Chapter 8
Plants as a Canary in the Mine: A Wetland Response to Ecosystem Failure

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8.1 Introduction

8.1.1 Canaries in the Mine, Canaries on the Surface

Canaries have been used by miners to detect the presence of toxic gases while working underground. This practice, initiated in the early twentieth century (1911), came to an end when automatized measurements became available. For decades, canaries were an early alert system of high carbon monoxide concentrations, to which canaries are more sensitive than humans, so they would become ill or die before humans felt the effects of the gas, alerting miners to exit the mine on time. The practice was widespread, and the expression became part of the everyday metaphoric language, referring to early alerts in general. This is a simple example of how nature expresses itself and talks to those who are willing to hear.

Though the expression refers to underground environments, surface "land canaries" are abundant but, unfortunately, they are usually not taken as seriously as were the canaries in the mines. Signals of ecosystem changes, for example, have been empirically and scientifically identified and documented for a very long time already. However, there are far too many examples where the signals have been acknowledged but utterly ignored by the numerous stakeholders involved in

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decision-making, from a very local to a worldwide level (Gedan et al. 2009; Jayawickreme et al. 2011; Zepeda et al. 2012).

"Canaries outside the mine" include physical and biological components at different levels of complexity (biosphere, ecosystems, communities, populations, and individuals) and can be from brutal to very subtle. All living organisms react to different levels of environmental changes according to both long-term adaptations and short-term phenotypic plasticity (Nicotra et al. 2010; Guo et al. 2017). Plant canaries can tweet from small, almost silent morphological, physiological or ecological variations to boasting species extinctions, habitat fragmentations or ecosystem losses. Examples include the timing of flower production, which can vary slightly from year to year according to temperature or water availability, the disappearence of pollinatoris, and the extinction of water-dependant species due to drying out desert springs, (Strayer 2006; Parker et al. 2020).

Due to their wide range of responses to environmental changes, plants are among the most reliable above-ground canaries (Chapin III et al. 1993b). They register variations in a large spatial-temporal range and can tell us about long- and short-term events that can even become evolutionary forces, for behind every evolutionary change there is an ecological process with long-term effects (Chapin III et al. 1993a; Chitwood and Sinha 2016). Ecological variations do not always translate into big evolutionary leaps, but they are always related to small or large environmental changes or to stochastic significant processes (Becklin et al. 2016).

8.2 Deserts, Water and Canaries

8.2.1 Desert Springs

Desert springs, which generate surface water bodies, are extremely important in arid lands, as they create environments that contrast with the prevailing dry conditions, which can be real fairy-tale oasis. Water bodies like springs, wetlands, creeks, rivers, lakes and artisan pools (*pozas*) generate patches of riparian, aquatic and subaquatic vegetation (Fig. 8.1). These water bodies also influence adjacent zones. Riparian areas are usually richer in species, for they are a transition between aquatic and terrestrial ecosystems, and as perennial fresh water sources, they sustain wildlife (Nilsson and Svedmark 2002; Hendrickson et al. 2008; Parker et al. 2020).

Riparian plant species live in the interphase between water and land and are distributed along the borders of superficial water bodies, creating discrete patches of vegetation that indicate water availability. Riparian species are hydrophytes, i.e. species with a high demand of water, which tolerate shifts from floods to relative droughts (Capon et al. 2013; Capon and Dow 2007). They can tolerate anoxic conditions due to floods, as well as different aerial conditions, including the harsh ones that characterize xeric environments. In the latter, survival, growth and reproduction depend on how they adapt to and how keen they are coping both with stochastic and periodical seasonal changes (Naiman and Décamps 1997; Leck and Brock 2000; Cronk and Fennessy 2001; Nilsson and Svedmark 2002).

