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Full Length Research Paper

Desert oases as genetic refugia of heritage crops: Persistence of forgotten fruits in the mission orchards of Baja California, Mexico

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The first introductions of agricultural crops to desert oases of Baja California, Mexico were initiated by Jesuit missionaries between 1697 and 1768 and historic records from these Jesuits provided a detailed benchmark by which temporal changes in agro-biodiversity can be measured. Longitudinal studies at the agricultural oases on the Baja California peninsula of Mexico can help determine whether such isolated "islands" of cultivation function as refugia or *de facto* reserves for *in situ* conservation of eighteen perennial species introduced by Jesuits. We compared survivorship of these historically introduced perennials at nine oases and determined that at least fifteen of the original eighteen Mission-era introductions of perennial species persist at these Baja California oases and one additional species persists on the peninsula outside of its original historic context. Despite this level of overall persistence, no species is cultivated in all nine oases. The archipelago of cultivated oases in Baja California should be considered as an aggregate worthy of conservation investments, rather than assuming that any single oasis is sufficient to maintain all historic varieties in the future. We use an analysis of the "forgotten fruits" of Baja California's missions and ranchos to propose that the theory of island biogeography may be applicable to conservation planning for agro-biodiversity, as it has been for wild biodiversity nested in isolated habitats.

Key words: Agro-biodiversity; *in situ* conservation, desert oases, heritage foods, heirloom fruits, Mexico, island biogeography, genetic erosion, Baja California.

INTRODUCTION

Over the last quarter century, conservation biologists, crop geneticists and ethnobotanists have proposed that *in situ* conservation of historically important crop varieties be formally adopted and promoted as an effective means to counter genetic erosion, the loss of agro-biodiversity and associated cultural traditions (Altieri and Merrick, 1987; Tuxill and Nabhan, 2001). And yet, few longitudinal studies have documented why (or how) such "informal" *in situ* conservation strategies have functioned in particular agrarian farming landscapes over time, but have failed in others.

Gebauer et al. (2007) and Nabhan (2007) have each documented how, in cultivated oases in two very different desert regions, heritage crop species and "land race" varieties have persisted in island-like agro-habitats even when they have been lost from production areas in the larger landscape. If such differential survival rates, particularly for perennial fruit crops, can be correlated with other ecological, geographic and socioeconomic

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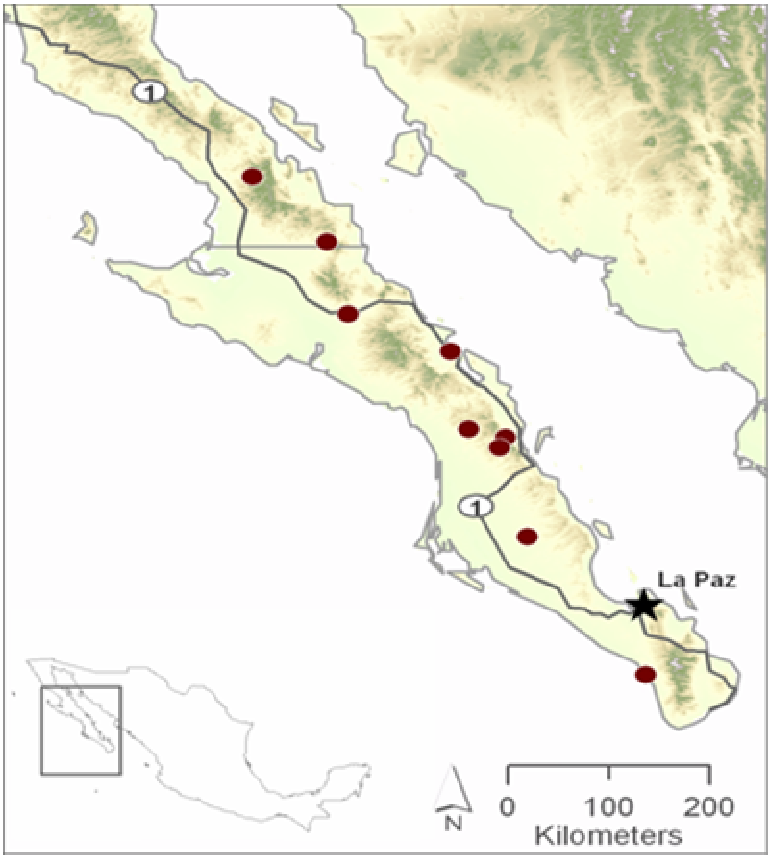

Figure 1. Locations of nine agricultural oases in Baja California, Mexico

factors, they may provide insights into the conditions under which *in situ* conservation efforts may function over time and why.

To test whether island-like desert oases function as refugia or *de facto* reserves for heritage crops, we surveyed nine oases where orchards where established during the Mission era of Baja California, Mexico. We located historic data, which indicate that several fruit tree and other perennial crop species were introduced during the Jesuit phase of the Mission era (1697 to 1768; hereafter referred to as the Jesuit Mission era). Prior to this era, the central and southern regions of the Baja California peninsula were inhabited exclusively by hunter-gatherer cultures. Nearly all of the initial orchard crop introductions to these oases were fruit trees and other perennial crops derived from Old World oases. This era can be compared as the horticultural equivalent of the Krakatoa eruption, which began the fresh recruitment of the wild biota to the oceanic island, a site whose subsequent history of colonization has empirically influenced the field of island biogeography.

