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The Colorado river delta (Mexico): ecological importance and management

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ABSTRACT. The Colorado river delta is a unique coastal system in the world, as it combines two important systems: the Colorado river and the Gulf of California. Consequently, the delta is dominated by bilateral interests, and influenced by administrative, political and natural processes, which involve the countries of the United States and Mexico. Located in the northern part of the Gulf of California, under a condition of natural isolation, a series of environmental attributes have been developed (biotic and abiotic) that are only observed in is region. In this work, the development of the bilateral political relations and the most important ecological characteristics are presented, as well as the management instruments that have been developed for over 80 years. From these issues, the possible scenario for the region is defined, and the development of methodologies for monitoring the effects of these possible tendencies on the natural components of the delta is proposed.

Key words: Ramsar, Colorado river delta, coastal zone management, environmental management of deltas.

RESUMO. O delta do rio Colorado (Mexico): importância ecológica e gerenciamento. O delta do rio Colorado é uma zona costeira única em todo o mundo, por associar dois importantes sistemas: o próprio rio Colorado e o Golfo da Califórnia. Conseqüentemente, o delta é dominado por interesses bi-nacionais e influenciado por processos administrativos, políticos e naturais, envolvendo os Estados Unidos e o México. Localizado no norte do Golfo da Califórnia, sob uma condição de isolamento natural, desenvolveu-se uma série de atributos ambientais (bióticos e abióticos) que só podem ser vistos nessa região. Neste trabalho, são apresentados o desenvolvimento das relações políticas bilaterais e as características ecológicas mais importantes, bem como os mecanismos de gerenciamento que vêm sido desenvolvidos por mais de 80 anos. A partir dessas questões, é definido um cenário tendencial possível para a região, e o desenvolvimento de metodologias para o acompanhamento dos efeitos dessas possíveis tendências sobre os componentes naturais do delta é proposto.

Palavras-chave: Ramsar, delta do rio Colorado, zona costeira, gerenciamento.

Introduction

The Ramsar Agreement is the world's oldest international agreement in the realm of conservation. Negotiations started in 1971 in the Iranian city that has given it its name, and the Ramsar Agreement nowadays imposed on 92 Member States to designate and protect wetlands of international importance and to promote its rational use. At present, its scope extends to nearly 800 areas (The Ramsar…, 2002).

Under the agreement, countries have the obligation to develop national policies for environmental conservation, as an integral part of the strategies that define the use of natural resources. Such policies entail for the communities to become aware of the importance of wetlands and the necessity to preserve them, especially those that coexist with them (International Union for Conservation of Nature, 1999).

The management of wetlands involves the need to develop their rational or sustainable use, which has been defined as "sustainable use that gives benefits to humankind in a manner consistent with the maintenance of the natural properties of the ecosystem" (Dixon, 2003). Sustainable use of wetlands should be developed through an integrated approach that considers the various associated ecosystems. For the case of inland wetlands, it is essential to talk about water basins as environmental units. Also, they have a strong influence on the marine water into which they flow .

Article 1 of the Ramsar Agreement defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters” (The Ramsar…, 2002). Generally, they can be identified as areas that are flooded temporarily, where the groundwater emerges onto the surface or in soils of low permeability covered by shallow water. All wetlands share a fundamental property: *water plays a vital role in the ecosystem, the determination of the structure and the ecological functions of the wetland* (IUCN, 1999).

The protection and the preservation of the freshwater resources are a goal explicitly considered in Agenda 21, recognized at the UNCED in Rio de Janeiro in 1992. The lack of fresh water in arid areas cannot occur beyond a point that meet the demand for public use, industrial or agricultural, so that it is a sustainable use of the resource (OECD, 1993).

This predominance of water determines that wetlands have different characteristics from terrestrial ecosystems; one of them is that they often display a great variability in time and space. This has important effects on the biodiversity that inhabits wetlands, which must develop adaptations in order to survive these changes, which can be extreme – for instance, hydrologic cycles of great magnitude, with periods of great drought and periods of flood.

