

**A STUDY OF WETLANDS MANAGEMENT:
APPLICATIONS TO RWANDA**

by

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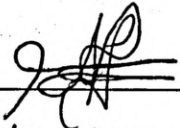
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ABSTRACT

The objective of this paper is to undertake a study of wetland management from a developing country's perspective. Through identification of wetland functions useful to agriculture and consideration of the consequences of past mismanagement practices toward wetlands in the USA and elsewhere, the link between wetlands and agriculture is identified, the compatibility of wetlands with sustainable agriculture is established, and principles and tools for implementing a management scheme for wetlands in Rwanda that balances protection and utilization of wetlands are proposed. These include integration of wetland-based waste treatment systems with food production schemes, elimination of nuisances associated with wetlands without loss of wetland vital functions, and preservation or reinforcement of wetlands capacity to store water, prevent floods, retain sediments, provide harvestable products and recycle organic wastes. A proposal is presented for rating wetland functionality as high, moderate or weakly functional using a prioritized assessment of their hydrology, food production potential, waste treatment potential, contribution to disease, and contribution to wildlife habitat. Under the conditions facing Rwanda, hydrology ranks first because it controls many of the wetland functions; food production is the second position because of the imperativeness of food production in Rwanda; bio-waste recycling potential has precedence over disease control because successful management of wastes may eliminate or decrease the occurrence of diseases. Moreover, bio-waste recycling may be viewed as the link between food production and disease control in wetlands. Consultative and collaborative processes involving various sectors and institutions using or responsible for the protection of environmental resources are recognized as an important component of an overall wetland management scheme.

CHAPTER 1

INTRODUCTION

The role of wetlands in regulating many processes vital to desirable functioning of ecosystems is no longer a matter subject to speculation. Many efforts by diverse groups are now oriented toward gaining better understanding of the mechanisms responsible for the multiple functions of wetlands and implementing measures intended to protect, preserve, or restore wetlands. Our current understanding of wetlands tells us that the value of wetlands has been underestimated for centuries.

Prior to the 1970s, land management policies of the United States federal government encouraged or subsidized conversion of wetlands for agricultural or other purposes not compatible with the existence of wetlands (Mitchell et al., 1992; Norgress, 1947; Mitsch and Gosselink, 1993; US. Environmental Protection Agency, 2000). By the mid 1980s, approximately only half the original wetlands in the U.S. remained (US. Environmental Protection Agency, 2000; Mitsch and Gosselink, 1993). Conversion of wetlands produced cropland that bolstered the agricultural and economic potential of the United States from colonial times through the middle of the 20th century and eliminated some of the socioeconomic nuisances associated with wetlands. But it also reduced the many of the valuable contributions of wetlands, including support of waterfowl and maintenance of water quality (Mitchell et al., 1992; US. Environmental Protection Agency, 2000; Mitsch and Gosselink, 1993).

Food production is a crucial issue in many parts of the world and in Rwanda in particular. Devastated by war, very mountainous and densely populated, Rwanda faces significant food production deficiencies. Consequently, wetlands in Rwanda are increasingly under pressure to be exploited and developed for expanding agricultural potential.

Farmers in Rwanda are facing progressive acidification of soils they farm, most of which are located on relatively steep slopes. Erosion, combined with inefficient cultural techniques, is impoverishing the agricultural lands at an alarming rate. This being the case, water and fertile sediment of wetlands and riparian systems make such areas attractive for agricultural use in Rwanda and other developing countries confronted with food shortages. Yet wetland destruction results in loss of important ecological functions that wetlands perform (Gorman, 1999; Firehock et al., 1998; Mitsch and Gosselink, 1993). This destruction warrants a policy of wetland conservation. However, for maintaining their benefits to society, a rigid global policy of wetland conservation and restoration can easily be viewed as unrealistic, undesirable and unenforceable.

Thus, a pressing question facing natural resource managers of Rwanda is: Does a sustainable wetland management strategy exist that is able to unify the economical and environmental concerns of regions facing pressure from agricultural development entities while ensuring wetland integrity? What kind of intervention can increase certain desirable functions of wetlands, either solely for their benefits or complementary to agriculture development? Can we eliminate some nuisances associated with wetlands without losing their vital functions? It is essential to sustainable agriculture to not be unnecessarily disruptive of the environment.

To answer these questions I will investigate wetlands and riparian ecosystems within the entire landscape and watershed and determine the functions that establish their unique, indispensable position. Intuitively, it is easily recognizable that the interaction between wetlands, riparian ecosystems and the rest of the landscape involves ecology, hydrology, soil chemistry and nutrient cycling. Thus, an integrative approach is essential. Hence, it is crucial to find management systems that optimize sustainable agriculture balanced with natural or managed ecological values.

The objective of my thesis research is to undertake a study of wetlands management from a perspective of an agriculturist in a developing country concerned with the dilemma of optimizing food production and keeping a healthy environment necessary for sustainable agriculture. The specific hypothesis I intend to verify is: wetland management can be approached with the objective of establishing a balance between protection of wetlands, utilization of wetlands, and sustainable agricultural production. A secondary hypothesis to be investigated is: losses or alterations caused by human interference to wetland functioning in the USA and elsewhere can be avoided in developing countries. I will then propose an approach and justification for achieving a balance between wetland preservation, restoration, and utilization in a developing country such as Rwanda. A significant component of this undertaking is a synopsis of the principles and tools for assessment and evaluation of the quality of wetlands and their judicious assigned management or function.

CHAPTER 2

MATERIALS AND METHODS

Wetland roles in the ecosystem, the relationship between wetlands and agricultural land practices, a historical perspective on wetland management, and approaches to compatible wetland management in agricultural settings in different parts of the world have been addressed by means of a literature review of diversified sources such as scientific journals, news papers, Internet, personal communications and opinions of wetland professionals and specialists operating in the Bozeman area.

The objective of this paper is not to shed new light on the mechanisms determining wetland functions. This would have required narrowing the scope of this paper. I have adopted a holistic approach, intending to link the different “compartments” of the current knowledge about wetlands in a creative and integrative way that aims at resolving the dilemmas faced by resources managers in developing countries. The situation facing developing countries is the scarcity of financial resources, the fragmentation and impoverishment of agricultural lands, the increased pressure on non-renewable environmental resources and the necessity to adequately address the imperative issue of food production.

In this regard, in addition to authoritative sources such as research literature (scientific journals), secondary references (popular press) such as news papers and online publications have been used, reflecting the desire to give an inclusive and balanced

dimension to the concept of wetland management. This approach also utilized the easy and fast accessibility of Internet sources - critical for meeting deadlines. Moreover, the Internet provided access to information about small scale development projects in developing countries that may not always meet the preoccupations of scientific journals in developed countries.

CHAPTER 3

RECOGNIZED FUNCTIONS OF WETLANDS

“Functions” of wetlands are often confused with “values” of wetlands. A [wetland] function is defined as any biological, chemical, physical or ecological process operating within a wetland habitat. Its benefit to humanity may not be clear (Firehock et al., 1998). A [wetland] value is the benefit provided by the wetland (Firehock et al., 1998). Substantial subjectivity is associated with the concept of wetland value.

Wetlands compete with tropical rain forests in productivity. They harbor a third of the USA’s endangered or threatened species of plants and animals (Mitchell et al., 1992; USDA-SCS, 1992). Wetlands provide feeding, spawning, and nursery grounds for more than half the saltwater fin and shellfish harvested annually in the U.S. and for most freshwater gamefish (Mitchell et al., 1992; USDA-SCS, 1992). They also provide habitat for a third of the U.S. resident bird species and more than half of its migratory birds. Wetlands are critical for wildlife using the vegetation and stream corridors for protective cover and transport (McCarthy, 1999; Mitsch and Gosselink, 1993; Gosselink and Lee, 1989).

Wetlands sequester large amounts of carbon in the form of peat and decaying plant material (Brinson, 1991; Brinson, 1993a; Mitchell et al., 1992), potentially reducing carbon dioxide in the atmosphere and countering global warming (Mitchell et al., 1992). Wetlands preserve water quality of lakes, rivers, reservoirs and aquifers (Mitchell et al., 1992), and control erosion of shorelines, rivers and lakes.