Fig. 8.1 Desert springs in Cuatro Ciénegas, Coahuila, Mexico. (**a**) Poza Churince, Churince system (50.90 m), (**b**) Los Hundidos system (600 m)

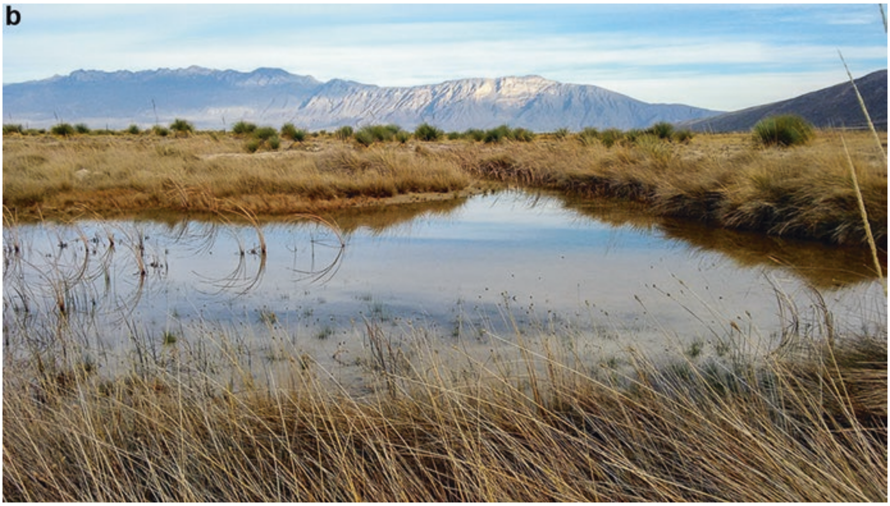


Fig. 8.1 (Continued)

Riparian species in arid and semiarid zones have to deal with contrasting selective forces, as they need to cope both with excess of underground water and above-ground lack of it. They also face extreme temperatures that can range from several degrees below zero to more than 45 °C, and different types of soils that imply different concentrations of salts and textures. In short, they have to deal simultaneously with both semi-aquatic and xeric conditions. Responses to this wide range of conditions are equally large (Naiman and Décamps 1997; Capon 2003; Bush 2006; Merlo et al. 2011; Huang et al. 2013; Cervantes-Campero et al. 2020; Rodríguez-Sánchez et al. 2020).

8.2.2 Water Systems in Cuatro Ciénegas

The Cuatro Ciénegas Basin (CCB), located at 26° 45′ 0″ and 27° 0′ 00" N 101° 48′ 49″ and 102°17′ 53" W, in the heart of the Chihuahuan Desert, is a unique place in many senses. As a result of its very complex geological history and of its latitude, it harbours an important set of different ecosystems and vegetation types (Minckley 1969; INE 1999; Wolaver et al. 2013; Souza and Eguiarte 2018; Ezcurra et al. 2020; Scheinvar et al. 2020). However, it is water that distinguishes this desert valley, where wetlands harbours many endemic species of aquatic animals, plants, fungi and prokaryotes in its Lagoons, rivers, and hundres of *pozas*. The presence of five hydrological systems (Churince, Garabatal-Becerra-Río Mesquites, Tío Cándido-Los Hundidos, Santa Tecla and El Anteojo) characterized the CCB. The Churince system was the most differentiated of them due not only to its gypsum-dominated soil but also because it is a little bit higher than the other systems (IMTA 2006). Churince used to have a terminal lagoon, an intermedia lagoon, a river and a spring. Not so long ago, superficial water bodies could be detected at a distance, because characteristic discrete patches of riparian vegetation announced them. These systems created unique aquatic and semiaquatic environments of great ecological importance, including the fact that they have been the habitat for stromatolites and microbial mats formed by complex microbiological communities (Souza et al. 2006, 2012; Corman and Elser 2018; De Anda et al. 2018a; Souza and Eguiarte 2018), and of several animal and plant endemic species or those species adapted to this unique conditions (Minckley 1969; Cole 1984; Pinkava 1984; INE 1999; Hendrickson et al. 2008; Villarreal-Quintanilla et al. 2017).