Among the hydrological processes that are developed in wetlands is the recharge of aquifers, when the accumulated water in the wetlands descends to the underground layers. The ecological functions that wetlands develop favor flood mitigation and coastal erosion. In addition, through retention, transformation and/or removal of sediment, nutrients and pollutants play a vital role in the matter and quality of water cycles.

Several human activities require natural resources provided by wetlands, and therefore depend on the maintenance of their ecological conditions. These activities include fishing, agriculture, forestry, wildlife management, grazing, transportation, recreation and tourism. One of the fundamental aspects which in recent years has turned more attention to the *c*onservation of wetlands is their importance in the supply of freshwater for domestic, agricultural or industrial use.

The Colorado river delta is located in the northwesternmost part of Mexico and covers the states of Baja California and Sonora (Figure 1). They include one a unique coastal ecosystem, with special attributes for its hydrographic situations, high degree of endemism, occurrence of endangered terrestrial and marine species, for being the habitat for raising and spawning for a large number of marine species (many of them of commercial interest), permanent and temporary habitat of resident and migratory birds, and as an area that sustains the main socio-economic activities of the communities in Puerto Peñasco and Santa Clara, Sonora; and San Felipe, Baja California.

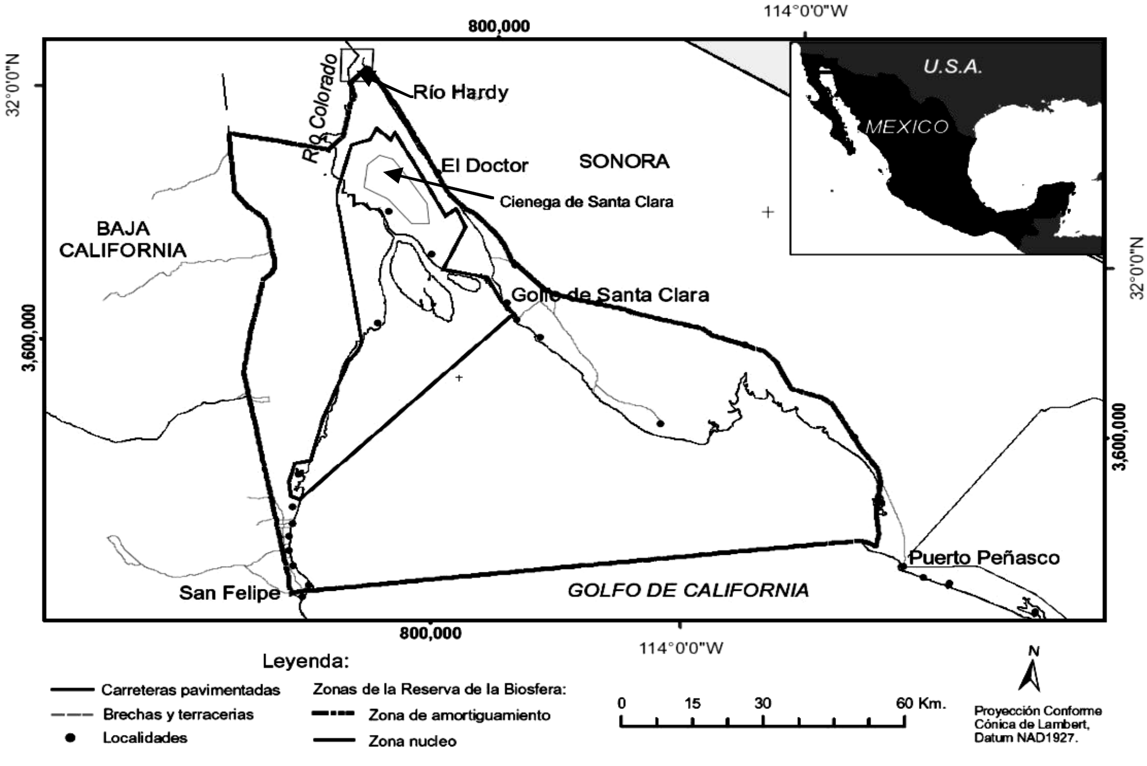

Figura 1. Colorado river delta natural reserve.

