Evaluation of the effects of CWPPRA hydrologic restoration projects on hydrology and marsh condition.

Final Report

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Introduction

Hydrologic restoration (HR) has been one of the most common wetland restoration techniques used by the Coastal Wetland Planning, Protection, and Restoration Act (CWPPRA) Task Force in coastal Louisiana. As of January 2006, there have been 16 HR projects constructed, 4 HR projects are under construction, and 8 HR projects are in the Engineering and Design Phase (Table 1). The general goal for hydrologic restoration projects is to restore a more natural hydrologic regime to wetland areas that have experienced human alterations to the hydrology primarily through the addition of channels (Dale et al. 2006). However "natural hydrologic regime" remains undefined. Monitoring plans exist for all constructed HR projects. Currently comprehensive monitoring reports have been produced for 9 of these projects (CS-17, CS-21, CS-27, ME-11, PO-06, TE-22, TE-26, TE-28 and TV-14) which can be downloaded at http:/ldnr.louisiana.gov/crm/. Five of these reports analyzed hydrologic data using reference and project area hydrology comparisons. Previous studies of a similar restoration technique, marsh management, have focused on the effects of hydrologic manipulation on wildlife, fisheries, sediment deposition, submerged aquatic vegetation, average salinity, and land loss (Duffy and Clark 1989, Reed 1992, Rogers et al. 1994, Nyman and Chabreck 1996, Nyman et al. 1993, Sazone and McElroy 1998).

The effects of constant salinity and flooding on marsh plant performance have been extensively studied (see references in Mitsch and Gosselink 2000, Visser et al. 2003). However, few studies have considered the natural variability that occurs in these hydrologic stressors. In this study, we focus on the duration of hydrologic and salinity events that are known to be stressful to the dominant vegetation. The longer a flooding event lasts, the more reduced the soil becomes (Gambrell and Patrick 1978), and the more stress the plants experience. Longer drainage events lower water availability to the plants and increase interstitial salinity. It has also been shown that vegetation can recover from short exposures to saline water, but are severely stressed by longer exposures (Howard and Mendelssohn 1999).

Table 1. List of Hydrologic Restoration Projects compiled from the CWPPRA web site (http://lacoast.gov/cwppra). This list omits four de-authorized projects.

Agency	Project Number	Project Name	Construction Status
USFWS	PO-16	Bayou Sauvage National Wildlife Refuge Hydrologic Restoration, Phase 1	Completed 1996
USFWS	CS-17	Cameron Creole Plugs	Completed 1997
USFWS	PO-18	Bayou Sauvage National Wildlife Refuge Hydrologic Restoration, Phase 2	Completed 1997
NRCS	ME-04	Freshwater Bayou Wetland Protection	Completed 1998
NRCS	TV-04	Cote Blanche Hydrologic Restoration	Completed 1999
NMFS	TE-26	Lake Chapeau Sediment Input and Hydrologic Restoration, Point Au Fer Island	Completed 1999
NRCS	BA-02	GIWW (Gulf Intracoastal Waterway) to Clovelly Hydrologic Restoration	Completed 2000
NMFS	TE-22	Point Au Fer Canal Plugs	Completed 2000
NRCS	CS-21	Highway 384 Hydrologic Restoration	Completed 2000
NRCS	TE-28	Brady Canal Hydrologic Restoration	Completed 2000
NRCS	CS-11b	Sweet Lake/Willow Lake Hydrologic Restoration	Completed 2001
NRCS	PO-06	Fritchie Marsh Restoration	Completed 2001
COE	TV-14	Marsh Island Hydrologic Restoration	Completed 2001
NMFS	CS-27	Black Bayou Hydrologic Restoration	Completed 2001
NRCS	TV-13a	Oaks/Avery Canal Hydrologic Restoration, Increment 1	Completed 2002
NRCS	ME-11	Humble Canal Hydrologic Restoration	Completed 2003
NRCS	BA-20	Jonathan Davis Wetland Restoration	Under construction
NMFS	PO-24	Hopedale Hydrologic Restoration	Under construction
NRCS	CS-29	Black Bayou Culverts Hydrologic Restoration	Under construction
USFWS	ME-16	Freshwater Introduction South of Highway 82	Under construction
NRCS	CS-09	Brown Lake Hydrologic Restoration	In Engineering and Design Phase
USFWS	TE-10	Grand Bayou Hydrologic Restoration	In Engineering and Design Phase
USFWS	TE-32a	North Lake Boudreaux Basin Freshwater Introduction and Hydrologic Management	In Engineering and Design Phase
NRCS	TE-34	Penchant Basin Natural Resources Plan, Increment 1	In Engineering and Design Phase
NRCS	ME-17	Little Pecan Bayou Hydrologic Restoration	In Engineering and Design Phase
NRCS	TE-39	South Lake De Cade Freshwater Introduction	In Engineering and Design Phase
USFWS	CS-32	East Sabine Lake Hydrologic Restoration	In Engineering and Design Phase
USFWS	ME-20	South Grand Chenier Hydrologic Restoration Project	In Engineering and Design Phase

Methods

Hydrology

Hydrology data for all hydrologic restoration projects was made available by the Louisiana Department of Natural Resources (LDNR). We selected those gauges that had at least 3 full years of data for water level relative to marsh surface and salinity (Table 2). Years before and after construction were determined by assigning each calendar year to either a before or after category. If construction was completed before June 30 the year was assigned to the after construction category. If construction was completed after June 30 the year was assigned to the before construction category. Only years with observations for the full year were included in the analyses.

Table 2. Construction completion for each project and dominant vegetation for each gauge with sufficient hydrologic data. Location maps for these gauges are provided in Appendix A.

Project	Construction Completion	Project Gauges	Reference Gauges	Dominant Plant Species
BA-02	October 2000	53, 54, 55, 56, and 57		*Spartina patens*
CS-21	January 2000	19	07R	*Juncus roemerianus*
		26/98, 29		*Spartina patens*
ME-04	October 1998	06, 29		*Spartina patens*
		19		*Panicum hemitomon*
			50R/143R	*Sagittaria lancifolia*
PO-06	March 2001	01, 06, 11, 03/60		*Spartina patens*
TE-26	May 1999	03, 04, 05	01R, 02R	*Spartina patens*
TE-28	July 2000	218	219R	*Sagittaria lancifolia*
TV-04	January 1999	02/22, 03	04R	*Sagittaria lancifolia*
TV-14	December 2001	01, 02/23	03R, 04R	*Spartina patens*

To evaluate the effect of different stressors on vegetation, it is important to understand that stressor effects will be more pronounced in periods in which the vegetation is actively growing. Plant species differ in the distribution of their productivity during the year. We used the different dominant plants near each gauge (*Juncus roemerianus, Spartina patens, Sagittaria lancifolia,* and *Panicum hemitomon*) as provided to us by the LDNR monitoring personnel familiar with the sites (Table 2). The distribution of productivity was estimated from the live biomass of two full years of bi-monthly data reported by Hopkinson et al (1978) for all species except *P. hemitomon*. If more than one observation occurred within a month the values were averaged for that month. If no observations occurred in a particular month, then the average of the month before and after were used. Percentage of total production was divided over four quarters of a year. The productivity index for a quarter was calculated as the sum of live biomass in each month of the quarter divided by the sum of the live biomass over all months.

For *P. hemitomon* we used the monthly productivity reported by Sasser and Gosselink (1984). Here the productivity index for a quarter was calculated as the sum of productivity in each month of the quarter divided by the total annual production. The resulting seasonal productivity index for dominant species is provided in Table 3.

Table 3. Seasonal productivity index for different marsh plants (based on Hopkinson et al. 1978 and Sasser and Gosselink 1984)

Quarter	*Juncus roemerianus*	*Spartina patens*	*Sagittaria lancifolia*	*Panicum hemitomon*
Jan-Mar	0.27	0.24	0.05	0.00
Apr-Jun	0.27	0.25	0.50	0.37
Jul-Sep	0.25	0.29	0.43	0.32
Oct-Nov	0.21	0.22	0.02	0.31

The salinity stress level for different plant species was derived from the literature review in Visser et al. (2003). No stress (stress level = 0) was assumed for salinities that show optimal productivity for the species (Table 4.). A medium stress level (stress level = 0.5) was assumed for salinities that show productivity that is greater or equal to 50% of optimal productivity. A high stress level (stress level = 1) was assumed for salinities that show productivity that is less than 50% of optimal productivity. Salinity stress number for each quarter is then calculated by multiplying the stress period (the proportion of hours that fall within the stress level) with its stress level and the percent productivity in that quarter:

$$Salinity\ Stress\ Index = \sum_{ij} Level_i \times Period_{ij} \times Production_j$$

Where: $Level_i$ = stress level i, $Period_{ij}$ = proportion of time level i was experienced during quarter j, $Production_j$ = proportion of production occurring in quarter j

Table 4. Stress index relative to salinity for different marsh plant species (based on Visser et al. 2003).

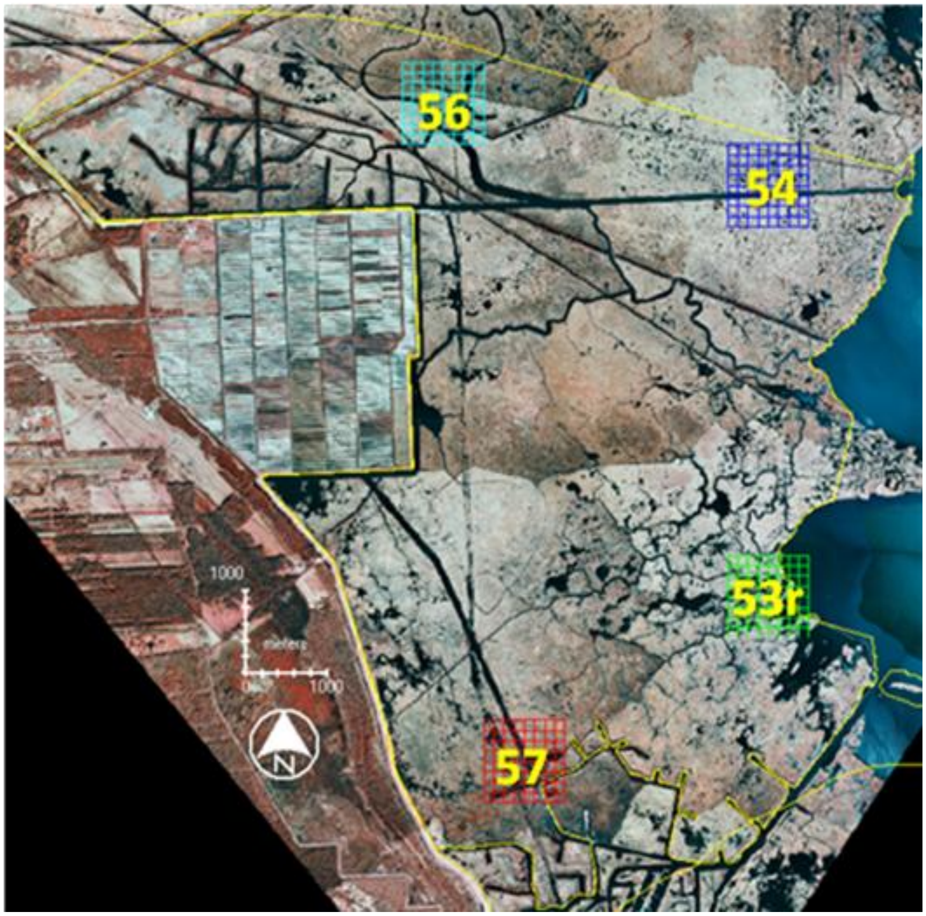
Species	No Stress Stress Level = 0	Medium Stress Stress Level = 0.5	High Stress Stress Level = 1
Juncus roemerianus	< 10 ppt	10 – 24 ppt	> 24 ppt
Spartina patens	< 2 ppt	2 – 22 ppt	> 22 ppt
Sagittaria lancifolia	< 2 ppt	2 – 4 ppt	> 4 ppt
Panicum hemitomon	< 2 ppt	2 – 4 ppt	> 4 ppt

Before analysis, missing data were replaced with the best prediction based on adjacent gauges if regression equations explained greater than 50% of the variation ($R^2 > 0.5$; Appendix B). Relationships among gauges were generated using the data from before and after project implementation independently. Data gaps were first filled in with the best (highest R^2 regression), followed by the second best for remaining gaps and so on.

We used LDNR's data of water level relative to the marsh surface, with values greater than 0 meaning that the marsh was flooded. The length of flood events was calculated by subtracting the date and time of the beginning of the flood event from the date and time at the end of the flooding event. At the start of each quarter a flood event was started if the water level was above the marsh surface, otherwise a draining event was started. At the end of each quarter the event was ended. Flooding stress was assumed to be the same for all species. A stress level of 0.5 was assigned to flood events that lasted between one and seven days. A stress level of 1 was assigned to flooding events that lasted more than seven days. Flooding events of less than one day were assumed to provide no stress to the plants (stress level = 0). The period stress index was calculated by multiplying the stress level by the percentage of time in the quarter that the stress level occurred and the percentage of productivity that occurred during that quarter. The yearly stress index was then calculated as the sum of all quarterly stress levels.

Landscape Change

For each site selected, we chose a pre-, during-, and post-construction time period with available color infrared aerial photography. All existing CWPPRA land:water images were assessed for appropriate dates, coverage, quality, and scale. Upon review it was determined that the photographs that were available were few in number and consisted of a lower resolution than appropriate for our analyses. Therefore, the original unclassified aerial photography in jpg format was obtained from LDNR (http://dnr.louisiana.gov/crm/coastres/projectlist.asp). Due to the inadequate quality of some project area photos, as well as the intensive nature of interpreting and classifying those images, this part of the analysis was limited to four stations each in projects BA-02 and PO-06 (Figure 1). These stations, which are all representative of *Spartina patens*-dominated marshes (Table 2), represent projects that have extensive pre-construction hydrology data. The dates of photography selected for analysis were 1993, 1996, and 2002 for BA-02, and 1996, 2000, and 2004 for PO-06. Because the extent of these photos are CWPPRA project wide, the Louisiana Coastal Area program (LCA, Twilley and Barras 2003) km^2 vector grid, was used for plot selection. Cells from the km^2 grid were used to select plots that included or were next to monitoring stations used in the designated CWPPRA projects. All photography was subset using the selected plot boundaries and then an unsupervised classification within ERDAS Imagine 8.7© software was performed on all subset photography. This land-water classification process was used to designate image pixels as either “water”, “land” or “other” classes based on individual pixel signature (Figure 2).

A.


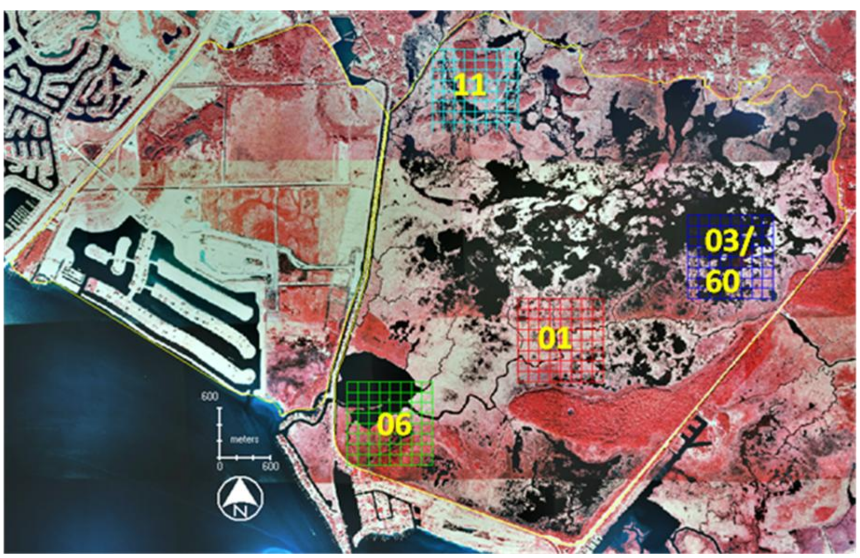
B.


Figure 1. Location of the 1 km^2 plots interpreted in this study. A. Is the BA-02 project area east of Cut Off, Louisiana. B. is the PO-06 project area near Slidell, LA. Project areas are indicated by yellow lines.

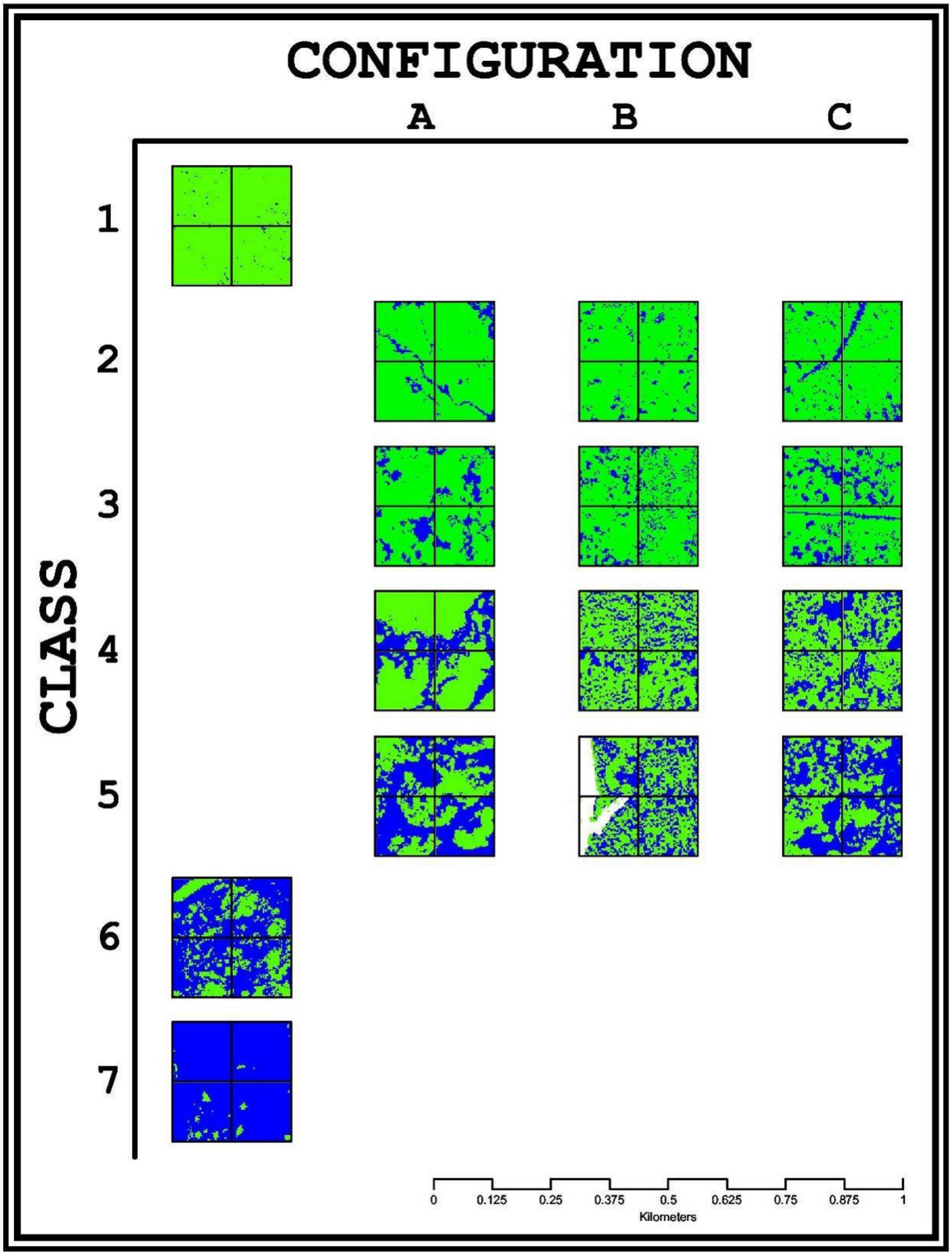


Figure 2. Examples of the system used to determine water connectivity and marsh condition. Classes are based on percentage of land and water. Configurations are based on the connectivity of water bodies.

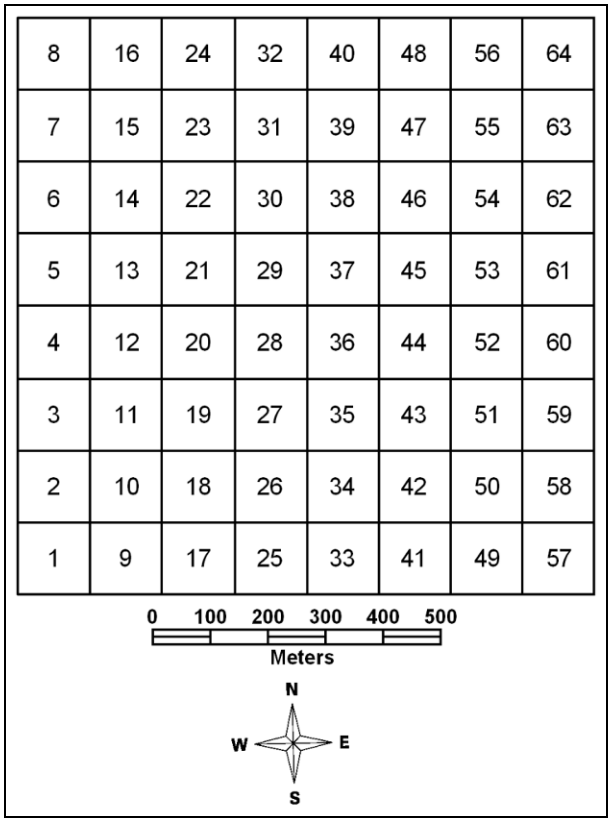


Figure 3. Grid numbering system used for each plot.

All non-water and non-marsh features were initially recoded into the "other" category. This category may consist of fastlands, forested, agricultural and developed lands. Tree canopies are problematic in classifications when the sun angle is such that it causes the trees to cast shadows which cannot be distinguished from water. Therefore, a secondary interpretation was performed which identified all tree canopies plus associated shadow areas and assigned these areas to an "other" class.

Each plot was divided into 64 (1/64 km ^{2}) grids as shown in Figure 3. To test for changes in both the marsh configuration, and hydro-connectivity, we employed landscape metrics that calculate the spatial pattern of water within a marsh. This method of analyzing and classifying marsh change is based on a manual system developed by Dozier (1983). This analytical system was then converted to a grid-based method developed by Steyer et al (2007, utilizing FRAGSTATS

(McGarigal et al., 2002). FRAGSTATS is a spatial pattern analysis program used to quantify the degree of change in both composition (degradation or promotion), and pattern (size, density, and shape) of a marsh landscape.

FRAGSTATS metrics can be used independently to evaluate change in specific configuration measures, or in combination with a two-part classification system to provide a general, yet more complete assessment of marsh condition. The two levels used in this system are: (1) *category*: ratio of water to land, and (2) *configuration*: marsh water density, shape and connectivity. As described in Steyer et al. (2007) and modified from Dozier (1983), this classification system assigns values 1-7 to represent percentages of water as: Category 1, 0%–<5% water within marsh, Category 2, 5%–<10% water, Category 3, 10%–<25% water, Category 4, 25%–<40% water, Category 5, 40–<60% water, Category 6, 60–<80% water, and Category 7, ≥80% water. The system subclasses are designated by the configuration of water bodies in the marsh. Subclass “A”, are configurations that are typically large water, (in relation to percent water class) and have connected water patches with linear edge. Subclass “B”, are configurations that are typically small (as related to associated percent water class) disconnected patches with a more random distribution, and fewer instances of connection. Subclass “C”, are configurations that are a combination of both subclass “A” and subclass “B” (with discernible regions of both). A total of eight metrics, with primary relationships to water patch size, connectedness, and aggregation within the marsh (Figure 2; Dozier et al. 1983, Steyer et al. 2007), were used to fit category and configuration thresholds which were used for final classification. Automation of this classification process was achieved via the FRAGSTATS Transformer — a module developed by United States Geological Survey (USGS) — which uses the FRAGSTATS output for each of the 64 grids within a plot, and the metric thresholds to assign grids to the appropriate landscape class.

