Multiple Demands on Wetlands

Florida cypress swamps can serve as a case study

Katherine C. Ewel

In a world with a rapidly increasing population and a shrinking resource base, it is becoming increasingly difficult to make uncontroversial land-use decisions. Demands for such consumptive land and uses as food production and industrial development conflict with nonconsumptive uses such as preservation of biodiversity and watershed protection. Unfortunately, land-use decisions are often made in response to a specific proposal and without regard for alternative uses. Because today so little latitude remains for irreversible mistakes, consideration of all the consequences of such decisions is necessary.

Wetlands are particularly vulnerable because they often represent the only undeveloped land in an area, and the tradition of converting wetlands to more intensive terrestrial or aquatic land uses is still prevalent in many countries. Sensitivity to the importance of wetlands increased dramatically during the last two decades as scientists became aware of the nature and magnitude of losses resulting from conversion of large wetlands to agriculture or urban development. Early efforts to outline the value of intact wetlands—such as river swamps (Wharton 1970), salt marshes (Gosselink et al. 1974), and mangrove swamps (Odum and Heald 1975)—provided much of the impetus toward halting wetland destruction. Most resource managers now appreciate the many ways in which large wetlands can benefit society.

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Determination of best use must be made to preserve the benefits

Small wetlands and wetlands of only regional importance have received relatively little attention, often because their value is less apparent or not easily measured. As more becomes known about the significance of hydrologic, biogeochemical, and biodiversity functions of many of these wetlands, it is becoming clear that the smaller areas can also provide a number of benefits. However, as active exploitation for some of these benefits increases, demands for both consumptive and nonconsumptive uses may conflict. It is ironic that where the values of wetlands are best understood, differences of opinion are likely to arise about the most appropriate use of a given wetland.

Cypress swamps, a common type of wetland in the southeastern United States, provide a variety of benefits with and without overt exploitation. Because of this, cypress swamps are therefore useful for demonstrating the kinds of land-use conflicts that may arise and for outlining considerations that are useful in resolving them.

Characteristics of cypress swamps

Two forms of cypress trees are generally recognized. Bald cypress trees (*Taxodium distichum*) are relatively fast-growing and are common where flowing water brings in nutrients and ameliorates reducing conditions in the soil. Bald cypress is often found with a variety of hardwood trees in floodplain forests. Monospecific stands of bald cypress are found in backwaters on these floodplains and along the edges of lakes.

Pond cypress trees are considered by some botanists (Brown and Montz 1986, Elias 1980, Little 1979) to comprise a separate variety (*T. distichum* var. nutans) and by others (Clewell 1985, Godfrey 1988, Wunderlin 1982) a distinct species (*Taxodium ascendens*). They are common in small stillwater swamps such as cypress ponds, which are also called domes or heads (Figure 1). Cypress ponds range from 0.5 ha to 15–20 ha and are widely distributed throughout Florida. They are also common in the Atlantic coastal zone north into Virginia and the Gulf coastal zone west into Louisiana. Cypress ponds are largely ombrotrophic; rainfall and runoff are the major sources of water (Heimburg 1984), and normally there is no surface outflow. Their geological structure is simple (Figure 2): organic matter accumulates in the basin and is underlain by sands and eventually clay.

Pond cypress trees also grow in flat, poorly drained savannas. There, growth is especially stunted, and the trees are called dwarf cypress or hatrack cypress.

Pond cypress trees are also common in cypress strands in which water moves slowly along a central slough (Figure 3). In shallow peripheral areas, water movement is virtually imperceptible. Some ponds become strands in particularly rainy years when shallow, normally dry channels fill and join adjacent ponds. In large strands, such as the National Audubon Society's Corkscrew Swamp in southwest Florida, the deep, central slough is dominated by bald cypress and the peripheral, shallow areas by pond cypress.

Although many individual pond cypress trees appear to be morphologically distinct from bald cypress, particularly in leaf and bark characteristics (e.g., C. A. Brown 1984), these differences may be slight. Individuals that grow where the two kinds of trees intergrade, such as in strands, may be especially difficult to differentiate.

