The ecology of sahuaro: Linking population ecology to conservation and management

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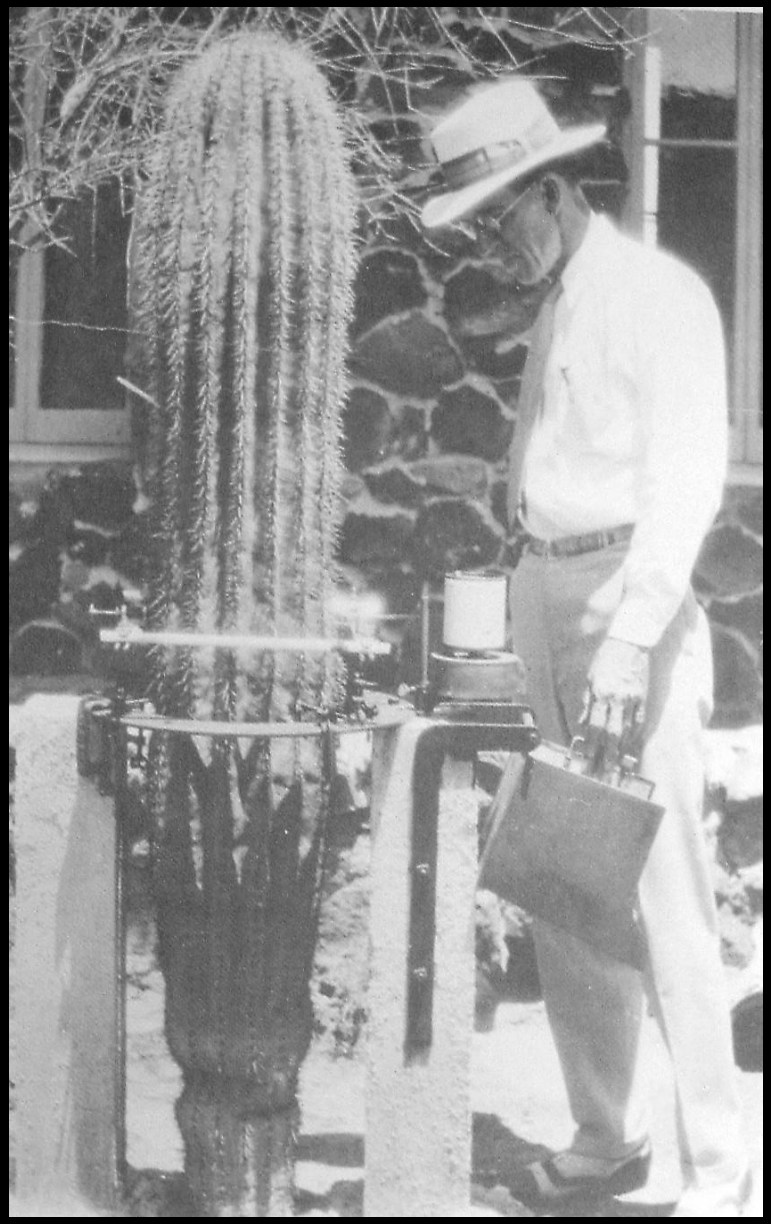


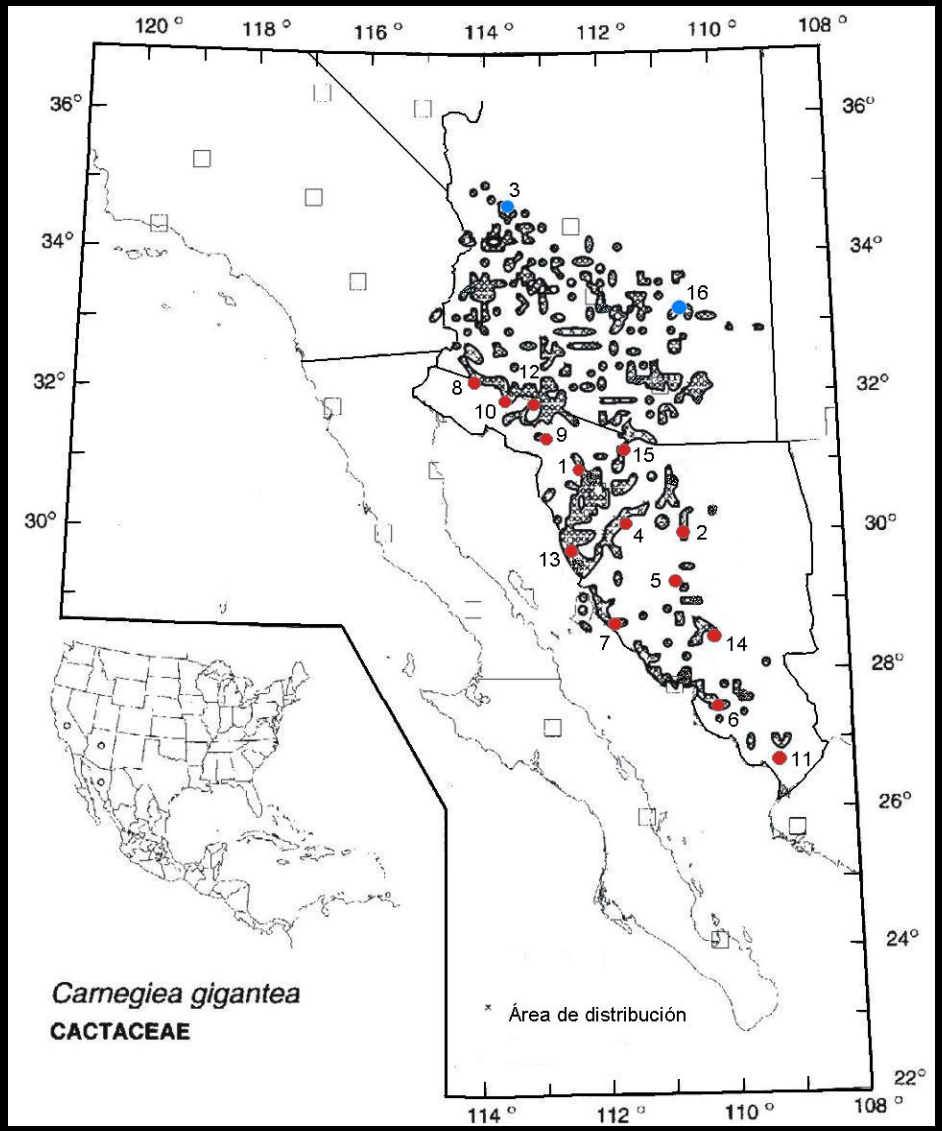
The sahuaro is an emblematic species of the Sonoran Desert. Its study goes back to the origin of the Desert Laboratory in Tucson, AZ in the early 1900. Since then, It has been subject of numerous studies ranging from physiological responses to environmental cues, to disentangling its population ecology, including the famous “Nurse Plant theory”.

