the linguistic and food crop relicts well-known from Appalachia (Veteto 2010). The Baja California peninsula oases represent a series of ''end of the line'' agricultural landscapes that may collectively function as a genotype repository just as it serves as an agroecological and cultural repository of traditional farming and foodways practices. These are not merely valuable from a historical perspective but may provide options for a more sustainable agricultural future in the face of an increasingly arid climatic scenario projected for the next century (Nabhan 2013).

Our decision to focus on perennial food crops to allow us to analyze the existence of Mission era species and varieties also limits our ability to compare total diversity within the mission oases to other agroforestry and agrobiodiversity studies. For instance, Geubauer et al. (2007) found 107 total species in Omani oasis gardens, including annual and perennial fruit, forage, vegetable, grain, medicinal and ornamental crops. Many authors have addressed species richness in tropical agroforestry systems. Kabir and Webb (2008) recorded 419 total species in Bangledeshi home gardens, including native, cultivated and exotic perennials and annuals. Hemp (2006) recorded 520 vascular plant species in Chaga homegardens in the Mount Kilamanjaro region, including 99 cultivated species. Nevertheless, all oases surveyed on the Baja California peninsula showed retention of some of the original mission species, indicating that these oases are sites worthy of protection as historic agroecological landscapes and reservoirs or refugia of relict heritage folk taxa.

The patterns of species richness per area among oases are notable–species-area curve calculations reveal that larger oases do not favor the retention of mission species any more than small oases. Patterns of agrobiodiversity within oases, addressed through rank-abundance curves, show that the oases with the most even distribution of species and therefore the highest potential of species persistence are the mid-sized, mid-peninsula oases of San Javier, Comondú, and San Ignacio that also closely fit the traditional species-area curve. The smaller, more isolated oases tended to have the lowest overall agrobiodiversity and be the most vulnerable to species loss. The two southern oases demonstrated the highest numbers of total species—of old and new introductions together—due to increased accessibility, foreign interest, industrialization of the agriculture, and strong agricultural economies. The mid-sized, mid-peninsula oases showed the greatest potential of heritage crop species retention as well as strong traditional farming practices and cultural foodways practices.

Conclusions

The critical conservation-oriented finding in this research is that high diversity of perennial food crops are partitioned among several oases so that conservation efforts focused on one or a few key sites will likely *not* retain as much of the total crop diversity represented on the peninsula as an ''archipelago approach'' might do. Oases are dynamic landscapes due to the frequency of hurricanes and floods, droughts, and human population changes as well as the nature of the sites as ''source and sink'' populations of heritage crops (Pulliam 1988). The geographic diversity of these oases, that is, the physical structure, distance from one another, and location on the peninsula with respect to urban development, highways, and industrialized agricultural production areas, produces the very differences needed to maintain agricultural diversity over long time periods and dispersed spatial patterns. We see farmers differentially engaging with environmental, political, economic, and cultural processes, and these same factors differentially working on or shaping the farmers, the oases, and the gardens. The geography of these oases as agroriparian landscapes on the Baja California peninsula, isolated by desert and saltwater and connected through families, migration, and transportation and communication networks, creates a chain of similar, yet distinct agricultural nuclei. This island biogeographic pattern analysis strongly suggests that oases should be considered components of an interconnected system or archipelago of heritage sites.

The Baja California archipelago of cultivated oases cumulatively (or collectively) feature and retain unique crop assemblages and traditional knowledge and practices that substantively differ from other sets of cultivated desert oases in Central Asia, the Middle East, and North Africa. As such, they could potentially be promoted as sites of informal and formal *in situ* conservation of farmer-bred genotyopes and traditional ecological knowledge of unique enough value that it may interest international programs such as UNESCO, Bioversity, FAO and GIAHS. If such international recognition is to proceed, we suggest that *Californio* farmers, gardeners and home cooks be engaged of every step of decision-making, from formulation, definition, designation (or not), benefits-sharing and landscape-level management. The three-century, shared history of agriculture in the oases has generated a *Californio* culture that continues to inform peninsula residents, shape identity, and support the persistence of heritage crop species and traditional agricultural practices. Promoting the oases as unique cultural landscapes through direct interaction with oasis and ranch families, conservation efforts through governmental and non-governmental organizations, and generating international recognition of the spaces which function as biologically and culturally diverse refugia, are critical conservation decisions to consider as the peninsula becomes more urbanized, globalized, and tourism-driven.

