VIII

PRINCIPLES FOR INTERFACING WETLANDS WITH DEVELOPMENT*

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INTRODUCTION

Wetland ecosystems are swamps, marshes, floodplains, sloughs, strands, and other areas intermittently submersed by waters. Wetlands do many kinds of useful work for the biosphere and for society such as maintaining water quality. Using wetlands as domesticated ecosystems in our landscape in symbiotic partnership is a challenge to planners, developers, governmental regulators, and to us all. Understanding wetlands leads us to principles for interfacing wetlands and humanity. Principles for interfacing humanity and nature so as to maximize economy of both are sometimes called ecological engineering. First, consider features of a typical wetlands ecosystem.

Properties of Wetland Ecosystems

The properties of a wetland are sketched in side view in Figure 1. There is a geologic substrate in which some means of maintaining a water seal and storage have developed such as layers of clay or organic matter. There are inflows of water and nutrients from land runoffs, flooding rivers, rains, or ground water seepages. A special pattern of vegetation develops which is adapted to use the favorable growth features of having good water and nutrients available to roots combined with having leaves that are exposed to sun and wind. A wetland system has plants adapted to live in waters when they are high but without water when it is low. There are many adaptions for fluctuating waters. Small plants develop in wet times and go to seed or spores in dry times. Trees are adapted to breathe when roots are water covered and when the microconsumers of organic matter use up oxygen. Adaptations for breathing include transport of air through plant tubes and processes for doing respiration without oxygen but with by-products reacting with oxygen later. Animals have various adaptations for land and water changes such as the land and water life cycles of amphibians, air breathing of fish, and the short life cycles of insects.

The typical processes of a wetland can be visualized with a systems diagram that shows inflows of energy and materials with a language of symbols (Odum and Odum, 1976). First, in Figure 2 is a very aggregated overview diagram of a wetland showing the main processes of production of plant matter, and the consumption of that plant matter and other organic matter by the consumers such as

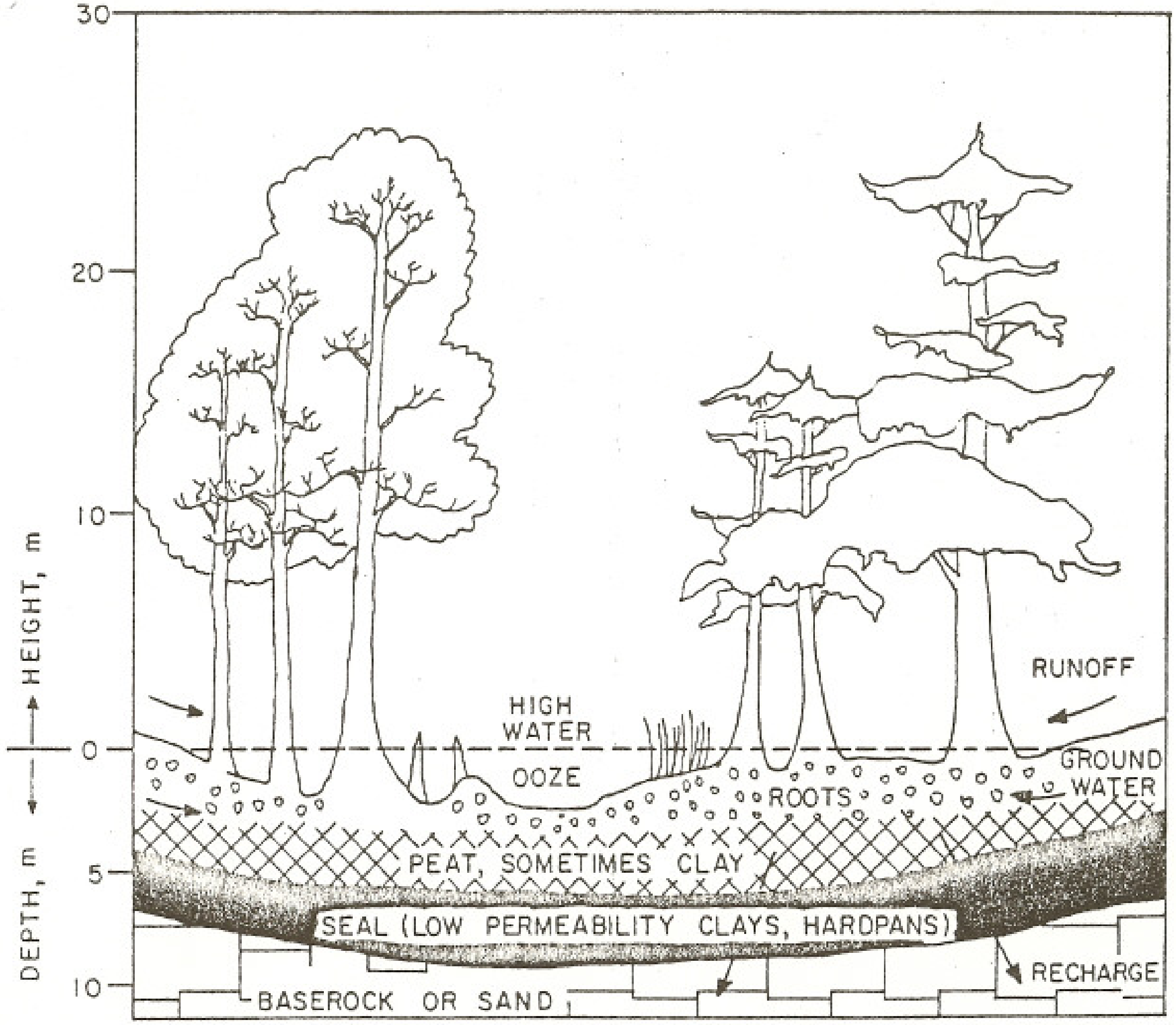


Fig. 1. Main features of a wetland ecosystem.

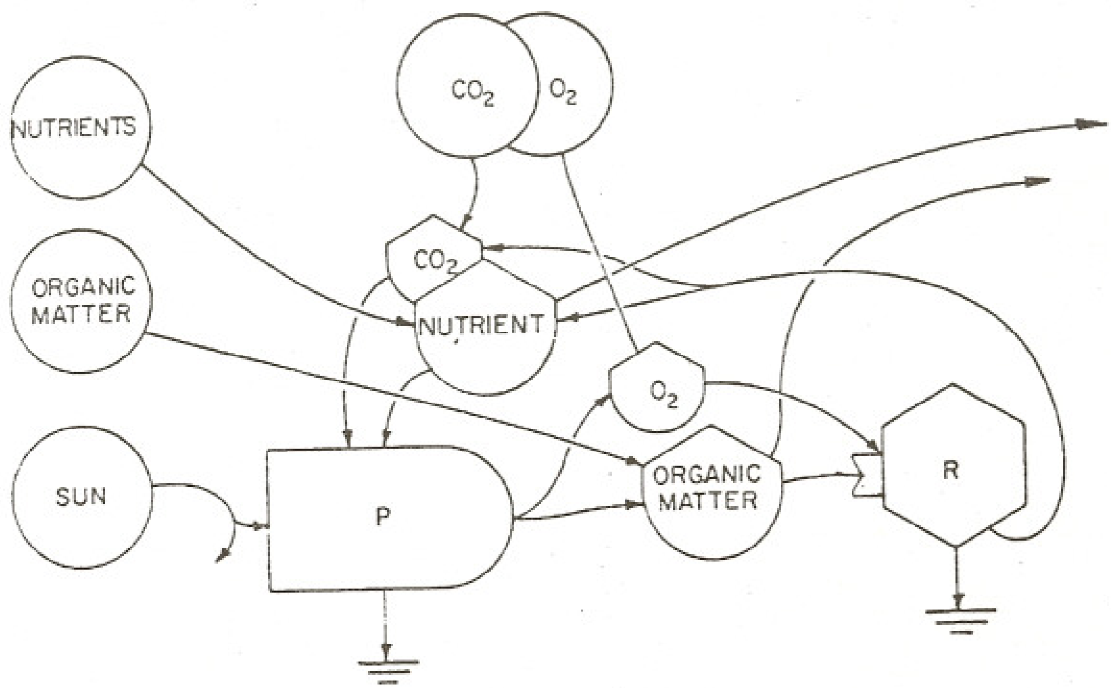


Figure 2. Main process of production, consumption, gaseous exchanges, and recycle.

microbes and the animals that manipulate them. Figure 2 includes the main exchange of gaseous carbon-dioxide and recycle of nutrients. Figure 3 is more complete.

