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ABSTRACT

The Cienega de Santa Clara, a little-known, 20,000 hectare brackish wetland area in the delta of the Colorado River in Sonora, Mexico, is undergoing alterations due to operation of the Yuma Desalting Plant in the United States. This is the largest remaining wetland in the delta region, containing rare and endangered species including Desert Pupfish (Cyprinodon macularius) and Yuma Clapper Rail (Rallus longirostris yumanensis), yet no official consideration has been given to the effect of the altered conditions on the wetland flora and fauna. Here we describe the present status of the wetland and raise questions on the future of the area when the desalting plant reaches full capacity.

The delta of the Colorado River is one of the major desert-river estuaries of the world and contains the largest wetland ecosystem in the Sonoran Desert. Much of the delta has been converted into irrigated farmland; but approximately 250,000 hectares of unconverted delta land, too low for drainage and too saline for agriculture, still exists at the southern end of the delta in Mexico. Within this area lies the Cienega de Santa Clara, the largest brackish wetland habitat in the lower delta. This wetland, never adequately surveyed, is about to undergo major alteration in flow and salinity of input water due to activation of the Bureau of Reclamation's Yuma Desalting Plant in Arizona.

Prior to the construction of Hoover Dam and other upstream water diversions, the majority of the delta was lushly vegetated with an estimated 200 to 400 plant species[1] as well as numerous bird, fish, mam-

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1. E. Ezcurra, R. S. Felger, A. D. Russel and M. Equihua, *Freshwater island in a desert sand sea: the hydrology, flora, and phytogeography of the Gran Desierto oases of northwestern Mexico,* Desert Plants 9, pp. 35–44 (1988).

mal and other animal species.[2] Substantial river water reached the sea each year[3] and provided nutrients and brackish spawning habitat for fish and crustaceans in the marine habitat.

Since completion of upstream projects, very little water reaches the sea in most years and the delta region below the farmland consists mainly of dried sand, mud and salt flats. Brackish and freshwater habitats are largely restricted to areas where agricultural wastewater is discharged onto the flats or to 'pozos,' small regions of upwelling from the water table onto the mud (see Ezcurra et al., footnote 1). As a consequence, the wetland character of the delta and the associated migratory and resident species are considered to be at risk. The state of Sonora, the Mexican Federal Government, the United States Fish and Wildlife Service and international conservation agencies are attempting to document and conserve critical habitats in the delta region.[4]

The largest source of water into the eastern side of the delta is the Wellton-Mohawk Main Outlet Drain Extension (M.O.D.E). This water originates in the aquifer under the Wellton-Mohawk Irrigation District in the United States. As a result of a complicated set of salinity problems and negotiations between the United States and Mexico,[5] an 80 km, concrete-lined canal was built to carry approximately 1.3×10^8 m^3/yr. of water from the Wellton-Mohawk to disposal in the Cienega de Santa Clara.[6] This is brackish drainage water pumped from underneath farm fields, and contains approximately 3,200 ppm total dissolved solids (mainly NaCl). Disposal began in 1977 and was intended to be temporary. Due to delays in building the desalting plant, it has continued to the present and has resulted in the re-establishment of a wetland in the discharge area with approximately 20,000 hectares of water surface.

2. E. W. Gifford, *The Cocopa*, Publications in American Archaeology and Ethnology, University of California, vol. 31, pp. 257–334 (1933). G. P. Hammond, G. P. and A. Rey, *Narratives of the Coronado Expedition 1540–1542*, Publications, Coronado Cuarto Centennial 1540–1940, Vol. II, Albuquerque (1940). R. W. H. Hardy, *Travels in the Interior of Mexico in 1825, 1826, 1827, and 1828*, Colburn and Bently, London (1829, reprinted 1977, Rio Grande Press, Glorieta, New Mexico). J. C. Ives, *Report upon the Colorado River of the West*, House Ex. Doc. No. 90, 36th Congress, 1st Session, Washington, D. C. (part 4 of the whole work) (1860). A. Leopold, A Sand County Almanac, Oxford University Press, New York (1949, reprinted 1968, Oxford University Press).

