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Coastwide Reference Monitoring System (CRMS) Vegetation Volume Index: An Assessment Tool for Marsh Habitat Focused on the Three-Dimensional Structure at CRMS Vegetation Monitoring Stations

Open-File Report 2015–1206

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

Cover, Photograph showing fresh marsh at site CRMS3169, in the Barataria hydrologic basin, Louisiana, August 2014 (photograph by Brett A. Patton, U.S. Geological Survey).

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SALLY JEWELL, Secretary

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

U.S. Geological Survey, Reston, Virginia: 2015

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Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as
°F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as
°C = (°F – 32) / 1.8.

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Coastwide Reference Monitoring System (CRMS) Vegetation Volume Index: An Assessment Tool for Marsh Habitat Focused on the Three-Dimensional Structure at CRMS Vegetation Monitoring Stations

By William B. Wood,[1] Jenneke M. Visser,[2] Sarai C. Piazza,[3] Leigh Anne Sharp,[1] Laura C. Hundy,[2] and Tommy E. McGinnis[1]

Abstract

A Vegetation Volume (VV) variable and Vegetation Volume Index (VVI) have been developed for the Coastwide Reference Monitoring System (CRMS). The VV is a measure of the amount of three-dimensional vegetative structure present at each CRMS site and is based on vegetation data collected annually. The VV uses 10 stations per CRMS site to quantify four vegetation layers: carpet, herbaceous, shrub, and tree. For each layer an overall live vegetation percent cover and height are collected to create a layer volume; the individual layer volumes are then summed to generate a site vegetation volume profile. The VV uses the two-dimensional area of live vegetative cover (in square meters) multiplied by the height (in meters) of each layer to produce a volume (in cubic meters) for each layer present in a 2-meter by 2-meter station. These layers are additive, yielding a total volume for each of the 10 herbaceous vegetation stations and an overall CRMS marsh site average.

The VV is an assessment of the quantity of vegetation present and is directly related to plant community structure. The VV differs from the previously developed Floristic Quality Index (FQI) in that the VV makes no assumptions about vegetation quality, giving each species equal weight; the FQI scores species with consistent site fidelity more favorably. We adapted the VV data into the VVI, which creates a representative score for all coastal marsh types. A VV and VVI will be generated annually for CRMS site, project, and basin-level analysis. The index is designed to assess areas undergoing habitat conversion, creation, and disturbance and to document project effectiveness when goals are to create, increase, or maintain emergent vegetation.

The VV and VVI will be used to establish trends, to make comparisons, and to evaluate restoration projects. Assessments that rely on the VVI will be included in appropriate Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) project reports and analyses. Implementation of the VVI will give coastal managers a new tool to design, implement, and monitor coastal restoration projects. A yearly trajectory of site, project, basin, and coastwide VVI will be posted on the CRMS Web site as data are collected. The primary purpose of the tool is to assess CWPPRA restoration project effectiveness, but it will also be useful in identifying areas in need of restoration and in coastwide vegetation assessments.

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Introduction

The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) is Federal legislation enacted in 1990 that is designed to identify, prepare, fund, implement, and monitor coastal wetland restoration projects (http://www.lacoast.gov/). In 2006, the Coastwide Reference Monitoring System (CRMS), a network of 391 monitoring sites along the coast of Louisiana, began collecting data under CWPPRA. CRMS monitoring site selection was not based on the ecological condition of the habitat being monitored; thus, a range of conditions exist within the monitoring network. CRMS monitoring sites are located within five wetland habitat types (that is, freshwater, intermediate, brackish, and saline marshes and forested wetlands) in order to ecologically characterize the Louisiana coast (Sasser and others, 2008). Monitoring sites are also located within and outside of CWPPRA restoration project boundaries. Sites located outside of project areas can be used as references against which to evaluate the effectiveness of CWPPRA restoration projects. The monitoring program classifies sites based on wetland habitat type (vegetation type), basin location, and location within restoration project or nonrestoration project areas (Steyer and others, 2003). Data collected at the CRMS site level have been used to develop indices for vegetation, hydrology, and soils in order to (1) evaluate restoration project effectiveness by using comparisons to a network of reference sites, (2) identify landscape-level trends within the discrete habitat types or basins, and (3) identify long-term and seasonal trends in coastwide conditions.

The emergent vegetation present in wetland habitats is controlled by environmental factors such as flooding, salinity, nutrient availability, and soil physicochemical characteristics (Baldwin and Mendelssohn, 1998; Shaffer and others, 2009; Wiseman and others, 1990). Changes in plant community composition thus can indicate change in landscape physical conditions (Day and others, 2011; Temmermann and others, 2012). The scope of this document is limited to data associated with the marsh vegetation component of the CRMS monitoring system and therefore excludes data from forested wetland sites.

Previous CRMS analyses have used the Floristic Quality Index (FQI) to assess the condition of a wetland area based on the plant community composition (Cretini and others, 2012). 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 local flora by regional plant experts (Chabreck and Linscombe, 1982). Scores for each species are assigned according to their specificity to a particular habitat type and temporal stability (Cretini and others, 2011). Species that are prominent after disturbances and display low habitat specificity were assigned a low CC score, whereas species that are highly habitat specific received a high CC score. The FQI can thus be used to detect and monitor changes in wetland conditions related to acute disturbances like storms or long-term disturbance events such as alterations in local hydrology, eutrophication, or habitat fragmentation (FitzGerald and others, 2008; Hatton and others, 1983).

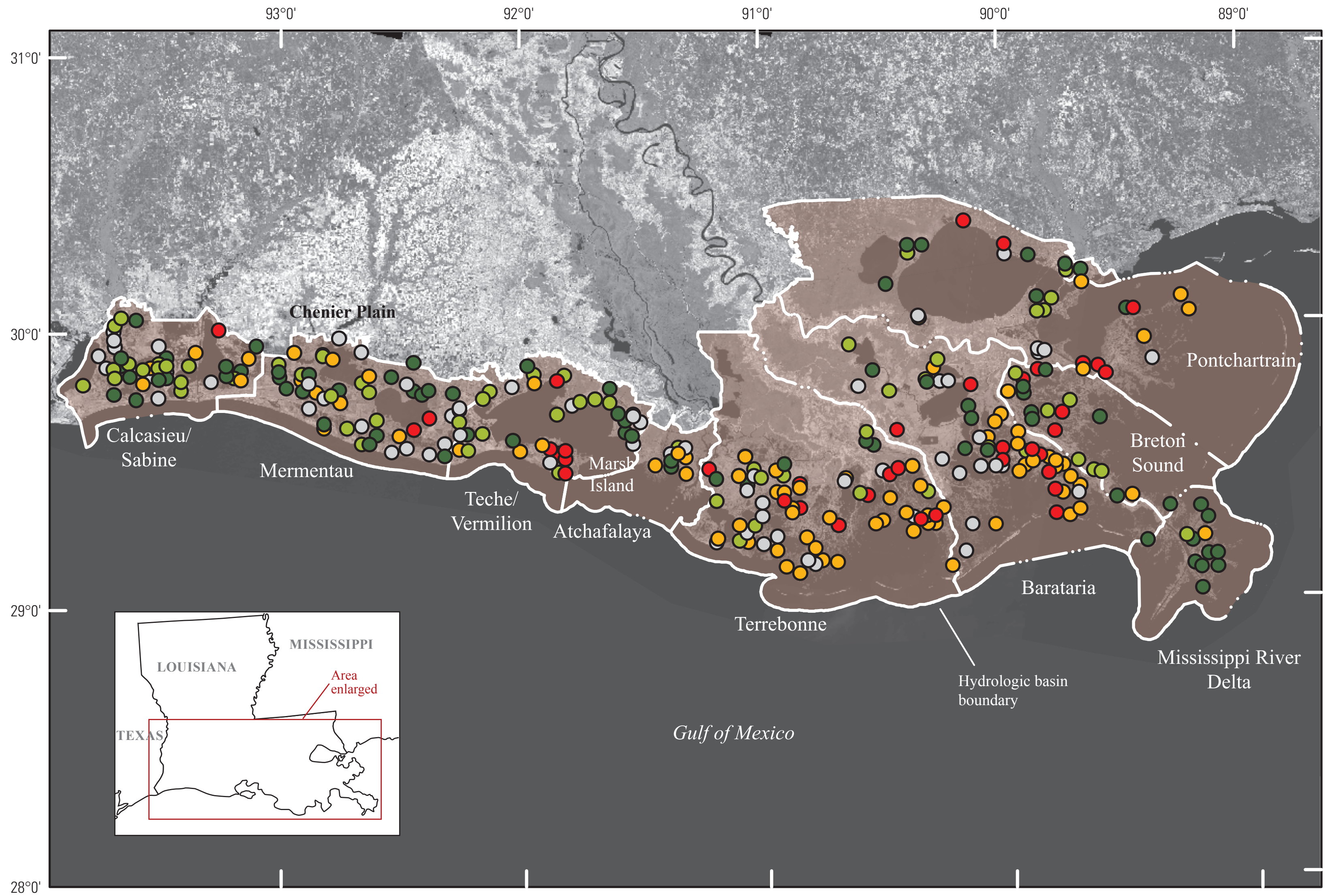
In contrast to the FQI, the Vegetation Volume (VV) variable quantifies the amount of vegetation within each site without consideration of vegetation type, species, or quality. The VV thus provides a surrogate measure of aboveground three-dimensional structure that can be compared among CRMS sites. The VV does not differentiate between newly created marshes, either naturally formed or man-made, and existing established marsh if the VV values are similar. The layer height component of the CRMS dataset is used to indicate the vigor of vegetation layers under its local environmental parameters. Thus, the VV can be used to determine the functional performance of similar marsh types under varying levels of degradation or restoration (Mayence and Hester, 2010; McKee and Mendelssohn, 1989). Further, changes in VV may have important implications for the ecosystem services provided by coastal marshes, such as storm surge reduction and detrital food chain support.