Wetlands act as a water quality buffer absorbing excess. If the organic matter inflow is in excess, it tends to be absorbed, and used by consumers. Then respiration (*R*) is greater than production (*P*), but any nutrients released tend to be bound in peat. If the inorganic nutrients are in excess, photosynthetic production (*P*) is stimulated, some organic matter is stored, and some may be eventually released. Wetlands which build up peat and store nutrients may lay down about a millimeter per year. A marsh can store its produce for many years.

A large marsh area buffers Lake Okeechobee by binding nutrients. Plans to raise the lake level may return these nutrients to the lake with a eutrophication effect (Browder, 1976). On the other hand, raising the level may reduce the scouring tendencies of recent years and allow deposition of organic sediments on the bottom binding nutrients. See Gayle (1976).

Wetlands store matter in peat, roots, plant matter, and clay layers. When the storages get large, some may be lost again, usually in the form of natural products, particles, and refractory organic matter that is in the natural pattern and fairly slowly decomposed, not reducing oxygen faster than oxygen can diffuse in from the air. Life in wetlands is usually adapted to survive low oxygen in waters and soils.

Wetlands have fairly low diversity of the plants and animals in the water. These use their energy more in adaptive work of adjusting to changing water and oxygen conditions than in developing diversity of biotic species interactions. However, among the branches above the waters, more uniform conditions support microarthropods of very high diversity that may be part of mechanisms for prevention of epidemics by disease or insects (McMahan, 1978).

A remarkable characteristic of some wetlands ecosystems is their conservation of water. In some there are some vegetational structures in dry season such as trunks and dead grasses that shield the water and wet surfaces from sun and wind (Dolan, 1978), and if live leaf masses are small, there may be less evapotranspiration than in reservoirs. These wetlands can be preserved as a water conservation system preferable to reservoirs, since they do not fill up, do not cost much, and improve quality. Examples are the cypress domes in Gainesville (Heimburg, 1976). S. Brown (1976) calculated the water savings in leaving the green swamp with its cypress ponds as greater than 10%.

The production process of a wetland generates organic matter by interacting sun, wind, water, carbon dioxide, nutrients, and substrate (Figures 2, 3, and 4). Where nutrients are small, the organic matter

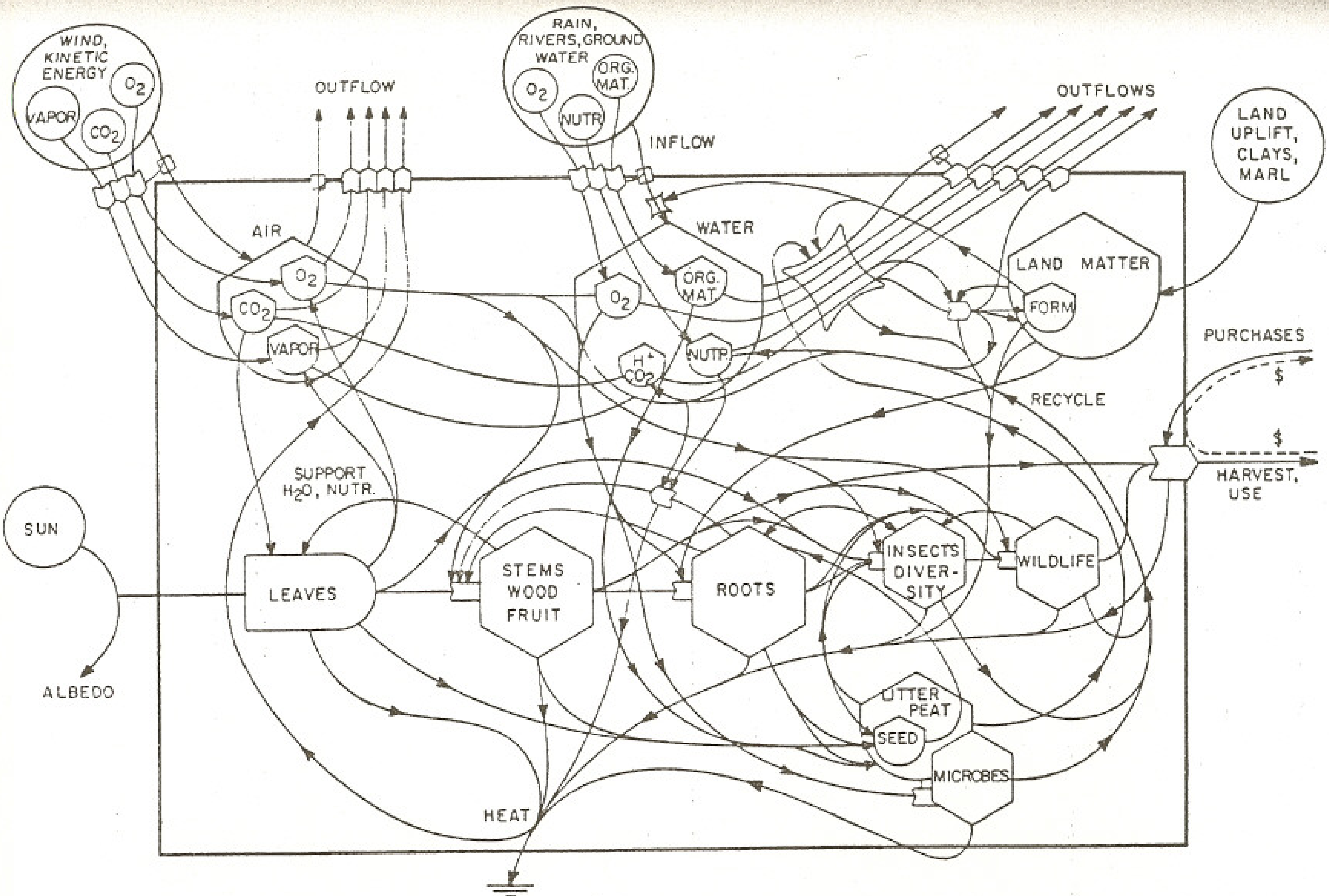


Figure 3. More complex diagram of some main components of a wetland ecosystem.

produced is low in nitrogen and phosphorus and high in cellulose and lignin, which are composed of carbon, hydrogen, and oxygen. For this organic matter to be consumed by bacteria and small animals and converted into the bodies which are more protein rich, additional nitrogen and phosphorus have to be added or concentrated from previous decomposition. Competition for nutrients may develop between the consumers and the plant producers. Thus, unlike Figure 4a where plants and consumers are symbiotic, they are competing in Figure 4b. One reason organic matter can build up in wetlands and be stored without much effort is the low oxygen in wet soils; another reason is the low nitrogen and phosphorus available for the decomposing consumers (Figure 4b). In many natural wetlands, nitrogen fixers of nitrogen in air are abundant and may be correlated with denitrifiers which use oxygen from nitrate, returning nitrogen to air.

