Chapter 11
Conservation of the Most Diverse Oasis of the World and the Future of Our Path in the Deserts: Lessons from Cuatro Ciénegas to the World

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11.1 The Past

As this book has shown, water in the desert and other arid and semiarid environments is both a gift and a curse. In an oasis, water is a gift of life, and its mere name conjures fantastic stories, places of gathering for thirsty wildlife (both local and migratory) and tired travellers, as well as the home of civilizations that vanished when the water disappeared. However, it is also a curse, given human ambition to conquer and use all the resources, water included, to exploit what we deem as a free recourse—even when it is scarce—to grow and develop what does not belong to the arid landscape.

We, modern people, forget that water was sacred for all ancient civilizations. This is no mystery: water is literally life. As Alberto Búrquez explained in Chap. 1 of this book, there has been an ancient fascination with the deserts, their landscape, and their beauty. In the second chapter, archaeologist Yuri de la Rosa told us about how ancient hunter and gatherers that populated the Chihuahuan desert revered the oasis of Cuatro Ciénegas, painting stories of water and stars in the caves around the valley. In Chaps. 3 and 4 we can see how these ancient dwellers of the desert were ferocious fighters and how the equally ferocious colonial Spaniards found them so hard to conquer. Nevertheless, by the end of the colonial period, there was already

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a small Spanish settlement in the Cuatro Ciénegas Basin (CCB). The water started to be managed to use it for the orchards and the town.

During the convoluted Mexican nineteenth century, Cuatro Ciénegas settlements, particularly the town with this same name, grew and developed, thanks to the ample water availability. Later it was home to intellectuals, military, and also entrepreneurs during the Mexican Revolution. Some of them played critical roles, including president Venustiano Carranza, who was born there in 1859.

According to Chap. 6 in this book (Leal et al. 2021), the environmental problems of Cuatro Ciénegas started with the early attempts to drain the basin through two canals that exported the water toward the east of CCB (Fig. 11.1). The first canal is called canal "Saca Salada" and was built primitively in 1902 with the explicit purpose of draining the wetland and allowing agricultural development. Saca Salada canal was much "improved" in the 1970s by making it wider and deeper. It is estimated that this canal now drains ca. 90% of the superficial water (1500 L/s) for ca. 80 km, toward the city of Monclova along with another canal, Santa Tecla (Fig. 11.1). Santa Tecla drains the water out of the CCB since ca. 1966, even if it has a smaller capacity (250 L/s). It has a length of ca. 53 km, crossing most of the east side of the basin and joining Saca Salada canal in its exit from the CCB.

Another canal was built around 1966, to conduct the water from the main spring, La Becerra, toward the Ejido de Cuatro Ciénegas (Fig. 11.1). Canal La Becerra has

Fig. 11.1 The different canals that have drained Cuatro Ciénegas

a capacity of 600 L/s, and its construction rapidly drained the wetland of El Garabatal (Minckley 1992).

Before the construction of these draining canals, wheat, vineyards, and pecan trees were productive options along with goats, cows, and horses in the valley. We strongly recommend the reading of *All the Pretty Horses* by Cormac McCarthy (1992) to have a feeling for this savage land before the canals where built. Minckley's (1992) paper depicts interesting pictures taken before the canals in the 1960s, and the wetland looked almost intact, including a river coming down from the valley of Ocampo-Calaveras, Río del Cañon, that no longer exist (Fig. 11.1). This river propelled the mills that produced flour for the local people. Less than 2000 people lived in the Cuatro Ciénegas village in those years, and the locals enjoyed the "pozas" (natural pools of spring water) for recreation and fished the large populations of endemic fish.

Thirty years later, Minckley in 1992 reported a totally different town, "with no more vineyards, no more wheat and flour production, dying pecan trees and drying wetlands. The main road from Monclova to Torreon crosses the basin, and now dry stromatolites are common. As the canals and the deep wells drained the wetland and interrupted the recharge of the aquifer, while alfalfa fields are everywhere within CCB and in the neighboring valleys." Here Minckley (1992) tells us the tragedy of the dead microbial communities (stromatolites) as a passing reference; however, these microbial communities are relicts of ancient oceans that survived at CCB all the known extinctions but, sadly, are not surviving the Anthropocene and the aquifer overexploitation (Souza and Eguiarte 2018). We have to remember that alfalfa (*M. sativa*) is a forage plant, native to Asia, introduced to America during the Spanish conquest to feed cattle and is one of the thirstiest cultivars, and in the desert up to 10,000 L of water is needed to irrigate just a square meter of alfalfa, for a mere kilogram of produce. The water utilization efficiency for harvested yield of alfalfa hay with 10–15% moisture is 1–2.0 kg/m^3 after the first year (FAO, http://www.fao.org/land-water/databases-and-software/crop-information/alfalfa/en/), and its moisture content as fresh green matter is about 80% (Saeed and El-Nadi 1997).