The landscape metrics, interpreted either individually or assimilated into fragmentation and degradation classes, allow for statistical and observational comparisons, both spatially and over all time periods. The results provide information as to the change in marsh configuration and hydrologic connectivity within the project areas. Individual metrics are used to quantify the proportion, density, shape, and connectivity of water and land patches within a landscape, and the transformation of those metrics over space and time. Those metrics can be combined using a conditional statement model to threshold grids into fragmentation classes which provide land and water patch distribution and configuration within the landscape. Additionally, the fragmentation classes were used to evaluate more general marsh condition by grouping tiles based on the degree of marsh degradation. There are three levels of marsh condition: solid marsh, degraded marsh, and water. These marsh conditions are classified using several marsh water-to-shape criteria. Solid marshes are all landscapes that contain less than 10 percent water and contain the relatively less degraded sub-classes "2a" and "2b" configurations. Degraded marshes are landscapes that are classified as degraded configuration sub-class "2c" or contain between 10-60 percent water. The "water" class is any tile that contains more than 60 percent water. Individual metrics were also evaluated for significance in explaining changes both within plots and within sites over time (Table 5).

Table 5. Description of FRAGSTATS metrics used individually.

Metric	Abbreviation	Description
Patch Cohesion Index	COH	Physical connectedness of the corresponding patches
Percentage of Landscape	PLAND	Percentage of the land and water composing the water class
Adjusted Patch Density	APD	Number of patches of the corresponding class divided by total of land and water area
Landscape Shape Index	LSI	Class perimeter length divided by minimum perimeter needed for maximum aggregation

Patch cohesion index measures the physical connectedness of the corresponding patch type. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; and therefore becoming more physically connected. This percentage is calculated by the equation:

$$COH = \left[1 - \frac{\sum_{j=1}^{n} P_{ij}}{\sum_{j=1}^{n} P_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1}(100)$$

Where p_{ij} is the perimeter of patch ij in terms of number of cell surfaces, a_{ij} is the area of patch ij in terms of number of cells, and A is the total number of cells in the landscape. *Patch cohesion index* ranges from 0 to 100, and equals 0 if the landscape consists of a single non-background cell.

Adjusted Patch density calculates the number of patches of the corresponding patch type, divided by total grid tile landscape area, excluding all "other" patches. This value – number per 100 hectares – is calculated with the equation:

$$APD = \frac{n_i}{A}(10{,}000)(100)$$

The *landscape shape index* is the total length of edge involving the corresponding class, given in number of cell surfaces, divided by the minimum length of class edge possible for a maximally aggregated class. Simply, this unit-less statistic is the number of cell surfaces divided by the minimum length of class edge as calculated by the equation:

$$LSI = 0.25\sum_{k=1}^{m} e''_{ik}$$

Where e_i is the total length of edge of class i in terms of number of cell surfaces; includes all landscape boundary and background edge segments involving class i, and min e_i is the minimum total length of edge of class i in terms of number of cell surfaces. The minimum value for *LSI* is 1, with the value increasing as the patch type becomes more disaggregated.

Relating Stress Indices to Land Loss

Landsat TM imagery at a 30m spatial resolution was used for the land-water assessment following a standard classification methodology previously used in coastal Louisiana (Barras et al. 2003; Morton et al. 2005; Barras 2007). Land-water classifications were conducted on the 8 projects identified in Table 2 then clipped to the same $1km^2$ vector grid cells used in the aerial photography landscape assessment. A multi-temporal assessment was conducted by using 8 to 12 classifications from available data in the period from 1988 through 2005 and fitting a linear regression to the available data on percentage land in each $1km^2$ plot. The slope of each linear regression provides an estimate of the percentage land change per year, with negative values indicating loss. The second component for this analysis was the average stress index for each plot. We averaged stress indices over the years for which data were available for all sites dominated by the same species. For *Spartina patens*-dominated plots the years for which data were available for all plots were 2001, 2002, and 2003. For *Sagittaria lancifolia*-dominated plots the years with data for all plots were 1999, 2000, and 2001. We then tested for significant linear relationships between each stress index and the land change rate using regression analysis (PROC REG in SAS/STAT software, version 9.1 of the SAS System for Windows). To improve the fit we removed one outlier.

Results and Discussion

Salinity Stress

Very few (20%) of the gauges showed significant changes in salinity stress after project implementation (Table 5). Of the 30 gauges tested only six showed significant differences ($\alpha = 0.10$) in salinity stress after project implementation, and three of these six were reference gauges. Several of the gauges showed a noticeable increase in salinity stress associated with the large drought experienced in coastal Louisiana starting in 1999 and peaking in 2000, followed by a return to lower stress levels in 2001 (Figure 4).

In project PO-06, a significant ($\alpha = 0.05$) reduction in salinity stress occurred at gauges 03/60 and 11, while the other two gauges (01 and 06) show reductions in salinity stress that are not statistically significant (Table 5). Figure 4a shows that the salinity stress patterns for gauges 01 and 06 are almost identical, while gauge 11 had similar levels of salinity stress before project implementation, with a larger reduction in salinity stress after project implementation. Gauge 03/60 experienced lower salinity stress than the other three gauges before project implementation and this stress was further reduced after project implementation. Since there are no reference gauges for this project it is not possible to know if a similar reduction in salinity stress occurred outside of the project area. Especially since the Louisiana coast experienced a historic drought that may have increased open water salinity in the area in 1999 and 2000 exacerbating salinity stress prior to project implementation. Gauges from BA-02, ME-04, and CS-21 show a similar pattern of relatively high salinity stress in 1998 that increases to a maximum in 2000 followed by rapidly decreasing salinity stress for the period of record. A notable exception is provided by the two gauges at TE-28, which show low salinity stress in 1999 and 2000, with a sharp increase in salinity stress in 2001, especially for gauge 219R.

In contrast, project TE-26 shows significant increases in salinity stress in both the project and reference gauges after project implementation. This is mostly driven by relatively low salinity stress experienced in the project area and its immediate surroundings in 1997 (Figure 4a). The low salinity stress in 1997 may be related to the above average discharge of the Atchafalaya River, a major source of fresh water in this area.

Table 5. Salinity stress index before and after project implementation. P value shows significance of the difference between before and after project implementation as determined with Analysis if Variance. Gauge numbers ending in R are reference gauges.

Project	Gauge	Stress Index Before Average (Std. Dev.)	Stress Index After Average (Std. Dev.)	P value
BA-02	53	0.42 (0.08)	0.42 (0.02)	0.91
	54	0.31 (0.17)	0.23 (0.07)	0.50
	55	0.29 (0.18)	0.22 (0.07)	0.56
	56	0.29 (0.18)	0.24 (0.06)	0.68
	57	0.37 (0.11)	0.31 (0.09)	0.44
CS-21	07R	0.30 (0.07)	0.45 (0.16)	0.30
	19	0.31 (0.14)	0.28 (0.35)	0.92
	26/98	0.50 (0.09)	0.40 (0.39)	0.77
	29	0.44 (0.17)	0.28 (0.25)	0.51
ME-04	06	0.42	0.26 (0.14)	0.33
	19	0.56	0.38 (0.35)	0.66
	29	0.46	0.31 (0.16)	0.42
	50R/143R	0.01	0.11 (0.16)	0.58
PO-06	01	0.49 (0.03)	0.38 (0.08)	0.10
	03/60	0.22 (0.07)	0.07 (0.07)	**0.03**
	06	0.48 (0.03)	0.40 (0.07)	0.13
	11	0.44 (0.04)	0.28 (0.07)	**0.02**
TE-26	01R	0.28 (0.08)	0.38 (0.06)	**0.08**
	02R	0.32 (0.25)	0.50 (0.05)	**0.07**
	03	0.38	0.44 (0.05)	0.36
	04/05	0.34 (0.05)	0.50 (0.03)	**<0.01**
TE-28	218	0.01 (0.01)	0.02 (0.03)	0.45
	219R	0.00 (0.00)	0.50	**<0.01**
TV-04	02/22	0.00	0.08 (0.10)	0.50
	03	0.00	0.05 (0.07)	0.54
	04R	0.00	0.00 (0.01)	0.69
TV-14	01	0.37 (0.02)	0.40 (0.11)	0.69
	02/23	0.35	0.40 (0.08)	0.64
	03R	0.45	0.40 (0.09)	0.65
	04R	0.34	0.36 (0.10)	0.86

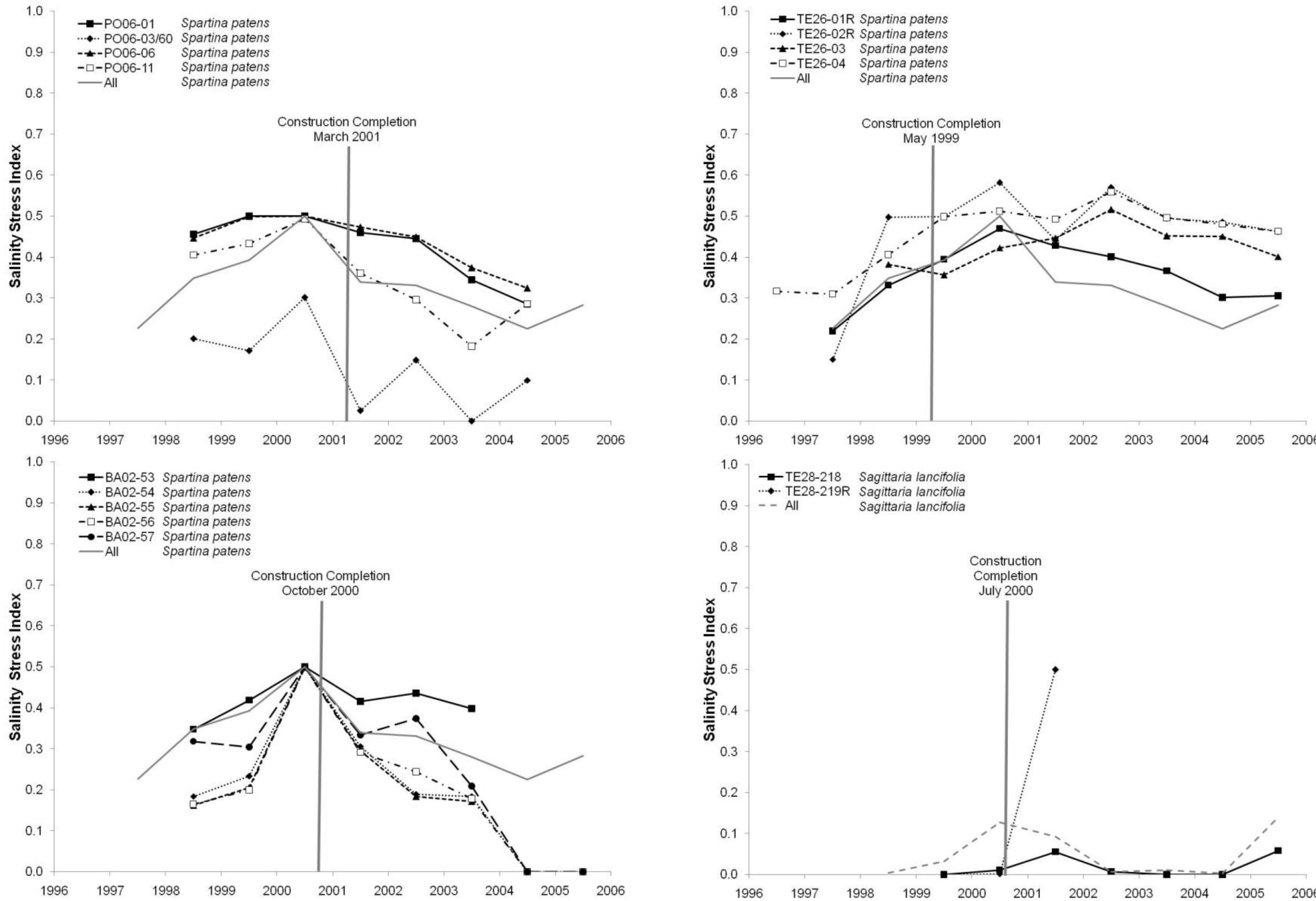


Figure 4a. Salinity stress index is shown in relationship to construction completion.

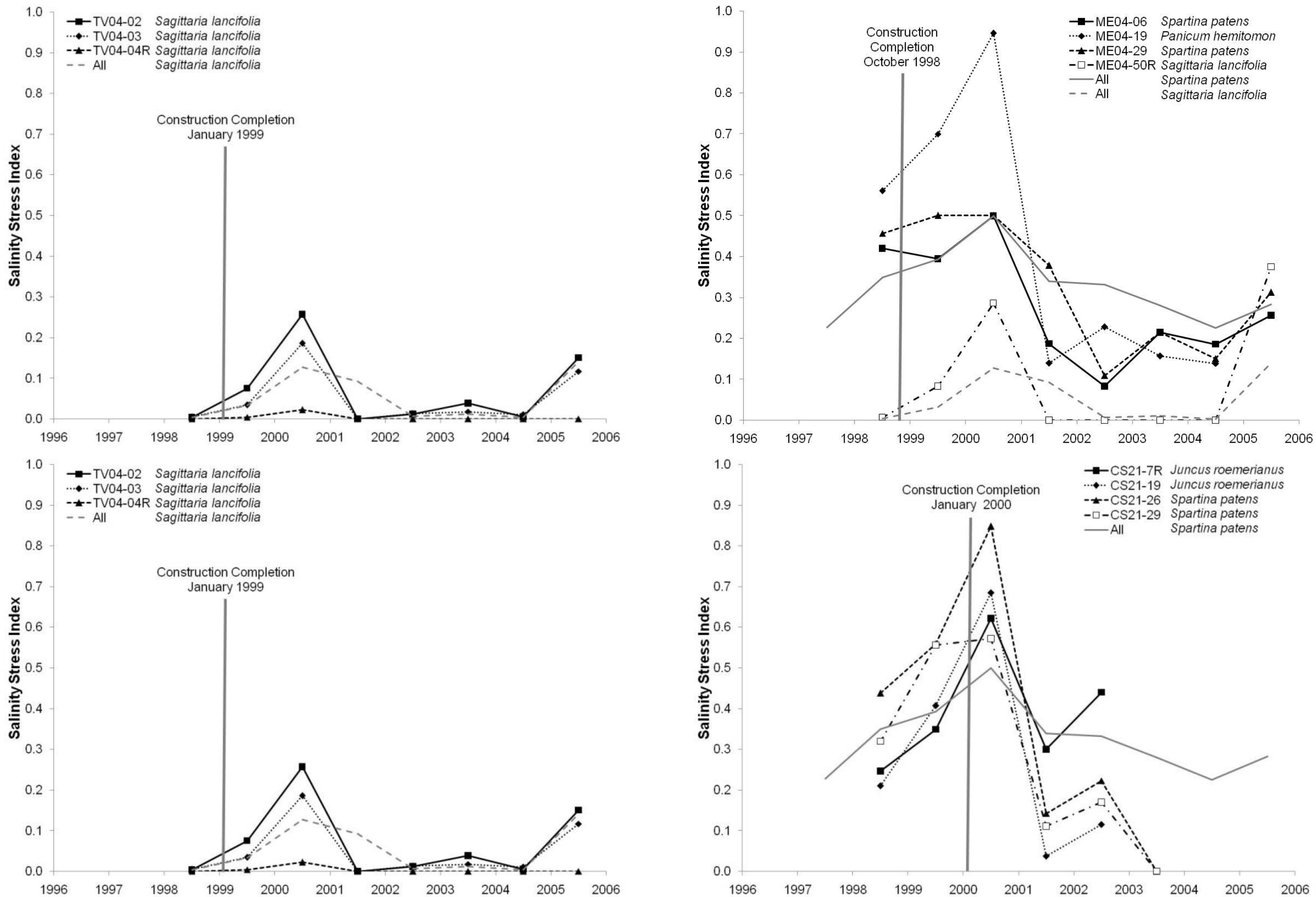


Figure 4b. Salinity stress index is shown in relationship to construction completion.

In project TE-28 the reference area showed a very large jump in salinity stress —from 0 in 2000 to 0.5 in 2001—(Figure 4), while the project area showed only a minor increase. This indicates that project TE-28 implemented in 2000 protected gauge 218 within the project area from this salinity stress.

Although changes were not significant, it is interesting to note that salinity stress increased in the reference sites for project CS-21, while salinity stress decreased in the project areas. This indicates that salinity stress reduction occurred as a result of the project and not a general reduction due to climate variation.

Flooding Stress

Thirty-seven percent of the monitoring gauges showed significant changes in flooding stress after project implementation (Table 6; Figure 5). Of the 30 gauges tested 11 showed significant differences ($\alpha = 0.10$) in flooding stress after project implementation. Of the 11 gauges with significant differences only 2 were reference gauges. Most gauges showed similar interannual patterns with low flooding stress in 1999 and 2000 and higher flooding stress in 2002 and 2003 (Figure 5).

Two (gauges 54 and 57) of the five BA-02 project gauges showed significant ($\alpha = 0.10$) increases in flooding stress after project implementation in 2000 (Figure 5). Gauge 57 is located just to the north of structure No. 1, an 80m fixed crest rock rip rap weir with a crest elevation of 4.0 ft NAVD88 and a 6.1m invert barge bay set at -6.4 ft NAVD88. Gauge 54 is just to the west of structure 14A a 507.5m fixed crest rock rip rap weir with a crest elevation of 4.0 ft NAVD88 and a 24.4m invert boat bay set at -6.5 ft NAVD88. These are two structures with highest crest elevations (even though they have barge bays) that were designed to limit rapid water level changes and limit rapid salinity increases.

Table 6. Flooding stress index before and after project implementation. Gauge numbers ending in R are reference gauges.

Project	Gauge	Stress Index Before Average (Std. Dev.)	Stress Index After Average (Std. Dev.)	P value
BA-02	53	0.03 (0.04)	0.04 (0.03)	0.70
	54	0.13 (0.07)	0.32 (0.11)	**0.04**
	55	0.34 (0.09)	0.40 (0.20)	0.68
	56	0.38 (0.02)	0.42 (0.16)	0.72
	57	0.36 (0.08)	0.47 (0.06)	**0.06**
CS-21	07R	0.13 (0.12)	0.15 (0.13)	0.89
	19	0.07 (0.07)	0.09 (0.08)	0.80
	26/98	0.04 (0.05)	0.14 (0.09)	0.24
	29	0.13 (0.15)	0.26 (0.15)	0.35
ME-04	06	0.31	0.21 (0.11)	0.44
	19	0.32	0.40 (0.27)	0.81
	29	0.82	0.63 (0.18)	0.38
	50R/143R	0.79	0.54 (0.22)	0.33
PO-06	01	0.27 (0.06)	0.41 (0.06)	**0.03**
	03/60	0.10 (0.14)	0.13 (0.06)	0.66
	06	0.16 (0.09)	0.23 (0.08)	0.34
	11	0.19 (0.07)	0.32 (0.08)	**0.07**
TE-26	01R	0.04 (0.04)	0.00 (0.00)	**0.03**
	02R	0.11 (0.02)	0.03 (0.04)	**0.03**
	03	0.09	0.02 (0.02)	**0.04**
	04/05	0.07 (0.06)	0.04 (0.04)	0.28
TE-28	218	0.33 (0.12)	0.83 (0.24)	**0.04**
	219R	0.21 (0.17)	0.22	0.97
TV-04	02/22	0.10	0.07 (0.04)	0.61
	03	0.16	0.04 (0.04)	**0.03**
	04R	0.05	0.02 (0.02)	0.32
TV-14	01	0.00 (0.00)	0.01 (0.00)	**0.05**
	02/23	0.06	0.01 (0.00)	**<0.01**
	03R	0.00	0.02 (0.01)	0.32
	04R	0.01	0.03 (0.02)	0.45

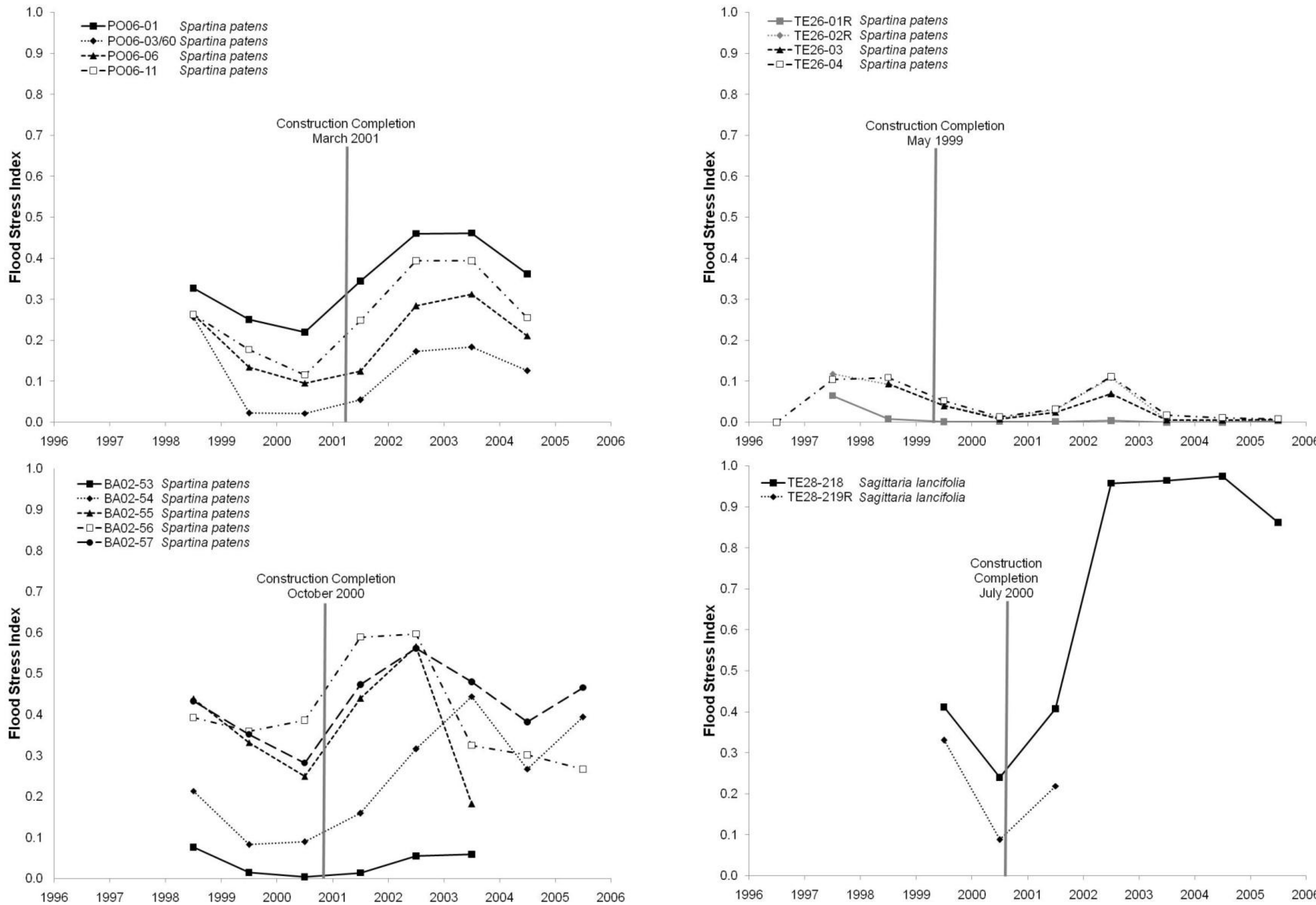


Figure 5a. Flooding stress index is shown in relationship to construction completion.