Organizing the CRMS site data into multiple, easily comparable datasets assists in the planning and performance evaluation of CWPPRA projects. The VV has been further refined into the Vegetation Volume Index (VVI), which ranges from 1 to 100 as a standardized score of the three-dimensional vegetation quantity. This approach allows data users to systematically investigate site, project, hydrologic basin, and coastwide scales for vegetation structure and compare the VVI value directly to other CRMS site data indices such as the FQI, the Hydrologic Index, and the Submergence Vulnerability Index. The VVI should be used in coordination with the other CRMS data derived indices by marsh type to determine overall ecological performance. For example, the Hydrologic Index, which combines the weighted average annual salinity and percent time flooded by marsh type, also generates a 0–100 site index value (Snedden and Swenson, 2012). This index is then further broken down within a CRMS site report card into the 25th and 75th quartile to frame where a specific CRMS site, project, or basin occurs in the overall coastwide population within a specific marsh type annually (http://www.lacoast.gov/crms2). Similar methodology is in place for the FQI and the Submergence Vulnerability Index, thereby allowing multiple variables to be assessed efficiently and compared to references of the same marsh type (Cretini and others, 2012; Stagg and others, 2013).

Methods

The CRMS network covers the Louisiana coastal zone with 391 1-square-kilometer (km^2) monitoring locations; each location has an imbedded 200- by 200-meter (m) data collection area. Within the data collection area a suite of physical and biological parameters are measured at varying intervals to describe the relative ecosystem function of the site. The emergent vegetation response variables were observed and recorded annually (2006–13) to document changes in vegetation assemblages associated with either natural conditions or restoration projects (Cretini and others, 2011). Monitoring sites were sampled and classified as freshwater, intermediate, brackish, or saline marsh types on the basis of the protocol outlined by Folse and others (2012). Sampling was conducted within ten 2- by 2-m (4-square-meter [m^2]) stations located randomly along a 282.2-m transect at least 3 m apart within the data collection area at each CRMS site. Within each vegetation station, the percent live cover of each plant species was visually estimated during peak standing crop (August 1 to September 30) when possible, but landowner restrictions caused estimates at some sites to fall outside of this timeframe. The total live cover within the plots and of each vegetation layer (that is, carpet, herbaceous, shrub, and tree) was visually estimated between 0 and 100 percent. Although the total live plot cover cannot exceed 100 percent, the sum of the individual species covers may exceed 100 percent because of the overlapping vegetation in the stations. Additionally, the average height (in meters) of each vegetation layer was measured in each station.

CRMS vegetation survey data from 2006 to 2013 in the four marsh types throughout the nine hydrologic basins of coastal Louisiana (fig. 1) were used to inform this model.



Base from 2014 Landsat OLI 8 Mosaic Band 5
April 15, 2015

EXPLANATION

Study area

Change in vegetation volume between 2008 and 2012, in cubic meters

- -7.4 to -1.0
- -0.9 to -0.3
- -0.2 to 0.3
- 0.4 to 1.0
- 1.1 to 9.2

0 10 20 30 40 50 60 KILOMETERS

0 10 20 30 40 50 60 MILES

Figure 1. Study area and change in vegetation volume from 2008 to 2012 in hydrologic basins in coastal Louisiana.

An annual sample size of 318 (in 2006), 493 (in 2007), 531 (in 2008), 538 (in 2009), 513 (in 2010), 556 (in 2011), 543 (in 2012), and 540 (in 2013) vegetation stations were used to calculate VV from 2006 to 2013. The vegetation cover and height data collected from each CRMS station were used to calculate a VV and a VVI for all stations from 2006 to 2013. VV for each station was calculated as the sum of the volume of each of the vegetation layers by using the following formula:

$$\text{Vegetation Volume } (m^3) = [\text{carpet layer live cover area } (m^2) \times \text{carpet layer height } (m)] + [\text{herbaceous layer live cover area } (m^2) \times \text{herbaceous layer height } (m)] + [\text{shrub layer live cover area } (m^2) \times \text{shrub layer height } (m)] + [\text{tree layer live cover area } (m^2) \times \text{tree layer height } (m)] \quad (1)$$

A CRMS site-level VV value was calculated as the average VV from the 10 stations within the CRMS site.

To index the VV variable, all individual CRMS station VVs within each marsh type were assigned a relative rank from 1 to 100 as a function of a normalized distribution across all years of the data collection. This rank represents the VVI score for each station at every site within a specific marsh type.

Changes in VV from 2006 to 2013 were compared among the four marsh types (freshwater, intermediate, brackish, and saline) and among the nine hydrologic basins that compose the Louisiana coastal zone: Atchafalaya (AT), Barataria (BA), Breton Sound (BS), Calcasieu/Sabine (CS), Mermentau (ME), Mississippi River (MR), Pontchartrain (PO), Terrebonne (TE), and Teche/Vermilion (TV).