3. G. Sykes, *The Colorado Delta*, Carnegie Institution of Washington, Publication No. 460 (1937).

4. Current projects to inventory and preserve the wetlands in the northern Gulf of California are being funded by Conservation International, The Nature Conservancy and Ducks Unlimited of Mexico in collaboration with the government agencies named in the text but none of the project participants were aware of Cienega de Santa Clara when we first contacted them.

5. Government Accounting Office, *Colorado River Basin Water Problems: How to Reduce their Impact*, GAO (May 4, 1979).

6. Bureau of Reclamation, *Yuma Desalting Plant: A Status Report*, BOR, Yuma (1990).

The cost-effectiveness and usefulness of the Yuma Desalting Plant have been questioned by federal auditors[7] and the scientific press[8] but the possible negative effects of the desalting plant on the Cienega de Santa Clara have not been considered, to our knowledge. The desalting plant, now completed, draws its supply from the brackish drainage water. Treated water from the plant pours into the Colorado River for delivery to Mexico, and the leftover brine is returned to the canal. At full operation, the net flow into the wetland will be reduced by 64 percent (depending upon the flows from Wellton-Mohawk) and the salinity will increase to approximately 7,300 ppm.[9]

No analysis of the effect of the flow reduction and salinity increase on Cienega de Santa Clara has been offered. The brief mention of the area in the Final Environmental Statement[10] assumed that the desalting plant would be quickly built and did not anticipate that a valuable wetland would develop in the M.O.D.E. discharge area before plant construction was completed. To our knowledge, the changes in this region have not been officially documented except for brief mentions of the endangered Desert Pupfish (*Cyprinodon macularius*)[11] and Yuma Clapper Rail (*Rallus longirostris yumanensis*)[12] populations.

Bureau of Reclamation reports refer to the discharge area as the Santa Clara Slough but this has led to confusion. According to Sykes (see footnote 3) the Santa Clara Slough is the short tidal channel at the extreme southeastern end of the delta (Figure 1). The discharge of M.O.D.E. water actually occurs 40 km north, in the area Sykes referred to as the Riito Salado, a former freshwater marsh fed by an overflow arm of the Colorado (Figure 1). The discharge does not actually reach either the Santa Clara Slough or the sea, even though Bureau of Reclamation[13] and International Boundary Water Commission[14] documents have stated that the water is discharged to the Gulf of California via the Santa Clara Slough. We use the

7. Government Accounting Office (1979). U. S. Dept. of Interior, *Survey Report on the Review of the Colorado River Basin Salinity Control Program*, Bureau of Reclamation, Washington (September, 1989).

8. Fred Pearce, *Banishing the salt of the earth*, New Scientist, pp. 53–56 (11 June 1987).

9. Bureau of Reclamation (1990).

10. Bureau of Reclamation, *Final Environmental Statement, Colorado River Basin Salinity Control Project, Title I*, BOR, Yuma (1975).

11. D. A. Hendrickson, and A.V. Romero, *Conservation status of the Desert Pupfish, Cyprinodon macularius, in Mexico and Arizona*, Copeia, 1989, volume 2, pp. 478–85 (1989).
E. W. Rinne and A. R. Guenther, *Recent changes in habitat characteristics of the Santa Clara Slough, Sonora*, in E. P. Pister (ed.), Proceedings of the Desert Fishes Council, V. IX, Desert Fishes Council, Bishop, CA, pp. 44–45 (1980).

12. W. R. Eddleman, *Biology of the Yuma Clapper Rail in the Southwestern United States and Northwestern Mexico*, U.S. Bureau of Reclamation, Yuma (1989).