Curiously, the perennial crop species composition of the Baja California oases exhibits overlap with that of oases surveyed in Egypt and Oman (Gebauer et al., 2007; Nabhan, 2007). Old World fruit species introduced to Baja California oases during the Jesuit era including Mission olives, dates, pomegranates, grapes and figs have played critical roles in the development of agriculture in the southwestern United States and in northwestern Mexico (Dunmire, 2004; Nabhan, 2008). These historically introduced fruits are known to be at risk of extinction in California and Arizona, although they may survive in other areas (Papadolupou et al., 2002; This et al., 2006; La Mantia et al., 2006; Nabhan, 2008b). However, in southern Arizona and (Alta) California, USA, the introduction and persistence of Mission-era crops appears less dependent upon true oasis habitats, and more associated with fertile floodplains along perennial or intermittent streams (Hardwick 2005).

One of our objectives has been to determine whether the conservation status of heritage perennial crops in the desert oases of Baja California, Mexico is any more secure than it is in other, adjacent regions which were agriculturally colonized during the same era, such as Alta California, Northern Sonora and Southern Arizona. The agricultural oases in Baja California (Figure 1, Table 1) are surrounded by a “sea” of non-arable desert lands on a peninsula bordered by the Gulf of California and the

Table 1. Mission oases on Baja California peninsula surveyed in 2009.

Mission name	Date of establishment	Latitude	Longitude
San Francisco de Borja Adac	1762	N 28º 44' 35.5"	W 113º 45' 13.8"
Santa Gertrudis La Magna de Cadacaman	1751	N 28º 03' 03.8"	W 113º 05' 05.5"
San Ignacio de Kadakaaman	1728	N 27º 17' 00.9"	W 112º 53' 55.3"
Santa Rosalia de Mulegé	1705	N 26º 53' 07.1"	W 111º 59' 10.7"
Visita de Las Parras	1699	N 25º 58' 02.3"	W 111º 29' 29.7"
San Francisco Javier de Biaundo	1699	N 25º 51' 40.0"	W 111º 32' 37.6"
San Jose/San Miguel de Comondú	1708	N 26º 03' 35.2"	W 111º 49' 19.5"
San Luis Gonzaga Chiriyaqui	1733	N 24º 54' 51.0"	W 111º 17' 42.0"
Santa Rosa de las Palmas/Todos Santos/La Huerta	1733	N 23º 26' 37.0"	W 110º 14' 20.0"

Pacific Ocean. Biologists have identified 184 naturally-occurring desert oases on the Baja California peninsula, but only 90 of these are sufficiently fed by year-round flows of groundwater that emerge from springs or seeps so as to provide moisture for extensive riparian ecosystems, or, in a limited number of cases, for agriculture as well (Rodriguez-Estrella et al., 2004). Specifically, agriculture was initiated during the seventeenth and eighteenth centuries in only a few of these oases where missions and *visitas* were established during Spanish military invasion and Jesuit missionization (Carino-Olvera, 1996; Crosby, 1994). Today, less than a dozen of the original oases where Mission-era orchards were established still have agricultural remnants (Vernon, 2002) and we have surveyed the nine in which agricultural landscapes remain most intact. In a prior survey of agricultural crops in Baja California Sur that largely included oasis orchards more recently-developed than those of the Mission era (Breceda et al., 1997), San Ignacio de Kadakaaman was the only oasis that overlapped with our study sites.

Early agricultural development in Baja California was exclusively associated with these oases, and can be dated to two initial historic periods (Table 2) the first during the Jesuit Mission era (1697 to 1768) and the second during the emergence of the Ranchero culture of the "Californios," from 1769 to 1869 (Carino-Olvera 1996; Crosby 1994).

During the Jesuit Mission era, agricultural production provided the sustenance necessary to acheive the spiritual objectives of the missions, with the provision of bread and wine for communion being paramount. The missions required agricultural products to feed their neophytes, and also served as training centers where indigenous people learned agricultural occupations as part of a broader conversion, one fundamental to acculturation away from their former lifestyle as hunter-gatherers. As some indigenous families rejected agriculture, while others died of introduced diseases, priests recruited immigrants from nearby Sinaloa, Sonora and Nayarit to be integrated into the oasis communities to more fully assimilate the remaining natives into a "hybrid" Ranchero culture. During this period, the majority of crop and livestock species were introduced from the Old World and (to a lesser extent) from Mesoamerica to the peninsula.

During the subsequent Ranchero era, the Jesuits lost exclusive control over the population and economy of Baja California. The Ranchero culture dynamically integrated the intensive use of resources found within the humid islands of these oases with the extensive use of other resources from surrounding ecosystems.

The Ranchero culture was successful at adapting certain heritage crops to regional conditions (Papadolupou et al., 2002; This et al., 2006; La Mania et al., 2006). They fine-tuned agricultural practices such as the production of multiple strata of fruit crops in gridded gardens (Castorena-Breceda, 2008; Nabhan, 2008a), that had earlier developed in the Middle East, the Maghreb, Andalucia and the Canary Islands (Arrellano, 2006; Dunmire, 2004). The Ranchero culture also integrated stategies of natural resource use from the indigenous peoples of the peninsula, the Cochimi, Guaycura and Pericu (Carino-Olvera, 1996). In the third era, the export of cash crops such as sugar cane and citrus began at Todos Santos and spread to other oases. Market production of water-consumptive crops enabled the introduction of more sophisticated techniques for groundwater extraction, but also made some of the oases vulnerable to groundwater depletion and salinization.

Using this historical framework to understand the political and cultural ecology of these oases, we wish to determine which of the agricultural oases of Baja California have retained the heritage crop varieties first introduced by Jesuits, understand why they may have persisted and propose means for further *in situ* conservation efforts. More specifically, we wish to test the hypothesis that the survival of historically introduced perennial crops at these oases is non-random and potentially influenced by geographic factors such as distances

Table 2. Historic periods in the development of Baja California Agriculture.

