COASTWIDE REFERENCE MONITORING SYSTEM (CRMS)

CRMS DATA SYNTHESIS – COASTWIDE LAND CHANGE 1985 TO 2021

REPORT: VERSION 01
DATE: SEPTEMBER 2025

PREPARED BY: BERNARD WOOD, ADAM CONSTANTIN, LEIGH ANNE SHARP, AND MARGARET DAIGLE

COASTAL PROTECTION AND
RESTORATION AUTHORITY
635 CAJUNDOME BLVD
LAFAYETTE, LA 70506
WWW.COASTAL.LA.GOV

COASTWIDE REFERENCE MONITORING SYSTEM (CRMS)

This document features data collected through Louisiana's Coastwide Reference Monitoring System (CRMS), a network of 390 coastal monitoring sites that provide comprehensive information on coastal trends necessary to plan, implement and assess coastal restoration projects and in support of CPRA's Coastal Master Plan. The CRMS network was established in 2005 to provide a complete suite of monitoring data for Coastal Wetland Planning, Protection and Restoration Act (CWPPRA) projects. CRMS monitoring is conducted by the Coastal Protection and Restoration Authority (CPRA) and the U.S. Geological Survey (USGS) and is currently funded by the CWPPRA program, the Louisiana Trustee Implementation Group for the Deepwater Horizon Natural Resource Damage Assessment (NRDA) Trustees, and the State of Louisiana. CRMS data are publicly available from CPRA's Coastal Information Management System (CIMS; link) and derived data are available through USGS's CRMS website (link).

CITATION

Wood, W. B., Constantin, A. J., Sharp, L. A., & Daigle, M. L. (2025). CRMS Data Synthesis – Coastwide Land Change 1985 to 2021 (p 29). Lafayette, Louisiana: Coastal Protection and Restoration Authority.

ACKNOWLEDGEMENTS

This document was prepared by the CRMS Analytical Team in CPRA's Lafayette Regional Office with support from US Geological Survey (USGS) scientists and other CPRA Regional Office staff. Work was reviewed and refined by CRMS funding partners including CWPPRA agencies (EPA, NOAA, USACE, NRCS, and USFWS) and members of the DWH LaTIG Monitoring and Adaptive Management Small Workgroup.

- Coastal Protection and Restoration Authority – Leigh Anne Sharp, Bernard Wood, Adam Constantin, Margaret Daigle, Melissa Hymel, and Todd Folse
- U.S. Geological Survey – Dave Hewitt, Rachel Villani, Gregg Snedden, Brady Couvillion, Don Schoolmaster, and Camille Stagg

EXECUTIVE SUMMARY

This coastwide data synthesis features all CRMS land change data collected between 2005 and 2021. It is the first in a series of coastwide synthesis reports intended to maximize the utilization and impact of the CRMS dataset.

The entire network of 390 sites was classified to land change groups using hierarchical clustering in order to assess coastwide trends. CRMS sites fell into seven (7) groups that captured a range of conditions including:

- **Continuous, ongoing land loss** in saline marshes on the lower deltaic plain (15% of CRMS network) with all vegetation removed from 2% of sites.
    - Continuous land loss was isolated to fringe marshes in Barataria, Terrebonne, and Breton Sound Basins.
    - Loss appears to be due to erosion of otherwise healthy vegetation (*not* drowning in place).
- **Landscape stability** coastwide (66% of CRMS network).
    - No land change and nearly 100% land in swamps and inland freshwater marshes (19.2%).
    - No land change and around 70% land at sites in every basin and every marsh type, including salt marsh (46.7%).
- **Landscape variability** with three different outcomes (19.2%)
    - **Variable Land Gain** (5.6%) – episodic land gain found mostly in deltas and recovering marshes. Net land gain.
    - **Variable Land Loss** (5.4%) – episodic land loss, typically due to hurricanes but occasionally due to inundation stress or vegetation rafting. Net land loss.
    - **Variable Stable** (7.7%) – episodic loss with recovery. No net land change.

Notable Trends:

- There is an emerging land loss hot spot in the Calcasieu/Sabine Basin in an area that was thought to be geologically stable. Saline impoundments were observed to destabilize during the last high sea level timeframe (2015-2021) and the loss appears to be related to **inundation stress**.
    - Calcasieu/Sabine Basin land loss within CRMS sites between 2005 and 2021 was at the same scale as loss in Barataria and Terrebonne basins (around 8% lost).
- The only landscape collapse happening now is in the Calcasieu/Sabine Basin. Ongoing deltaic plain land loss appears to be due to tidal erosion and hurricanes.

