Drying of Floodplain Forests Associated with Water-Level Decline in the Apalachicola River, Florida—Interim Results, 2006

By Melanie R. Darst and Helen M. Light

The interim results presented herein are from an ongoing study and may be used for discussion or mediation concerning water use in the Apalachicola-Chattahoochee-Flint River basin. The final report for this project is expected to be available in the fall of 2007. In this USGS Open-File Report release of interim results, a comparison of the present (2004-06) composition of floodplain forests to the composition of forests surveyed in the late 1970s documents some of the changes that have occurred on the Apalachicola River floodplain. For additional information contact: mdarst@usgs.gov, 850-942-9500 ext. 3009.

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Contents

Abstract 1
Introduction 2
Setting and Background 2
Floodplain Study Area and Forest Types 2
Influence of Flooding on Tree Regeneration in Floodplain Forests 3
Water-Level Decline in the Apalachicola River 3
Methods 3
Floodplain Forest Sampling Conducted in the Late 1970s 4
Thesis Plots at Blountstown and Wewahitchka 4
Apalachicola River Quality Assessment (ARQA) Cruise Transects and Intensive Plots 4
Eichholz Transects 4
Present Floodplain Forest Sampling 5
Comparison of Late 1970s and Present Forests 5
Using Size Classes of Trees to Indicate Past and Future Forest Composition 6
Statistical Analyses 7
Results of Forest Change Analyses 7
Replicate Plot Analysis 7
Late 1970s Size Class Analysis 7
Present Size Class Analysis 8
Actual and Potential Drying of Floodplain Forests 8
Acknowledgments 8
References 9
Glossary 10
Appendix I. List of Common and Scientific Names and Floodplain Species Categories for Selected Tree Species on the Apalachicola River Floodplain, Florida 13

Figures

1. Map showing drainage basin of the Apalachicola, Chattahoochee, and Flint Rivers in Florida, Georgia, and Alabama 2
2. Map showing major reaches, sampling sites, and locations of surface-water gages on the Apalachicola River and floodplain 2
3. Graph showing long-term water-level decline corresponding to map location on the Apalachicola River, Florida, in April, May, July, and August during drought conditions 3
4. Photograph showing clear-cut plots at the Wewahitchka thesis site near the Wewahitchka gage, Florida. 4

Tables

1. Methods used to collect and analyze late 1970s (1976-79) and present data (2004-06) from forests of the Apalachicola River floodplain, Florida 4
2. Use of the Floodplain Species Category to calculate forest types for floodplain forests sampled in the late 1970s on the Apalachicola River, Florida....5
3. Example illustrating the use of the Floodplain Index to calculate change in composition in floodplain forests of the Apalachicola River, Florida....6
4. Floodplain indices for replicated forest plots in the Apalachicola River floodplain, Florida 7
5. Floodplain indices for canopy tree size classes on late 1970s forest plots in the Apalachicola River floodplain, Florida 7
6. Floodplain indices for canopy and subcanopy tree size classes on present forest plots (2004-06) in the Apalachicola River floodplain, Florida 8
7. Actual and potential change in composition of floodplain forests of the Apalachicola River, Florida, from pre-1954 to 2050 or later 8

Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Abbreviations and Acronyms

ACF	Apalachicola-Chattahoochee-Flint River Basin
ARQA	Apalachicola River Quality Assessment
ba	Basal area
ba/ha	Basal area per hectare
BLT	Blountstown
BR	Brickyard
CH	Chattahoochee
dbh	Diameter at breast height
dens/ha	Density per hectare
EI	Eichholz transects
FI	Floodplain Index
FSC	Floodplain Species Category
GIS	Geographic Information System
GPS	Global Positioning System
>	Greater than
≥	Greater than or equal to
<	Less than
≤	Less than or equal to
HiBlh	High bottomland hardwood
LoBlh	Low bottomland hardwood
MR	Muscogee Reach
n	Number of plots
na	Not applied
OR	Old River
%	Percent
p	Probability
PL	Porter Lake
rba	Relative basal area
rd	Relative density
rm	Rivermiles
SW	Sweetwater
TO	Torreya
USACE	U.S. Army Corps of Engineers
WEW	Wewahitchka

Drying of Floodplain Forests Associated with Water-Level Decline in the Apalachicola River, Florida—Interim Results, 2006

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Abstract

Floodplain forests of the Apalachicola River, Florida, are drier in composition today (2006) than they were before 1954, and drying is expected to continue for at least the next 50 years. Drier forest composition is probably caused by water-level declines that occurred as a result of physical changes in the main channel after 1954 and decreased flows in spring and summer months since the 1970s.

Forest plots sampled from 2004 to 2006 were compared to forests sampled in the late 1970s (1976-79) using a Floodplain Index (FI) based on species dominance weighted by the Floodplain Species Category, a value that represents the tolerance of tree species to inundation and saturation in the floodplain and consequently, the typical historic floodplain habitat for that species. Two types of analyses were used to determine forest changes over time: replicate plot analysis comparing present (2004-06) canopy composition to late 1970s canopy composition at the same locations, and analyses comparing the composition of size classes of trees on plots in late 1970s and in present forests. An example of a size class analysis would be a comparison of the composition of the entire canopy (all trees greater than 7.5 cm (centimeter) diameter at breast height (dbh)) to the composition of the large canopy tree size class (greater than or equal to 25 cm dbh) at one location. The entire canopy, which has a mixture of both young and old trees, is probably indicative of more recent hydrologic conditions than the large canopy, which is assumed to have fewer young trees.