Agricultural development	Approximate dates	Major effects on Agro-biodiversity
Jesuit Mission: Introduction of Agriculture	1697-1768	18 perennial and at least 8 annual crop species introduced to mission gardens and orchards
Ranchero Culture: Adoption and Adaptation of Mission Crops	1768-1848	Maladapted crops (rice, apples, peaches) abandoned, while others further adapted to local oasis conditions
Market Production of Crops: Extraction and Initial Globalization	1848-1875	Groundwater extraction for water-consumptive cash crops (sugar cane, citrus, grapes, figs, dates) grown for export, or for nearby mines
Porfiriato: Intensification of Extractive Economy	1876-1910	Exports of a few shippable cash crops increase, but realized profits decline; some Ranchero crops marginalized
Agrarian Reform and Truck Transport: Initial industrialization	1920-1993	Over-extraction and salinization of groundwater cause demise of coastal oasis orchards, while many new crops are introduced in southern regions
High-Tech Production including Drip Irrigation, Row Covers, Greenhouses and Airline Transport: Modernization and Intensification of Fossil Fuel Use	1990-2008	Intensification of groundwater extraction and soil modification to suit newer (exotic) crops, with recruitment of migrant farm workers for harvests
Cyber-globalization through Internet Niche-Marketing, Agri-Tourism and Venture Capitalism: Post-Industrial Economic Transformation	1994- present	Both exotic tropical fruits and heritage fruits are economically valued by tourists and elite, but hotels usurp space and water from fields and orchards

from globalized markets in the larger cities of Baja California.

MATERIALS AND METHODS

We tested our hypothesis by recording presence/absence data for species and varieties in nine agricultural oases on the Baja California peninsula and by comparing our crop surveys to those noted in archival records of the agricultural introductions by the Jesuit missionaries (1697 - 1768). We focused our surveys on Eurasian fruit tree species and varieties first noted in Jesuit reports at oases on the Baja California peninsula. We then compared our rapid assessment survey data on the loss or persistence of perennial crops from the Mission era in Baja California with existing data from northern Sonora (Nabhan, 2008; Garcia field notes), southern Arizona (Felger et al., 1992) and Southern California (Hardwick., 2005; J. Sortomme field notes) for the same crop species and varieties.

We surveyed nine oases in January and February of 2009. We recorded presence/absence and abundance for perennial crop species in three to five *Huertas* (orchard-garden plots) per oasis, using an inventory list based on mission agricultural species listed in Dunmire (2004). We selected the oases on the basis of meeting two criteria: 1) mention in the historic record of Jesuit Mission-era cultivation (Clavijero 1982; Del Barco 1980); and 2) descriptions or photos of persisting agriculture (Crosby 1994; Vernon 2002). In the larger oases (San Ignacio, Comondu), we used a snowball technique to identify the oldest *Huertas* in the oases, in which the most traditional farming methods were practiced. At large oases, five different orchards were sampled to assess heterogeneity within each oasis landscape, and at smaller oases, the data was treated as though derived from a single sample.

The collaboration of local guides and permission to enter private lands were obtained at each location. We conducted two- to four-hour surveys accomplished by at least two field recorders at each site. We visually assessed the age of the perennial crops and conducted on-site interviews to determine if crops were historic or recently planted. We visited local nurseries identified by agriculturalists as fruit tree sources to verify new varieties. Taxonomic determinations generally follow Janick and Paul (2008). The dates of establishment and locations of each oasis have been presented in Table 1. A few preliminary geographic, cultural and ecological attributes of these oases are included in Table 2, and were compiled as part of conservation efforts by RIDISOS, the Baja California oasis initiative based at the Universidad Autónoma de Baja California Sur (Rodriguez-Estrella et al., 2004). Our attempted correlation of socioeconomic and geographic variables associated with agrobiodiversity is ongoing, and comments here are not intended to be the “last word” on this issue.

In addition to the historic data taken from edited, annotated and translated works such as Clavijero (1982) and Del Barco (1980), we drew upon primary documents from Jesuit priests available through the special collections of

the Arizona State Museum and the Archivo General de la Nacion, Mexico. We cite the specific and varietal names for the perennial crops in archaic and contemporary Spanish noted in these historic documents (Table 3), but some English and scientific names for them (Table 5) are only approximate, since the identities of several of the historic crops are difficult to reconstruct with absolute confidence.

RESULTS

Historic species composition

Extensive treatises on the natural, cultural, and agricultural history of the Baja California peninsula written near the end of the Jesuit Mission era enabled us to compile documentation for sixteen of the eighteen perennial crops initially introduced to the Baja California oases (Table 3). Although Franciscan and Dominican documents and translated summaries do not provide as much detail about subsequent introductions (Table 4), they do note the presence of two additional Old World introductions, the custard apple and sugar cane (Mora et al., 1772-1774; Aschmann, 1957; Zimzumbo-Villareal, 1996).

We verified that at least eighteen species of fruit tree and other perennial crops were introduced to Baja California oases during the Jesuit Mission era, two-thirds of them of Old World origin. Coconuts may have arrived in Panama prehistorically, but were not found in Mexico until the time of Hernan Cortes (Zizumbo-Villareal, 1996). At least eleven of these species were then adopted and adapted by the Ranchero culture. One additional (but non-domesticated) introduction, the sweet-podded mesquite from the Yaqui Valley in Sonora, has persisted in Loreto kitchen gardens but not in oasis agro-habitats; European-born Jesuits likened it to the carob or *algarrobbo* of the Old World, *Ceratonia siliquia,* with which they were already familiar. Avocado, custard apple, passion fruit, and sapote were among the other New World fruits initially introduced to oasis orchards on the peninsula.

