USGS
science for a changing world

Prepared in cooperation with the Coastal Protection and Restoration Authority of Louisiana and the Coastal Wetlands Planning, Protection and Restoration Act

Forested Floristic Quality Index: An Assessment Tool for Forested Wetland Habitats Using the Quality and Quantity of Woody Vegetation at Coastwide Reference Monitoring System (CRMS) Vegetation Monitoring Stations

Open-File Report 2017–1002

U.S. Department of the Interior
U.S. Geological Survey

Cover. Forested wetland on Bayou Black southwest of Gibson, Louisiana (photograph by Brett Patton, U.S. Geological Survey).

Forested Floristic Quality Index: An Assessment Tool for Forested Wetland Habitats Using the Quality and Quantity of Woody Vegetation at Coastwide Reference Monitoring System (CRMS) Vegetation Monitoring Stations

By William B. Wood, Gary P. Shaffer, Jenneke M. Visser, Ken W. Krauss, Sarai C. Piazza, Leigh Anne Sharp, and Kari F. Cretini

Prepared in cooperation with the Coastal Protection and Restoration Authority of Louisiana and the Coastal Wetlands Planning, Protection and Restoration Act

Open-File Report 2017–1002

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2017

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod/.

Suggested citation:
Wood, W.B., Shaffer, G.P., Visser, J.M., Krauss, K.W., Piazza, S.C., Sharp, L.A., and Cretini, K.F., 2017, Forested Floristic Quality Index—An assessment tool for forested wetland habitats using the quality and quantity of woody vegetation at Coastwide Reference Monitoring System (CRMS) vegetation monitoring stations: U.S. Geological Survey Open-File Report 2017–1002, 15 p., https://doi.org/10.3133/ofr20171002.

ISSN 2331-1258 (online)

Contents

Figures

Tables

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)

Forested Floristic Quality Index: An Assessment Tool for Forested Wetland Habitats Using the Quality and Quantity of Woody Vegetation at Coastwide Reference Monitoring System (CRMS) Vegetation Monitoring Stations

By William B. Wood,[1] Gary P. Shaffer,[2] Jenneke M. Visser,[3] Ken W. Krauss,[4] Sarai C. Piazza,[4] Leigh Anne Sharp,[1] and Kari F. Cretini[5]

Abstract

The U.S. Geological Survey, in cooperation with the Coastal Protection and Restoration Authority of Louisiana and the Coastal Wetlands Planning, Protection and Restoration Act, developed the Forested Floristic Quality Index (FFQI) for the Coastwide Reference Monitoring System (CRMS). The FFQI will help evaluate forested wetland sites on a continuum from severely degraded to healthy and will assist in defining areas where forested wetland restoration can be successful by projecting the trajectories of change. At each CRMS forested wetland site there are stations for quantifying the overstory, understory, and herbaceous vegetation layers. Rapidly responding overstory canopy cover and herbaceous layer composition are measured annually, while gradually changing overstory basal area and species composition are collected on a 3-year cycle.

A CRMS analytical team has tailored these data into an index much like the Floristic Quality Index (FQI) currently used for herbaceous marsh and for the herbaceous layer of the swamp vegetation. The core of the FFQI uses basal area by species to assess the quality and quantity of the overstory at each of three stations within each CRMS forested wetland site. Trees that are considered by experts to be higher quality swamp species like *Taxodium distichum* (bald cypress) and *Nyssa aquatica* (water tupelo) are scored higher than tree species like *Triadica sebifera* (Chinese tallow) and *Salix nigra* (black willow) that are indicators of recent disturbance. This base FFQI is further enhanced by the percent canopy cover in the overstory and the presence of indicator species at the forest floor. This systemic approach attempts to differentiate between locations with similar basal areas that are on different ecosystem trajectories. Because of these varying states of habitat degradation, paired use of the FQI and the FFQI is useful to interpret the vegetative data in transitional locations. There is often an inverse relation between the health of the overstory and health of the herbaceous community beneath it because of resource competition (for example, light) and differing environmental preferences between the two communities. The herbaceous layer vegetation responds rapidly to basic environmental factors such as flooding, salinity, and nutrients and can offer insight into the sustainability of swamps on a temporal scale shorter than that of the slowly growing woody vegetation.

The FFQI will be available via the CRMS spatial viewer (http://lacoast.gov/crms2/home.aspx), and a new score will be calculated annually for each CRMS forested wetland site as data are collected to establish trends, to compare among sites, and to evaluate specific restoration projects when applicable. The FFQI will identify forested wetland areas in need of restoration and conservation and will help define targets and trajectories for restoration planning.

Introduction

The Coastwide Reference Monitoring System (CRMS) was established in 2003 under the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA). The CRMS network was established to provide a comprehensive, standardized monitoring and assessment program that can be used to evaluate coastal restoration projects throughout the Louisiana coastal zone. The monitoring program classifies sites on the basis of marsh class (vegetation type), hydrologic basin location, and whether sites are within restoration

[1]Coastal Protection and Restoration Authority of Louisiana.

[2]Southeastern Louisiana University.

[3]University of Louisiana at Lafayette.

[4]U.S. Geological Survey.

[5]Cherokee Nation Technology Solutions, LLC.

project areas (Steyer and others, 2003). CRMS data are used to develop individual indices for vegetation, hydrology, and soils to (1) evaluate restoration project effectiveness by using comparisons to reference sites, (2) identify potential areas in need of restoration, and (3) identify long-term and seasonal trends in coastwide conditions.

The woody vegetation present in coastal forested wetland habitats is controlled by flooding, salinity, and herbivory, as well as by nutrient and sediment input from upstream sources (Conner and others, 1997; Dickson and Broyer, 1972; Lane and others, 2003; Myers and others, 1995; Shaffer and others, 2009). Thus, changes in plant community composition can act as reliable indicators of change in the physical conditions associated within a landscape. Previous analyses of CRMS vegetation data used the Floristic Quality Index (FQI) to assess the condition of sites based on herbaceous plant community composition. The FQI is a widely used method to assess site condition based on species composition (Andreas and Lichvar, 1995; Lopez and Fennessy, 2002; Andreas and others, 2004; Cohen and others, 2004; Herman, 2005; Bourdaghs and others, 2006). The FQI is based on a coefficient of conservatism (CC), a score from 0 to 10 that is assigned to each plant species in a community by a panel of local plant experts. Scores for each species are assigned according to their tolerance to disturbance and specificity to a particular habitat type. Species that are highly tolerant to disturbance and display low habitat specificity are assigned a lower CC score, whereas species that do not tolerate disturbance and are highly habitat specific are assigned a higher CC score. The FQI represents a standardized metric of vegetation quality that can be used to assess restoration effectiveness, identify target areas for restoration, and evaluate the ecological condition of Louisiana's coastal wetlands (Cretini and others, 2011, 2012).

The U.S. Geological Survey, in cooperation with the Coastal Protection and Restoration Authority of Louisiana and the Coastal Wetlands Planning, Protection and Restoration Act, developed the Forested Floristic Quality Index (FFQI) for the CRMS. The FFQI, which is similar to the FQI, was developed to evaluate ecosystem structural changes among forested wetland sites. The FFQI will be used to evaluate forested wetland sites on a continuum from severely degraded to healthy, will assist in defining areas where forested wetland restoration is needed, and will help determine the effectiveness of future restoration projects in returning specific degraded forested wetlands into healthy ecosystems. While the FQI is based on the percent cover of emergent herbaceous species, the FFQI uses the herbaceous layer data at the forest floor in conjunction with the basal area at a species level and canopy cover to place a specific forested wetland site into a structural context coastwide. As such, the FFQI is a natural extension of the FQI and can be used in conjunction with the FQI of the understory herbaceous community in forested wetland systems, as there is typically an inverse relation between tree and herbaceous layer vegetation dominance in Louisiana's coastally restricted forested wetlands that represents natural succession (Conner and Day, 1992a; Shaffer and others, 2009; Nyman, 2014). As environmentally driven temporal shifts occur in the ecosystem, the FFQI contains valuable information that depicts a trajectory in system function. Generally, coastal flooded forested wetlands have transitioned to shrub-scrub; fresh, floating, and intermediate marshes; and open water as anthropogenic alterations to the landscape have taken place in the 20th and 21st centuries (Barras and others, 1994; Day and others, 2000; Krauss and others, 2009). Conversely, in a few select locations, such as the Atchafalaya River Delta, the natural deltaic cycle causes the reversal of this trend. In this emerging deltaic environment, the succession of fresh marsh is transitioning into young forested wetlands populated by low value pioneer and disturbance woody species, leading to the development of fledgling swamps (Johnson and others, 1985; Shaffer and others, 1992). These two contrasting successional trajectories occurring within the same coastal system and same monitoring network highlight the need for a multivariable and index approach to site and restoration assessment.