Change in forest composition from the pre-1954 period to approximately 2050 was estimated by combining results from three analyses. The composition of pre-1954 forests was represented by the large canopy size class sampled in the late 1970s. The average FI for canopy trees was 3.0 percent drier than the average FI for the large canopy tree size class, indicating that the late 1970s forests were 3.0 percent drier than pre-1954 forests. The change from the late 1970s to the present was based on replicate plot analysis. The composition of 71 replicate plots sampled from 2004 to 2006 averaged 4.4 percent drier than forests sampled in the late 1970s. The potential composition of future forests (2050 or later) was estimated from the composition of the present subcanopy tree size class (less than 7.5 cm and greater than or equal to 2.5 cm dbh), which contains the greatest percentage of young trees and is indicative of recent hydrologic conditions. Subcanopy trees are the driest size class in present forests, with FIs averaging 31.0 percent drier than FIs for all canopy trees. Based on results from all three sets of data, present floodplain forests average 7.4 percent drier in composition than pre-1954 forests and have the potential to become at least 31.0 percent drier in the future. An overall total change in floodplain forests to an average composition 38.4 percent drier than pre-1954 forests is expected within approximately 50 years.

The greatest effects of water-level decline have occurred in tupelo-cypress swamps where forest composition has become at least 8.8 percent drier in 2004-06 than in pre-1954 years. This change indicates that a net loss of swamps has already occurred in the Apalachicola River floodplain, and further losses are expected to continue over the next 50 years. Drying of floodplain forests will result in some low bottomland hardwood forests changing in composition to high bottomland hardwood forests. The composition of high bottomland hardwoods will also change, although periodic flooding is still occurring and will continue to limit most of the floodplain to bottomland hardwood species that are adapted to at least short periods of inundation and saturation.

Introduction

Large coastal plain rivers of the southeastern United States have extensive forested floodplains with a diversity of aquatic and wetland habitats. Hydrology is recognized as the most important factor determining the structure and ecological processes in floodplains (Greeson and others, 1979; Gosselink and others, 1990; Lugo and others, 1990; Carter, 1996). Inundation, soil saturation, flood depths, and flowing water affect plant regeneration and survival and, to a great extent, the composition of floodplain forests (Light and others, 1993; 2002).

River floodplains provide many important ecological services such as the absorption and retention of floodwaters, ameliorating the effects of both floods and droughts, and improvement of water quality by removing pollutants. Floodplain forests are important habitat for many species of animals, both aquatic and terrestrial. The benefits of protecting and maintaining healthy floodplain ecosystems have been described by many authors (Brinson and others, 1981; Clark and Benforado, 1981; Wharton and others, 1982; Davis and others, 1996; Messina and Conner, 1998; Mitsch and Gosselink, 2000).

Increased demands for water in the Apalachicola-Chattahoochee-Flint (ACF) River basin (**fig.1**) have resulted in conflicts among water-user groups, the States of Georgia, Alabama, and Florida, and various Federal agencies, particularly during periods of regional drought. The effect of altered hydrologic conditions on floodplain forests is an important issue to be considered in resolving these conflicts.

The interim results presented herein are from an ongoing study and may be used for discussion or mediation concerning water use in the ACF basin. This U.S. Geological Survey (USGS) Open-File Report release of interim results, prepared in cooperation with the Northwest Florida Water Management District and the Florida Department of Environmental Protection, documents changes in the composition of present (2004-06) forests on the Apalachicola River floodplain compared to the composition of forests surveyed in the late 1970s.

Metric units are used in this report except for measurements of streamlength, which are in miles or **rivermiles** (**rm**) and floodplain area, in square miles or acres. Rivermiles correspond with mile markers posted along the banks of the river, on navigation charts, and on USGS quadrangle maps, and may not be exact measures of distance because of the natural meandering of the river channel.

Setting and Background

The Apalachicola River is the largest river in Florida in terms of flow, and the fourth largest river in the southeastern United States (Iseri and Langbein, 1974). The Apalachicola River is formed by the confluence of the Chattahoochee and Flint Rivers and all three rivers drain 19,600 mi^2 in Florida, Georgia, and Alabama. The Chattahoochee and Flint Rivers drain about 90 percent of the basin in Georgia and Alabama (**fig. 1**). The remaining 10 percent of the basin, primarily in Florida, is drained by the Apalachicola River and its largest tributary, the Chipola River. Flooding of the Apalachicola River typically occurs in late winter through early spring with low flows in September through November (Leitman and others, 1984).

Floodplain Study Area and Forest Types

The **floodplain** of the Apalachicola River is the land covered by water from the Apalachicola River during the typical annual flood. The floodplain is within the physiographic area called the Coastal Lowlands (Puri and Vernon, 1964), an area that is generally low in elevation; the fall of the river from the head at Jim Woodruff Dam to the **gage** at Sumatra is about 12.5 m over a stream length of 86 rm in the nontidal reaches (Light and others, 2006). The floodplain of the Apalachicola River covers about 82,200 acres of nontidal and 9,800 acres of tidal land.

The study area comprises the nontidal floodplain of the Apalachicola River, which is divided into three reaches marked by gage locations (**fig. 2**). The **upper reach** begins just below Jim Woodruff Dam at rm 106 and extends about 29 rm downstream to the Blountstown gage at rm 78. The **middle reach** is the longest reach, about 36 rm long, ending at the Wewahitchka gage at rm 42. The **lower reach** is about 21 rm long**,** extending from the Wewahitchka gage to the gage at Sumatra at rm 20.6.