Having natural wetlands as a buffer between property and streams not only reduces peak or flash floods, but also protects the stream from filling with sediment that is transported by the overland flow of water (Firehock et al., 1998). Wetlands diminish the amount of channel erosion that occurs during floods by slowing runoff water. This also reduces the amount of sediment pollution entering rivers and lakes (Firehock et al., 1998). Wetlands convey floodwaters from upstream to downstream points (USDA-SCS, 1992). Wetlands can provide food (i.e., animals and plants for humans, forage for livestock) and shelter for livestock (i.e., for calving and during the winter) (Mitchell et al., 1992; McCarthy, 1999).

Wetlands are an important source of water: they store flood and rain water, gradually releasing it to adjacent streams or water bodies, maintaining late summer stream flows (McCarthy, 1999). Often these late summer flows are critical for irrigating crops, watering stock, sustaining fisheries and recharging aquifers and wells. Wetlands maintain a higher water table than non-wetland areas, which increases subsurface irrigation and production of forage (McCarthy, 1999). By filtering sediment, wetlands prolong the life of irrigation pumps, and reduce siltation of ponds and irrigation ditches (McCarthy, 1999). Other recognized functions of wetlands include recreation and timber production (USDA-SCS, 1992).

Differences in Functions among Wetlands

The type of wetland (inland or coastal, fresh or salt water, peatland or riparian), wetland size, geographic location and position in the landscape determine the preeminence

of certain functions over others. Wetlands that have pulses of inflow and outflow of water are among the most productive. For example tidal marshes, coastal marshes and floodplains are more productive than bogs. Pulsing, by the action of high tides and floods, keeps the system oxygenated and brings in nutrients (Mitsch and Gosselink, 1993; Firehock et al., 1998).

Atmospheric exchanges are examples of wetland functions associated with size, as indicated by the capacity of extensive boreal peatlands to neutralize acid deposition. Peatlands of recently glaciated areas have a propensity to act as significant atmospheric sinks for carbon dioxide (Brinson, 1993a). Landscape maintenance is yet another wetland function associated with size. For example, in a portion of North Carolina's pocosins (extensive peatlands), accretion of peat has been shown to keep pace with rising sea levels to maintain emergent wetlands (Brinson, 1993a; Brinson, 1991). Small wetlands (e.g., prairie potholes) significantly contribute to recharge of regional groundwater (Weller, 1981; Mitsch and Gosselink, 1993). Conversely, energy dissipation is relatively more important in riverine systems than in potholes (Hauer and Cook, 1996a and 1996b).

Different types of wetlands share certain functions in the landscape such as regulation the hydrology of a region by storing surface water and actively interacting with aquifers, nutrient cycling, water quality regulation, organic carbon export and maintenance of biodiversity. The differences found in the literature merely reflect the variation in degree and the lack of harmonization in the nomenclature of functions.

Position of the wetland in the landscape is also important. For example, wetlands in different parts of the watershed improve water quality in different ways. Wetlands located

near headwaters might be important for nitrogen processing and retention of large-sediment particles, while trapping of fine particle sediments and phosphorus retention might be more important in floodplain wetlands further downstream (Firehock et al., 1998).

As Brinson (1993a) indicates, most interaction between land and water involves riparian areas of small streams because most stream length is in headwater streams (i.e., 2.8 million miles for 1st to 3rd order streams versus 52,000 miles for 7th to 10th order streams in the U.S.). Thus, headwater wetlands and riparian systems are critical buffer zones for water quality. Flood attenuation will depend on watershed features and flow routing (e.g., the flow must pass through the buffer to be affected). Wetlands isolated from overland influxes have a small influence on water quality. Because overbank flow increasingly becomes important downstream, downstream wetlands are also the most effective for flood reduction. Similarly, for wetlands to be effective in this capacity, flood water must pass through or come in contact with the wetlands. Thus, flood events due to climatic events downstream from wetlands are unaffected by wetlands.

Wetlands and basins without unused surface water storage capacity, that is, when saturated and flooded after rainy seasons, offer little potential to reduce flooding (Mitsch and Gosselink, 1993; Novitzki, 1985). Groundwater-dominated wetlands are vulnerable to change when upslope groundwater dynamics are altered, (i.e., competition by consumptive withdrawal by municipalities, diversion from aquifers by impervious surfaces, degradation of water quality in the recharge area) (Brinson, 1993a).

Wetland functions interact with each other. Water purification is an example of this. Maintenance of the quality of surface and ground waters involves trapping sediment,

accumulating and recycling nutrients, transforming contaminants and removing dangerous microorganisms from surface waters. The wetland processes contributing to water quality are biochemical reduction-oxidation reactions associated with microbes, rhizosphere activities (uptake of soluble contaminants), macrophytes elevating dissolved oxygen in the water, causing oxidation and precipitation of toxic ions, reduction of velocity of water flow, and filtration and sedimentation that remove sediments and attached contaminants. Other processes involved include adsorption of chemicals induced by high ion exchange capacity and surface area associated with fine textured soils rich in organic matter, and the raising of pH associated with organic sediments, resulting in precipitation of heavy metals (Hauer et al., 1999; Firehock et al., 1998; USDA-SCS, 1992).

Longer residence time as water passes through wetlands allows greater modification of water quality. The effectiveness for nutrient removal increases with the rate of input of nutrients before reaching a plateau or a drop. Disturbance of wetlands is likely to reverse long-term accumulation processes, causing the wetland to become an exporter of sediment and nutrients. The net outcome here is the degradation of water quality downstream (Brinson, 1993a). Static surface water storage adds moisture to the soil's unsaturated zone and has a significant effect on biochemical cycling. Prolonged saturation leads to anaerobic soil conditions, often initiating chemical reactions that are highly dependent upon the reduction-oxidation capacity of the soil. This function has a very significant impact on vegetation and invertebrate and vertebrate populations (Hauer et al., 1999).

Sedimentation in wetlands not only affects water quality, but also has a significant effect on nutrient cycling and retention of particulates, elements and compounds within

wetlands. For instance, nutrients tend to bind to coarse particles, while heavy metals such as copper, nickel and zinc bind to fine particles (Lau and Chu, 1999). Organic carbon binding of metals in reduced sediments is one of the chemical processes having the greatest influence on metal bioavailability in wetlands (Wood and Shelley, 1999). Besides anoxia, the presence of organic carbon (i.e., as an energy source) in the sediment enhances denitrification processes in wetlands (Kleiss, 1996). The sedimentation processes have been used relatively efficiently to remove lead and suspended solids by means of small artificial wetlands (Hoai et al., 1988). Sediments carry new nutrients to the wetland. Sediments may bury organic material and thus largely remove it from the cycling process (Hauer et al., 1999).

Generalizations on the mechanisms presiding over wetland functions are likely to be overstated. Each element, chemical compound, nutrient and heavy metal has its own biogeochemical pathway once it enters the wetland (Firehock et al., 1998). However reduction resulting from inundation and subsequent anoxic or anaerobic conditions is largely responsible for elemental immobilization in wetlands (Hauer et al., 1999). Likewise, wetland vegetation is a critical factor for erosion control, reducing bank erosion along streams and shorelines (coastal wetlands), and buffering the impact of storm tides and waves and spring thaws before they reach upland areas (i.e., inland wetlands adjoining lakes and rivers) (Delesalle et al., 1998; USDA-SCS, 1992). However, the relative efficacy of erosion control will also depend upon vegetation density and composition (i.e., tree, shrub, herbaceous plants), the presence of large wood debris, macrotopography, microtopographic complexity and the frequency of overbank flooding (Hauer et al., 1999).

Functions such as energy dissipation and retention of particulates are complementary and are affected by the same variables (i.e., shrub and tree density, coarse woody debris, macrotopography and microtopographic complexity and frequency of overbank flooding) (Hauer and Cook, 1996a). Some other functions are competitive. For example wetland fragmentation may increase total species richness (biological diversity) at the expense of native biota (Gosselink and Lee, 1989).