The sahuaro is one of the largest columnar cacti

- Can attain up to 17 m
- Maximum diameter up to 1 m
- Usually none, or few arms
- 12-26 “ribs” with areoles armed with spines
- It has a woody skeleton –secondary growth
- Infrequent recruitment

There is much variation on these traits in natural populations

The Sahuaro (also saguaro: *Carnegiea gigantea* (Engelmann) Britton & Rose 1908) is a widespread species that delimits most of the Sonoran Desert Continental extent



Its usage in southwest style construction and furniture has led to a wider usage of its wooden “ribs”

The sahuaro has been the source of food (fruits and seeds), and construction materials for native Americans

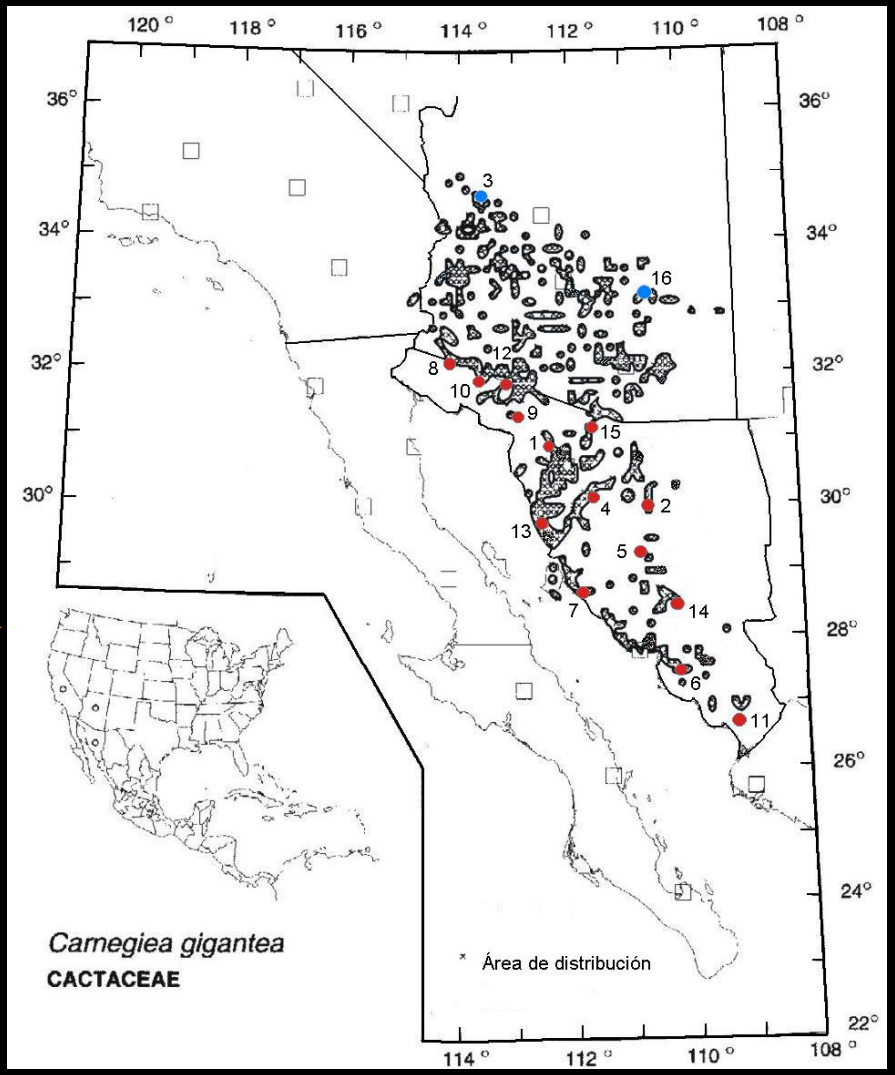
This study was primarily designed to assess the status of the sahuaro within the Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora). Funds from CONABIO-SEMARNAT-CITES

It was a unique opportunity to propose a research scheme to gather basic information, to explore new research avenues, and to apply the results to conservation and management.

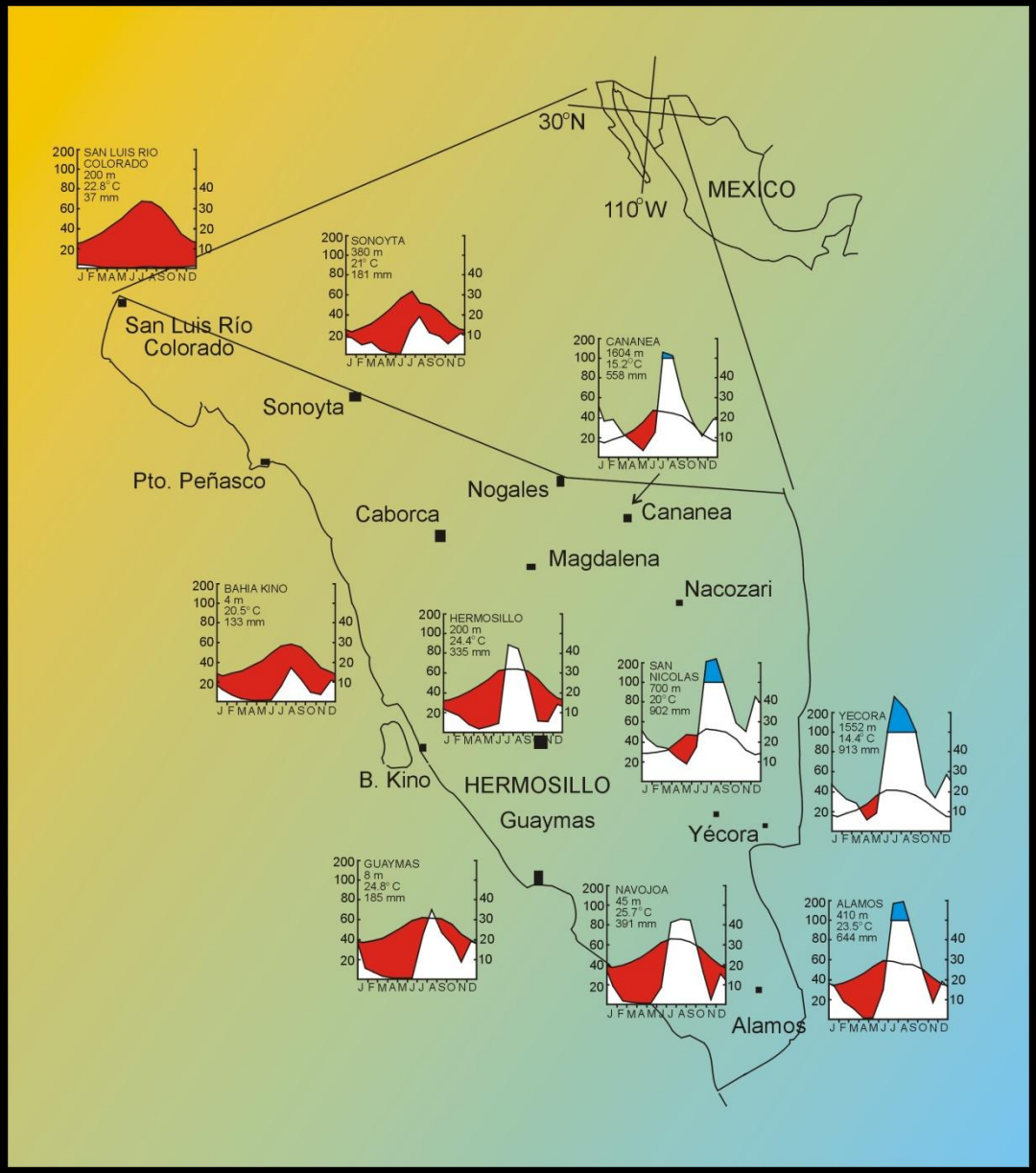
1. Model the niche extent in terms of the physical environment using GARP.
2. Describe and model the phenotypic variation in terms of allometry and adult traits, and correlate that variation with the physical and biological environment.
3. Assess and model the spatial variation among populations in ecological structure, recruitment and growth.
4. Assess the standing dead individuals and their structure.
5. Explore the regional knowledge and use of sahuaro products, particularly the use and trade of sahuaro ribs.
6. Model the expected standing crop of dead individuals suitable for trade in the near and far future, and the trade value, all framed in the sustainability-ecosystem services paradigm.