The lowest elevations of the floodplain (excluding permanent open-water bodies) are covered with tupelo-cypress **swamps**. Swamps are continuously flooded for an average of 4 to 9 months per year. **Low bottomland hardwood (LoBlh)** forests are present on low ridges and flats where continuous flooding averages 2 to 4 months per year. **High bottomland hardwood (HiBlh)** forests grow on the higher elevations of the floodplain (levees and ridges) that are commonly inundated for 2 to 6 weeks each year. More than 70 different species of trees grow in Apalachicola River floodplain forests.

Influence of Flooding on Tree Seedling Regeneration in Floodplain Forests

Floodplain forests are subjected to inundation, saturation, and flowing water. Seeds of trees in the floodplain usually do not germinate underwater, so seedlings begin growth between floods. The long duration of inundation and deep flooding that occurs in floodplain swamps controls forest composition primarily through a process of exclusion, drowning the seedlings of most bottomland hardwood species before they can become established (Hosner, 1960; Light and others, 1993). The seedlings of two common swamp trees, water tupelo (*Nyssa aquatica*) and bald cypress (*Taxodium distichum*), are more likely to survive in swamps because they grow faster than most bottomland hardwood species, and, because they are taller, these seedlings are less likely to be totally submerged by floods. Swamp tree species also have physiological adaptations for growing in saturated, anoxic soils (Harms, 1973; Hook and Crawford, 1978; Brown, 1984). Solitary individuals of bald cypress grow well at higher elevations in the floodplain, and even do well when planted on upland sites, but natural stands with large numbers of bald cypress trees are present only where flooding lasts long enough to limit competition from other species. Limited competition is also a necessary prerequisite for the establishment of water tupelo trees, but unlike bald cypress, water tupelo requires wet conditions to thrive in the seedling stage and will not grow well under drier conditions (Applequist, 1959; Dickson and others, 1965). More tree species are adapted for survival in bottomland hardwoods than in swamps. Bottomland hardwood species that recover quickly from periods of inundation and saturation in the growing season have a competitive advantage over most upland species in the floodplain.

Water-Level Decline in the Apalachicola River

Water levels have declined over the past 50 years as a result of both erosion of the river channel locally, and decreased spring and summer flow from the upstream watershed (Light and others, 2006). During drought conditions in April, May, July, and August, combined effects of both types of **water-level decline** vary by location along the river with a maximum decline of almost 2 m at the Chattahoochee gage, and declines of about 1 m for most of the remaining nontidal river (**fig. 3**).

In the upper 40 miles of the Apalachicola River, water-level declines caused by channel erosion (tan bars, **fig. 3**) occurred primarily because trapping of sediment in the reservoir formed by Jim Woodruff Dam (constructed in 1954) resulted in scour of riverbed sediments in the river downstream from the dam. The influence of the dam on bed scour progressively decreased with increasing distance from the dam to a decline of less than 0.2 m about 10 miles downstream from the Blountstown gage. Water-level declines caused by channel erosion increased to 0.9 m in the lower reach of the river probably as a result of the construction of several cut-offs (1956 and 1969) that shortened the length of the lower reach main channel by 2 miles, and also from navigation improvements conducted throughout the entire river, including dredging, dredge material disposal, and snagging (dead tree removal). Channel maintenance practices were changed in the late 1970s to reduce environmental impacts, so water-level declines attributed to channel erosion have been relatively minor since that time.

Decreased spring and summer flow from the upstream watershed during drought conditions have resulted in further declines since 1975 that have lowered water levels throughout the entire river (blue bars, **fig. 3**). Water-level declines caused by these seasonal decreases in flow have been similar to or greater than the declines caused by channel erosion along 56 miles of the river and for more than two-thirds of the nontidal floodplain area (primarily in the middle and lower reaches). Less flow during the spring and summer in recent decades is likely caused by a combination of changes in rainfall patterns and increased human activities in the ACF basin including agricultural irrigation, municipal water use, flow regulation, and reservoir evaporation.

Methods

Methods are presented here for studies conducted in the 1970s and the present study. Sampling conducted from 1976 to 1979 is referred to as **late 1970s** data, and sampling conducted from 2004 to 2006 is referred to as **present** data. Sampling sites used for late 1970s and present data are shown in figure 2. The following abbreviated names are used throughout this report for sampling sites: CH, Chattahoochee; TO, Torreya; SW, Sweetwater; BLT, Blountstown; OR, Old River; MR, Muscogee Reach; PL, Porter Lake; WEW, Wewahitchka, EI, Eichholz transects; and BR, Brickyard. Sample points and plots in this study are named using the abbreviated site name as a prefix followed by a unique identifier that is either the original or an assigned name or number.

Floodplain Forest Sampling Conducted in the Late 1970s

Three vegetation studies were conducted in the Apalachicola River floodplain in the late 1970s using different methods to achieve varying objectives. A comparison of methods used to collect and analyze late 1970s and present forest composition data is presented in **table 1**.

Thesis Plots at Blountstown and Wewahitchka

The objective of H.M. Leitman's thesis (1978) was to correlate elevations, water levels, and soils to tree communities on the Apalachicola River floodplain. Two sites located near gaging stations on the river were studied, Blountstown (BLT) and Wewahitchka (WEW), each about 1 ha in size, (Leitman, 1978). All trees greater than or equal to (≥) 7.5 cm in **diameter at breast height** (**dbh**) were identified, measured, surveyed for elevation, and mapped using an alidade and plane table. Buttressed, forked, or deformed trees were measured according to Avery (1967). Canopy trees with multiple trunks were counted as one tree, and only the largest trunk was measured for dbh. **Basal area** (**ba**) (stem cross-sectional area) was computed from dbh (basal area = π*dbh/2 ^{2}), and **density** was determined as the number of trees per hectare. Two major floodplain forest types were identified: cypress-tupelo and mixed bottomland hardwoods. Sites were subdivided into 11 plots (5 at BLT, 6 at WEW) based on ground elevations and species associations. Species dominance at sites was calculated as **relative basal area** (**rba**) (the sum of basal area for all trees of each species divided by the total basal area) and as **relative density** (**rd**) (the total number of trees of each species divided by the total number of trees on each plot).