CHAPTER 4

LOSS OF WETLAND FUNCTIONS INDUCED BY AGRICULTURE

Soil Unsuitability and Toxicity

The destructive impact of agriculture on wetlands is obvious in the case of conversion of wetlands to upland crop production: almost all the functions of the wetland are eliminated. The ramifications of such an action may, however, be subtle in that the total effects may be observed only after a certain length of time, varying according to the dynamics of the set of phenomena triggered by a specific alteration. Drainage of wetlands has the potential to create some chemical imbalances which may lead to toxicity. An example of this is the acidification and salinization of mangrove wetlands on latent acid-sulfate soils when converted into agriculture wetlands. Extended dry periods and intense solar radiation, often common to agricultural areas in the tropics, may cause extreme loss of soil moisture and accelerate soil oxidation and advanced soil salinity and acidity (Khoa and Roth-Nelson, 1994).

Forested sapric peatlands containing deep deposits of organic matter are important for agriculture throughout the Great Lakes basin of the U.S. Once drained and cleared of natural vegetation, these peats produce moist-soil, high-cash crops, such as lettuce and onions (Fisher et al., 1996). Moreover, peat can be harvested to produce horticultural soil additives and fuel (Firehock et al., 1998). However, farmed mucklands are "non-renewable" (Fisher et al., 1996; Firehock et al., 1998). Subsidence caused by oxidation, compaction, and erosion (Fisher et al., 1996), as well as by cultural practices like burning (i.e., for ash) and

weed control (Rojstaczer and Derevel, 1995) eventually render highly organic soils (i.e., histosols and highly organic mineral soils) unfit for cultivation.

Zhang and Moore (1997), comparing wet and laboratory dried wetland sediment samples, reported that concentration of soluble and adsorbed selenium increased greatly if samples were dried. The effect was more pronounced at high temperatures, indicating a higher risk for tropical countries. They attributed the increased concentration of soluble and absorbed Se in dried sediment to conversion of organic Se through rapid decomposition of organic sediment and Se oxidation to selenate.

Agricultural drainage water enriched with nutrients and other pollutants can cause significant damage to wetland ecosystems. Selenium- impacted wetlands are such an example. The drainage of selenium-impacted wetlands, resulting in selenium enriched agricultural drainage water, can cause serious health issues. For example, Wu et al. (1995) describe selenium biomagnification in the trophic chain of wetlands converted to upland grassland.

Eutrophication of streams is another example of loss of wetland functions induced by agriculture. Eutrophication is often linked to the erosion processes. For example, the highest levels of nitrate and phosphate in the Swan River Estuary, Western Australia, are recorded during the rainy season (winter) and for that portion of the watershed dominated by cultivated land in rural areas (John, 1994). Excesses of nutrients cause algae populations to grow rapidly (US. Fish and Wildlife Service, 1999). In shallow wetlands and lakes, the magnitude of nitrification increases with increasing eutrophication (Kleiss, 1996). Algae blooms reduce sunlight and dissolved oxygen in wetlands. Without enough sunlight and

oxygen, submerged aquatic vegetation upon which waterfowl and fish depend (U.S. Fish and Wildlife Service, 1999) perishes. Decay of the algae population further depletes the dissolved oxygen, causing substantial fishkill during the summer when oxygen in solution decreases because of heat. Thus, the effects of eutrophication are potentially severe in tropical regions.

Clearing deep-rooted native vegetation from catchment basins and replacing it with shallow-rooted crop and pasture species that use less water may, in addition to increasing erosion and siltation, cause the water table to rise and dissolve salts. Subsequently, as the water table lowers in summer, salt crusts may be left on the topsoil, rendering the soil unsuitable for cultivation. As water later flows through salt affected areas, it becomes more saline, eventually contaminating water bodies in the watershed (John, 1994). This is very well illustrated by the salinity of several lakes in the catchment of the Swan River, Australia (John, 1994). This is also another good illustration of the high risk of salinization of drained wetlands and riparian areas in tropical regions, because of their extended dry periods and intense solar radiation.

Alteration of the Hydrology

Much of the flooding of the Yangtze River, China, is not caused by nature, but by inappropriate use of the land around the river in the watershed (Gorman, 1999). Recent deforestation of the Yangtze watershed is responsible for topsoil erosion during monsoon heavy rains. Monsoon rains carry topsoil down to the river, raising the Yangtze river bottom and pushing the floodwaters overbank. Additionally, drainage of wetlands and lakes in eastern China for agricultural purposes has reduced the region's ability to absorb rainfall and

provide a buffer for the Yangtze River. This is consistent with Novitzki's (1979) observations that peak flows are 80% lower in watersheds with 40% wetland and lake area than in watersheds with no lakes and wetlands and that there are substantial reductions in peak flows if wetlands and lakes are more than 5 to 10% of the watershed area.

Comparison of the damage caused by hurricane Andrew in Florida and in Louisiana in 1992 gives another indication of the risk reduction function provided by wetlands. Hurricane Andrew caused \$20 billion in damage to the developed coasts of Florida. But when Andrew hit the Louisiana coast with the same force, it cost a lower \$2.5 billion to repair the damages (Firehock et al., 1998). Louisiana's coastal wetlands decreased the disastrous effects of the hurricane. Iowa, Illinois and Missouri have lost between 85% and 90% of their original wetlands. As a partial consequence, they suffered billions of dollars in property damage during the 1993 Midwest floods along the Mississippi River (Firehock et al., 1998).

Dams typically decrease downstream peak flow and sediment load (Friedman et al., 1988). However, an increase in the lower Mississippi River peak flows - that usually produce flood damage (Novitzki, 1979) - is attributed partially to levees and other flood controls (Belt, 1975; Mitsch and Gosselink, 1993). Construction projects that artificially confine a river to its channel or limit a river's incursion on the floodplain serve to limit the sediment retention function of the floodplain wetlands (Kleiss, 1996; Belt, 1975, Mitsch and Gosselink, 1993). Thus, it may be that reduction of peak flows upstream is compensated for by an increase of peak flows downstream, challenging the assumption that streams can be forced to flow along certain paths without any associated environmental risk. For this reason,

many scientists doubt that dams and other engineering projects will ever be able to tame future Yangtze River floods (Gorman, 1999). Intact wetlands can be more cost effective for flood attenuation than flood-control structures (U.S. Army Corps of Engineers, 1972; Firehock et al., 1998; Mitsch and Gosselink, 1993).

Subtle, long-term changes in hydrology can have major impacts on wetland functions and structure (Fisher et al., 1996). Hydrologic conditions can directly modify or change chemical and physical properties such as nutrient availability, degree of substrate anoxia, soil salinity, sediment properties, and pH. For example, changes in hydrology are known to have dramatic influence on peatland landform evolution (i.e., subsidence of histosols) (Fisher et al., 1996). In nutrient-poor peatlands, the impact of soil moisture gradients on plants may be of less importance than factors of nutrient stress and competition. In highly minerotrophic peatlands where nutrients are generally readily available, water stress may be of greater importance to community structure and composition (Fisher et al., 1996).

When hydrologic conditions in wetlands change, the biota respond with massive changes in species composition and richness and in ecosystem productivity (Mitsch and Gosselink, 1993). An illustration of this is the effect of dams on bottomland vegetation (Friedman et al., 1988). The principal response of a braided channel to an upstream dam is channel narrowing. Channel narrowing promotes the establishment of native and exotic woody riparian pioneer species in the former channel. The principal response of a meandering channel is reduction in channel migration rates, resulting in a decrease in reproduction of woody riparian pioneers. This may be exacerbated by effort to stabilize the channel banks or by channel incision caused by sediment starvation (Friedman et al., 1988).

The relationship between groundwater and vegetation patterns can easily be observed in association with changes in the hydrology of the Cache River riparian wetlands, in Arkansas, U.S. A gradual and consistent reduction in groundwater elevation of the area happened between the 1930s and 1970s. This period coincided with an increase in rice production and clearing of more than half of the bottomland forests in the area (Long and Nestler, 1996). Wilbert et al. (1996) also report that extreme low flows have become more frequent in the Cache River basin since the 1970s, coincident with the dramatic increase in rice farming in the basin and its associated irrigation. Annual drawdowns in the alluvial aquifer are positively correlated with the annual area of rice crops, with no evidence that the change in climatic conditions accounts for the increase in the extreme low flow frequency.