Methods

The base FFQI score was calculated by using the CC scores provided by a panel of experts (Cretini and others, 2011) for as many as 58 CRMS forested wetland sites distributed along Louisiana's coastal zone over six annual sampling events. Sites were distributed in the following basins: Lake Maurepas (24), Pearl River (4), Barataria (11), Terrebonne (6), and Atchafalaya-Vermilion (13) (U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service, 2013). The full suite of forested wetland site variables (that is, tree species composition and diameter, canopy cover, understory and herbaceous vegetation) was collected at the 58 sites annually from 2007 to 2009, a subset of 22 sites was sampled in 2010, and all active sites were monitored again in 2012 and 2015. In 2013 and 2014 only the herbaceous layer vegetation and canopy cover data were collected. Thus the FFQIs calculated for 2013 and 2014 were excluded from any statistical analysis because they used the 2012 overstory basal area by species calculation. The sampling of each site was conducted within a main data collection area of 200 by 200 meters (m) (40,000 square meters [m^2]) (fig. 1). Three randomly positioned 20- by 20-m (400-m^2) areas were used to sample overstory vegetation ("F" stations), and nine 2- by 2-m (4-m^2) areas were used to sample herbaceous layer vegetation ("V" stations). These stations were established along the diagonal transect that bisects the main plot at all CRMS forested wetland sites (Folse and others, 2012). For the FFQI determinations, the larger 20- by 20-m overstory stations were used to generate station-specific base FFQI values and canopy cover scores.

On the basis of a review of the literature, a basal area of 80 square meters per hectare (m^2/ha) was considered to be the total possible basal area that occurs in healthy Louisiana

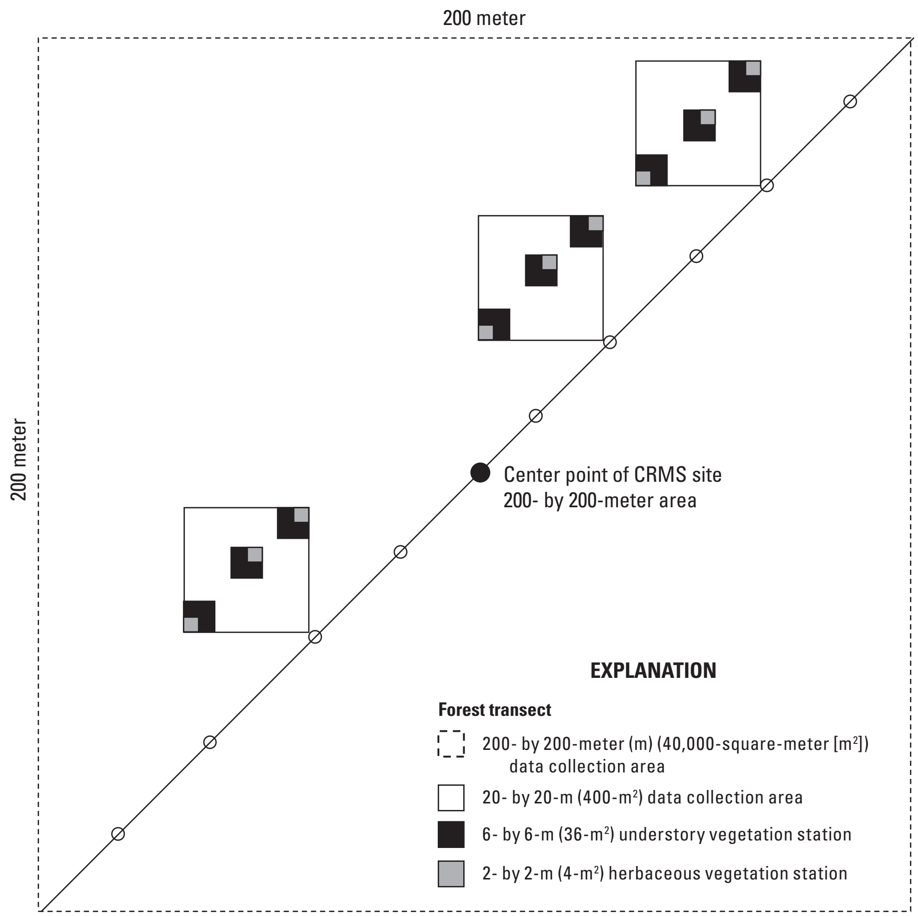

Figure 1. A typical vegetation station layout within a Coastwide Reference Monitoring System (CRMS) forested wetland site. CRMS data used to develop the Forested Floristic Quality Index (FFQI) for the CRMS network were collected from overstory vegetation stations at each of the 20- by 20-meter (m) area stations and the 2- by 2-m area herbaceous layer vegetation stations.

coastal forested wetlands (table 1). Where the sum of basal areas by species at an overstory station within a CRMS site at time t is less than or equal to 80 m^2/ha, we used the following formula:

$$Base\,FFQI_t = \left(\frac{\Sigma\left(BASAL\ AREA_{it} * CC_i\right)}{80} \right) * 10 \qquad (1)$$

where

$BASAL\ AREA_{it}$ is the sum of basal area for species i at an overstory station within a CRMS site at time t, and

CC_i is the coefficient of conservatism for species i.

This equation allows for stations with sparse high-CC-score trees and densely wooded low-CC-score species to receive a similarly low index value. The alternative equation for basal areas greater than 80 m^2/ha was not used, as these highly dense stands were lacking from the CRMS data (Cretini and others, 2011).

The diameter at breast height of all trees larger than 5 centimeters (cm) within the three overstory stations was measured to calculate species-specific basal area (in square meters per hectare). The basal area for each tree species is collected at a minimum of every 3 years. The basal area was multiplied by the species-specific CC score ranging from 0 to 10 (table 2). The CC scores of the most frequently identified tree species are listed in table 2 (CC scores for all trees and marsh plants in coastal Louisiana are available in Cretini and others, 2011). The calculated species-specific base FFQI value

Table 1. Literature review of maximum basal area reported for coastal Louisiana forested wetlands.

[m^2/ha, square meter per hectare; values with asterisks estimated from publication figures]

Maximum basal area (m^2/ha)	Source
81.6	Conner and Brody, 1989
71.6	Conner and others, 1986
68*	Shaffer and others, 2009
65*	Hesse and others, 1998
54.4	Conner and others, 2002
70.6	Krauss and others, 2009
45*	Visser and Sasser, 1995
38.3	Conner and Day, 1992b
35*	Conner and others, 1981

Table 2. Commonly occurring woody species in the Coastwide Reference Monitoring System (CRMS) 2015 overstory stations and their associated coefficient of conservatism scores (Cretini and others, 2011).

[CC, coefficient of conservatism]

Scientific name	Common name	CC score	Number of occurrences 2015
Acer rubrum	Red maple	7	3,343
Nyssa aquatica	Water tupelo	9	1,234
Taxodium distichum	Bald cypress	10	925
Fraxinus caroliniana	Carolina ash	7	864
Salix nigra	Black willow	2	748
Morella cerifera	Wax myrtle	6	650
Fraxinus profunda	Pumpkin ash	7	582
Nyssa biflora	Swamp tupelo	8	278
Cephalanthus occidentalis	Common buttonbush	6	233
Triadica sebifera	Chinese tallow	0	159

was then summed across the station and divided by 80 m^2/ha, which was found to be greater than the maximum basal area among the CRMS forested wetland sites in Louisiana. This value was then multiplied by 10 to scale the final product from 0 to 100. The CRMS station level base FFQI scores were then modified on the basis of both the station-specific canopy cover and the herbaceous layer vegetation present at the forest floor to incorporate habitat characteristics that quickly respond to stimuli on an annual basis. The canopy cover modifier (CCM) and an herbaceous layer indicator species modifier (ISM) were given equal weight to affect the final FFQI value at each CRMS station:

$$FFQI_t = CCM * Base\ FFQI_t * ISM \qquad (2)$$

Canopy cover was recorded annually via a spherical densiometer on a scale from 0.0 to 100.0 at the center of each 20- by 20-m station. This measurement was recorded in duplicate by separate personnel and not finalized until separate readings were within 20 percent of one another (Folse and others, 2012). The CCM ranged linearly from fully closed canopy multiplying the base FFQI by 1.25 times to an open absent canopy reducing the station base FFQI by as much as 0.25 (fig. 2).

$$CCM = 0.75 + 0.005 * Percent\ Canopy\ Cover \qquad (3)$$

The live herbaceous layer vegetation was measured inside three 2- by 2-m plots per station embedded diagonally in the larger 20- by 20-m overstory plot. Live herbaceous layer data were recorded in the form of species-specific percent cover of the 2- by 2-m station along with total cover, height, and nonvegetated surface data (Folse and others, 2012).