The Colorado river, like most of the great rivers in the world, has been manipulated for human use – dams have been built to maintain large pools of water, generate electrical power and to use them as recreation areas. Its flow has been diverted and regulated towards the California Gulf delta (Figure 1). All this has altered the natural environment of contiguous zones (Zamora-Arroyo *et al.*, 2001).

Native wetlands that were previously in the Colorado river delta have almost disappeared; there are only the bog of Santa Clara and the Hardy river, which are very important as natural habitats for wildlife and need water in constant amounts to support them.

Riparian ecosystems from the southwestern United States and northwestern Mexico have experienced changes in the composition of their plant communities. Originally, they were dominated by gallery forests of native trees, such as *Populus fremontii* and poplars (*Salix gooddingii*) and species like *Baccharis salicifolia*. However, they have been replaced by an exotic species, tolerant to the salinity – the salt cedar (*Tamarix ramosissima*) (Vandersande *et al.*, 2001).

Study area

The Colorado river delta is located in the northwest of the Mexican Republic, and is shared by the States of Baja California and Sonora. It is now less than 60 km from the border with the United States of America (USA). It has an approximate area of 164,779 ha and forms part of the Biosphere Reserve of the High Gulf of California and the Colorado river delta. It is located between the latitudes of 31°00' and 32°10'N and the longitudes of 113°30' and 115°15'W and occupies the northern High Gulf of California.

Because the marine portion of the delta is a small sea, surrounded by the Sonora Desert and the Baja California mountain chain, with heights from 1 to 3 km (decreasing with the influence of the Pacific Ocean), it displays a more continental than oceanic type of climate. There are two seasons, temperate winter from November to May, and subtropical summer from June to October (Mosiño and Garcia, 1974). The rainy period is presented in summer and winter, and the number of days of rain per year is about 5, with an average annual precipitation smaller to 100 mm (Lavin and Organista, 1988).

Material and methods

Natural characteristics and ecological importance

Variations in the flow of the Colorado river

The Colorado river originates in the mountains of Wyoming and Colorado, flows through 2,300 km into the Gulf of California, crossing seven states in the United States and two in Mexico. During the past 100 years, the free flow of the Colorado river has been blocked by the construction of ten large dams. At the beginning of the 1930s, the construction of the Hoover dam resulted in the first interruption of free flow of the stream, for six years. In 1963 the flow was interrupted again, due to the construction and filling of the Glen Canyon dam (USGS, 2000).

The water use quotas have been established by the Bureau of Reclamation Office (BRO) of the United States and the International Commission of Limits and Waters of Mexico (CILA). The annual water availability of the Colorado river, estimated at 20,353 million m^3, has been distributed between the High and Low Watershed (in United States and Mexico). The High Watershed includes the states of Colorado, Wyoming, Utah and New Mexico. The Low Watershed, the states of California, Arizona, Nevada and Mexico. The allocation of water for the United States and Mexico represents 90 and 10%, respectively (Table 1).

The main water users of Southern California have carried out active negotiations to reassign the water quotas of the Colorado river water to the state and reducing dependence of California on water surpluses, so that the state operates within its assigned legal quota of 5.4 billion m^3. On December 31st 2002, the district of Irrigation of the Imperial Valley (Imperial Irrigation District or IID) of California requested additional concessions, the result was that the agreement was not signed and determined that the IID was wasting water (Cornelius *et al.*, 2003).

Table 1. Water levels of the Colorado river (Mexicano Vargas, 2004).