These water bodies are vital for human activities, like cattle raising and agriculture. We guess that right now you are thinking: Agriculture in the middle of the desert? Well, yes, and even if it sounds unbelievably wrong, alfalfa, which is one of the most water-demanding cultivars in the world, is the main cultivated species in the area. Now you must be thinking: Are they mad? No, they are not. Soils in arid lands are rich in salts, and their concentration prevents many other cultivated species from growing even when water which, by the way, is also salty, is available. Alfalfa stands the high soil salinity, which is a dominant characteristic in CCB (INE 1999). As there seemed to be plenty of water in the CCB area, impoverished *ejidatarios* accepted to grow alfalfa and sell it to passing trucks that give them 2 pesos (0.10 USA dollars) per kilogram, given its low quality. However, the cultivation of alfalfa has generated a major disturbance in the hydrological system of the valley.

Water has been overexploited in the Cuatro Ciénegas region for a very long time. The first important hydraulic change took place in the 1890s, when a canal was built to carry water from the valley to another river (Río Salado de los Nadadores), thus providing additional water many kilometres downward CCB (Hendrickson et al. 2008). Since then, other canals have been built, through which large volumes of water have been displaced at a huge environmental cost for the CCB, including the decline of the water table.

Different parts of the CCB complex hydrological system have been drying out progressively and sometimes dramatically fast. Maybe you wonder if no one ever thought that this would happen or maybe no one even noticed. Conflicts around water, land use and property, and conservation efforts are not scarce and, as could be expected, they influence decision-making and are increasing permanently. Please keep this in mind when reading the next pages.

The Churince system is an important part of the complex hydrological structure of the CCB. However, during the first two decades of this century, it has been deeply disturbed by the overexploitation of groundwater, and except for Poza Churince, mostly all of the surface water of this system is now gone, probably forever (Souza et al. 2006; Rodríguez et al. 2007; Cerritos et al. 2011; Pisanty and Rodríguez-Sánchez 2017; De Anda et al. 2018b; Souza and Eguiarte 2018; Pisanty et al. 2020). Its desiccation is already having effects not only on the water bodies, where dry lake beds have substituted the lagoons and most parts of the river, but also in the surrounding areas, like the borders and the highly saline plain in the south bank of the river (Pisanty et al. 2020).

You can easily imagine how serious the loss of these hydrological systems could be and then think that local stakeholders would avoid it at any cost. Well, the first thing is true, but the second proved not to be so. This desiccation process—a real tragedy—has been documented elsewhere, so we will go back to our canaries, for learning from their early advice might make us able to prevent further disturbances and help to avoid yet another one with the concomitant major socio-ecosystemic disruption and all its hard ecological, social, and personal repercussions.

8.2.3 Being Riparian in a Changing Arid Environment

Riparian plants in CCB include species from different families that have different growth habits and life cycles. Most of them are perennials, as is common in deserts with dry winters (Ezcurra et al. 2020). The most common riparian species include *Flaveria chlorifolia* (Asteraceae), *Samolus ebracteatus* var. *coahuilensis* (Primulaceae) and *Schoenus nigricans* (Cyperaceae) (Villarreal-Quintanilla et al. 2017; Pisanty et al. 2013, 2020).

As their original habitat disappeared because of the desiccation of the Churince system, several of the riparian species were able to colonize new habitats created by the disturbance affecting this hydrological system. As part of these new habitats, sinkholes were formed when the loss of strength of the water flux from the spring in Poza Churince began. This caused a sublevel flow of water in the plain close to the south bank of the Churince river (actually more a creek than a river), since water cannot reach the river mouth and the lagoon. This sublevel flow caused the loss of soil cohesion and the dispersal of soil particles, thus forming sinkholes, which, in lower quantites, are not uncommon in karstic and semi-karstic substrates. As surface water disappeared, so did the riparian habitats, and the plants inhabiting them died. However, many of these plants disperse easily, and they started colonizing the sinkholes (Fig. 8.2), which emulated their original habitat since they were humid and could even had water in them, at least for some time (Pisanty et al. 2013, 2020).