Apalachicola River Quality Assessment (ARQA) Cruise Transects and Intensive Plots

Two methods of collecting vegetative data were used in ARQA studies. ARQA was part of a national USGS river water-quality assessment program. The objectives of ARQA included describing the distribution, composition, and hydrologic conditions of floodplain forests. Cruise transects were sampled with prisms to quantify overall forest composition in the floodplain, and intensive plot sampling was conducted to quantify forest composition in more detail at selected sites (Leitman and others, 1984). Vegetative data collection at both cruise transects and intensive plots began in August 1979 and continued through December 1979.

*ARQA cruise transects***-** Seven transects across the floodplain were approximately equally spaced from the Jim Woodruff Dam at Chattahoochee to just downstream from the gage at Sumatra (**fig. 2**). One of these transects, Porter Lake (PL), did not span the full width of the floodplain because of logging activities. No transect was surveyed between Wewahitchka and the gage at Sumatra because of clear-cutting. Although the Brickyard (BR) transect is downstream from the Sumatra gage, data from the eastern half of the transect are included in the late 1970s data used in the current study because tidal influence is minimal in forests on the eastern end of the transect. An eighth ARQA cruise transect located downstream from the BR transect was not included because of tidal influence. Locations of transects in the field were determined using USGS quadrangle maps and field-reckoning techniques. Cruise-transect points were spaced at 91.5-m intervals across each transect, determined by pacing.

Sampling at each point along transects was conducted using glass wedge prisms. The prism sampling method uses no minimum tree diameter limit and no defined plot size. Species, dbh, and prism size were recorded for every tree sampled at each point. Prism size was selected in the field based on the heterogeneity of the plot and the optimum number of trees per sample. Basal area per hectare (ba/ha), rba, density per hectare (dens/ha), and rd were calculated for tree species at sampled points using formulas developed for the prism sampling method (Kulow, 1965; Avery, 1967).

ARQA intensive plots – Sixteen plots were established at two of the cruise transects, Sweetwater (SW) and BR, where hydrologic and vegetative data were collected more intensively than at cruise-transect points. Five intensive plots on the western end of the BR transect are not used in the current study because of tidal influence. Intensive plots were located on or close to the cruise transects in all forest types. The optimum plot size was determined by conducting a nested-plot test (Mueller-Dombois and Ellenberg, 1974). Intensive plots were square and 506 m^2 in area. Rules for determining dbh and basal area were similar to those used on Leitman's thesis plots. Species and diameter were determined for every tree in the plot with a dbh ≥ 7.5 cm. Calculations of ba/ha, rba, dens/ha, and rd were made for species in each plot.

Eichholz Transects

The purpose of the Eichholz study (Eichholz and others, 1979) was to assess the impact of U.S. Army Corps of Engineers (USACE) dredged material disposal practices on fish and wildlife resources of the Apalachicola River. Twelve spoil disposal sites were selected for sampling; five of these sites were located in the nontidal part of the floodplain. At each site, transects perpendicular to the river's edge were established across spoil sites and in adjacent areas not affected by disposal. The unaffected

transects were controls for assessing the effects of disposal practices. Site maps were created and forests were delineated as two types: ash-gum-cypress and levee mixed hardwoods. Ash (*Fraxinus*) and gum (*Nyssa*) trees were not identified to species. Plots at 30-m intervals along transects were sampled using a point-centered quarter method. Transects were surveyed for elevation relative to water-level elevation in the main channel at sites. Average percent cover for species for entire transects was summarized in tables, but forest composition at the original sampling points is unknown because the field data from this study were not saved. Data were collected in November 1978. Although late 1970s data are not used from the Eichholz study, present plots were placed on some Eichholz transects.

Present Floodplain Forest Sampling

Present vegetation was sampled from October 2004 to August 2006 at 95 plots located at both thesis sites, 7 ARQA cruise transects, 8 ARQA intensive plots, and 3 Eichholz transects. At the thesis sites, the exact location of the plots was recovered and surviving individual trees were remapped. Part of the original levee plot at BLT has eroded into the river. The WEW site was logged sometime between 1999 and 2004, destroying two of the original six plots completely (**fig. 4**). Two plots (one was a willow bar that was not used in the current study) remained intact, and two plots were partially intact. Comparisons between late 1970s and present forest composition for damaged plots were based on partial plots with boundaries defined by the present extent. The exact locations of original ARQA cruise transects, ARQA intensive plots, and Eichholz transects were not recoverable, so transects were located on **Geographic Information System** (**GIS)** maps and aerial photographs using maps and field notes from the original studies. The location of plots to be sampled was predetermined on GIS maps to reduce the possibility of being subjectively located in the field. Plots in the most undisturbed and homogeneous areas were selected for sampling after traversing the entire transect. Three plots were located between the locations of two cruise-transect points where the intermediate location seemed more representative of a homogeneous section of forest (OR-5.5, OR-32.5, and MR-16.5). Two plots were located in undisturbed areas near transects that were clear-cut (CH-L2, WEW-BSX). Plots at the Eichholz transects were spaced 50 m apart to prevent unintentional overlap resulting from global positioning system (GPS) error.