The remaining forest stands in the Cache River basins are fragmented and small in size. Forest cover declined from 65% to 15% over a 52-year period (from 1935 to 1987) (Kress et al., 1996). In addition to reduced capacity to support wildlife species that require a large core area, fragmentation resulted in a reduction of the rainfall storage and interception. This often translates into significant changes in the timing and duration of discharge, and an increase in sedimentation rates in the remaining forested wetlands. As Kleiss (1996) also mentions, swamps in the Cache River system are filling at an accelerated rate and flood events early in the rainy season may have much higher rates of sediment retention than those late in the season. Antecedent conditions on the floodplain play an important role in the net sediment deposition rate. As Firehock et al. (1998) point out, wetlands are delicate ecosystems that have threshold levels for the extent to which they can perform various functions.

Threats to Biodiversity

Agriculture expansion has reduced the width and area of remaining bottomland hardwood forest fragments (Wakeley and Roberts, 1996). As noted in the previous section, fragmentation of wildlife habitats results, among other things, in a reduced capacity to support wildlife. Habitat fragmentation produces more “edge” habitat where risks of predation are greater as parasites and predators penetrate deeply into remaining forest tracts. Habitat fragmentation also increases the isolation of patches (Wakeley and Roberts, 1996).

It is easy to dismiss small wetlands as having an insignificant role in the environment. This point of view seems to prevail even in the U.S., where wetlands are strongly regulated. For example, legislation in the U.S. protects wetlands above a certain area threshold (e.g., 10 acres for freshwater wetlands in Maine) (Gibbs, 1993). While small, legally unregulated wetlands may comprise a relatively small portion of the total wetland area in a region, small wetlands can be numerically abundant and can play an important role in reducing isolation among patches of wetland habitats. Thus, loss of small wetlands can potentially increase extinction rates of wetland organisms by decreasing migration rates and the likelihood of rescue or recolonization of local populations (Gibbs, 1993). This is well illustrated by a simulation of loss of small, legally unprotected freshwater wetlands in a 600-km² area of Maine. The simulation resulted in total area of wetlands declining by 19%, total wetland number declining by 62%, average inter-wetland distance increasing by 67%, average upland-wetland proximity decreasing by 50%, such that just 54% of the landscape was within

the maximum migration distance of terrestrial-dwelling and aquatic breeding amphibians after loss of small wetlands, versus 90% before loss (Gibbs, 1993).

CHAPTER 5

SUCCESSFUL WETLAND MANAGEMENT PRACTICES

Management of Pests Associated with Wetlands

Wetlands often constitute an excellent environment for mosquitoes. These habitats provide shallow water, microorganisms and organic matter necessary for the development of mosquito larvae and also offer areas protected from wave action by vegetation and floating objects (mosquitoes rarely breed in moving water). Therefore, wetland habitats can be important breeding habitats for pestiferous mosquitoes and those that spread diseases (Batzer and Resh, 1994). For example, agricultural wetlands (i.e., rice growing areas) are often associated with a high incidence of malaria (Barutwanayo, 1991). *Eastern encephalitis* is intimately associated with freshwater marshes and swamps in the western hemisphere (Morris, 1994).

These diseases can often have a significant economic and social impact in their endemic zones of occurrence. For example, malaria kills twice as many people worldwide as AIDS. Drugs no longer work against some strains of malaria, and mosquitoes in diverse parts of the United States now carry the disease (Shell, 1997). Malaria contributes to the highest morbidity and mortality of all infectious diseases in Kenya (Ouma, 1998). Malaria is the major cause of premature death (Embassy of Rwanda, 2000). During *Eastern encephalitis* outbreaks, tourism and outdoor related businesses often suffer (Morris, 1994).

Mosquito attacks on farm animals can cause loss of weight and decreased milk production (Floore, 2000).

Thus, presence of mosquitoes in wetlands cannot be ignored, particularly in habitats near human population centers. Consequently, one of the main reasons for drainage of wetlands has been control of disease vectors (Mitsch and Gosselink, 1993). Several techniques are commonly available for mosquito control in wetlands but many have been reported to be cost ineffective or very damaging to the environment (Carlson et al., 1994).

The goal of contemporary mosquito control is to implement new and innovative management strategies to control wetland mosquito populations while maintaining the integrity of wetland ecosystems. To be successful, management strategies must be based on knowledge of the environmental characteristics critical to the mosquito's life cycle. For example, all mosquitoes pass through four life stages (egg, larva, pupa, and adult), and the first three stages must have water for development (Potter and Knapp, 1994). Hence, a properly designed ditching system can provide drainage, thereby preventing mosquitoes from completing their life cycle.

Salt marsh mosquitoes lay their eggs only on damp soil (Carlson et al., 1994). The eggs hatch after flooding. Therefore one effective way to prevent mosquito oviposition in salt marshes is to flood the marsh during the mosquito producing summer months (i.e., salt marsh impoundment) (Carlson et al., 1994).

However, this cannot be applied for malaria vectors (*Anopheles*) as they lay their eggs on water. Thus, they require a different strategy: mosquito larvae live in the water and come to the surface to breathe. The newly emerged adult rests on the surface of the water for a

short time to dry and allow its body parts to harden. The wings have to spread out and dry properly before it can fly. Additionally, adult mosquitoes prefer to rest on weeds and other vegetation (Floore, 2000). Therefore, the alteration of wetland hydrology such as accomplished with runnelling or mowing wetland vegetation is recommended. Tidal flushes (i.e., runnelling) result in turbulent waters, disturbing mosquito breeding activities (Dale, 1994; Batzer and Resh, 1994; Floore, 2000). Mowing wetland vegetation deprives mosquitoes of shelter from wind and waves. In the case of application of pesticides, because of limited time of action, it is more efficient to target the more concentrated mosquito larvae and pupae (limited movement) than the dispersed adult mosquitoes (Ritchie and Dale, 1994; Zimmerman and Berti, 1994; Surtherland, 1996).

Sustainable mosquito management strategies must minimize the use of insecticides. They must also use the environmentally safest control in only those areas needing control. For example insecticides which are non-persistent should be preferentially applied only on sites predetermined by a study of the resting and biting pattern of mosquitoes (Dale, 1994; Ritchie and Dale, 1994; Zimmerman and Berti, 1994). Thus, the indiscriminate action of pesticides that also impact non-target organisms (e.g., beneficial or endangered species) and select for pesticide-resistant strains of vectors is avoided.

Regulation of the hydrology of a wetland is potentially dangerous. The elimination of the characteristic hydrology of a wetland changes the wetland (Committee on Characterization of Wetlands, 1995). For example, impoundment dikes prohibit marsh access by aquatic organisms, particularly organisms which must use the high marsh during a portion of their life cycle. Excessive or prolonged flooding of impoundments can stress or

kill existing high marsh vegetation. Prolonged flooding can result in low dissolved oxygen concentrations and elevated hydrogen sulfide levels that can have negative impacts upon the marsh aquatic communities (Carlson et al., 1994).

In order for mosquito management not to compromise the integrity of wetlands, structures intended to regulate water movement (e.g., dikes, culverts and ditches) must seasonally optimize exchange of nutrients and organisms between the wetland and the associated water bodies, enhance water circulation and quality within the wetland, and enhance desirable vegetation and animal communities (e.g., invertebrates and waterfowl) within the wetland (Carlson et al., 1994; Batzer and Resh, 1994). For example, "rotational impoundment management", a mosquito management technique designed for Florida's marsh, uses culverts with flapgated risers installed through impoundment dikes to seasonally reconnect the impounded marsh and estuary, flood the marsh during the mosquito producing summer months, and keep the minimum water level necessary for mosquito control and healthy vegetation. Additionally, ditches can connect the wetland to permanent water bodies, thus providing access for larvivorous fish (Carlson et al., 1994).

Thus, reduction of mosquitoes in a wetland can be accompanied by an increase in wetland desirable functions and a decrease in the need for chemical control (Carlson et al., 1994; US. Fish and Wildlife Service, 2000). As experimental results in California and Minnesota showed (Batzer and Resh, 1994), seasonal flooding of wetlands to water depths that cover much of the thick emergent vegetation increased open-water for waterfowl use, increased densities of the macro-invertebrates consumed by ducks, and decreased mosquito density in the wetlands. The same results were obtained by mowing the wetlands' vegetation

prior to flooding and temporary water level drawdowns of perennial water marshes (Batzler and Resh, 1994). Impoundment of marshes often enhances marsh utilization by waterfowl and wading birds (Carlson et al., 1994).