Therefore, given this tragedy of the commons (Hardin 1968), what does the law on water management says about conservation and regulation in México? In few words, the answer is nothing or very little, as explained in Chap. 5 by Teresa Souza. The section of the Mexican federal government in charge of water administration and use regulation, the National Water Commission (CONAGUA), seems to be prone to build dams and canals. It has an uncanny talent for selling water rights but not on checking on them. CONAGUA, particularly, did not even acknowledge some international treaties in the past, despite these having been signed and ratified by México, such as the Wetlands of International Importance, better known as RAMSAR (https://www.ramsar.org), where CCB wetlands are included as having high importance for conservation and water management.

This was a tragedy that kept on getting worse in CCB, despite the fact that it was declared protected area in 1994 (CONANP 2020, https://www.gob.mx/conanp), just after Minckley's plead to preserve this amazingly diverse oasis became public in México. What Minckley did not know but suspected, was CONAGUA's legendary corruption and that the lack of regulation of water usage in the desert was not going to change easily. So the endemic aquatic species became protected under the umbrella of Area de Protección de Flora y Fauna (APFF) de Cuatro Cienegas (Diario Oficial 07/11/1994; http://www.dof.gob.mx/nota_detalle.php?codigo=4759233&fecha=07/11/1994). Paradoxically, at least to us though not to the federal politicians and bureaucrats of that era, the drainage of the wetland was not stopped.

In the 1990s, the pozas, rivers, and lagoons in CCB started to reduce their water levels, some of them getting to be critically low, endangering the micro-endemic aquatic life they nurture in their distinctively crystalline waters. In desperation, Minckley, who was a professor at the Arizona State University (ASU), turned to a brand new program of astrobiology of NASA, the Astrobiology Institute (NAI) founded in 1998, which made a call to apply for grants for teams to study different models of early Earth, as well as planetology, in particular to explore the question: Is there life beyond our planet?

Minckley, a fish expert that had worked in the natural history of CCB from 1958, had the intuition that the conditions of ancient Earth had been preserved at their azure blue pozas rich in microbial mats and in particular stromatolites (ancestral complex microbial communities abundant in the Proterozoic) (Minckley 1969). Given these pozas are also very poor in nutrients, he suggested that the ancient Mars planet had similar conditions and minerals than CCB. Minckley convinced Jim Elser to work together on an astrobiology grant to study this special oasis in Northern México. Jim, a limnologist, and also an expert in phosphorous (P), was then a young professor from ASU. NAI grant first review was mixed, the site looked promising, but they needed evolutionary microbiologists in their team, and they also needed Mexican scientist, since CCB was in México and required for its study sampling permits. Minckley was delighted, as he wanted to involve Mexican scientists in order to "pass the task" of conservation of this Mexican paradise to the nationals. That is how NASA found us, Luis Eguiarte and Valeria Souza. We travelled for the first time in 1999 to the site and became in love with its beauty and all the potential mysteries of life in these extremely oligotrophic pools (very low P) (Souza et al. 2018a).

Twenty years later we found that Minckley's "hunch" of the existence of a hydrothermal vent from the Panthalassa Ocean of the Jurassic period trapped in this oasis, which explained its marine like conditions, was not farfetched. Minckley got almost everything right, except the dates, as apparently, this oasis that stored the history of bacterial life in this planet is even older (Souza et al. 2018b). We believe now that that the Sierra de San Marcos y Pinos (Figs. 11.1 and 11.2), which forms at the center of CCB an arrow-shaped magnificent uplift from the Cretaceous period, stored in its depths ancient microbes, along with ancient ocean conditions. In our hypothesis, the water cycle between the wetland and the deep aquifer is propelled by a magmatic anomaly (Wolaver et al. 2013) that moves water and life from a deep mineral biogeochemical cycle to a "sun-powered cycle," as the water moves toward the sun-drenched pozas, and microbes organize themselves in microbial mats (Fig. 11.3) and stromatolites.