A full factorial analysis of variance (ANOVA, JMP, version 11.0) was used to test for any significant year, marsh type, and hydrologic basin main effects on mean VV along with all possible interactions of the main effects by applying a three-way ANOVA. Tukey adjusted post hoc tests with an alpha level of 0.05 were used to determine significance

Results

Yearly Trends

The VV site values ranged from 0.0 in burned, denuded, and open water locations to 35.89 in sites dominated by robust vegetation types over the course of the study. Overall the highest VV values were found in *Phragmites australis* monocultures, whereas the lowest values with vegetation present varied between thin mat floating marsh and highly fragmented locations where a conversion to open water was prevalent. The 10th and the 90th percentiles for the entire range of the VV data collected were 1.32 and 4.39, respectively. An ANOVA on mean VV found significant differences among the 8 years ($F_{7, 2304} = 11.45$, $p < 0.0001$). The mean VV was highest in 2011 (3.61 ± 0.08; mean ± standard error) and lowest in 2006 (2.69 ± 0.17) (all means are reported as least squares unless otherwise noted). The mean VV from 2008 was significantly lower than those from all other years of the vegetation survey (fig. 2). The change in VV between 2008 and 2012 was depicted geospatially by showing specific areas of VV change and stability on a coastwide scale (fig. 1). The hydrologic basins in the Chenier Plain (Calcasieu/Sabine, Mermentau, and Teche/Vermilion) showed a substantial increase in VV, as did the Mississippi River Delta hydrologic basin. The lower portion of the Barataria hydrologic basin, the Terrebonne hydrologic basin, and Marsh Island all had reduced VV from 2008 to 2012. The year-by-basin interaction was also significant ($F_{49, 2304} = 2.94$, $p < 0.0001$), with the Mississippi River Delta hydrologic basin and the Pontchartrain hydrologic basin producing lower mean VV values during 2008 and 2006, respectively (fig. 3).

Marsh Type Trends

An ANOVA detected a significant difference in mean VV between the four marsh types ($F_{3, 2304} = 102.49$, $p < 0.0001$). Intermediate marsh mean VV (4.08 ± 0.05) was significantly greater than that of the fresh marsh (3.37 ± 0.07). Saline marsh had the lowest mean VV (2.53 ± 0.10) but did not differ from brackish marsh (2.75 ± 0.10) (fig. 4). Analysis of the relation between marsh type and year revealed no significant interaction effects. There was a trend, however, of increasing mean VV throughout the study regardless of marsh type (fig. 5). The largest variations occurred in fresh marsh and intermediate marsh, with low values during 2010 and 2008 respectively, while the other marsh types showed no major negative response over the same period.

Basin Trends

An ANOVA detected a significant main effect of hydrologic basin ($F_{7, 2304} = 33.82$, $p < 0.0001$). Mean VV was greatest in the active deltaic basins of the Mississippi and Atchafalaya Rivers: the Mississippi River Delta hydrologic basin and the Atchafalaya hydrologic basin (fig. 6). The Mermentau hydrologic basin had the lowest mean VV but did not statistically differ from the Calcasieu/Sabine hydrologic basin; the other five hydrologic basins produced similar mean VV and were not significantly different from one another. The Atchafalaya hydrologic basin was removed from the analysis because it did not contain all marsh types. The basin-by-marsh-type interaction was also significant ($F_{21, 2304} = 29.89$, $p < 0.0001$), with the largest difference in the overall trend being the extremely high mean VV of the intermediate marshes in the Mississippi River Delta hydrologic basin. Intermediate marsh dominated the overall high mean VV of the Mississippi River Delta hydrologic basin; mean VV values of the other marsh types in this basin were more in accordance with values from the other basins coastwide (fig. 7).

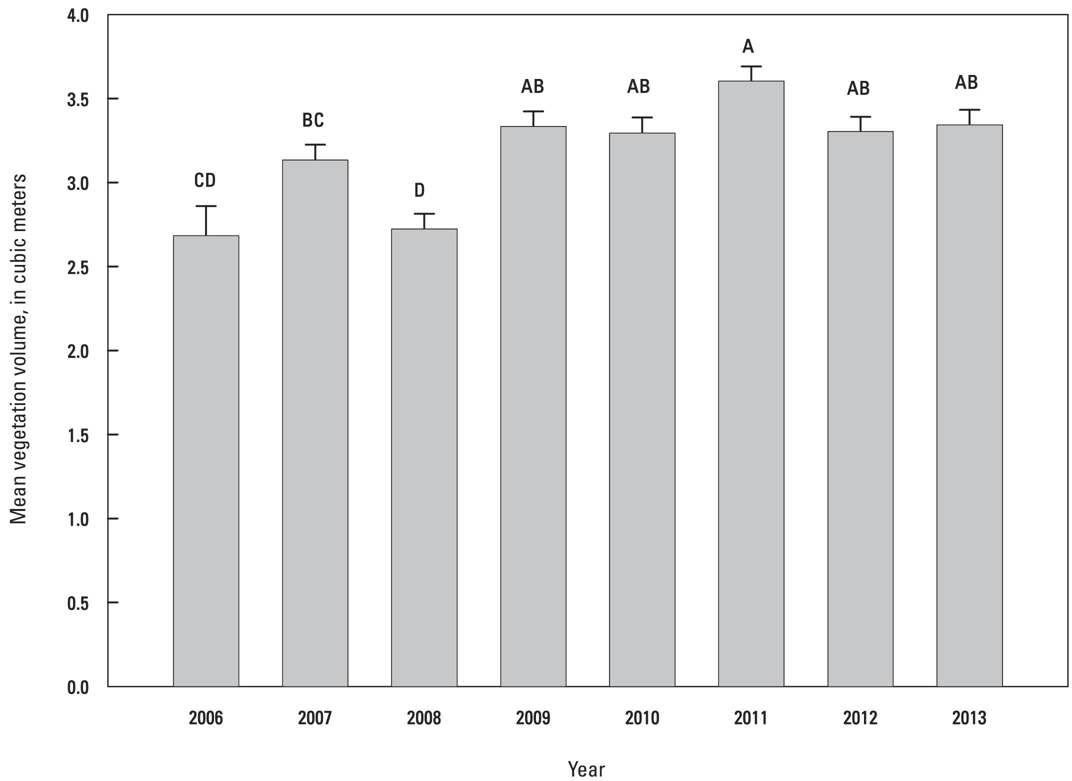


Figure 2. Vegetation volume means from 2006 to 2013 with yearly variation in average vegetation volume on a coastwide scale for hydrologic basins in coastal Louisiana. Marsh types not identified by the same letter are significantly different at p = 0.05.