The Sahuaro (also saguaro: *Carnegiea gigantea* (Engelmann) Britton & Rose 1908) is a widespread species that delimits most of the Sonoran Desert Continental extent

(Shreve, 1951) Subdivisions	Site
Plains of Sonora	El Dipo
	El Orégano
	Caborca
	Cucurpe
Arizona Upland	La Primavera
	Sáric[3]
	Winkelman
	Date Creek Ranch[1]
Lower Colorado River Valley	La Joyita[2]
	Los Vidrios[2]
	MacDougal[2]
Central Gulf Coast	Bahía Kino
	Rancho Lobos[3]
Foothills of Sonora*	Las Guásimas
	San Marcial
Coastal Thornscrub*	Masiaca[4]



It ranges from extremely xeric and warm conditions to relatively mesic environments, and it is difficult to ascribe its present distribution to single climatic factors

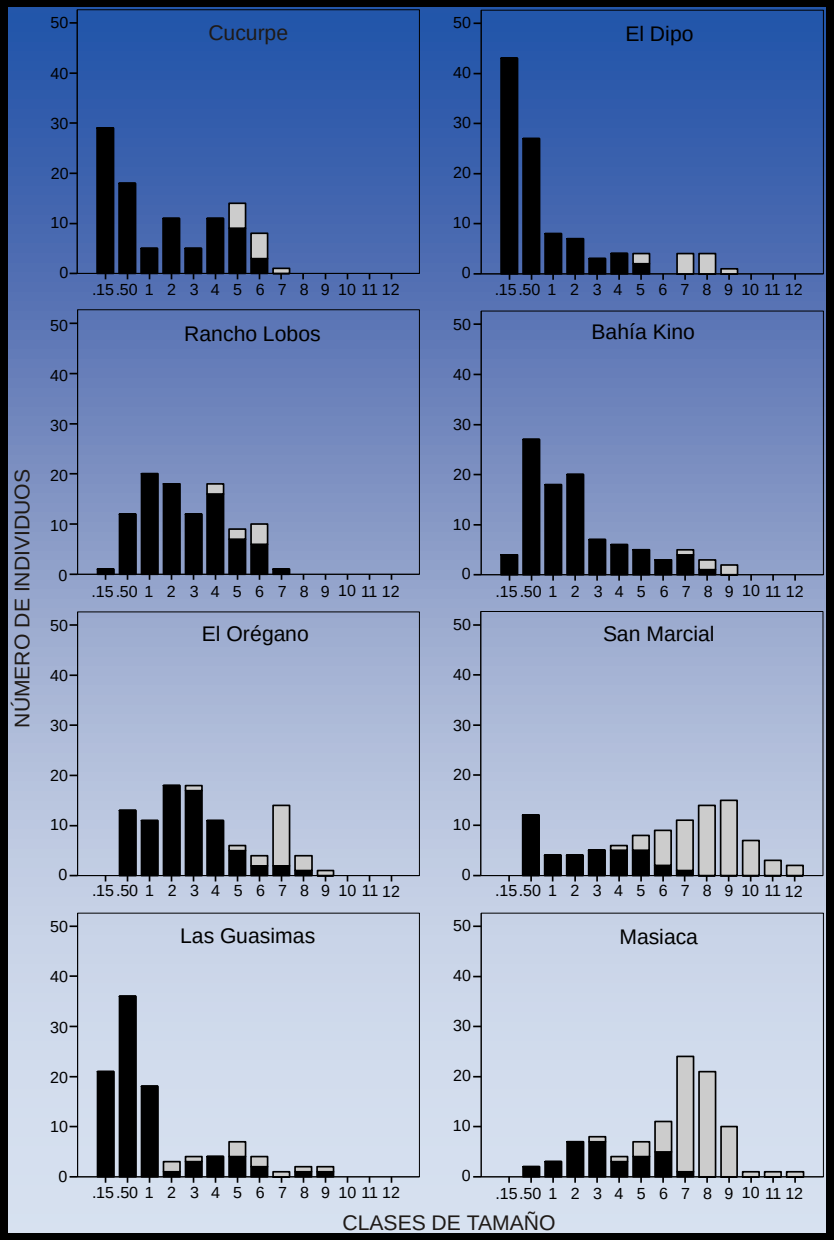


Despite the conscious effort to select the densest populations at the core of local distribution on each locality…there is great variation. Low vs High density in highest density sites

					HEIGHT CATEGORIES								
		Total			0-50 cm			50-250 cm			>250 cm		
POPULATION	N	MEAN	SEM	CD	MEAN	SEM	CD	MEAN	SEM	CD	MEAN	SEM	CD
El Dipo	**12**	**218.8**	**50.4**	**5.6**	**145.8**	**42.9**	**6.0**	**33.3**	**18.3**	**4.8**	**39.6**	**10.4**	**1.3**
El Orégano	**534**	**4.7**	**0.9**	**3.5**	**0.6**	**0.2**	**1.6**	**1.9**	**0.4**	**2.0**	**2.1**	**0.5**	**2.5**