13. Bureau of Reclamation (1990).

14. Government Accounting Office, Appendix X (1979).

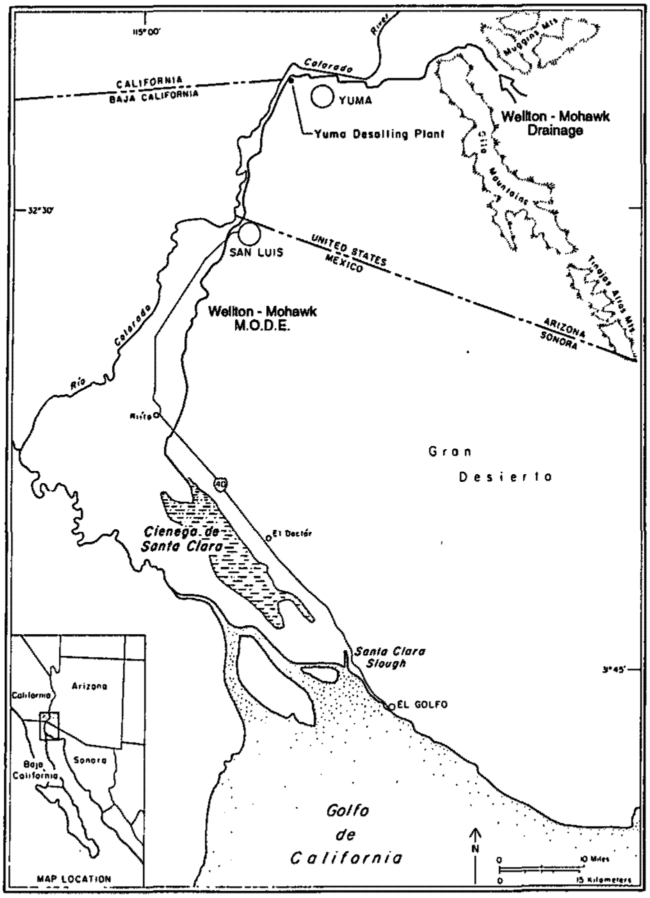

FIGURE 1. Cienega de Santa Clara

place name Cienega de Santa Clara for the discharge area because it appears on Mexican maps of the area.

Historically this part of the delta was a vast marsh fed by overflow from the Colorado River.[15] By 1974, when the area was inspected as a potential discharge area for brine water from the desalting plant, the marsh had shrunk to upper and lower portions of approximately 30 ha and 180 ha, respectively, separated by salt flats.[16] The upper marsh had a salinity of approximately 5,200 ppm whereas the lower marsh was as high as 82,000 ppm. The two marshes were fed by agricultural runoff and by brackish-water seeps of 1,200 ppm or greater salinity. Despite its small

15. Sykes (1937).
16. Bureau of Reclamation (1975).

size, the upper marsh was a habitat for two endangered delta species: the Desert Pupfish and the Yuma Clapper Rail.

Satellite images (LandSat 1979, 1989, 1991) which we have examined are difficult to interpret in terms of details of vegetation coverage and water area, but they do show that a substantial wetland area has been created by the M.O.D.E. discharge that appears to lack a surface connection to the sea. In 1979 the surface area of the wetland was approximately 20,000 ha whereas the present area appears to be approximately 12,500 ha, less than in 1979 due to narrowing of the width of the area (flows in the M.O.D.E. have also reduced—see data in footnotes 10 and 12). The satellite images also show possible sources of additional water into the wetland from local sources in Mexico, via canals leading from the irrigated areas to the north. The amount of flow from these sources is unknown.

The wetland, though vast, is in a remote portion of the delta, nowhere accessible or even visible by paved road, although the point of M.O.D.E. discharge can be reached by driving south for approximately 10 km along either bank of the canal where it crosses Mexico Highway 40 south of the settlement at Riito. Since no monitoring program has been conducted on the effects of discharge on the landscape, information on the area is restricted to a few mentions of the area in recent scientific reports. We have augmented this information by site visits and airplane overflights of the region.

A site visit by one of us (Glenn) in 1979 confirmed that a large, brackish water lake had formed at the discharge end of the M.O.D.E. canal. Very little emergent vegetation was present at that time. Mexican fishermen and families were camped at the end of the canal, launched boats into the lake, and caught mullet in nets near the end of the canal. The water in the canal and around the discharge point was clear and odorless at that time, and children swam in the canal water.