Contemporary species composition

Within the thirty-eight orchards we sampled in nine Baja California oases, we encountered fifty-seven cultivated species of perennial (most fruit-bearing) crops being cultivated. If we add to this number of species the distinct cultivated varieties or land races (*razas criollas)* and cultivars, which we have positively identified, the alpha diversity of the nine oases combined is comprised of at least seventy-one distinct perennial land races or “folk taxa” of heritage crops (Table 5). Our sample is considerably richer than the twenty domesticated perennial fruit species of forty-two crop species found by Breceda et al. (1997) at eight historic and recently-developed agricultural oases in Baja California Sur. In our surveys, we confirmed that sixteen varieties of fruits are still grown at these sites, presumably introduced during the Jesuit Mission era. These taxa were among the earliest horticultural introductions to the Californias, as confirmed from mission-specific reports, Del Barco (1980), and Dunmire (2004), and highlighted by asterisks in Table 5.

Indicators of heritage crop erosion/heterogeneity

These results indicate that of the total taxa found among all nine oases in Baja California, particular varieties of apricot, peach, and muscat grape were likely lost since the Jesuit Mission era, as were annual crops such as rice. We are unclear whether particular varieties of avocado, banana, custard apple, citrus, garlic, and onions were retained, or lost and then replaced by other varieties of the same species. Sweet-podded mesquite disappeared from all nine oases, but survives in the urban Loreto landscape.

Some of these heritage crops may represent original genetic material introduced to the region, and are now being considered for *in situ* and *ex situ* conservation efforts through initiatives such as the Kino Heritage Fruit Tree Project. Of the nine mission oases, the following locations rank highest in their retention of Mission-era species and varieties: Santa Gertrudis, San Ignacio, Mulege, San Javier, and San Miguel de Comondu. The oases exhibiting the lowest agro-biodiversity of Mission-era perennial species include San Luis Gonzaga Chiriyaqui and Todos Santos; the latter also has the highest number of post-Mission fruit and nut tree introductions. Todos Santos has been fully abandoned twice since the Ranchero era and has served as an international port for cargo ships periodically since the 1840s; these factors have rendered it vulnerable to the processes of heritage crop and cultural erosion and replacement.

DISCUSSION

Of the fifty-seven crop species we found in our recent surveys of the agricultural oases in Baja California (Table 5), we confirmed the continuing cultivation of sixteen presumably introduced prior to 1768, although it is virtually impossible to verify that each of these crops is now represented by exactly the same land race or folk taxa that was present in 1768. Nevertheless, a substantial number of fruit trees and other perennial crops introduced during the Jesuit Mission era have persisted as “relictual crops” in Baja California. Most remarkably, at San Javier and San Miguel de Comondu, one can still witness enormous olive trees reputed to be the first plantings of this species on the northwest coast of Mexico. Although our

Table 3. Fruit tree and perennial crop introductions noted by Jesuits (pre1697-1768).

Spanish name	English name	Location of arrival	Source/Agent	Reference
uva negra y Moscatel, parra	grape, Black Mission and Muscat	San Miguel de Comondú and San Javier	Sent to Juan de Ugarte from New Spain/Mexican mainland	del Barco 1980 p. 140; Clavijero 1982 p. 23
ciruela[1]	plum	Missions	Southern peninsula (Cape region?)	del Barco 1980p. 112; Clavijero 1982 p. 23
zapote[2]	white or yellow sapote	Unclear	Unclear	del Barco 1980 p. 110; Clavijero 1982 p. 23
mesquite con pechita dulce[3]	sweet-pod honey mesquite	Loreto and other missions	Yaqui Valley, Sonora	del Barco 1980 p. 116
aceituna, olivo	olive	San Miguel de Comondú and San Javier	Sent to Juan de Ugarte from New Spain/Mexican mainland	del Barco 1980 p. 140; Clavijero 1982 p. 23
durazno	peach	San Miguel de Comundu and San Javier	Sent to Juan de Ugarte from New Spain/Mexican mainland	del Barco 1980 p. 140
granada	pomegranate	San Miguel de Comondú and San Javier	Sent to Juan de Ugarte from New Spain/Mexican mainland	del Barco 1980 p. 140; Clavijero 1982 p. 23
higo	Mission fig	San Miguel de Comondú and San Javier	Sent to Juan de Ugarte from New Spain/Mexican mainland	del Barco 1980 p. 140; Clavijero 1982 p. 23
plátano	banana	San Miguel de Comondú and San Javier	Sent to Juan de Ugarte from New Spain/Mexican mainland	del Barco 1980 p. 140
limón real	lemon	San Miguel de Comondú and San Javier	Sent to Juan de Ugarte from New Spain/Mexican mainland	del Barco 1980 p. 140; Clavijero 1982 p. 23
naranja	orange	San Miguel de Comondú and San Javier	Sent to Juan de Ugarte from New Spain/Mexican mainland	del Barco 1980 p. 140; Clavijero 1982 p. 23
granadilla de China o rosal de la pasión[4]	passion fruit	Missions	From New Spain after coming from Peru or the Philippines	del Barco 1980 p. 162
palma de dátil	date palm	Mission San Ignacio (1730)	Unknown	Luyando in Carino-Olvera 1996;Clavijero 1982 p. 23
alberichigo	apricot	Missions	Unknown	Clavijero 1982 p. 23
aguacate	avocado	“One or another place”	Unknown	Clavijero 1982 p. 23
palma de coco	coconut palm	Loreto	Unknown	Clavijero 1982 p. 23

Table 4. Crops introduced before 1775 as recorded by Franciscan missionaries (Mora et al., 1772-1774).