Fig. 11.2 Cuatro Ciénegas Basin and the Sierra de San Marcos y Pinos from the height of the Sierra la Madera (photo David Jaramillo)

Fig. 11.3 A microbial mat from the hypersaline site "Archean domes" at the ranch Pozas Azules. All of life's functions are in between Valeria Souza's fingertips. (Photo Miguel de la Cueva)

In these complex microbial communities, life assembled, since the beginning, all the gears of the biogeochemical cycles in a compact cohesive way (Souza and Eguiarte 2018). The bottom black layer is the most ancient; it is anoxic and chemolithotroph. In this layer we have the methanogens that fix CO_2 from the atmosphere, making methane and small sugars that fermenting heterotrophs consume. The next layer is also anoxic and depends on sulfur, while the third constitutes the layer of ancient anoxic photosynthesis, where the purple sulfur and non-sulfur bacteria assemble the photosystem II, while the green sulfur and non-sulfur bacteria assemble the photosystem I (Madiga and Jung 2009). These bacteria, however, were already connected to cyanobacteria (Baumgartner et al. 2006). Cyanobacteria live in the uppermost layer and have both photosystem I and II in tandem, as well as more powerful pigments that allow them to capture the more energetic photons and break the surrounding water and in the process liberating oxygen. It is this process that changed Earth's atmosphere and oceans from anoxic orange to oxygen-rich blue (Govindjee and Shevela 2011). We are here as humans reflecting on the history of life on Earth, thanks to the concerted work of these humble microbial communities for billions of years.

Stromatolites and microbial mats are the first fossilized evidence of life on Earth (Souza and Eguiarte 2018). They dominated the ancient oceans till the extremely low phosphorous conditions of those oceans changed with the second snowball Earth event (Souza and Eguiarte 2018). The glacier activity in the Cryogenian period, because of its extreme cold conditions, eroded the continental shelf, liberating large quantities of phosphate that allowed metazoan evolution (Filippelli 2008; Planavsky et al. 2010; Brocks et al. 2017). In this new world rich in phosphorous, the slow-growth communities did not stand a chance. However, they survived in sites where the conditions were extreme enough to prevent growth of algae and herbivores and where there was a deep source of sulfur. CCB is still one such sites, and when the diversity of these oasis' communities is compared to other sites with stromatolites, we observe that microbial and viral communities in CCB are much more diverse and unique (Souza et al. 2018b; Taboada et al. 2018). The preservation of CCB stromatolites through stopping the aquifer overexploitation of the Anthropocene is therefore paramount.

The hydrological system of El Churince (Fig. 11.1) succumbed as a result of the aquifer overexploitation for the irrigation of alfalfa crops. In Chap. 7 of this book, Evan Carson tells us the sad story, including the loss in fish species and other aquatic animals after the dry out of the Churince system due to the aquifer overexploitation. A major disturbance that also impacted plants and, no doubt, microorganisms. Hopefully, the ancient microbes are still there, out of reach for us, hidden in the sierra depths and have followed the water. What is more disturbing is that the disappearance of Churince was a tragedy long foreseen, as indicated above. This overexploitation of water is not new; it has been occurring since the 1960s both by canals that drain the superficial water and through deep wells that drain the deep layers, as described in Chap. 6 by Oscar Leal. These deep wells increased in numbers in the late 1990s both in the valley of Ocampo, north of CCB, and in 2002 in the valley of Hundido, south of CCB (Fig. 11.1). The water of these three valleys is connected by tectonic faults that move the deep water (Souza et al. 2006). Therefore, the increase in the exploitation of the water in these three valleys sharply decreased the level of the water table.

In recent years, we obtained an enormous amount of data on the Churince system. With a very large team of researchers, we have been following the path of the superficial water and the biodiversity that it sustained, making the Churince system the best studied site in México (this book series by Springer is a testimony). Between 2002 and 2006, we lost the main lagoon of the Churince system (Souza et al. 2008), a large evaporating lagoon that used to measure 2 km in diameter (Fig. 11.4a and b),

