CHAPTER 27

Using ecotechnology to address water and habitat loss quality in estuarine systems, Gulf of Mexico: a synthesis

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Abstract

This contribution is based on a previous technical report in *Science and Information Technology for Sustainable Management of Aquatic Ecosystems*. Universidad de Concepción, International Water Association, 7th ISE & 8th HIC Chile, pp. 90–99, 2009. In the Mississippi basin (USA) and Grijalva-Usumacinta basin (México), there has been a large-scale loss of wetlands and water quality deterioration over the past 50 years. Wetland loss is due to reclamation, mainly for agriculture, urban development, oil and gas industry, and isolation of rivers by levees from their floodplains and deltas. Water quality has deteriorated throughout the basin due to several factors including heavy use of fertilizers, efficient drainage, wetland loss, erosion, and reduced diversity of crops. Habitat loss and poor water quality are the results of cumulative impacts of actions throughout the basin. Wetlands promote nitrogen removal, not only through de-nitrification, but also through burial and plant uptake, which offer a sound ecotechnological solution. There are additional benefits of restoration of wetland and riverine ecosystems such as flood control, reduction in public health threats, enhanced landscape, wildlife and fisheries, increased accretion rates to help offset subsidence, and financial and energy saving of capital not invested in conventional tertiary treatment systems.
Keywords: Residual waters, eco-technology, ecological engineering, wetlands, Gulf of Mexico.

1 Introduction

In this paper, we address ecological approaches to solving water quality and habitat deterioration in coastal ecosystems and their watersheds. We focus on the Mississippi (US) and Grijalva-Usumacinta (Mexico) basin and delta. Human impacts are occurring from local to global scales. This is especially important in large river basins where there has been large-scale loss of habitat degradation, especially wetlands and riparian areas, and water quality deterioration. We use the Mississippi basin and delta and Grijalva-Usumacinta basin and delta as a model for both environmental impact and holistic management. Many wetland and riparian ecosystems have been isolated from rivers and streams and there has been widespread loss of wetlands, both in the Mississippi basin and elsewhere.

Wetlands improve water quality in a number of ways. Both phosphorus and nitrogen can be assimilated via plant uptake and burial and nitrate can be lost to the atmosphere via de-nitrification. At the level of the drainage basin, changes in farming practices and use of wetlands for nutrient assimilation can reduce nutrients in rivers. Postel [1], Vitousek [2], Mitsch *et al.* [3], and Mitsch and Day [4] discussed how wetlands could be used to reduce fertilizer runoff to streams and showed that a return to more traditional farming practices, what they called multifunctional agriculture, would also promote lower fertilizer runoff from farm fields. Restoration of wetland and riparian ecosystems also results in improved flood control, reduction in public health threats such as blue baby syndrome, and more habitats for wildlife and fisheries. Reconnection of the river to the floodplain and delta is an integral part of restoration of river basins. The use of river diversions can address both problems of coastal land loss and water quality deterioration; nitrate levels in river water can be removed in wetlands by the process of de-nitrification; wetlands are being used throughout the Mississippi basin to assimilate nutrients in municipal wastewater and agricultural runoff; this approach is costeffective and results in improved water quality, enhanced wetland productivity, and increased accretion [3, 4].

2 The coastal zone under severe risk

The problems described earlier for the Mississippi basin occur unfortunately throughout the world. During the 20th century, the effects of human activities affected ecological and biogeochemical processes at the global level (United Nations Environment Program, 2006, Millennium Ecosystem Assessment, www.millenniumassessment.org). For example, humans directly or indirectly use about 40% of net terrestrial primary productivity and about 30% of the accessible renewable fresh water runoff, and in the upper Mississippi basin, up to 90% of natural habitat has been converted to other uses, mostly agriculture [2–4]. About 55% of tropical forests have been cut with strong impacts on biodiversity [5]. Even greater losses have occurred in the vast bottomland forests of the lower Mississippi floodplain and the lower Grijalva-Usumacinta floodplain. There is widespread land degradation due to soil erosion, salt intrusion, and desertification [6] and persistent flooding in low-lands due to subsidence. Human activity has affected the global nitrogen cycle and in many of the world's rivers, nutrient levels in rivers are increasing [7–9]. As a result, hypoxia is a common phenomenon in many shallow continental shelf areas that receive significant fresh water input, such as the Mississippi and Grijalva-Usumacinta deltas. To solve the problem, a basin-wide approach using ecotechnology and ecological engineering is required [4, 10].