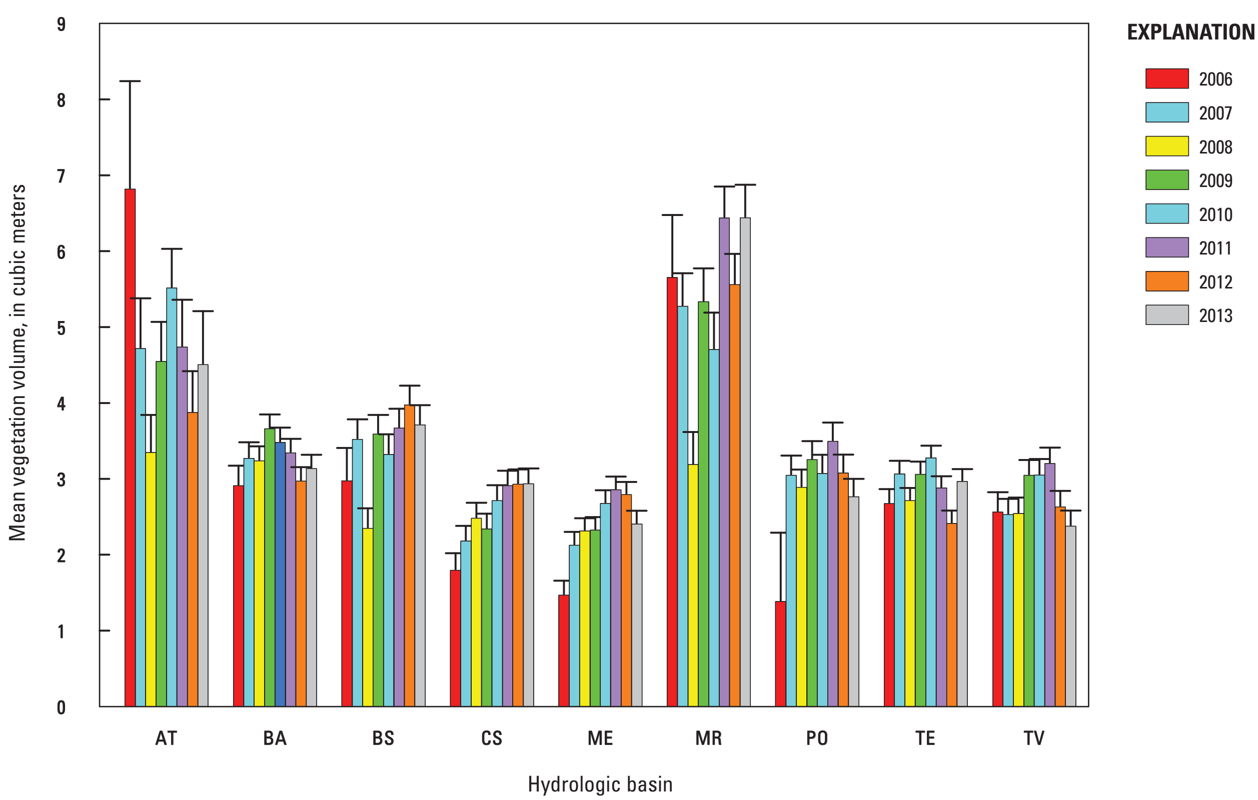


Figure 3. Vegetation volume means per hydrologic basin in coastal Louisiana over the 8-year study period from 2006 to 2013. AT, Atchafalaya; BA, Barataria; BS, Breton Sound; CS, Calcasieu/Sabine; ME, Mermentau; MR, Mississippi River Delta; PO, Pontchartrain; TE, Terrebonne; TV, Teche/Vermilion.

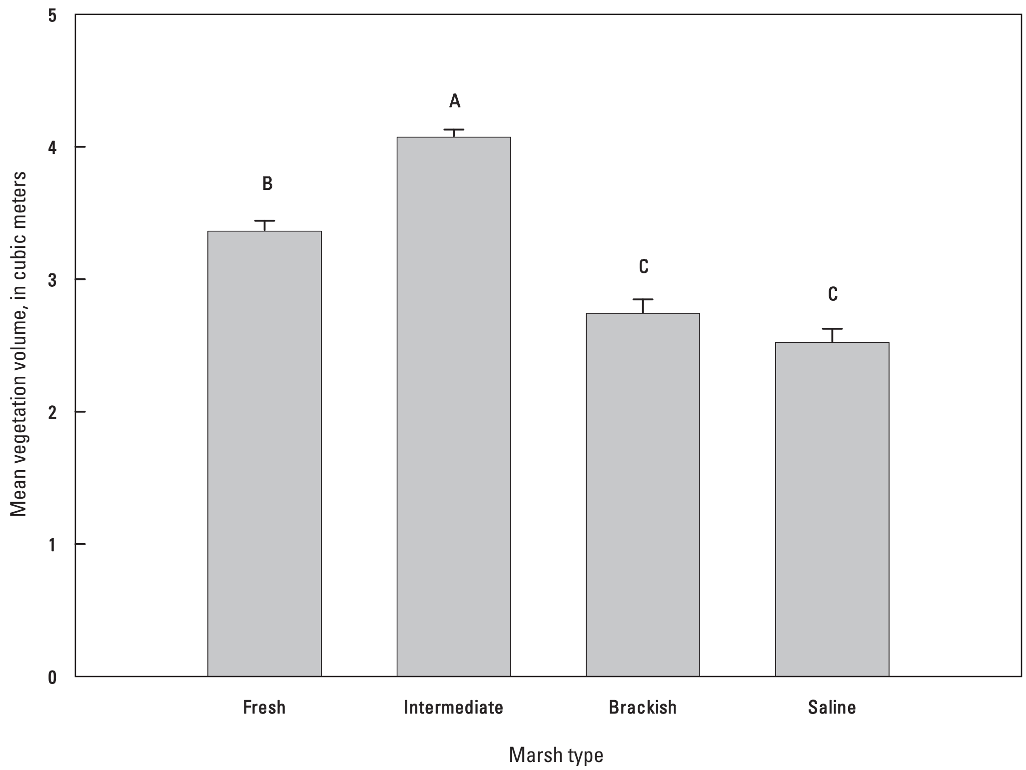


Figure 4. Vegetation volume means of all marsh types averaged over the 8-year study period from 2006 to 2013 in coastal Louisiana. Marsh types not identified by the same letter are significantly different at p = 0.05.

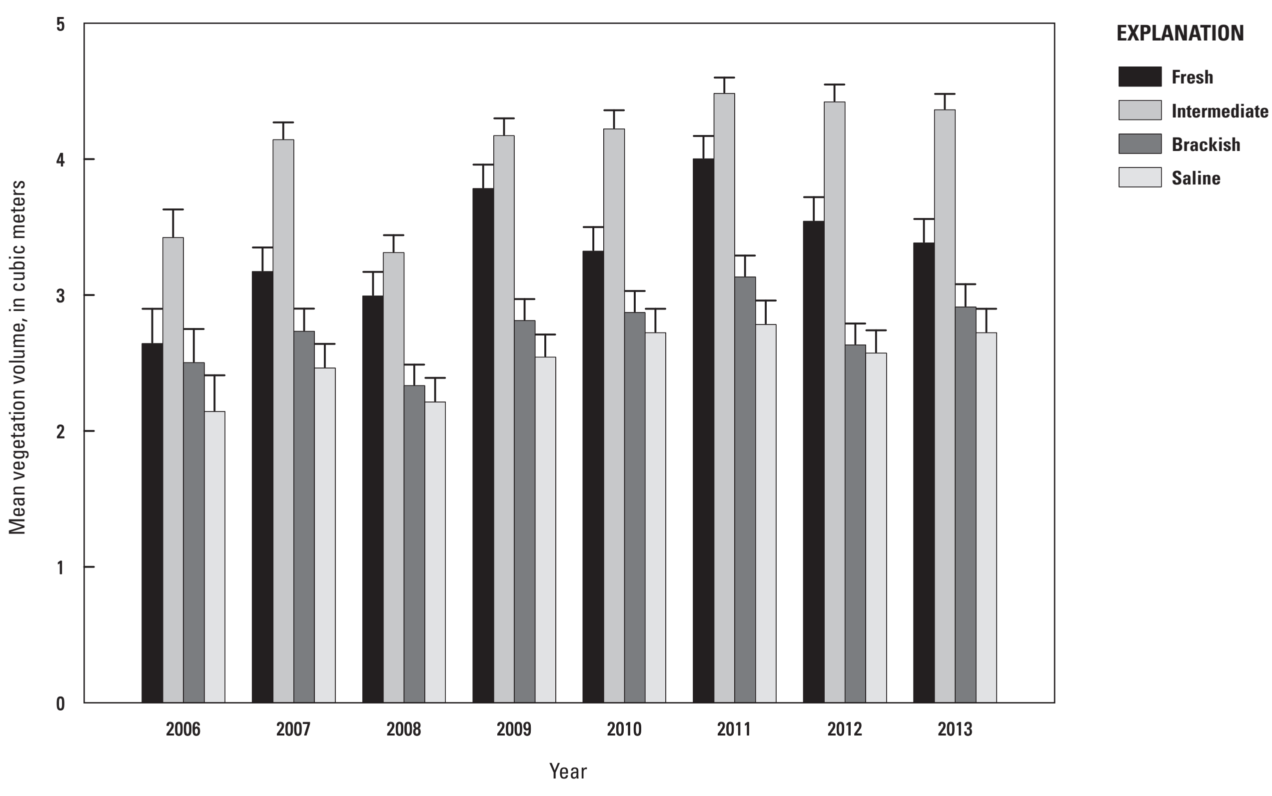


Figure 5. Vegetation volume means of all marsh types from 2006 to 2013 in coastal Louisiana.