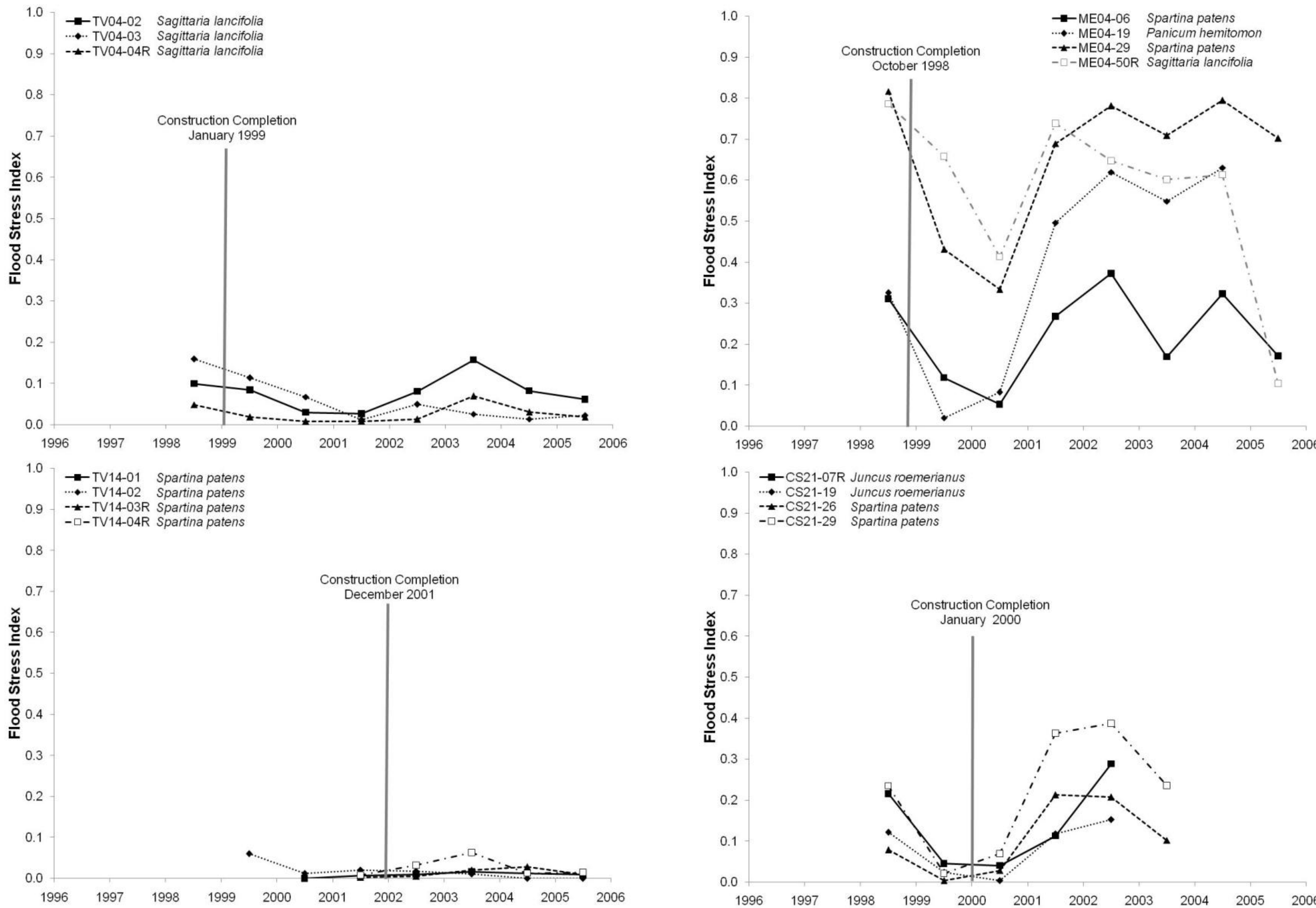


Figure 5b. Flooding stress index is shown in relationship to construction completion.

At PO-06 two (gauges 01 and 11) of the four project gauges showed a significant increase in flooding stress after project implementation in 2001 (Figure 5). However, all four gauges showed a similar pattern in flooding stress over time. For both of these projects, no reference information is available to evaluate if these represent true project effects.

Gauges from project TE-26 showed that flooding stress was generally low in the project and reference area, with a statistically significant decrease in flooding stress at one project gauge and both reference gauges (Figure 5). Gauges from project TE-28 show that flooding significantly increased in the project area after 2001. However, no water level information was available at the reference gauge. This increase in flooding stress probably related to the storm surge in the area due to tropical storm Allison (June 2001).

Gauges for project TV-04 showed a general decline in the already low flooding stress of both the project and reference areas due to the higher flood stress in the year prior to project implementation (Figure 5). Only the decline at gauge 03 was statistically significant. Although the decrease in flood stress is statistically significant for gauges 01 and 02/23 of project TV-14 the flood stress is so small that this is not biologically significant (Figure 5).

Landscape Change

Interpretation of the landscape change was complicated by a drought that occurred between 1999 and 2002 in Louisiana which caused a wide-spread Brown Marsh Phenomenon (Lindstedt and Swenson, 2006). This phenomenon affected the aerial extent of vegetation in some of the mapped plots in 2000 and 2002. While some of the area looked like open water in the 2000 imagery, it had recovered by 2004. In some instances, this caused a higher proportion of water in the 2000 and 2002 maps compared to 1993, 1996 and 2004 maps (Table 7). Figures illustrating landscape classification and marsh condition are provided in Appendix C.

Of the three images used to determine the effect of the implemented changes in hydrology in the BA-02 project area, the image from 2002 had the best differentiation between land and water. Many of the changes recorded in 1996 were due to poor image quality.

Table 7. Summary of land and water in each of the four plots within projects BA02 and PO06.

Project	Plot	Year	Land (ha)	Water (ha)	Other (ha)	Change Rate (ha/yr)
BA02	53	1993	51.3	48.7	0	
BA02	53	1996	52.4	47.6	0	0.36
BA02	53	2002	52.7	47.3	0	0.05
BA02	54	1993	81.7	18.3	0	
BA02	54	1996	79.9	20.1	0	-1.10
BA02	54	2002	76.6	23.4	0	-0.55
BA02	56	1993	78.2	21.8	0	
BA02	56	1996	75.1	24.9	0	-1.03
BA02	56	2002	73.6	26.4	0	-0.25
BA02	57	1993	66.5	27.4	6.2	
BA02	57	1996	65.9	27.9	6.2	-0.20
BA02	57	2002	63.2	30.7	6.2	-0.45
PO06	1	1996	80.2	19.8	0	
PO06	1	2000	76.5	23.5	0	-1.23
PO06	1	2004	76.9	23.1	0	0.07
PO06	6	1996	51.4	41.0	7.6	
PO06	6	2000	50.4	42.0	7.6	-0.33
PO06	6	2004	50.0	42.5	7.6	-0.07
PO06	11	1996	54.6	25.7	19.8	
PO06	11	2000	55.6	24.6	19.8	0.33
PO06	11	2004	53.6	26.7	19.8	-0.33
PO06	03/60	1996	36.6	63.4	0	
PO06	03/60	2000	34.6	65.4	0	-0.67
PO06	03/60	2004	27.2	72.8	0	-1.23

In plot 53 of BA-02 very little change was detected over time (Figure 6, Table 7) with 81% of the grids remaining in the same landscape class over time. Results of mapping indicate that this plot gained land before project implementation and this gain continued after project implementation but at a much lower pace. The largest change in this plot occurred at the location where the shoreline protection structure ties into the marsh (Figure 7) and is probably not related to changes in hydrology. The significant change in patch density with little increase

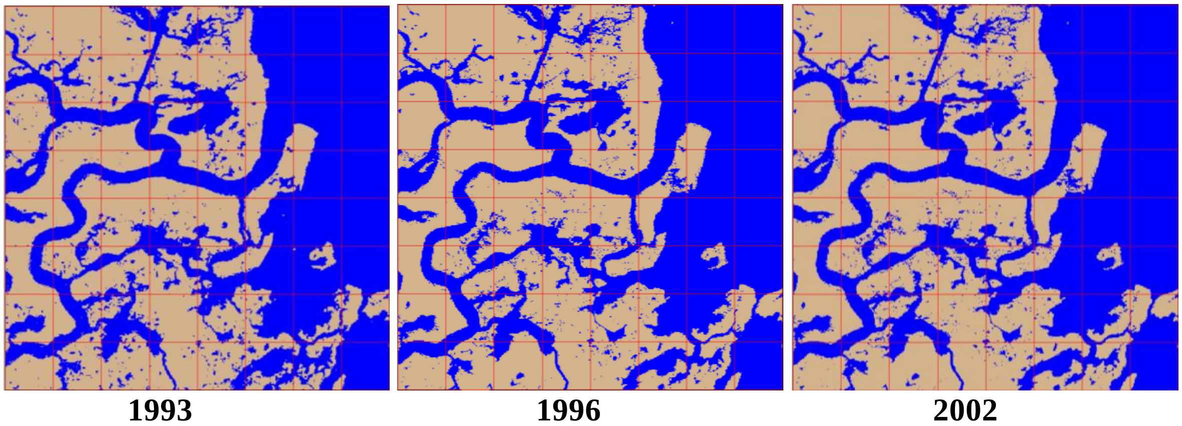


Figure 6. Land (brown) and water (blue) distribution is shown for plot 53 of BA-02.

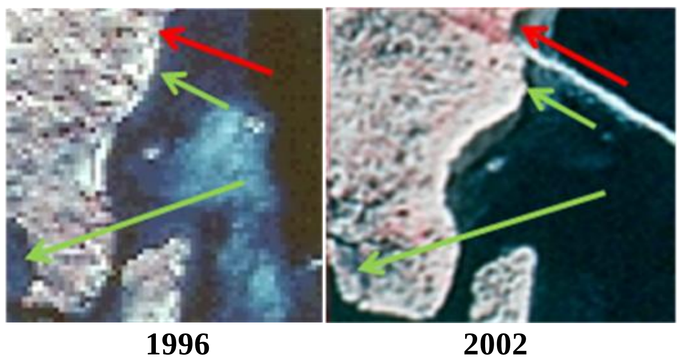


Figure 7. Areas of erosion (red arrows) and deposition (green arrows) in grid 44 within plot 53 of BA-02 between 1996 and 2002.

in water within the site as shown in Table 8 indicates interior marsh breakup. The Landscape Shape Index significantly increased in Plot 53, indicating that the water patches became more irregular in shape over time.

In plot 54 of BA-02 a general degradation of marsh over time occurred (Figure 8, Table 7). Forty-two percent of the grid cells in this plot degraded and switched to a landscape class with more water, while the other fifty-eight percent remained in the same class between 1993 and 2002. This was the only plot to show a significant increase in class and percentage of water.

Table 8. Statistics results for each plot and year. Values represent mean of 64 cells ± SE, along with letters signifying significant differences. Yellow boxes represent significant differences.

Plot	Year	Percentage Water	Adjusted Patch Density	Landscape Shape Index	Cohesion	Average Landscape Class
BA02-53	1993	48.72±3.63 (A)	**7.85±0.73 (B)**	3.29±0.20 (A)	98.47±0.30 (A)	4.67±0.19 (A)
	1996	47.58±3.63 (A)	**10.28±1.05 (AB)**	3.29±0.22 (A)	98.55±0.20 (A)	4.66±0.19 (A)
	2002	47.31±3.78 (A)	**13.05±1.31 (A)**	3.22±0.22 (A)	97.58±0.92 (A)	4.66±0.20 (A)
BA02-54	1993	**18.31±1.55 (B)**	**17.27±1.31 (C)**	**5.62±0.28 (C)**	93.86±0.55 (A)	**2.89±0.13 (C)**
	1996	**20.15±1.75 (AB)**	**31.59±1.74 (B)**	**7.06±0.33 (B)**	92.97±0.65 (A)	**3.15±0.13 (B)**
	2002	**23.38±1.66 (A)**	**50.63±3.21 (A)**	**8.17±0.44 (A)**	93.08±0.64 (A)	**3.30±0.12 (A)**
BA02-56	1993	21.88±2.51 (A)	**7.13±0.91 (B)**	**3.46±0.25 (B)**	93.88±4.63 (A)	3.06±0.20 (A)
	1996	24.85±2.75 (A)	**24.75±2.46 (A)**	**5.14±0.36 (A)**	90.99±1.38 (A)	3.22±0.20 (A)
	2002	26.41±2.96 (A)	**26.41±4.04 (A)**	**5.63±0.50 (A)**	89.69±2.09 (A)	3.28±0.21 (A)
BA02-57	1993	30.48±3.12 (A)	**16.85±1.54 (C)**	**5.02±0.87 (C)**	93.62±0.87 (A)	3.53±0.23 (A)
	1996	31.04±3.17 (A)	**27.10±2.84 (B)**	**6.36±0.98 (B)**	93.42±0.98 (A)	3.56±0.21 (A)
	2002	34.06±3.31 (A)	**56.19±4.33 (A)**	**7.72±1.42 (A)**	91.21±1.42 (A)	3.83±0.22 (A)
PO06-01	1996	19.75±1.74 (A)	74.24±6.02 (A)	11.30±0.65 (A)	91.47±1.20 (A)	3.02±0.14 (A)
	2000	23.52±2.04 (A)	86.34±7.98 (A)	11.42±0.66 (A)	92.27±0.86 (A)	3.23±0.15 (A)
	2004	23.08±1.83 (A)	92.68±6.42 (A)	12.00±0.65 (A)	91.89±1.00 (A)	3.33±0.13 (A)
PO06-06	1996	44.64±4.80 (A)	62.9±20.45 (A)	5.77±0.69 (A)	89.79±2.40 (A)	4.14±0.28 (A)
	2000	45.92±4.75 (A)	37.92±19.77 (A)	4.32±0.46 (A)	91.65±2.31 (A)	4.22±0.28 (A)
	2004	46.32±4.81 (A)	32.75±5.78 (A)	4.80±0.58 (A)	90.05±2.26 (A)	4.27±0.28 (A)
PO06-11	1996	29.48±2.78 (A)	**37.21±4.48 (B)**	8.55±0.64 (A)	90.66±2.75 (A)	3.55±1.70 (A)
	2000	28.48±2.56 (A)	**27.65±2.01 (B)**	7.24±0.41 (A)	93.80±1.11 (A)	3.43±0.20 (A)
	2004	31.41±2.77 (A)	**52.84±5.02 (A)**	8.75±0.48 (A)	90.88±2.37 (A)	3.55±1.60 (A)
PO06-60	1996	63.44±3.63 (A)	**23.7±3.14 (AB)**	5.21±0.46 (A)	97.83±0.68 (A)	5.50±0.21 (A)
	2000	65.36±3.44 (A)	**16.34±2.01 (B)**	4.93±0.41 (A)	98.50±0.43 (A)	5.66±0.18 (A)
	2004	72.76±3.46 (A)	**27.63±4.54 (A)**	4.66±0.56 (A)	98.73±0.39 (A)	5.93±0.17 (A)

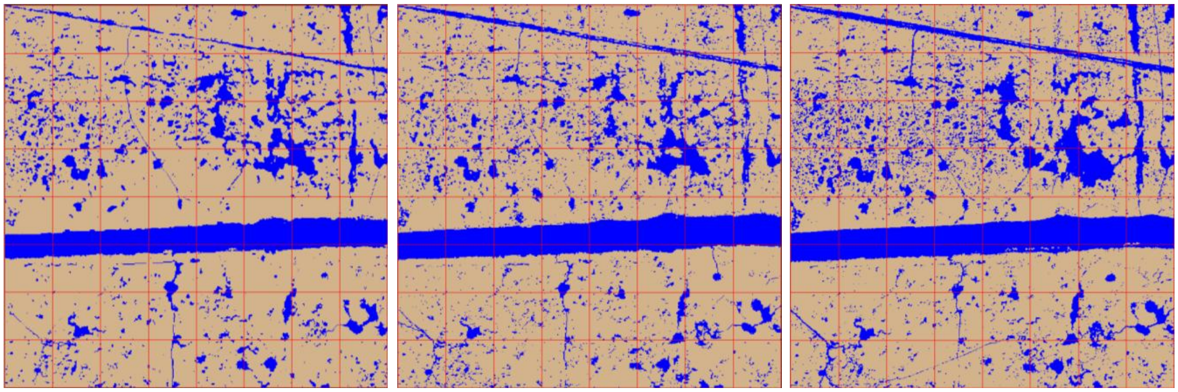
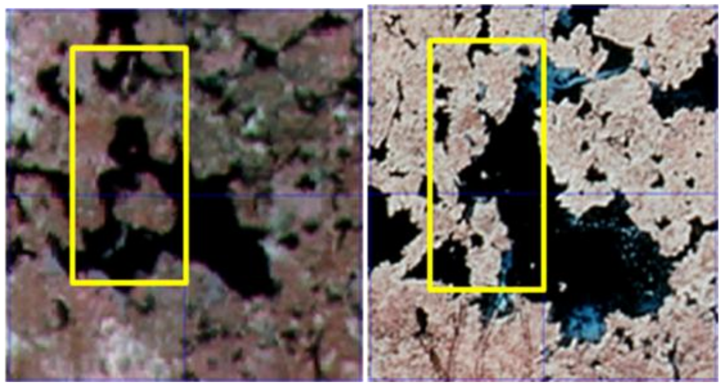


Figure 8. Land (brown) and water (blue) distribution is shown for plot 54 of BA-02.

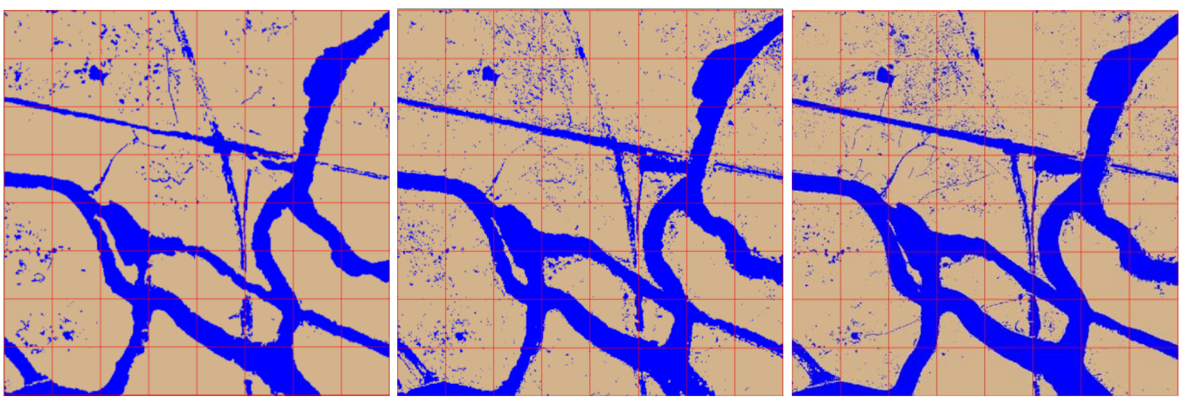
The significant increase in number of patches in Plot 54 can be explained by the breakup of interior marsh, which seems to be mostly from small ponds increasing in size or changing from many small ponds within the marsh to one larger pond. The loss rate in this plot declined after project implementation, however, the higher loss rate pre-project may be the result of the poor image quality for 1996. There are indications that some of the marsh within BA-02 Plot 54 is floating marsh. We documented marsh movement between 1993 and 2002 within grids 44 and 45 (Figure 9). Not only did an island change configuration and orientation, but other shorelines in the area were changed. The Landscape Shape Index significantly increased in Plot 54, again indicating that the water patches became more irregular in shape.

Plot 56 in BA-02 shows an increase in both Patch Density and Landscape Shape Index with 1993 being significantly lower than either 1996 or 2002 for both of these statistics (Table 8). This trend indicates that interior marsh breakup is the source for most of the land loss in plot 56 (Figure 10, Table 7). Although some of the loss is attributable to shoreline erosion, the percentage of water did not increase significantly. Similar to plot 54, the loss rate in plot 56 declined after project implementation, however the higher loss rate pre-project maybe the result of the poor quality of the 1996 photography.



1993 **2002**

Figure 9. The yellow boxes show an example of marsh movement in grids 45 and 46 of plot 54 between 1996 and 2002. The island in the lower half of the box in 1993 has changed configuration, along with some shoreline changes.



1993 **1996** **2002**

Figure 10. Land (brown) and water (blue) distribution is shown for plot 56 of BA-02.

Plot 57 of BA-02 experienced moderate land loss that accelerated after project implementation (Figure 11, Table 7). Even though no significant increase in percentage of water was detected in plot 57 (Table 8), some increase in water occurred over time and was due to erosion along bayous and canals. However interior marsh loss increased as denoted by a significant increase in Patch Density. A large segment of marsh located along a pipeline corridor in the northwestern corner of this plot moved into the pipeline pond, revealing the presence of floating marsh in this plot (Figure 12).

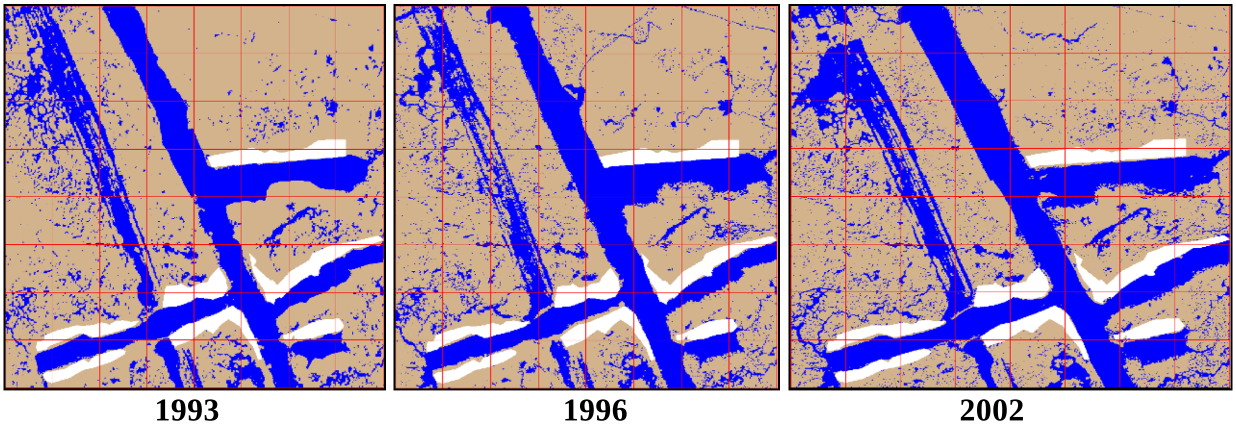


Figure 11. Land (brown) and water (blue) distribution is shown for plot 57 of BA-02. The area removed due to trees and their shadows is shown in white.

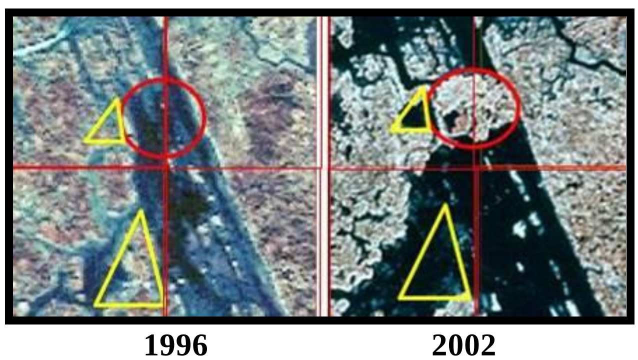
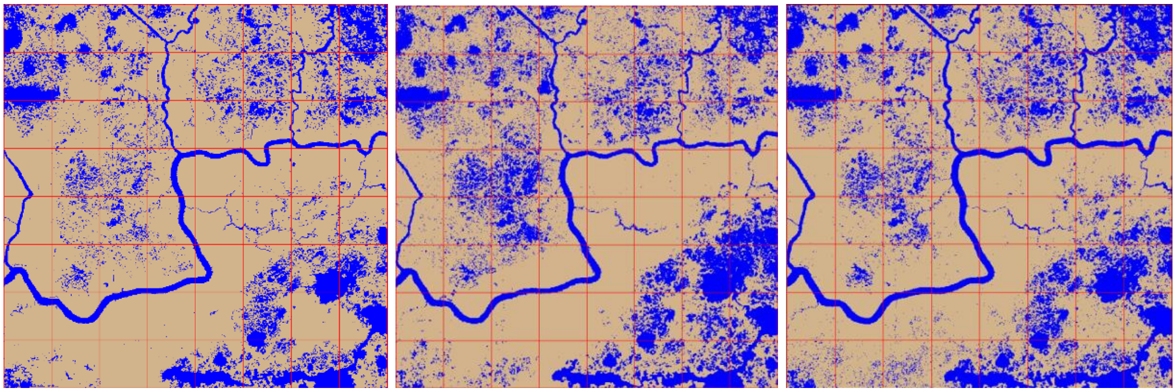


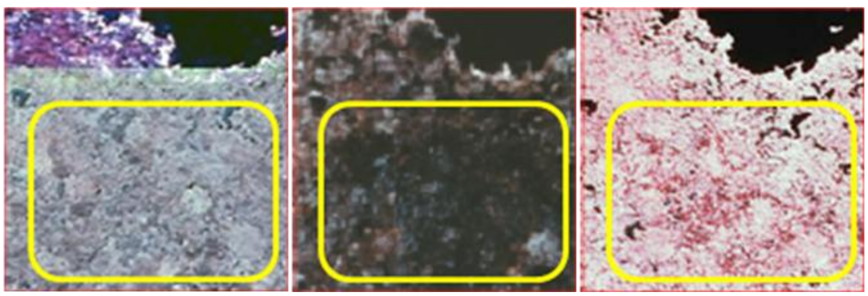
Figure 12. Displacement of marsh shown between 1996 and 2002 in BA02-57. The images represent grids 7, 8 15 and 16 within the 1 km^2 plot. The yellow triangles mark the original marsh and the red circle shows where the marsh moved.