Ocular species-specific percent covers were estimated by no fewer than two observers agreeing to the nearest whole number from 0 to 100. These data were used in concert with a list of indicator species (table 3) developed by a panel of Louisiana wetland forest experts and species-specific salinity scores developed for a marsh type assignment algorithm (Visser and others, 2002). This indicator species list consists of two main groups, (1) positive indicator species often seen in association with healthy swamp ecosystems and (2) negative indicator species common to floating, intermediate, brackish, and saline marshes and disturbed forested wetlands (table 3).

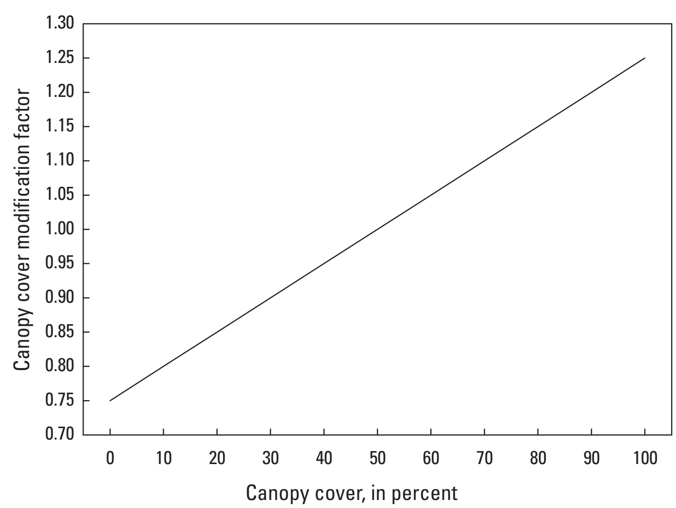

Figure 2. The relation between the Forested Floristic Quality Index (FFQI) canopy cover modification factor and canopy cover. A modification factor of 1.25 was applied to the station level FFQI for fully closed canopies (100 percent canopy cover value), whereas station level FFQI for open canopies was reduced by a modification factor of 0.25.

Table 3. Indicator taxa that modify base Forested Floristic Quality Index scores.

[Positive indicator taxa are often observed in association with healthy forested wetland ecosystems. Negative indicator taxa are common in floating, intermediate, brackish, and saline marsh types and disturbed forested wetlands]

Positive indicator taxa	Negative indicator taxa
Acer rubrum var. *drummondii* (Drummond's maple)	Saltwater intrusion
Boehmeria cylindrica (smallspike false nettle)	*Distichlis spicata* (saltgrass)
Crinum americanum (seven sisters)	*Iva frutescens* (Jesuit's bark)
Fraxinus caroliniana (Carolina ash)	*Panicum repens* (torpedo grass)
Fraxinus profunda (pumpkin ash)	*Schoenoplectus americanus* (chairmaker's bulrush)
Hymenocallis occidentalis var. *occidentalis* (northern spiderlily)	*Bolboschoenus robustus* (sturdy bulrush)
Iris virginica (Virginia iris)	*Spartina alterniflora* (smooth cordgrass)
Juncus effusus (common rush)	*Spartina patens* (saltmeadow cordgrass)
Nyssa aquatica (water tupelo)	*Symphyotrichum subulatum* (eastern annual saltmarsh aster)
Nyssa biflora (swamp tupelo)	*Symphyotrichum tenuifolium* (perennial saltmarsh aster)
Phanopyrum gymnocarpon (savanna-panicgrass)	All other species with a salinity score of 2.75 and above (Visser and others, 2002)
Quercus spp. (oak)	Flood stress
Sagittaria latifolia (broadleaf arrowhead)	*Bacopa monnieri* (herb of grace)
Saururus cernuus (lizard's tail)	*Bidens laevis* (smooth beggartick)
Tradescantia ohiensis (bluejacket)	*Habenaria repens* (waterspider bog orchid)
Taxodium distichum (bald cypress)	*Hydrocotyle ranunculoides* (floating marshpennywort)
	Ludwigia peploides (floating primrose-willow)
	Pontederia cordata (pickerelweed)
	Sacciolepis striata (American cupscale)
	Schoenoplectus californicus (California bulrush)
	Typha spp. (cattail)
	Zizaniopsis miliacea (giant cutgrass)
	Disturbance/transition to marsh
	Amaranthus australis (southern amaranth)
	Cephalanthus occidentalis (common buttonbush)
	Eleocharis sp. (spikerush)
	Ludwigia sp. (primrose-willow)
	Salix nigra (black willow)
	Sesbania drummondii (poisonbean)
	Sesbania herbacea (bigpod sesbania)
	Triadica sebifera (Chinese tallow)

The individual species within a single 2- by 2-m station were categorized into positive, negative, or inert percentages of indicator type present and then averaged at the herbaceous vegetation plot level and then again at the 20- by 20-m station level to spatially correspond to the other constituents of the FFQI. The indicator species percent cover theoretically ranged from 100 percent positive to 100 percent negative with all possible intermediate states.

The ISM was given the same weight as the CCM with 100 percent positive indicator species modifying the base FFQI by 1.25, whereas a 100 percent cover of negative indicator species would reduce the base FFQI by as much as

25 percent (fig. 3). After the base FFQI was modified via the CCM and the ISM, the new FFQI scores were rescaled by the maximum station level value, thereby creating a 0–100 FFQI scale.

$$ISM = 0.75 + 0.0025 * Percent\ Net\ Indicator\ Species \quad (4)$$

This approach allows the FFQI to change annually even as basal area and species composition in the overstory plots remain fixed by using the yearly collected canopy cover and herbaceous layer indicator species data.

This annual FFQI assessment generally corresponds favorably with environmental stimuli such as hurricanes, floods, and droughts, which typically occur during a single year. These data can then be used to compare across years to evaluate coastal forested wetlands at the site, basin, and restoration project scales. A simple linear regression between FFQI and FQI (bivariate fit, JMP data analysis software, ver. 11.0, SAS Institute, Inc.) was used to test for a relation between the two vegetation indices in the CRMS forested wetland sites for the survey year 2015. The vegetation survey year 2015 was chosen because it is the most recent dataset to contain both herbaceous layer and the full suite of forested data from the entire CRMS network.

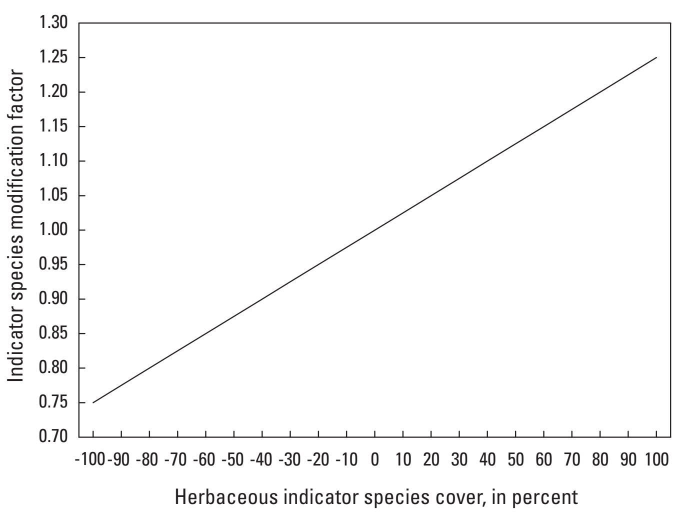

Figure 3. The relation between the herbaceous indicator species cover and the Forested Floristic Quality Index (FFQI) canopy cover modification factor. The canopy cover modifier with 100 percent positive indicator species modified the base FFQI by a modification factor of 1.25, and 100 percent cover of negative indicator species reduced the base FFQI by a modification factor of 0.25.

Results

The CRMS station level FFQI scores during the 2015 survey year ranged from 0.00 to 100.00 with an average score of 33.15 (standard error [SE] = 1.8) across all stations surveyed (n = 170). The CRMS site level FFQI scores during the 2015 survey year ranged from 0.39 to 78.01 with an average score of 33.02 (SE = 3.05) across all sites surveyed (n = 57). The 25th quartile of the FFQI scores (n = 14) was below 11.27 and contained both emergent and degraded locations in the Atchafalaya-Vermilion and Lake Maurepas Basins, respectively. Most of the developing forested wetland sites in the lower Atchafalaya-Vermilion Basin scored in the 25th quartile, which contrasted with sites within the Lake Maurepas Basin, where the sites varied from some of the highest scores coastwide to the lowest. The 75th quartile (n = 14) had FFQI scores greater than 52.08 and comprised sites spread across the coastal forested wetlands (fig. 4). Sites within the lower quartile represent both poorly functioning CRMS forested wetland sites and newly emergent sites. The sites between the 25th and 75th quartiles (n = 29) were generally in a low to moderate state of deterioration.