Some wetlands have plants rooted in inorganic clays and sands; others build a platform of their own peat; others are attached to marls and limestones in which decomposition develops pockets and porosities. Where limestones or ground waters are involved there can be hard-water wetlands. Where rainwaters are mainly involved, wetlands are soft water types and nutrient poor. Peat masses help hold water and protect roots from fire in dry season.

The conditions for wetlands can be classified by the nutrient levels, hardness levels, by hydroperiods and water depth, and by salinity where the wetland is marine (Penfound, 1952; Heikurainen, 1964). The chemical characteristics may depend on the extent of the land drainage from which nutrients and minerals may be leached as an input to the wetland. The hydroperiod is so wide ranging that dry periods can support fire that burns deeply. Swamps (wetlands with trees) result when hydroperiods maintain root bases wet. A classification of forested wetland ecosystems was generated at the Center for Wetlands and is available in a Wetlands Use Manual (Wharton *et al*, 1976). In Figure 5 forested wetlands of peninsular Florida are arranged according to the amount of inflow runoff bringing water and nutrients. When there is only rainwater, low nutrient peats accumulate and help to hold water. Evergreens such as bays predominate, possibly because they hold their nutrients in their tissues and out of th. competition with the peats. With slightly more flows, more standing water is maintained so that pond cypress and swamp black gum predominate. This system conserves water. Then, with more flows, as in strands, bald cypress and the tupelo gum prevail and growth is faster; photosynthesis per area and per tree is larger. Finally, when waters converge to form regular streams and springs, there are floodplains with even higher growth rates, but times of standing water regimes are not so long and more insects can prevail.

Particularly in marsh studies, measurements of productivity have been done with net measurements of accumulation, so called net production. (In Figure 2, see P_{41}, $\dot{Q}_1$, $\dot{Q}_2$, P_5, P_6 where Q dot is rate of change of Q.) These data can be very misleading because they depend on the time interval for measurement and do not measure the

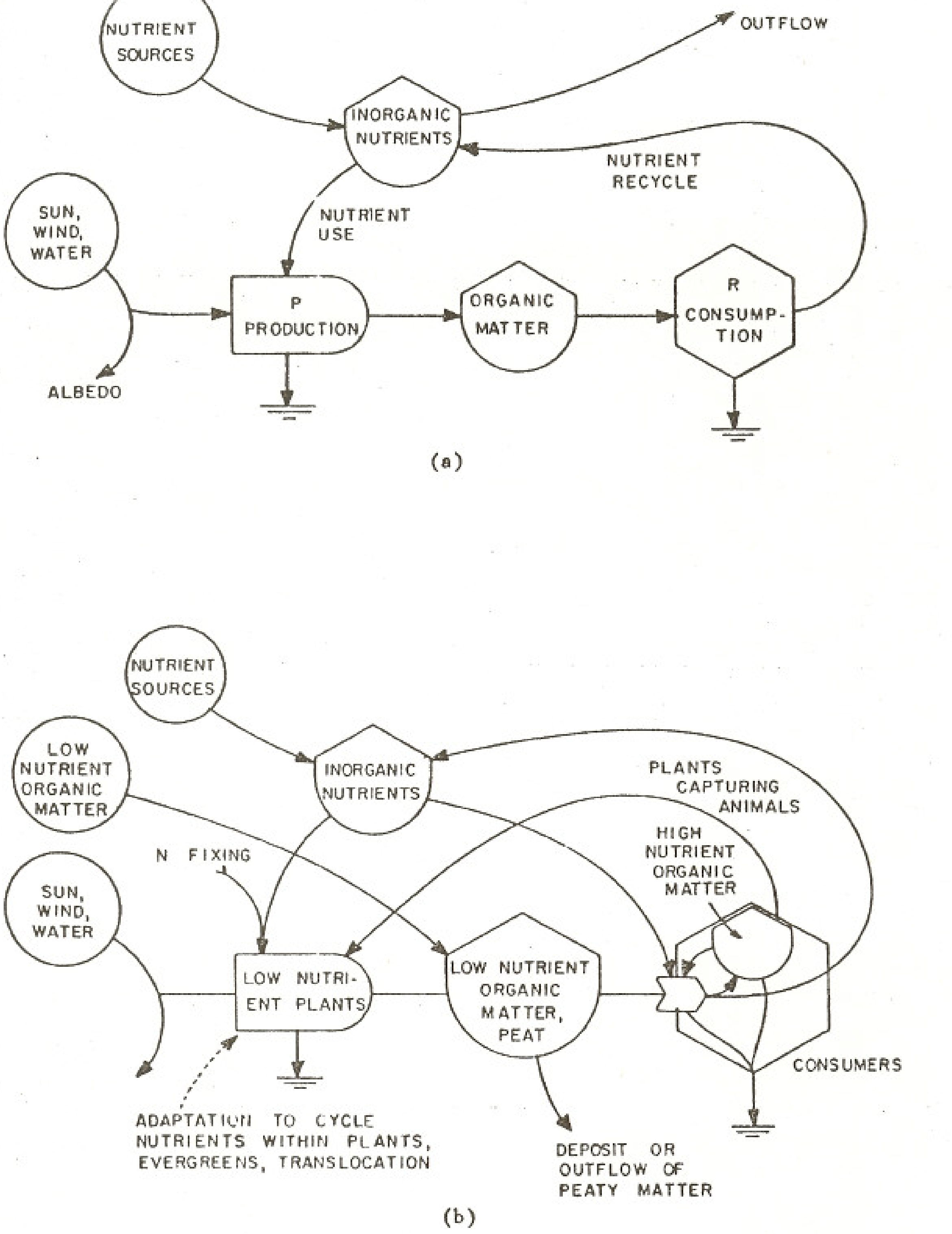
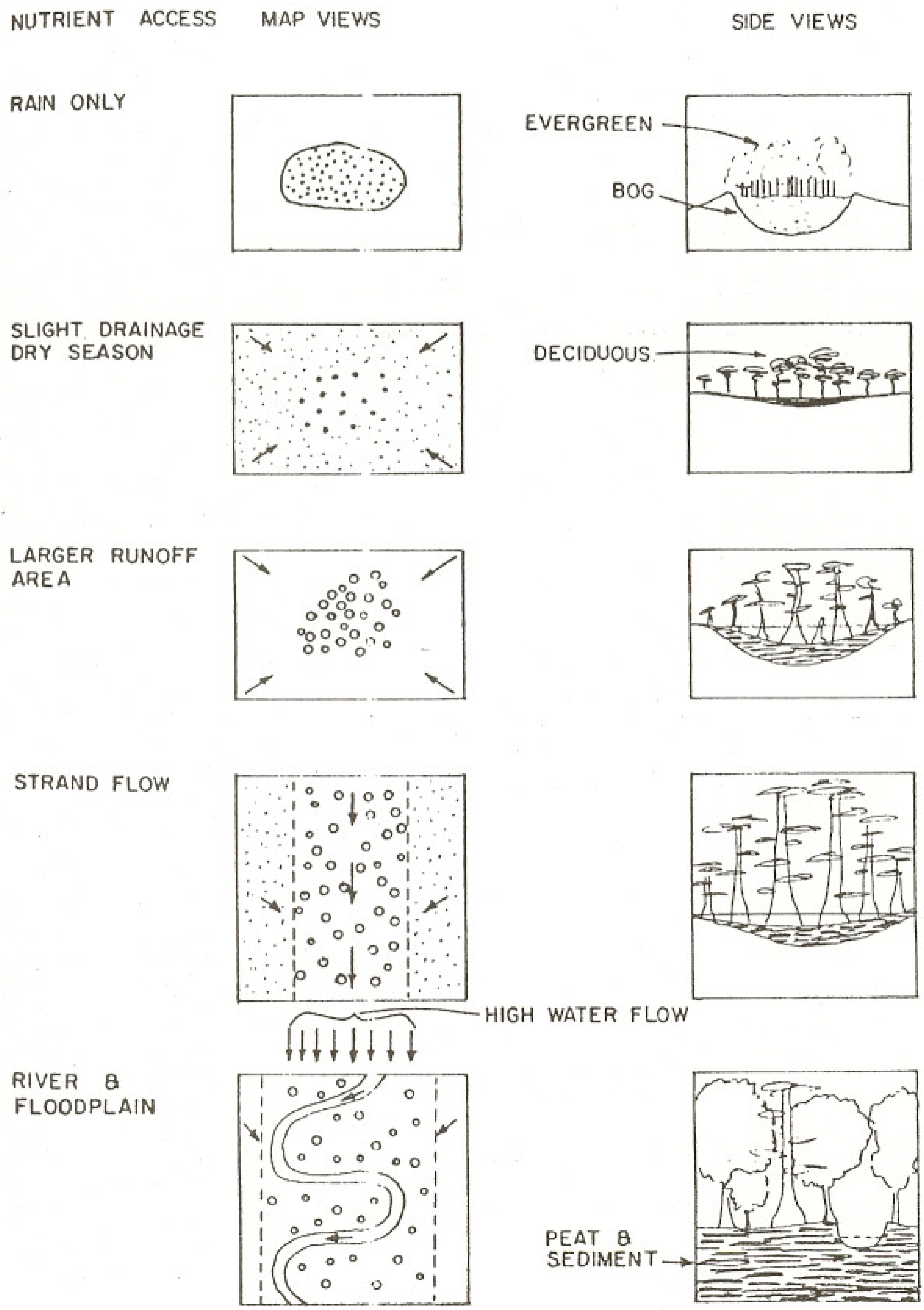


