



# Interactions between river stage and wetland vegetation detected with a Seasonality Index derived from LANDSAT images in the Apalachicola delta, Florida

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## ABSTRACT

The distribution of swamp floodplain vegetation and its evolution in the lower non-tidal reaches of the Apalachicola River, Florida USA, is mapped using Landsat Thematic Mapper and Enhanced Thematic Mapper Plus (TM/ETM+) images captured over a period of 29 years. A newly developed seasonality index (SI), the ratio of the NDVI in winter months to the summer months, shows that the hardwood swamp, dominated by bald cypress and water tupelo, is slowly replaced by bottomland hardwood forest. This forest shift is driven by lower water levels in the Apalachicola River in the last 30 years, and predominantly occurs in the transitional area between low floodplains and high river banks. A negative correlation between maximum summer NDVI and water levels in winter suggests the growth of more vigorous vegetation in the vicinity of sloughs during years with low river flow. A negative correlation with SI further indicates that these vegetation patches are possibly replaced by species typical of drier floodplain conditions.

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## 1. Introduction

Floodplain swamps offer multiple beneficial ecological services. Not only they mitigate flood risk and improve water quality, but also provide habitat for endangered species [20]. In recent times, these delicate environments are threatened by anthropogenic stresses and climate change. Changes in river hydrology can modify the flooding regime of the floodplain endangering its ecosystems.

Hydrology is identified as the major driving variable defining and influencing the ecosystem structure and functions in floodplains [1,27]. Floodplain ecosystems are the complex interrelated systems of floral and faunal communities that welcome water during high discharge events [4,44]. During riverine low stages, floodplains are usually fed by groundwater that maintains a saturated soil. When the water level becomes too low, as for instance during droughts, the hydrological connection between river and floodplain is lost. In these periods, the ground is exposed more frequently, soil moisture tends to evaporate more easily, thus affecting floodplain vegetation. Reduced water availability often leads to a change in the composition of floodplain vegetation, with dramatic consequences for the entire ecosystem [15,32].

The complexity of floodplain ecological interactions can be explained by means of the flood pulse concept [19,40]. The pulsing

of river discharge during floods stimulates the exchange of energy, matter, and organisms across the river floodplain. This cycling phenomenon of long duration appears to be a dominant factor for the development of biorhythms characteristics of floodplain ecosystems [40]. Floodplains store large quantities of organic matter that is slowly decomposed causing a concentration of nutrients. The flood pulse mobilizes and distributes these nutrients through the whole floodplain creating at the same time vital ecosystemic connections. Moreover, part of the nutrients and organic matter is washed downstream and supports estuarine and marine ecosystems [2].

A loss of tree density in floodplain wetlands would lead to a decrease in tree and leaf litter biomass, which would have additional effects on swamp organisms. Both the loss of litter and the cut off of lateral connections between aquatic and terrestrial environments would result in a loss of substrate [8,22], with possible consequences for benthic organisms in the floodplain and, ultimately, in the downstream waters of the river and estuary. Moreover, floods have the ability to affect germination, seedlings survival, regeneration success, and plant succession [17]. Inundations alter the spatial distribution of habitats, and this is essential to maintain the richness and diversity of species in floodplains [36,43]. Due to the high level of primary productivity and habitat heterogeneity, floodplains are often considered regional biodiversity hotspots [23,39]. In large subtropical lowland rivers with a constant temperature during the growing season, the connections

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between the river and its floodplain become more apparent after major inundations.

Here we investigate vegetation dynamics in the floodplain of the Apalachicola River, Florida USA, by exploring the relationship between satellite-derived vegetation indices and river stage. The lower non-tidal reaches of the Apalachicola River underwent several human interventions to maintain a now rarely used inland water transport system, such as dredging and disposal of sediments on the floodplain and straightening of the main river course [24]. The hydrological alterations in the Apalachicola River are also directly related to the construction of dams, which regulate the flow preventing frequent floods. Although large floods can still occur because the reservoirs volume is limited, the sediments are trapped by the dams and the river bed is subject to excavation downstream [8]. This process makes the existing banks higher relative to the bottom, thus reducing the hydrological connection between the river and the floodplain. In addition, water withdrawal for agricultural and municipal purposes has increased in the last five decades. All these factors have contributed to declining water levels in the last 30 years, leading to shorter durations for floodplain inundations, a disconnection of the floodplain with the main channel, and eventually to a change in forest characteristics [25,36,35].

In our study, we used the vegetation indicator NDVI (Normalized Difference Vegetation Index) derived from a time series of data from Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper Plus. Field data are typically expensive and are usually collected at small spatial and temporal scales, whereas remote sensing data are ideal for monitoring large areas. Therefore, satellite imagery has become a powerful tool for ecologists and geomorphologists in riverine studies [21,41,46–48]. A common drawback of satellite images is the reliability of the observations. However, new algorithms are available to reduce noise in NDVI time-series, for instance by detecting and disregarding pixels covered by clouds, snow, ice or standing water [45].