The varying nature of forested wetland degradation coastwide is evident in the continuum that exists in the FFQI scores throughout the Louisiana coastal zone. CRMS sites transition between the quartiles as the physical characteristics of the local environment change, which in many cases is evident in the appearance of the forest structure at each CRMS site (fig. 5). The 25th through 50th quartile grouping illustrates the general lack of a complete overstory canopy, typically with ample herbaceous layer vegetation (fig. 5*B*). The more densely wooded 75th quartile maintains noticeably larger canopy structure reducing the amount of growing season sunlight at the forest floor (fig. 5*C*). The more open 25th quartile has a savanna-like visual aspect that generally contains relic individual overstory trees and isolated clusters of overstory trees in areas of increased elevations, often along waterways (fig. 5*A*). This site level FFQI can be computed annually as canopy cover and indicator species data are collected by using the previously collected basal area by species, which is typically very stable on an annual basis. This allows for FFQI scores to be generated annually and not intermittently when the basal area by species is collected every third year. The average annual percent cover of positive and negative indicator species in the forested plots can display trends in the understory community composition as it relates to forest persistence (fig. 6). These individual CRMS sites can be tracked annually through time as data are collected to determine what specific vegetative attribute is generating change in the site FFQI score, whether or not basal area and species composition are static (fig. 7). However, as the Louisiana coastal zone does contain active delta formation and deterioration, the FFQI alone cannot differentiate between newly forming forests and severely degrading habitat.

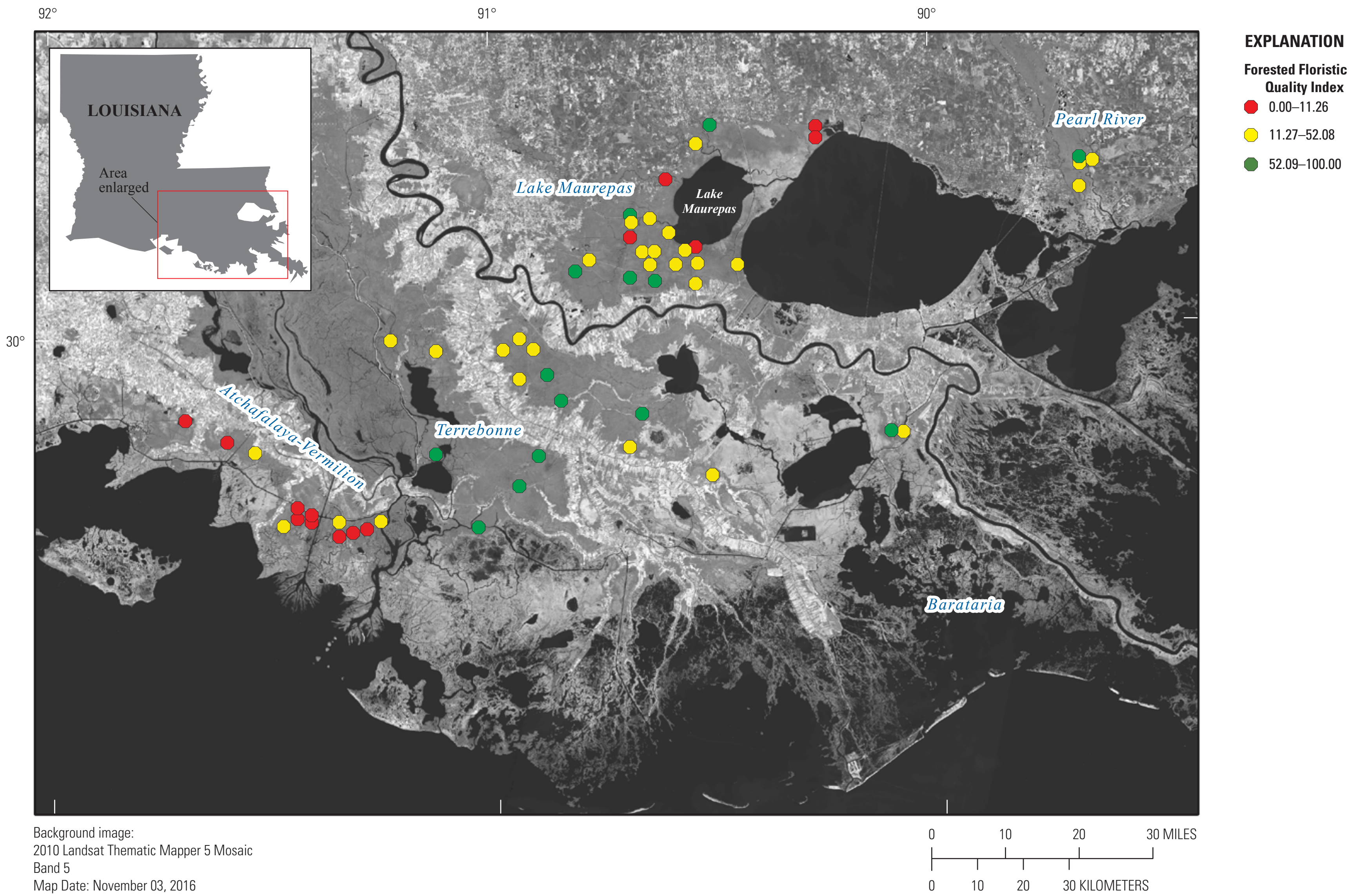

Figure 4. The Forested Floristic Quality Index (FFQI) scores for 2015 from Coastwide Reference Monitoring System forested wetland sites separated into the 25th and 75th quartiles. Most sites in the lower Atchafalaya-Vermilion Basin scored in the 25th percentile because of low basal area and presence of early successional species. Contrast this with the Lake Maurepas Basin, where the sites varied from some of the highest scores coastwide to the lowest, as saltwater intrusion, nutrient limitation, and impoundments near Lake Maurepas degrade the forest structure.

A

B

C

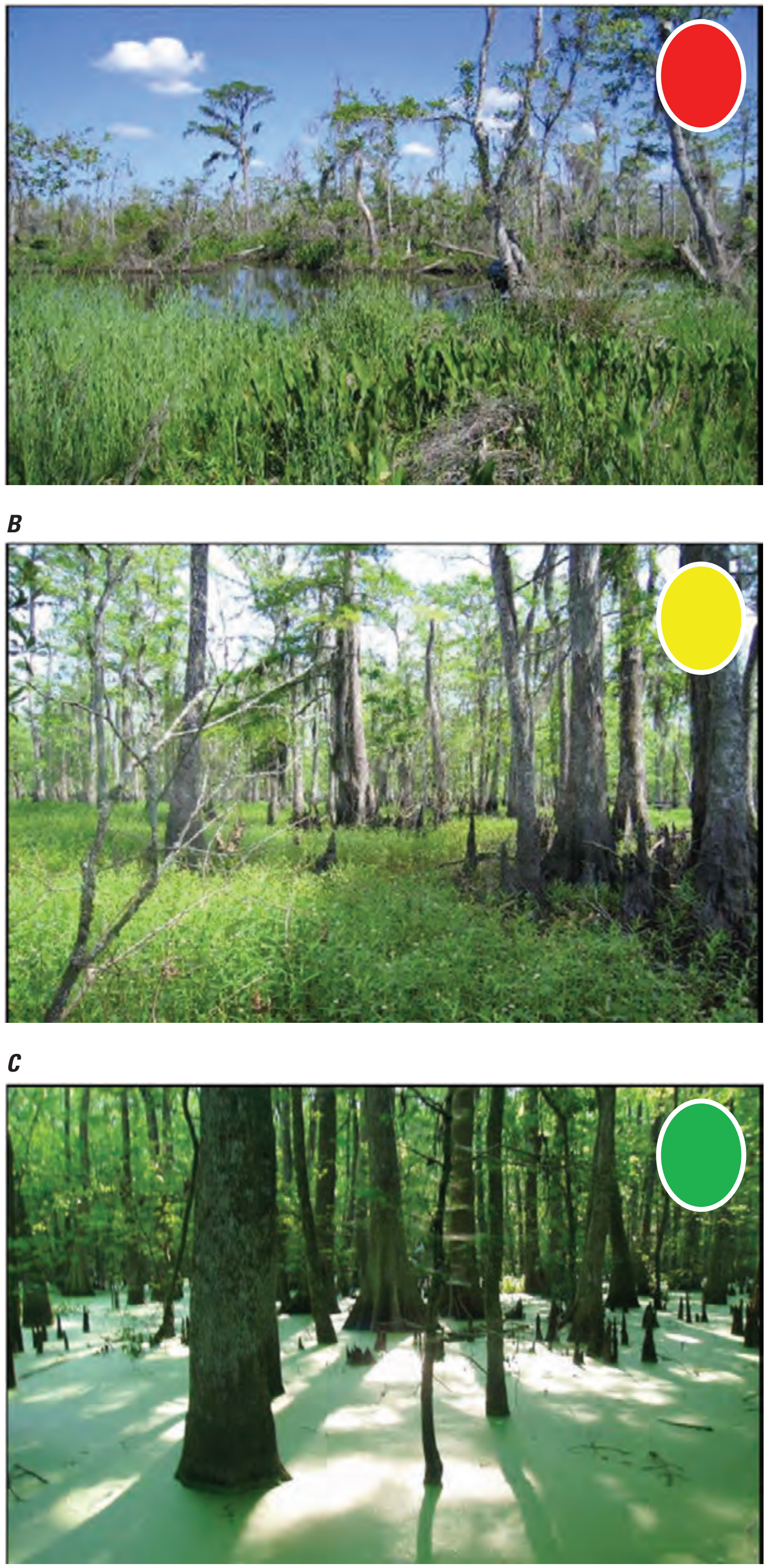

Figure 5. Coastwide Reference Monitoring System (CRMS) forested wetland sites and their associated 2015 Forested Floristic Quality Index (FFQI) scores. *A*, Site CRMS6209 and *B*, site CRMS0089 are located in the Lake Maurepas Basin and scored 0.39 (red category, 25th quartile) and 30.41 (yellow category, 25th–75th quartile), respectively. *C*, Site CRMS5672 is located within the Barataria Basin and received an FFQI score of 53.16 (green category, 75th quartile).