At all sites except BLT and WEW, circular plots with a 13-m radius and 531 m^2 in area, were created using fiberglass tape and flagging to delineate the outer perimeter. All trees with a dbh ≥ 7.5 cm were identified to species and measured for dbh. Rules for determining dbh and basal area were the same as those used on the thesis plots. In addition to canopy data, subcanopy trees greater than (>) 3 m in height and with dbh's less than (<) 7.5 cm but ≥ 2.5 cm were identified to species and counted for density calculations. Calculations of ba/ha, rba, dens/ha, and rd were made for species at each plot. A numbered aluminum tag was nailed into the tree closest to the center of each plot. Plots may be recoverable for future surveys depending on the accuracy of GPS locations, logging activities, and the survival of marked trees.

Comparison of Late 1970s and Present Forests

Three analyses of late 1970s and present floodplain forests were made using the dominance of species weighted by a factor called the **Floodplain Species Category (FSC)** to quantify the relative dryness of the forest sampled. The sum of weighted dominance of tree species is called the **Floodplain Index (FI)**.

The value of the FSC for a species reflects the tolerance of that species to inundation and saturation in the floodplain and consequently, the typical habitat where that species grows on north Florida floodplains. Four values are used: FSC-1, species typically more dominant in swamps; FSC-2, species typically more dominant in low bottomland hardwoods; FSC-3, species typically more dominant in high bottomland hardwoods; and FSC-4, upland species that were unusual on the late 1970s Apalachicola River floodplain and typically grew on the higher elevations (**table 2**). A list of trees found on the floodplain with common and scientific names and assigned FSC is given in **appendix I**. The FSC values for each species were based primarily on dominance by forest type in the late 1970s Apalachicola River floodplain (Leitman and others, 1984, table 10). Others sources of species information were: dominance patterns on five other north Florida stream floodplains (Light and others, 1993, 2002), wetland indicator status (Reed, 1988), and other scientific reports (Fowells, 1965; Clark and Benforado, 1981).

Although comparisons can be made between late 1970s and present forests with all data combined for each, it is more informative to compare late 1970s to present forest data using data grouped by forest types. It is also possible to convert results by forest type into results by area using forest type areas from the floodplain map (Leitman, 1984). Three floodplain forest types are used in these analyses: high bottomland hardwoods (HiBlh), low bottomland hardwoods (LoBlh), and Swamps. The HiBlh forest type is analogous to "Type A" from Leitman and others (1984); and the LoBlh forest, "Type B." The forest types C, D, and E were combined into the Swamp type. Minor forest types such as Pioneer that were included in the forest map are not included in this study.

Forest type determinations are based on dominance of species grouped by their FSC category. Dominance for canopy trees is calculated from rba. The rba of mature trees is a better approximation of canopy cover or biomass than rd. Rules for determining forest types for late 1970s data were modified from those in Leitman and others (1984, p. A31) so that forest types would be mutually exclusive and to allow all field samples to be typed.

The rules for defining forest types are:
Swamp -- Total rba of FSC1 species ≤ 50 percent
LoBlh -- Total rba of FSC1 + FSC2 species ≥ 50 percent and total rba of FSC1 is less < 50 percent
HiBlh -- Total rba of FSC3 + FSC4 species ≥ 50 percent and total rba of FSC4 is < 50 percent
Upland -- Total rba of FSC4 species ≥ 50 percent
An example of the determination of forest type is given in **table 2**.

Using these rules, 4 cruise-transect points (out of a total of 160 points) and 1 intensive plot changed forest type from that originally assigned, and all 13 previously unidentified cruise-transect points were given a forest type. Present plots replicating late 1970s forest samples were assigned a forest type based on the recalculated late 1970s forest types. The Eichholz transect plots, one plot at WEW, and one plot at the CH transect were located on 1979 aerial infrared photographs and designated a late 1970s forest type based on visual signatures, site maps from Eichholz and others (1979), and the floodplain map (Leitman, 1984).

The Floodplain Index (FI) was used to quantitatively compare the hydrologic condition of plots, cruise-transect points, and **tree size classes** (subsets of trees within plots grouped by dbh). Values of FIs range from 1.000 to 4.000 and represent a continuum from pure Swamp (1.000) to pure upland (4.000) forest types. Wentworth and others (1988) proposed the use of a similar type of index as a basis for wetland designation. The FI was calculated for each cruise-transect point, plot, and size class by multiplying the relative dominance, based on rba for canopy trees or rd for subcanopy trees, of each species by the FSC value. The determination of forest types is not based on FI values, but on the rules for defining forest types. If 100 percent of the trees on a plot are low bottomland hardwood (FSC-2) species, then the FI value will be 2.000 (100 percent x 2). If 50 percent of the composition of the plot changes to high bottomland hardwood species (FSC-3), then the FI of the plot will then be 2.5 [(50 percent x 2) + (50 percent x 3)]. **A change of +0.50 in an FI value is a change of 50 percent of the composition (as determined by dominance) toward a drier forest type.** An example of the use of FIs to calculate change in composition at a plot is given in **table 3**.

Replicate plot analysis compares 71 present plots to 71 plots sampled in the late 1970s using FI values. Replicate plots were located as nearly as possible at the site of late 1970s cruise-transect points or intensive plots. In the case of thesis plots, replicate plots were in the same exact location as late 1970s plots. Plots on Eichholz transects (n = 22) and two plots located near, but not on, original sampling sites were not used as replicate plots.