The variation between populations is also evident in morphological terms

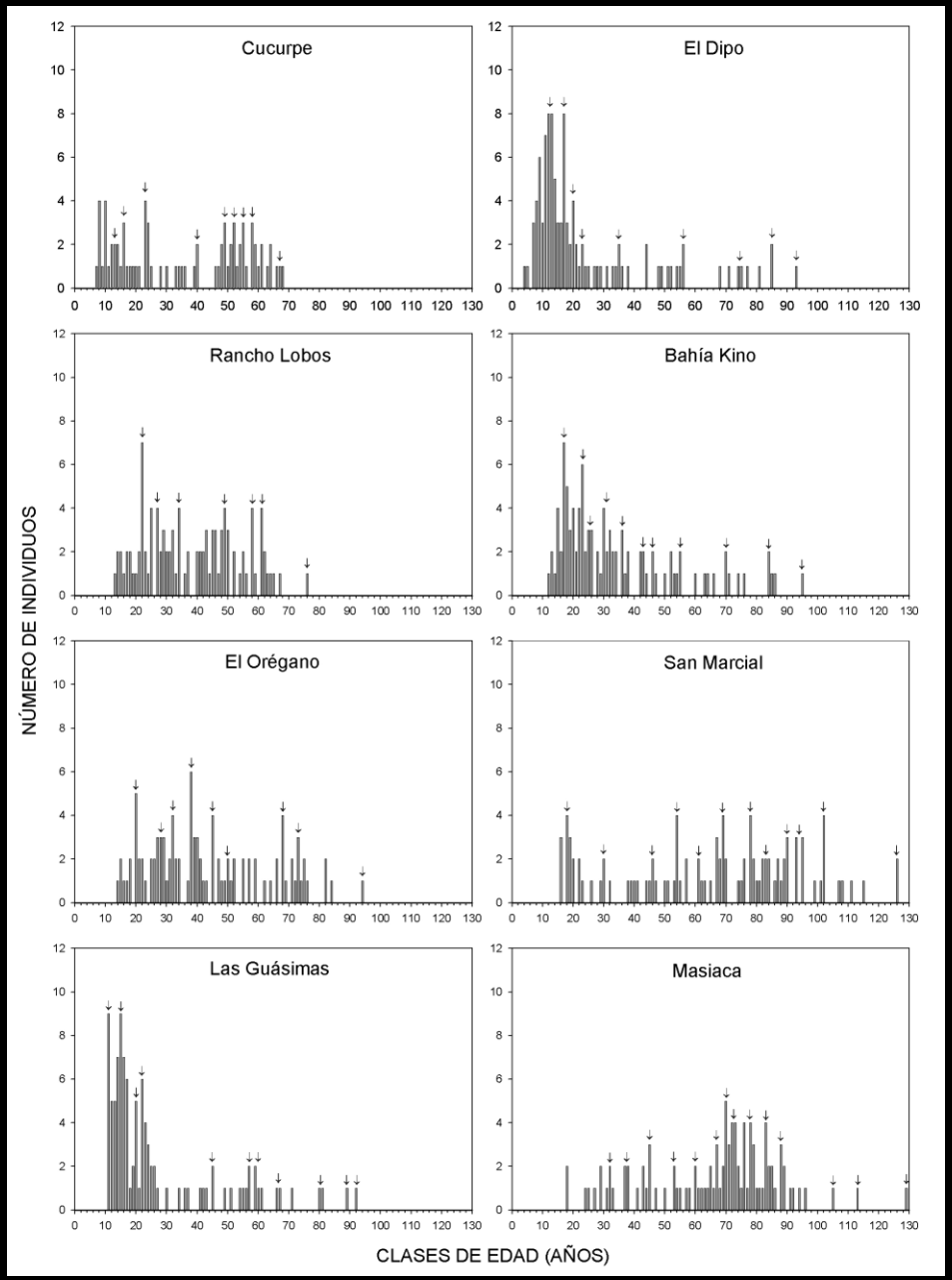
	N	% non-branched individuals	% branched individuals	mean number of arms
Date Creek Ranch	**76**	**54**	**46**	**5.2**
Bahía Kino	**100**	**95**	**5**	**2.0**



Size distributions do not fit into a stable size distribution.

The multimodal distributions in size clearly point out to “Episodic Recruitment” events

In the absence of growth data, we used the relationship between height and age proposed by Steenbergh and Lowe in the 70s to translate size into age



The general shape of the age distributions is the same. It offers more resolution on the small-size age-classes

Recording the classes that where numerically higher than the neighboring younger age-classes, we were able to estimate the intervals between recruitment events.

	N	MEAN	SEM	LAST EVENT
Caborca	10	11.33	2.28	18
Cucurpe	9	6.87	1.77	12
Date Creek Ranch	10	9.00	1.85	21
El Dipo	9	10.00	2.47	9
El Orégano	9	9.25	2.27	20
Las Guásimas	11	8.10	2.07	11
Bahía Kino	11	7.80	1.34	17
La Joyita	10	8.66	1.45	17
La Primavera	12	9.45	3.90	13
Cráter MacDougal	11	10.50	2.26	19
Masiaca	13	6.83	1.04	**31**
Los Vidrios	12	9.63	3.59	19
Rancho Lobos	7	9.33	2.27	22
San Marcial	12	9.81	1.70	18
Sáric	7	12.00	4.70	15
Winkelman	10	9.88	2.77	16

The 6.9-12 yr periodicities are consistent with modulation by strong to very strong El Niño events (Between 1525-1988 the recurrence of strong El Niño events has periods of 6.75 and 14.0 years)

But the last events of recruitment show a longer periodicity, up to 31 years in some populations. Enticing…The actual El Niño return intervals vary between 4 and almost 40 years. For each site there are, of course, site-specific modifiers

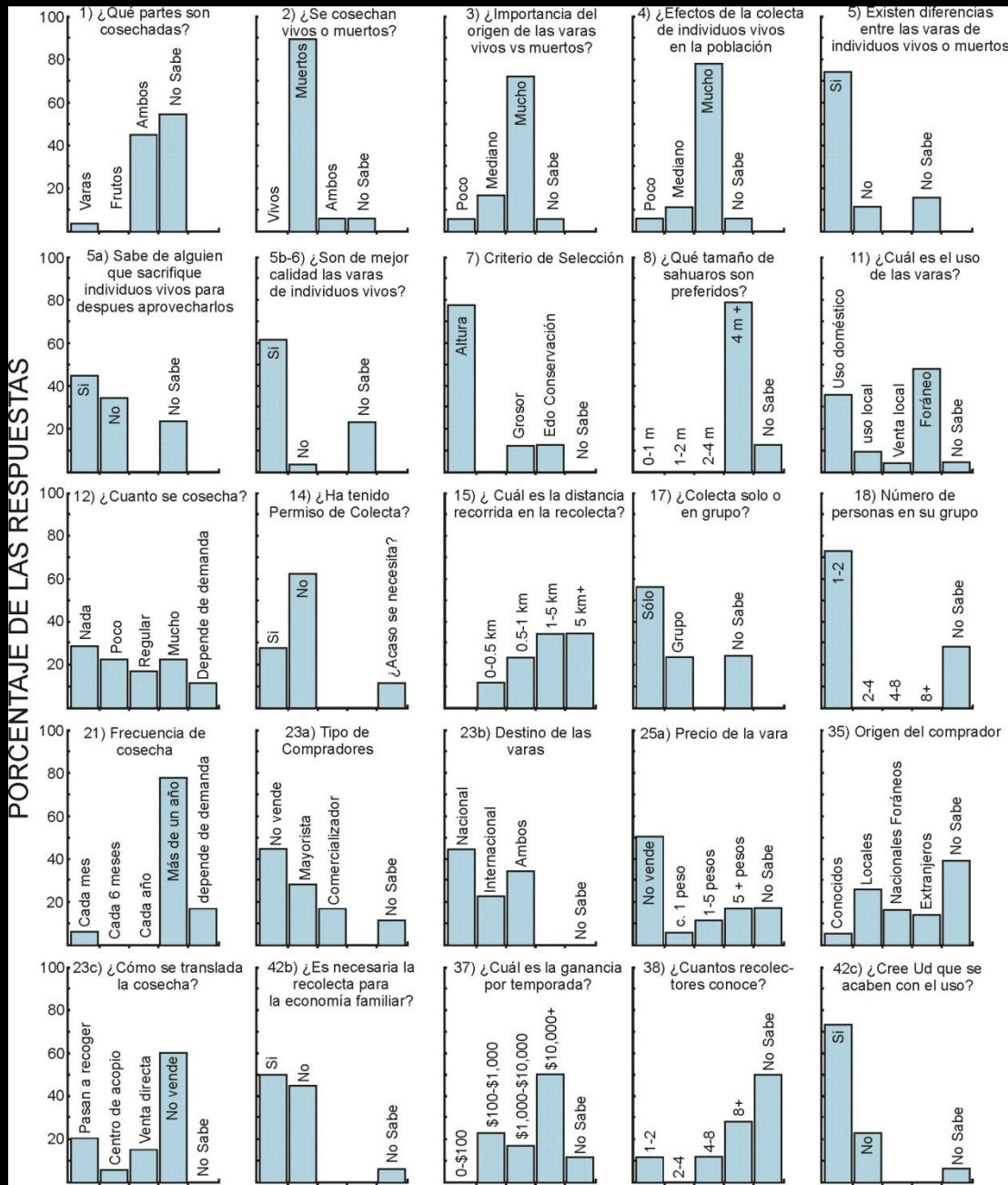
That´s enough of basic ecology. How this data drives conservation and management policies?