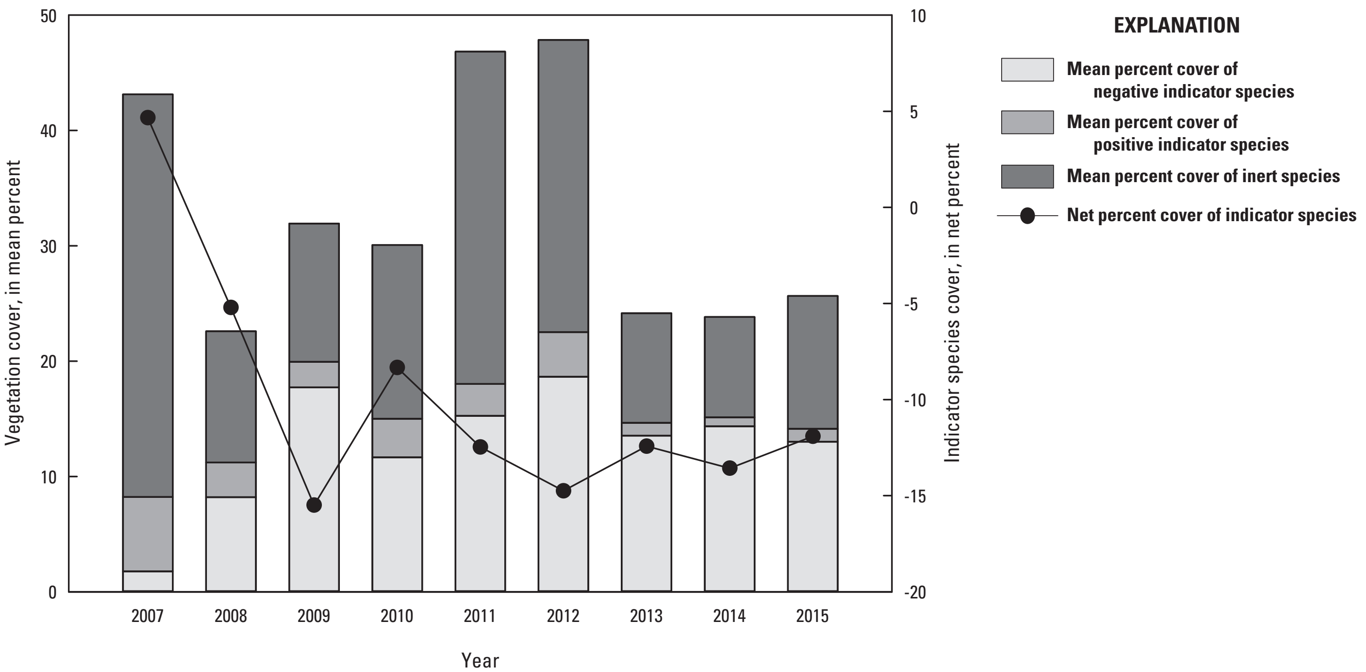

Figure 6. Mean percent cover of positive, negative, and inert indicator vegetation species and net percent cover of indicator vegetation species from site CRMS0089 within the Lake Maurepas Basin from 2007 to 2015. The herbaceous layer community at the forest floor shows a trend towards recruitment of negative indicator species through time.

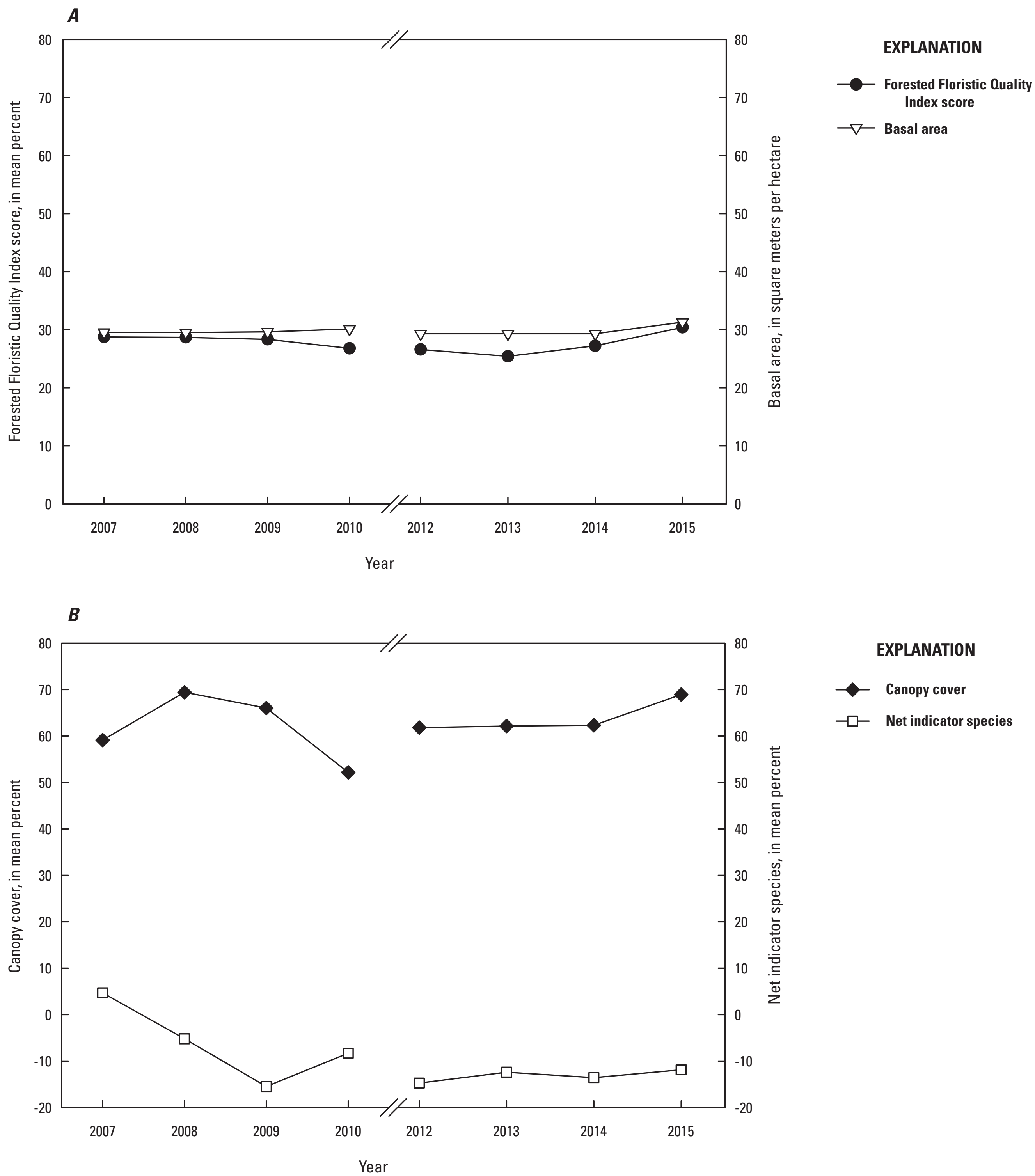

Figure 7. Data from site CRMS0089 within the Lake Maurepas Basin. *A*, The Forested Floristic Quality Index (FFQI) score and basal area from 2007 to 2015. *B*, Canopy cover and net indicator species cover from 2007 to 2015. Data from 2011 were lacking and therefore are not presented.