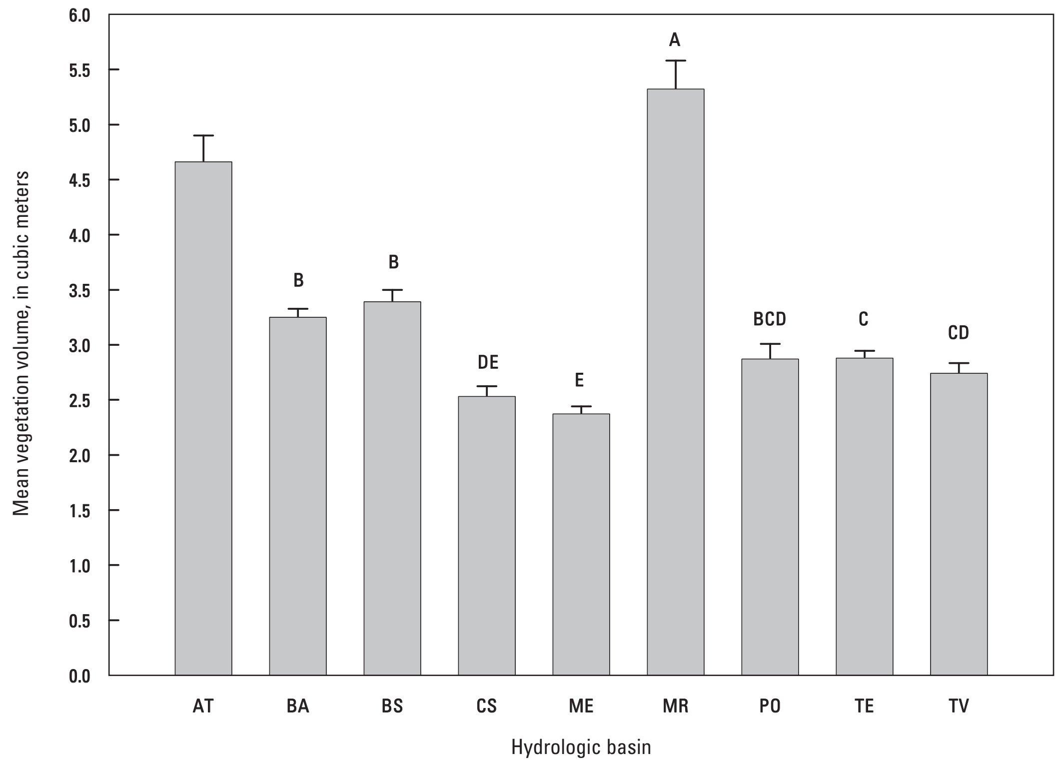


Figure 6. Vegetation volume means per hydrologic basin over the 8-year study period from 2006 to 2013 in coastal Louisiana. The Atchafalaya hydrologic basin was removed from comparison as it did not contain all marsh types. Basins not identified by the same letter are significantly different at p = 0.05. AT, Atchafalaya; BA, Barataria; BS, Breton Sound; CS, Calcasieu/Sabine; ME, Mermentau; MR, Mississippi River Delta; PO, Pontchartrain; TE, Terrebonne; TV, Teche/Vermilion.

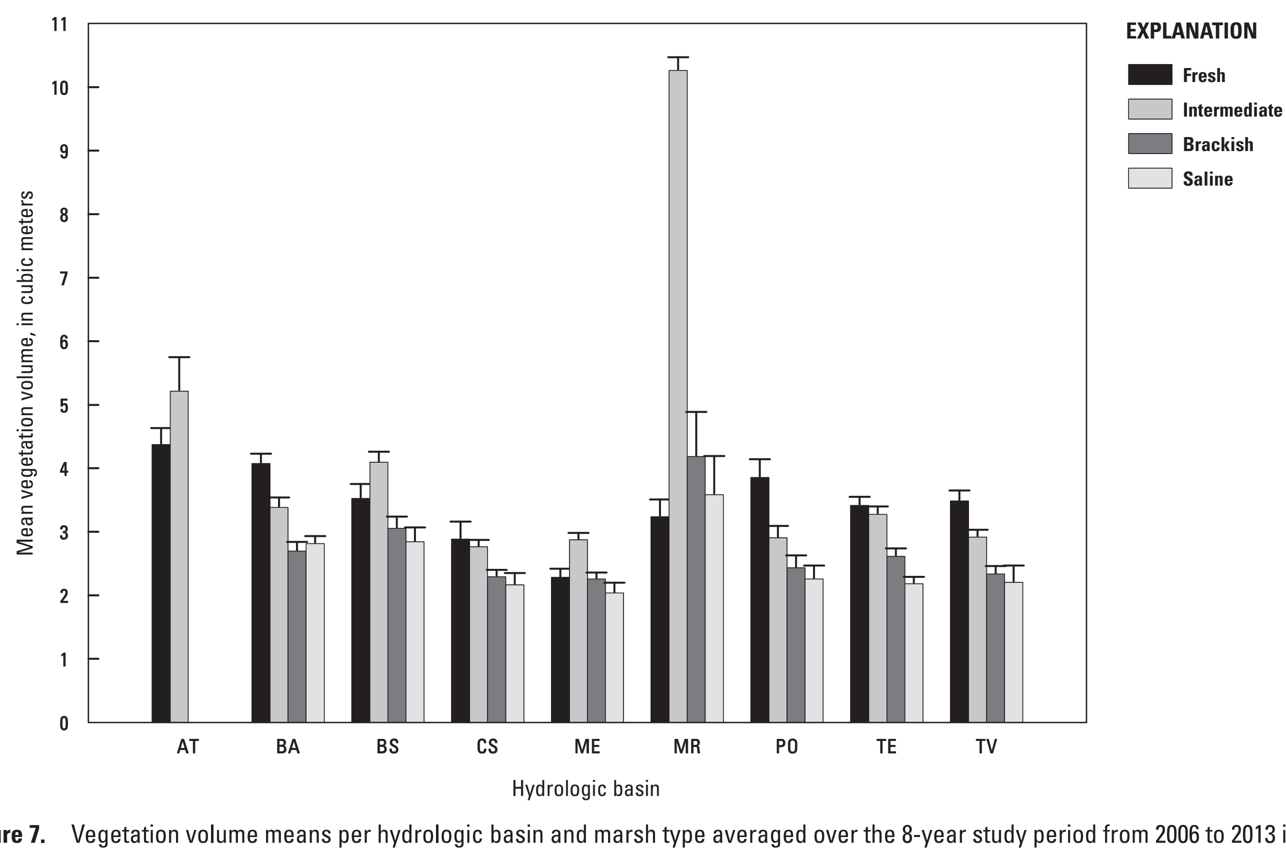


Figure 7. Vegetation volume means per hydrologic basin and marsh type averaged over the 8-year study period from 2006 to 2013 in coastal Louisiana. AT, Atchafalaya; BA, Barataria; BS, Breton Sound; CS, Calcasieu/Sabine; ME, Mermentau; MR, Mississippi River Delta; PO, Pontchartrain; TE, Terrebonne; TV, Teche/Vermilion.

Overall Vegetation Volume Trends

The trends observed in the VV data were also present in the VVI data. Coastwide yearly mean VVI from 2006 to 2013 (fig. 8) followed the same pattern as did VV over the same temporal scale. The mean VVI generally increased from a low of 41.8 in 2006 to a maximum of 52.6 in 2010; in 2011 it was essentially unchanged, and in 2012 it fell marginally (fig. 8). The annual VVI mean varies, but the range of the distribution remains fixed at 0–100 (fig. 9). There were annual changes in the VVI score at the CRMS site, project, and basin scales. The spatial variation in the VVI for 2012 indicated locations where robust stands of vegetation were grouped together (green symbols) and, conversely, locations with low three-dimensional vegetation structure cluster (red symbols) (fig. 10). Most of the CRMS sites in the Mississippi River Delta hydrologic basin are in the 75th quartile coastwide, whereas the CRMS sites on Marsh Island are in the 25th quartile, displaying areas of both positive and negative VVI trajectories. Proximal hydrologic basins displayed similar annual patterns in VVI, such as the increases in the Calcasieu/Sabine and Mermentau hydrologic basins from 2006 to 2012 (fig. 11). In contrast, the VVIs in the Mississippi River Delta, Breton Sound, and Atchafalaya hydrologic basins decreased in 2008 and then recovered at different rates.