Plot 01 in PO-06 represents a relatively robust marsh along the flanks of Salt Bayou. This plot experienced land loss pre-construction that was exacerbated by the drought in 2000 (Figure 13, Table 7). Some of this marsh recovered after project implementation (Figure 14, Table 7). Most of the loss between 1996 and 2000 occurred in areas that were already degraded (Figure 13). While overall the plot gained land between 2000 and 2004, nine of the 11 grids that appeared stable (class 1A and 2A) in 2000, became degraded by 2004. However, none of the attributes measured showed significant changes over time (Table 8).



1996 2000 2004

Figure 13. Land (brown) and water (blue) distribution is shown for plot 01 of PO-06.

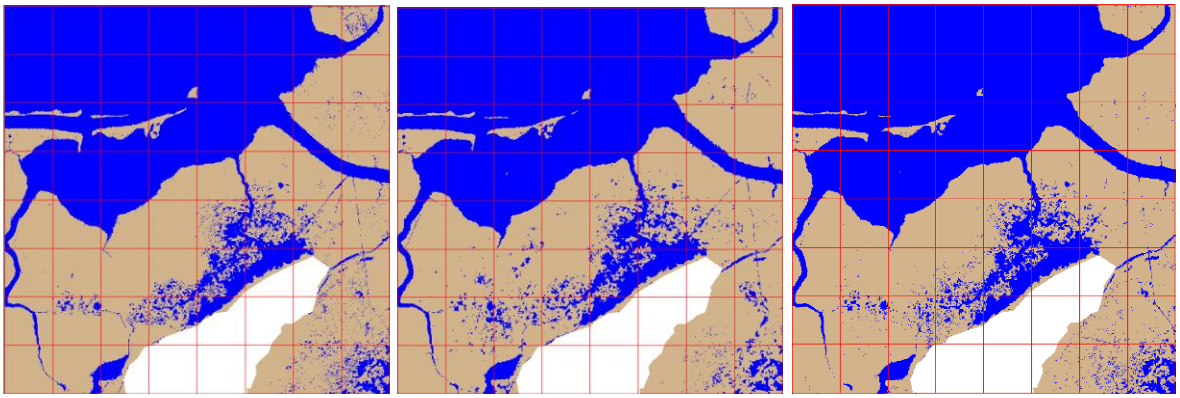


1996 2000 2004

Figure 14. Comparison over time of grid 51 in Plot 01 of PO-06, depicting the difference in the 2000 imagery as compared to 1996 and 2004. The yellow rectangles show that the area in 2002 had much more water than either of the other years.

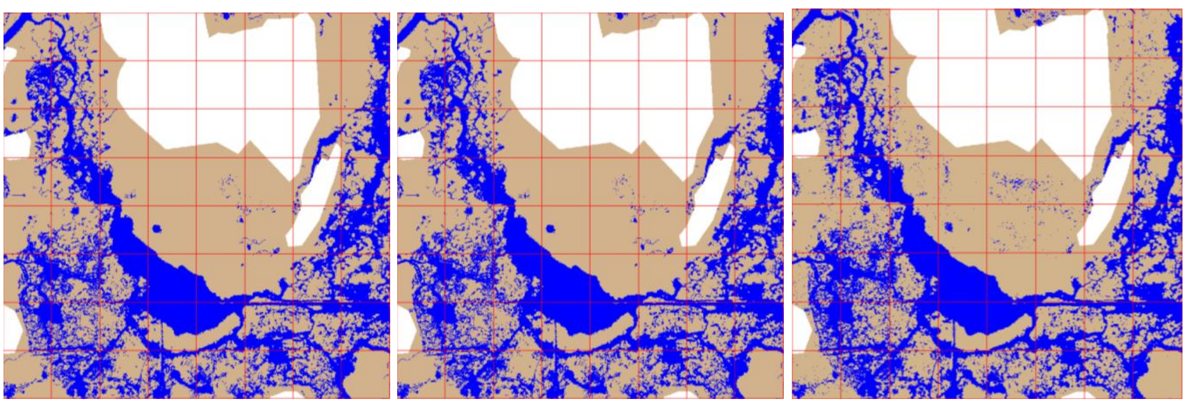
Pre- and post- project implementation, the loss rate in plot 06 of PO-06 was relatively low (Figure 15, Table 7). Sixty-eight percent of the grids remained in the same class between 1996 and 2004. None of the attributes measured showed significant changes over time (Table 8).

Plot 11 of PO-06 gained land before project implementation, however those gains were negated by greater amounts of loss after 2000 (Figure 16, Table 7). Thirty-nine percent of the grids remained in the same class between 1996 and 2004. The significant change in patch density over time in this plot 11 (Table 8), indicates interior marsh breakup.



1996 2000 2004

Figure 15. Land (brown) and water (blue) distribution is shown for plot 06 of PO-06. The area removed due to trees and their shadows is shown in white.



1996 2000 2004

Figure 16. Land (brown) and water (blue) distribution is shown for plot 11 of PO-06. The area removed due to trees and their shadows is shown in white.

Plot 03/60 is in one of the more degraded areas of PO-06, and marsh loss in this area was higher after project implementation (Figure 17, Table 7). Thirty-eight percent of the grids were almost completely open water (class 7) in 1996 and 2000, and by 2004 fifty percent of the grids were classified as such (Figure 18). Of the 15 severely degraded grids (class 6) in 1996, eight had changed to open water by 2004. Many of the other grids also changed from a more solid to a more degraded class over time, and by 2004 no robust marsh (class 1A and 2A) remained (Figure 19). The high level of degradation, as well as the large bodies of water in the area, has

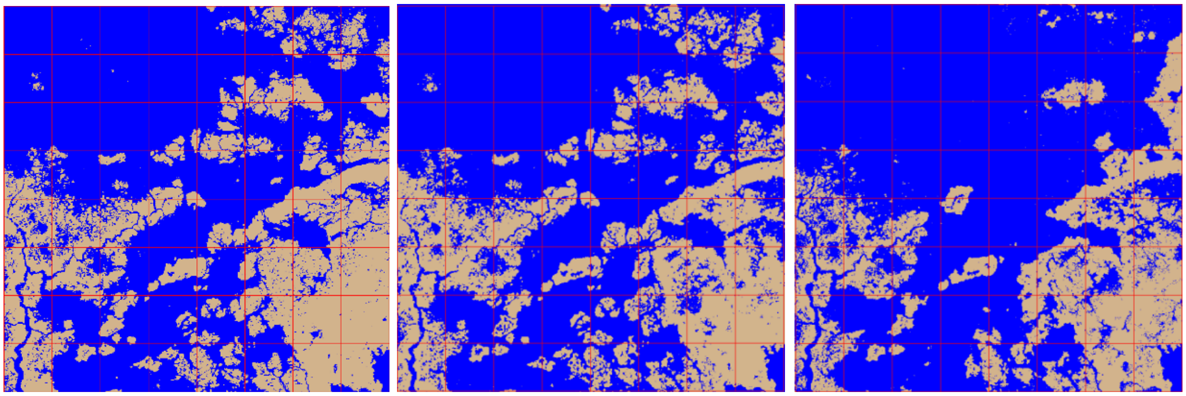


Figure 17. Land (brown) and water (blue) distribution is shown for plot 03/60 of PO-06.

made the remaining marsh more susceptible to wind erosion. Several smaller islands and peninsulas were lost between 2000 and 2004, while interior loss continued as well (Figure 19) making this the plot with the most land change in the study. Table 8 shows significant change in Patch Density in Plot 03/60 due to a decrease in number of patches in 2000.

Site Analyses

The 4 plots within each site were combined in an effort to examine overall changes in sites BA-02 and PO-06. Regression analysis of the number of water patches in BA-02 showed a significant increase from 1993 to 2002, while patch size did not change significantly (Table 9). In contrast regression analysis of the number and size of water patches at PO-06 showed no significant trends from 1996 to 2004. Land loss at BA-02 seems to be the result of the formation of new water bodies (interior land loss), while land loss at PO-06 seems to occur mostly through the enlargement of existing water bodies (edge erosion) with some formation of new water bodies.

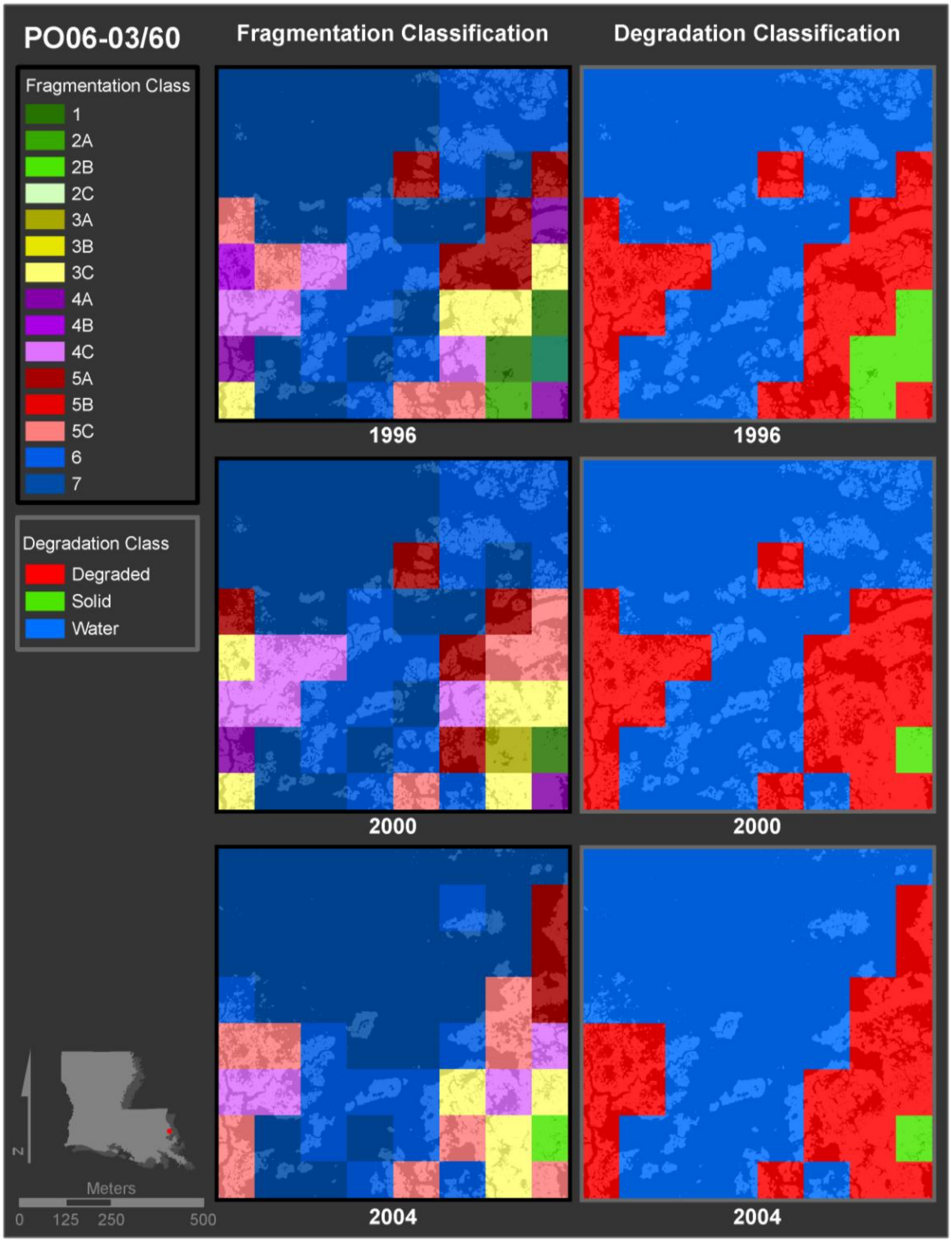


Figure 18. The two tier classes (category and configuration), and degradation associations (solid marsh = 1, 2a, 2b; degraded marsh = 2c, 3a, 3b, 3c, 4a, 4b, 4c, 5a, 5b, 5c; and water = 6, 7) are shown by grid tile for plot PO06-03/60a in 1996, 2000 and 2004.

Table 9. Regression analysis results for BA-02 and PO-06 using data from all plots within each site.

Site / Landscape Characteristic	slope	p	R^2
BA02			
Number of patches	+	**0.0142**	0.4676
Landscape shape index	+	0.2720	0.1191
Cohesion	+	0.9473	0.0005
Patch Size	-	0.3430	0.0901
PO06			
Number of patches	+	0.7812	0.0081
Landscape shape index	+	0.8723	0.0024
Cohesion	+	0.9671	0.0002
Patch Size	+	0.9763	0.0001

Relating Landscape Change to Hydrology

A significant ($\alpha < 0.05$) linear relationship between the flooding stress index and land change in *Sagittaria lancifolia* dominated sites (Figure 19) was noted, with loss increasing (more negative change) as the flooding stress increased. In the regression for Spartina patens we removed the results from plot PO06-03/60, because a large portion of the loss may be due to shoreline erosion and not interior loss due to flooding stress (Figure 19). For *Spartina patens* dominated sites we observed no significant relationship between the flooding stress index and land change (Figure 19). These results are opposite to previous studies for these species, which show a high sensitivity to flooding by *Spartina patens* (Webb et al. 1995, Pezeshki and DeLaune 1993, Burdick et al. 1989) and relatively low sensitivity to flooding by *Sagittaria lancifolia* (Martin and Shaffer 2005). However, Howard and Mendelssohn (1995) show a decrease in root production and postulate that reduction of rhizome biomass will take longer than one or two growing seasons. Our results may reflect the effect of flooding stress on a decadal time scale.

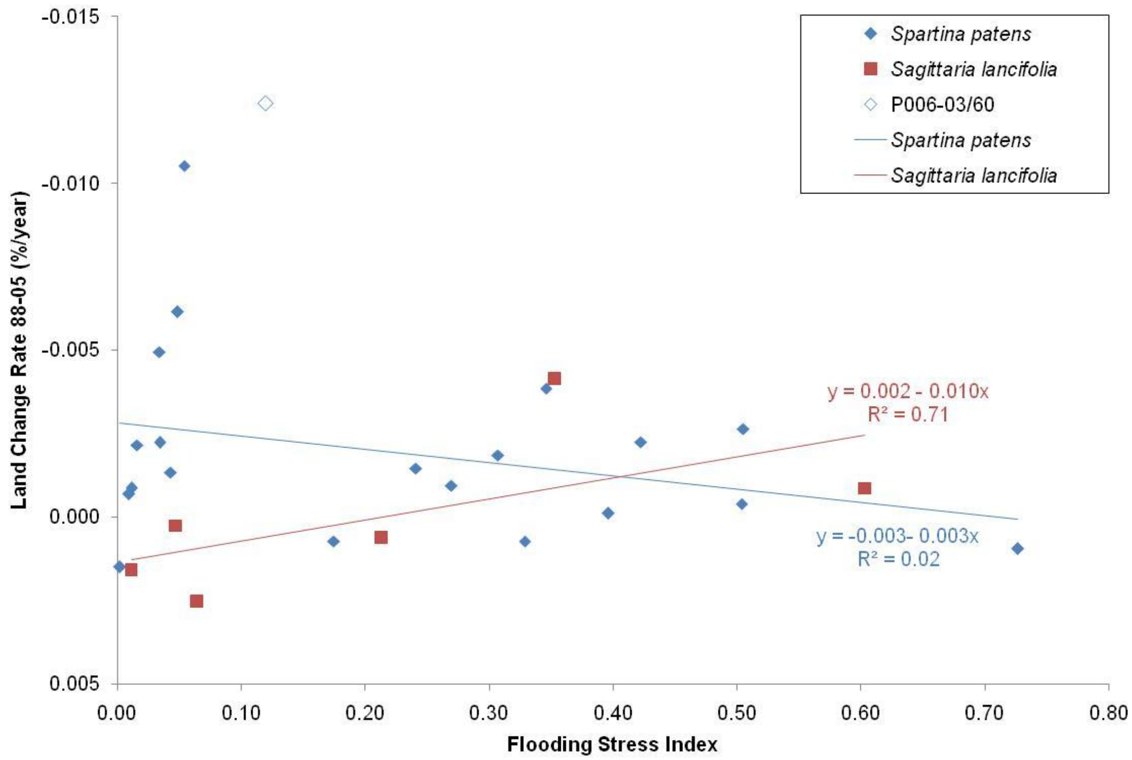


Figure 19. Relationship between the flooding stress index and land change rates for sites dominated by *Spartina patens* and sites dominated by *Sagittaria lancifolia*.

No significant linear relationship was observed between the salinity stress index and land change. However, land loss tended to increase as the salinity stress index increased for *Spartina patens* dominated sites (Figure 20). The salinity stress index for the *Sagittaria lancifolia* dominated sites had a very limited range and a larger data set is necessary to test this relationship. The effect of increasing salt stress on *Spartina patens* dominated sites may reflect both a decrease in primary production as well as increased organic matter decomposition (Rejmankova and Post 1996).

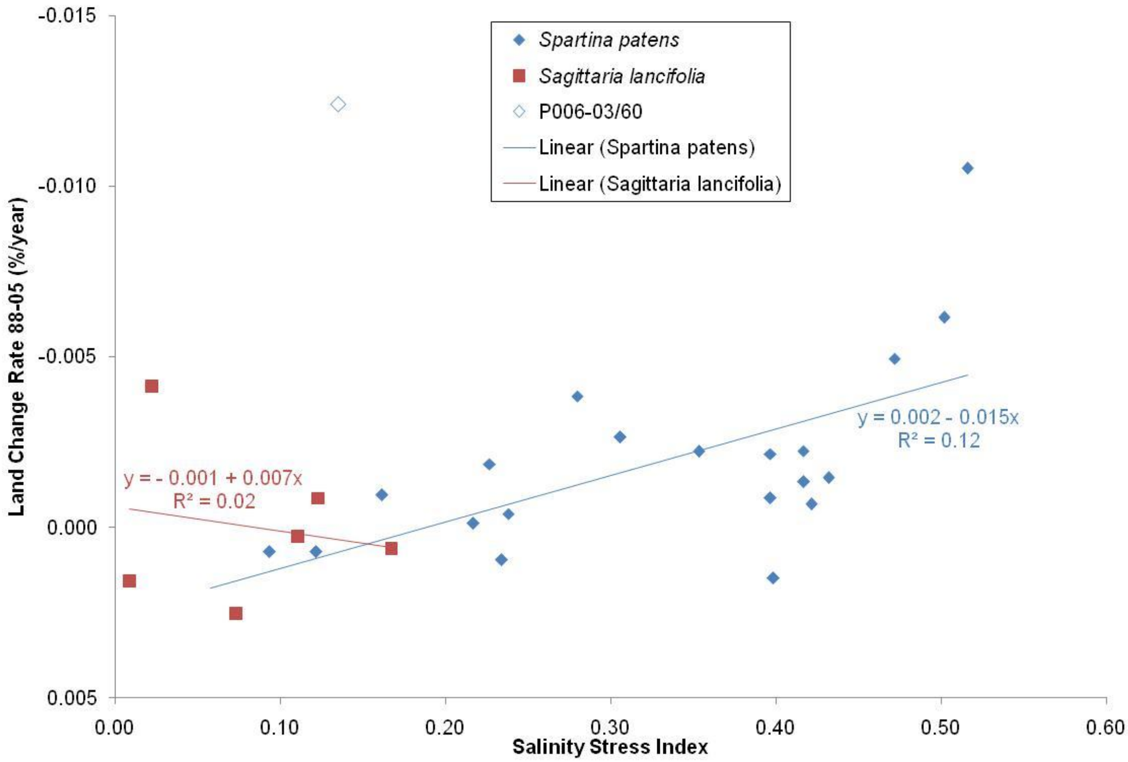


Figure 20. Relationship between the salinity stress index and land change rates for sites dominated by Spartina patens and sites dominated by Sagittaria lancifolia.

Summary

- We developed a method to convert hourly observations of salinity into an annual salinity stress index for the dominant plant species at the site.

- We developed a method to convert hourly observations of water level relative to the marsh surface into an annual flooding stress index for the dominant plant species at the site.

- We mapped land/water distribution for a 1 km^2 site adjacent to the gauge location before, during, and after construction and determined land loss and degradation at four sites each in Project BA-02 and PO-06.

- Of the 30 gauges tested only six showed significant differences ($\alpha = 0.10$) in salinity stress after project implementation, and three of these six were reference gauges. Project CS-21 shows no significant differences. However salinity stress decreased in these project areas, while it increased in the reference areas indicating some positive effects on salinity stress in these projects. Overall, there is little evidence that the hydrologic restoration projects had a significant effect on salinity stress.

- Of the 30 gauges tested eleven showed significant differences ($\alpha = 0.10$) in flooding stress after project implementation, only two of these eleven were reference gauges. However, in general reference gauges show the same interannual variation patterns as project gauges. For example in TE-26 a similar decrease in flooding was observed between the reference and project gauges. In TV-14 flooding stress was almost negligible (<0.1) but decreased significantly in the project gauges, while the reference gauges showed no significant difference. In BA-02 two of the five project gauges showed significant increased flooding stress after implementation. Overall, there is little evidence that the hydrologic restoration projects had a significant effect on flooding stress.

- Land loss rates varied greatly among different plots within a project. Due to the coincidence of project construction and an unprecedented drought in the region from 1999 through 2002 it is not possible to interpret land loss rates before and after construction.

- Relating the land loss rates between 1988 and 2005 of a 1km^2 site surrounding the gauge to the salinity and flooding stress indices showed that land loss at *Spartina patens* dominated plots was positively correlated with the average salinity stress index for the plot and not significantly correlated with the flooding stress. In contrast, land loss in *Sagittaria* dominated plots was positively correlated with flooding stress and the data range for salinity stress was insufficient to establish a relationship.

Conclusions

This study has illustrated the usefulness of salinity and flooding indices as tools to describe the natural variability that occurs in these hydrologic stressors within coastal Louisiana. The effects of the drought in 1999 and 2000 are clearly evident in the data. The short length of the hydrologic data records used in this assessment, especially the availability of pre-construction data, together with the timing of project construction completion with drought conditions, prohibited a robust evaluation of the effects of hydrologic restoration projects. The land loss rate relationship with salinity stress in *S. patens* dominated sites and with flooding stress in *S. lancifolia* dominated sites needs to be further investigated using a larger sample size. The relationships suggest other ecological interactions may play an important role in land loss, such as flooding interactions on biogeochemistry or physical marsh edge erosion which was identified from the landscape fragmentation pattern analysis. The integration of landscape assessments with field data driven indices will become a powerful evaluation tool once longer data records are available. Two FRAGSTATS metrics proved useful in identifying small changes in marsh loss that occurred over time. For instance, an increase in number of patches (APD) with no significant increase in water may indicate interior marsh breakup. The usefulness of these metrics also underscores the need for careful mapping of small water bodies with consideration for the ultimate use in ecological analyses.