The evolution of cypress into two forms may be due in large part to the action of fire (Harper 1927). Pond cypress trees with their shaggier bark are found in stillwater swamps, which accumulate peat and may burn during a dry season (Figure 4). They are better able to survive fire than many of the hardwoods that grow at the edges of these swamps (Ewel and Mitsch 1978). Bald cypress trees are less exposed to fire. On floodplains and at the edges of lakes there is insufficient fuel to carry a fire. Greater moisture retention protects bald cypress in the center of a strand, whereas the edges, where pond cypress trees grow, burn more frequently.

Water levels fluctuate in all cypress swamps. This fluctuation is important, because cypress seeds will not germinate under standing water, and high water is necessary to reduce competition from more rapidly growing vegetation. Most cypress ponds in Florida are dry from three to seven months during a year with normal rainfall. North Florida swamps may be flooded during the summer, when approximately 60% of the rainfall occurs, and during the winter, when occasional cold fronts bring additional rain. There is little rain during fall and spring, and swamps often dry out completely (Figure 5). In south Florida, where cold fronts seldom penetrate during the winter, most of the rain falls during the summer, and swamps normally are wet from late spring to midfall.

Figure 1. Profile of a cypress pond in a young north Florida pine plantation. Photo by J. Marois.

Gross primary productivity in cypress swamps is closely related to rate of nutrient inflow (Brown 1981), and aboveground net primary productivity tends to be highest in swamps with intermediate hydroperiods (Mitsch and Ewel 1979), approximately six months. Cypress ponds appear to be intermediate among Florida swamps in both gross and net primary productivity (Ewel in press); net productivity as measured by tree growth rates is not related to size of the cypress swamp (Ewel and Wickenheiser 1988).

Only within the past decade has the full range of values of cypress ponds begun to be recognized. Without any overt management, for instance, cypress ponds provide wildlife habitat, recharge groundwater, and play a role in regional flood control. In addition, interest is growing in use of swamps to collect runoff from urban areas and to recycle wastewater, and trees are commonly harvested from cypress swamps. This article reviews the importance of these uses, both consumptive and nonconsumptive, as well as their intercompatibilities, to demonstrate the need for evaluating more than one alternative in decision-making.

Wildlife habitat

Florida's wildlife is certainly one of its greatest treasures. Many wildlife species have specific habitat requirements, and numbers of both species and individuals are dwindling throughout the state. Careful attention therefore must be paid to evaluating the importance to wildlife of remaining natural areas.

Cypress ponds do not support a unique fauna (Harris and Vickers 1984), but they are used extensively by animals that range throughout neighboring upland communities and by rare and endangered species such as limpkins and wood storks. They have a diverse community of benthic invertebrates (e.g., Brightman 1984), which are a major source of food for vertebrates. Insect populations in the canopy may comprise a more important food source than is generally recognized (McMahan and Davis 1984). Fish populations vary in composition and importance, because most swamps regularly dry out. Reptiles and amphibians tend to dominate the fauna in summer, whereas birds are more common in winter (Harris and Vickers 1984).

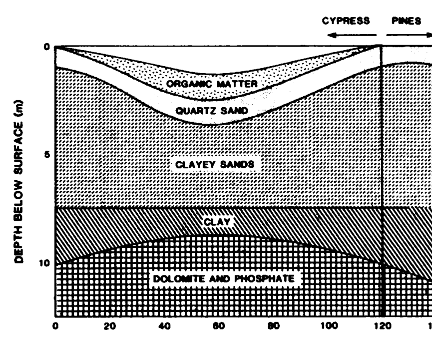

Figure 2. Geological profile of a cypress pond. (From Ewel in press.)