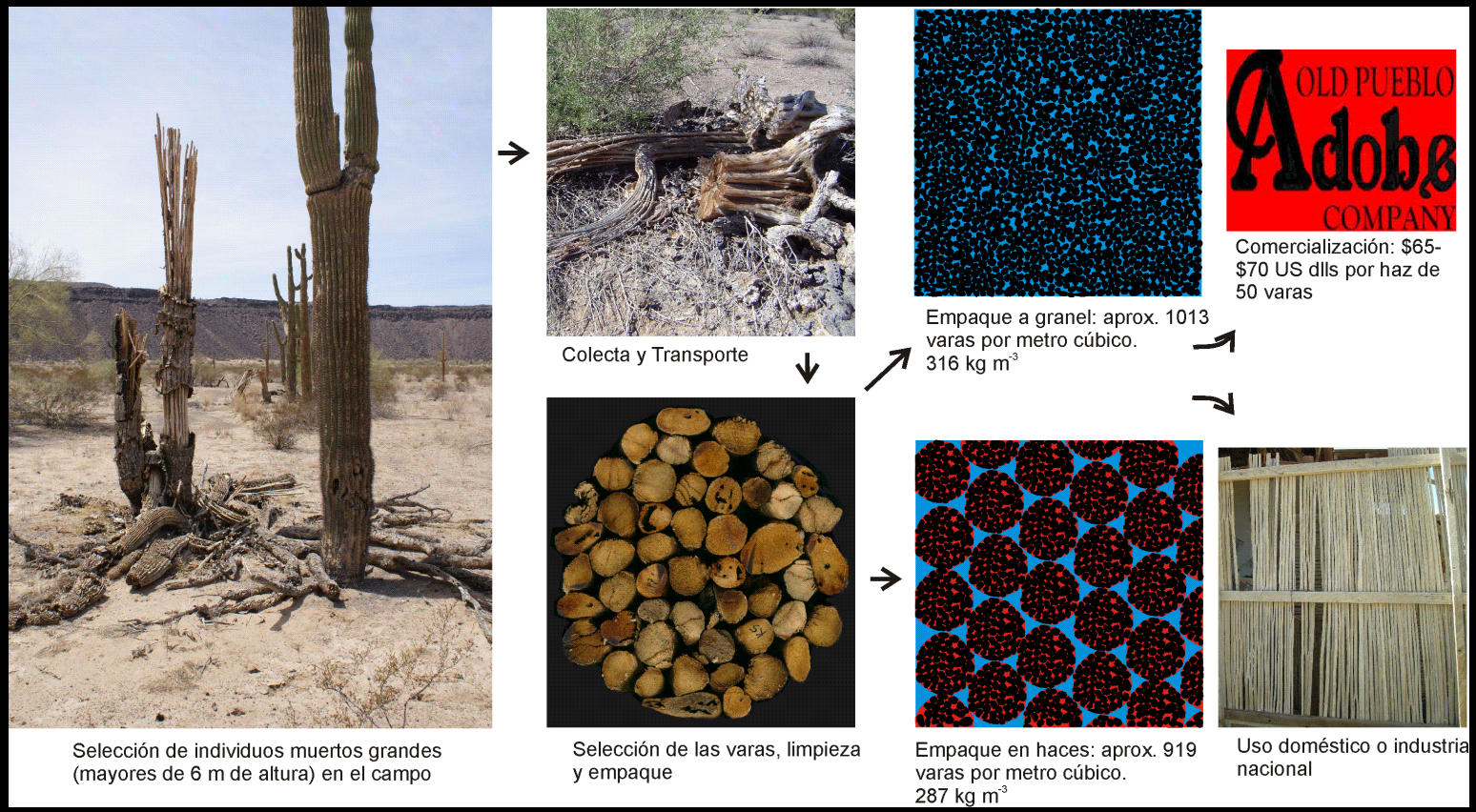
First, let's see how people use the resource

people use it a lot!

While the traditional harvest of sahuaro fruits is fast disappearing…

the commercial harvest of its ribs, fueled by a hungry international market, show a steady growth, and at $0.50 a rib at the local ranch, it seems good business. Not only Free Enterprise, but Free Ecosystem Services!





Modus Operandi: harvesting, processing and trading

But first…more science.

How many ribs a given sahuaro can produce?

Considering that there was a general agreement than useful ribs should have at least 1” (2.54 cm) in diameter.