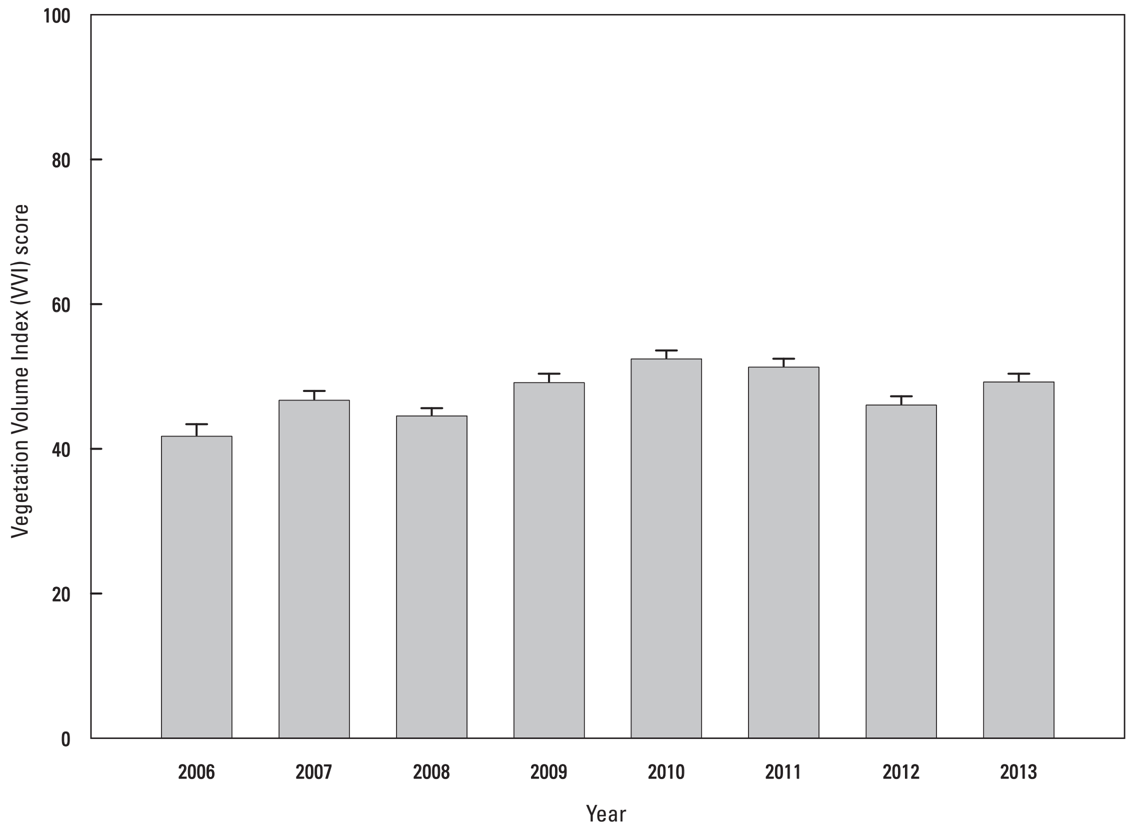


Figure 8. Mean Vegetation Volume Index (VVI) score by year from 2006 to 2013 for hydrologic basins in coastal Louisiana.

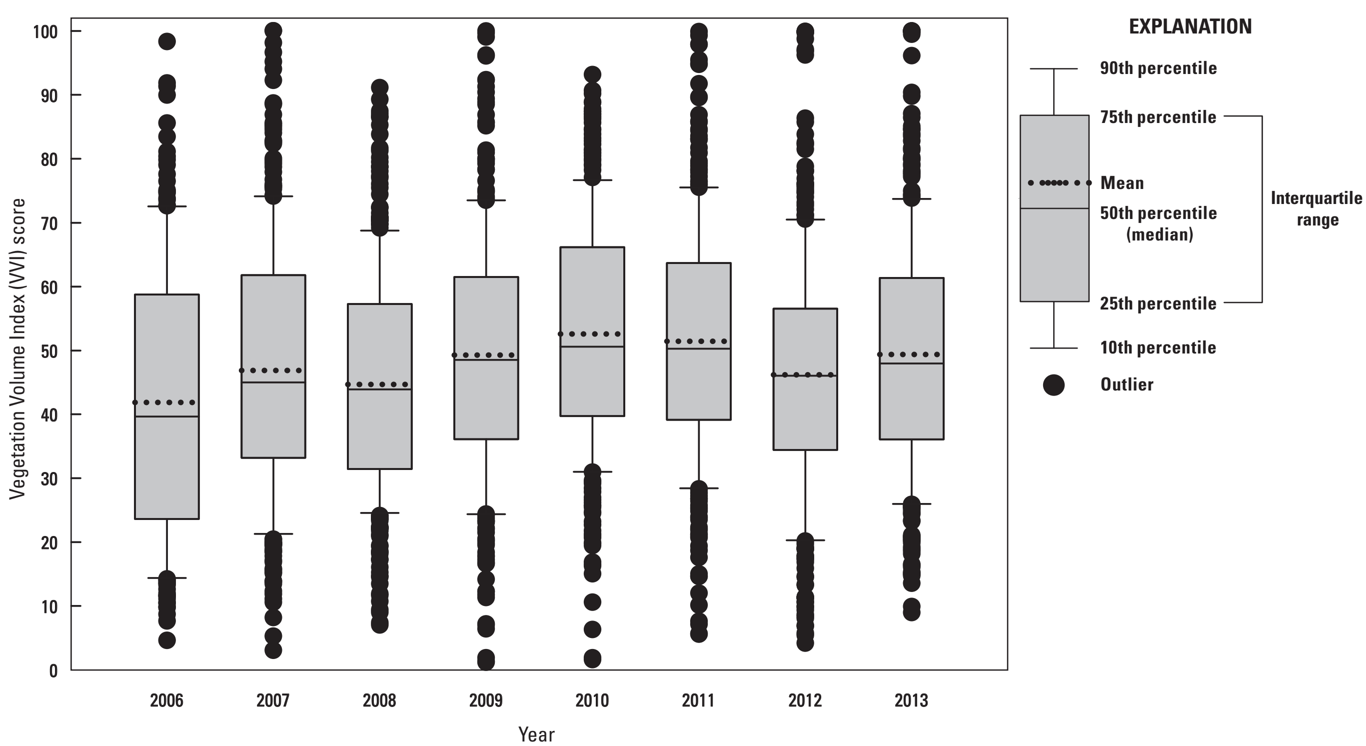


Figure 9. Distribution of Vegetation Volume Index (VVI) scores across all years of the study data collection (2006–2013) with the annual means.