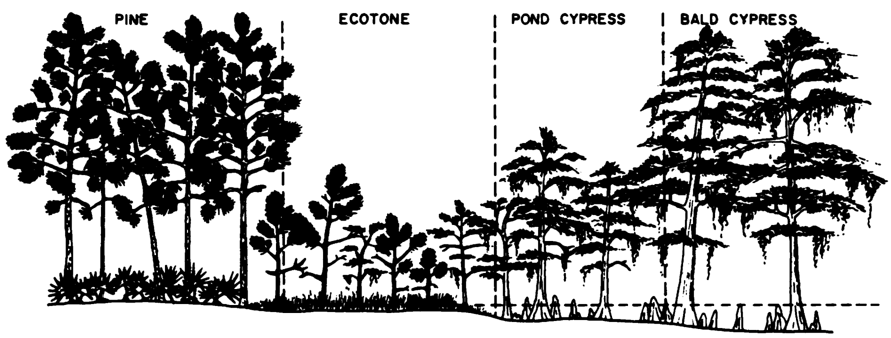

Figure 3. Cross-section of a cypress strand from middle of central slough to uplands. (From Myers 1984.)

Dense vegetation makes many cypress swamps valuable habitat to large mammals, and the high frequency of cavities (cypress trees are prone to heartrot) makes them attractive to birds and small arboreal mammals (Harris and Mulholland 1983).

Because wildlife often use a variety of ecosystems in a region, depending to some extent on all of them, it is difficult to evaluate the contribution of a single swamp. The density of swamps in a landscape may be as important as the presence or absence of an individual swamp. Wading birds, especially wood storks, frequently form rookeries in cypress swamps. Because of declining populations and uncertainty about how rookery sites are chosen, there is some concern that changes in vegetation density and composition of individual cypress swamps or in the density of swamps in a landscape could further endanger these populations.

Some of the benefits that cypress swamps provide to wildlife are indirect. For instance, a cypress strand may not contain a large or diverse wildlife population, but the pattern of change in quality and quantity of water that flows from it may be critical to maintaining important habitat in downstream water bodies and associated wetlands.

It is not possible to put a market value on a wildlife population. Rare and endangered species do not generate any hunting revenue. Nor is it clear that protecting a small population of an endangered species is any more important than sustaining another population at or above the critical level at which it can be maintained, in order to prevent it from becoming endangered as well. Cypress swamps are clearly important to regional wildlife populations, but it is difficult to quantify this benefit, both to wildlife and to people.

Groundwater recharge

Groundwater recharge, another nonconsumptive benefit of many cypress swamps, is also difficult to measure but may have substantial indirect importance. Because the water level in a cypress pond is generally continuous with the water table in the surrounding landscape (Heimburg 1984), groundwater flows into the swamp when heavy rainfall raises the water table, and groundwater is recharged at the end of the rainy season, when water tables drop more rapidly than water levels in the ponds.

In addition, cypress ponds seem to have a lower evapotranspiration rate than surrounding ecosystems (Brown 1981, Ewel 1985). Tightly appressed needles with sunken stomates are characteristic of pond cypress and may engender low transpiration rates. Because the trees shed their needles in November and regrow them in March, there is no transpiration during this time, and high stem density slows evaporation from the pond as well (Mitsch 1984). Consequently, rain entering a cypress pond is less likely to evaporate or transpire than is rain falling on the surrounding landscape. This water slowly recharges the shallow groundwater aquifer, perhaps increasing net flow into the deep aquifer as well. Unfortunately, few evapotranspiration data are available for either swamps or adjacent uplands, and the spatial variation in groundwater flows is difficult to evaluate.

One regional analysis suggests that groundwater recharge by cypress swamps can be significant. In the Green Swamp in central Florida, cypress swamps comprise approximately 30% of the land area. A water budget of the Green Swamp indicates that 8% of rainfall recharges shallow aquifers. If 80% of the wetlands were to be drained (resulting in higher streamflow rates and replacement by ecosystems with higher evapotranspiration rates), available groundwater could be reduced by 45% (S. Brown 1984).

Figure 4. A cypress pond in north-central Florida. Photo by J. Marois.

Flood control

Flood control is another benefit that is poorly documented, but it is widely recognized as an important attribute of many wetlands. Depressions such as cypress ponds can store more water than equivalent volumes of soil. For instance, a small (1–2-hectare) pond holds approximately 6000 m^3 of water (Ewel 1985). Less than half this amount would be held by the same volume of soil at saturation.