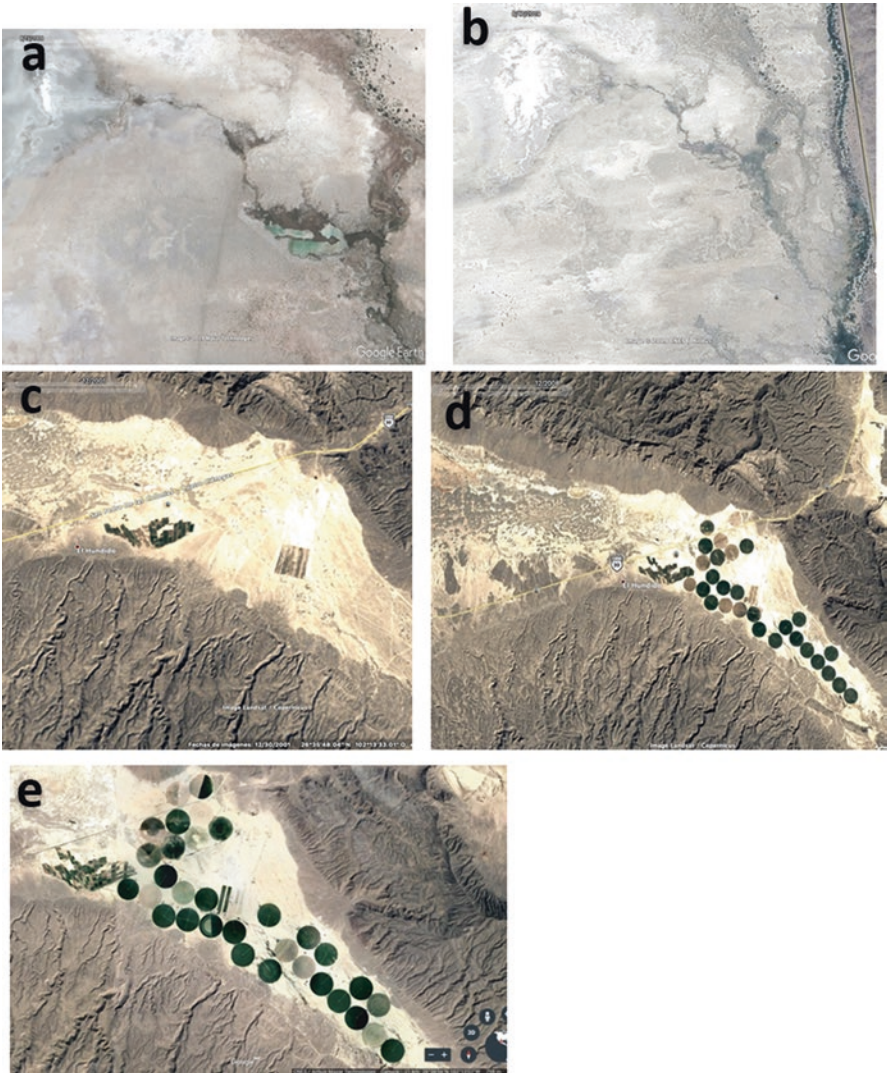

Fig. 11.4 (**a**) View of the Churince water system in 2009 and (**b**) 2019. (**c**) View of the of the alfalfa fields at Los Hundidos agricultural development, in 2001, (**d**) Los Hundidos in 2008, and (**e**) Los Hundidos in 2019. Google Earth images

and then the slightly deeper Intermedia lagoon (Fig. 11.1) started to lose its water, reaching a dramatic moment in the summer of 2011, when the levels got so low that there was a massive death of fishes, covering the sediment with a grim layer of corpses that glowed green due to the bacterial growth on top of them. The system got a respite by the end of 2012, when the canal La Becerra was closed to prevent further decay, and the system started to recover in summer 2013 (De Anda et al. 2018). Sadly, it was a just a mirage, as the canal got reopened by the ranchers in early 2014, and the system died completely by 2016 (Fig. 11.4b). At the same time, the number of alfalfa “rondines” (as the central pivot irrigation systems are locally called) in the nearby Hundido valley increased from almost nothing to a large density of alfalfa plots (Fig. 11.4c–e). It is fascinating that the riparian plants had predicted the decay of the system, before we could see it, as Irene Pisanty and colleagues describe in Chap. 8.

11.2 The Present

We have been working at understanding CCB’s extraordinary biodiversity for the last 20 years (see other books from this collection by Springer), and 18 of those years trying to preserve the wetland from dying. It has been a long battle against powerful companies and persons, federal and state governments, and lame local action by the county authorities, but mostly it has been a battle against ignorance, fear, and poverty.

In order to try to win such a battle, we decided to fight it along with the owners of the future, the children from CCB. Since 2004 we have engaged with the local high school to share our knowledge with students and teachers, design experiments, and take the kids outdoors to see the wetland (as most of them had never visited the pozas). In 2011, with the support of WWF-Fundación Slim and Fundación LALA (the latter, a dairy giants that were our previous opposers, now our allies in conservation), we built a molecular biology laboratory in the CBTA22 high school. We aimed to empower the students with firsthand knowledge of the biological treasure they had in CCB and the sense of discovery that DNA can give you when finding new species and doing experiments to learn about the great biological capabilities and biotechnological potential of these invisible creatures.