Global climate and the availability and cost of energy will make coastal and drainage basin restoration much more challenging [11]. Climate change is leading to increased temperature, sea level rise, and changes in rainfall patterns [12, 13]. Eustatic SLR was about 15 cm (1.5 mm/year) during the 20th century. The IPCC predicts the sea level rise of about 40 cm in the 21st century, but recent satellite measurements indicate that it is already about 3 mm/year. Information from the arctic on decreasing sea ice and snow cover, decreasing albedo, and more rapid melting of the Greenland ice mass has suggested to some climate scientists that sea level rise will be higher, perhaps a meter [14]. Thus, RSLR in deltaic areas with high levels of subsidence will be considerably higher than a meter in this century. Recent evidence also suggests that there is a trend toward stronger, more frequent hurricanes in the Gulf. Energy scarcity will likely become an important factor affecting delta management. Recent analyses suggest that world oil production will soon peak implying that demand will consistently be greater than supply and that the cost of energy will increase significantly [15]. Some argue that the peak is occurring now while others argue it is 2–3 decades away. But the planning horizon for coastal and basin protection and restoration is 50 to 100 years, so energy scarcity will certainly affect how we manage the coast. Levees, barrier island restoration, and pumping of sediments are energy intensive both in construction and maintain. River diversions and wetlands for water quality improvement have relatively low long-term maintenance costs.

3 Eco-technology and ecological engineering: toward a sustainable future

It is clear that in the coming decades, society will be faced with restoring valuable ecosystems in a time of climate change and energy scarcity. This restoration will be necessary for the services they provide because in the time of declining energy, services from ecosystems will become relatively more important in supporting the human economy. In order to be able to carry out ecological restoration in the time of energy scarcity, energy efficient ecotechnologies will be necessary [16, 17].

This kind of ecotechnology is ecological engineering [4, 10, 11], and the concepts and tools for dealing with such as problems are explained in [4, 16, 17]. Ecological engineering is defined as '*the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both*' [18]. Ecological engineering involves creating and restoring sustainable ecosystems that have value to both humans and nature. Ecological engineering combines basic and applied science for the restoration, design, and construction of aquatic and terrestrial ecosystems. Ecological engineering uses mainly the energies of nature with human energy used in design and control of the key process. This will become extremely important in a time of energy scarcity. The goals of ecological engineering are 1) the restoration of ecosystems that have been substantially disturbed by human activities such as environmental pollution or land disturbance and 2) the development of new sustainable ecosystems that have both human and ecological value. The primary components of ecological engineering are self-designing ecosystems with their biological species and biogeochemical processes.

Restoration ecology and the restoration fields (e.g. terrestrial, aquatic, and wetlands) have many features in common with ecological engineering. Ecosystem restoration is 'ecological engineering of the best kind' because we are putting back ecosystems that use to exist.

Self-design and the related concepts of self-organization are important properties of ecosystems in the context of their creation and restoration. Self-organization is the property of systems to reorganize themselves, given an unstable and non-homogeneous environment. Self-organization applies well to ecosystems where species are continually introduced and deleted; species interactions (e.g. predation and mutualism) change in dominance and the environment itself changes. All of these activities go on to some extent continuously. Self-organization is a characteristic of the system itself. The species that succeed in an ecosystem are those that reinforce other species through nutrient cycles, aids to reproduction, control of spatial diversity, population regulation, and other means [19]. Self-organization develops flexible networks with a higher potential for adaptation to new situations. Thus, self-design is desirable for solving many ecological problems, particularly in coastal river basin wetlands. When biological systems are involved, the ability for the ecosystems to change, adapts, and grow is very important. Self-design is defined by Odum [19] as '*the application of self-organization in the design of ecosystems*'. Self-design is an ecosystem, which functions in a way where the chance introduction of species is analogous to chance mutations in evolution. In the concept of the ecosystem development, self-design means that if an ecosystem is open to allow 'seeding', of enough species, the system itself will optimize its design by selecting for the assemblage of species and processes that is best adapted for existing conditions.

4 Wetland habitat loss and water quality deterioration in the Gulf of Mexico

4.1 The Mississippi basin and delta

The Mississippi basin has a 3.2 million km^2 watershed that includes about 40% of the landmass of the lower 48 United States and delivers about 90% of the freshwater discharge to the Gulf of Mexico. The mean discharge is slightly larger than 18,000 m^3/s. The Mississippi delta is a large regional coastal ecosystem that encompasses about 25,000 km^2 of wetlands, shallow inshore water bodies, and low elevation upland areas, mainly ridges associated with current and former channels of the river. About 25% of the coastal wetlands of the delta were lost during the 20th century [20]. There were also large losses of wetlands in the basin, as high as 90% in some states, mostly due to agricultural reclamation. A marked deterioration of water quality occurred at the same time as the wetland loss. One of the most well-known water quality problems is the large zone of low oxygen in the near shore Gulf of Mexico adjacent to the Mississippi delta. But water quality has declined throughout the basin due mainly to agricultural runoff. The decline in water quality is due to a number of cumulative impacts including loss of wetlands, efficient drainage of the landscape, heavy fertilizer use, and a reduction of agricultural diversity to that dominated by corn and soybeans [3].