Cypress ponds delay the onset of overland flow as a landscape becomes saturated. Constructing drainage channels to eliminate 80% of the storage in such depressions in the Green Swamp region could increase streamflow from the region by 16% (S. Brown 1984).

There is considerable interest in Florida in exploiting this benefit through discharge of stormwater runoff into cypress ponds and other wetlands (e.g., Livingston 1988). It is not clear, however, how urban runoff water, even after pretreatment, will affect either plants or animals. Increase in hydroperiod and in the average rate of water level increase in a swamp could also affect habitat value. Nor is it clear that using existing swamps for stormwater runoff will serve a region well. If well-drained areas adjacent to swamps are paved and runoff is channelled into swamps, the additional water may exceed the absorptive capacity of a region, not only risking increased downstream flooding but increasing the rate of water delivery as well.

Water quality control

The value of cypress swamps for water quality control is relatively well-documented. Cypress ponds can remove both phosphorus and nitrogen from secondarily treated wastewater, primarily via soil processes. Trees removed at least 20% of the added nitrogen and 1% of the added phosphorus in one swamp (Dierberg and Brezonik 1984b). Laboratory analyses of soil columns suggested that wastewater discharge at the rate of 2.5 cm/week could continue for a long time without exhausting the soil's capacity to absorb the added nutrients (Dierberg and Brezonik 1984a).

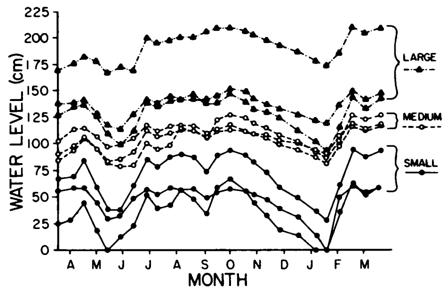

Figure 5. Typical hydrographs recorded in the centers of nine swamps in central Florida (Ewel and Wickenheiser 1988). Water levels are depths of water above ground in each basin. Small swamps are less than 1 ha, medium swamps are 1–2 ha, and large swamps are more than 5 ha.

Growth rates of cypress trees in swamps receiving moderate amounts of wastewater increase almost immediately (Brown and van Peer 1989), and these faster growth rates can be sustained for several decades (Nessel et al. 1982). Greater availability of nutrients apparently overcomes whatever detrimental effects are derived from longer hydroperiods (Brown and van Peer 1989).

Animal populations, however, change dramatically when swamps receive wastewater. Addition of high-nutrient wastewater induces the formation of a mat of duckweed over the water's surface, blocking light from the water column and quickly rendering it virtually anoxic (Figure 6; Dierberg and Brezonik 1984a). Diversity and biomass of benthic invertebrates drop dramatically, leaving only a few pollution-tolerant organisms (Brightman 1984). Water birds that depend on sight to find invertebrates, herps, and fish in the water column are replaced by passerines that feed on surface insects (Harris and Vickers 1984). Therefore, use of a cypress pond for wastewater recycling causes important ecological changes in the swamp, even though cypress remains the dominant tree species.

Wood products

The value of cypress swamps for yielding wood products has been realized since Florida was first settled. Durable heartwood in the large, centuries-old bald cypress trees was the primary target for many years, but even the smaller, less rot-resistant pond cypress trees have been used for specialty items such as ladders and crab traps.

Limitations of equipment and market probably restricted most early harvests to selective cuts of only the largest trees with the best forms. Many swamps are now being harvested for the second time. The ability of vehicles to penetrate deep swamps and the rapid increase in the use of cypress chips for mulch have accelerated the intensity of harvest. Although cypress swamps appear to be capable of recovering from selective harvest in as short a time as 50 years

Figure 6. A cypress swamp containing secondarily treated wastewater. Note the mat of duckweed covering the surface of the water.

(Terwilliger and Ewel 1984) as well as from clearcutting (Ewel et al. 1989), the rate at which swamps are today being clearcut may preclude alternative uses for several decades.