Besides teaching and collaborating with teenagers and their teachers, we have been working with children from kindergarten to sixth grade. In a fantastic program of consciousness through art led by Liliana Riva Palacio and ConcentrArte, a group of artists and teachers has been working since 2007 with all the children, every year, supported by Fundación LALA. With this project, they transform everything they touch and has been transformative for the CCB society (Lobo 2009; https://www.wwf.org.mx/?208550/presentan-libro-cuatro-cienegas-la-mirada-de-sus-ninos/).

Nowadays, the students from the CBTA 22 high school travel to our labs in México City and Guanajuato to learn biotechnology. They now have a sense of duty to the ecosystem. Even more so, the CCB society is transforming because of these kids. It is impressive what knowledge, along with consciousness, can do to a small town. Actually, one of the many kids that were captivated early on by our science projects in the CBTA 22 high school was Héctor Arocha (see Chap. 10). Hector has now a Ph.D. in biotechnology, which he obtained studying the strains from Cuatro Ciénegas. Héctor, along with his family members and friends, has been leading a fantastic social program named Plan Cuatro Ciénegas 2040, determined to ensure health and education for every child and a sustainable future for CCB. Héctor is now in charge of Genesis 4C, showing the students of his former high school how to tap the genetic recourses of this unique oasis. They will be the example of the Nagoya treaty for México: the first case where the owners of the land also own the knowledge to understand and develop the potential of this extraordinary biodiversity.

However, as Oscar Leal and collaborators reminds us in Chap. 6, the overexploitation of the aquifer is extreme, and we need to do something very soon. Parts of the canal Santa Tecla are already closed, and the wetland is recharging; also, parts of canal La Becerra have been diverted to recharge the aquifer, slowly but surely. The best news of all was that by the end of 2020, the canal Saca Salada was diverted to many small lagoon systems that started to restore the river Rio Mesquites (Fig. 11.1). However, those efforts were destroyed 5th of May, 2021 by a mob of angry ranchers from outside the basin. Before that, the president of México, Andrés Manuel López Obrador promised to the country to protect the CCB wetland. Let's hope it is not too late for the wetland animals whose populations have been depleted. We suspect it won't be too late for the resilient and hyper-diverse microbiota.

11.3 The Future?

While our crystal ball is still cloudy, our hope is that CCB becomes a lesson, a survival lesson for México and the world. We are exhausting our natural resources everywhere and badly managing the most important asset of the entire world: water.

Water is the essence of life; it is, simply, what determines the possibility of life. Earth is a blue planet, the only blue planet that we know in the universe, a planet apparently full of water and oxygen. However, even if 71% of the planet is covered in water, 96.5% of it is salty ocean water. Most of the drinking water is either deep in the underground, or forming ice in glaciers and ice caps, or already more or less polluted, leaving just 0.007% available for human use. From this tiny portion of clean water, 80% is used for agriculture (Albinia 2020).

In many cases, the water used for agriculture can be reduced and optimized, in particular in the desert and arid lands. Most people in the world will soon live in water-scarce sites; therefore, it is paramount to learn how to live and produce with less water. For México, the example can be CCB.

Many things have to happen in CCB to become such an example. The CCB canals have to be finally closed, so the wetland starts to recharge. Ranchers, as part of the local society, have to learn how to feed their cattle with less water-demanding crops and implement better agricultural practices. Children and students will teach their parents that each pond and stream, each water body, is a treasure trove, relevant for the future of human society, agriculture, industry, medicine, and ecosystem functions. Both because the water is by itself priceless and also because the invisible microbes in these waters contribute to the entire planet's functions and also hold in their biochemistry innumerable possibilities.

Many things must occur to arrive at this hopeful end, but it is like "the Lorax" children book by Dr. Seuss, "Unless someone like you cares a whole awful lot, nothing is going to get better. It's not."

We believe that this series of books edited by Springer is a testimony not only of the importance and fragility of this extraordinary oasis but also an ode of love by all the scientists that have painstakingly worked to describe as fast as possible a site that was on the verge of collapse. But most importantly, to work as hard as possible to transmit our passion to transform consciences and therefore change the future for a better one. We want a valley where the rivers run and the wetland is wet, a place where children, turtles, fishes, and stromatolites can share the wetland, a world where the future for all creatures is important, because we do care a whole awful lot.

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