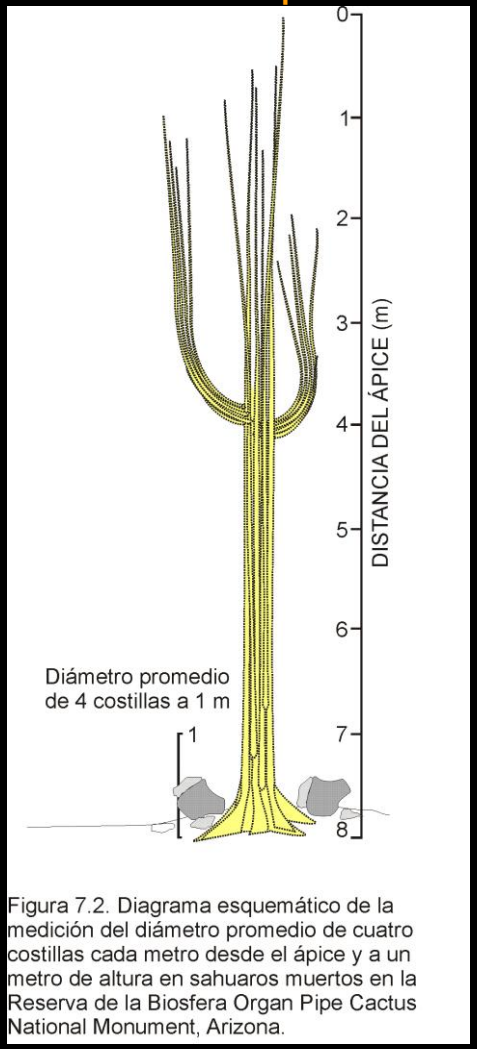
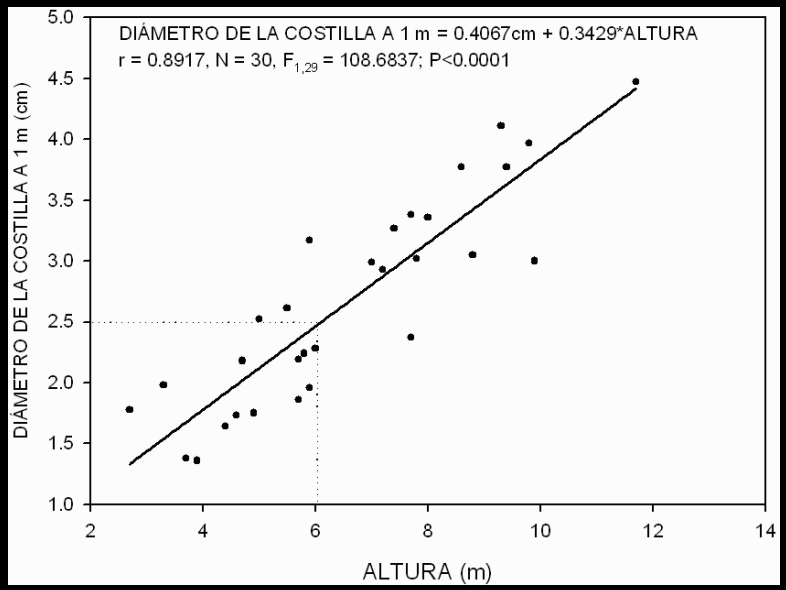
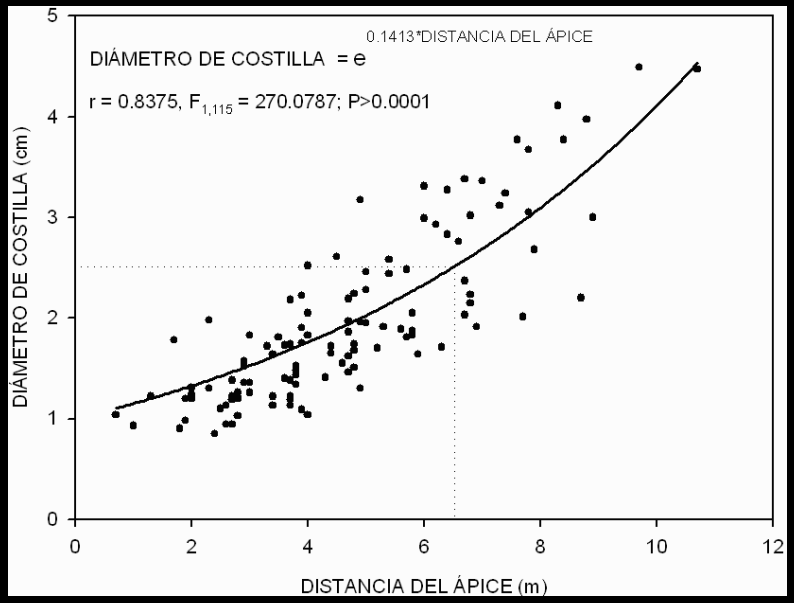


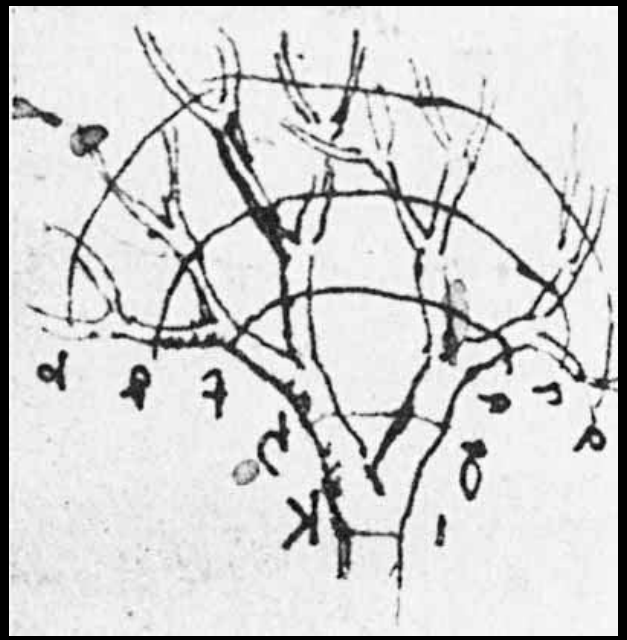
Figura 7.2. Diagrama esquemático de la medición del diámetro promedio de cuatro costillas cada metro desde el ápice y a un metro de altura en sahuaros muertos en la Reserva de la Biosfera Organ Pipe Cactus National Monument, Arizona.





We measured dead sahuaros using two methods, and discovered that their wooden skeletons were not useful (from a trade standpoint) until they reached about 6 m in height .

Something that was obvious when we did the allometric relationships.



The number of dead saguaros (and ultimately ribs for trade) depend on three variables:

1) The actual number of dead individuals
2) The population structure and demographic parameters
3) The permanence of dead saguaros on site (decay)

As dead sahuaros can stay for decades on site, either standing, of lying in the ground, the ratio between dead and alive individuals should be high in non-harvested populations.