The distribution of CRMS forested wetland sites reached a maximum FFQI value of 78.01 for the 2015 site averages, although higher values (100.0) were recorded at the station level. There were no CRMS forested wetland sites containing 100 percent *Taxodium distichum* (bald cypress) monocultures with 80 m^2/ha basal area, full canopies, and 100 percent cover of positive herbaceous indicator species in any of the three 20- by 20-m overstory monitoring stations. Thus, the distribution of FFQI for CRMS sites is generally spread over the 0–80 scale that corresponds well with the lack of pristine coastal forests in the coastal zone (fig. 8). There also is an increase in the number of sites between 2007 and 2015 that scored FFQI values between the 20–30 range in the lower tail of the distribution and the 15–35 range. The higher proportion of the distribution in the lower tail highlights the general declining state of the habitat and the cross classification with emerging forested sites.

Generally a site FFQI score changes slowly over time (years), and the yearly distributions have changed little coastwide since the first CRMS forested wetland survey in 2007. However, the 2010 subset data collection reduced the lower tail of the distribution disproportionately to the upper tail, thereby causing a notable increase in the 2010 mean because only a subset of the network was sampled (fig. 9).

A simple linear regression was used to test the perceived inverse relation between the FFQI and the corresponding herbaceous-only FQI at the same CRMS forested wetland sites. The regression showed a significant negative relation between the woody and herbaceous vegetation scores ($F_{1, 56} = 23.45$, $p < 0.0001$) (fig. 10). However, the R^2 value was relatively low, 24.54 percent.

Discussion

The FFQI score at a forested wetland site is a measure of the site's structural integrity (and perhaps function) as a forested ecosystem in relation to healthy and degraded locations in the geographic region in which the data were collected. Low FFQI values in coastal Louisiana most commonly resulted from the degradation of forested wetland habitat towards a community dominated by herbaceous marsh vegetation and open water due to isolation from alluvial inputs, saltwater intrusion, impoundments, and nutrient limitation. The FFQI is one of several CRMS environmental diagnostic indices that can help to determine the ecological drivers locally and at larger spatial and temporal scales. The FFQI is the long-term reflection of the forested sites' woody response to the physicochemical variation of salinity, flooding duration, and elevation change and how these factors are expressed in the short-term changes of herbaceous vegetation and canopy structure. These variables are monitored via the CRMS network and distilled into a site's FFQI to begin exploring why restoration is necessary and if restoration is plausible in a given location. The Hydrologic Index (HI) is a valuable ancillary index that combines percent time flooded with weighted average annual salinity by vegetation type to generate an index comparable across site, project, and basin (Snedden and Swenson, 2012). The HI is calculated on an annual basis and is acting at a temporal scale that the woody vegetation that produces the base FFQI cannot respond to in a synchronized manner. However, the inclusion of indicator species in the herbaceous layer and overstory CCMs allows these indices to be more temporally linked, potentially responding in concert.

The FFQI must eventually react to chronic flooding and salinity, but it may do so multiple years after an event or only after several growing seasons of chronic stress. The severity of these responses also depends on the available nutrients and movement of the surface water. However, the herbaceous vegetation that is used in the FQI will respond in a much shorter timeframe to metrics of change, such as the HI. This relation of FFQI and FQI is largely driven by the effect of the hydrologic regimes on the vegetation and the subsequent light availability at the forest floor. The FFQI and the FQI are inversely correlated to one another when a continuum of forested wetland degradation is assessed, as basal area and stable late stage successional woody species are replaced with more disturbance-oriented shrubs and multiple herbaceous vegetation communities that change depending on the cause of habitat transition and light availability. There also are many subtle relations between the two indices on a specific scale. For example, an upward trend in FQI coupled with a stable FFQI score over time may indicate that the location is losing sapling and midstory stems while maintaining the overstory trees, thereby beginning the transition towards more herbaceous vegetation. Alternatively, sites with low but increasing FFQI scores may be indicative of a succession from a marsh or shrub-scrub community towards a forested wetland, either through natural processes or as a consequence of restoration activities. This also may be reflected in site-specific Submergence Vulnerability Index (SVI), which is a measure of the sites' net elevation change compared to the site-specific hydrologic prism provided at all applicable CRMS sites (Stagg and others, 2013). An increase in elevation with most other environmental constituents remaining constant would generate a floral shift to shrub-scrub, midstory, and possibly canopy tree establishment (Johnson and others, 1985; Shaffer and others, 1992). This trend is seen to some degree in the FFQI, FQI, and the SVI in the CRMS forested wetland sites of the Atchafalaya-Vermilion Basin. As sediment accumulates in fresh marshes, the herbaceous vegetation transitions to woody vegetation as seeds germinate and seedlings colonize new sediments. However, this is an uncommon trajectory in the CRMS network and coastal wetlands of Louisiana; the vast majority of sites are subsiding and becoming increasingly degraded. A steady decrease in FQI and stable FFQI scores could suggest that herbaceous vegetation quality in an area is declining either through natural succession towards a mature forested community or through disturbance and (or) restoration activities meant to encourage tree colonization and growth.

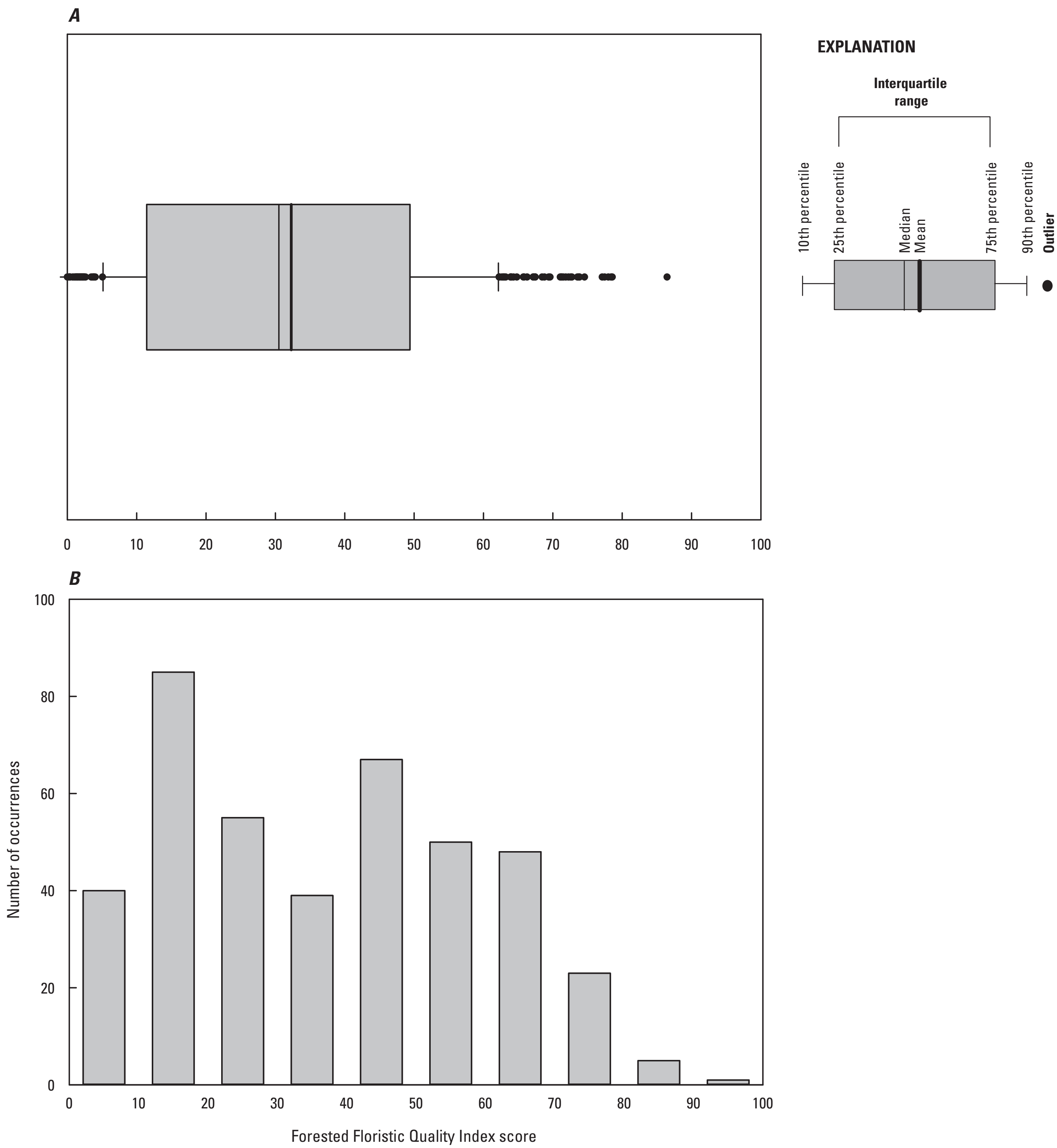

Figure 8. *A*, The overall distribution of the Forested Floristic Quality Index (FFQI) site scores from 2007 to 2015. Data from 2011 were lacking and therefore are not presented. *B*, The number of occurrences of FFQI scores. Sites with low FFQI scores generally represent systems that are transitioning away from a mature forest community but rarely also reflect emergent forests of the Atchafalaya-Vermilion Basin.