	Millions of m^3	(%)	Millions de Sq. Acres
Cuenca Alta			
Colorado	4,687	23.02	3.80
Wyoming	2,122	10.42	1.72
Utah	1,394	6.84	1.13
New Mexico	1,048	5.14	0.85
Subtotal	9,251	45.45	7.50
Cuenca Baja			
California	5,427	26.66	4.4
Arizona	3,454	16.97	2.8
Nevada	370	1.81	0.3
Subtotal	9,251	45.45	7.5
México	1,851	9.09	1.5
Grand Total	20,353	100	16.5

The records of the Colorado river flow through the U.S.-Mexico border from 1904 to 1934, prior to the construction of dams, show an annual cycle with a maximum in June and a minimum in December (Lavin and Sanchez, 1999). The maximum discharges in summer must have significant impact on the plains of the Colorado river delta, nourishing wetlands with water of low salinity and high levels of suspended sediments, which allowed the blossoming of the ecosystems in the zone of the delta (Figure 2).

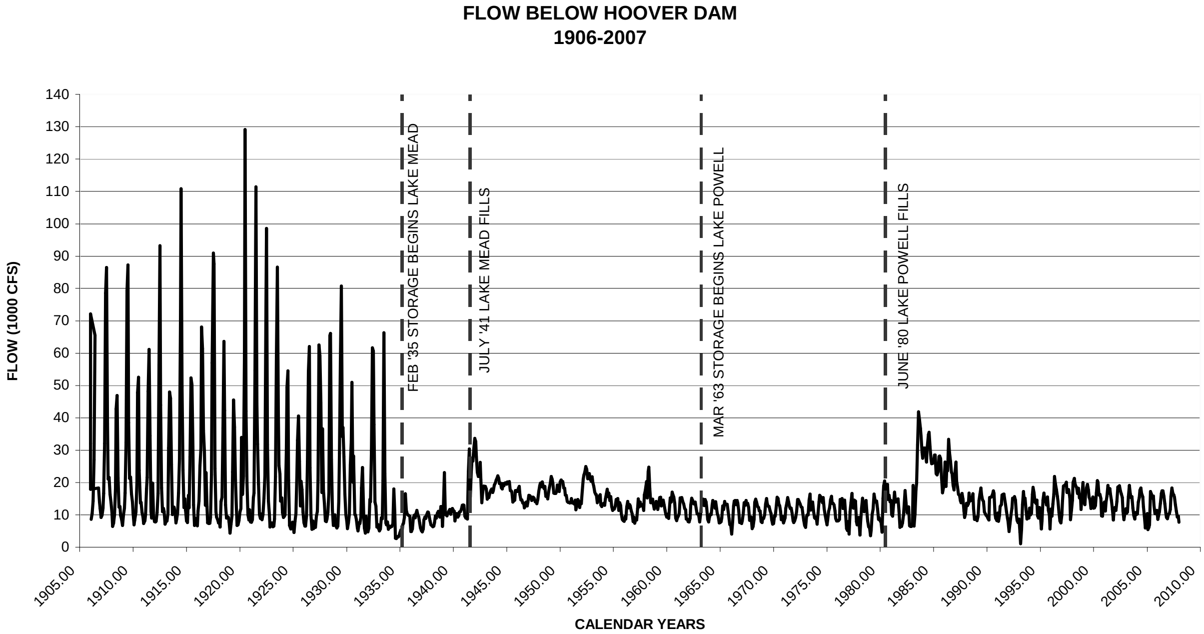

Figure 2. Flow of the Colorado river from the US to Mexico in $m^3 s^{-1}$ from 1904 to 1998. The interruption of the annual cycle began in 1935 with the construction of the Hoover Dam (Mexicano Vargas, 2004).

Since 1935, the natural annual cycle has been interrupted and the current discharges to the delta are negligible compared to past records. The exceptions to this phenomenon have been the controlled discharges of the dams due to abnormal defrosting or to excessive rains in the high and low river basins of the Colorado river. One of these events happened from 1984-1985, which flooded great extensions in the Delta, including the Laguna Salada, which like the Salton depression, is below sea level and floods when the flow of the Colorado river is abundant and persistent (All, 2002).