An internal Bureau of Reclamation memorandum[17] described exploring the wetland by boat in 1981, supporting the observation that this was a vast, open water surface in the first few years after flooding. However, another Bureau of Reclamation report at that time,[18] in evaluating various sites for discharging the Yuma Desalting Plant brine, described the Santa Clara Slough as a "... small salt marsh containing 14 species of marine fish." This description is inconsistent with the actual condition of the M.O.D.E. discharge area at that time, or subsequently. It may refer to the actual Santa Clara Slough, the tidal channel by the Gulf.

17. Cited in Eddleman (1989).

18. Bureau of Reclamation, *Potential Consequences of Reject Stream Replacement Projects on Aquatic, Terrestrial, and Recreation Resources: Volume II, Aquatic Resources*, BOR, Boulder, Nevada (1980).

We revisited the area around the discharge point in August, 1990; March, 1992; and May, 1992. Low-level aerial surveys were made in June and July, 1992. At present the flooded area is 36 km long and varies from approximately 15 km in width in the north to 2 km at the southern end. The northernmost one-third, covering approximately 4,000–6,000 ha, is thickly vegetated with cattail (*Typha domingensis*) 3–4 m tall with patches of common reed (*Phragmites australis*) and bulrush (*Scirpus americanus*) interspersed.

Numerous open channels of water, 1–2 m deep, interrupt the vegetation in this northern portion. The water in the final stretch of canal and near the discharge point is considerably more turbid than formerly, green from algal growth and with a distinctly sulfurous odor near the discharge point. A delta has developed near the point of discharge due to siltation, and obstructed water has flowed back along the sides of the canal to create backwaters.

The backwaters support numerous halophytic wetland species including: iodine bush (*Allenrolfea occidentalis*), saltbushes (*Atriplex lentiformis, A. canescens*), salt grass (*Distichlis spicata*), alkali heliotrope (*Heliotropium curassavicum*), Mexican sprangletop (*Leptochloa uninervia*), arroweed (*Pluchea sericea*), rabbitfood grass (*Polypogon monspeliensis*), screwbean (*Prosopis pubescens*), cañaigre (*Rumex dendatus* subsp. *klotzschianus*), salt-marsh bulrush (*Scirpus maritimus*), purslane (*Sesuvium verrucosum*), and saltcedar (*Tamarix australis*). Large quantities of the submerged aquatics, such as widgeon grass (*Ruppia maritima*), an important food resource for waterfowl, are common in shallow water.[19]

By contrast to the northern third of the wetland, the southern two-thirds is devoid of vascular plants. Although this area has only been surveyed by air, and not sampled, it is possible that a salinity gradient exists due to evaporation of the water from the lagoon, such that emergent vegetation is restricted to the upper portion of marsh closest to the inflow point. Mats of red-colored algae coat the bottom of the lagoon in the region below the *Typha* zone. Evaporative deposits line the shores of the southern end of the wetland, supporting the hypothesis that the discharge lagoon is essentially a large evaporation basin. Normally there is no surface connection to the Gulf of California, except at occasional highest tides. There is no surface connection to the Santa Clara Slough, which in any case has been partially obstructed by earthen access roads crossing to a shrimp farm on the mud flats south of the wetland.

The Cienega de Santa Clara has become a major bird habitat. Eddleman[20] declared in 1989 that this wetland contained a higher concen-

19. Plant specimens are deposited at the Herbario Nacional, Departamento de Botanica, Instituto de Biología, Universidad Nacional Autónoma de México, and the Herbarium of the University of Arizona.