Compatibility of multiple demands

An undisturbed cypress swamp is maintaining wildlife, recharging groundwater, and effecting flood control. Can a swamp be managed to provide more than one of the types of benefits described? How do management practices intended to increase flood control change water quality? How do thinning and clearcutting affect intrinsic, nonconsumptive values? Because of the increase in intensity of management, both direct and indirect impacts of various management practices must be considered to ascertain that attempting to derive greater benefit by one type of use does not preclude another benefit that may in the long run prove to be more important.

Some benefits can be obtained without compromising others, but some cannot be realized without putting the others in jeopardy (Table 1). Of the benefits listed, only groundwater recharge does not preclude the other uses, but recharge is not widely recognized as an important benefit of cypress swamps. Because of its benign nature and its potential for serving an important role in a state dependent on groundwater resources, the contribution of groundwater discharge in areas where swamps are common should be determined.

At the opposite end of the spectrum is wildlife habitat. Use of swamps specifically for wildlife habitat precludes use for water-quality improvement and wood products, because of the changes in habitat that management practices for these values would engender, at least temporarily. Active use of a swamp for flood control (i.e., storm water runoff) may decrease wildlife habitat as well as water quality and habitat for benthic invertebrates change.

Use of a swamp for wood products is likely to have a significant effect only on wildlife. Clearcutting a swamp removes nesting cavities, cover for birds and mammals, and structure for rookery locations. Successful use for flood control and water quality improvement depend primarily on hydrologic and geomorphologic characteristics of a swamp, which timber harvesting is not likely to affect. It is not yet clear if evapotranspiration rates from a clearcut swamp will increase significantly or, if they do, how long they will remain high. It is possible, however, that benthic food chains would remain intact.

Table 1. Proposed general effects of active management practices on multiple benefits. (+) indicates that management practices designed to take advantage of one of the benefits listed along the top are compatible with the benefits listed along the side. (−) indicates that management practices oriented toward one of these benefits conflicts with the other benefit.

Benefits	Wildlife habitat	Groundwater recharge	Flood control	Water quality improvement	Wood harvest
Wildlife habitat		+	−	−	−
Groundwater recharge	+		+	+	?
Flood control	−	+		−	+
Water quality improvement	−	+	−		+
Wood harvest	−	+	?	+	

These benefits should also be compared in terms of the amount of wetland that is needed and the size of the audience that realizes a gain. For wildlife habitat, groundwater recharge, and flood control, the importance of single swamps cannot be calculated. Rather, these values are strongly related to the density of swamps in a landscape, and their associated benefits are realized by the inhabitants of a region (or even society as a whole) rather than specific municipalities or individuals. Other uses may specifically benefit small communities, for example, using one or more swamps to retain stormwater runoff or to process wastewater. Harvesting wood products, on the other hand, provides direct benefits to an individual or a business.

How can conflicts be resolved? Decisions about use of an individual swamp must consider its regional importance. Decisions could be made at the level of counties or even water-management districts to regulate the rate at which swamps are put to use for flood control, wastewater treatment, or timber production, or to determine the percentage of wetlands, by area or number, that is to remain undisturbed.

Current laws in Florida permit cypress swamps to be considered for stormwater retention systems and for wastewater treatment. Careful evaluation of individual swamps is required, and use of ditched, drained, or artificial wetlands is encouraged. Permits must be obtained from the Florida Department of Environmental Regulation for wastewater treatment. Permits for stormwater treatment are considered by the water-management district in some areas and by the Department of Environmental Regulation in others. Recent increases in clearcutting activity have led both county governments and water-management districts to contemplate regulation. At least two counties in south Florida have wetland protection ordinances that prohibit harvesting; another requires that a plan for silvicultural activities be approved.

Incorporating large-scale considerations into land use management will not be easy. The time course of succession, both natural and human-influenced, must also be considered, as well as the possible importance of fire to a cypress swamp over a century's time. The role of periodic small fires in creating cavities in some trees or of occasional extensive fires in reducing peat accumulations may be obviated by use of swamps for flood control or wastewater discharge. And the apparent importance of fire in cypress ponds suggests that periodic destruction of a swamp may be a natural phenomenon (e.g., Odum 1984). But fire is not likely to be encouraged by resource managers because of the lack of experience with controlled burns in such areas. Nor is periodic destruction of the relatively few remaining cypress swamps that are used for wading bird rookeries likely to be attractive to wildlife managers. Under these circumstances, management for any benefit except groundwater recharge is likely to be detrimental to maintenance of wildlife habitat.