The free flow of the river helps to maintain biodiversity, not only by creating temporary niches of regeneration, but by also creating microhabitats that vary spatially in relation to the water source, amount of lightening and soil properties. These microhabitats vary in depth, texture and nutrient content, and bear different plant communities (Stromberg, 2001).

The hydrological patterns in time and space, for the delta, determine significantly the topography, geomorphology, soil type and composition and distribution of vegetation and fauna (Glenn *et al.*, 1999).

Another zone affected by the deviation of the flow is the Mexicali Valley (Mexico), where the lack of water has increased the soil salinity and reduced the harvests. In the southern portions, the agriculturists have left their lands because of the high concentrations of salt.

Results and discussion

Colorado river delta wetlands

The marshland of Santa Clara (Figure 1) is the largest Colorado river wetland, the distribution of species and the size of area covered with vegetation is related mainly to the salinity and water depth. The vegetation patterns are dominated by *Typha dominguensis* (tule); in addition to eight subdominant hydrophytes, a total of 24 species was documented.

In the east portion of the marsh the influence of freshwater appears, which comes from a series of artesian wells and generates a salinity gradient (15 to 2 ppm) that generates a variation in the diversity of vegetation, and a presence of less salinity-tolerant species such as *Baccharis, Eleocharis, Pluchea* and *Rumex*, as well as species more tolerant to salinity (Zengel *et al.*, 1995).

The changes in the natural composition of the delta have occurred by the establishment of opportunistic species like the salt cedar (*Tamarix ramosissima*), which has replaced native species such as *P. fremontii* and *S. gooddingii*, which are the most abundant species in the Colorado river delta, with 40% of coverage, followed by *S. gooddingii* (10-9%) and *Pluchea sericea* (10-3%). The loss of these native species has led to the collapse of habitat for numerous species of plants, birds, mammals and reptiles, of which 45 species in the low part of the Colorado river are listed as sensitive, threatened or endangered according to (Zamora-Arroyo *et al.*, 2001).

The salt cedar consumes a huge amount of water – a single tree can transpire 1.1355 m^3 of water per day; in comparison, an (acre=4046.86 m^2) of *Populus fremonti* consumes 223.250 m^3 of water per year, whereas 4046.86 m^2 (an acre) of salty pine consume 343.461 m^3 of water per year. An increase in salty pine may dry the water source next to it, and this can contribute to the effects of a drought. On the other hand, it is a plant that the majority of animals do not consume, as domestic cattle and wild animals do not like it. Also, the salty pine secretes excess salt through its leaves and is deposited in the substrate, making the environment more saline, which in turn eliminates the native plants that are not tolerant to high levels of salinity (CWC, 2003).

The combined effects of abiotic changes (physical conditions) and vegetation in riparian habitats have endangered many species that depend on them, such as the willow flycatcher (*Empidomax taillii*), the Yuma clapper rail (*Rollus longirostris*), and the Bell's vireo (*Vireo bellii pusillus*), as well as a large variety of fish that are in danger or becoming extinct.

The previous phenomenon is presented as one of the environmental challenges of the Colorado river delta region, and demands strategies and commitments to increase the abundance of native vegetal species of the riparian areas, with the purpose of modifying the dominance of exotic plants over native, in order to improve the wildlife habitat and the recreational attractiveness (Stromberg, 2001). This requires a set of actions that allow a restoration of the river's natural flow, recharge of underground water, thus reducing the rates of underground water extraction, municipal water recycling, reduction in the dependency of energy demand generated by water and the elimination of selected dams.