Name in Spanish Name	Name in English Name	Location of Arrival	References
dátil, palma	date palm	San Miguel de Comondú and San Javier	Mora 1774; Aschmann 1954, from Baegert
zapote (amarillo)	yellow or white sapote	San Miguel de Comondú and San Javier	Mora 1774
chirimoya	custard apple	San Miguel de Comondú and San Javier	Mora 1774
naranja	orange	Todos Santos, San Miguel de Comondú and San Javier	Crosby 1994, from Venegas and Taraval
granada	pomegranate	San Miguel de Comondú, San Javier and Todos Santos	Mora 1774; Crosby 1994, from Venegas and Taraval
olivo, acietuna	olive	San Miguel de Comondú and San Javier	Mora 1774; Crosby 1994, from Venegas and del Barco
límon	lemon	San Miguel de Comondú and San Javier	Mora 1774; Crosby 1994, from Venegas and del Barco
plátano	banana	San Miguel de Comondú and San Javier	Crosby 1994, from Venegas and del Barco
higo	fig	Todos Santos, San Miguel de Comondú and San Javier	Mora 1774; Crosby 1994, from Venegas and Taraval
uva	grape	San Miguel de Comondú, San Javier, Todos Santos	Mora 1774; Crosby 1994, from Venegas and Taraval
durazno	peach	Santa Getrudis or San Pablo	Mora 1774
caña de azucar	sugar cane	Todos Santos, San Ignacio, San Miguel de Comondú	Mora 1774; Crosby 1994, from Venegas and Taraval
coco	coconut	Loreto	Zizumbo-Villareal 1996; Crosby 1994, from Clavijero

sampling and documentation of crop diversity in the oases in Sonora and Arizona has occurred (since 1980) over a longer period of time, it appears that the same crop species and varieties have not persisted on as large a scale in northern Sonora, nor has as much diversity persisted in Alta California and in Arizona, USA (Table 6).

More than other agrarian landscapes known to us in the Sonoran Desert and Alta California, the geographically-remote oasis orchards of central and southern Baja California have served as refugia or *de facto* reserves for historic mission crops. We hypothesized but have not yet proven that losses have appeared to be greater in the Mission oasis orchards located nearer to large cities and nearer to the international border. In Alta California, perhaps only Mission olives, figs, pomegranates, grapes and prickly pears have persisted on a large scale, with a few apricots and pears surviving that may date back to the Mission era. In southern Arizona, the only fruit crops substantively retained from the Jesuit era are Mission figs, pomegranates, and prickly pears, while a few quinces, apricots, sour oranges and sweet limes may have partial ancestry from the Mission eras. At the Arizona oasis most comparable to those in Baja California, Quitobaquito in Organ Pipe Cactus National Monument, only Mission figs and pomegranates have survived.

The most comparable Mission orchards to those in Baja California are situated around the Missions scattered across north-central Sonora, from San Ignacio and Magdalena to Caborca and Quitovac, but there are few published surveys of agro-biodiversity at particular oases (e.g. Nabhan, 2008b for the Quitovac oasis near the U.S.-Mexico border). However, it appears that just sixteen Mission- era varieties have persisted among the many oasis and riparian sites, including figs, grapes, prickly pears, quinces, mulberries, pomegranates and citrus, as well as a few rare olives, zapotes, plums, peaches and dates. Over a much larger area of arable land, Sonora retains roughly the same number of Jesuit-introduced fruit crops, but in much lower population numbers per crop, and at fewer sites as well.

In short, globalization pressures have had a much more severe effect on food biodiversity over many more decades in Arizona, Alta California, and the Sonoran borderlands than in the hinterlands of the Baja California peninsula. In addition, most of the historic agricultural sites near missions in these states are not so much island- Many of the heritage crops were introduced within a relatively brief period of seven decades (1697 - 1768), and were maintained and then disseminated to other oases over the following centuries.

Table 5: Perennial land races, “folk taxa” of heritage crops in nine Baja California oases.

Name	Species	Spanish Name	San Borja	Santa Gertrudis	San Ignacio	Mulegé	Las Parras	San Xavier	San Miguel de Comondú	San Luis Gonzaga	Todos Santos
apple	*Malus X domestica*	manzano	1	1	0	0	0	0	1	0	0
apricot*	*Prunus armeniaca*	chabacano, albaricoque, alberichigo	1	0	0	0	0	0	0	0	1
asparagus	*Asparagus officinalis*	esparragos	0	0	1	0	0	0	0	0	0
avocado*: fuerte	*Persea americaña*	aguacate fuerte	1	1	1	1	1	1	1	0	1
avocado*: other	*Persea americaña*	aguacate pagua	0	0	0	0	1	0	0	0	1
banana, plantain*	*Musa X paradisiaca*	plátano	1	1	1	1	1	1	1	0	1
century plant	*Agave spp.*	maguey, mescal	0	0	0	1	0	1	0	0	1
custard apple	*Annona cherimola*	chirimoya	0	0	0	0	0	0	1	0	0
chiltepin	*Capsicum annuum*	chiltepín	0	1	1	0	1	0	1	0	1
chive	*Allium schoenoprasum*	cebollita	0	0	1	0	0	0	0	0	0
citrus: citron	*Citrus medica*	cidra	0	0	0	1	0	0	1	0	0
citrus: grapefruit	*Citrus paradisi*	toronja	0	1	1	1	1	1	1	0	1
citrus: lemon sweet*	*Citrus limon*	limón real	0	1	1	1	1	1	1	1	1
citrus: lime sour	*Citrus aurantifolia*	limón	1	1	1	0	1	1	0	0	1
citrus: lime sweet	*Citrus aurantifolia*	lima dulce chichona	1	1	1	0	1	1	1	0	1
citrus: orange sweet*	*Citrus sinensis*	naranja dulce	1	1	1	1	1	1	1	1	1
citrus: orange sour*	*Citrus aurantium*	naranja amarga	0	1	1	1	1	1	1	0	1
citrus:lime-orange	*C. aurantifolia X sinensis?*	naranja lima	0	0	0	1	0	0	1	0	0
citrus: pumelo	*Citrus maxima*	pomelo	0	0	0	0	0	0	1	0	0
citrus: tangerine	*Citrus reticulata*	mandarina	0	0	1	1	1	1	1	0	0
coconut*	*Cocos nucifera*	coco	0	0	0	0	0	0	0	0	1
date palm*	*Phoenix dactylifera*	dátil	1	1	1	1	1	1	1	1	1
fig: white	*Ficus carica*	higo blanco	1	1	1	1	0	0	1	0	0
fig: Mission black*	*Ficus carica*	higo prieto	1	1	1	1	1	1	1	1	0
garlic	*Allium sativum*	higo negro	0	0	1	0	0	0	1	1	1
grape: Mission*	*Vitis vinifera*	uva misionera	1	1	1	0	1	1	1	1	0
grape: other	*Vitis vinifera*	otras uvas	1	0	1	0	0	1	0	0	1