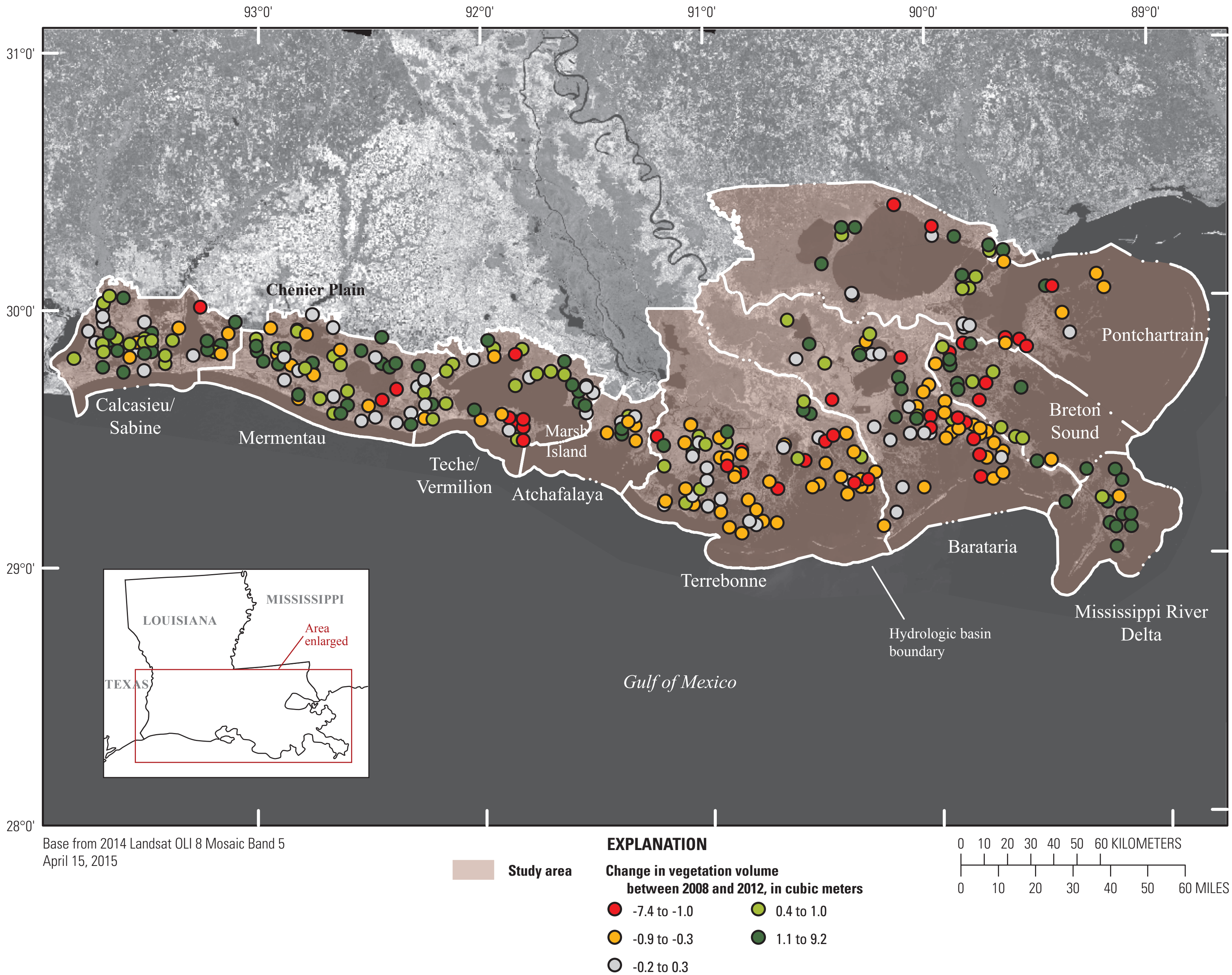


Figure 10. Vegetation Volume Index (VVI) score in hydrologic basins in coastal Louisiana at each study site during 2012 separated into 25th and 75th quartiles.

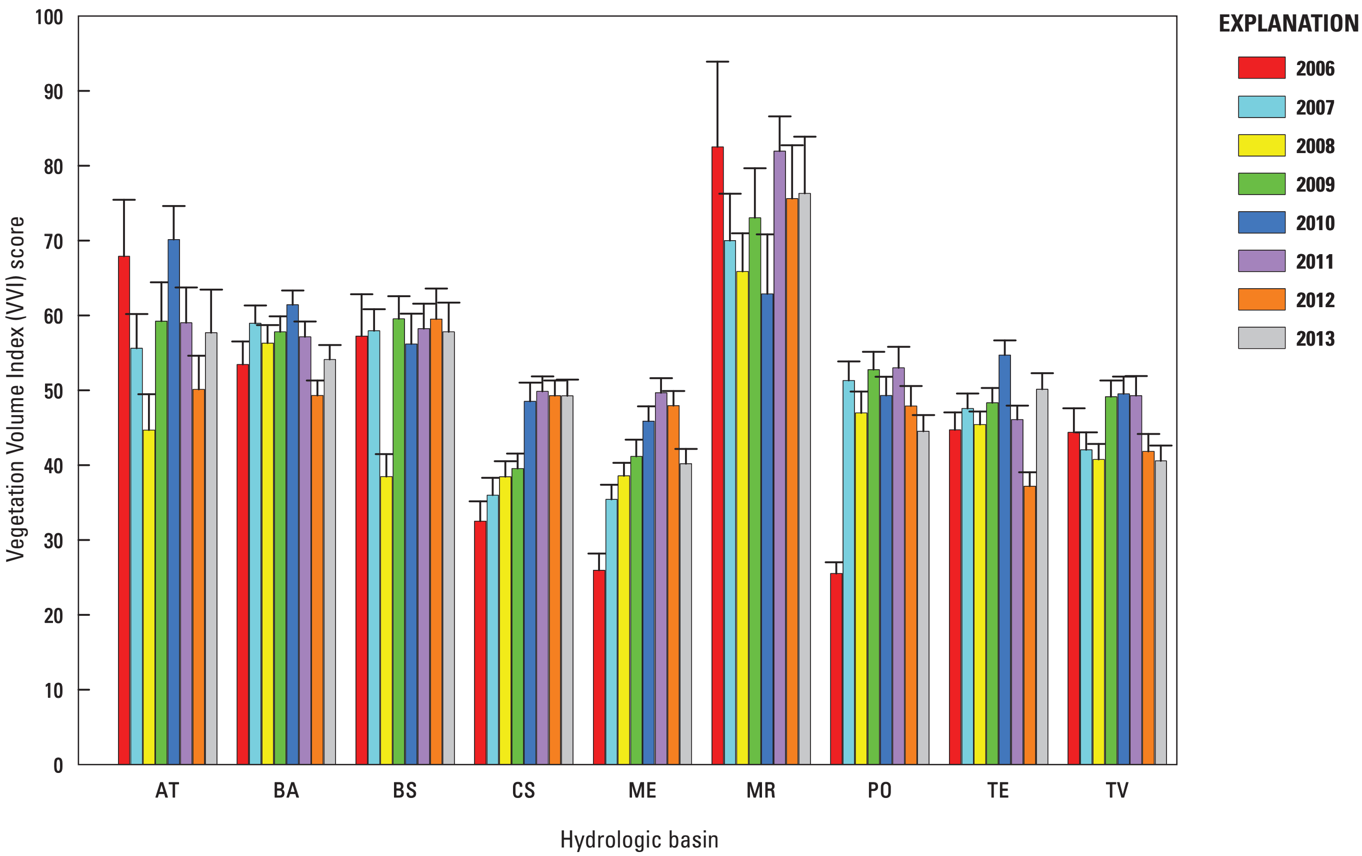


Figure 11. Mean Vegetation Volume Index (VVI) score per hydrologic basin over the 8-year study period from 2006 to 2013 in coastal Louisiana. AT, Atchafalaya; BA, Barataria; BS, Breton Sound; CS, Calcasieu/Sabine; ME, Mermentau; MR, Mississippi River Delta; PO, Pontchartrain; TE, Terrebonne; TV, Teche/Vermilion.