Integrated Wetland-based Production Systems

Waste Treatment

The mis-management of domestic wastewater in urban areas of many developing countries is a frequent cause of many health hazards. Accumulation of unmanaged human bio-waste contributes to contamination of many fresh water supplies (Rose, 1999). Adoption of centralized, highly engineered human and animal waste management systems practiced in the “first world” has not been successful in much of the developing world context: such systems require high capital investment, high ongoing operation and maintenance costs, have relatively short life-cycles, rely on imported equipment, and require highly specialized operators (Rose, 1999). As a result, approximately two-thirds of the population in the developing world has no hygienic means of disposing of excreta, and an even greater percentage lacks adequate means of disposing of total wastewater (Rose, 1999; Munasinghe, 1992; Niemczynowicz, 1996). The human and sociological costs of under-managed domestic waste are very high (i.e., hygiene related diseases and associated economical costs).

Decentralized sustainable organic waste recovery systems that integrate best available rural technologies (i.e., a combination of waste management with livestock rearing, aquaculture, agriculture and agro-industry in an ecologically-balanced system for food production) and promote multi-layer utilization of space and energy sources would be best

suited for mostly rural populations: these technologies can easily fit within the rural populations' skills and style of life (Rose, 1999). Furthermore, organic waste recovery can supply production inputs for agriculture (i.e., bio-waste derived organic fertilizer), enhance food security and link different sectors of local economies. Moreover, decentralized organic recovery allows the segregation of domestic wastewater from industry waste, which is difficult to realize under centralized wastewater treatment systems; sewers often contaminate human and animal wastes with heavy metals or toxic chemicals, making recovery and reuse very difficult (Rose, 1999).

Calcutta wetlands (India) that occupy more than 3,000 ha, provide an example of an integrated system of waste treatment, aquaculture and agriculture. A series of shallow ponds acts as a stabilization lagoon, while water hyacinth acts to accumulate heavy metals, and multiple forms of bacteria, plankton and algae act to further purify the water. Fish production in the treated effluent is integrated to agriculture and forestry (Rose, 1999; Ghosh, 1991). Treated wastewater can be used for irrigation, gardening, flushing and cooling of air-conditioning systems (Chawathe and Kantawala, 1987)

Macrophyte-based waste treatment systems have commercial applications in developed countries as well. Commercial companies capitalize on tightened environmental regulations, lower costs than conventional sewage treatment plants, and recycling of waste nutrients into animal food (Robertson, 2000; Skillicorn, 2000). For example, the Greene County Town of Hookerton, North Carolina, was fined \$3,689 by the state for violating pollution limits at the Contentnea Creek in the early 1990s and \$3,000 in 1999 (Robertson, 2000). This same Town is faced with a \$2 million price tag to pipe its waste to a location 10

miles away (i.e., Snow Hill). The capital cost of implementing a *Lemna spp* (duckweed) based system was evaluated at one third the cost of piping Hookerton's waste to Snow Hill. Additionally, harvested duckweed could be sold as livestock feed (Robertson, 2000).

Multiple Uses of Wetland Macrophytes

Macrophytes can form a critical part of the biogeochemical processes of waste treatment systems, both by uptake and by providing a carbon source to microbial populations (Kadlec, 1994; Rose, 1999). Most macrophytes have the capacity - finite and variable - of purifying water. They can absorb and transform pollutants such as nutrients and some heavy metals (Yan and Zhang, 1994). For example a demonstration floating aquatic treatment system in Huangzhou City, China, greatly reduced biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen, phosphorus, viruses and bacteria in wastewater, allowing its use in irrigation and aquaculture (Rose, 1999).

Similarly, macrophyte-based wastewater treatment systems are capable of producing huge biomass (Skillicorn, 2000) and can provide large amounts of green fodder for fish, ducks and some can provide raw material for building and fuel (Yan and Zhang, 1994). For example, Yan and Zhang (1994) report that the bay of Lake Taihu, China, is 13,507 ha in area, of which 13,334 ha are aquatic macrophytes (9,334 ha submerged vegetation, 3,467 ha of wild rice [*Zizania latifolia*], and 533 ha of reeds). A total of 278,000 tons of aquatic vegetation (49% of the annual total production) is harvested every year. They estimated this to be equivalent to 917 tons of nitrogen and 137 tons of phosphorous removed from this bay.

Additionally, about 270,900 tons per year of aquatic vegetation (48% of annual total production) were grazed by native fish.

Cultivated or hydroponic plants such as tomatoes, lotus, vegetables, water spinach, and vegetable sponge are mainly economic plants with a high purifying capacity (Yan and Zhang, 1994).

Lemna spp. (duckweed) is a macrophyte commonly used in constructed wetlands for wastewater treatment (Rose, 1999; Skillicorn, 2000). Duckweed is believed to be the world's fastest-growing plant (Robertson, 2000). A combination of high biomass production rate and high relative nitrogen content endows duckweed with an excellent potential for treatment of human and animal wastes (Skillicorn, 2000). Duckweed-based wastewater treatment systems are efficient in the removal of nutrients and play a significant role in total suspended solids reduction (Rose, 1999). Likewise, duckweed's combination of low fiber and high protein, vitamin (i.e., carotene) and mineral content, makes it a potentially valuable component of livestock, fish and poultry diets (Men et al., 1995; Skillicorn, 2000). For example, PRISM-Bangladesh, a non-government organization based in Dhaka, Bangladesh, has developed a highly successful duckweed cropping system for domestic wastewater treatment and the production of fish protein (Skillicorn, 2000; Rose, 1999). An association of women workers in Ferrenafe, Peru, successfully recycled the waste nutrient product of Ferrenafe's 50,000 citizens, using a duckweed-based system. The continually harvested duckweed was dried and then marketed to a large dairy cooperative (Skillicorn, 2000).

Duckweed produces more protein on average than soybean (Robertson, 2000) and at a lower cost (i.e., use of wastewater). The protein yields of duckweed can be as high as 10

tonnes/ha/year, compared with less than one tonne/ha/year for soybean protein (Men et al., 1995). Duckweed's excellent digestibility and its favorable nutrient profile suggest that it should command a significant price premium over soymeal (Leng et al., 1995; Skillicorn, 2000). For example, it has been estimated that 10 acres of duckweed could theoretically supply 60% of the nutritional needs of 100 dairy cows. One hectare of duckweed cover is sufficient to produce protein for 480 ducks during the warm season (Armstrong, 2000). A communal farm south of Havana, Cuba, unable to acquire pre-mix for poultry, reported a drop of poultry mortality from an earlier 15% to close to zero with the addition of duckweed to the feed (Skillicorn, 2000). An experiment conducted by the Cantho University, Vietnam concluded that fresh duckweed can completely replace roasted soybeans and pre-mix in broken rice diets for fattening ducks without reduction in growth performance or carcass traits (Men et al., 1995).

Duckweed mats can be composted and used as green manure (Armstrong, 2000). Genetically engineered duckweed may produce proteins such as insulin more cheaply and in greater quantities than through traditional methods (Robertson, 2000). Furthermore, duckweed provides habitat for a vast number of aquatic organisms (Evans, 2000).

Pistia stratiotes (water lettuce) is another example of a floating macrophyte used in constructed wetlands for a combination of purposes, including wastewater reclamation, food production and wildlife habitat. Water lettuce grown on effluent ponds can purify effluents through active absorption of organic matter and minerals. Harvested water lettuce can be used as animal feed (Bensouda et al., 1997).

The fine, long and decorative roots of the water lettuce provide breeding and hiding-places for surface fish (Wet Web Media, 2000). The addition of ground plant material, especially *Pistia stratiotes* to manure, improves the performance of the cattle manure fermentation process, thus increasing the resulting yield of biogas that can be used as an alternative to forest wood or fossil fuels as energy sources. In an experiment by Bensouda et al. (1997) the anaerobic digestion of a mixture of cattle manure and *Pistia stratiotes* gave higher performance than cattle manure alone. The mineral and protein enrichment provided by *Pistia stratiotes* and a bacterial consortium adapted to *P. stratiotes* increases the CH₄ content of the biogas (Bensouda et al., 1997). Compost obtained from a mixture of *Pistia* and domestic organic wastes has a high nitrogen content. Such compost reduced the need for chemical fertilizers in rural areas (Agendia et al., 1997).