Table 5. Contd.

guamúchil	*Pithecellobium dulce*	guamúchil	0	1	1	1	0	1	0	0	1
guava: white	*Psidium guajava*	guayaba blanca	1	1	1	1	1	1	1	0	1
guava: red	*Psidium guajava*	guayaba rosa	1	1	1	1	1	1	1	0	1
hibiscus	*Hibiscus sabdariffa*	jamaica	0	0	0	0	0	0	1	0	0
kumquat	*Fortunella margarita*	naranja china	0	0	0	1	0	1	1	0	1
leek	*Allium porrum*	puerro, ajo porro	0	0	0	0	0	0	0	0	0
lychee	*Litchi chinensis*	litchi	0	0	0	0	0	0	0	0	1
loquat	*Eriobotrya japonica*	níspero	0	0	0	0	0	0	1	0	1
macadamia nut	*Macadamia integrifolia*	macademia	0	0	0	0	0	0	0	0	1
mango	*Mangifera indica*	mango	1	1	1	1	1	1	1	0	1
mulberry	*Morus alba*	mora blanca	0	0	1	0	0	0	0	0	0
olive: Mission*	*Olea europaea*	olivo misionero	1	1	1	1	1	1	1	0	0
olive: other	*Olea europaea*	olivo	0	1	0	0	1	0	0	0	0
onion	*Allium sepa*	cebolla	0	0	1	0	0	1	1	0	1
papaya: maradol	*Carica papaya*	papaya maradol	0	0	1	1	0	1	1	0	1
papaya: havana	*Carica papaya*	papaya habanera	0	0	0	0	0	0	0	0	1
passion fruit*	*Passiflora ligularis*	granadilla	0	0	0	0	0	0	0	1	1
peach*: white	*Prunus persica*	durazno blanco	0	0	1	0	0	0	0	0	0
peach*:other	*Prunus persica*	durazno	1	0	1	0	0	0	1	0	1
pear	*Pyrus communis*	pera	1	0	0	0	0	0	0	0	0
pineapple	*Ananus comosus*	piña	0	1	0	0	0	0	0	0	0
pistachio nut	*Pistachia vera*	pistachio	0	0	0	0	0	0	0	0	1
plum	*Prunus domestica*	chabacano	1	0	0	0	0	0	0	0	0
pomegranate*: late	*Punica granatum*	granada roja tarde	1	1	1	1	0	1	1	0	1
pomegranate*: early	*Punica granatum*	granada temprana	1	1	1	1	1	1	1	0	1
prickly pear	*Opuntia ficus-indica*	nopal, tuna	1	1	1	0	0	1	1	1	1
false prickly pear	*Nopalea sp*	nopalillo	0	0	1	0	0	1	1	0	1
quince	*Cydonia oblonga*	membrillo	1	0	0	1	0	0	0	0	0
rosemary	*Rosmarinus officinalis*	romero	0	0	1	0	0	0	0	0	0
soursop	*Annona muricata?*	anona, guanábana	0	0	0	0	0	0	1	0	0
star fruit	*Averrhoa carambola*	carambola	0	0	0	0	0	0	0	0	1
Spanish plum*: purple	*Spondias purpurea*	ciruela roja	0	0	0	0	1	1	0	1	1

Table 5. Contd.

Spanish plum*: yellow	*Spondias purpurea*	ciruela amarillo	1	0	1	1	1	1	1	1	0
spearmint	*Mentha spicata*	yerbabuena	1	0	1	0	1	0	0	0	1
sugarcane: purple	*Saccharum officinarum*	caña morada	0	0	0	0	0	0	1	0	1
sugar cane: white	*Saccharum officinarum*	caña blanca	1	1	1	1	0	0	1	0	1
sugar cane: striped	*Saccharum officinarum*	caña pinta	0	0	0	0	0	0	1	0	0
tamarind	*Tamarindus indica*	tamarindo	0	0	0	0	0	1	1	0	0
taro	*Colocasia esculenta*	papa de agua	0	0	0	0	0	0	1	0	0
taro/cocoyam	*Xanthosoma sagittifolium*	taro, chicamote	0	0	0	0	0	0	1	0	1
tepeguaje/white lead tree	*Leucaena leucocephala*	tepeguaje	0	0	0	0	0	0	0	0	1
yam/sweet potato	*Dioscorea trifida*	camote	0	0	0	0	0	0	1	0	0
sapote: white/yellow*	*Casimiroa edulis*	zapote amarillo	0	1	0	1	1	0	1	0	0
Mission-era survivors			12	15	14	14	14	14	16	8	13
Total varieties			27	26	31	26	24	29	42	9	41
Mission/Total ratio			0.44	0.58	0.45	0.54	0.58	0.48	0.38	0.88	0.32

* Fruit tree and perennial crop introductions noted by Jesuits, not variety specific. See Table 3.