Figure 4. Simplified diagram of wetland nutrients. (a) Nutrients in symbiotic recycle; (b) plants and consumers competing for scarce nutrients.


NUTRIENT ACCESS
MAP VIEWS
SIDE VIEWS
RAIN ONLY
EVERGREEN
BOG
SLIGHT DRAINAGE
DRY SEASON
DECIDUOUS
LARGER RUNOFF
AREA
STRAND FLOW
HIGH WATER FLOW
RIVER &
FLOODPLAIN
PEAT &
SEDIMENT

main basic work processes of the plants and animals use organic matter as fast as it is made. For example, some northern marshes have high net rates of accumulation of organic matter ($\dot{Q}_1$, $\dot{Q}_2$) for a few months followed by slow consumption and utilization for the rest of the year, whereas many Florida marshes grow for much longer periods, but have more of the consumption and utilization going on concurrently rather than at a later season. The net cropping methods make the northern marshes or those in large tidal situations where marsh growth is exported before consumption seem larger than Florida marshes. However, when the basic process is measured with gross production methods that use gas metabloism chambers to measure the process (Figure 6 data from Young, 1974).

Florida marshes are found to produce much more (P_2) and to consume more (R_1 and R_2), making a faster cycle as labeled in Figure 7. For example, gross production in Florida *Juncus* marsh in summer is as high as that of *Spartina* marsh, but the respiration is higher so that net production is less. The total biotic work being done is greater in *Juncus*, as Figure 7 shows. Net production methods are not useful or comparable unless they are done in conjunction with a model diagram in which the gross production, total consumption (respiration), and the several kinds of net production can also be distinguished and definitions clarified.

In areas short of rain, inflow of freshwater may be critical to maintenance of potential productivity and values. Simulation of the model in Figure 8 showed mangroves like those in the Everglades park area were converted from dwarf status to regular growth status by one meter of freshwater flow per year, because the salts in the soils made briny by mangrove transpiration could be replaced and diluted so as to prevent tree stress. Mangroves have lower transpiration rates than other trees (Lugo *et al*, 1975). Thus, freshwater released to do useful work in estuarine and mangrove waters is better conserved than in some other typical uses in Florida.

Interaction With Humans

Many wetlands were drained under programs labeled flood control or reclamation. However, wetlands were the natural landscape's way of controlling floods, absorbing the waters in their volumes, slowing down rush of water with friction by grass and trees and providing a space for waters to spread out. Channelizing and draining the wetlands caused flood problems in Florida, since waters were no longer retained on the flat uplands to be released slowly, but were dumped rapidly to flood the lower lands often into the seas through estuaries that were not adapted to freshwater surges.

Some wetlands have nuisance mosquitoes and some do not. Most of the regularly inundated wetlands have a diversity of life including some fishes that provide a check on large numbers of any one insect

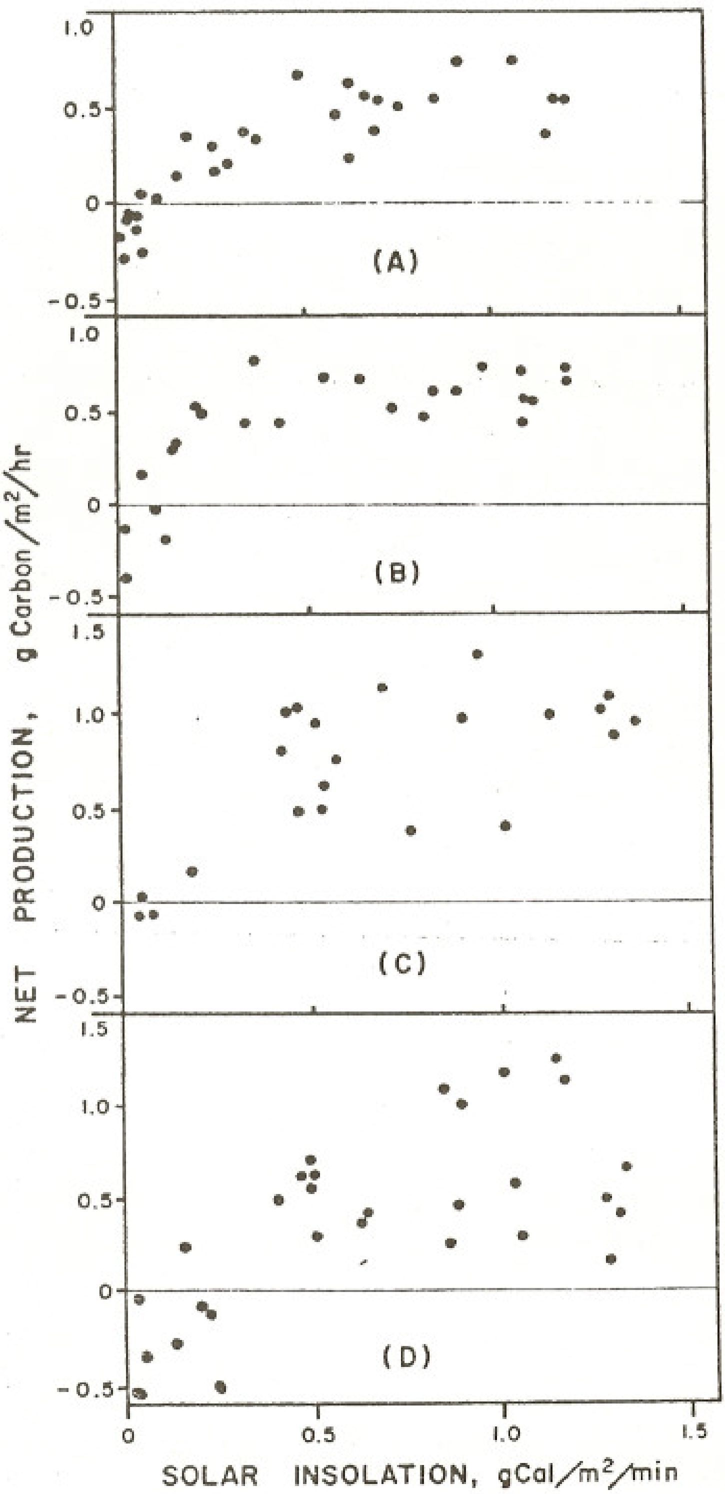


Figure 6. Metabolism of marsh plots at Crystal River, Florida, as a function of light intensity obtained by Don Young. (a) *Spartina* in March, 1974; (b) *Juncus* in March, 1974; (c) *Spartina* in July and August, 1974; (d) *Juncus* in July and August, 1974.