Eichhornia crassipes (water hyacinth) grows profusely in many parts of the tropics. Wastewater treatment with water hyacinth has been successfully implemented by the city of San Diego, USA, to produce a treated effluent attaining quality standards expected from advanced secondary treatment processes (Rose, 1999). Compared to duckweed, water hyacinth wastewater treatment systems play a bigger role in biochemical oxygen demand (BOD). Water hyacinth produces a high yield. However it has low nutrient value and low digestibility (Rose 1999).

Reeds (*Phragmites communis*) can purify wastewater containing many kinds of heavy metals and at the same time be used as raw material for making paper and building material (Yan and Zhang, 1994). A reed zone along the Changjiang River in Zhenjian, China, has

been preferred to a wastewater treatment plant for the treatment of most of the domestic effluent from the city.

Integrated Aquaculture

Filterivorous animals are stocked and harvested in some water bodies to promote transfer, regeneration, cycling, indirect export, and decrease of phytoplankton and nutrients, thus improving water quality and preventing eutrophication. Furthermore, in the process, an additional economic benefit is generated (i.e., marketable products) (Yan and Zhang, 1994). For example, in order to control eutrophication of Lake Jinghihu and Lake Dushuhu, China, (730 and 800 ha, respectively) resulting from domestic effluents, large numbers of fingerlings of filterivorous fishes are stocked in both lakes every year. The dominant species of phytoplankton in the lakes, *Microcystis*, constituted about 55% of the body weight of the two major fishes in the lakes, silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) (Yan and Zhang, 1994).

The standing crops of fishes in both lakes were 0.5 to 1.5 tons per ha, and the annual yield by catching and stocking in rotation was about 1.5 to 1.8 tons per ha. In both lakes, about 416 to 1249 tons fresh weight of phytoplankton could be eaten daily by filterivorous fishes. The annual output of fishes to the market from both lakes is equivalent to an export of 73.5 to 89.3 tons of nitrogen and 5.03 to 5.61 tons of phosphorus (Yan and Zhang, 1994).

Integrated Recreation

Wetlands can be designed for wastewater treatment and wildlife habitat as well. A design to enhance wildlife promotes the vegetation "edge effect" preferred by many birds and

other animals (Kadlec, 1994) by incorporating a mosaic of open water and emergent vegetation in the constructed wetland. The layout of the system contains twists and curves, as opposed to typical rectangular cells (Kadlec, 1994). The facility may be operated as a park, with walking trails, picnic facilities and signboards. The pond and island treatment system at Arcata, northern California (Kadlec, 1994) is an illustration of such a combination.

Integrated Production Constraints

Unlike fresh water irrigation, reclaimed wastewater is restricted to certain uses due to public health or water quality concerns (Rose, 1999). For example, reclaimed water cannot have direct contact with crops consumed uncooked and irrigation methods must reduce the contact of wastewater with edible crops. There must be human exposure control for workers, crop-handlers and final consumers. Furthermore, the use of reclaimed wastewater is conditioned upon the reduction of pathogen concentrations so as to meet the WHO (World Health Organization) guidelines (Rose, 1999).

A common trait of the floating aquatic macrophytes mentioned above (duckweed, water lettuce and water hyacinth) is that they often grow very rapidly and shade out other less robust plants in ponds, lakes and reservoirs (Santa Fe Tropical Fish, 1999; Skillicorn, 2000; Rose, 1999). In this regard, control must be exercised in order to prevent them from expanding out of control, becoming a pest that can clog waterways, hamper navigation, and worsen eutrophication (i.e., massive decomposition of macrophytes which further depletes water oxygen). Regular harvesting of macrophytes provides an economic income as well as preventing secondary pollution of water.

An incident reported by Yan and Zhang (1994) highlights the importance of harvesting macrophytes in a macrophyte-base wastewater treatment system: about 1400 ha of dense wild rice grew lushly on the littoral of Lake Taihu. After each Autumn, large amounts of decaying stems and leaves of wild rice were deposited in the littoral area, increasing the chemical oxygen demand, the concentration of nitrogen, phosphorous and reducing the dissolved oxygen in about 220 ha of the lake area during the summer of the following year (decomposition due to increased temperatures).

CHAPTER 6

WETLAND VALUATION AND MANAGEMENT IN RWANDA

In this section I will attempt to establish a scheme for achieving a balance between wetland preservation, restoration, and utilization in Rwanda. To this end, I will present principles and tools for the assessment and evaluation of the quality of wetlands and their appropriate management to attain these qualities.

Principles Guiding the Valuation of Wetlands

Formulation of a specific and detailed management plan for wetland ecosystems that are multiple-value systems (Mitsch and Gosselink, 1993) requires the setting of priorities and specific objectives (Thompson and Hansen, 1993). Estimates and supposition attached to some wetland values are subject to personal endowment and individual or society biases.

The complexity of natural processes involved in functioning wetlands adds to the difficulty of a thorough assessment of a wetland value. Use of conventional economic tools for the assessment of wetland value requires a great deal of caution. For example, the concept of marginal value assigns an increasing value to decreasing stocks of a commodity. Yet, the marginal value of a wetland as a habitat for large mammals ceases to increase below a certain size and may even equal zero (Mitsch and Gosselink, 1993).

A comparison of economic short-term gains with long-term wetland value is often inappropriate. Whereas commercial value derived from wetland development is often finite,

wetlands provide value in quasi-perpetuity values (Mitsch and Gosselink, 1993). Moreover, wetland development is often irreversible (Mitsch and Gosselink, 1993; Fisher et al., 1996; Wilbert et al., 1996). The most valuable products of wetlands are public amenities that may not have commercial value for the private wetland owner (Mitsch and Gosselink, 1993). However, monetary cost may be associated with the loss of wetlands (i.e., loss due to floods).

Wetlands are open ecosystems that maintain strong ties (interspersed) with adjacent ecosystems (Mitsch and Gosselink, 1993; Fisher et al., 1996; Wilbert et al., 1996; Long and Nestler, 1996). A small wetland area may play a very limited role in the reduction of the effects of flooding but this same area may be extremely important for migratory species that spend only a day or a week in the area (Mitsch and Gosselink, 1993). Thus, any wetland evaluation that isolates wetlands from adjacent ecosystems carries intrinsic flaws.

Different social contexts determine different priorities and grant different weight to the same wetland functions. For example recreational functions of wetlands are granted more attention in developed countries than in developing countries. Thus, the weighting of wetland values is driven by ecological, social and economical considerations.

Tools for Wetland Valuation

Wetland ecosystems share a number of characteristics such as relatively long periods of inundation or saturation, hydrophytic vegetation, and hydric soils. However, wetlands occur under a wide range of climatic, geologic, and physiographic situations, and exhibit a wide variety of physical, chemical, and biological characteristics. This variability presents a challenge to the development of assessment methods that are both accurate and practical.

Generic methods designed to assess multiple wetland types lack the resolution necessary to detect significant changes in function (Hauer et al., 1999).

Because of the difficulties involved in the valuation of wetlands, there is no wetland valuation procedure bearing the seal of universal approval (Mitsch and Gosselink, 1993). The many wetland assessment procedures that have been developed in Northern America and Europe acknowledge the difficulty of designing a universal wetland valuation procedure. I will discuss briefly a few assessment procedures practiced in North America.

The Habitat Evaluation Procedure (HEP) is a species-habitat approach in which habitat suitability for (a) selected species determined using a Habitat Suitability Index (HSI) scaled from 0 to 1. This value is derived from an evaluation of the ability of key habitat components to supply the life requisites for selected species. The HSI score is reached by comparing existing habitat conditions to optimum habitat conditions for the species of interest (Mitsch and Gosselink, 1993; Anonymous, 2000; Novitzki, 1995). HEP can also be used for assessing impacts of development on the quality and quantity of available habitat for selected wildlife species by determining the difference between index values of existing conditions and conditions that will result from a proposed project. The beneficial or adverse impacts anticipated from projected development are then expressed in terms of Habitat Units (HUs) gained or lost ($HU = HSI * \text{area of available habitat}$). Habitat Units serve as the principal units of comparison in HEP and as a standard platform of communication that integrates both quality and quantity of habitat (US. Fish and Wildlife Service, 2000).