At the same time, we see an emerging need for cross-cultural and geographic comparisons of agrobiodiversity which use the same measures, methodologies, and ethics. A recent paper of the measurement of agrobiodiversity (Love and Spaner 2007) is a partial start toward this, but a more effective and lasting means to foster such comparisons is by ''open source'' sharing of methodologies and related computational software as well as farmer-researcher ethical protocols that allow these comparisons to function across time and space. We look forward to being part of such a larger discussion.

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References Cited

Adams, D.K. and A.C. Comrie
1997 The North American Monsoon. *Bulletin of the American Meteorological Society* 78: 2197–2213.

Altieri, M.A. and L.C. Merrick
1987 In Situ Conservation of Crop Genetic Resources through Maintenance of Traditional Farming Systems. *Economic Botany* 41:86–96.

Aradhya, M.K., E. Stover, D. Velasco, and A. Koehmstedt
2010 Genetic Structure and Differentiation in Cultivated Fig (*Ficus carica* L.). *Genetica* 138:681–694.

Aschmann, H.
1967 *The Central Desert of Baja California: Demography and Ecology*. Manessier Publishing Company, Riverside, CA.

Baegert, J.J.
1979 *Observations in Lower California*. University of California Press, Berkeley, CA. Available at: http://ark.cdlib.org/ark:/13030/ft5r29n9xv/. Accessed May 2012.

Brush, S.B. ed.
2000 *Genes in the Field: On-Farm Conservation of Crop Diversity*. Lewis Publishers, Boca Raton, FL.

Cariño Olvera, M.M.
1996 *Historia de las Relaciones Hombre/Naturaleza en Baja California Sur, 1500–1940*. Centro de Investigaciones Biologicas del Noroeste, A.C., 2nd edition, UABCS SEP, La Paz, México.

Cariño Olvera, M.M., A. Breceda, A. Ortega, and L. Castorena
2013 *Evocando El Eden: Conocimiento, Valoracióny Problemática del Oasis de Los Comondú*. Icaria Editorial, Barcelona, Spain.

Clavijero, F.J.
2007 *Historia de la Antigua o Baja California*. Editorial Porrúa, México, D.F.

Collins, M.D., D.P. Vázquez, and N.J. Sanders
2002 Species-Area Curves, Homogenization and the Loss of Global Diversity. *Evolutionary Ecology Research* 4:457–464.

Comrie, A.C. and E.C. Glenn
1998 Principle Components-Based Regionalization of the Precipitation Regimes across the Southwest United States and Northern Mexico, with an Application to Monsoon Precipitation Variability. *Climate Research* 10: 201–215.

CONAGUA.
2011 Comisión Nacional de Agua. La Paz, México. Information requested in May 2011.

Crosby, H.W.
1994 *Antigua California: Mission and Colony on the Peninsular Frontier, 1697–1768*. University of New Mexico Press, Albuquerque, NM.

Davis, L.
2006 Baja California's Paleoenvironmental Context. In *The Prehistory of Baja California: Advances in Archeology of the Forgotten Peninsula*, edited by D. Laylander and J.D. Moore. University of Florida Press, Gainsville, FL.

Del Barco, M.
1980 *A Natural History of Baja California*. Dawson's Bookshop, Los Angeles, CA.

De Grenade, R. and G.P. Nabhan
2013 Baja California Peninsula Oases: An Agro-Biodiversity of Isolation and Integration. *Journal of Applied Geography* 41:24–35.

De Mora, Fr.V., D. Gines, and M. Perez
1774 *California Antigua: Padrones y Noticias de Estado de Las Misiones en el Año del 1774*. Archivo General de la Nacion, México. Provincias Internas (092)/Vol 166. Accessed on March 1–4 2011.

Del Rio, I.
2003 *El Regímen Jesuítico de la Antigua California*. Universidad Nacional Autónoma de México; Instituto de Investigaciones Históricas, México, D.F.