As far as fauna, the negative effects of the changes in the natural conditions of the delta can be seen in the variation of natural resources population that are significant for fishing and conservation, since the species that conform these resources depend on the biotic and abiotic conditions that are directly related to the levels of the Colorado river flow. One of the important fisheries in the region is the shrimp, whose population depends directly on the pulses of fresh water brought by the river (Galindo-Bect *et al.*, 2000). Similarly, the presence of endemic fish species (vaquita marina (*Phocoena sinus*), totoaba (*Totoaba macdonladi*), pez cachorrito del desierto (*Cyprinodon macularius macularius*), palmoteador de Yuma (*Rallus longirostris yumanensis*), gruñon (*Colpichtys hubbsi*)) – all important for conservation – depends largely on the delta's ecological function as a reproduction and refuge area for these species.

Strategies for the environmental management of wetlands in the Colorado river delta

There are a series of international agreements, treaties and laws that are indispensable to enforce the environmental principles and rules throughout the world, not only because they establish worldwide norms, but because the mere fact that they exist on an international level is reason enough for governments to become signatories or to enact their own laws.

From Mexico to Panama, there is an important density of wetlands; 25 of them have been declared Wetlands of International Importance or Ramsar sites by the International Convention on Wetlands. The government of Mexico is a signatory of the Ramsar Convention and therefore includes eight sites designated as wetlands of international importance, with an area of 1,157,121 hectares. These sites are under different schemes of administration, which include national parks, forest reserves, special reservations and wildlife refuges.

In Mexico, the Mexican Official Norm under denomination PROY-NOM-022-SEMARNAT-2003 was published in the Official Journal of the Federation, dated Thursday, April 10th 2003, in which it settled the specifications of management for the conservation of coastal wetlands. In this Norm, the Secretary of Environment and Natural Resources (SEMARNAT), through the General Law of Ecological Balance and Environmental Protection, establishes that an authorization of SEMARNAT is required for the accomplishment of works or activities that may cause ecological imbalance or exceed the limits and conditions, in order to protect the environment and preserve and restore ecosystems.

The present environmental management in the Colorado river delta is the product of a series of implemented policies that began with the Colorado river Compact program in 1922, where the distribution of the river water was divided between the high and low river basin. Later, the treaty between the United States and Mexico regarding the use of waters of the Colorado river, from February 3rd 1944, assigned to Mexico 9% of the Colorado river's waters, which corresponds to 1,852 million m^3. In 1964, another commitment was signed on the quality of water that the United States must give to Mexico, signed in the summary 242 of the treaty of 1944.

In these treaties, the highest priority is given to consumptive water uses, and the lowest priority to the "public benefit", understood as maintaining a river's flow sufficient to maintain fish, wildlife and habitat in the delta area; to date, the laws of the Colorado river do not cover the destination of water to maintain the ecological health of the riparian zone of the Colorado river delta and high part of the Gulf of California (Glenn *et al.*, 2001).

In 1987, the Recovery Plan for the High Basin of the Colorado river in the United States was implemented to protect and improve the contribution to the flow, restore habitats and reduce the adverse effects of exotic fish species. In 1994 the water users in the Lower Basin of the districts and counties of the U.S. implemented the Multi-species Conservation Program of the Low Colorado (MSCP) to mitigate the impact on the habitat of endangered and threatened species.

In 1966, the Bureau of Reclamation released an amount of stored water, in an effort to redistribute sediments of the basin of the Colorado and rebuild eroded beaches. All of these efforts suggest an increasing awareness of the importance of the ecological health and show the desire of water users and their representatives to modify management practices (Glenn *et al.*, 1999).

On the other hand, the Colorado river delta was recognized as part of the Network of Birds Reserves of the Western Hemisphere since 1992. In 1994, Mexico joined Canada and the United States in the American Management Plan of Aquatic Birds, and in 1996, the Colorado Delta wetlands were designated as part of the Ramsar Wetlands Convention (Glenn *et al.*, 1999).

On June 10th 1993, the delta was integrated as part of the High Gulf of California and Colorado river delta Biosphere Reserve, with an area of 934,756 ha, located in waters of federal jurisdiction in the Gulf of California and the Municipalities of Mexicali, Baja California and San Luis Río Colorado and Puerto Peñasco, Sonora. With this decree, the delta was included within the National System of Natural Protected Areas (SINAP).