The oases have since faced threats from agricultural modernization and urban development. Such pressures began to accelerate in the late 1840s, when Todos Santos first became a port in the “Manila Galleon” shipping line between San Blas, Mexico and San Francisco, US (Table 2). A boom-and-bust economic cycle first fueled by sugar cane production, and then wedded to tourism development has changed the agricultural landscape of the oasis. Todos Santos now exhibits the lowest ratio of extant Mission era crops to total perennial species.

Most modifications to traditional Ranchero agriculture at the other oases date from the last quarter of the nineteenth century. The large-scale cultivation of export crops such as sugar cane, tobacco, table grapes and citrus began in Mulege, San Ignacio, and San Jose de los Cabos, but was only partially adopted at other oases (Carino-Olvera 1996). In the late nineteenth century, these agricultural exports, along with brown sugar *panocha*, olive oil, and mescal were transported by cargo ship to ports on the west coasts of Mexico and the United States. Production and distribution of these crops were negotiated by European immigrants or American investors. These structural and compositional changes in the agricultural system accelerated in the early twentieth century.

The politics of agrarian reform led to the establishment of *ejido* collectives, which not only impacted the oases but the other arable lands of the peninsula as well.

Cash crop introductions and their need for frequent irrigation led to depletion of the aquifers, which fed artesian springs, riparian vegetation, wetlands and more traditional *acequia* irrigation systems (Carino-Olvera 2001). Since the 1970s, refrigerated truck transport of fruits has been facilitated by the highways which now run from Tijuana to the Cape, and this factor alone has increased the impacts of globalization on these oases. Today, roughly a third of the total cultivated perennial crop varieties of the nine oases are comprised of post-World War II cultivars introduced during or after the last quarter of the nineteenth century, when external market demand increased (Carino-Olvera, 2001). These recent horticultural introductions are competing with more historic land races at Todos Santos, the oasis closest to a large urban center, and to some extent at Mulege, San Ignacio, and San Miguel de Comondu.

Six of the oases, Santa Gertrudis, San Ignacio, Mulege, Las Parras, San Javier, and San Miguel de Comondu, each retain fourteen or more varieties of Mission-era crops; all but Las Parras also

Table 6. Jesuit and Franciscan Introductions Persisting in Alta California, Arizona or Sonora (from Felger et al., 1992), Dunmire (2004), Hardwick (2005), Nabhan (2008b), Garcia and Sortomme, unpublished.

Spanish name	English name	Alta California (Mission Sta. Barbara)	Arizona (Quitobaquito and Tumacacori)	Sonora (Quitovac-Tubutama and Altar River Valley)	Sonora (Magdalena-San Ignacio River Valley)
uva negra y Moscatel, parra	grape, Black Mission and Muscat	Black Mission introduced by 1771, still commercial	Lost, then reintroduced from Alta California	Introduced 1687-1706, lost	Introduced 1687-1706, none remaining
ciruela	plum	Introduced 1792, lost	Introduced 1687-1706, lost	Introduced 1687-1702, lost	Introduced 1687-1702, few individual trees in San Ignacio
zapote	white or yellow sapote	Introduced by 1810, lost	Never introduced because of cold?	None remaining	Several individuals throughout the valley
mesquite con pechita dulce	sweet-pod honey mesquite	Already a native	Already a native	Already a native	Already a native
aceituna, olivo	Mission olive	Introduced 1795, many populations persisting, still commercially grown	None remaining	None remaining	A couple of small orchards near Magdalena
durazno	peach	Several varieties introduced by 1792, Sespe persisting at San Buenaventura, but most early varieties lost?	Introduced and lost	Introduced, nearly lost, few survivors	Introduced 1687-1706, but few left in San Ignacio and la Misión
guayaba	guava	Introduced later	Introduced and lost	Introduced and lost?	Introduced and lost?
granada	pomegranate	Introduced by 1792, several strains persisting	Introduced, still commercially grown	Introduced 1687-1706, still commercially grown	Introduced 1687-1706, still commercially grown
higo	Mission fig	Introduced by 1777, still commercial	Introduced, no longer commercially grown	Introduced, many populations persisting	Introduced 1687-1706, still available
plátano	banana	Introduced by 1792, lost	Never introduced because of cold?	Never introduced, poor climate	Never introduced, poor climate
limón real	sour lime	Introduced by 1834	Introduced 1687-1706, lost	Introduced 1687-1706, many persisting	Introduced 1687-1706, many persisting
naranja	orange	Introduced between 1792-1804	Introduced 1687-1706, nearly lost	Introduced 1687-1706, many persisting	Introduced 1687-1706, many persisting
naranja agria	sour orange	Introduced between 1792-1804	Introduced, lost, reintroduced	Introduced, many populations persisting	several individuals throughout the valley
madarina	tangerine	Introduced between 1811 and 1834, status unclear	Introduced later, lost	Introduced later, a few trees persisting	Introduced 1687-1706, many trees in orchards
Limas	sweet limes	Introduced	Persisting in nearby Tucson	Several trees in back yards	Many trees throughout the region

Table 6. Contd.