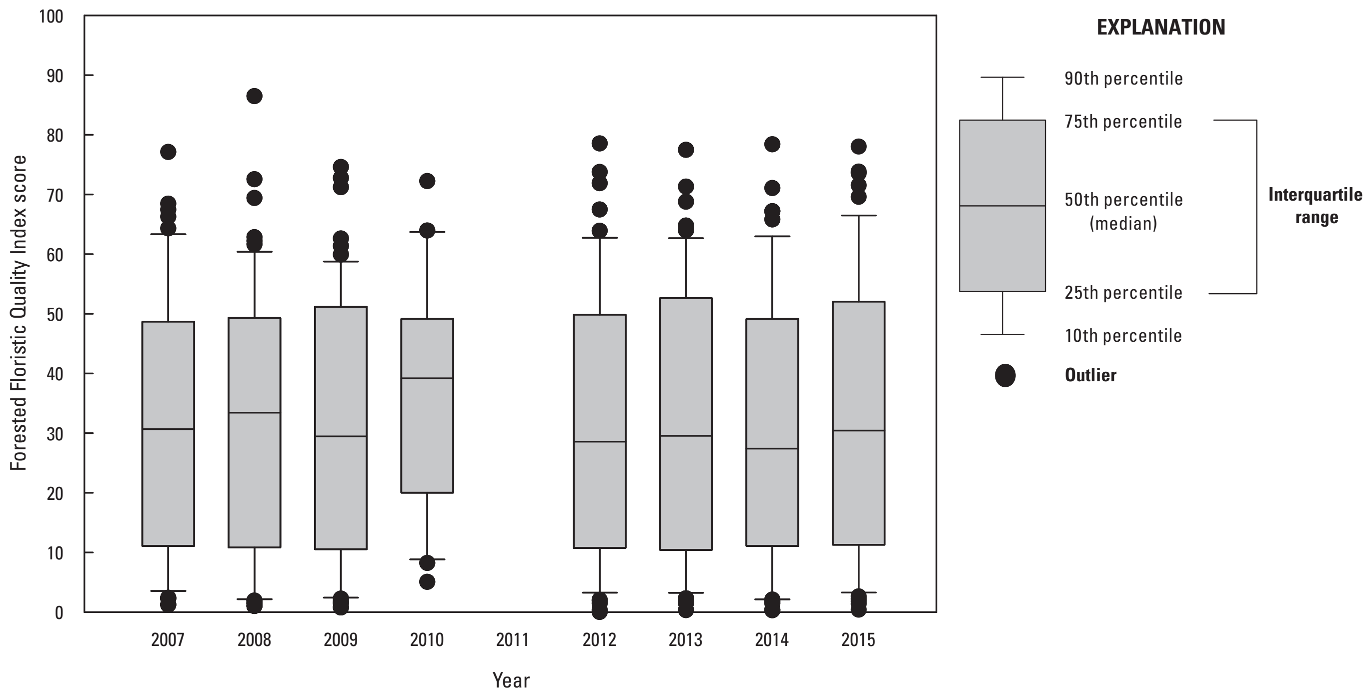

Figure 9. The distribution of the Forested Floristic Quality Index (FFQI) scores at Coastwide Reference Monitoring System (CRMS) forested wetland sites coastwide from 2007 to 2015. The 2010 dataset has an abbreviated distribution because of the sampling of a subset (n = 22) of the total CRMS forested wetland site network that year. Data from 2011 were lacking and therefore are not presented.

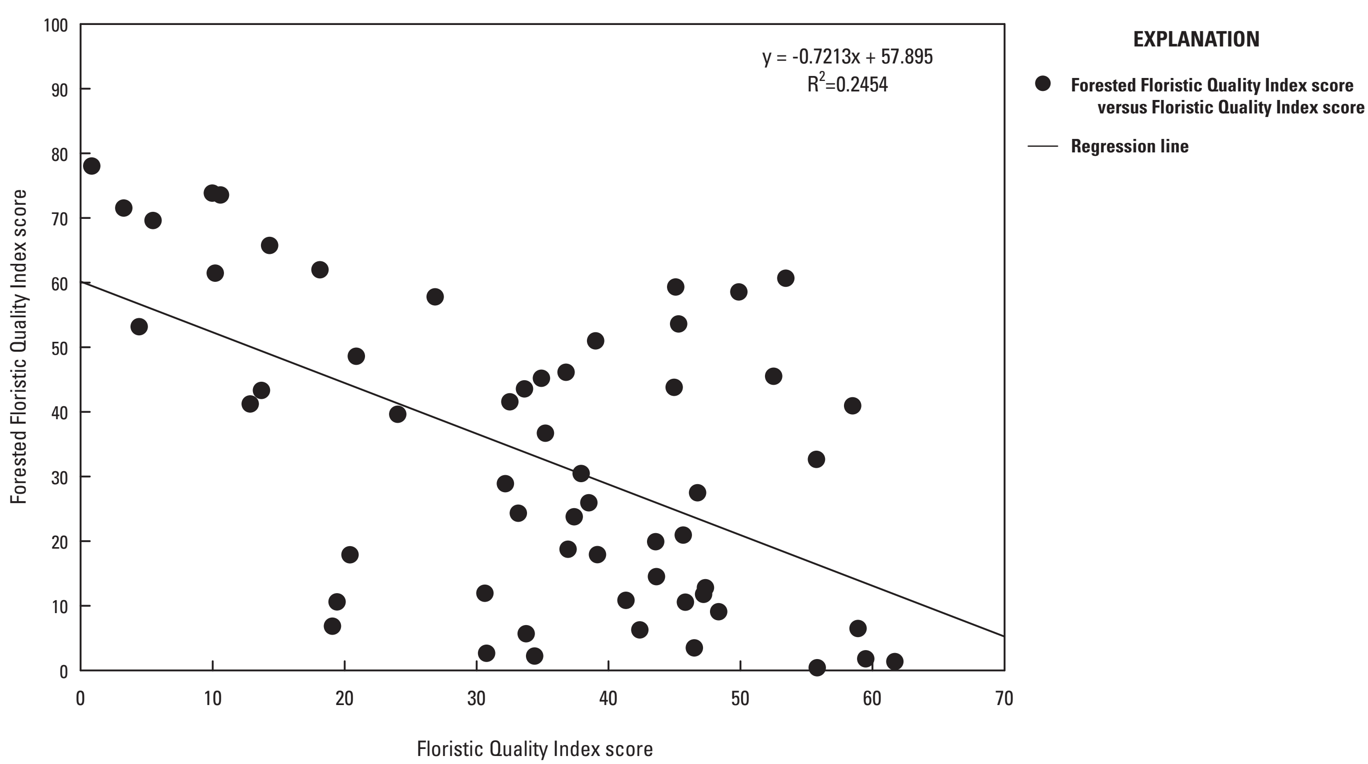

Figure 10. The relation between the Forested Floristic Quality Index (FFQI) score and the Floristic Quality Index (FQI) score. A significant negative correlation exists between the two vegetation indices: as the FFQI decreases, the FQI increases, thereby depicting a transitional habitat.

However, the more consistent pattern of slow decrease in FFQI scores at many CRMS sites is the standard given the overall decline in forested wetland habitat area that has been observed in recent decades (Conner and Toliver, 1990; Effler and Goyer, 2006; Shaffer and others, 2009; Hoeppner and Rose, 2011). The FFQI is a valuable tool for assessing the health of Louisiana's swamps. When used in conjunction with other biotic and physical parameters provided through the CRMS network, the FFQI can be used to examine the trajectory of forested wetland habitat change, direct restoration efforts, and monitor the effectiveness of restoration activities.

Implementation of the FFQI will give the coastal restoration community a tool to identify, design, and implement cost-effective restoration projects in forested wetlands. Assigning an FFQI value to every CRMS forested wetland site similar to the FQI in marsh sites will allow for more rapid site assessment. By using the FFQI, FQI, and other CRMS report card indices, project managers, team members, and the public will be able to evaluate project and reference areas to determine if restoration projects are performing as designed. As data become available, the trajectory of site, project, basin, and coastwide forested wetlands will be posted on the CRMS website. Areas not targeted for restoration can be efficiently monitored on an annual basis to determine if intervention is required to reverse a trajectory away from ecosystem collapse. This tool will compile data collected onsite, thereby allowing restoration efforts to have identified performance criteria for comparing failing forested wetlands to highly productive forested wetlands. Although the FFQI was developed for application to CRMS data, it has the utility to be modified for many coastal forested wetland systems worldwide.

References Cited

Andreas, B.K., and Lichvar, R.W., 1995, Floristic index for assessment standards—A case study for northern Ohio: Vicksburg, Mississippi, U.S. Army Corps of Engineers Waterways Experiment Station, Wetlands Research Program Technical Report WRP–DE–8, 14 p.