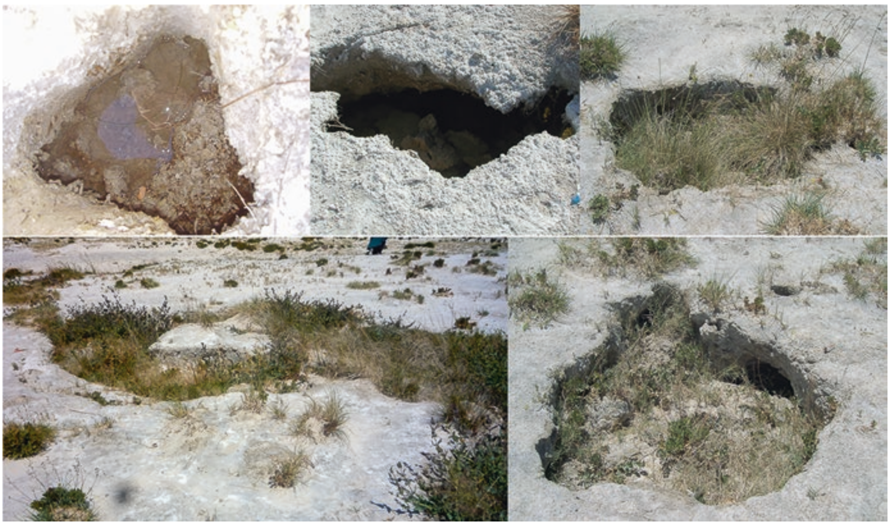


Fig. 8.2 Sinkholes with colonizing riparian species in the south bank of the Churince river, Cuatro Ciénegas, Coahuila, Mexico

Fig. 8.3 *Distichlis spicata* growing on the plain on the south bank of the Churince river

Some species, like *Samolus ebracteatus* var. *coahuilensis*, were also able to establish on the surrounding plain, where only *Distichlis spicata* (Poaceae) (Fig. 8.3), a salt-loving grass, would grow before this catastrophic mess. However, as water continued to be lost, the sublevel flow came to an end, and less and less water reached the sinkholes. Finally, basically all the sinkholes of the Churince system stopped having water in 2012, with only a few intermittent occasions, and by the end of 2017 there was no water in any of the more than 240 sinkholes that were formed through the desiccation period (Pisanty et al. 2020). As a matter of fact, numerous sinkholes are already closed covered with dry sand, with only a few riparian plants still growing where they had established. All this happened in a relatively short period of time, starting roughly in 2003.

Well, you might be saying, more than 15 years is not such a short time, but it is a terribly short one if you think of how long these hydrological systems and the aquatic, subaquatic and riparian habitats had been there before cows mooed and before alfalfa was even domesticated for cultivation. It took a short time to make superficial water, which had been there for millions of years, simply disappear. Shocking, isn't it? Having an accelerated formation of sinkholes is really bad news, the sad song of a canary that was not heard, but having dry sinkholes that will eventually close and disappear is even worse, for it means no water is left.

Unfortunately, canaries were there, and if their agony had been realized and accepted by decision-makers and other stakeholders, none of this would have happened, or at least it could have been stopped once it had started. Why our conservation efforts, and those of many other researchers and conservationists, were ignored in this process deserves a profound analysis that goes beyond the scope of this chapter.

How can we prevent this from happening again in other water bodies in the CCB and other desert hydrological systems? Many things are needed, and knowledge is indeed one of them. Albeit it not being enough on its own, science is badly needed in these cases, so we will start by introducing you to three of the above-ground canaries we have identified without forgetting that the formation of sinkholes is also a robust early warning system by itself.

8.3 Plant Canary # 1: *Samolus ebracteatus* var. *coahuilensis*

Samolus ebracteatus var. *coahuilensis* (Fig. 8.4) is a prostrate or erect plant from the primrose family (Primulaceae), and it is a very common species around water bodies throughout the CCB valley (Henrickson 1983; SEINet 2018). However, during the peak of sinkhole formation, it colonized the plain in the south bank of the Churince river, forming small clumps, as well as the newly formed sinkholes. In the seasonal census (2008–2017) of the sinkholes we mentioned above, this species tweeted a lot, initially occupying 85% of the sinkholes, with some seasonal variations.