Discussion and Conclusions

The VV can be used to examine both spatial and temporal trends in the coastal marshes of Louisiana. One of the major findings of the preliminary VV investigation was that the active deltas, Mississippi River Delta and Atchafalaya hydrologic basins, generated more VV than did the abandoned deltas and the Chenier Plain. The marshes in the Mississippi River Delta hydrologic basin contained significantly more VV than did the marshes of other hydrologic basins, including the Atchafalaya. A likely explanation for the increase in observed VV in the Mississippi River Delta, as well as in the Atchafalaya River Delta to a lesser extent, is the cyclical availability of nutrients, sediments, and soil salinity reduction in these two alluvial locations. The variation in VV between these two deltas is likely due to the maturity of the Mississippi River Delta and its general erosive pattern and the relative youth of the Atchafalaya River Delta and its current land area expansion. The latter contains expansive annual mud flat formation and colonization, whereas the former is in a state of declining land mass and monoculture stability. The Mississippi River Delta is dominated by robust monospecific stands of perennial *Phragmites australis* that are classified as intermediate marsh by the current CRMS marsh type algorithm. This species generally needs stability and time to colonize an area (Grace and Tilman, 1990). Because of the formation dynamics of the Atchafalaya River Delta, its vegetation cohort is more likely dominated by annuals that can take advantage of the seasonal sediment and nutrient availability without remaining permanent residents of a specific location that could change drastically from year to year.

Conversely, VV is significantly reduced in the Mermentau and Calcasieu/Sabine hydrologic basins because of their distance from large alluvial inputs and separate but related stressors. The Calcasieu/Sabine hydrologic basin is severely salt stressed because of the landward penetration of the Calcasieu Ship Channel from the Gulf of Mexico to Lake Charles, La. This salinity stress, over much of the basin, limits the plant species that can colonize the area, thereby reducing the potential for multiple vegetation layers to be present.

Instead much of the basin is dominated by monospecific stands of *Spartina patens* in areas where the elevation is suitable. This overall reduction in species diversity due to salinity stress is a large component of consistently low VV in the basin. In the Mermentau hydrologic basin, however, there are areas that are submerging because of hydrologic alterations. Agricultural and other types of impoundments keep large areas of the basin under near-permanent year-round flooding, which exacerbates sea-level rise and subsidence along Louisiana's coast (Morris and others, 2002). The vegetation of the Mermentau hydrologic basin, where VV is low and flooding is high, is typical of other impounded coastal areas dominated by flood-tolerant perennials and seasonal annuals. Both the Calcasieu/Sabine and the Mermentau hydrologic basins score low on the Hydrologic Index and are dependent on localized upland rainfall for nutrient, sediment, and freshwater input. As a result, their three-dimensional marsh structure is likely to be substantially less than the other, more alluvial basins previously discussed. This differentiation in VV scores among basins that are undergoing different environmental disturbances indicates that the VV is an efficient method for looking at vegetation differences not only across basins but also at other scales in which environmental variation occurs. The cluster of low VV CRMS sites on Marsh Island in the Teche/Vermilion hydrologic basin in 2012 represents extensive herbivory damage by *Myocastor coypus*, which led to an extermination effort in 2013 by the Louisiana Department of Wildlife and Fisheries. This eradication effort in conjunction with an unusually cold winter in 2013 has led to a significant rebound in VV through 2014 and which has carried forward into 2015 (Mark Mouledous, unpub. data, 2015).

The temporal span of the CRMS data, now reaching nearly a decade, provides the necessary framework to examine annual trends such as hurricanes, droughts, floods, and other disruptive factors interspersed among less dynamic years. The CRMS database was begun in 2006, and the damage associated with Hurricanes Katrina and Rita in 2005 was still very evident in the yearly VV means. The low VV means in 2006 and 2008 are likely a result of hurricane disturbance causing the lowest VV in the 8-year study. It is likely that in 2008 Hurricanes Gustav and Ike caused the temporary VV rebound of 2007 to reverse and made 2008 the lowest VV year to date along the Louisiana coast. Conversely, 2009 through 2013 had relatively high VV means when compared to 2006 and 2008, but there were some mean fluctuations in the VV over this period, as 2011 was the highest VV measured. The high VV that year was likely due to conflicting events. The historically high levels of the Mississippi River in 2011 affected the east and central coasts of Louisiana, while drought conditions were predominant west of the Atchafalaya River Delta. This historic flooding early in the growing season may have stimulated vegetative growth later in the season throughout much of the coastal zone. The western portion of the coast, which in many areas underwent prolonged drought conditions, also produced larger, more robust vegetation in areas where persistent flooding might normally retard vegetation growth. The Deepwater Horizon oil spill of 2010 did not have a significant impact on VV except in the Mississippi River Delta hydrologic basin, where VV dropped to its second lowest level of the study. This decreased VV in the Mississippi River Delta hydrologic basin following the oil spill was due to lack of site access and logistical issues rather than direct oiling of vegetation within the annual vegetation survey. The sites in the Mississippi River Delta hydrologic basin that were not accessible because of oil spill restrictions were generally among the most productive VV sites in the basin, and on the coast, because they are dominated by *Phragmites australis*. Access limitations prevented site assessment, thereby lowering the Mississippi River Delta hydrologic basin VV average in 2010. The CRMS network does not have stations located on barrier islands and thus did not record major damage from oil or an oil-induced coastwide reduction to the VV in 2010. As a result of the longevity of the CRMS network, capturing both positive and negative episodic variability from the annual norm has been possible. This variability and its correlation to specific environmental conditions bolster the ability of landowners, managers, and planners to implement projects and restoration strategies that either are effective across this variation or help to diminish the negative effects.

Many of the CWPPRA restoration projects have goals to establish and promote vegetation growth rather than to establish a particular species or community. Newly restored sites often have low initial FQI scores for many years because of the presence of annual species that either do not indicate stability or are only common in high numbers during early successional stages. Therefore, at the project scale, an assessment of the VV and the indexed values may be more informative than relying solely on the FQI for monitoring and adaptive management purposes. The VV will be calculated at the coastwide scale annually and will be used to generate geospatial maps to depict areas where the VV is maintaining or increasing or conversely reducing as vegetation becomes more sparse or stunted. Interpretation of the VV can be used to identify areas where degradation is taking place and where healthy thresholds are in place. With the potential of several large-scale Mississippi River diversions being completed over the next two decades, the receiving basins of those diversions will be disrupted in the short term as new vegetated habitats emerge and eventually evolve to stable states. Using VV to assess this type of restoration strategy could work well as species-specific transitions are ignored and more robust and vigorous marshes are ranked as superior. Most restoration projects disrupt the stable and typically deteriorated state of the wetland into which they are placed. This disruption causes successional changes in the local environment as a new stable state is reached. During this transitional phase many negatively perceived plant species may persist. The FQI is sensitive to these changes and in most cases responds negatively to these shifts, as it is designed to do. Although the VV has utility in its current form, future CRMS data will add to the predictive power of this variable on a project, basin, and coastwide scale. There are ways, however, to improve the usefulness of this metric, such as developing a link with aboveground annual production or peak standing crop biomass across marsh types. This linkage of the VV to a production metric would strengthen the CRMS database and coastal data collection as a whole by allowing for a more efficient and cost effective measure of productivity change at a restoration project scale. Including the VV and the VVI as metrics for use in assessing coastal planning and monitoring projects will allow a broader view of the vegetation present beyond a species-specific approach, which is needed to more accurately determine restoration success or failure.

The development and analysis of the VV and the VVI can benefit wetland restoration planning and monitoring efforts in coastal Louisiana. Vegetation primary productivity can be an important indicator of wetland health; however, accurately measuring primary productivity is labor intensive, lengthy, and expensive. The VV calculation uses data already collected at each of the 331 herbaceous marsh CRMS sites coastwide and can be a proxy for productivity. VV is also amenable for comparison with other historical datasets of vegetation cover and height variables in wetlands. Spatial and temporal trends in VV can be used to document the effects of human activities, climate, weather, and restoration projects on the coastal landscape. These trends can inform managers, stakeholders, and landowners of where restoration is needed or where restoration efforts are being implemented effectively with regard to vegetation structure. The VV may also inform restoration planning by providing data on whether specific types of restoration have proven useful in increasing vegetation within a specific habitat type or environmental niche. Overall, the VV is another potential tool for informing decision making in wetland habitats where time and monetary restrictions prevent a more intensive approach.

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