The ability of HEP to detect the types and magnitudes of project impacts on a specific habitat is dependent upon the validity and sensitivity of the HSI models used to generate data

for HEP. Moreover, HEP conceptually addresses only issues of species population and habitat (US. Fish and Wildlife Service, 2000).

Hydrogeomorphic (HGM) approaches evaluate wetland functions and values by assessing the physical, chemical, and biological functions of wetlands. HGM identifies wetland and landscape variables (e.g., topography, plant community, stem density, flood duration, annual turnover of detritus) that indicate that a function is performed (Brinson, 1993b, Hauer and Cook, 1996a; Novitzki, 1995). HGM scales the assessed variable to suggest the degree to which a function is performed.

The degree of performance of the expected functions is determined by comparing variables in individual wetlands to those of a sample of wetlands in the region (reference wetlands) that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human altered wetland sites (Hauer et al., 1999). When the condition of a variable is within the range of conditions exhibited by reference wetlands, a variable subindex [Functional Capacity Index (FCI)] of 1 is assigned. As the condition of a variable deviates from the conditions exhibited in reference wetlands, the variable receives a progressively lower subindex, reflecting its decreasing contribution to functional capacity (0 being the lowest value) (Hauer et al., 1999). When variables cannot be measured, indicators of variable conditions [e.g., among others, silt lines, sediment deposition and directionally bent vegetation, may be indicators or indirect measures of the frequency of overbank flooding (variable) otherwise directly measured by gage data] may be used (Hauer and Cook, 1996a).

In order to increase the resolution of HGM in the assessment of changes in wetland functions, the level of variability exhibited by wetlands being considered is reduced. To this end, groups of wetlands that function similarly at the lowest geographical scale affordable are identified, using three criteria that fundamentally influence the functioning of wetlands: geomorphic setting (landform and position in the landscape), water source (precipitation, overbank flood water, or groundwater), and hydrodynamics (level of energy and direction of flow) (Hauer et al., 1999).

The concept of reference wetlands is central to the HGM assessment procedure. Not only do reference wetlands characterize and define the sustainable level of a set of functions selected for a specific group of wetlands (e.g., specific region and subclass); they also provide the data necessary for the calibration of model variables, and constitute a concrete representation of wetland ecosystems that can be repeatedly observed and measured (Hauer et al., 1999).

The Wetland Evaluation Technique (WET) uses predictors of physical, chemical or biological processes to rate wetland function on a scale of high, moderate, and low in terms of social significance, effectiveness, and opportunities (Mitsch and Gosselink, 1993). Social significance relates to the value of a wetland to society in terms of its economic value, strategic location (e.g., upstream location from an area requiring flood protection) or any special attribute (e.g., habitat for endangered species). Effectiveness refers to the site's ability to carry out a function because of its physical, chemical, or biological characteristics (e.g., storage of flood waters, storm abatement). Opportunity relates to whether a wetland has the

opportunity to perform a function to its level of capacity (e.g., whether the upstream watershed can produce flood waters).

The result of this assessment process is a list of functions, each involving a quality rating for the three attributes (social significance, effectiveness and opportunity). To facilitate comparison between wetland conditions, the qualitative ratings are converted in a numeric rating (e.g., low associated with 0 or 0.5, moderate equal to 2, and high given a score of 3).

The integrated evaluation of a wetland condition using WET takes into account all the functions assessed, weighing each selected function according to its assigned relative importance. Among the limitations of WET are the facts that WET does not reflect a landscape focus and its results are only semi-quantitative (Mitsch and Gosselink, 1993).

Management purposes, type of wetland, and the social context within which the wetlands exist are key elements that dictate the valuation procedure used for the assessment of wetlands. A high degree of precision in assessment and comprehensiveness are practically mutually exclusive. For example, HEP's narrow focus on species habitat allows a thorough assessment of a species habitat requirement, but lacks assessment from the economic or social perspective that may be provided by WET.

The proximity of Rwanda to the equator [between 1 and 3 degrees latitude south (Embassy of Rwanda, 2000)], its relatively high elevation [most of the country lies above 1000 m, with half of it 1500-2000 m above sea level (Embassy of Rwanda, 2000)], its rolling and diversified topography (country of "one thousand hills"), its location in a region of relative abundance of lakes and rivers (Great Lakes Region, headwaters of the Nile) and extensive wildlife reserves (eastern African savanna), its very high rural population density,

its very poor economy, relying heavily on agriculture, obviously all locate Rwanda's wetlands in a different context than those in North America where HEP, HGM or WET have been designed. Wetlands associated with depressions, rivers, lakes and groundwater are likely to be the dominant classes of wetlands in Rwanda, given the geographical features mentioned above. Precipitation and overbank flow are probably the major sources of water for wetlands [900-1600 mm average annual precipitation (Embassy of Rwanda, 2000)]. However, groundwater may be an equally important water source (depending upon the relative importance of slope wetlands).

Priorities for Wetland Management

Wetland functions likely to receive paramount attention are the ones affecting or related to hydrology (flood mitigation, aquifer recharge, water storage, shoreline protection, sediment retention) because of the violence of the rainy season, which can generate huge floods, soil erosion and sediment transport. In addition, severity of drought during the dry season often dramatically reduces water availability for human activities (shortage of water supply in urban areas), agriculture and livestock. Wetland harvestable productivity, organic carbon export and organic waste recycling are obviously valuable functions in the context of a country facing shortages in food production and public health issues associated with poor handling of urban human wastes. Because of the potential contribution of tourism to the economy of Rwanda, and East Africa in general, wetland contribution to recreation and wildlife diversity and abundance should be investigated. Wetlands constituting breeding

habitats for large populations of mosquitoes or other vectors of diseases will be considered a public health hazard unless economically and environmentally feasible remediation procedures are (or can) successfully (be) implemented.

Wetland functions are often mutually competitive. The maximization of one function is usually accompanied by the reduction of (an)other function(s) (Firehock et al., 1998). Therefore, wetland functions associated with the regulation of hydrology, food production, organic waste recycling, and disease control will be granted the highest weight in a functional assessment of wetlands in Rwanda because of their pivotal position in the Rwandan economy and social context. However, among those four functions, hydrology will receive the highest ranking because it controls all the others. Due to the imperative nature of food production in Rwanda, food production in wetlands will rank second. Bio-waste recycling will have precedence over the disease control function, because successful management of wastes may eliminate or decrease the occurrence of diseases, and also because bio-waste recycling is complementary to food production.

Wetland functions related to wildlife habitat will be assigned a secondary weight, while wetland functions favorable to the thriving of vector populations will receive a negative weight.

Wetlands that will be rated *highly functional* according to the scheme described above will be protected and managed to improve their multiple functionality. Human activity that will interfere with the natural processes of wetlands will be forbidden unless rigorous provisions for the reestablishment of equally functional wetlands elsewhere are provided. Wetlands rated *moderately functional* may only be subjected to compatible alterations or

alterations that may increase their functional value. For example, they may be carefully altered or expanded with constructed wetlands that recycle wastewater. However, any risk for functional degradation should be thoroughly assessed and avoided. Wetlands rated *negligibly functional* will be preferentially targeted for functional restoration or enhancement projects; however, development projects with recognized social importance may replace these wetlands without any mitigation requirement.

Undoubtedly, field investigation is essential in the identification and measurement of the variables/indicators auxiliary to the assessment of functions of wetlands in Rwanda. To date, little effort, if any, has been undertaken in this direction. Nonetheless, some, if not many, of the variables or indicators used in the assessment of wetland functions in Northern America and Europe, where a considerable amount of research has been realized, will have validity in the Rwandan context (e.g., use of variables such as frequency of wetland flooding, average depth of inundation and flood duration for the assessment of surface water storage function of a wetland of interest) (see Hauer and Cook, 1996a; Hauer et al., 1999).

However, only formation of an interdisciplinary team of research scientists and regulatory managers, working in consultation with all the major groups involved in activities affecting wetlands and the environment in Rwanda (government, municipalities, local communities, non-governmental organizations (NGO), academic institution, water regulatory bodies, industries and farmers) can provide an approach to wetland assessment which is sufficiently comprehensive and thorough enough to overcome the deficiencies inherent to the lack of awareness of the current status of wetlands in Rwanda and the embryonic stage of the environmental sciences in the world, in general.