Sinkholes were colonized very successfully by this plant, which was always among the first three species to establish in these newly opened habitats. When sinkholes were shallow and wide, *S. ebracteatus* var. *coahuilensis* thrived, producing many short branches and attaining a considerable plant cover; when they were narrow and deep, it also did well, for this plant shifted its growth from vertical and horizontal to only vertical, responding to shade with a long morph looking to get some light, although its plant cover was lower and the number of branches diminished considerably (Cervantes-Campero et al. 2020). In one way or another, it remained a frequent and dominant species in the sinkholes. As other species colonized the latter, sometimes *S. ebracteatus* var. *coahuilensis* would lose cover, probably through interspecific competition, but it continued being present (Pisanty et al. 2020).

Starting 2011, fewer and fewer sinkholes had water in them, and by January 2012 not a single sinkhole had water. As this process moved forward, conditions in the sinkholes were no longer so good for this canary, and it started tweeting less and sighing with more urgency, until the inevitable started happening, and this species clearly showed that something was going terribly wrong. By the end of 2017, *S. ebracteatus* var. *coahuilensis* was in less than 50% of the sinkholes and represented only 2% of the total plant cover (Pisanty et al. 2020), and plants in the plain became smaller and scarcer.

Additionally, many sinkholes closed during the desiccation process, due to the strong wind and sandstorms that are common in this valley, with the consequent loss of possible safe sites for this species. In January 2012, for example, in only 2 days 29% of the 148 sinkholes that were open in that date were covered by sand, and many of them did not re-open, for when there is no water to disperse its particles, soil accumulates permanently and eventually covers the depressions completely. Some of the riparian plants can remain for some time on top of what once was a sinkhole, indicating there is still some water availability, but if conditions remain as

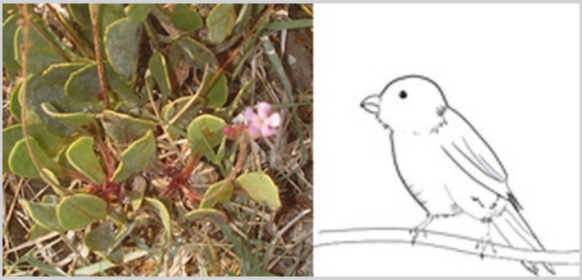
Fig. 8.4 *Samolus ebracteatus* var. *coahuilensis* in the Churince system, Cuatro Ciénegas, Coahuila, Mexico. (**a**) On the plain, (**b**) colonizing a sinkhole

they are now, eventually they will die. *Samolus ebracteatus* var. *coahuilensis* is one of the first species to suffer under these conditions, as its morphological plasticity (Cervantes-Campero et al. 2020), frequency and cover indicate (Pisanty et al. 2020). First come, first served… and among the first to go.

Although the seeds of this species have a quick germination response as soon as water becomes available (Peralta-García et al. 2016, 2020), and the seeds can remain viable at least for a year, they do not seem to be well represented in the seed bank now (A. Santiago and I. Pisanty, pers. obs.).

Samolus ebracteatus var. *coahuilensis* tweeted again, starting in 2015. This plant started establishing on the riverbed (Torres Orozco-Román 2017; Pisanty et al. 2020), where there were no plants when water was flowing in the river. What was a terrestrial plant doing in the middle of a river? Well, it is because it was not a river anymore. There was no water flowing, and the aquatic habitat was gone. This was the only substrate that still held some water underneath. With seeds easily dispersed by wind and a rapid response to water, this canary easily started colonizing this newly opened habitat but was loud about the dramatic loss of water, again.

Inbox 1



Canary dialogues 1: *Samolus ebracteatus* var. *coahuilensis*

First warning: Changes in distribution, including decreasing abundance and eventual disappearance from riparian habitats. Colonization of new environments, like a more humid (due to sublevel flow) flatland, the desiccated lake and riverbeds and the disturbance-induced sinkholes.

Time is ticking: Less abundance in the new habitats, signs of population decrease and loss of fitness.

Too late! Disappearance of the zones it occupied before and after the desiccation of the water bodies, establishment of less water-demanding species in them. The species becomes locally extinct.