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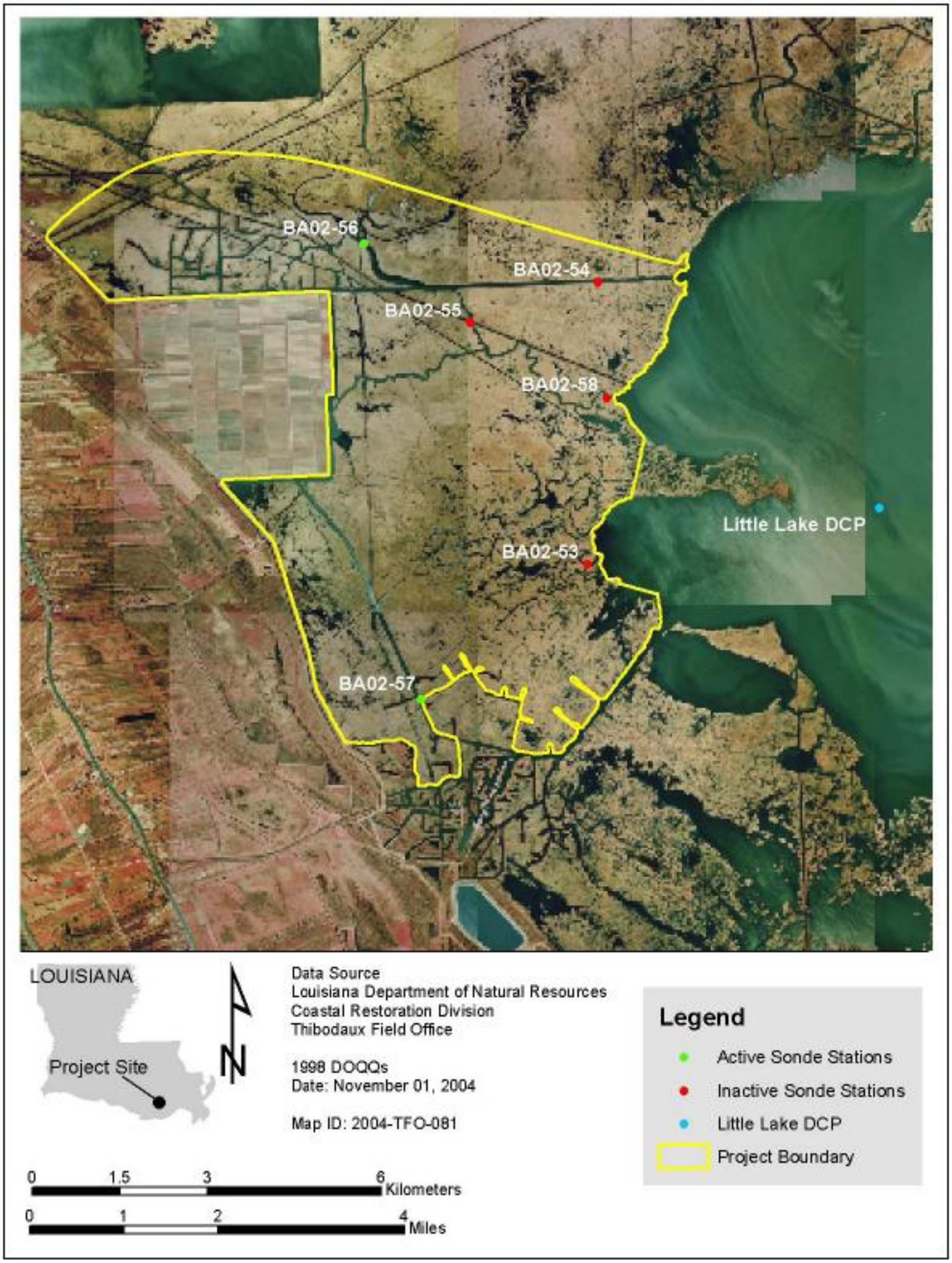
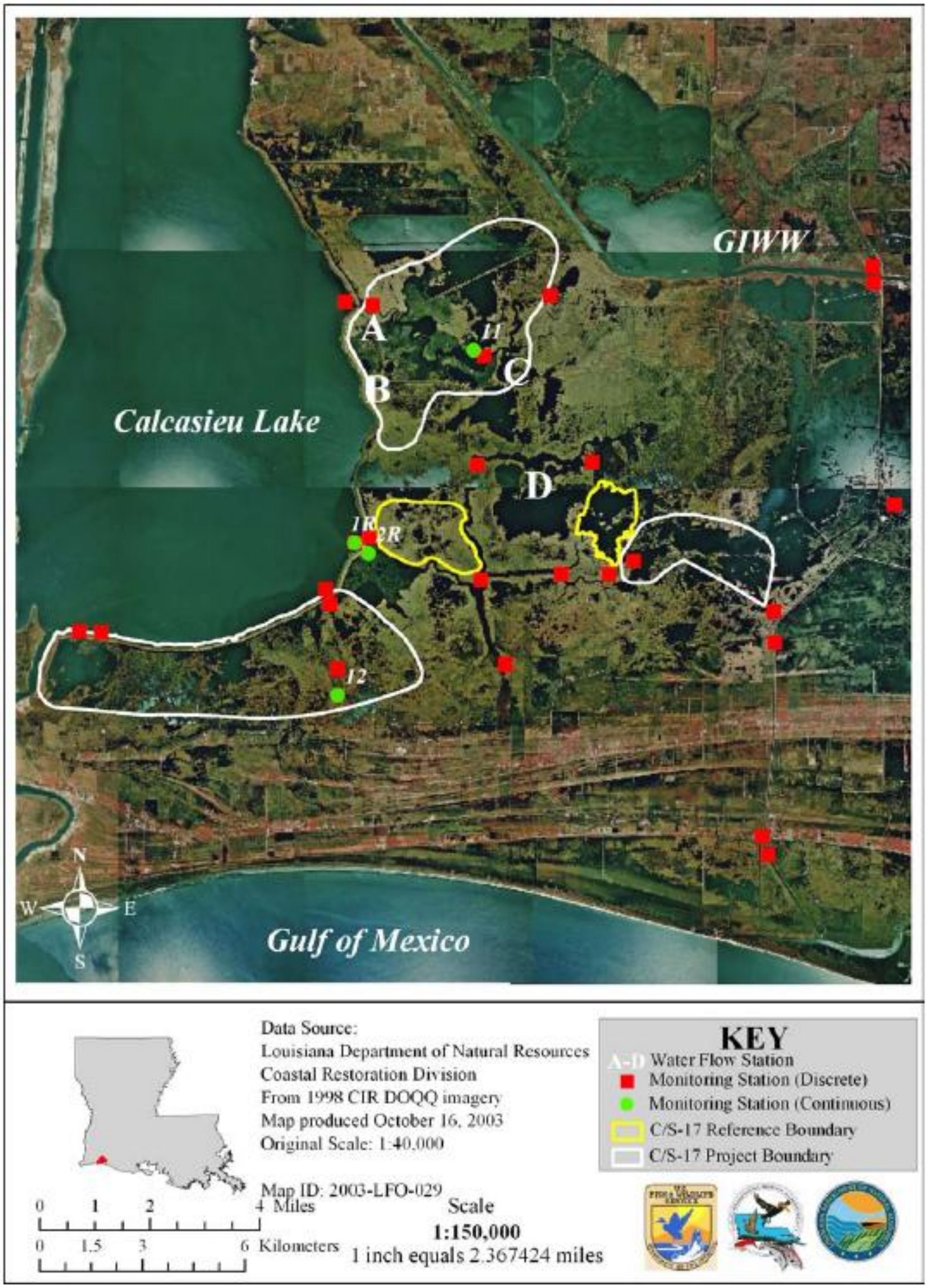
APPENDIX A:
MAPS OF HYDROLOGY GAUGE LOCATION FOR EACH PROJECT

Project Map Showing Gauge Locations for BA-02



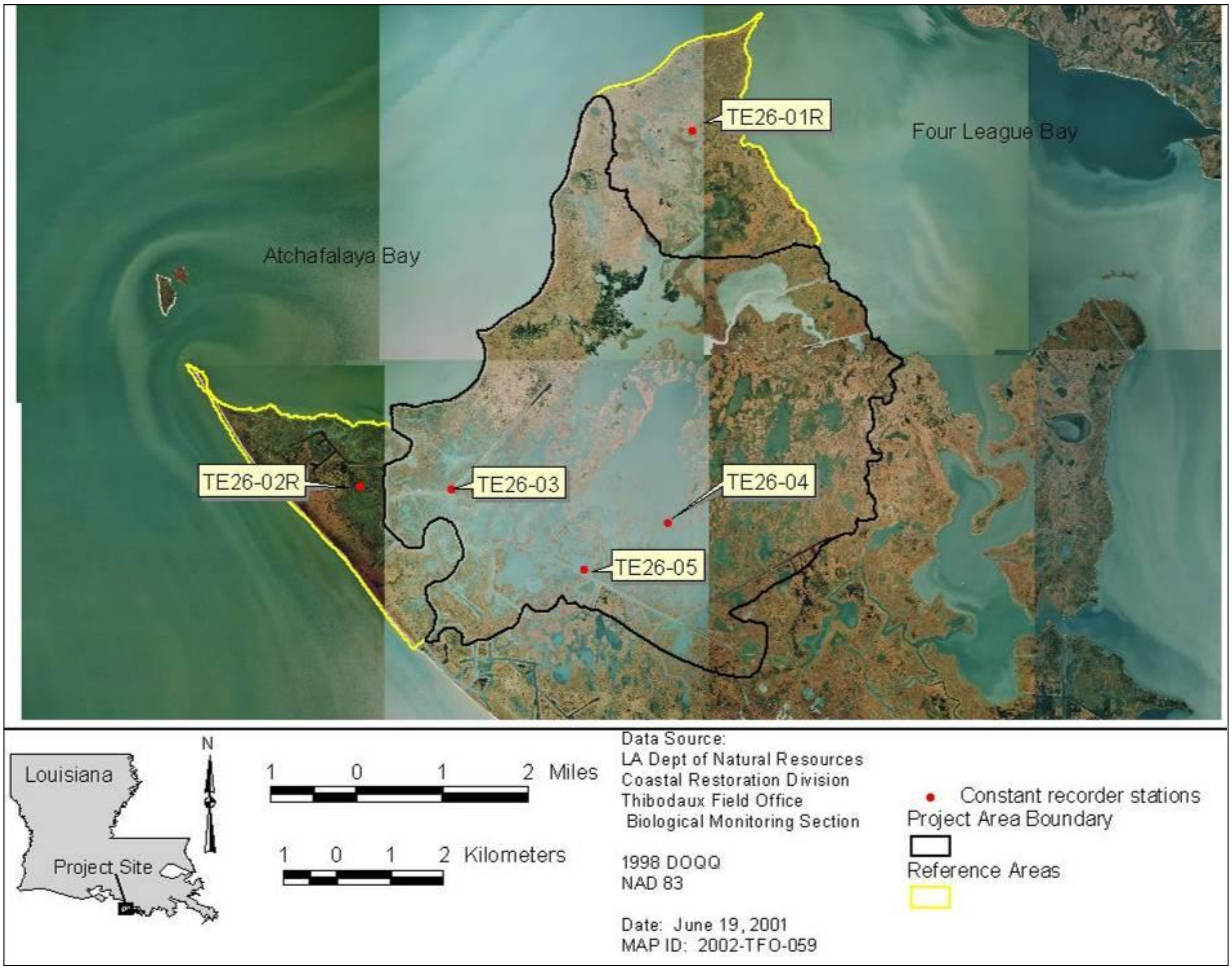
Project Map Showing Gauge Locations for CS-17



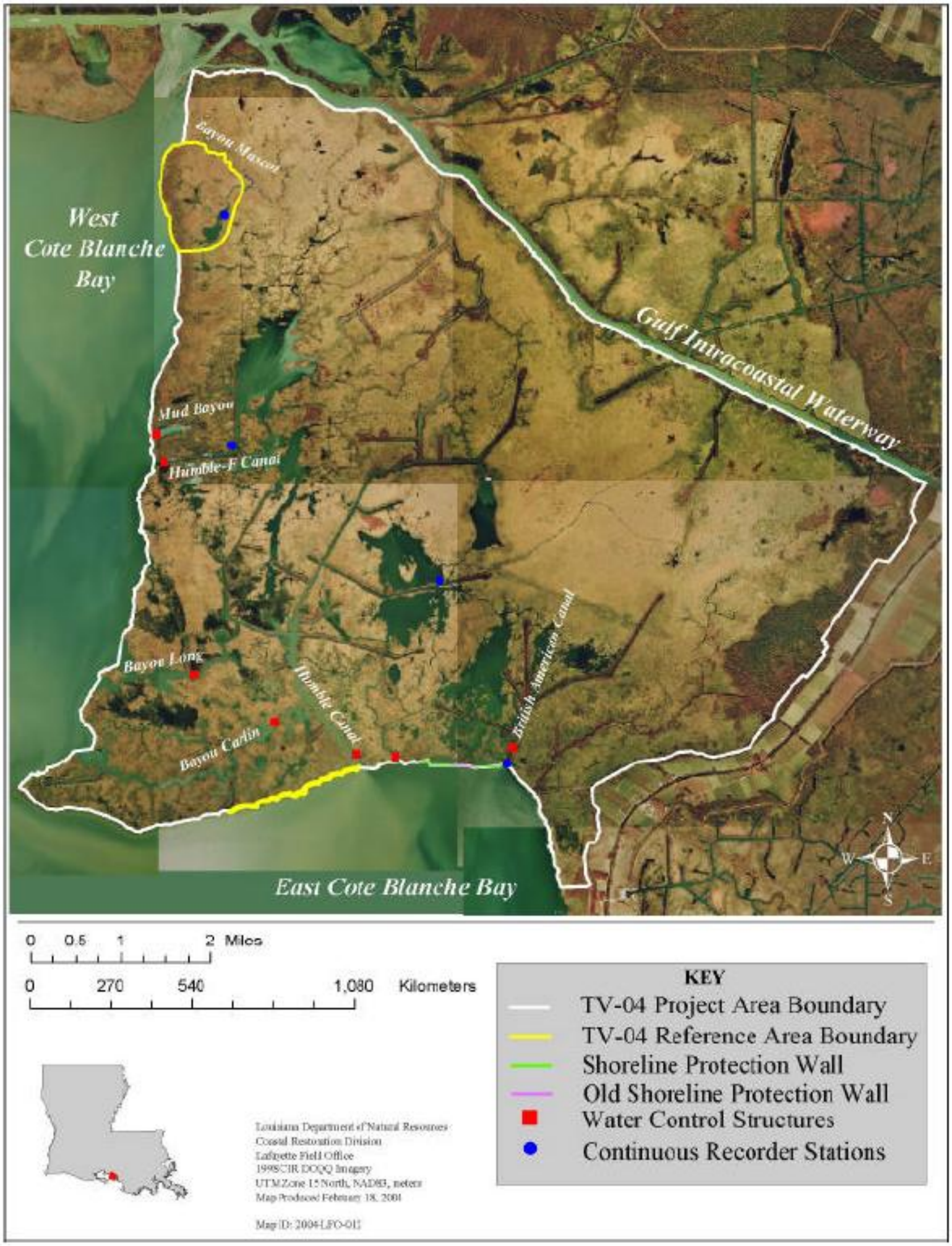
Project Map Showing Gauge Locations for CS-23

Project Map Showing Gauge Locations for PO-06

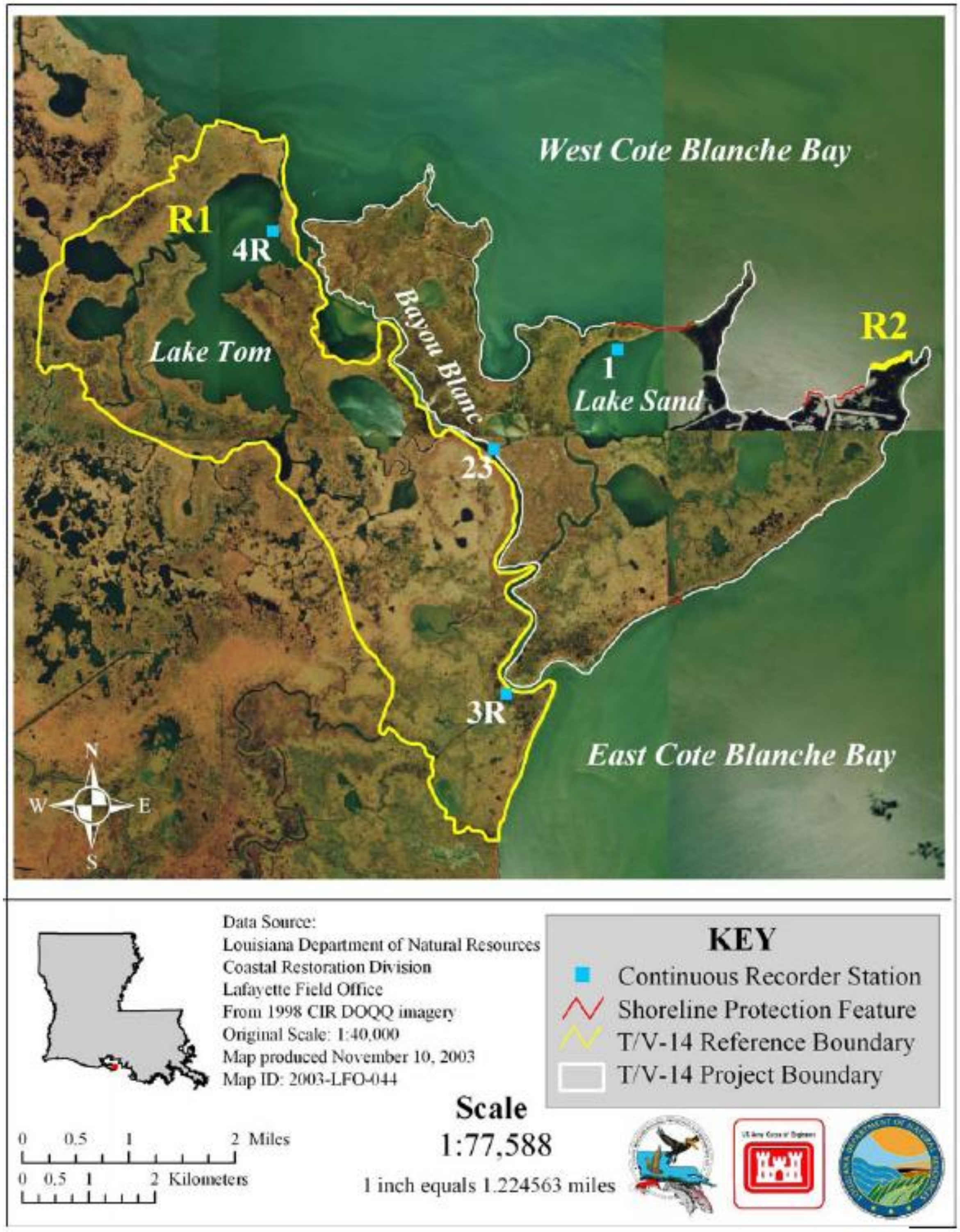
Project Map Showing Gauge Locations for TE-26



Project Map Showing Gauge Locations for TV-04



Project Map Showing Gauge Locations for TV-14



APPENDIX B:
RELATIONSHIP BETWEEN PROJECT GAUGES

BA-02

Water Level Relative to Marsh Surface

Before Project

wlmar53 = -0.751 + 0.995*wlmar57	$R^2 = 0.95$	$p < 0.0001$
wlmar53 = -0.376 + 1.059*wlmar54	$R^2 = 0.93$	$p < 0.0001$
wlmar53 = -0.668 + 1.021*wlmar55	$R^2 = 0.90$	$p < 0.0001$
wlmar53 = -0.657 + 0.974*wlmar56	$R^2 = 0.84$	$p < 0.0001$
wlmar54 = -0.272 + 0.974*wlmar55	$R^2 = 0.94$	$p < 0.0001$
wlmar54 = 0.314 + 0.875*wlmar53	$R^2 = 0.93$	$p < 0.0001$
wlmar54 = -0.335 + 0.884*wlmar57	$R^2 = 0.92$	$p < 0.0001$
wlmar54 = -0.265 + 0.908*wlmar56	$R^2 = 0.86$	$p < 0.0001$
wlmar55 = -0.066 + 0.935*wlmar57	$R^2 = 0.95$	$p < 0.0001$
wlmar55 = 0.263 + 0.962*wlmar54	$R^2 = 0.94$	$p < 0.0001$
wlmar55 = 0.590 + 0.882*wlmar53	$R^2 = 0.90$	$p < 0.0001$
wlmar55 = 0.008 + 0.944*wlmar56	$R^2 = 0.88$	$p < 0.0001$
wlmar56 = -0.055 + 0.904*wlmar57	$R^2 = 0.90$	$p < 0.0001$
wlmar56 = -0.006 + 0.931*wlmar55	$R^2 = 0.88$	$p < 0.0001$
wlmar56 = 0.261 + 0.946*wlmar54	$R^2 = 0.86$	$p < 0.0001$
wlmar56 = 0.575 + 0.865*wlmar53	$R^2 = 0.84$	$p < 0.0001$
wlmar57= 0.071 + 1.017*wlmar55	$R^2 = 0.95$	$p < 0.0001$
wlmar57= 0.072 + 0.955*wlmar53	$R^2 = 0.95$	$p < 0.0001$
wlmar57= 0.359 + 1.036*wlmar54	$R^2 = 0.92$	$p < 0.0001$
wlmar57= 0.066 + 0.998*wlmar56	$R^2 = 0.90$	$p < 0.0001$

After Project

wlmar53 = -0.522 + 1.014*wlmar54	$R^2 = 0.92$	$p < 0.0001$
wlmar53 = -0.736 + 0.994*wlmar57	$R^2 = 0.90$	$p < 0.0001$
wlmar53 = -0.644 + 0.791*wlmar56	$R^2 = 0.68$	$p < 0.0001$
wlmar53 = -0.467 + 0.702*wlmar55	$R^2 = 0.60$	$p < 0.0001$
wlmar54 = 0.477 + 0.911*wlmar53	$R^2 = 0.93$	$p < 0.0001$
wlmar54 = -0.150 + 0.947*wlmar57	$R^2 = 0.85$	$p < 0.0001$
wlmar54 = -0.043 + 0.677*wlmar56	$R^2 = 0.57$	$p < 0.0001$
wlmar54 = 0.045 + 0.678*wlmar55	$R^2 = 0.56$	$p < 0.0001$
wlmar55 = -0.173 + 0.992*wlmar56	$R^2 = 0.97$	$p < 0.0001$
wlmar55 = -0.252 + 0.985*wlmar57	$R^2 = 0.83$	$p < 0.0001$
wlmar55 = 0.392 + 0.858*wlmar53	$R^2 = 0.60$	$p < 0.0001$
wlmar55 = -0.011 + 0.821*wlmar54	$R^2 = 0.56$	$p < 0.0001$

wlmar56 = 0.174 + 0.981*wlmar55	$R^2 = 0.97$	$p < 0.0001$
wlmar56 = -0.137 + 0.954*wlmar57	$R^2 = 0.86$	$p < 0.0001$
wlmar56 = 0.587 + 0.855*wlmar53	$R^2 = 0.68$	$p < 0.0001$
wlmar56 = 0.103 + 0.840*wlmar54	$R^2 = 0.57$	$p < 0.0001$
wlmar57= 0.674 + 0.902*wlmar53	$R^2 = 0.90$	$p < 0.0001$
wlmar57= 0.140 + 0.898*wlmar56	$R^2 = 0.86$	$p < 0.0001$
wlmar57= 0.169 + 0.894*wlmar54	$R^2 = 0.85$	$p < 0.0001$
wlmar57= 0.245 + 0.842*wlmar55	$R^2 = 0.83$	$p < 0.0001$

Salinity

Before Project

sal53 = 0.193 + 1.096*sal57	$R^2 = 0.89$	$p < 0.0001$
sal53 = 1.208 + 0.902*sal54	$R^2 = 0.76$	$p < 0.0001$
sal53 = 0.899 + 1.136*sal55	$R^2 = 0.74$	$p < 0.0001$
sal53 = 1.372 + 1.034*sal56	$R^2 = 0.69$	$p < 0.0001$
sal54 = 0.064 + 1.137*sal56	$R^2 = 0.89$	$p < 0.0001$
sal54 = -0.019 + 1.144*sal55	$R^2 = 0.88$	$p < 0.0001$
sal54 = -0.516 + 1.038*sal57	$R^2 = 0.86$	$p < 0.0001$
sal54 = -0.236 + 0.846*sal53	$R^2 = 0.76$	$p < 0.0001$
sal55 = 0.114 + 0.964*sal56	$R^2 = 0.93$	$p < 0.0001$
sal55 = -0.216 + 0.834*sal57	$R^2 = 0.88$	$p < 0.0001$
sal55 = 0.362 + 0.765*sal54	$R^2 = 0.88$	$p < 0.0001$
sal55 = 0.161 + 0.649*sal53	$R^2 = 0.74$	$p < 0.0001$
sal56 = 0.093 + 0.962*sal55	$R^2 = 0.93$	$p < 0.0001$
sal56 = 0.280 + 0.785*sal54	$R^2 = 0.89$	$p < 0.0001$
sal56 = -0.300 + 0.844*sal57	$R^2 = 0.87$	$p < 0.0001$
sal56 = 0.061 + 0.667*sal53	$R^2 = 0.69$	$p < 0.0001$
sal57= 0.244 + 0.810*sal53	$R^2 = 0.89$	$p < 0.0001$
sal57= 0.581 + 1.062*sal55	$R^2 = 0.88$	$p < 0.0001$
sal57= 0.826 + 1.027*sal56	$R^2 = 0.87$	$p < 0.0001$
sal57= 0.906 + 0.833*sal54	$R^2 = 0.86$	$p < 0.0001$