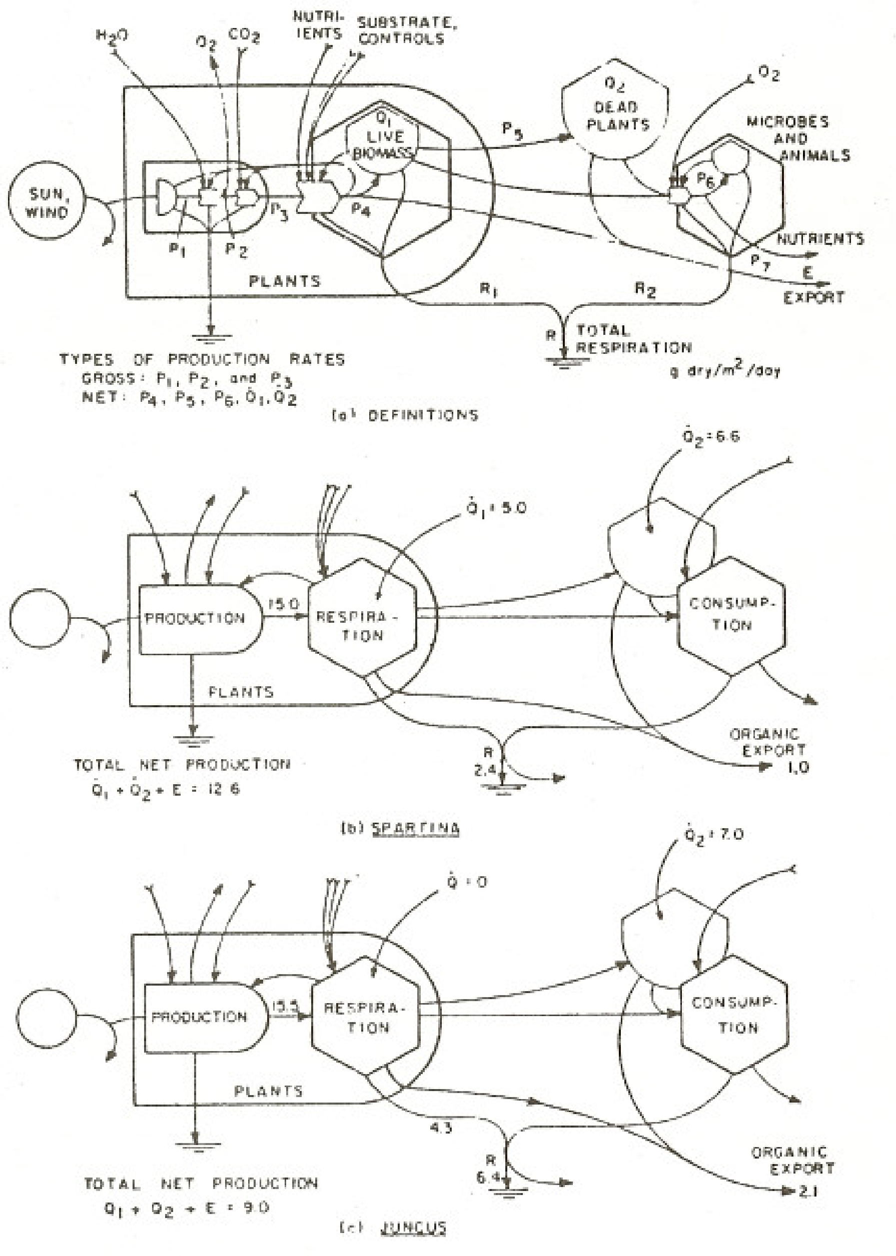


Figure 7. Relation of gross production to net production in Florida marshes (data from Young, 1974). Numbers are grams organic matter per m^2 per day in July (data from 1973 and 1974).