Using Size Classes of Trees to Indicate Past and Future Forest Composition

The size of trees roughly correlates to comparative age, because dbh increases with age. In a mature, relatively stable system such as most of the Apalachicola River floodplain, trees are constantly dying and being replaced by younger, usually smaller trees. Ultimately, all replacement canopy trees come through the ranks of sizes from seedling to sapling to subcanopy tree to canopy tree. For size class analyses in this study, trees have been grouped by their dbh into three groups: **large canopy trees** with dbh ≥ 25 cm; **small canopy trees** with dbh < 25 and ≥ 7.5 cm; and **subcanopy trees** with dbh < 7.5 and ≥ 2.5 cm. For thesis and ARQA intensive plots, there were no data available for subcanopy size class comparisons. Although there was a small amount of data on subcanopy trees in the ARQA cruise-transect data (42 trees), size class analyses could not be performed on data collected using the prism sampling method.

It was assumed that most large canopy trees on late 1970s plots were at least 50 years old or older when surveyed. The late 1970s large canopy trees were probably seedlings or root sprouts during or before the 1920s, and hydrologic conditions since then have influenced growth and survival of this size class. The composition of the late 1970s large canopy tree size class is the best representation of pre-1954 forest composition. Present forests still contain large canopy trees that grew prior to 1954, but they also contain some younger trees that have lived the greater part of their lives in hydrologic conditions since 1954. The subcanopy tree size class contains the greatest percentage of young trees. Although some subcanopy species will never grow into large canopy trees, the subcanopy composition reflects the hydrologic conditions during their lifetime. For example, possum haw (*Ilex decidua*), a species of limited size potential, is most commonly found growing in high bottomland hardwoods and is rarely found in Swamps. The presence of possum haw in a Swamp subcanopy could indicate drying conditions at the site. The composition of the subcanopy tree size class is the best indicator of the effects of recent hydrologic conditions (perhaps the last 20 years) and the future composition of a forest plot as canopy trees are replaced.

In this study, the FI value for each size class was compared to the FI value for all canopy trees on the plot. For example, if the large canopy tree size class has a lower FI value than the FI value for the composition of all canopy trees, the difference may indicate that hydrologic conditions at the site were generally wetter, perhaps more frequently saturated, during the period of time for establishment and growth of the large canopy trees than during the more recent past when the smaller canopy trees became established and grew. If subcanopy trees have drier FIs than canopy trees, the site has probably been drier in recent years, and the canopy will probably have a drier species composition in the future.

Statistical Analyses

The Wilcoxon Matched-Pairs Signed-Ranks test was used to determine the significance of results from replicate plot and size class analyses. This non-parametric procedure tests whether the median difference between paired observations equals zero (Helsel and Hirsch, 1992). Results are considered significant if the Wilcoxon probability (p) is ≤ 0.05. Computed values in analyses with $p < 0.10$ but > 0.05 are noted in the text and in tables, because change in forest composition is a gradual process, and results, even with slightly lower significance levels than are usually applied, provide an indication of the direction of the process being measured.

Results of Forest Change Analyses

Changes in forest composition were determined using three analyses. Replicate plot analysis compared FI values for late 1970s cruise-transect points and plots to FI values for present plots at the same locations. FI values for large and small canopy tree size classes of trees were compared on late 1970s intensive and thesis plots, and FI values of large canopy, small canopy, and subcanopy tree size classes were compared at present plots.

Replicate Plot Analysis

Forest composition of 71 replicate plots sampled from 2004 to 2006 averaged 4.4 percent (+0.044) drier than late 1970s plots ($p \leq 0.09$, **table 4**). Analysis of replicate plots grouped by forest type indicates that most of this drying occurred in swamps. Present Swamp plots were significantly drier (8.8 percent) than Swamp plots sampled in the late 1970s ($p \leq 0.05$) (**table 5**). Replicate plots in HiBlh and LoBlh forests were not significantly drier or wetter than in the late 1970s.

Results of replicate plot analysis by river reaches were not significant ($p > 0.05$) for any reach. Replicate plots in the upper reach ($n = 30$) averaged 5.0 percent drier in composition than late 1970s forests ($p \leq 0.07$). Replicate plots in the middle reach ($n = 33$) averaged 6.3 percent drier and replicate plots in the lower reach ($n = 8$) were 6.1 percent wetter in composition than late 1970s plots.

Late 1970s Size Class Analysis

The late 1970s large canopy tree size class is the best indicator of pre-1954 forest composition. At late 1970s intensive and thesis plots ($n = 21$), the average FI value for all canopy trees was significantly drier (3.0 percent) than the FI value for large canopy trees (**table 5**), indicating that the forest composition had become drier when sampled in the late 1970s than the forest composition was prior to 1954.

The upper reach had the largest sample size ($n = 12$) of any reach or forest type, and the average differences in FI values for size classes were significant only in this subset. Forests in the upper reach were 3.6 percent drier in composition than they were prior to 1954 (using the large canopy tree size class to represent the pre-1954 forest composition and all canopy trees to represent the late 1970s forest). The average difference in FIs between the small canopy tree size class and all canopy trees in the upper reach was 13.1 percent drier. Most of the water-level decline in the upper reach occurred rapidly in the first 10 years after the dam was constructed in 1954 (Light and others, 2006), and it appears that effects of this water-level decline on small canopy tree composition was evident by the late 1970s.

Present Size Class Analysis

At 95 present forest plots, large canopy trees averaged 1.6 percent wetter, small canopy trees averaged 10.5 percent drier, and subcanopy trees were 31.0 percent drier than all canopy trees (**table 6**), and all of these differences were highly significant ($p \leq 0.01$). Additionally, average differences between subcanopy trees and all canopy trees were highly significant for all plots combined by reach or forest type.