After Project

sal53 = 0.699 + 0.920*sal57	$R^2 = 0.63$	$p < 0.0001$
sal53 = 1.328 + 0.808*sal54	$R^2 = 0.54$	$p < 0.0001$
sal53 = 1.226 + 0.960*sal55	$R^2 = 0.47$	$p < 0.0001$
sal53 = 1.245 + 0.956*sal56	$R^2 = 0.44$	$p < 0.0001$
sal54 = 0.002 + 1.122*sal56	$R^2 = 0.90$	$p < 0.0001$
sal54 = 0.018 + 1.108*sal55	$R^2 = 0.83$	$p < 0.0001$
sal54 = -0.244 + 0.884*sal57	$R^2 = 0.71$	$p < 0.0001$
sal54 = -0.044 + 0.667*sal53	$R^2 = 0.54$	$p < 0.0001$
sal55 = 0.043 + 0.977*sal56	$R^2 = 0.89$	$p < 0.0001$
sal55 = 0.256 + 0.753*sal54	$R^2 = 0.83$	$p < 0.0001$
sal55 = -0.072 + 0.695*sal57	$R^2 = 0.76$	$p < 0.0001$
sal55 = 0.211 + 0.490*sal53	$R^2 = 0.47$	$p < 0.0001$
sal56 = 0.185 + 0.799*sal54	$R^2 = 0.90$	$p < 0.0001$
sal56 = 0.124 + 0.914*sal55	$R^2 = 0.89$	$p < 0.0001$
sal56 = -0.107 + 0.733*sal57	$R^2 = 0.77$	$p < 0.0001$
sal56 = 0.300 + 0.457*sal53	$R^2 = 0.44$	$p < 0.0001$
sal57= 0.713 + 1.047*sal56	$R^2 = 0.77$	$p < 0.0001$
sal57= 0.651 + 1.091*sal55	$R^2 = 0.76$	$p < 0.0001$
sal57= 0.984 + 0.804*sal54	$R^2 = 0.71$	$p < 0.0001$
sal57= 0.389 + 0.690*sal53	$R^2 = 0.63$	$p < 0.0001$

CS-21

Water Level Relative to Marsh Surface

Before Project

wlmar7R = 0.228 + 1.041*wlmar19	$R^2 = 0.76$	$p < 0.0001$
wlmar7R = 0.431 + 1.063*wlmar26	$R^2 = 0.67$	$p < 0.0001$
wlmar7R = 0.001 + 0.685*wlmar29	$R^2 = 0.28$	$p < 0.0001$
wlmar19 = 0.197 + 0.960*wlmar26	$R^2 = 0.91$	$p < 0.0001$
wlmar19 = -0.247 + 0.728*wlmar7R	$R^2 = 0.76$	$p < 0.0001$
wlmar19 = -0.220 + 0.524*wlmar29	$R^2 = 0.26$	$p < 0.0001$
wlmar26 = -0.236 + 0.942*wlmar19	$R^2 = 0.91$	$p < 0.0001$
wlmar26 = -0.448 + 0.627*wlmar7R	$R^2 = 0.67$	$p < 0.0001$
wlmar26 = -0.370 + 0.614*wlmar29	$R^2 = 0.35$	$p < 0.0001$
wlmar29 = 0.035 + 0.562*wlmar26	$R^2 = 0.35$	$p < 0.0001$
wlmar29 = -0.185 + 0.407*wlmar7R	$R^2 = 0.28$	$p < 0.0001$
wlmar29 = -0.073 + 0.496*wlmar19	$R^2 = 0.26$	$p < 0.0001$

After Project

wlmar7R = 0.222 + 0.862*wlmar19	$R^2 = 0.39$	$p < 0.0001$
wlmar7R = 0.130 + 0.810*wlmar26	$R^2 = 0.38$	$p < 0.0001$
wlmar7R = -0.142 + 0.465*wlmar29	$R^2 = 0.18$	$p < 0.0001$
wlmar19 = -0.115 + 0.934*wlmar26	$R^2 = 0.91$	$p < 0.0001$
wlmar19 = -0.394 + 0.646*wlmar29	$R^2 = 0.65$	$p < 0.0001$
wlmar19 = -0.354 + 0.453*wlmar7R	$R^2 = 0.39$	$p < 0.0001$
wlmar26 = 0.081 + 0.979*wlmar19	$R^2 = 0.91$	$p < 0.0001$
wlmar26 = -0.308 + 0.638*wlmar29	$R^2 = 0.59$	$p < 0.0001$
wlmar26 = -0.264 + 0.470*wlmar7R	$R^2 = 0.38$	$p < 0.0001$
wlmar29 = 0.366 + 1.007*wlmar19	$R^2 = 0.65$	$p < 0.0001$
wlmar29 = 0.245 + 0.931*wlmar26	$R^2 = 0.59$	$p < 0.0001$
wlmar29 = 0.030 + 0.380*wlmar26	$R^2 = 0.18$	$p < 0.0001$

Salinity

Before Project

sal7R = 2.593 + 0.863*sal19	$R^2 = 0.90$	$p < 0.0001$
sal7R = 3.657 + 0.827*sal26	$R^2 = 0.88$	$p < 0.0001$
sal7R = 7.612 + 0.627*sal29	$R^2 = 0.60$	$p < 0.0001$
sal19 = 1.325 + 0.962*sal26	$R^2 = 0.94$	$p < 0.0001$
sal19 = -1.565 + 1.042*sal7R	$R^2 = 0.90$	$p < 0.0001$
sal19 = 5.723 + 0.765*sal29	$R^2 = 0.66$	$p < 0.0001$
sal26 = -0.728 + 0.980*sal19	$R^2 = 0.94$	$p < 0.0001$
sal26 = -2.598 + 1.062*sal7R	$R^2 = 0.88$	$p < 0.0001$
sal26 = 4.103 + 0.773*sal29	$R^2 = 0.71$	$p < 0.0001$
sal29 = -1.598 + 0.917*sal26	$R^2 = 0.71$	$p < 0.0001$
sal29 = -2.634 + 0.868*sal19	$R^2 = 0.66$	$p < 0.0001$
sal29 = -4.052 + 0.950*sal7R	$R^2 = 0.60$	$p < 0.0001$

After Project

sal7R = 5.301 + 0.734*sal19	$R^2 = 0.81$	$p < 0.0001$
sal7R = 7.411 + 0.665*sal26	$R^2 = 0.69$	$p < 0.0001$
sal7R = 8.202 + 0.810*sal29	$R^2 = 0.65$	$p < 0.0001$
sal19 = 3.365 + 0.859*sal26	$R^2 = 0.88$	$p < 0.0001$
sal19 = -4.220 + 1.099*sal7R	$R^2 = 0.81$	$p < 0.0001$
sal19 = 4.449 + 1.063*sal29	$R^2 = 0.80$	$p < 0.0001$
sal26 = 1.018 + 1.242*sal29	$R^2 = 0.93$	$p < 0.0001$
sal26 = -2.556 + 1.019*sal19	$R^2 = 0.88$	$p < 0.0001$
sal26 = -5.946 + 1.044*sal7R	$R^2 = 0.69$	$p < 0.0001$
sal29 = -0.455+ 0.750*sal26	$R^2 = 0.93$	$p < 0.0001$
sal29 = -2.453 + 0.752*sal19	$R^2 = 0.80$	$p < 0.0001$
sal29 = -5.221 + 0.797*sal7R	$R^2 = 0.65$	$p < 0.0001$

ME-04

Water Level Relative to Marsh Surface

Before Project

wlmar06 = -0.357 + 1.111*wlmar29	$R^2 = 0.61$	$p < 0.0001$
wlmar06 = -0.138 + 1.002*wlmar19	$R^2 = 0.58$	$p < 0.0001$
wlmar06 = -0.475 + 0.657*wlmar50R	$R^2 = 0.46$	$p < 0.0001$
wlmar19 = 0.046 + 0.583*wlmar06	$R^2 = 0.58$	$p < 0.0001$
wlmar19 = -0.386 + 0.722*wlmar50R	$R^2 = 0.58$	$p < 0.0001$
wlmar19 = -0.190 + 0.770*wlmar29	$R^2 = 0.50$	$p < 0.0001$
wlmar29 = 0.272 + 0.551*wlmar06	$R^2 = 0.61$	$p < 0.0001$
wlmar29 = 0.213 + 0.653*wlmar19	$R^2 = 0.50$	$p < 0.0001$
wlmar29 = -0.046 + 0.528*wlmar50R	$R^2 = 0.43$	$p < 0.0001$
wlmar50R = 0.479 + 0.799*wlmar19	$R^2 = 0.58$	$p < 0.0001$
wlmar50R = 0.599 + 0.704*wlmar06	$R^2 = 0.46$	$p < 0.0001$
wlmar50R = 0.315 + 0.815*wlmar29	$R^2 = 0.43$	$p < 0.0001$

After Project

wlmar06 = -0.357 + 0.995*wlmar29	$R^2 = 0.56$	$p < 0.0001$
wlmar06 = -0.141 + 0.874*wlmar19	$R^2 = 0.52$	$p < 0.0001$
wlmar06 = -0.345 + 0.525*wlmar50R	$R^2 = 0.36$	$p < 0.0001$
wlmar19 = -0.209 + 0.541*wlmar50R	$R^2 = 0.56$	$p < 0.0001$
wlmar19 = 0.072 + 0.593*wlmar06	$R^2 = 0.52$	$p < 0.0001$
wlmar19 = -0.169 + 0.736*wlmar29	$R^2 = 0.47$	$p < 0.0001$
wlmar29 = 0.290 + 0.566*wlmar06	$R^2 = 0.56$	$p < 0.0001$
wlmar29 = 0.205 + 0.639*wlmar19	$R^2 = 0.47$	$p < 0.0001$
wlmar29 = 0.108 + 0.299*wlmar50R	$R^2 = 0.20$	$p < 0.0001$
wlmar50R = 0.379 + 1.032*wlmar19	$R^2 = 0.56$	$p < 0.0001$
wlmar50R = 0.468 + 0.678*wlmar06	$R^2 = 0.36$	$p < 0.0001$
wlmar50R = 0.207 + 0.666*wlmar29	$R^2 = 0.20$	$p < 0.0001$

Salinity

Before Project

sal06 = -0.323 + 0.848*sal43R	$R^2 = 0.66$	$p < 0.0001$
sal06 = 0.325 + 0.816*sal19	$R^2 = 0.63$	$p < 0.0001$
sal06 = -0.448 + 0.728*sal36R	$R^2 = 0.58$	$p < 0.0001$
sal06 = 0.260 + 0.631*sal26R	$R^2 = 0.56$	$p < 0.0001$
sal06 = 0.194 + 0.852*sal29	$R^2 = 0.40$	$p < 0.0001$
sal06 = 0.572 + 2.492*sal50R	$R^2 = 0.25$	$p < 0.0001$
sal19 = -0.305 + 1.146*sal29	$R^2 = 0.74$	$p < 0.0001$
sal19 = -0.207 + 0.755*sal43R	$R^2 = 0.73$	$p < 0.0001$
sal19 = -0.452 + 0.773*sal36R	$R^2 = 0.65$	$p < 0.0001$
sal19 = 0.505 + 0.778*sal06	$R^2 = 0.63$	$p < 0.0001$
sal19 = 0.387 + 0.650*sal26R	$R^2 = 0.51$	$p < 0.0001$
sal19 = 0.569 + 2.754*sal50R	$R^2 = 0.29$	$p < 0.0001$
sal29 = 0.762 + 0.643*sal19	$R^2 = 0.74$	$p < 0.0001$
sal29 = 0.642 + 0.448*sal43R	$R^2 = 0.61$	$p < 0.0001$
sal29 = 0.442 + 0.502*sal36R	$R^2 = 0.48$	$p < 0.0001$
sal29 = 0.849 + 0.468*sal26R	$R^2 = 0.47$	$p < 0.0001$
sal29 = 0.749 + 2.510*sal50R	$R^2 = 0.41$	$p < 0.0001$
sal29 = 1.103 + 0.472*sal06	$R^2 = 0.40$	$p < 0.0001$
sal50R = 0.181 + 0.162*sal29	$R^2 = 0.41$	$p < 0.0001$
sal50R = 0.233 + 0.103*sal26R	$R^2 = 0.39$	$p < 0.0001$
sal50R = 0.156 + 0.122*sal43R	$R^2 = 0.36$	$p < 0.0001$
sal50R = 0.301 + 0.106*sal19	$R^2 = 0.29$	$p < 0.0001$
sal50R = 0.217 + 0.090*sal36R	$R^2 = 0.25$	$p < 0.0001$
sal50R = 0.307 + 0.101*sal06	$R^2 = 0.25$	$p < 0.0001$

After Project

sal06 = 0.061 + 0.918*sal19	$R^2 = 0.86$	$p < 0.0001$
sal06 = -0.407 + 0.890*sal26R	$R^2 = 0.81$	$p < 0.0001$
sal06 = -0.722 + 0.878*sal43R	$R^2 = 0.80$	$p < 0.0001$
sal06 = -0.864 + 0.746*sal36R	$R^2 = 0.70$	$p < 0.0001$
sal06 = -0.076 + 0.812*sal29	$R^2 = 0.61$	$p < 0.0001$
sal06 = 0.813 + 1.418*sal50R	$R^2 = 0.55$	$p < 0.0001$
sal19 = -0.412 + 0.929*sal26R	$R^2 = 0.86$	$p < 0.0001$
sal19 = 0.300 + 0.934*sal06	$R^2 = 0.86$	$p < 0.0001$
sal19 = -0.739 + 0.916*sal43R	$R^2 = 0.84$	$p < 0.0001$
sal19 = -0.551 + 1.040*sal29	$R^2 = 0.82$	$p < 0.0001$
sal19 = -0.875 + 0.821*sal36R	$R^2 = 0.79$	$p < 0.0001$
sal19 = 0.674 + 1.720*sal50R	$R^2 = 0.60$	$p < 0.0001$

sal29 = 0.971 + 0.792*sal19	$R^2 = 0.82$	$p < 0.0001$
sal29 = 0.190 + 0.800*sal43R	$R^2 = 0.75$	$p < 0.0001$
sal29 = 0.178 + 0.728*sal36R	$R^2 = 0.74$	$p < 0.0001$
sal29 = 0.522 + 0.798*sal26R	$R^2 = 0.73$	$p < 0.0001$
sal29 = 1.233 + 0.757*sal06	$R^2 = 0.61$	$p < 0.0001$
sal29 = 1.633 + 1.149*sal50R	$R^2 = 0.41$	$p < 0.0001$

sal50R = 0.136 + 0.350*sal19	$R^2 = 0.60$	$p < 0.0001$
sal50R = 0.136 + 0.385*sal06	$R^2 = 0.55$	$p < 0.0001$
sal50R = -0.316 + 0.411*sal43R	$R^2 = 0.48$	$p < 0.0001$
sal50R = -0.162 + 0.414*sal26R	$R^2 = 0.47$	$p < 0.0001$
sal50R = -0.028 + 0.243*sal36R	$R^2 = 0.44$	$p < 0.0001$
sal50R = 0.030 + 0.357*sal29	$R^2 = 0.41$	$p < 0.0001$

PO-06

Water Level Relative to Marsh Surface

Before Project

wlmar01 = 0.189 + 0.924*wlmar11	$R^2 = 0.94$	$p < 0.0001$
wlmar01 = 0.122 + 0.754*wlmar06	$R^2 = 0.77$	$p < 0.0001$
wlmar01 = 0.242 + 0.593*wlmar03	$R^2 = 0.58$	$p < 0.0001$
wlmar03 = -0.422 + 0.972*wlmar01	$R^2 = 0.58$	$p < 0.0001$
wlmar03 = -0.240 + 0.937*wlmar11	$R^2 = 0.54$	$p < 0.0001$
wlmar03 = -0.337 + 0.804*wlmar06	$R^2 = 0.45$	$p < 0.0001$
wlmar06 = 0.030 + 0.992*wlmar11	$R^2 = 0.78$	$p < 0.0001$
wlmar06 = -0.179 + 1.016*wlmar01	$R^2 = 0.77$	$p < 0.0001$
wlmar06 = 0.072 + 0.554*wlmar03	$R^2 = 0.45$	$p < 0.0001$
wlmar11 = -0.204 + 1.017*wlmar01	$R^2 = 0.94$	$p < 0.0001$
wlmar11 = -0.080+ 0.775*wlmar06	$R^2 = 0.78$	$p < 0.0001$
wlmar11 = 0.050+ 0.575*wlmar03	$R^2 = 0.54$	$p < 0.0001$

After Project

wlmar01 = 0.133 + 0.972*wlmar11	$R^2 = 0.97$	$p < 0.0001$
wlmar01 = 0.141 + 0.870*wlmar06	$R^2 = 0.92$	$p < 0.0001$
wlmar01 = 0.429 + 0.951*wlmar03	$R^2 = 0.91$	$p < 0.0001$
wlmar03 = -0.437 + 0.961*wlmar01	$R^2 = 0.91$	$p < 0.0001$
wlmar03 = -0.293 + 0.885*wlmar06	$R^2 = 0.89$	$p < 0.0001$
wlmar03 = -0.309 + 0.922*wlmar11	$R^2 = 0.88$	$p < 0.0001$
wlmar06 = -0.155 + 1.063*wlmar01	$R^2 = 0.92$	$p < 0.0001$
wlmar06 = 0.297 + 1.009*wlmar03	$R^2 = 0.89$	$p < 0.0001$
wlmar06 = -0.014 + 1.031*wlmar11	$R^2 = 0.89$	$p < 0.0001$
wlmar11 = -0.133 + 0.995*wlmar01	$R^2 = 0.97$	$p < 0.0001$
wlmar11 = 0.010+ 0.859*wlmar06	$R^2 = 0.88$	$p < 0.0001$
wlmar11 = 0.294+ 0.952*wlmar03	$R^2 = 0.88$	$p < 0.0001$

Salinity

Before Project

sal01 = 0.224 + 0.900*sal06	$R^2 = 0.93$	$p < 0.0001$
sal01 = 1.954 + 0.869*sal11	$R^2 = 0.89$	$p < 0.0001$
sal01 = 5.369 + 0.664*sal03	$R^2 = 0.20$	$p < 0.0001$

sal03 = 0.633 + 0.318*sal11	$R^2 = 0.23$	$p < 0.0001$
sal03 = 0.627 + 0.297*sal01	$R^2 = 0.20$	$p < 0.0001$
sal03 = 0.500 + 0.246*sal06	$R^2 = 0.16$	$p < 0.0001$
sal06 = 0.259 + 1.035*sal01	$R^2 = 0.93$	$p < 0.0001$
sal06 = 1.959 + 0.950*sal11	$R^2 = 0.84$	$p < 0.0001$
sal06 = 5.707 + 0.658*sal03	$R^2 = 0.16$	$p < 0.0001$
sal11 = -1.305 + 1.020*sal01	$R^2 = 0.89$	$p < 0.0001$
sal11 = -0.878+ 0.889*sal06	$R^2 = 0.84$	$p < 0.0001$
sal11 = 4.355+ 0.714*sal03	$R^2 = 0.23$	$p < 0.0001$

After Project

sal01 = -0.367 + 0.846*sal06	$R^2 = 0.87$	$p < 0.0001$
sal01 = 1.600 + 0.804*sal11	$R^2 = 0.78$	$p < 0.0001$
sal01 = 2.290 + 1.325*sal03	$R^2 = 0.39$	$p < 0.0001$
sal03 = 0.103 + 0.275*sal11	$R^2 = 0.40$	$p < 0.0001$
sal03 = -0.295 + 0.298*sal01	$R^2 = 0.39$	$p < 0.0001$
sal03 = -0.469 + 0.268*sal06	$R^2 = 0.38$	$p < 0.0001$
sal06 = 0.932 + 1.024*sal01	$R^2 = 0.87$	$p < 0.0001$
sal06 = 2.540 + 0.842*sal11	$R^2 = 0.70$	$p < 0.0001$
sal06 = 3.243 + 1.402*sal03	$R^2 = 0.38$	$p < 0.0001$
sal11 = -1.139 + 0.964*sal01	$R^2 = 0.78$	$p < 0.0001$
sal11 = -1.578+ 0.834*sal06	$R^2 = 0.70$	$p < 0.0001$
sal11 = 0.951+ 1.462*sal03	$R^2 = 0.40$	$p < 0.0001$

TE-26

Water Level Relative to Marsh Surface

Before Project

wlmar01R = -0.556+ 0.964*wlmar03	$R^2 = 0.89$	$p < 0.0001$
wlmar01R = -0.682+ 0.958*wlmar02R	$R^2 = 0.87$	$p < 0.0001$
wlmar01R = -0.590+ 1.002*wlmar04	$R^2 = 0.71$	$p < 0.0001$
wlmar02R = 0.111+ 0.929*wlmar03	$R^2 = 0.88$	$p < 0.0001$
wlmar02R = 0.625+ 0.905*wlmar01R	$R^2 = 0.87$	$p < 0.0001$
wlmar02R = 0.045+ 0.916*wlmar04	$R^2 = 0.64$	$p < 0.0001$
wlmar03 = 0.508+ 0.928*wlmar01R	$R^2 = 0.89$	$p < 0.0001$
wlmar03 = -0.114+ 0.949*wlmar02R	$R^2 = 0.88$	$p < 0.0001$
wlmar03 = -0.025+ 0.999*wlmar04	$R^2 = 0.76$	$p < 0.0001$
wlmar04 = 0.022+ 0.764*wlmar03	$R^2 = 0.76$	$p < 0.0001$
wlmar04 = 0.414+ 0.705*wlmar01R	$R^2 = 0.71$	$p < 0.0001$
wlmar04 = -0.028+ 0.701*wlmar02R	$R^2 = 0.64$	$p < 0.0001$

After Project

wlmar01R = -0.593+ 1.004*wlmar03	$R^2 = 0.94$	$p < 0.0001$
wlmar01R = -0.611+ 0.894*wlmar02R	$R^2 = 0.90$	$p < 0.0001$
wlmar01R = -0.720+ 1.134*wlmar04	$R^2 = 0.68$	$p < 0.0001$
wlmar02R = -0.005+ 1.066*wlmar03	$R^2 = 0.95$	$p < 0.0001$
wlmar02R = 0.566+1.010*wlmar01R	$R^2 = 0.90$	$p < 0.0001$
wlmar02R = -0.179+1.139*wlmar04	$R^2 = 0.62$	$p < 0.0001$
wlmar03 = -0.019+ 0.894*wlmar02R	$R^2 = 0.95$	$p < 0.0001$
wlmar03 = 0.526+ 0.933*wlmar01R	$R^2 = 0.94$	$p < 0.0001$
wlmar03 = -0.132+ 1.118*wlmar04	$R^2 = 0.70$	$p < 0.0001$
wlmar04 = -0.009+ 0.623*wlmar03	$R^2 = 0.70$	$p < 0.0001$
wlmar04 = 0.339+ 0.596*wlmar01R	$R^2 = 0.68$	$p < 0.0001$
wlmar04 = -0.026+ 0.545*wlmar02R	$R^2 = 0.62$	$p < 0.0001$