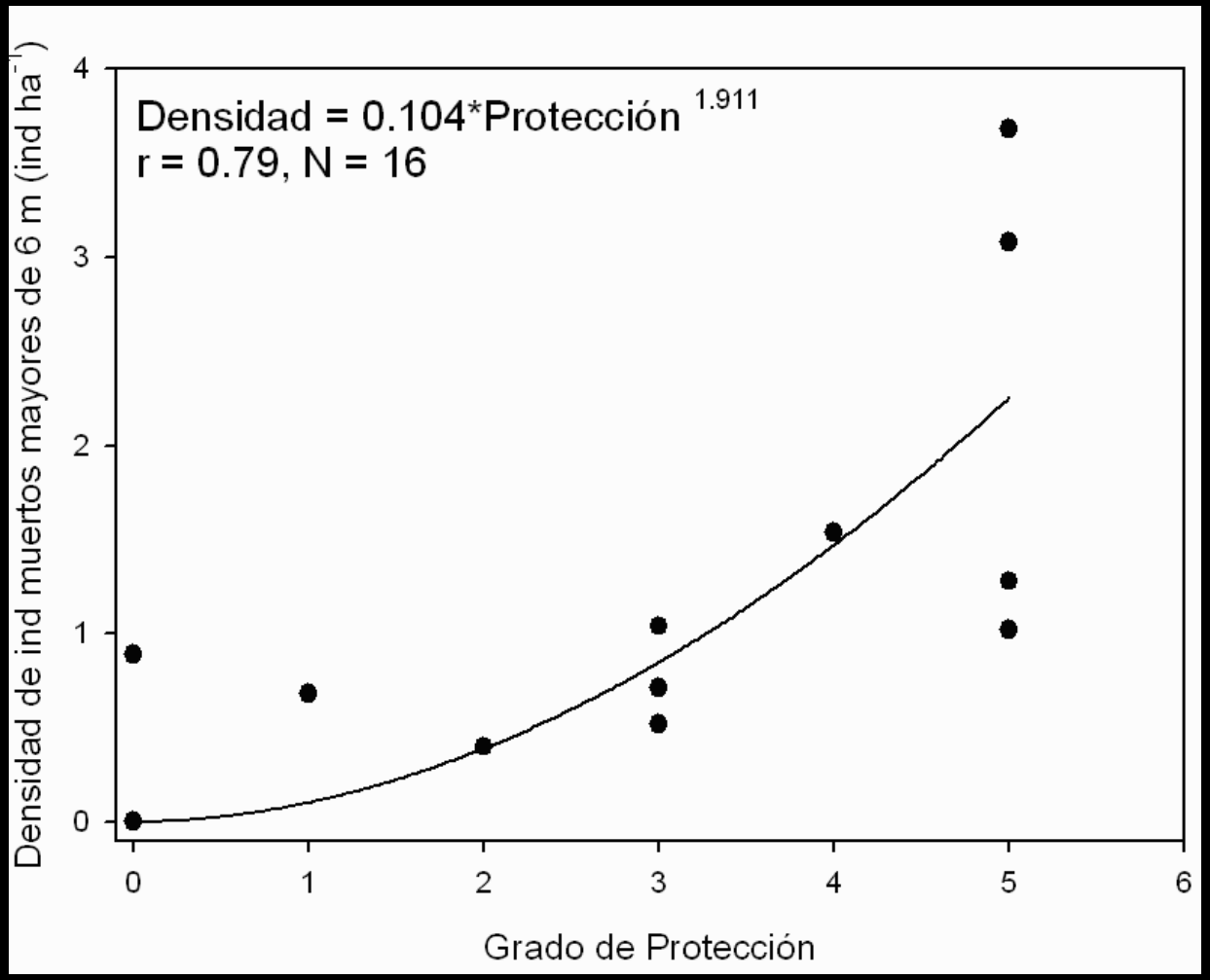
It is evident that most populations have been harvested, some of the relentlessly

		Live Individuals ha-1			Dead Individuals ha-1			Dead/Alive
Population	N	Mean	SEM	CD	Mean	SEM	CD	Ratio
Caborca	91	28.02	3.58	1.66	1.65	0.65	0.94	0.06
Cucurpe	14	182.14	49.13	7.42	5.36	2.85	0.85	0.03
Date Creek Ranch	49	38.78	5.93	1.77	2.04	0.99	0.94	0.05
El Dipo	12	218.75	50.39	5.57	2.08	2.08	1.00	0.01
El Orégano	534	4.68	0.88	3.54	0.28	0.13	1.32	0.06
Las Guásimas	28	91.07	15.23	2.85	11.61	4.36	1.83	0.13
Bahía Kino	37	67.57	10.06	2.22	5.41	1.97	1.06	0.08
La Joyita	114	22.15	3.05	1.91	6.36	1.28	1.17	**0.29**
La Primavera	24	104.17	18.35	3.10	5.21	2.12	0.83	0.05
Cráter MacDougal	68	34.19	5.16	2.12	11.76	2.54	1.49	**0.34**
Masiaca	105	24.05	3.33	1.94	1.90	0.73	1.19	0.08
Los Vidrios	73	34.59	4.07	1.40	9.25	2.04	1.31	**0.27**
Rancho Lobos	48	52.60	6.28	1.44	4.69	1.77	1.28	0.09
San Marcial	309	8.09	1.18	2.14	1.38	0.38	1.30	**0.17**
Sáric	15	170.00	36.20	4.63	3.33	2.27	0.93	0.02
Winkelman	39	64.74	9.03	1.97	5.13	2.09	1.33	0.08

Little is known about the precise role of dead sahuaros on wildlife, but many animals find shelter and reproduce on dead sahuaros.

When considering only 6+m individuals, some populations simply vanish…

Further support for the idea of heavy usage comes by correlating the density of dead sahuaros and the degree of protection of the sites



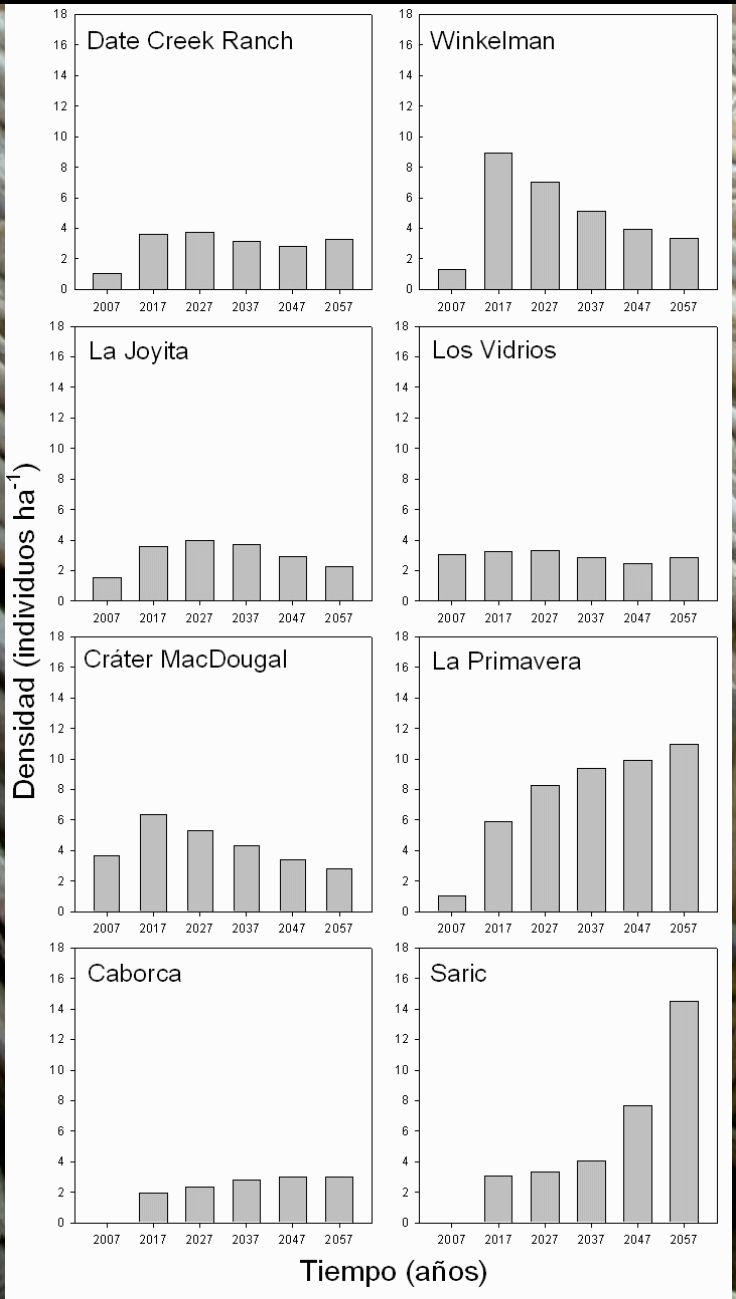
Once known the population densities, the demography, the mortality schedule, the permanence of dead individuals in the field and their numbers, and the prices and trade on sahuaro ribs, we were able to estimate the present yield on each population… and the profit