tejocote	hawthorn	Not introduced	Never introduced?	Introduced later, status unknown	Introduced later, several trees in the valley
níspero	loquats	Introduced later	Introduced later, status unknown	Status unknown	Introduced later, many trees throughout the region
granadilla de China o rosal de la pasión	passion fruit	Introduced, but later	Never introduced because of cold?	Status unknown	Not found, probably too cold
palma de dátiles	date palm	Introduced, possibly persisting	Introduced, eradicated from Quitobaquito	None remaining	Very few individuals throughout the valley
alberichigo/albaricoque	apricot	Introduced by 1772, possibly persisting several places	Introduced, very few individuals of early varieties	Introduced, early varieties persisting	few populations in the valley
aguacate	avocado	Found in the region but might be newer varieties	Recent intro? One older tree found in Aravaipa Canyon	Recent intro	Not introduced until recently
pera	pear	Several varieties introduced by 1792, Padre persisting at Arroyo Hondo, most early varieties lost?	Introduced, then lost. Few individuals in Southern AZ.	Introduced, nearly lost, few survivors	Several varieties and individuals throughout the valley
membrillo	quince	Introduced, northern latitudes	Several single individuals throughout the state.	Many populations	Several healthy orchards, commercially grown for local and international market
mora	mulberry	Introduced, but later	Possibly introduced by 1706, lost?	Introduced 1687-1706, scattered persistence	Introduced between 1687-1702, scattered persistence
manzano	apple	Introduced by 1792, few persisting	Introduced between 1687-1702, lost	Introduced between 1687-1706, probably lost	Introduced between 1687-1702, probably lost
nopal	prickly pear	Introduced by 1779, many persisting	Introduced 1687-1702, lost	Introduced multiple times, common	Introduced multiple times, common

also have considerable levels of within-oasis heterogeneity among the *Huertas* we sampled. When taken together, these six oases might be considered the highest priority for formal *in situ* conservation designations aimed to protect the integrity of Ranchero cultural landscapes in Baja California (Rodriguez-Estrella et al., 2004). Since no single oasis retains all presumed Mission-era crops, this study strongly supports the notion that an "aggregate" of multiple oases should be protected to ensure both complementarily and redundancy.

This finding is theoretically supported by Gollin and Smale's (1999: 250) contention that, "farm-level diversity need not necessarily consist of multiple varieties or species being utilized simultaneously on an individual farm. Diversity can be achieved across space or over time. For example,

if farmers in different locations specialize in different species or varieties, [the value of] the aggregate diversity may be high even though no individual farmer has a [fully] diversified farming system."

If such analyses as these are to be used to ensure the long-term conservation and continued evolution of the Mission-era and Ranchero cultural heritage of crops extant in Baja California, we suggest that either the entire archipelago of desert oases should collectively receive a single designation, or that five or more oases with rich heritage crop diversity should be selected and offered different forms of protection. Currently, some of these oases fall within the boundaries of larger protected areas. The San Ignacio oasis is considered to be included in the territory of the Viscaino Biosphere Reserve in Baja California Sur. San Borja and Santa Gertrudis are within the Protected Area for the Flora and Fauna of Los Cirios (Boojums) in Baja California Norte, and have recently been recognized by the federal government as indigenous (corporate) communities, although these are not "Indian reservations" in the formal sense. Recently, because of the insistence of environmental scientists who have worked for years at these oases in attempt to improve their status, seven sites, including the San Miguel and San Jose de Comondu oases, were designated RAMSAR protected wetland reserves in February of 2008. At the time of this writing, all of the oases still lack management plans that would effectively safeguard their heritage crops.

At the same time, it is immensely important to consider the necessity of dynamically protecting Ranchero culture itself, since its communities have been the stewards and sustainers of the heritage crops introduced by the Jesuits. From this perspective, it may be necessary to devise conservation strategies, which specifically protect the tangible and intangible heritage of this agrarian culture, just as there are strategies to protect the oases and the land tenure of their inhabitants. No current management plan proposes any strategy for safeguarding heritage crop diversity in sufficient detail to tangibly ensure that the cultural landscapes of the oases are maintained through community participation. There is discussion at FAO, UNEP, and UNESCO regarding globally important agri-landscapes of heritage significance (GIAHS), but this concept has not yet been made operative in Mexico. The country does, however, have significant momentum in legally protecting heritage food products through denominations of origin labeling, which currently includes the Mission grapes in Baja California Norte (Munozledo, 2006).

In conclusion, we suggest that:

Informal *in situ* conservation has, to a large measure, maintained at least sixteen heirloom fruit species introduced by Jesuit missionaries 250 to 300 years ago. Agricultural practices, farming systems and the traditional ecological knowledge which sustain these heritage crops remain intact where-ever the Ranchero culture has persisted at desert oases.

However, because of recent globalization pressures and groundwater extraction, greater loss of this historic agrobiodiversity may be probable at sites closer to the border and closer to cities. The remaining traditional Ranchero cultural stewards may need external support and investment from networks such as RIDISOS, Cultura Del Oasis, and Slow Food International, as well as denominations of origin to promote and safeguard heritage crops, their culinary uses and the aquifers on which they depend.

New community-based protected area strategies should be considered that value the cultural landscapes and intangible values of the Ranchero culture as much as their heritage crops and wetlands habitats.

Conservation biologists should assess the effects of impending climate change, groundwater extraction and surface water depletion on the resilience of these oases, paying particular attention to the issue of reduced winter chill hours on fruit tree production (Leudeling et al., 2009).

Protection of the entire "archipelago" of desert oases on the peninsula (or at least five of the most significant cultural landscapes therein) should be considered, to maintain redundancy as a buffer from stochastic processes of extinction or from potentially disastrous effects of globalization.

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