8.4 Plant Canary # 2: *Flaveria chlorifolia*

This erect plant from the daisy family (Asteraceae; Fig. 8.5) is common in the CCB for several reasons: it needs more water than xeric species, so it grows along the water bodies that used to be common, and it is a gypsovague, meaning that it can tolerate

Fig. 8.5 *Flaveria chlorifolia* in the Churince system, Cuatro Ciénegas, Coahuila, Mexico. (**a**) *Flaveria chlorifolia* in a sinkhole, (**b**) colonizing the dry lake bed of the Churince lagoon, (**c**) in the border of the Churince river, forming a scrub

c

Fig. 8.5 (Continued)

high concentrations of gypsum ($CaSO_4 \cdot 2H_20$), which is a sulphate that frequently limits the establishment and growth of many species (Palacio et al. 2007, 2014; Escudero et al. 1999, 2000, 2015; Moore et al. 2014). While *F. chlorifolia* does not need gypsum to grow (Flores-Olvera et al. 2016; Peralta-García et al. 2016; Rodríguez-Sánchez 2018; Pisanty et al. 2020; Rodríguez-Sánchez et al. 2020), as true gypsophytes do (Meyer 1986; Escudero et al. 2015), but it can stand gypsum well. This trait makes it competitive in face of other species that cannot tolerate this salt. Even among other gypsovagues, *F. chlorifolia* is a frequent and successful colonizer of desert riparian habitats and of the new habitats the disturbance in the Churince system has created.

Flaveria chlorifolia was usually among the first three species to colonize sinkholes in the Churince and was found in 60% of them in the summer of 2008, reaching a maximum in August 2009 (68%) (Pisanty et al. 2013, 2020). The frequency of

F. chlorifolia has a clear seasonal pattern, decreasing in the cold season and increasing in summer. Nevertheless, in a longer term it showed much less variation and remained relatively constant, unlike that of the other canaries we identified (Pisanty et al. 2020). Plant cover of this species changes drastically during the cold season, for all leaves are shed, but, contrasting with *S. ebracteatus* var. *coahuilensis*, this species does not lose so much cover during the micro-successional process implied in the colonization of sinkholes.

Besides establishing in the cosy sinkholes, and sporadically on the plain, this species does what other riparian plants that characterized the borders of the water bodies in the CCB do not do: it profits of the underground water it can find in the cracks of the large, gypsum-rich lacustrine bed. Right, you got it: This species was the first to start colonizing the dry, inhospitable bed of the Churince lagoon, after several years of nothing growing there (Fig. 8.5b). Up to now, *F. chlorifolia* has been the most—actually almost the only—successful colonizer of the new and dry Churince area, an extreme habitat, but its demography proves colonizing this place is not an easy task (Rodríguez-Sánchez 2018). Scarce water, a very low content of nutrients and a thick gypsum crust add to the regular harsh arid conditions that make survival rates low, despite the many strategies the plant shows (Rodríguez-Sánchez et al. 2020). The latter include a perennial life cycle, based on the survival of meristems placed between the stem and the roots, which are frequently buried by sand. Leaves can be produced underground and have characteristic purple colour that turns into green as the young leaves emerge and are exposed to the intense sunlight.

Flaveria chlorifolia also establishes, sporadically, probably following temporal pits, but it has spectacular establishment on the dry plain and growth flushes around the borders of the water borders, impressively changing the typical landscape dominated by very short plants. In 2015, this species dominated the landscape around the river borders, with unusually large plants, more than a metre high, profusely branched and intensely producing flowers (Fig. 8.5c). Although it seemed they would dominate the riparian landscape soon, all of these uncommon individuals died after a couple of years.

A few years later, as the river desiccated further towards the spring, this process happened again, and many *F. chlorifolia* individuals settled around the river borders, where water was disappearing. Again, the landscape changed in part of the Churince system, with *F. chlorifolia* boastingly showing off its efficient colonization skills and use of the abundant sublevel water by intensively reproducing.

Unfortunately, our canary soon started sighing. Again, this sensitive canary was announcing the same tragedy: the loss of water. All these individuals died after a short period, while seedlings tried to establish in the newly desiccated part of the riverbed. *Flaveria chlorifolia* is not only an audacious and successful colonizer, but it can also be a hardy survivor once it establishes, as it can opportunistically occupy microsites in different environments and then endure selective pressures that can quickly eliminate other species, for example, gypsum concentration.