20. Eddleman (1989).

tration of Yuma Clapper Rails than his team had observed at any other location. He documented numerous other wetland bird species and concluded this area may be the largest wetland bird habitat left in the delta. Among the species he documented around the discharge point on a two day visit were

> . . . soras (*Porzana carolina*), Virginia rails (*Rallus limicola*), least bitterns (*Ixobrychus exilis*), American coots (*Fulica americana*), common moorhens (*Gallinula chloropus)* (at least one brood of 3-week chicks seen), dowitchers (*Limnodromus* sp.), American avocets (*Recurvirostra americana*), black-necked stilts (*Himantopus mexicanus*), cinnamon teal (*Anas cyanoptera*), northern shovelers (*A. clypeata*), white-faced ibis (*Plegadis chichi*), green-backed heron (*Butorides striatus*), snowy egret (*Egret thula)*, black-crowned night heron (*Nycticorax nycticorax*), and Caspian terns (*Sterna caspia*).

He reported plentiful signs of crayfish and speculated that invertebrate production was high in the area, providing food for many of the bird populations. Of particular interest was the possibility that least terns (*Sterna antillarum*) were breeding in the area. Our aerial observations in 1992 disclosed that bird populations were even higher in the open water south of the cattails than in the vegetated portion of the wetland observed by Eddleman; birds were observed rafting in very large numbers in the open water area.

Based on our observations, we wish to raise the following questions concerning the fate of this wetland area:

1) Since there appears to be no outlet to the sea, the discharge area may be viewed as a closed evaporation basin. Will salinity build up over time and eventually kill the emergent vegetation?
2) Is buildup of boron, selenium, molybdenum or arsenic of possible concern as hazards to wildlife as evaporative processes continue over time, as occurred at Kesterton Reservoir, California,[21] another closed evaporation basin for agricultural wastewater, albeit one perhaps with different water chemistry?
3) What effects will operation of the desalting plant have on the biology of the wetland area? The reduction in flow will unavoidably reduce the area of wetland and the increased salinity of the flow will almost certainly exceed the salt toler-

21. U. S. Dept. of Interior and California Resources Agency, *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley, Final Report of the San Joaquin Valley Drainage Program*, Department of Water Resources, Sacramento, California (1990).

ance level of the emergent vegetation (e.g. cattails) in the upper, vegetated area.[22] Will this lead to a vegetation die-off, eutrophication and loss of wildlife habitat in the presently vegetated portion of the marsh?

4) What monitoring and mitigation measures are available to minimize damage and unforeseen negative consequences of the present M.O.D.E. discharge and future brine discharges? Possible mitigation measures include modifying the schedule of operation of the desalting plant to permit a full flow of M.O.D.E. water during critical periods for vegetation and wildlife, plus measures at the discharge end (e.g., cutting a canal to the sea at the southern end to permit a flow).

Policy decisions regarding this unique wetland area need to weigh the benefits to be derived from the desalting plant against the costs associated with loss of wildlife habitat in the Cienega de Santa Clara, including the costs already incurred in improving habitat for the endangered species elsewhere in the delta. The Bureau of Reclamation has expressed the view[23] that since the Cienega de Santa Clara did not exist when they first did their Environmental Statement in 1975, they were not obligated to consider the impact of desalting plant brine on the area in 1992 when plant operation finally began; hence, they started plant operation and brine discharge at one-third capacity without further study of the area. A different point of view would be that the Bureau of Reclamation is responsible for evaluating the effects of the brine on the ecosystem that exists now at the discharge point and providing for a safe and stable ecosystem in the area for the future.[24]

22. P. A. Beare and J. B. Zedler, *Cattail invasion and persistence in a coastal salt marsh: the role of salinity reduction*, Estuaries 10, pp. 165–70 (1987). J. B. Zedler, E. Paling and A. McComb, *Differential responses to salinity help explain the replacement of native Juncus kraussi by Typha orientalis in Western Australian salt Marshes*, Aust. J. Ecology 15, pp. 57–72 (1990).

23. Lori Myrland, *Researcher's claims about desalt plant inaccurate: USBR official*, The Yuma Sun, p. 4 (Dec. 15, 1991).

24. In October 1992, a binational study of the Cienega de Santa Clara was initiated with support from U.S. Fish and Wildlife Service and the Bureau of Reclamation. We thank Sandy Lanham for conducting aerial surveys.