Salinity

Before Project

sal01R = -0.437+ 0.693*sal04	$R^2 = 0.67$	$p < 0.0001$
sal01R = 0.042+ 0.515*sal03	$R^2 = 0.62$	$p < 0.0001$
sal01R = -0.103+ 0.471*sal2R	$R^2 = 0.58$	$p < 0.0001$

sal02R = 0.892+ 0.980*sal03	$R^2 = 0.89$	$p < 0.0001$
sal02R = 1.036+ 1.157*sal04	$R^2 = 0.66$	$p < 0.0001$
sal02R = 2.944+ 1.225*sal01R	$R^2 = 0.58$	$p < 0.0001$
sal03 = -0.079+ 0.908*sal02R	$R^2 = 0.89$	$p < 0.0001$
sal03 = 0.037+ 1.161*sal04	$R^2 = 0.74$	$p < 0.0001$
sal03 = 2.480+ 1.200*sal01R	$R^2 = 0.62$	$p < 0.0001$
sal04 = 1.524+ 0.641*sal03	$R^2 = 0.74$	$p < 0.0001$
sal04 = 2.017+ 0.968*sal01R	$R^2 = 0.67$	$p < 0.0001$
sal04 = 1.104+ 0.569*sal02R	$R^2 = 0.66$	$p < 0.0001$

After Project

sal01R = -1.698+ 0.687*sal04	$R^2 = 0.66$	$p < 0.0001$
sal01R = -0.997+ 0.549*sal03	$R^2 = 0.59$	$p < 0.0001$
sal01R = -1.140+ 0.517*sal02R	$R^2 = 0.58$	$p < 0.0001$
sal02R = 1.225+ 0.972*sal03	$R^2 = 0.83$	$p < 0.0001$
sal02R = 1.004+ 1.095*sal04	$R^2 = 0.71$	$p < 0.0001$
sal02R = 5.632+ 1.115*sal01R	$R^2 = 0.58$	$p < 0.0001$
sal03 = 0.447+ 0.856*sal02R	$R^2 = 0.83$	$p < 0.0001$
sal03 = 0.070+ 1.096*sal04	$R^2 = 0.78$	$p < 0.0001$
sal03 = 4.728+ 1.073*sal01R	$R^2 = 0.59$	$p < 0.0001$
sal04 = 1.666+ 0.711*sal03	$R^2 = 0.78$	$p < 0.0001$
sal04 = 1.679+ 0.652*sal02R	$R^2 = 0.71$	$p < 0.0001$
sal04 = 4.414+ 0.956*sal01R	$R^2 = 0.66$	$p < 0.0001$

TE-28

Water Level

Before Project

wl218 = 2.017+ 0.422*wl07R	$R^2 = 0.69$	$p < 0.0001$
wl218 = 2.530+ 0.129*wl02	$R^2 = 0.40$	$p < 0.0001$
wl218 = 2.384+ 0.236*wl04R	$R^2 = 0.29$	$p < 0.0001$
wl218 = 2.365+ 0.118*wl219R	$R^2 = 0.23$	$p < 0.0001$
wl218 = 2.636+ 0.108*wl05R	$R^2 = 0.16$	$p < 0.0001$
wl219R = 1.974+ 0.672*wl02	$R^2 = 0.71$	$p < 0.0001$
wl219R = 2.305+ 0.884*wl05R	$R^2 = 0.63$	$p < 0.0001$
wl219R = 1.803+ 0.919*wl01	$R^2 = 0.58$	$p < 0.0001$
wl219R = 0.909+ 1.323*wl07R	$R^2 = 0.44$	$p < 0.0001$
wl219R = -2.080+ 1.914*wl218	$R^2 = 0.23$	$p < 0.0001$
wl219R = 2.982+ 0.078*wl04R	$R^2 = 0.00$	$p < 0.0001$

After Project

wl218 = 2.210+ 0.569*wl02	$R^2 = 0.72$	$p < 0.0001$
wl218 = 1.391+ 0.532*wl219R	$R^2 = 0.66$	$p < 0.0001$
wl218 = 2.599+ 0.430*wl05R	$R^2 = 0.58$	$p < 0.0001$
wl218 = 2.158+ 0.447*wl07R	$R^2 = 0.48$	$p < 0.0001$
wl218 = 2.395+ 0.239*wl04R	$R^2 = 0.37$	$p < 0.0001$
wl218 = 2.715+ 0.166*wl01	$R^2 = 0.20$	$p < 0.0001$
wl219R = 2.052+ 0.893*wl05R	$R^2 = 0.98$	$p < 0.0001$
wl219R = 1.693+ 0.835*wl02	$R^2 = 0.93$	$p < 0.0001$
wl219R = 1.261+ 0.789*wl07R	$R^2 = 0.78$	$p < 0.0001$
wl219R = -0.815+ 1.239*wl218	$R^2 = 0.66$	$p < 0.0001$
wl219R = 1.915+ 0.671*wl01	$R^2 = 0.64$	$p < 0.0001$
wl219R = 2.023+ 0.342*wl04R	$R^2 = 0.38$	$p < 0.0001$

Salinity

Before Project

sal218 = 0.439+ 0.501*sal05R	$R^2 = 0.53$	$p < 0.0001$
sal218 = 0.213+ 0.857*sal219R	$R^2 = 0.53$	$p < 0.0001$
sal218 = 0.691+ 0.485*sal02	$R^2 = 0.49$	$p < 0.0001$
sal218 = 0.763+ 0.164*sal01	$R^2 = 0.20$	$p < 0.0001$
sal218 = 0.858+ 0.123*sal04R	$R^2 = 0.15$	$p < 0.0001$
sal218 = 0.953+ 0.271*sal07R	$R^2 = 0.14$	$p < 0.0001$
sal219R = 0.445+ 0.616*sal218	$R^2 = 0.53$	$p < 0.0001$

sal219R = 0.855+ 0.261*sal02	$R^2 = 0.19$	$p < 0.0001$
sal219R = 1.024+ 0.170*sal05R	$R^2 = 0.11$	$p < 0.0001$
sal219R = 1.164+ 0.126*sal07R	$R^2 = 0.05$	$p < 0.0001$
sal219R = 1.149+ 0.035*sal01	$R^2 = 0.01$	$p < 0.0001$
sal219R = 1.211+ 0.007*sal04R	$R^2 = 0.00$	$p = 0.0021$

After Project

sal218 = 0.623+ 0.950*sal02	$R^2 = 0.84$	$p < 0.0001$
sal218 = 0.845+ 0.618*sal01	$R^2 = 0.68$	$p < 0.0001$
sal218 = 1.174+ 1.047*sal07R	$R^2 = 0.27$	$p < 0.0001$
sal218 = -2.460+ 1.859*sal219R	$R^2 = 0.19$	$p < 0.0001$
sal218 = 0.993+ 0.357*sal05R	$R^2 = 0.14$	$p < 0.0001$
sal218 = 1.263- 0.034*sal04R	$R^2 = 0.01$	$p < 0.0001$

sal219R = 2.027+ 0.103*sal218	$R^2 = 0.19$	$p < 0.0001$
sal219R = 2.124+ 0.058*sal05R	$R^2 = 0.16$	$p < 0.0001$
sal219R = 2.184+ 0.052*sal02	$R^2 = 0.06$	$p < 0.0001$
sal219R = 2.197- 0.008*sal07R	$R^2 = 0.00$	$p < 0.0001$
sal219R = 2.199+ 0.005*sal04R	$R^2 = 0.00$	$p < 0.0001$
sal219R = 2.193+ 0.002*sal01	$R^2 = 0.00$	$p = 0.0540$

TV-04

Water Level Relative to Marsh Surface

Before Project

wlmar02 = -0.393 + 1.105*wlmar03	$R^2 = 0.83$	$p < 0.0001$
wlmar02 = 0.401 + 1.137*wlmar04R	$R^2 = 0.79$	$p < 0.0001$
wlmar02 = -4.523 + 0.948*wl01R	$R^2 = 0.65$	$p < 0.0001$
wlmar03 = 0.717 + 1.023*wlmar04R	$R^2 = 0.95$	$p < 0.0001$
wlmar03 = 0.292 + 0.748*wlmar02	$R^2 = 0.83$	$p < 0.0001$
wlmar03 = -3.454 + 0.819*wl01R	$R^2 = 0.77$	$p < 0.0001$
wlmar04R = -0.702 + 0.925*wlmar03	$R^2 = 0.95$	$p < 0.0001$
wlmar04R = -0.428 + 0.695*wlmar02	$R^2 = 0.79$	$p < 0.0001$
wlmar04R = -3.695 + 0.709*wl01R	$R^2 = 0.66$	$p < 0.0001$

After Project

wlmar02 = 0.524 + 1.003*wlmar04R	$R^2 = 0.93$	$p < 0.0001$
wlmar02 = 0.308 + 0.876*wlmar03	$R^2 = 0.74$	$p < 0.0001$
wlmar02 = -3.706 + 0.798*wl01R	$R^2 = 0.74$	$p < 0.0001$
wlmar03 = -0.359 + 0.842*wlmar02	$R^2 = 0.74$	$p < 0.0001$
wlmar03 = 0.102 + 0.867*wlmar04R	$R^2 = 0.72$	$p < 0.0001$
wlmar03 = -3.764 + 0.734*wl01R	$R^2 = 0.66$	$p < 0.0001$
wlmar04R = -0.524 + 0.922*wlmar02	$R^2 = 0.93$	$p < 0.0001$
wlmar04R = -0.244 + 0.827*wlmar03	$R^2 = 0.72$	$p < 0.0001$
wlmar04R = -3.784 + 0.694*wl01R	$R^2 = 0.61$	$p < 0.0001$

Salinity

Before Project

sal02 = 0.101 + 0.866*sal01R	$R^2 = 0.89$	$p < 0.0001$
sal02 = 0.480 + 0.721*sal03	$R^2 = 0.42$	$p < 0.0001$
sal02 = 0.588 + 1.230*sal04R	$R^2 = 0.11$	$p < 0.0001$
sal03 = 0.104 + 0.589*sal02	$R^2 = 0.42$	$p < 0.0001$
sal03 = 0.179 + 0.435*sal01R	$R^2 = 0.24$	$p < 0.0001$
sal03 = 0.232 + 1.342*sal04R	$R^2 = 0.16$	$p < 0.0001$
sal04R = 0.209 + 0.128*sal01R	$R^2 = 0.19$	$p < 0.0001$
sal04R = 0.226 + 0.122*sal03	$R^2 = 0.16$	$p < 0.0001$
sal04R = 0.217 + 0.093*sal02	$R^2 = 0.11$	$p < 0.0001$

After Project

sal02 = 0.214 + 0.821*sal01R	$R^2 = 0.71$	$p < 0.0001$
sal02 = 0.310 + 0.933*sal03	$R^2 = 0.69$	$p < 0.0001$
sal02 = 0.494 + 1.747*sal04R	$R^2 = 0.38$	$p < 0.0001$
sal03 = 0.066 + 0.741*sal02	$R^2 = 0.69$	$p < 0.0001$
sal03 = 0.196 + 0.568*sal01R	$R^2 = 0.42$	$p < 0.0001$
sal03 = 0.351 + 1.376*sal04R	$R^2 = 0.30$	$p < 0.0001$
sal04R = 0.144 + 0.249*sal01R	$R^2 = 0.46$	$p < 0.0001$
sal04R = 0.148 + 0.219*sal02	$R^2 = 0.38$	$p < 0.0001$
sal04R = 0.208 + 0.216*sal03	$R^2 = 0.30$	$p < 0.0001$

TV-14

Water Level Relative to Marsh Surface

Before Project

wlmar01 = -0.109 + 0.998*wlmar04R	$R^2 = 0.94$	$p < 0.0001$
wlmar01 = 0.022 + 0.833*wlmar03R	$R^2 = 0.80$	$p < 0.0001$
wlmar01 = -0.507 + 0.075*wlmar02	$R^2 = 0.05$	$p < 0.0001$
wlmar02 = -0.592 + 0.719*wlmar04R	$R^2 = 0.05$	$p < 0.0001$
wlmar02 = -0.481 + 0.633*wlmar03R	$R^2 = 0.05$	$p < 0.0001$
wlmar02 = -0.495 + 0.642*wlmar01	$R^2 = 0.05$	$p < 0.0001$
wlmar03R = -0.180 + 0.958*wlmar01	$R^2 = 0.80$	$p < 0.0001$
wlmar03R = -0.303 + 0.939*wlmar04R	$R^2 = 0.70$	$p < 0.0001$
wlmar03R = -0.781 + 0.081*wlmar02	$R^2 = 0.05$	$p < 0.0001$
wlmar04R = 0.068 + 0.937*wlmar01	$R^2 = 0.94$	$p < 0.0001$
wlmar04R = 0.056 + 0.750*wlmar03R	$R^2 = 0.70$	$p < 0.0001$
wlmar04R = -0.508 + 0.076*wlmar02	$R^2 = 0.05$	$p < 0.0001$

After Project

wlmar01 = -0.248 + 0.854*wlmar04R	$R^2 = 0.84$	$p < 0.0001$
wlmar01 = -0.138 + 0.843*wlmar02	$R^2 = 0.78$	$p < 0.0001$
wlmar01 = -0.292 + 0.638*wlmar03R	$R^2 = 0.57$	$p < 0.0001$
wlmar02 = -0.166 + 0.830*wlmar03R	$R^2 = 0.85$	$p < 0.0001$
wlmar02 = -0.202 + 0.858*wlmar04R	$R^2 = 0.78$	$p < 0.0001$
wlmar02 = 0.016 + 0.925*wlmar01	$R^2 = 0.78$	$p < 0.0001$
wlmar03R = -0.109 + 1.029*wlmar02	$R^2 = 0.85$	$p < 0.0001$
wlmar03R = 0.082 + 0.900*wlmar01	$R^2 = 0.57$	$p < 0.0001$
wlmar03R = -0.151 + 0.744*wlmar04R	$R^2 = 0.47$	$p < 0.0001$
wlmar04R = 0.184 + 0.984*wlmar01	$R^2 = 0.84$	$p < 0.0001$
wlmar04R = 0.102 + 0.913*wlmar02	$R^2 = 0.78$	$p < 0.0001$
wlmar04R = -0.115 + 0.629*wlmar03R	$R^2 = 0.47$	$p < 0.0001$

Salinity

Before Project

sal01 = -0.376 + 1.021*sal02	$R^2 = 0.94$	$p < 0.0001$
sal01 = -0.116 + 1.042*sal04R	$R^2 = 0.85$	$p < 0.0001$
sal01 = 0.078 + 0.725*sal03R	$R^2 = 0.81$	$p < 0.0001$

sal02 = 0.561 + 0.926*sal01	$R^2 = 0.94$	$p < 0.0001$
sal02 = 0.364 + 0.989*sal04R	$R^2 = 0.90$	$p < 0.0001$
sal02 = 0.379 + 0.797*sal03R	$R^2 = 0.86$	$p < 0.0001$
sal03R = 0.182 + 1.081*sal02	$R^2 = 0.86$	$p < 0.0001$
sal03R = 0.697 + 1.113*sal01	$R^2 = 0.81$	$p < 0.0001$
sal03R = 0.573 + 1.052*sal04R	$R^2 = 0.73$	$p < 0.0001$
sal04R = 0.066 + 0.910*sal02	$R^2 = 0.90$	$p < 0.0001$
sal04R = 0.646 + 0.814*sal01	$R^2 = 0.85$	$p < 0.0001$
sal04R = 0.609 + 0.698*sal03R	$R^2 = 0.73$	$p < 0.0001$

After Project

sal01 = 0.066 + 1.074*sal04R	$R^2 = 0.93$	$p < 0.0001$
sal01 = -0.050 + 0.950*sal02	$R^2 = 0.91$	$p < 0.0001$
sal01 = 0.305 + 0.828*sal03R	$R^2 = 0.82$	$p < 0.0001$
sal02 = 0.274 + 0.901*sal03R	$R^2 = 0.92$	$p < 0.0001$
sal02 = 0.483 + 0.961*sal01	$R^2 = 0.91$	$p < 0.0001$
sal02 = 0.503 + 1.030*sal04R	$R^2 = 0.91$	$p < 0.0001$
sal03R = 0.186 + 1.021*sal02	$R^2 = 0.92$	$p < 0.0001$
sal03R = 0.677 + 0.984*sal01	$R^2 = 0.82$	$p < 0.0001$
sal03R = 0.763 + 1.036*sal04R	$R^2 = 0.80$	$p < 0.0001$
sal04R = 0.232 + 0.867*sal01	$R^2 = 0.93$	$p < 0.0001$
sal04R = 0.001 + 0.879*sal02	$R^2 = 0.91$	$p < 0.0001$
sal04R = 0.353 + 0.773*sal03R	$R^2 = 0.80$	$p < 0.0001$

APPENDIX C:
SUMMARY OF LANDCHANGE FOR EACH SITE

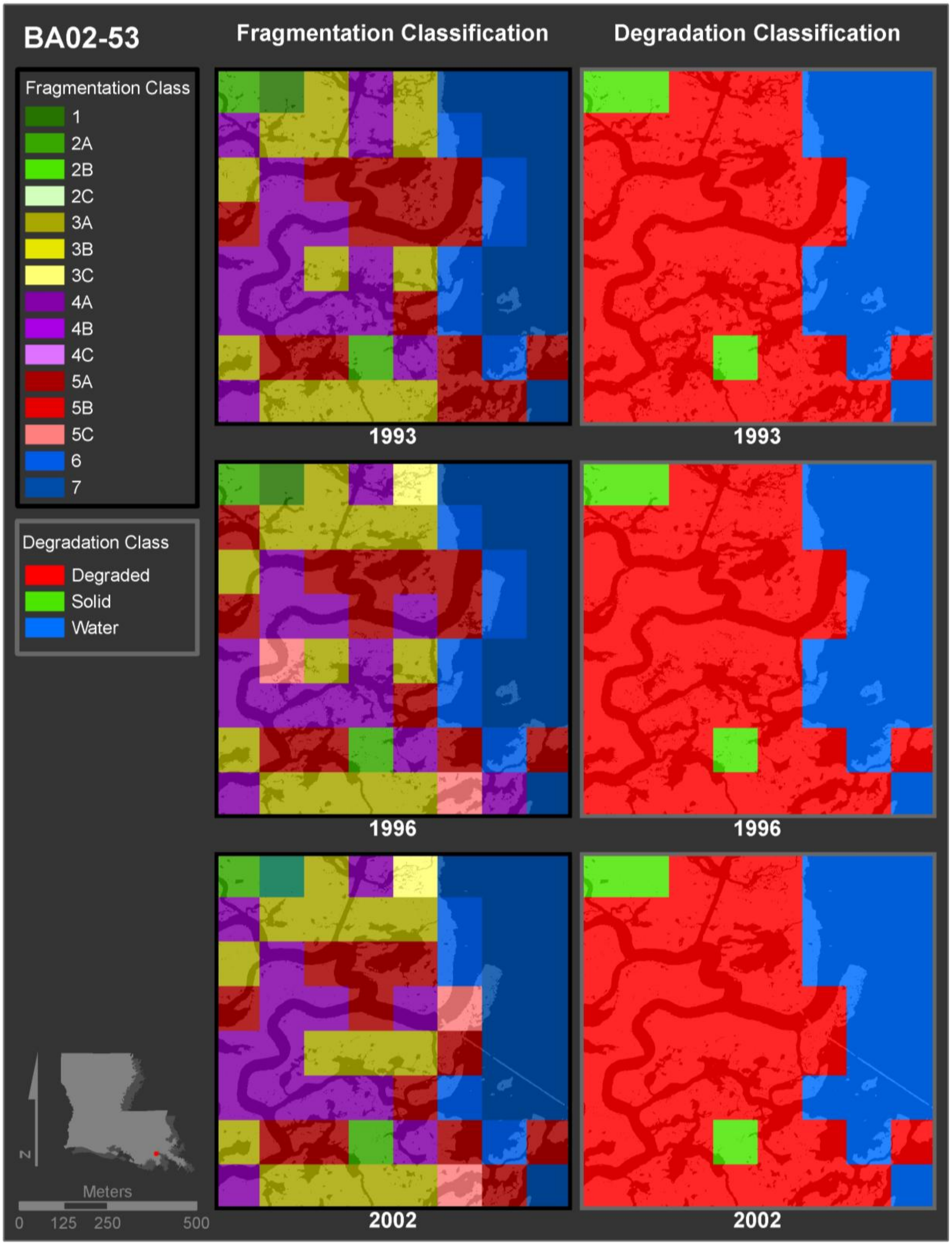


Figure C1. The two tier classes (category and configuration), and degradation associations (solid marsh = 1, 2a, 2b; degraded marsh = 2c, 3a, 3b, 3c, 4a, 4b, 4c, 5 a, 5b, 5c; and water = 6, 7) are shown by grid tile for plot BA02-53 in 1993, 1996 and 2002.

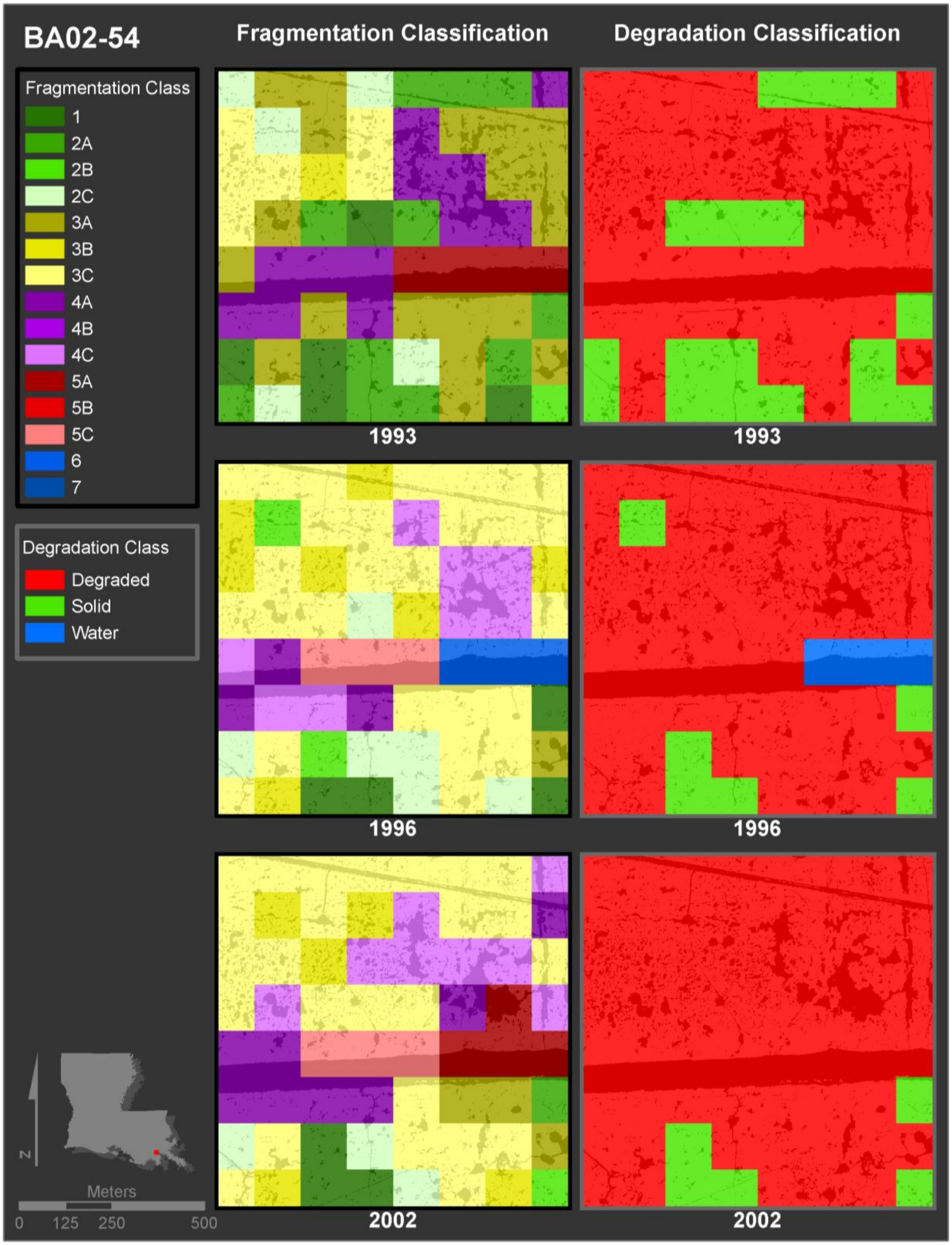


Figure C2. The two tier classes (category and configuration), and degradation associations (solid marsh = 1, 2a, 2b; degraded marsh = 2c, 3a, 3b, 3c, 4a, 4b, 4c, 5 a, 5b, 5c; and water = 6, 7) are shown by grid tile for plot BA02-54 in 1993, 1996 and 2002.