	Ribs ha^{-1}	Bulk ha m^{-3}	Bunch ha m^{-3}	kg ha^{-1}	ha Mg^{-1}	Dollars ha^{-1} @$0.09	@$0.46	@$1.29
Caborca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cucurpe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Date Creek	32.00	31.79	28.84	9.94	100.60	2.90	14.52	41.24
El Dipo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
El Orégano	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Las Guásimas	15.50	65.41	59.34	4.83	206.98	1.41	7.06	20.05
Bahía Kino	12.50	80.24	72.80	3.94	253.90	1.15	5.75	16.34
La Joyita	58.00	17.45	15.83	18.11	55.21	5.29	26.46	75.15
La Primavera	17.00	59.39	53.88	5.32	187.93	1.56	7.77	22.08
MacDougal	105.50	9.61	8.72	32.89	30.40	9.61	48.05	136.47
Los Vidrios	78.00	12.96	11.76	24.39	41.00	7.13	35.63	101.19
Masiaca	18.50	54.34	49.30	5.82	171.93	1.70	8.50	24.13
Rancho Lobos	9.50	106.66	96.76	2.96	337.48	0.87	4.33	12.29
San Marcial	9.00	112.48	102.04	2.81	355.91	0.82	4.10	11.66
Sáric	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Winckelman	34.00	29.75	26.99	10.62	94.13	3.10	15.52	44.08

In some populations, a big profit can be made with a cheap, small chain saw…

It is good to know how much we can presently harvest, but the real question is if the harvesting is sustainable

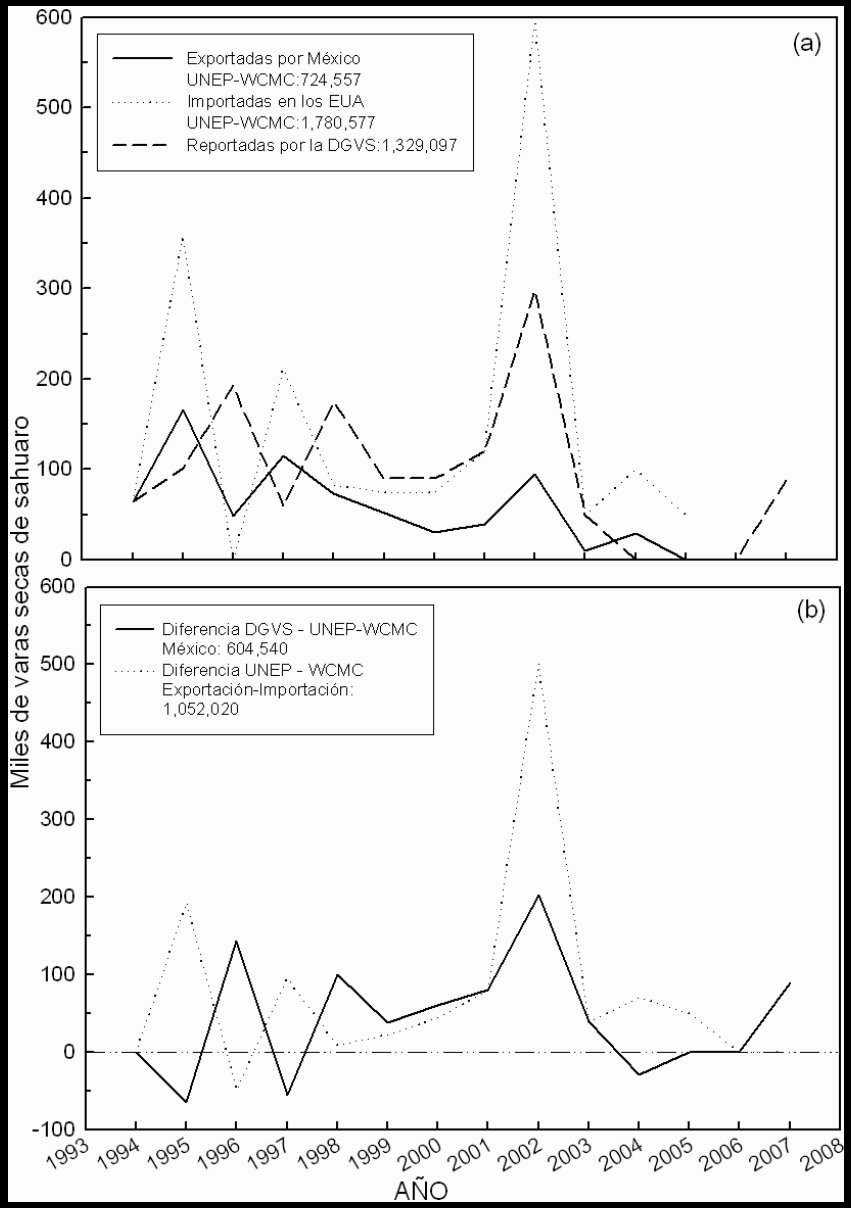
So, using the mortality schedules and the population structure, we were able to model the dead 6+m individuals expected in10, 20…50 years



In populations with little change through time we can be sure that no live individuals have been taken, but in populations where the increase is steady there is suspicion of deliberate extraction of live specimens

Not only populations have been impacted, but large illegal quotas have been collected .

Most of these have managed to go into the US market



Conclusions:

1. From the GARP analysis we conclude that the sahuaro is strongly affected by the thermal environment. Irradiance seems the best modulator of distribution. At the northern edge freezing temps limit its distribution. In the south, vegetation density impedes recruitment. High irradiance restores “aridity” in the tropical south and adds “warmness” in the cool north.

2. Phenotypic differences among populations are large. Some characters are likely to have a strong genetic component.

3. The variation among populations in ecological structure, recruitment and growth is difficult to interpret. 1) All populations show multimodal age distributions. 2) The recurrence time of recruitment seems linked to El Niño events, but last recruitment events have occurred many years ago. 3) We labelled individuals to measure growth. Hints of differential growth (and age) among populations.

4. In terms of resource use, not all dead sahuaros are the same: only those bigger than 6 m tall are valued. In some populations large dead sahuaros have all been harvested. From the analysis of population structure and mortality schedule the return times vary from 10-50 years.

5. Trade is highly profitable. It has been much higher than the quotas allowed by the permits. Live specimens have been killed for later harvesting. It is difficult to have a sustainable use sahuaro ribs whit little control and long return times. Little is known about the role of dead sahuaros on wildlife.

6. The sahuaro should remain within Appendix II of CITES. If trade is allowed a much tighter control on its trade should be enforced: from the assessment for harvesting, to the verification of origin, and traded amounts.