Dengler, J.
2009 Which Function Describes the Species-Area Relationship Best? A Review and Empirical Evaluation. *Journal of Biogeography* 36:728–744.

Dunmire, W.W.
2004 *Gardens of New Spain: How Mediterranean Plants and Foods Changed America*. University of Texas Press, Austin, TX.

Engelhardt, Z.
1908 *The Missions and Missionaries of California, Vol. I. Lower California*. The James H. Barry Company, San Francisco, CA.

Frese, L., G.K. Bjørn, F. Franca, B.V. Ford-Lloyd, C.U. Germeier, J.M. Iriondo, A. Katsiotis, S.P. Kell, V. Negri, and M.A.A. Pinheiro de Carvalho
2012 Genetic Reserve Conservation of European Crop Wild Relative and Landrace Diversity. In *Agrobiodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces*, edited by N. Maxted, M. Ehsan Dulloo, B.V. Ford-Lloyd, L. Frese, J. Iriondo and M.A.A. Pinheiro de Carvalho, pp. 1–6. CABI International, Wallingford, UK.

Gebauer, J., E. Luedeling, K. Hammer, M. Nagieb, and A. Buerkert
2007 Mountain Oases in Northern Oman: An Environment for Evolution and In Situ Conservation of Plant Genetic Resources. *Genetic Resources and Crop Evolution* 54: 465–481.

GRIN: Germplasm Resources Information Network [Online Database].
National Germplasm Resources Laboratory, Beltsville, Maryland. Available at: http://www.ars-grin.gov. Accessed in March 2011.

Hammer, K., J. Gebauer, S. Al Khanjari, and A. Buerkert
2009 Oman at the Cross-Roads of Inter-Regional Exchange of Cultivated Plants. *Genetic Resources and Crop Evolution* 56: 547–560.

Hammer, K. and Y. Teklu
2008 Plant Genetic Resources: Selected Issues from Genetic Erosion to Genetic Engineering. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 109:15–50.

Hemp, A.
2006 The Banana Forests of Kilimanjaro: Biodiversity and Conservation of the Chagga Homegardens. *Biodiversity and Conservation* 15:1193–1217.

Janick, J. and R.E. Paull
2008 *The Encyclopedia of Fruits and Nuts*. CAB International, Wallingford, UK.

Kabir, Md. E. and E.L. Webb
2008 Can Homegardens Conserve Biodiversity in Bangladesh? *Biotropica* 40:95–103.

Lassépas, U.U.
1859 *Historia de la Colonización de la Baja California*. Decreto de 10 Marzo de 1857. Vicente Garcia Torres, México, D.F.

Lenné, J.M.
2011 Food Security and Agrobiodiversity Management. In *Agrobiodiversity Management and Food Security: A Critical Review*, edited by Lenné, J.M. and D. Wood, pp. 12–25. CAB International, London, UK.

León de la Luz, J.L. and R.D. Cadena
2006 Hydrophytes of the Oases in the Sierra de la Giganta of Central Baja California Sur, México: Floristic Composition and Conservation Status. *Journal of Arid Environments* 67:553–565.

Love, B. and D. Spaner
2007 Agrobiodiversity: Its Value, Measurement, and Conservation in the Context of Sustainable Agriculture. *Journal of Sustainable Agriculture* 31:53–82.

Maya, Y., R. Coria, and R. Dominguez
1997 Caracterización de Los Oasis. In *Los Oasis de La Península de Baja California*, edited by L. Arriaga and R.Rodríguez Estrella, 5–26. Centro de Investigaciones Biológicas de Noroeste, La Paz, BCS, México.

Minnich, R.A., E.F. Vizcaíno, and R.J. Dizzani
2000 The El Niño/Southern Oscillation and Precipitation Variability in Baja California, México. *Atmósfera* 13:1–20.

Nabhan, G.P.
2007 Agrobiodiversity Change in a Saharan Desert Oasis, 1919–2006: Historic Shifts in Tasiwit (Berber) and Bedouin Crop Inventories of Siwa, Egypt. *Economic Botany* 61: 31–43.
2012 *Desert Terroir: Exploring the Unique Flavors and Sundry Places of the Borderlands*. University of Texas Press, Austin, TX.
2013 *Growing Food in a Hotter, Drier Land: Lessons from Desert Farmers on Adapting to Climate Uncertainty*. Chelsea Green Publishing, White River Junction, VT.