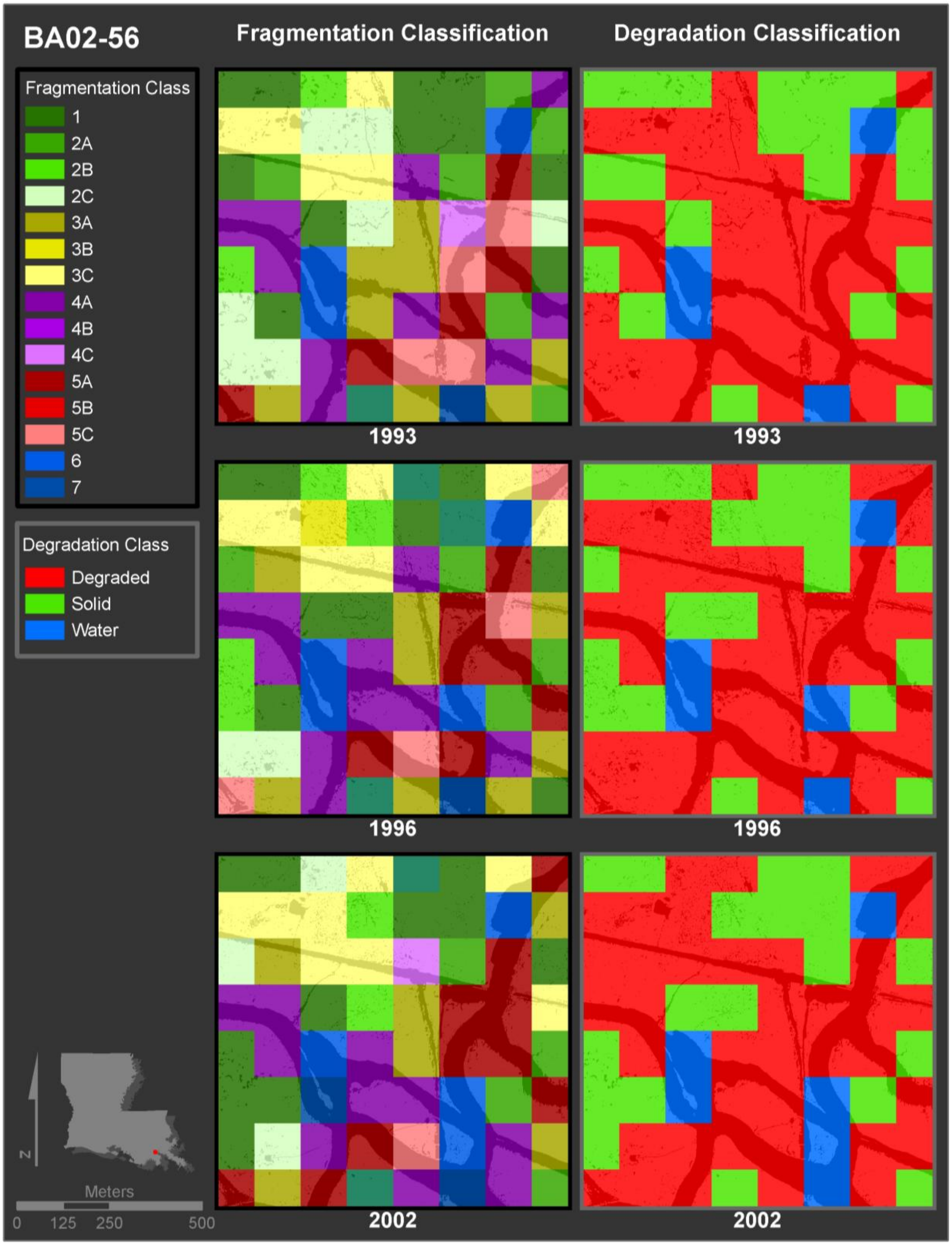


Figure C3. The two tier classes (category and configuration), and degradation associations (solid marsh = 1, 2a, 2b; degraded marsh = 2c, 3a, 3b, 3c, 4a, 4b, 4c, 5 a, 5b, 5c; and water = 6, 7) are shown by grid tile for plot BA02-56 in 1993, 1996 and 2002.

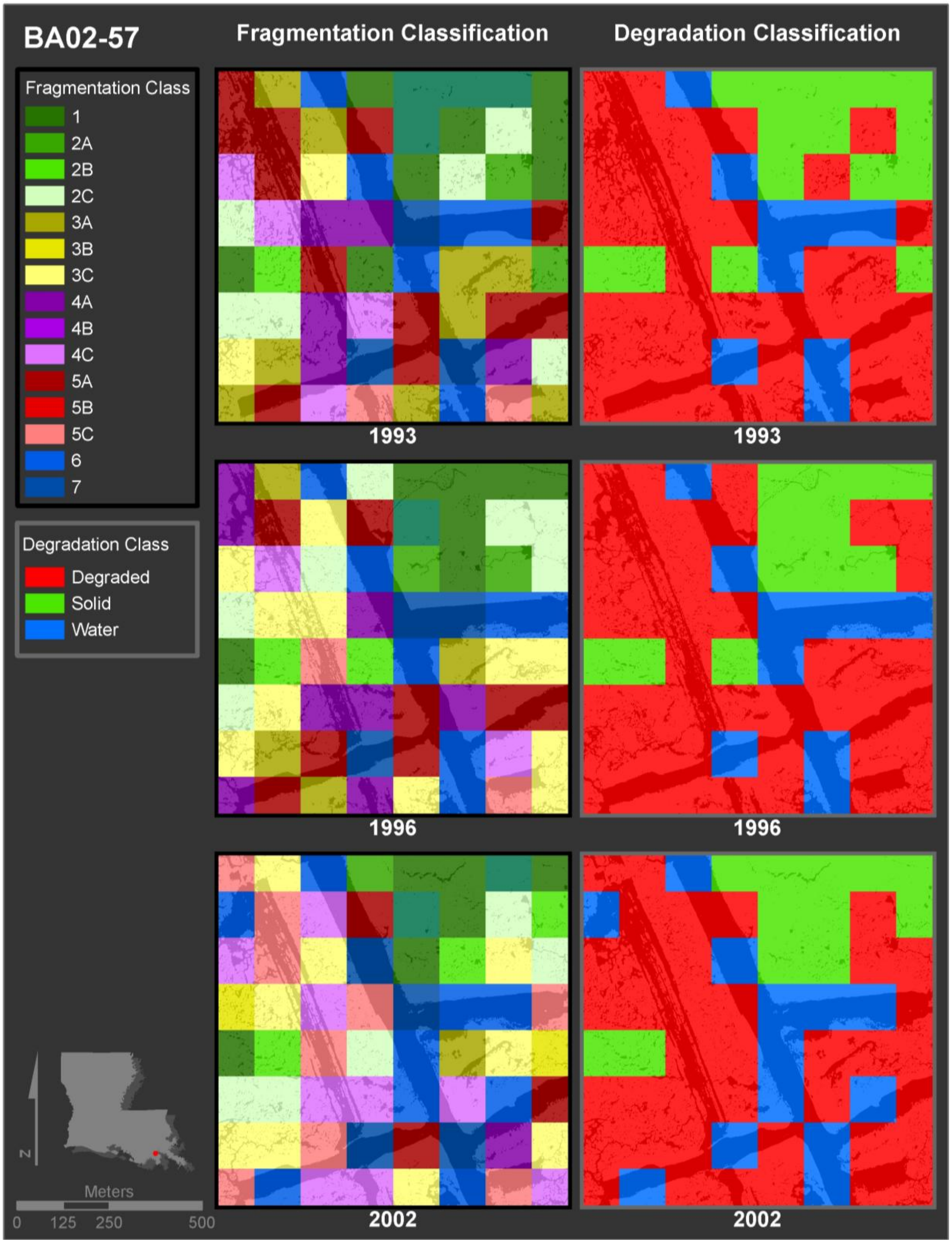


Figure C4. The two tier classes (category and configuration), and degradation associations (solid marsh = 1, 2a, 2b; degraded marsh = 2c, 3a, 3b, 3c, 4a, 4b, 4c, 5 a, 5b, 5c; and water = 6, 7) are shown by grid tile for plot BA02-57 in 1993, 1996 and 2002.

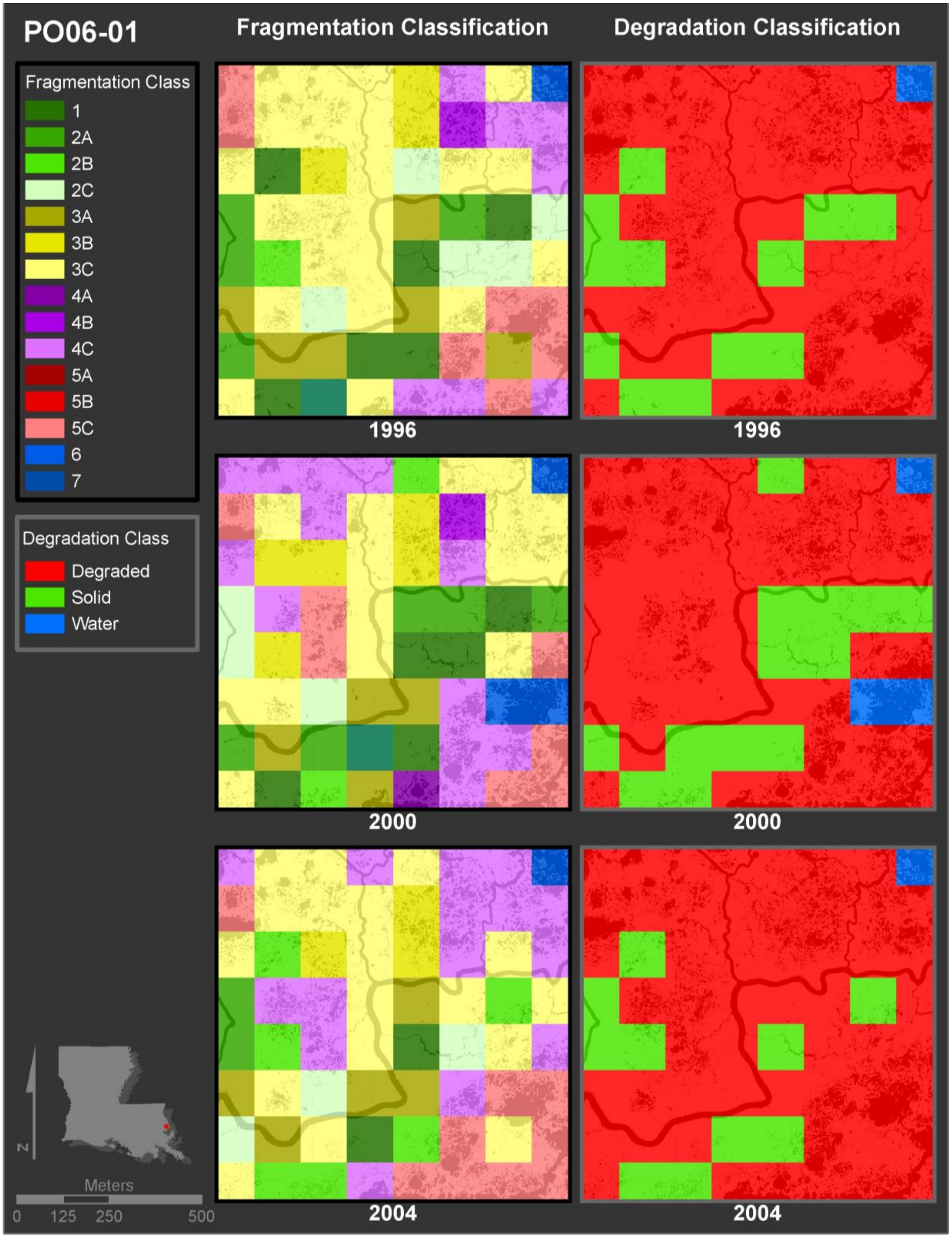


Figure C5. The two tier classes (category and configuration), and degradation associations (solid marsh = 1, 2a, 2b; degraded marsh = 2c, 3a, 3b, 3c, 4a, 4b, 4c, 5a, 5b, 5c; and water = 6, 7) are shown by grid tile for plot PO06-01 in 1996, 2000 and 2004.

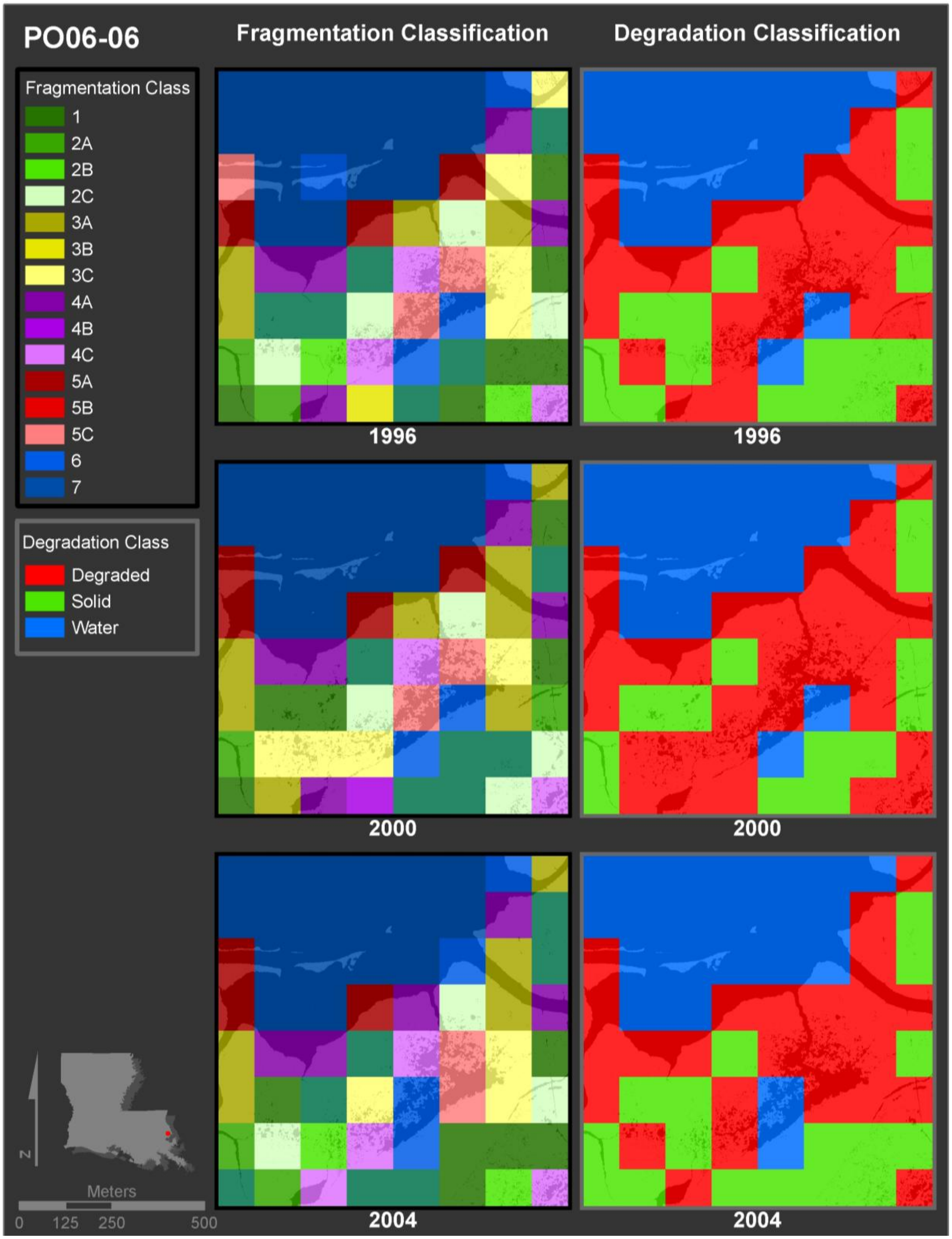


Figure C6. The two tier classes (category and configuration), and degradation associations (solid marsh = 1, 2a, 2b; degraded marsh = 2c, 3a, 3b, 3c, 4a, 4b, 4c, 5a, 5b, 5c; and water = 6, 7) are shown by grid tile for plot PO06-06 in 1996, 2000 and 2004.

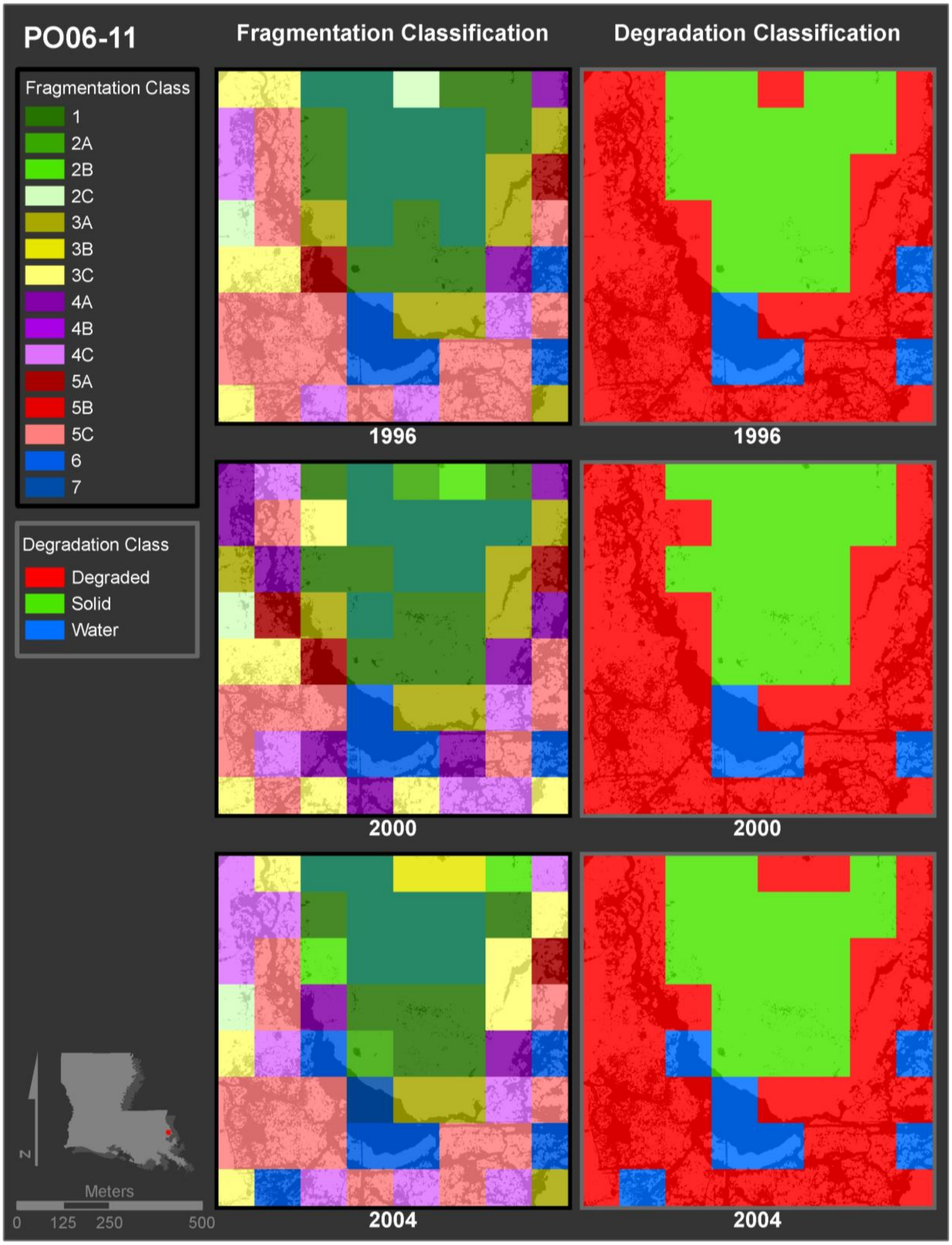


Figure C7. The two tier classes (category and configuration), and degradation associations (solid marsh = 1, 2a, 2b; degraded marsh = 2c, 3a, 3b, 3c, 4a, 4b, 4c, 5a, 5b, 5c; and water = 6, 7) are shown by grid tile for plot PO06-11 in 1996, 2000 and 2004.

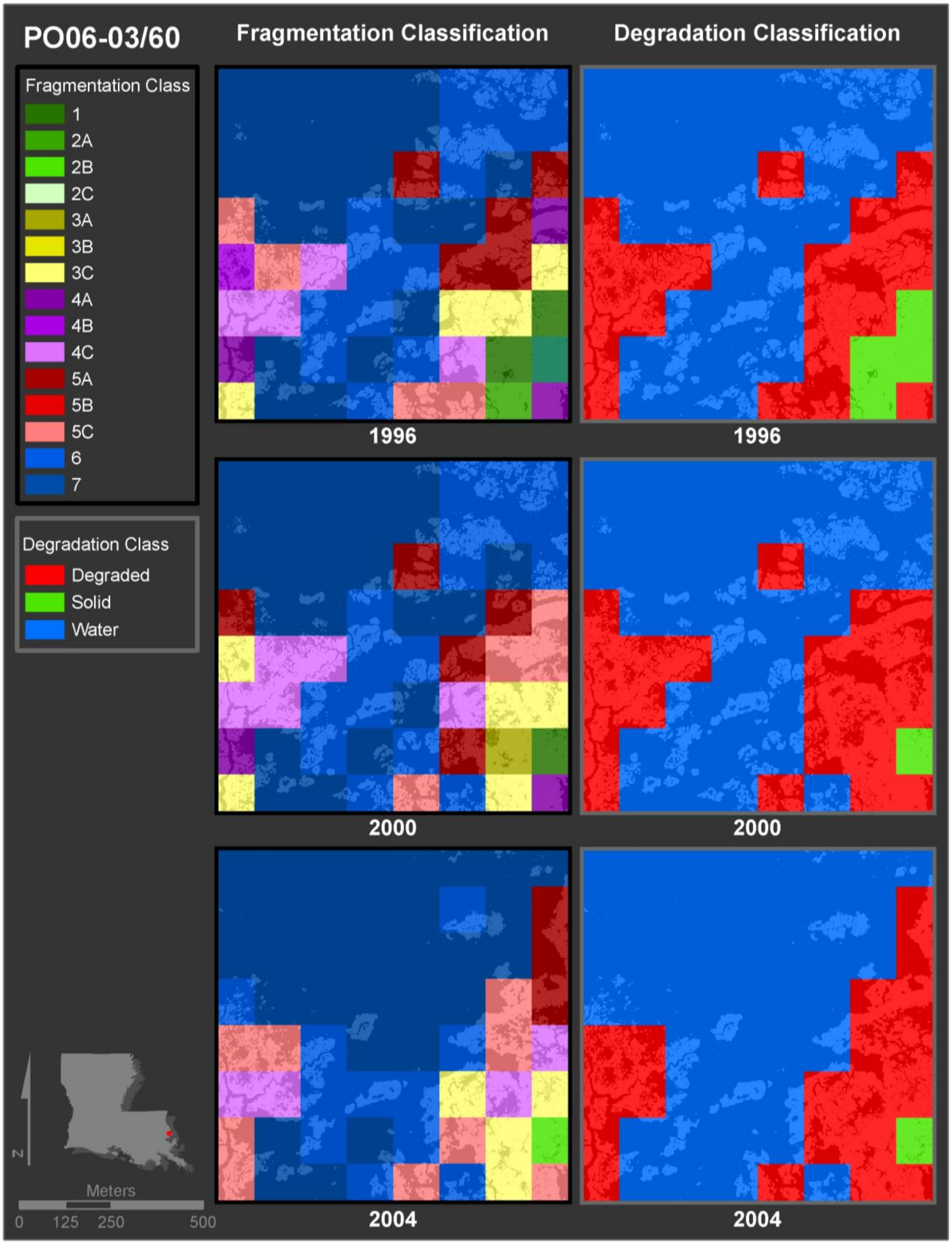


Figure C8. The two tier classes (category and configuration), and degradation associations (solid marsh = 1, 2a, 2b; degraded marsh = 2c, 3a, 3b, 3c, 4a, 4b, 4c, 5a, 5b, 5c; and water = 6, 7) are shown by grid tile for plot PO06-03/60 in 1996, 2000 and 2004.