Seven states in the upper Mississippi River basin (e.g. Indiana, Illinois, Iowa, Minnesota, Missouri, Ohio, and Wisconsin) have collectively had about 18.6 million ha (46 million acres) of land drained [21], much of which was wetland. The landscape has lost much its ability to maintain a biogeochemical balance and the streams are no longer buffered from agricultural areas. The environmental services associated with these wetlands have also been lost.

In the Mississippi delta, 25% of wetlands present at the beginning of the 20th century are gone with rates of loss as high as 150 km^2/year, and a total loss of about 3900 km^2 of coastal wetlands has been lost [22]. Coastal wetland loss is the result of several interacting impacts, including: 1) elimination of riverine input to most of the coastal zone due to construction of flood control levees along the Mississippi River, 2) reduction of the suspended sediment in the Mississippi River, 3) alteration of the internal hydrology of the delta, mostly due to canal construction, 4) saltwater intrusion resulting from lower freshwater input and canals, 5) wave erosion of marsh shorelines, and 6) high relative sea level rise (RSLR) resulting from geologic subsidence [23, 24]. Thus, wetland loss is a complex interaction of different factors acting at different spatial and temporal scales, but the loss of riverine input to most of the delta is probably the most important factor [20, 25]. Hypoxia conditions (low dissolved oxygen conditions in bottom waters, generally <2 mg/l) on the continental shelf of the northern Gulf of Mexico [26, 27], is related to land use changes and high fertilizer use in the Mississippi basin [28]. A reduction of nutrients in the Mississippi river can help reduce the problem of hypoxia.

4.2 The Grijalva-Usumacinta basin and delta

The ecosystem characterization has been well documented [10, 29, 30]. A typical tropical rain feature in the upper basin of this region is more than 3,000 mm/year, with a minimum of 1200 mm/year. The torrential rains during summer time are associated with cyclones (hurricanes). Almost 35% to 40% of the cyclones originating in the Caribbean Sea affect the Mexican coast in the Gulf of Mexico. The watershed of the Grijalva and Usumacinta rivers encompass a total of 118,500 km^2 remaining from its historical extension of 186,000 km^2 due to land conversion to agriculture (for a 36% of the original total), and gas pipelines and other petroleum-industry-related activities. The delta prairies are assemblages of Mescalapa, Grijalva, Chilapa, and Usumacinta Rivers, and together they have constituted a large delta with more than 20,000 km^2. The delta comprises a main river, the Usumacinta, and a major tributary, the Grijalva River. The watershed drains one of the largest areas of contiguous tropical forest in the region, including 177,987 ha in Campeche, 724,547 ha in Tabasco, 2,175,718 ha in Chiapas (all of three states in Mexico), and 4,241,271 ha in Guatemala. The Usumacinta River begins a meandering course through the swampy low lands of the southern shores to the Bay of Campeche in the Southern Gulf of Mexico and the main branch joins the Grijalva River before emptying into the Bay of Campeche. The eastern arm, known as the Palizada River, empties into the Terminos Lagoon in the State of Campeche.

The combined discharge is 3000 m^3/s to 4700 m^3/s or 120,000 × 10^6 m^3/year. Recently the Comisión Nacional del Agua (CONAGUA México) reported a combined discharge of 4402 m^3/s, and [29, 30] reported 4700 m^3/s, and an extreme combined river discharge of 7500 m^3/s (October 1999) after El Niño1998 and La Niña 1999. Total combined discharge is about 30 × 10^6 m^3/year. The main physical factors for explaining the extensive wetlands area are 1) rains, 2) floods, and 3) the extensive coastal plain of Tabasco and Campeche states. Because of high river input, extensive wetlands, and the semienclosed nature of the shallow shelf, this area has very high primary and fishery productivity.

4.3 Perspectives for both Deltaic Systems

Water quality deterioration is a result of point (e.g. inadequately treated sewage) and non-point (e.g. agricultural and urban runoff) pollutants. High nutrient input and altered hydrology both contribute to poor water quality. Most upland runoff used to flow through wetlands before reaching water bodies, leading to a reduction of nutrients. The use of wetlands to improve water quality is an economical and environment friendly approach to improving water quality and the application of ecotechnology offers an ecologically sound and cost-effective method to their solution. The benefits of restoring wetland habitat include improved water quality, increased accretion rates to balance sea level rise in coastal wetlands affected by the sea level rise, improved plant production and habitat quality, and decreased cost compared to conventional approaches. Wetland assimilation can be designed and operated to restore deteriorating wetlands and maintain existing wetlands. Wetlands are appropriate for receiving municipal and some types of industrial (e.g. non-toxic effluent such as for fish processing plants) effluents (Fig. 1). In many coastal deltaic wetlands, geologic subsidence results in a rate of relative sea level rise that is more than the eustatic sea level rise. It is also likely that tropical storms will significantly increase in intensity in the coming decades. Fresh water in effluent can help offset salinity intrusion due to storms. The use of wetlands to assimilate nutrients should be incorporated into comprehensive management plans designed to increase sediment and nutrient input into coastal wetlands in the Gulf of Mexico.