Multiple demands on other wetlands

Similar conflicts mark the use of other kinds of small isolated wetlands in the United States. Atlantic white cedar (*Chamaecyparis thyoides*) bogs and pocosins along the Atlantic coast, playa lakes in the Southern High Plains, and vernal ponds in California have been greatly affected by drainage, harvesting, or conversion to agriculture, often with substantial effects on wildlife or downstream aquatic ecosystems.

The impact of drainage and agricultural conversion of potholes in the prairie states and Canadian provinces on waterfowl production in particular has been well documented (e.g., Van der Valk 1989). As with cypress swamps, the issues to be resolved deal with conflicts between private use of individual prairie potholes (in this case for planting crops) and the value of intact regional systems to a larger population. Before human alteration, the prairie potholes were instrumental in controlling flooding by storing rainfall and runoff. A mosaic of potholes of different sizes and shapes adjacent to suitable upland nesting habitat produced abundant wildlife populations. Like the cypress swamps, these potholes are effective in retaining nutrients (now primarily from agricultural runoff), but the accumulation of pollutants and the resulting change in vegetation productivity and composition often decrease value to wildlife.

The intensity of use of these wetlands for wildlife production and agriculture has therefore led to substantial conflict between private and public interests. Compromises between these interests are being sought in both the United States and Canada.

Conversion of larger, less well-defined wetlands to agricultural uses or urban development has also led to conflicts in values. Loss of coastal wetlands (i.e., mangrove swamps and salt marshes), is believed to affect offshore fisheries, but the impact is likely to vary from site to site and is difficult to quantify.

Strategies for dealing with conflicts

One of the major difficulties in evaluating these strategies is the lack of a common currency among consumptive and nonconsumptive uses. Yet because active exploitation for one set of benefits can have a definite impact on another set, consideration and regulation of all these uses are needed. Because many of these benefits cannot be realized from individual swamps, determination of best use must clearly be made on a regional basis to preserve these benefits for future generations.

Considerably more research is needed on the critical functions of individual wetlands (e.g., evapotranspiration rates, relationships with groundwater, and wildlife production). However, documentation of the function of the landscape mosaic is also important. No system is well understood until it is viewed in the context of a larger system.

Ecosystem science must stress the role of ecosystems within a landscape, particularly because wetlands are by definition closely associated with neighboring terrestrial and aquatic ecosystems. Human-dominated systems such as cities and agricultural fields must be included in these landscapes as well.

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References cited

Brightman, R. S. 1984. Benthic macroinvertebrate response to secondarily treated wastewater in north-central Florida cypress domes. Pages 186–196 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.

Brown, C. A. 1984. Morphology and biology of cypress trees. Pages 16–24 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.

Brown, C. A., and G. N. Montz. 1986. *Baldcypress: The Tree Unique, The Wood Eternal*. Claitor's Publ. Div., Baton Rouge, LA.

Brown, S. 1981. A comparison of the structure, primary productivity, and transpiration of cypress ecosystems in Florida. *Ecol. Monogr.* 51: 403–427.

______. 1984. The role of wetlands in the Green Swamp. Pages 405–415 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.

Brown, S., and R. van Peer. 1989. Response of pondcypress growth rates to sewage effluent application. *Wetlands Ecology and Management* 1: 13–20.

Clewell, A. F. 1985. *Guide to the Vascular Plants of the Florida Panhandle*. University Presses of Florida, Gainesville.

Dierberg, F. E., and P. L. Brezonik. 1984a. The effect of wastewater on the surface water and groundwater quality of cypress domes. Pages 83–101 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.

______. 1984b. Nitrogen and phosphorus mass balances in a cypress dome receiving wastewater. Pages 112–118 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.