When this yellow-flowered canary gets sick and sighs, it is announcing lack of water in a desperate way since, due to its gypsovague character, it can grow under harsher soil conditions that include considerable concentrations of salt and gypsum, than the other two species of plant canaries we are looking at in this chapter. It is not notifying dangerous salt and gypsum concentrations, it is yelling that it is thirsty.

Inbox 2

Canary dialogues # 2: *Flaveria chlorifolia* **(Asteraceae)**

First warning: Changes in distribution, including loss of density, frequency and dominance in original riparian habitats and occupation of sinkholes, riverbed and, notoriously, the gypsum-rich dry lakebed. In the latter, it is among the first and few species that are able to establish in this difficult substrate. Short-term establishment of numerous individuals with a high growth rate where sublevel and deep water accumulations take place indicates an underground flow.

Time is ticking: No *F. chlorifolia* in the original riparian habitats, less individuals and loss of plant cover in sinkholes. Negative growth rates in the dry lakebed. Disappearance of the shrub-like clumps established near the river in the short-term establishment mentioned above.

Too late! Less water-demanding species displace this canary, more quickly in the sinkholes, the flatland and the dry riverbed than in the dry lakebed, due to the high tolerance to gypsum. It will soon disappear locally.

8.5 Plant Canary # 3: *Schoenus nigricans*

Schoenus nigricans (Fig. 8.6) is also a highly water-demanding riparian species. This is a grass-like plant from the sedge family (Cyperaceae). It plays a game of its own and is, thus, a very loud-mouthed canary. *Schoenus nigricans* has a very high affinity with water, as do many other members of its family (Bryson and Carter 2008; Simpson et al. 2011; Diego-Pérez and González-Elizondo 2013). It grows along river and lake borders and is an important element of the riparian landscape in the CCB.

Fig. 8.6 *Schoenus nigricans* in the Churince system, Cuatro Ciénegas, Coahuila, Mexico (**a**) at the border of *Poza Azul* in its natural riparian habitat, (**b**) growing in a sinkhole on the south bank of the Churince river

Schoenus nigricans grows both vertically (in height) and laterally, as it produces many tillers connected through very short internodes, thus forming clumps that can be quite large (Fig. 8.6). It reproduces through an annual period, producing many characteristic flowers and numerous seeds per fruit (50–120) that can be dispersed by wind or water.

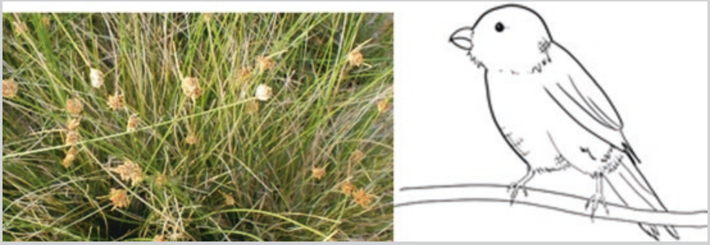
This species has a contrasting germination response when compared with the above-mentioned *S. ebractatus* var. *coahuilensis* and *F. chlorifolia,* for seeds germinate very occasionally in natural conditions, and only in wet sites, with a low germination rate (velocity) in controlled conditions (Peralta-García et al. 2020). Contrasting with the other two species we have mentioned, it does not germinate in rich-nutrient soils under experimental conditions, even if its seedlings love all the nutrients and grow successfully on this type of substrate. Seeds might have a conditional dormancy (Martínez-Sánchez et al. 2006; Peralta-García et al. 2020) that can prevent germination under conditions of low water availability.

Schoenus nigricans was among the first canaries notifying that something was wrong, for it soon resented the lack of water in the original riparian habitats and disappeared from them, successfully moving to the sinkholes, where both lonely single stems and large, dense clumps could be found, thus indicating the availability of water. Being one of the three most common colonizers in the sinkholes, *S. nigricans* always grew in them or on their borders, but never far from them, i.e. this species would not colonize the flatland, neither frequently, as *S. ebracteatus* var. *coahuilensis* did, nor much more sporadically as *F. chlorifolia*.