This study has two goals: i) to define a simple index, based on easily available remote sensing information, that relates vegetation dynamics to the hydrological regime; ii) to use the index to interpret the medium-term changes that are occurring in the Apalachicola river floodplain. The methodology used here allows monitoring of the dynamics of swamp vegetation in alluvial river floodplains, so as to better understand this complex ecosystem and to provide critical information for flow regulation.

## 2. Study site

The Apalachicola River is part of a three-river system (the Apalachicola-Chattahoochee-Flint or ACF basin) that originates in the Appalachian Mountains and drains 50,800 km<sup>2</sup> within Alabama, Georgia, and Florida (Fig. 1A). The Chattahoochee River flows for about 700 km from its source in North Georgia to the Florida border, and serves as the boundary between Georgia and Alabama for part of this distance. The river meets sixteen dams, with the last one at Lake Seminole where it joins the Flint River. The Flint River originates south of Atlanta, and flows about 600 km through southwestern Georgia. The Apalachicola River begins at the Flint-Chattahoochee confluence and flows unimpeded through Florida for about 170 km to Apalachicola Bay. The Apalachicola River is 21st in magnitude in terms of flow in the conterminous United States with a mean annual flow of 630 m<sup>3</sup>/s (average value in the period 1922–1995).

### 2.1. Dominant vegetation species

Our study site was chosen within the non-tidal reaches of the river, 32 km upstream from the river mouth in Apalachicola Bay (Fig. 1B). According to the Florida Fish and Wildlife Conservation Commission [11], five vegetation classes are present in

the Apalachicola floodplain: cypress swamp, hardwood swamp, bottomland hardwood forest, mixed wetland forest, and pineland forest ([11], Fig. 2B). The vegetation cover map in Fig. 2B was derived by the FWC from a Landsat ETM+ scene, previous land cover datasets created by different agencies, and a digital orthographic quarter quadrangle aerial photography. Specific areas of the map were visited in the field for ground-truthing (see [37] for details). Cypress swamps are found along the investigated segment of the Apalachicola River and in depressions which occur within the floodplain. These forested zones are habitually inundated, with either bald cypress (*Taxodium distichum*) or pond cypress (*Taxodium ascendens*) dominating these wetlands. Furthermore, both understory and vegetated ground cover are rarely present because of the prolonged time of standing water.

The most common tree species of the hardwood swamps are water tupelo (*Nyssa aquatica*) and bald cypress (*Taxodium distichum*) [9]. Both species lose their leaves in winter, and grow in low, saturated, and seasonally inundated soils and in deep swamps. In fact, both the long duration of inundations and the high water levels during floods control forest composition through a process of exclusion, drowning the seedlings of most bottomland hardwood species before they can become established [16,25]. Bald cypress usually achieves dominance when competing with water tupelo. However, the adverse condition of moving water in sloughs confines bald cypress trees to the margins and more shallow areas. Water tupelo requires more stringent wet conditions to be competitive at the seedling stage, is less shade-tolerant and favors mineral soils with high silt content [14]. As the flood depth in the swamp becomes deeper and the water stagnant, the two species occupy much of the same area [18]. Other hardwood species are also present, the most common are Carolina ash (*Fraxinus caroliniana*), and planer tree (*Planera aquatica*), as well as other tupelo species: swamp tupelo (*Nyssa biflora*), Ogeechee tupelo (*Nyssa ogeche*), and blackgum (*Nyssa sylvatica*).

Reduced inundation periods and higher ground elevation characterize the levees of the Apalachicola River, where sediments tend to settle during overbank flows creating alluvial deposits (Fig. 2A). As a result, drier conditions and a diverse mosaic of habitats are produced, thus allowing many tree species to survive. Here bottomland hardwood forests thrive [8]. In our area of interest this type of forest has a predominance of deciduous trees, such as water hickory (*Carya aquatica*), overcup oak (*Quercus lirata*), sweetgum (*Liquidambar styraciflua*), green ash (*Fraxinus pennsylvanica*), and sugarberry (*Celtis laevigata*) [24].

The category of the mixed wetland forest includes a mix of hardwoods such as bald cypress (*Taxodium distichum*) and pines, primarily loblolly pine (*Pinus taeda*), in which both communities are equally present. This habitat is regarded as a transition environment from hydric to mesic sites. Finally, the pineland forests present in the research area are dominated by loblolly pine (*Pinus taeda*) and longleaf pines (*Pinus palustris*).

### 2.2. LiDAR and Landsat data

The main goal of our analysis is to determine the relationships between hydraulic conditions and vegetation cover in the Apalachicola floodplain over time. To this end, we rely on 29-year series of satellite data (Landsat Thematic Mapper TM and Enhanced Thematic Mapper Plus ETM+) to reconstruct the vegetation distribution in our study site from 1983 to 2011. Satellite data are combined with a Digital Elevation Model based on LiDAR data collected in 2010 and water level data recorded at a nearby gauging station. LiDAR data for the area of interest are available from the North West Florida Water Management District Public LiDAR Data Server [28]. The Digital Elevation Model was derived from bare earth LiDAR points collected in spring 2010 by the Florida Department of Emergency Management. We applied a coordinate

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