The Reserve Management program was officially submitted in 1995 and implemented with the Annual Operative Programs of 1996 and 2000, and is administered and managed by the National Commission of Natural Protected Areas of the SEMARNAT. In 1996 began the field station operation of the Gulf of Santa Clara, coordinated with the State of Sonora Government. The Commission is a division of the Secretariat established June 5th 2000, and managed under the Internal Procedures of SEMARNAT, 2000.

In December 2000, the Joint Declaration between the United States Department of the Interior (DOI) and the SEMARNAT was signed, to expand the cooperation in the Colorado river delta as well as the 306 Conceptual Draft of the International Water and Boundaries Commission (CILA/IWBC). In September 2001, in the city of Mexicali, B.C., the Bi-national Symposium on the Colorado river delta was held, in which the legal and technical aspects of water management in Mexico and United States were spelled out, as well as the results of recent studies on the current conditions of the delta and its biodiversity, diffusion, protection conservation and restoration activities.

Conclusion

Future scenarios in the management of the delta

Long drought and new competition for resources

A drought scenario currently prevails in the entire of the Colorado river basin, and may possibly last a considerable period of time. As a result, at present the dams along the Colorado river are at extremely low levels. This scenario of decrease in water reserves and uncertainty feeds an intense political debate, both bi-national and within each country, on the forms of administration of water resources.

As an example, the southern states of the United States, and in particular those in the lower basin of the river, have used the drought as an argument to propose strategies that allow them to maintain the full water quotas, in the levels they currently receive and in some cases requesting an increase in these amounts. For the Mexican side of the basin, it represents a greater pressure, because of the water usage in the entire northern region of the Baja California peninsula, without even considering the possibility of allowing flows with ecological purposes in the river or the delta (Cornelius *et al.*, 2003).

Hydric projects development in the United States

The use of water quotas from the United States of the upper watershed has not come to consume the assigned total (Colorado, New Mexico, Utah and Wyoming). However, is predicted that during the next 40 years the demand on the water levels by the upper watershed states will increase significantly, by means of hydrological projects, which are currently in evaluation (Pitt *et al.*, 2000).

These increasing pressures on the river's hydric resources will inevitably reduce the flows to Mexico and the delta. Studies by the DOI to predict the flows below the river dams, found that, for 2040, the probability of any flow reaching beyond the point of deviation in Mexico is less than 20%. Since the river salinity tends to increase as the flows are reduced, it is likely that with time the salinity of the water delivered to Mexico will also increase (Zamora-Arroyo *et al.*, 2001).

Finally, it is important to emphasize that in the past 5 years actions have been taken that allow a timely follow-up on the evolution of environmental problems and impacts that affect the Colorado river delta through the use of indirect methods, such as the use of satellite images, which allow the monitoring of the changes of abiotic and biotic conditions that control the conditions of the delta. As part of these works, there currently exists a distribution map of *T. domingensis* in the Bog of Santa Clara, developed from the definition of the spectral signature of the species through the use of satellite imagery, combined with geographic positioning systems and spectrometry, and with the implementation of the subpixel rendering technique to solve the problem of the heterogeneity of plant communities in a wetland, which was used to measured the defined areas as composed of the dominant species *T. domingensis* (Nagler *et al.*, 2002; Sánchez *et al.*, 2001).

Similarly, vegetation indices (NVDI) have been developed for the population of the delta from DyCam and TM satellite images, with the goal of generating a time series from which it will be possible to estimate the recent vegetal cover evolution and its correlation with the river flow and delta topography (Nagler *et al.*, 2002; Mexicano Vargas, 2004). Continuing with these studies will allow the creation of a database, which will be the base for the integration of planning models, environmental management and monitoring of the delta, and which will operate as tools to help the technical and political issues related to the allocation of water quotas for the United States and Mexico.

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