The frequency of *S. nigricans* in the sinkholes increased with time while water was available, but it diminished very soon as the whole area desiccated. However, due to the fact that in the older and larger sinkholes it had already formed large clumps, plant cover remained relatively constant, for green and dry stems, which are slender, remain mingled. Additionally, dry and green stems mingle and coexist, which can lead to an overestimation of their cover. Of course, if living stems are present, some water must still be available.

Schoenus nigricans is a major canary due to its strict association with water availability and to the time seeds take to sense the environment seedlings would grow in if they germinate (Baskin and Baskin 1971, 2014; Rojas-Aréchiga and Vázquez-Yanes 2000; Martínez-Villegas et al. 2012). Since it forms big clumps, changes in the riparian habitat they occupy are usually soon visible through the landscape modification along the water bodies. When new habitats are formed due to disturbance, this species is reluctant to act as a colonizer unless a good supply of water is guaranteed. This canary will become restless and sick very soon, leaving no doubt that something is not as it should be. Early warnings can be so useful when properly attended!

Inbox 3



Canary dialogues# 3: *Schoenus nigricans* **(Cyperaceae)**

Early warning: Strips of *S. nigricans* start losing density, and patches disappear along the riparian area. As sinkholes form, isolated stems appear and eventually form thick clumps, especially in the large ones. Seedlings appear in the dry riverbed.

Time is ticking: Clumps of *S. nigricans* show an increasing number of dry stems, mingled with green ones. Small clumps or isolated stems become less and less abundant. If, due to conservation efforts and a better management, water returns while underground stems are still alive, new stems will be formed. If there is a seed a bank or seeds from other sites in the CCB are dispersed, germination and new recruitments can take place, despite the characteristically difficult germination of this species.

Too late! Only dry clumps of *S. nigricans* remain. Local disappearance of the species will take place.

8.6 Conclusions and Perspectives

The canaries in the mine were clearly alarmed, they tweeted in despair, we as scientist together with other stakeholders and were listening. However, even if we tried to amplify their despair with our voices, the inertia of the government, the lack of understanding of the powerful and the unwillingness to act at all levels left the canaries agonizing or dead and the people facing the consequences of the aquifer depletion. Initially, *Samolus ebracteatus* var. *coahuilensis*, *F. chlorifolia* and *S. nigricans*, together with other less frequent and dominant species, lost their original riparian habitat in the Churince system from CCB but found alternate ones that, in some way, emulate it, like the sinkholes. They also found a habitat to colonize on the riverbed and in those parts of the plain where water was flowing through abnormally numerous minuscule canals. The succesful colonization of these new habitats was stopped by the progressive loss of water in them.

Very little is known about other species that could also act canaries, like the grass *Sporobolus airoides* (Poaceae). This species is a halophyte and needs water to be available, but it is not a riparian species. Nevertheless, it requires more water than strict xerophytes and found sinkholes suitable to establish in, especially on the borders, because of water availability (Pisanty et al. 2013, 2020). Today, it is very abundant and dominant in the plain, and is transforming it into a grassland of ca 50 cm high.

Further studies about these and other species will certainly highlight the conditions its growth indicates, but before that is known, we must keep in mind that quick changes in arid and semiarid places always indicate intense physical and/or biological changes. When the latter are anthropogenic (Pimm and Raven 2000), they are usually bad news, especially in this type of ecosystems (Unmack and Minckley 2008)

What comes next for the Churince and similar disturbed areas in CCB? Early warnings, like the formation of sinkholes and changes in abundance and distribution of our canary species have not been turned off, and many other have started tweeting hard and clear. The complete modifications of local environments and the local extinction of riparian species are the most probable scenarios.

And then? We need to identify canaries, not only from the Churince system but from all the systems in CCB and similar ecosystems, and then to observe and listen to them, for early warning can—and must—be a major conservation tool and, thus, a tool for the viability of local and regional human societies and their permanence. Every population that goes extinct contributes to the risk of permanently losing whole species especially when small populations of endemic and microendemic species are involved (Lande 1993; Lande et al. 2003; Mathies et al. 2014).

Indeed, tangible and intangible ecosystem services are at stake, and preserving them in such a unique place is in the interest of all stakeholders. It is in our own interest as humans. Desert springs are severely threatened by human activities. Time is ticking.

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