The capacity of local research institutions to undertake comprehensive wetland assessment should be strengthened (e.g., training for expertise in the ecological functions of wetlands and adequate financial resources). Among the tasks of these research institutes would be the inventory and description of all major and environmentally significant wetlands in Rwanda, identification of their particular attributes and functions, the quantification of such functions, establishment of a database from desk and field studies, and conceptualization and development of wetland assessment models fitted to specific conditions of Rwandan wetlands. Special attention would be devoted to identification, protection and collection of data from relatively pristine wetland sites.

The outcome of this multidimensional undertaking - ideally integrating the goals and aspirations of the different parties - would be creation of tools for the assessment of wetlands and minimization of unavoidable project impacts, design and monitoring of compensatory mitigation, and identification of potential mitigation sites. Existing environmental impact assessment techniques and cost-benefit analysis procedures could be integrated in the frame of these wetland assessment tools specially designed for wetlands in Rwanda.

Research Priorities

Hydrology

Because of the importance of hydrology to wetlands and agriculture as well, the regional hydrology should be thoroughly studied, the wetlands inventoried and the interaction between wetlands and hydrology investigated. This will include the general inventory of

rivers, lakes, and wetlands (i.e., types, size, and distribution); and determination of the effects and related remediation solutions of potential hydrologic manipulations for disease control, food production, and waste treatment.

Food Production

In order to maximize space and energy utilization, the potential of riparian areas to contribute to current and potential food production and riparian wetlands functions compatible with food production should be investigated. Measures to minimize the loss of incompatible wetland functions should be investigated as well.

Organic Waste Recycling

Measures to promote the use of wetlands for the recycling of urban and rural bio-wastes should include an inventory of potentially useful native macrophytes whose growth and nutritional profile will permit fast and efficient recycling of bio-wastes and will provide a marketable harvest as well. Macrophytes with medicinal properties should receive a substantial attention. Wetlands capacity to retain sediment and nutrients from agricultural run-off should be investigated. Wetland functions adversely affected by sediment and nutrient retention and remediation measures to address this problem should be identified..

Disease vectors management

The current knowledge regarding favorable environment factors for malaria vectors should be integrated with a wetland management scheme that eliminates the favorable environmental factors with minimal impact on other desirable wetland functions. Wetlands

functions that may potentially be affected by such a management scheme should be determined and appropriate mitigation mechanisms determined. Ways to integrate disease management with food production and waste treatment, such as the use of filterivorous and larvivorous fish, should be investigated.

Upstream transfer of resources

Another aspect of wetland management that should be addressed is the development of mechanisms to facilitate the transfer of resources from downstream beneficiaries of wetland functions to the protection and management of upstream wetlands (e.g., economic incentives for upstream wetland owners). The economics of alternative flood control approaches may serve as one of the elements determining the worth of upland wetlands and the taxation of downstream beneficiaries. Taxation should not necessarily imply a monetary form because the rural economy in many parts of the developing world are not completely monetary. One of the important goals of the taxation should be to raise the awareness of the benefits of upstream wetlands. The sale or exchange of upstream wetlands marketable products to downstream centers should help enhance the value of wetlands and enshrine the protection of wetlands in the common interest, while promoting welfare in areas where poverty is prevalent.

Supplementary Measures for Wetland Management

There is little awareness of the importance of the environment in the “modern” Rwandan society. Traditional knowledge is deemed irrational and irrelevant. Consequently,

emphasis is put on activities generating financial fast income (pressure from poverty); forests and wetlands are severely endangered. Environmental practices sanctioned by centuries of a close proximity with nature are being dismissed in the name of modernism. This being the case, it would be wise to revisit some of the traditional environmental practices and assess them in light of current environmental science. If some of these practices have some validity, their implementation may turn out to be time and money saving (e.g., time and money associated with novel research). Moreover, their implementation would not require extensive foreign expertise.

Awareness of the advantage granted by a sound environment should be cultivated in schools. Field trips for classes could constitute a kind of local ecotourism designed to raise the awareness of the value of wetlands and set a healthy pattern of behavior for coming generations: a sense of stewardship that may result in unexpected ramifications (educating upon the bad effects of irresponsible behavior and hopefully diverting from divisive issues?)

In this regard, a determined portion of the existing wetlands could be preserved as natural parks or reserves. Similarly, stringent environmental laws and incentive economical regulations should converge on the promotion of sustainable environmental practices.

The promotion of constructed wetlands for treatment of sewage is an example of an undertaking in this regard: water quality issues, health issues resulting from poor water quality, the relatively low cost for constructed wetlands for sewage wastewater treatment make them the only affordable wastewater treatment option for poor communities. Rural communities should therefore be taught the value and process of construction and maintenance of (mandatory) village wetlands for sewage treatment. The additional outputs

of this system (e.g., green manure, livestock feed) could be exempt from taxation or enhanced by government subsidization.

Another course of action should be directed toward forging partnerships between organizations or institutions involved in wetland related activities. To this end, communication and exchange of information and issues relevant to the promotion of wetlands (conferences, seminars, fora and journals) must be enhanced.

Open discussions involving management agencies and local communities should help to identify issues, needs and problems related to wetlands. The success of this campaign could be measured by public awareness of the many-fold utilitarian aspect of wetlands as precious environmental assets and sources of financial income as well. It might be expected that public awareness would be solidified into citizen wetland monitoring programs (community-based organizations and NGOs) that would undertake and supervise on their own initiative needed wetland management projects in their communities, validating public (citizen) endorsement of responsibility for wetlands.

CHAPTER 7

CONCLUSION

The prime intent of this paper was to identify the link between wetlands and agriculture and investigate the possibility that wetlands are, indeed, complementary to agriculture instead of being antagonistic to agriculture. For this purpose, I have attempted to identify the multitude of values and functions of wetlands, and the losses or alterations human interference to wetlands functioning has caused in the USA and other parts of the world. By the same token, I have discussed the crucial importance of wetlands in the preservation of wildlife (i.e., waterfowl, fish, shellfish, and endangered species), regulation of surface and underground hydrology (flood mitigation, storm abatement, aquifer recharge, and water quality), prevention and remediation of pollution, and recycling of nutrients, thus showing that wetland preservation profits agriculture and the society as a whole, and that thoughtful wetland management lays the basis of a sustainable agricultural practice.

Integration of wetland-based waste treatment systems with food production schemes suggests that sustainable wetland management strategies exist that can unify the economical, health and environmental (i.e., losses of wetland functions) concerns both in developing and developed countries. This is even more so as nuisances associated with wetlands potentially can be eliminated without the loss of wetland vital functions. The harvesting of wetland macrophytes is an example of an intervention that increases a desirable wetland function (recycling and removal of nutrients) and simultaneously complements agriculture.

However, the need to adapt findings of research from different parts of the world to local conditions and different contexts modifies the above positive assertions with a sense of caution.

Geographic and social circumstances specific to Rwanda endow hydrology, sediment retention, food production, and organic waste recycling related wetland functions with special significance. These functions should be given special consideration in a functional assessment of wetlands in Rwanda. Wildlife related wetland functions are less preeminent in the present Rwandan context but are likely to gain in importance as tourism, environmental awareness, political and the economic integration lead to a certain level of universalism of human or society values. Anticipating this move, assessment tools for the identification of wetlands endowed with a high potential for wildlife may be designed. Because of economic limitations and health costs imposed on the Rwandan society by vectors of diseases that may breed in wetlands, wetland functions favoring these vector populations should be identified and eliminated when possible. Functions unfavorable to vector populations should be promoted, and accordingly valued in functional assessment procedures.

Finally, consultative processes involving various sectors and institutions using or responsible for the protection of environmental resources constitute an important component of the overall wetland management scheme, as they are key to the identification of the problems to be resolved and the effective implementation of adopted solutions. The absence of this element can potentially nullify the outcome of expansive and intensive years of research. Accompanying measures such as strict environmental laws and economic

incentives would undisputably add to the strength of the whole process of promotion, regulation, protection, and rational utilization of wetlands.

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