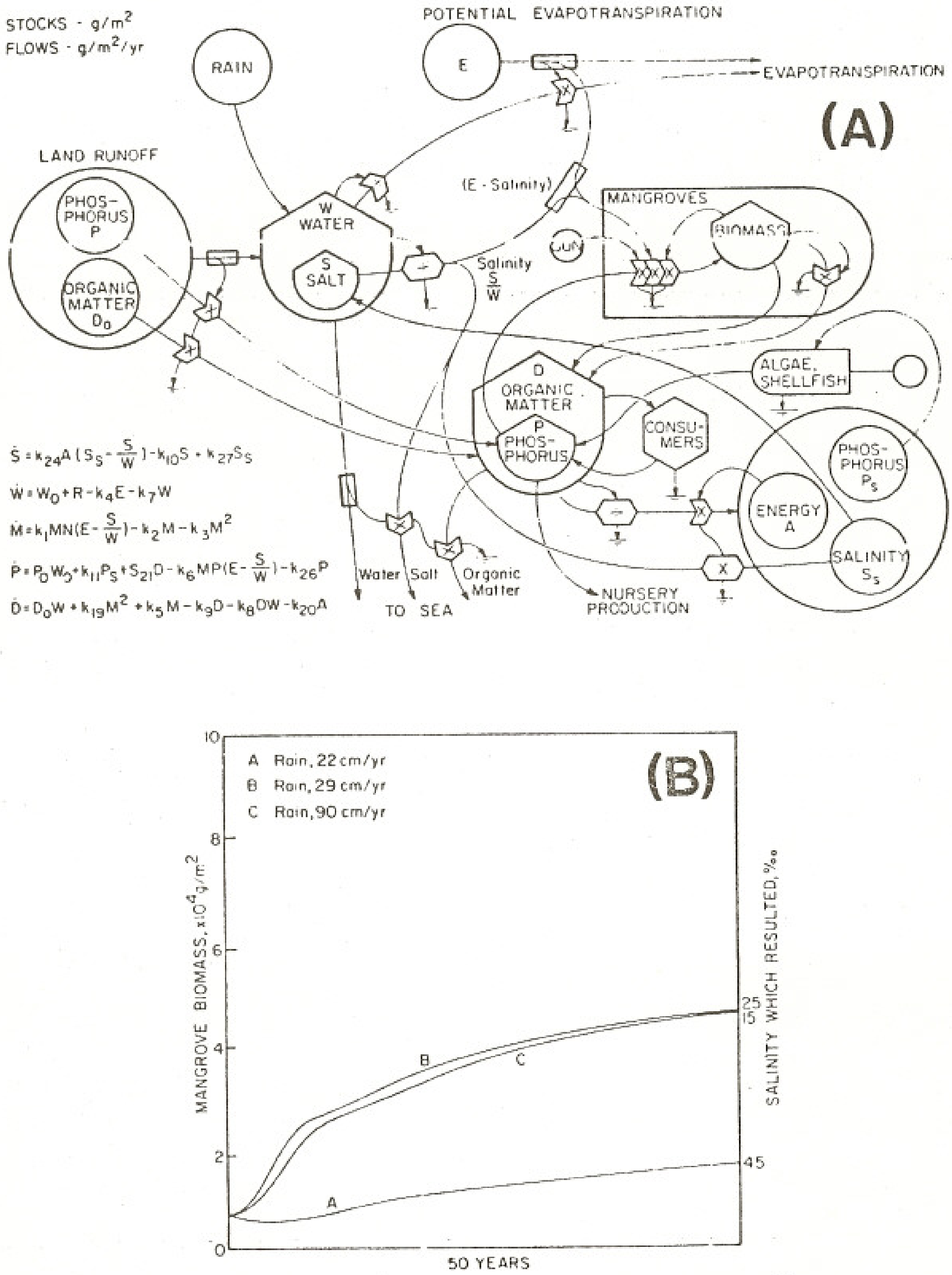


Figure 8. Simulation of a model of mangrove growth and salinity (H.T. Odum and Maurice Sell). (a) Model; (b) effect of freshwater.

including mosquitoes. For example, one is not generally bothered with mosquitoes in the Okeefenokee Swamp, the typical cypress pond, or the usual slough.

At the coast there is a barren zone between the land and *Juncus* marsh or mangrove vegetation which develops enormously abundant mosquitoes in pockets of brackish water after rains or very high tides. This zone makes the area almost uninhabitatable. Management of this zone has sometimes made the mosquitoes worse by making more mosquito depressions. For example, grazing cattle and construction of small roads have cut off pickets. Mosquito control measures have attempted to deal with this zone by elevating the waters, filling the zone, ditching to provide easier fish access, etc. Kuenzler and Marshall's (1973) study of mosquito ditching in North Carolina suggested that such efforts were not effective, but for Florida there is no clear demonstration and the effects are controversial.

In freshwater wetlands, efforts to drain marshes or swamps often make mosquitoes worse because temporary pools are substituted for a regular pattern of inundation to which fishes and other organisms are adapted as controls.

Many of the swamps of Florida have bird mosquitoes that have encephalitis of eastern and western varieties that are apparently involved in bird reservoirs or other animals and occasionally in humans. Another variety of encephalitis, the St. Louis type, has caused serious disease epidemics but usually in the middle of cities, and the connection with swamps is unknown. Human living in swamps is not recommended because of uncertainties about encephalitis.

SUGGESTIONS FOR INTERFACING WETLANDS WITH HUMANITY

Our experiments recycling treated sewage into cypress domes (Odum and Ewel, 1975, 1976, 1977, 1978), and observations of swamps (Flohrschutz, 1978: Boyt, 1976; Nessel, 1978), marshes (Marshall, 1970; Dolan, 1978; Mitsch, 1977; Woodwell, 1977), and mangroves (Sell, 1977) absorbing wastewaters from sewages, agriculture, and city runoff suggest principles for using wetlands well. The wetland is retained to operate as part of the mosaic of cooperative land uses by nature and humanity.

Principle 1. *Allow the Wetland to Maintain Its Self Organizing Patterns*

Allow the wetland system to receive waters and nutrients, on a reasonable regime, seeding it with multiple species of plants, microbes, soil animals, and soil components so that it can self organize, developing combinations of life which make the ecosystem competitive and useful. Success at self organization can be measured by gross production (*P*) and total ecosystem comsumption (*R*) (Figure 2).

If there is already a good wetland ecosystem, try to maintain its existing pattern of hydroperiod, water inflows, nutrients, etc., so that it does not have to go through a stress period and reorganize.

The system that survives is the one that develops more of a web of life so as to capture and feed energy back into useful processes that are adaptive to various conditions. The ecosystem adapted to do more work of survival in one set of environmental circumstances may not be adapted to other conditions.

Principle 2. *Don't Drop the Water Table*

Ditching drops the water table, lowering levels in other people's land because the porous (25% or more) nature of Florida's sands and marls causes water to flow laterally easily. A canal can draw down waters up to a mile away (Wang, 1978). When water tables are dropped, as shown in Figure 9, the hydroperiod changes from a wetland one to a monsoon type hydroperiod. In south Florida trees from monsoon type climates are invading, apparently because of the drop in water table that makes their growth more competitive. Drainage causes tree-killing fires, whereas fire does not burn to roots in undrained wetlands. Burns, (1978) found drained plots with less growth of trees in the Fahkahatchee Strand.

Principle 3. *Don't Change the Hydroperiod; Don't Channelize*

Don't change hydroperiod except where a different type of wetland is desired; changing hydroperiod changes species patterns that are adapted. Efforts to make Corkscrew Swamp more secure as a wetland by damming water flows of the strand caused a longer inundation period, depressed cypress tree growth, and inhibited new germination. Changed drainage patterns in southwest Florida changed periods of water expansion and contraction to which fishes were adapted. Wood stork breeding was an index of a good water expansion-contraction regime (Browder, 1977). Raising water tables kills many swamp trees such as mangroves and floodplain oaks. Examples are impounding ponds to kill mangroves on Marco Island and the flooding of trees due to the Oklawaha River dam. Channelization eliminates water storages, brings in more terrestrial vegetation, increases flooding downstream, and loses nutrients (Kunzler *et al*, 1977).

In the Kissimmee River, channelization caused the peak of summer rains to arrive quickly in Lake Okeechobee where water exposed to more evaporation was a hurricane threat and sometimes dumped to sea, whereas the prechannelization pattern with meanders and floodplains caused the peak of waters to arrive in the fall during a drier time (Gayle, 1975). The natural organization of swamps and flows evolved over long periods maximizing its survival patterns by optimal use of water with mechanisms to conserve water interacting it with solar productivity over the broadest possible area.

Experiments done by us at Morehead City in 1967-71 showed that treated sewages released into salt marshes accelerated marsh growth and were generally favorable to aquatic birds(Odum and Chestnut, 1970; Figure 10). Where these rich waters go into the waters, however, the studies showed a fertile but less diversified fauna of algae, copepods, capitellid worms, and abundant killifish, mullet, and blue crabs. The more diverse populations of fishes were excluded because of low oxygen conditions late at night in the shallow marsh waters. Thus, recycling to coastal zones is best through swamps and marshes and not directly to the tidal waters.

Principle 5. *Swamps and Marshes Can Be Planted If the Water Seal and Inflow-Outflow Patterns Can Be Adjusted To Give a Wetlands Hydroperiod and Nutrient Supply.*

If water is to be saved, nutrients should be low and flow-through small so that leaf canopies are less and transpiration less. If water is to be used up and transpired,exotic *Melaleuca* can be used with a very dry period and fire regime. In the long run the type of monoculture developing from an exotic may eventually be changed by invading insects and disease. Also, the solid growth pattern lacks many features of value, such as wildlife and self renewing sequences. Diversity of seeding is a safer principle for insuring that some wetlands ecosystem can be established quickly.

Principle 6. *Wetlands Should Be About 10% of the Landscape to Use Their Service In Water Conservation, Flood Protection, Nutrient Control, and Greenbelt Life Support.*

The ratio is based on the ratio of about 10 to 20% wetlands evolved by the original landscape in maximizing water use for productivity and survival.

The principle particularly applies to intensive agriculture by which runoff from farms and pastures containing high fertilizer and pesticides can be caught and buffered on private lands with useful effect on tree growth, local ground water levels, ponds for cattle, and without the stress of these materials in public waters.