The large canopy tree size class in present forests indicated that the longest time period, including many years prior to 1954, had the wettest hydrologic conditions; the small canopy tree size class indicated that conditions were drier in a more recent period, possibly between 1964 and the present; and the subcanopy tree size class indicated that the driest conditions occurred in the last two decades. Although some subcanopy trees are older than 20 years, the subcanopy tree size class is the only size class with many trees 20 years or less in age. The average change for subcanopy trees (31.0 percent drier) is large, indicating drier conditions during the lifetime of trees in the subcanopy and a large potential for drying of the canopy in the future. Preliminary results from size class analyses on five other north Florida rivers sampled from 1987 to 1995 did not show consistent trends by river, but when all plots were combined, the large canopy trees averaged 1.6 percent wetter; small canopy trees, 1.4 percent drier; and subcanopy trees, 11.4 percent drier.

Actual and Potential Drying of Floodplain Forests

Results from replicate plot and size class analyses were combined in **table 7** to show total drying of forests from pre-1954 to the present, and estimated future drying of forests expected to occur in about 50 years (by 2050 or later). In this summary table, only percent changes with $p < 0.10$ are used. Forest changes from pre-1954 to the late 1970s were represented by the difference in FI values between the large canopy tree size class and all canopy trees on late 1970s plots. Forest changes from the late 1970s to the present were based on replicate plot analysis, and the potential for future drying was represented by the difference in FI values between present canopy and subcanopy trees. Subcanopy composition may continue to change to drier forest types in the future, and estimates of potential drying described in this report may be underestimated.

Upper reach forests had already become 3.6 percent drier when sampled in the late 1970s (**table 7**). Upper reach replicate plots averaged 5.0 percent drier in 2004-06 than in the late 1970s. These changes are additive, thus the total difference for the upper reach is 8.6 percent drier from pre-1954 to the present. The present subcanopy in the upper reach is 36.0 percent drier than the present canopy. If the future forest composition becomes similar to the present subcanopy, the total change in composition of upper reach forests from pre-1954 to about 2050 will be at least 44.6 percent drier. Changes in forest composition from pre-1954 to the present were not significant in the middle and lower reaches; however, present forests in both reaches are expected to become significantly drier (23.3 percent drier in the middle reach and 33.7 percent drier in the lower reach) by 2050 or later. Using similar calculations for forest types, HiBlh forests may have a total change in composition to 15.9 percent drier; LoBlh, 42.3 percent drier; and Swamps, 37.7 percent drier than they were prior to 1954.

For all forest types in all reaches, the total change averages 38.4 percent drier from the pre-1954 period to about 2050 when the youngest surviving trees in the present subcanopy will be at least 70 years old. The full impact of hydrologic change, if it is assumed to be limited, may not occur until the present canopy is fully replaced by a new forest, which may take a century or more.

The greatest effects of water-level decline to date have occurred in swamps where present forest composition is at least 8.8 percent drier than in pre-1954 years. This indicates that a net loss of swamps has already occurred in the Apalachicola River floodplain, and further losses are expected to continue over the next 50 years. Drying of floodplain forests will result in some low bottomland hardwood forests changing in composition to high bottomland hardwood forests. The composition of high bottomland hardwoods will also change, although periodic flooding is still occurring and will continue to limit most of the floodplain to bottomland hardwood species that are adapted to at least short periods of inundation and saturation.

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Glossary

Basal area (ba) is the cross-sectional area of a tree trunk, which is calculated from diameter at breast height (dbh), in cm, using the formula πr^2, in which $\pi = 3.1416$ and $r = dbh/2$. (See **relative basal area**.)

Bottomland hardwoods (Blh) are forests on levees, flats, and slopes of floodplains that are flooded continuously for several weeks or longer every 1-2 years and contain species adapted to periodic inundation and saturation.

Low bottomland hardwoods (**LoBlh**) grow on low flats and in transition areas between swamps and high flats or levees where continuous flooding averages 2 to 4 months per year. **LoBlh** is a forest type, defined in this report as having dominance (as determined by relative basal area) of FSC-1 and FSC-2 species > dominance of FSC-3 and FSC-4 species and dominance of FSC-1 species < 50%.

High bottomland hardwoods (**HiBlh**) grow on the higher elevations of the floodplain (levees and ridges) that are usually inundated for 2 to 6 weeks each year. **HiBlh** is a forest type, defined in this report as having dominance (as determined by relative basal area) of FSC-3 and FSC-4 species > dominance of FSC-1 and FSC-2 species and dominance of FSC-4 species < 50%.

Density is the number of individual plants per unit of sampling area. (See **relative density**.)

Diameter at breast height (dbh) is the diameter of a tree trunk measured at about 1.4 m above ground level. The dbh of trees with swollen bases were measured for diameter above the swelling.

Floodplain is the land covered by water from the river during a typical annual flood.

Floodplain Index (FI) of a sample site is the sum of the products of the relative basal area of species and their Floodplain Species Categories. FI values range from 1.000 to 4.000 and represent a continuum from pure swamp to upland forest types.

Floodplain Species Categories (FSC) are numbers from 1 to 4 that indicate the typical association between species and their occurrence in the floodplain. FSC-1 species most commonly grow in swamps; FSC-2 species, in low bottomland hardwoods; FSC-3 species, in high bottomland hardwoods; and FSC-4 species are typically rare on the floodplain, growing only on the highest elevations, and more usually growing in upland forests.

Gage refers to a long-term streamflow gaging station at which a time-series of stage measurements (elevation of river surface) have been recorded, and measurements of instantaneous streamflow discharge may have been made.