Andreas, B.K., Mack, J.J., and McCormac, J.J., 2004, Floristic quality assessment index (FQAI) for vascular plants and mosses for the State of Ohio: Columbus, Ohio Environmental Protection Agency, Division of Surface Water, Wetland Ecology Group, 217 p.

Barras, J.A., Bourgeois, P.E., and Handley, L.R., 1994, Land loss in coastal Louisiana 1956–90: National Biological Survey, National Wetlands Research Center Open-File Report 94–01, 4 p., 10 pls.

Bourdaghs, Michael, Johnston, C.A., and Regal, R.R., 2006, Properties and performance of the floristic quality index in Great Lakes coastal wetlands: Wetlands, v. 26, p. 718–735.

Cohen, M.J., Carstenn, S., and Lane, C.R., 2004, Floristic quality indices for biotic assessment of depressional marsh condition in Florida: Ecological Applications, v. 14, p. 784–794.

Conner, W.H., and Brody, Michael, 1989, Rising water levels and the future of southeastern Louisiana swamp forests: Estuaries, v. 12, p. 318–323.

Conner, W.H., and Day, J.W., Jr., 1992a, Water level variability and litterfall productivity of forested freshwater wetlands in Louisiana: American Midland Naturalist, v. 128, p. 237–245.

Conner, W.H., and Day, J.W., Jr., 1992b, Diameter growth of *Taxodium distichum* (L.) Rich. and *Nyssa aquatica* L. from 1979–1985 in four Louisiana swamp stands: American Midland Naturalist, v. 127, p. 290–299.

Conner, W.H., Gosselink, J.G., and Parrondo, R.T., 1981, Comparison of the vegetation of three Louisiana swamp sites with different flooding regimes: American Journal of Botany, v. 68, p. 320–331.

Conner, W.H., McLeod, K.W., and McCarron, J.K., 1997, Flooding and salinity effects on growth and survival of four common forested wetland species: Wetlands Ecology and Management, v. 5, p. 99–109.

Conner, W.H., Mihalia, Ioana, and Wolfe, Jeff, 2002, Tree community structure and changes from 1987 to 1999 in three Louisiana and three South Carolina forested wetlands: Wetlands, v. 22, p. 58–70.

Conner, W.H., and Toliver, J.R., 1990, Long-term trends in the bald-cypress (*Taxodium distichum*) resource in Louisiana (U.S.A): Forest Ecology and Management, v. 33–34, p. 543–557.

Conner, W.H., Toliver, J.R., and Sklar, F.H., 1986, Natural regeneration of baldcypress (*Taxodium distichum* (L.) Rich.) in a Louisiana swamp: Forest Ecology and Management, v. 14, p. 305–317.

Cretini, K.F., Visser, J.M., Krauss, K.W., and Steyer, G.D., 2011, CRMS vegetation analytical framework—Methods for data collection, development, and use of vegetation response variables: U.S. Geological Survey Open-File Report 2011–1097, 60 p.

Cretini, K.F., Visser, J.M., Krauss, K.W., and Steyer, G.D., 2012, Development and use of a floristic quality index for coastal Louisiana marshes: Environmental Monitoring and Assessment, v. 184, p. 2389–2403.

Day, J.W., Jr., Shaffer, G.P., Britsch, L.D., Reed, D.J., Hawes, S.R., and Cahoon, Donald, 2000, Pattern and process of land loss in the Louisiana coastal zone—An analysis of spatial and temporal patterns of wetland habitat change: Estuaries, v. 23, p. 425–438.

Dickson, R.E., and Broyer, T.C., 1972, Effects of aeration, water supply, and nitrogen source on growth and development of tupelo gum and bald cypress: Ecology, v. 53, p. 626–634.

Effler, R.S., and Goyer, R.A., 2006, Baldcypress and water tupelo sapling response to multiple stress agents and reforestation implications for Louisiana swamps: Forest Ecology and Management, v. 226, p. 330–340.

Folse, T.M., West, J.L., Hymel, M.K., Troutman, J.P., Sharp, L.A., Weifenbach, D., McGinnis, T.E., Rodrigue, L.B., Boshart, W.M., Richardi, D.C., Miller, C.M., and Wood, W.B., 2012, A standard operating procedures manual for the Coast-wide Reference Monitoring System-Wetlands—Methods for site establishment, data collection, and quality assurance/quality control: Baton Rouge, Louisiana Coastal Protection and Restoration Authority, 207 p. [Revised 2014.]

Herman, B.D., 2005, Testing the floristic quality assessment index in natural and created wetlands in Mississippi, USA: Mississippi State, Mississippi State University, M.S. thesis.

Hesse, I.D., Day, J.W., Jr., and Doyle, T.W., 1998, Long-term growth enhancement of baldcypress (*Taxodium distichum*) from municipal wastewater application: Environmental Management, v. 22, p. 119–127.

Hoeppner, S.S., and Rose, K.A., 2011, Individual-based modeling of flooding and salinity effects on a coastal swamp forest: Ecological Modeling, v. 222, p. 3541–3558.

Johnson, W.B., Sasser, C.E., and Gosselink, J.G., 1985, Succession of vegetation in an evolving river delta, Atchafalaya Bay, Louisiana: Journal of Ecology, v. 73, p. 973–986.

Krauss, K.W., Duberstein, J.A., Doyle, T.W., Conner, W.H., Day, R.H., Inabinette, L.W., and Whitbeck, J.L., 2009, Site condition, structure, and growth of baldcypress along tidal/non-tidal salinity gradients: Wetlands, v. 29, p. 505–519.

Lane, R.R., Mashriqui, H.S., Kemp, G.P., Day, J.W., Jr., Day, J.N., and Hamilton, A., 2003, Potential nitrate removal from a river diversion into a Mississippi delta forested wetland: Ecological Engineering, v. 20, p. 237–249.

Lopez, R.D., and Fennessy, M.S., 2002, Testing the floristic quality assessment index as an indicator of wetland condition: Ecological Applications, v. 12, p. 487–497.

Myers, R.S., Shaffer, G.P., and Llewellyn, D.W., 1995, Baldcypress (*Taxodium distichum* (L.) Rich.) restoration in southeast Louisiana—Relative effects of herbivory, flooding, competition, and macronutrients: Wetlands, v. 15, p. 141–148.

Nyman, J.A., 2014, Integrated successional ecology and the delta lobe cycle in wetland research and restoration: Estuaries and Coasts, v. 37, p. 1490–1505.

Shaffer, G.P., Sasser, C.E., Gosselink, J.G., and Rejmanek, Marcel, 1992, Vegetation dynamics in the emerging Atchafalaya Delta, Louisiana, USA: Journal of Ecology, v. 80, p. 677–687.

Shaffer, G.P., Wood, W.B., Hoeppner, S.S., Perkins, T.E., Zoller, Jason, and Kandalepas, Demetra, 2009, Degradation of baldcypress-water tupelo swamp to marsh and open water in southeastern Louisiana, U.S.A.—An irreversible trajectory?: Journal of Coastal Research, v. 54, p. 152–165.

Snedden, G.A., and Swenson, E.M., 2012, Hydrologic index development and application to selected Coastwide Reference Monitoring System sites and Coastal Wetlands Planning, Protection and Restoration Act projects: U.S. Geological Survey Open-File Report 2012–1122, 25 p.

Stagg, C.L., Sharp, L.A., McGinnis, T.E., and Snedden, G.A., 2013, Submergence Vulnerability Index development and application to Coastwide Reference Monitoring System sites and Coastal Wetlands Planning, Protection and Restoration Act projects: U.S. Geological Survey Open-File Report 2013–1163, 12 p.

Steyer, G.D., Sasser, C.E., Visser, J.M., Swenson, E.M., Nyman, J.A., and Raynie, R.C., 2003, A proposed coast-wide reference monitoring system for evaluating wetland restoration trajectories in Louisiana: Environmental Monitoring and Assessment, v. 81, p. 107–117.

U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service, 2013, Federal standards and procedures for the National Watershed Boundary Dataset (WBD) (4th ed.): U.S. Geological Survey Techniques and Methods 11–A3, 63 p., accessed November 3, 2016, at http://pubs.usgs.gov/tm/tm11a3/.

Visser, J.M., and Sasser, C.E., 1995, Changes in tree species composition, structure and growth in a bald cypress-water tupelo swamp forest, 1980–1990: Forest Ecology and Management, v. 72, p. 119–129.

Visser, J.M., Sasser, C.E., Chabreck, R.H., and Linscombe, R.G., 2002, The impact of a severe drought on the vegetation of a subtropical estuary: Estuaries, v. 25, p. 1184–1195.

Publishing support provided by
Lafayette Publishing Service Center

Wood and others—**Forested Floristic Quality Index: An Assessment Tool for Forested Wetland Habitats at CRMS Vegetation Monitoring Stations**—OFR 2017–1002

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20171002