A simulation model of pastures as affected by intensity of management was studied by Gutierrez (1977) for the Kissimmee area, finding that with increasing relative prices of purchased fuels and fuel based goods and services, advantages of intensive improved pastures decreased in favor of more diversified unimproved pastures.

Principle 7. *Wetlands As Contributors to the Economy Can Match and Attract Investments in Surrounding Economic Activity of About $500 Per Year Per Acre of Wetlands.*

This concept of values is based on direct evaluation of the environmental energy basis of human economy.

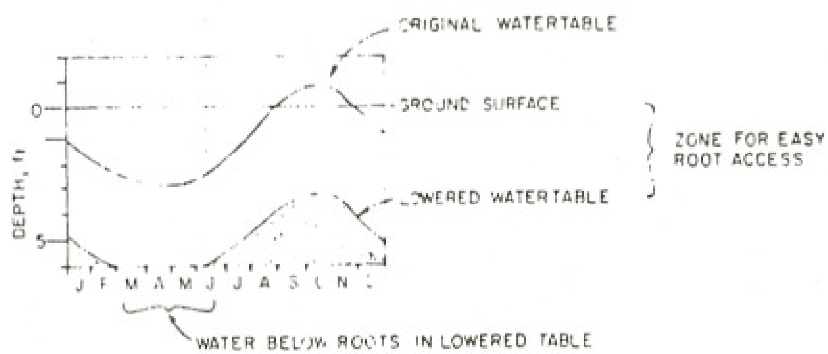


Figure 9. Effect of lowering water table on hydroperiod converting a Florida type of wet regime to a monsoon type. Example from Naples, FL (Littlejohn, 1973)

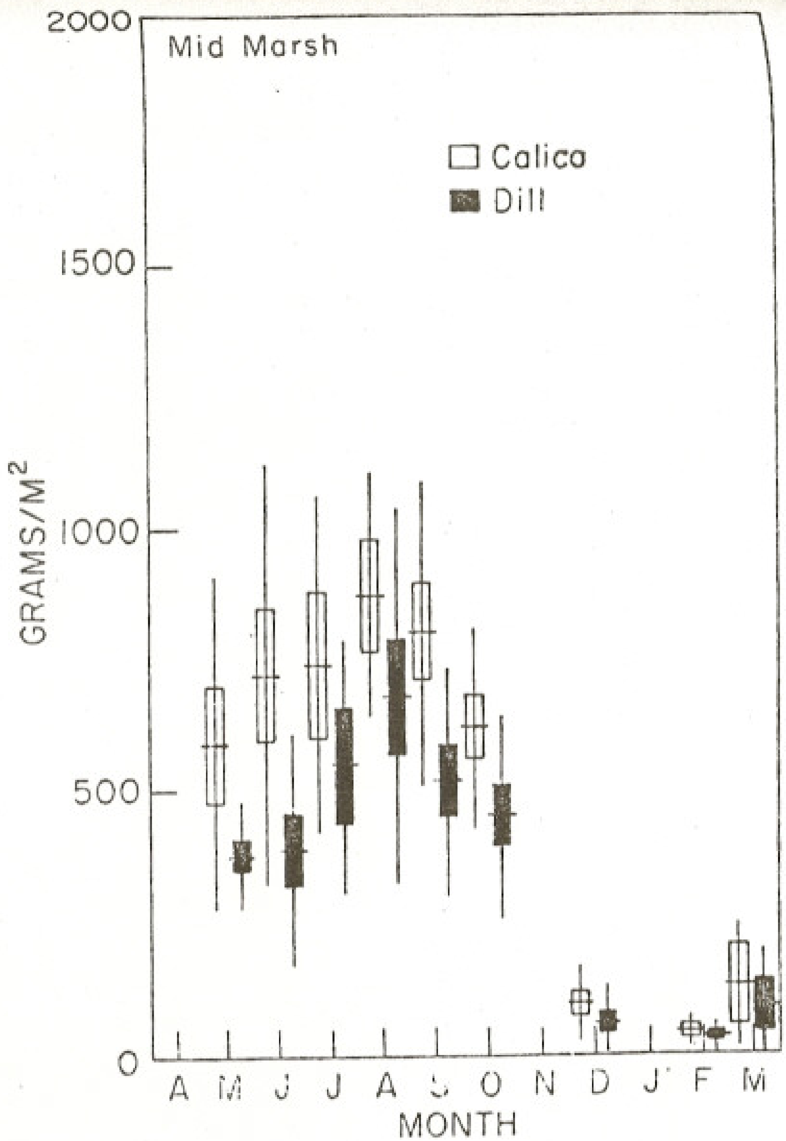


Figure 10. Effect of treated sewage (Calico Marsh) on growth of *Spartina alterniflora* as compared with a control marsh (Dill Marsh) in Morehead City, N.Y. 1969-1970. (D. Marsh with H.T. Odum)

Value can be defined as a contribution to survival of the economy (nature and man). For the symbiotic functions of wetlands, value can be estimated by the work done by the environment in generating attractions to an economy. Ultimately environmental work brings in a flow of dollars, which is made competitive because of the free services of the wetland in making the economic activity competitive. As shown in Figure 11, the average ratio of dollars attracted to Calories of environmental work generated is about 2.5, based on the U.S. ratio of economic activity to environmental energy flow. One third of the activity of the United States economy is from environmental work, which is usually taken for granted. Externalities are not correctly evaluated by prices, but such work does make the economy competitive and the economy would stop without these free services.

Thus, the potential value of a wetland ecosystem may be estimated as the energies of sun, wind, rain, land, water, chemical flows, etc., converging on an area. Then the dollar potential which this work should attract if and when an economic activity is connected to it is estimated using the U.S. ratio. A wetland that absorbs waste, provides wildlife, rebuilds soils, and provides other life supports may be providing this facilitation to a local economy without anyone being aware of it. If the wetland is removed, the economic base is undermined and competitive position is lost, and the economic activity such as tourists go elsewhere. The energy approach indicates the input to the economy which money does not do, since it is only paid for human services.

Examples of calculations of marsh values with energy methods in a region are given by Bayley, Odum, and Kemp (1976). Examples of evaluations of cypress swamp to a county are given by Burr (1977). A controversy over these methods is scheduled for publication in a forthcoming issue of the Journal for Coastal Management.

Principle 8. *Wetland Strands, Floodplains, and Sloughs Should Be Retained as Corridors Rather Than Changed Into Impoundments.*

Flowing wetlands are self-regulating in their redistribution of waters, nutrients, and species. Ecosystems are not fully functional without larger wildlife and fishes, and these need to be connected over wide ranges by corridors so that population excesses in one place can restock population deficits in other areas.

Lake levels should be allowed to fluctuate so as to make a broad wetlands perimeter zone, increasing fishing potentials (Grocki, 1975).

Substitution of locks and dams also blocks the necessary migration of fish populations that generally have a different place of reproduction from that of principal growth. For example, mullet, important in the Oklawaha drainage, have been cut off by the Rodman Pool dam because no fish ladder was provided. They breed out to sea, but develop and feed in waters of wetlands.