Geographic Information system (GIS) is a collection of computer software and data files designed to store, analyze, and display geographically referenced information.

Late 1970s forest data refers to data collected from 1976 to 1979 in three studies conducted on the Apalachicola River floodplain.

Present forest data refers to data collected from 2004 to 2006 in the Apalachicola River floodplain.

Reach refers to a length-subdivision of the Apalachicola River (figure 2).

The **upper reach** begins just below Jim Woodruff Dam at rm 106.3 and extends about 29 miles downstream to the Blountstown gage at rivermile (rm) 77.5.

The **middle reach** is the longest reach, about 36 miles long, ending at the Wewahitchka gage at rm 41.8.

The nontidal **lower reach** is the shortest reach, approximately 21 miles long, and ends at the Sumatra gage at rm 20.6. The tidal reach of the river is not discussed in this report.

Relative basal area (rba) is the percentage dominance of a species in a forest type or sampling area based on basal area. It is calculated by dividing the total basal area of that species by the total basal area of all species in that forest type or sampling plot.

Relative density (rd) is the percentage dominance of a species in a forest type or sampling area based on density. It is calculated by dividing the total density of that species (number of individuals per unit of area) by the total density of all species in that forest type or sampling plot.

Replicate plot is a plot sampled in the present period (2004-06) that was located as nearly as possible at the site of a late 1970s cruise-transect point, intensive plot, or thesis plot.

Rivermile (rm) refers to a reference frame of distances along the river channel. In this report, rivermile values are those depicted on the most recent USGS quadrangle maps that were available in 2005. Rivermile distances are similar to, but not exactly the same as, the most recent navigation mile system used by USACE. Slight differences in distance reference frames are to be expected because the river moves and changes length through time in response to various processes, both natural and anthropogenic.

Swamps are forests in the lowest elevations of the floodplain that are either inundated or saturated most of the time. Swamps contain tree species that have special adaptations for survival in anoxic soils. **Swamp** (always capitalized) is a forest type, defined in this report as having dominance (as determined by relative basal area) of FSC-1 species ≥ 50 percent.

Tree size classes are trees grouped by diameter at breast height (dbh). Trees in this study have been grouped by their dbh into three groups:

Large canopy trees are trees with dbh ≥ 25 cm.
Small canopy trees are trees with dbh < 25 and ≥ 7.5 cm.
Subcanopy trees are trees with dbh < 7.5 and ≥ 2.5 cm.

Water-level decline is a term referring to changing conditions in which periods of low water levels become more frequent and longer in duration. Such declines may result from some type of channel change, which usually occurs over a period of years. Another type of water-level decline refers to a long-term decrease in the amount of water delivered from the upstream watershed.

Appendix I. List of common and scientific names and Floodplain Species Categories for selected tree species on the Apalachicola River floodplain, Florida.

[Plant nomenclature used in this report follows that by Godfrey (1988) unless otherwise indicated. blh, bottomland hardwood]

		Floodplain species category	
Common name	**Scientific name**	**Numeric value**	**Category explanation**
American elm	*Ulmus americana*	2	low blh
American holly	*Ilex opaca*	3	high blh
bald cypress	*Taxodium distichum*	1	swamp
bitternut hickory	*Carya cordiformis*	3	high blh
black tupelo	*Nyssa sylvatica*	4	upland
black willow	*Salix nigra*	1	swamp
box elder	*Acer negundo*	3	high blh
buttonbush	*Cephalanthus occidentalis*	1	swamp
cherry laurel	*Prunus caroliniana*	4	upland
chinaberry	*Melia azedarach*	4	upland
Chinese tallow tree	*Sapium sebiferum*	3	high blh
green ash	*Fraxinus pennsylvanica*	2	low blh
green haw	*Crataegus viridis*	2	low blh
hackberry	*Celtis laevigata*	3	high blh
ironwood	*Carpinus caroliniana*	3	high blh
laurel oak	*Quercus hemispherica*	4	upland
loblolly pine	*Pinus taeda*	4	upland
Ogeeche tupelo	*Nyssa ogeche*	1	swamp
overcup oak	*Quercus lyrata*	2	low blh
persimmon	*Diospyros virginiana*	3	high blh
pignut hickory	*Carya glabra*	4	upland
planer tree	*Planera aquatica*	1	swamp
popash	*Fraxinus caroliniana*	1	swamp
possum haw	*Ilex decidua*	3	high blh
red maple	*Acer rubrum*	2	low blh
red mulberry	*Morus rubra*	3	high blh
river birch	*Betula nigra*	2	low blh
silverbell	*Halesia diptera*	4	upland
slippery elm	*Ulmus rubra*	4	upland
southern magnolia	*Magnolia grandifolia*	4	upland
Spanish red oak	*Quercus falcata*	4	upland
spruce pine	*Pinus glabra*	3	high blh
stiffcornel dogwood	*Cornus foemina*	2	low blh
swamp cottonwood	*Populus heterophylla*	1	swamp
swamp laurel oak	*Quercus laurifolia*	2	low blh
swamp privet	*Forestiera acuminata*	2	low blh
swamp tupelo	*Nyssa biflora* [1]	1	swamp
sweetbay	*Magnolia virginiana*	3	high blh
sweetgum	*Liquidambar styraciflua*	3	high blh
sycamore	*Platanus occidentalis*	3	high blh
water hickory	*Carya aquatica*	2	low blh
water locust	*Gleditsia aquatica*	2	low blh
water oak	*Quercus nigra*	3	high blh
water tupelo	*Nyssa aquatica*	1	swamp
winged elm	*Ulmus alata*	4	upland

[1] Clewell (1985).