Nabhan, G.P., A.M. Rea, K.L. Reichhardt, E. Mellink, and C.F. Hutchinson
1982 Papago Influences on Habitat and Biotic Diversity: Quitovac Ethnoecology. *Journal of Ethnobiology* 2:124–143.

Nabhan, G.P., J. Garcia, R. Routson, K. Routson, and M.M. Cariño Olvera
2010 Desert Oases as Genetic Refugia of Heritage Crops: Persistance of Forgotten Fruits in the Mission Orchards of Baja California, México. *International Journal of Biodiversity and Conservation* 2:56–69.

Ortiz, R.
2011 Agrobiodiversity Management for Climate Change. In *Agrobiodiversity Management for Food Security: A Critical Review*, edited by Lenné, J.M. and D. Wood, pp. 189–211. CAB International; London, UK.

Pimentel, D., U. Stachow, D.A. Takacs, H.W. Brubaker, A.R. Dumas, J.T. Meaney, J.A.S. O'Neil, D.E. Onsi, and D.B. Corzilius
1992 Conserving Diversity in Agricultural/Forestry Systems. *Bioscience* 42:3354–3362.

Pulliam, H.R.
1988 Sources, Sinks and Population Regulation. *The American Naturalist* 132:652–661.

Ramón Laca, L.
2003 The Introduction of Cultivated Citrus to Europe via Northern Africa and the Iberian Peninsula. *Economic Botany* 574: 502–514.

Rivera, D., D. Johnson, J. Delgadillo, M.H. Carrillo, C. Obón, R. Krueger, F. Alcarez, S. Ríos, and E. Carreño
2012 Historical Evidence of the Spanish Introduction of Date Palm (*Phoenix dactylifera* L., Arecaceae) into the Americas. *Genetic Resources and Crop Evolution* 60:1433–1452. DOI 10.1007/s10722-012-9932-5.

Rosenzweig, M.L.
1995 *Species Diversity in Space and Time*. Cambridge University Press, Cambridge, UK.

Routson, R.J.
2012 *Conservation of Agrobiodiversity in Baja California Desert Oases*. Unpublished Doctoral Dissertation, Department of Geography, University of Arizona, Tucson, AZ.

Soleri, D., A. Koehmstedt, M.K. Aradhya, V. Politi, and K. Pinney
2010 Comparing the Historic Olive Trees (*Olea europaea* L.) of Santa Cruz Island with Contemporaneous Trees in the Santa Barbara, CA Area: A Case Study of Diversity and Structure in an Introduced Agricultural Species Conserved In Situ. *Genetic Resources and Crop Evolution* 57:973–984.

This, P., T. Lacombe, and M.R. Thomas
2006 Historical Origins and Genetic Diversity of Wine Grapes. *Trends in Genetics* 22:511–519.

Thrupp, L.A.
2000 Linking Agricultural Biodiversity and Food Security: The Valuable Role of Agrobiodiversity for Sustainable Agriculture. *International Affairs* 76:265–281.

USDA (United States Department of Agriculture) Plants Database [online database]. Available at: http://plants.usda.gov. Accessed August 2013.

Venegas, M.
1757 *Noticia de la California: y De Su Conquista Temporal, y Espiritual Hasta el Tiempo Presente*. Viuda de M. Fernandez, Madrid, Spain.

Vernon, E.W.
2002 *Las Misiones Antiguas: The Spanish Missions of Baja California, 1683–1855*. Viejo Press, Santa Barbara, CA.

Veteto, J.R.
2010 *Seeds of Persistence: Agrobiodiversity, Culture and Conservation in the American Mountain South*. Unpublished Doctoral Dissertation, Department of Anthropology, University of Georgia, Athens, GA.

Wiggins, I.L.
1980 *Flora of Baja California*. Stanford University Press, Stanford, CA.

Zizumbo-Villareal, D.
1996 History of the Coconut in México: 1549–1810. *Genetic Resources and Crop Evolution* 43:505–516.