Elias, T. S. 1980. *The Complete Trees of North America*. Van Nostrand Reinhold, New York.

Ewel, K. C. 1985. Effects of harvesting cypress swamps on water quality and quantity. University of Florida Water Resources Research Center Publication No. 87.

______. In press. Swamps. In R. L. Myers and J. J. Ewel, eds. *Ecosystems of Florida*. University Presses of Florida, Gainesville.

Ewel, K. C., H. T. Davis, and J. E. Smith. 1989. Recovery of Florida cypress swamps from clearcutting. *South. J. Appl. For.* 13: 123–126.

Ewel, K. C., and W. J. Mitsch. 1978. The effects of fire on species composition in cypress dome ecosystems. *Fla. Sci.* 41: 25–31.

Ewel, K. C., and L. P. Wickenheiser. 1988. Effect of swamp size on growth rates of cypress (*Taxodium distichum*) trees. *Am. Midl. Nat.* 120: 362–370.

Godfrey, R. K. 1988. *Trees, Shrubs, and Woody Vines of Northern Florida and Adjacent Georgia and Alabama*. University of Georgia Press, Athens.

Gosselink, J. G., E. P. Odum, and R. M. Pope. 1974. The value of the tidal marsh. Center for Wetland Resources Publ. LSU-SG-74-03, Louisiana State University, Baton Rouge.

Harper, R. M. 1927. Natural resources of southern Florida. Pages 25–206 in the *18th Annual Report of the Florida Geological Survey*. Tallahassee.

Harris, L. D., and R. Mulholland. 1983. Southeastern bottomland ecosystems as wildlife habitat. Pages 63–73 in D. M. Flinchum, G. B. Doolittle, and K. R. Munson, eds. *Appraisal of Florida's Wetland Hardwood Resource*. School of Forest Resources and Conservation, University of Florida, Gainesville.

Harris, L. D., and C. R. Vickers. 1984. Some faunal community characteristics of cypress ponds and the changes induced by perturbations. Pages 171–185 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.

Heimburg, K. 1984. Hydrology of north-central Florida cypress domes. Pages 72–82 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.

Little, E. L. Jr. 1979. Checklist of United States Trees (Native and Naturalized). USDA Agricultural Handbook 541, Washington, DC.

Livingston, E. H. 1988. The use of wetlands for urban stormwater management. Pages 467–489 in L. A. Roesner, B. Urbonas, and M. B. Sonnen, eds. *Design of Urban Runoff Quality Controls*. American Society of Civil Engi-

neers, New York.
McMahan, E. A. and L. R. Davis Jr. 1984. Density and diversity of microarthropods in manipulated and undisturbed cypress domes. Pages 197–209 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.
Mitsch, W. J. 1984. Seasonal patterns of a cypress dome in Florida. Pages 25–33 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.
Mitsch, W. J., and K. C. Ewel. 1979. Comparative biomass and growth of cypress in Florida wetlands. *Am. Midl. Nat.* 101: 417–426.
Nessel, J. K., K. C. Ewel, and M. S. Burnett. 1982. Wastewater enrichment increases mature pondcypress growth rates. *For. Sci.* 28: 400–403.
Odum, H. T. 1984. Summary: cypress swamps and their regional role. Pages 416–443 in K. C. Ewel and H. T. Odum, eds. *Cypress Swamps*. University Presses of Florida, Gainesville.
Odum, W. E., and E. J. Heald. 1975. Mangrove forests and aquatic productivity. Pages 129–136 in A. D. Hasler, ed. *Coupling of Land and Water Systems*. Springer-Verlag, New York.
Terwilliger, V. J., and K. C. Ewel. 1986. Regeneration and growth after logging in Florida cypress domes. *For. Sci.* 32: 493–506.
Van der Valk, A., ed. 1989. *Northern Prairie Wetlands*. Iowa State University Press, Ames.
Wharton, C. H. 1970. The southern river swamp: a multiple use environment. School of Business Administration, Georgia State University, Augusta.
Wunderlin, R. P. 1982. *Guide to the Vascular Plants of Central Florida*. University Presses of Florida, Gainesville.