5 The use of wetlands for water quality improvement

Numerous studies have shown that both natural and constructed wetlands can be effective tertiary processors of wastewater effluent and agricultural runoff [10, 18, 25, 31]. Wetlands are efficient at removing excess nutrients and pollutants

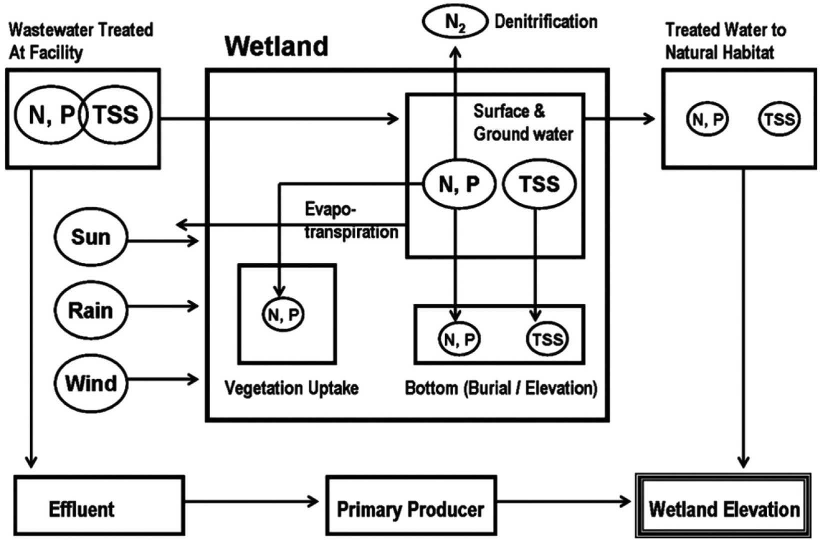

Figure 1: A conceptual model of wastewater assimilation by wetlands showing the three main pathways of permanent nutrient uptake (e.g. vegetative uptake, de-nitrification, and burial). The global positive ‘feedback’ on the effects of effluent application to wetland is shown in a flow from effluent, to primary producers, to accretion (elevation). N = nitrogen, P = phosphorous, TSS = total suspended sediments.

by physical settling and filtration, chemical precipitation and adsorption, and biological metabolic process that result in burial, storage in vegetation, and de-nitrification (Fig. 1). These wetland functions can be especially critical for coastal regions affected by degraded water quality. It is important that the size of the wetland be matched with the amount of effluent or agricultural runoff entering the wetland so that significant nutrient reduction can take place. It is also important to note that wetlands should not be used to treat raw sewage.

Sewage should be treated to a certain extent before discharge to wetlands. Wastewater effluent may also serve as a restoration tool in flood plain systems and in coastal wetlands impacted by high rates of the relative sea level rise (RSLR). Coastal wetlands have been shown to persist in the face of RSLR when vertical accretion and elevation gain equals or exceed the rate of water level rise [32]. Historically, seasonal over bank flooding from river such as the Mississippi River deposited sediments and nutrients into wetlands of delta plains [21]. Not only did floods provide an allochthonous source of material or mineral sediments, which contributed directly to vertical accretion, but the nutrients associated with these sediments promoted vertical accretion through organic matter production as well as deposition. In such stressed wetland systems, there are several benefits derived from the discharge of treated effluent: 1) improved water quality, 2) increased accretion rates, 3) increased productivity of vegetation, and 4) financial and energy savings [33].

6 Conclusions

Result from numerous studies of wetland assimilation systems indicate that they are achieving the ecological goals of enhancing water quality, stimulating accretion, and increasing productivity. At low loading rates, nutrient reductions are high, often greater than 80%, due to plant uptake, de-nitrification, and burial. There are substantial economic and energy saving for communities and non-toxic industrial processors and wetland assimilation offers an ecologically sensitive way to deal with agricultural runoff. Properly designed regulatory review and permit processes ensure that projects comply with State and Federal clean water laws. Wetland wastewater treatment can provide an economically viable, effective, and sustainable alternative to expensive conventional tertiary treatment. In combination with improved agronomic practices, wetland assimilation also offers a practicable way of dealing with agricultural runoff.

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