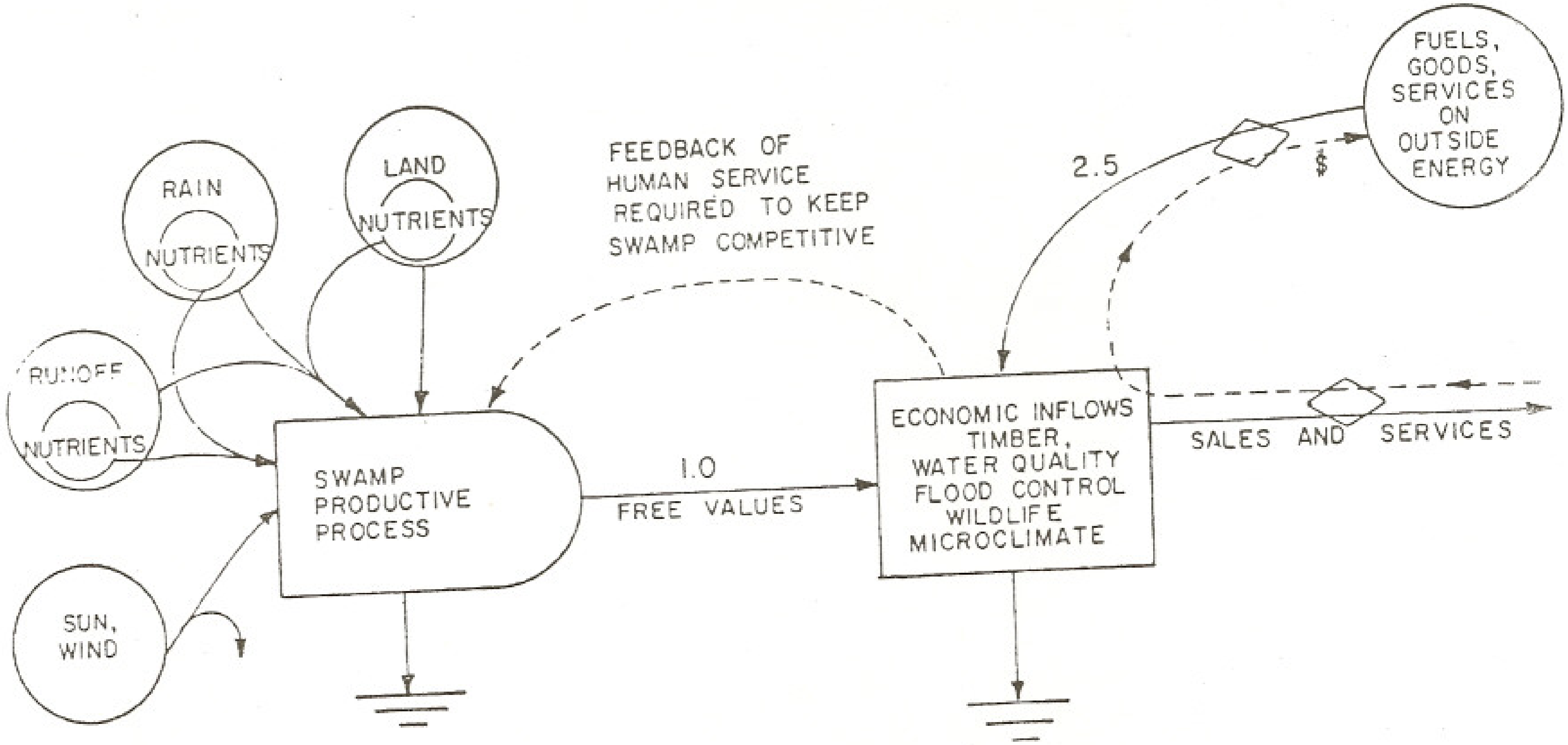


Figure 11. Flow of money made competitive by free services of environmental energies. 2.5 Cal of coal equivalents of embodied energy from fuels are attracted in economic activity for each one coal equivalent Calorie of environmental energy generated.

Roads over wetlands should have high trestles rather than fill and culverts so that wildlife flow can be regular under the road and so that the road does not act as a dam during high water.

A major need is for reconstitutions of a river of grass corridor south of Lake Okeechobee as shown in Figure 12. Perhaps one to five miles wide, such a corridor could solve many problems in water, nutrient, and wildlife management in south Florida. The lands could be leased for 50 to 100 years in exchange for tax free status. Back pumping of waste waters from agriculture and towns could go into this corridor in place of release to Lake Okeechobee or deep injection. The flow would probably develop eutrophic vegetation such as cattails in the north and rebuild muckland peats rapidly, whereas further down the corridor vegetation would grade into low nutrient sawgrass. Waters could be pumped out of the corridor and wildlife could move longitudinally. More normal species hydroperiods, fire, and other conditions should help conserve some species. After 50 years or so the corridor could be farmed and a new corridor operated adjacent to it, thus constituting a form of long range land rotation.

SOME RECENT STUDIES OF WETLANDS

There have been many recent studies of Florida wetlands, many of which are in project reports, theses and dissertations. Some of these references are not cited, but are given in the literature section that follows.

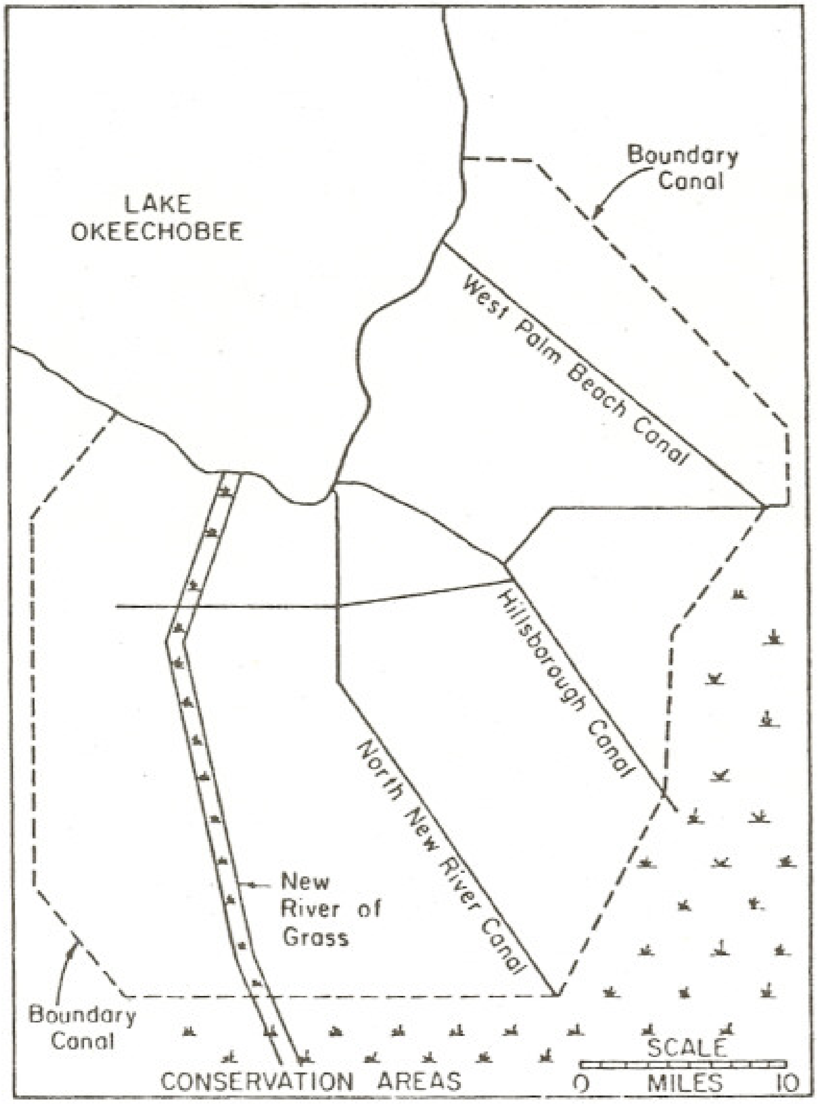


Figure 12. Proposed small river of grass for managing water, rebuilding muck, absorbing nutrients, and providing wildlife corridor.

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