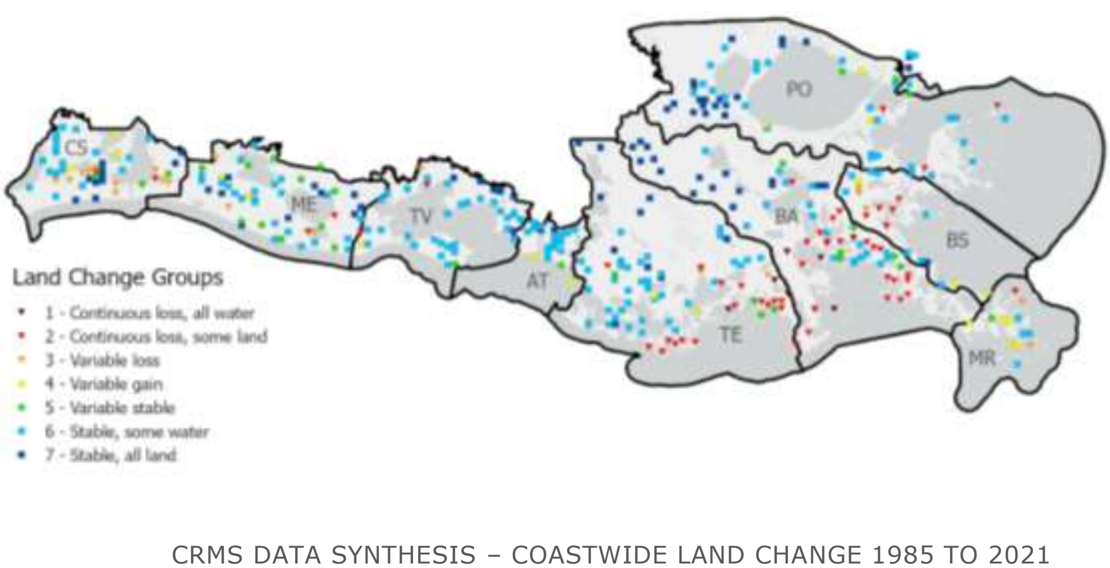


TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AT .... ATCHAFALAYA BASIN
BA .... BARATARIA BASIN
CIMS .... COASTAL INFORMATION MANAGEMENT SYSTEM
CPRA .... COASTAL PROTECTION AND RESTORATION AUTHORITY
CS .... CALCASIEU/SABINE BASIN
CWPPRA .... COASTAL WETLANDS PLANNING, PROTECTION, AND RESTORATION ACT
CRMS .... COASTWIDE REFERENCE MONITORING SYSTEM
DWH .... DEEPWATER HORIZON
EPA .... ENVIRONMENTAL PROTECTION AGENCY
LDWF .... LOUISIANA DEPARTMENT OF WILDLIFE AND FISHERIES
NOAA .... NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ME .... MERMENTAU BASIN
MR .... MISSISSIPPI RIVER DELTA BASIN
NRCS .... NATURAL RESOURCES CONSERVATION
NRDA .... NATURAL RESOURCE DAMAGE ASSESSMENT
PCA .... PRINCIPAL COMPONENT ANALYSIS
PO .... PONTCHARTRAIN BASIN
RESTORE .... RESOURCES AND ECOSYSTEMS SUSTAINABLITY, TOURIST OPPORTUNITIES, AND REVIVED ECONOMIES OF THE GULF COAST STATES
TIG .... TRUSTEE IMPLEMENTATION GROUP
TE .... TERREBONNE BASIN
TV .... TECHE/VERMILION BASIN
USACE .... U.S. ARMY CORPS OF ENGINEERS
USFWS .... U. S. FISH AND WILDLIVE SERVICE
USGS .... U. S. GEOLOGICAL SURVEY SERVICE

1.0 INTRODUCTION

1.1 ABOUT THE CRMS PROGRAM

The Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) of 1990 was enacted to restore, create, enhance and protect Louisiana's coastal wetlands. As required by the Act, a restoration plan was developed that specifically requires: (1) "an evaluation of the effectiveness of each coastal wetland restoration project in achieving long-term solutions to arresting coastal wetland loss in Louisiana;" and (2) "a scientific evaluation of the effectiveness of the coastal wetlands restoration projects carried out under the plan in creating, restoring, protecting and enhancing coastal wetlands in Louisiana."

The CWPPRA program initially addressed its monitoring mandate with a paired project/reference area approach. Monitoring data were collected in both a project area and a reference area for six months to a year pre-construction, and those data would be compared to twenty years of data collected from the same project and reference areas post-construction. Extremes in the pre-construction dataset (like a drought or a hurricane) or changes to reference areas over time (like being incorporated into a new project area) could easily confound project assessment. Further, any findings would only apply to the immediate project area and there was no opportunity to assess combined effects of restoration projects on the landscape.

In 2004, the CRMS design was developed and implemented to provide a network of reference sites, which would replace the paired project/reference monitoring approach and would provide information on landscape change at multiple spatial scales (Figure 1. Steyer et al., 2003). Because CRMS was designed to determine the ecological condition and trajectory of all of Louisiana's coastal wetlands (not just those assigned to project areas), CRMS also provides the opportunity to evaluate coastwide trends and whether whole ecosystems are being restored.

CRMS sites were randomly selected from thousands of LDWF transect points historically utilized for aerial wildlife surveys. Sites were proportionally allocated to basins and marsh types within basins, which allows for inference from the dataset at multiple scales including project, marsh type, basin, and coastwide scales. Each site is potentially a reference for any other site in the monitoring network. Each site effectively collects the same data at about the same time as every other site in the network each year (with exceptions in floating marshes and swamps).

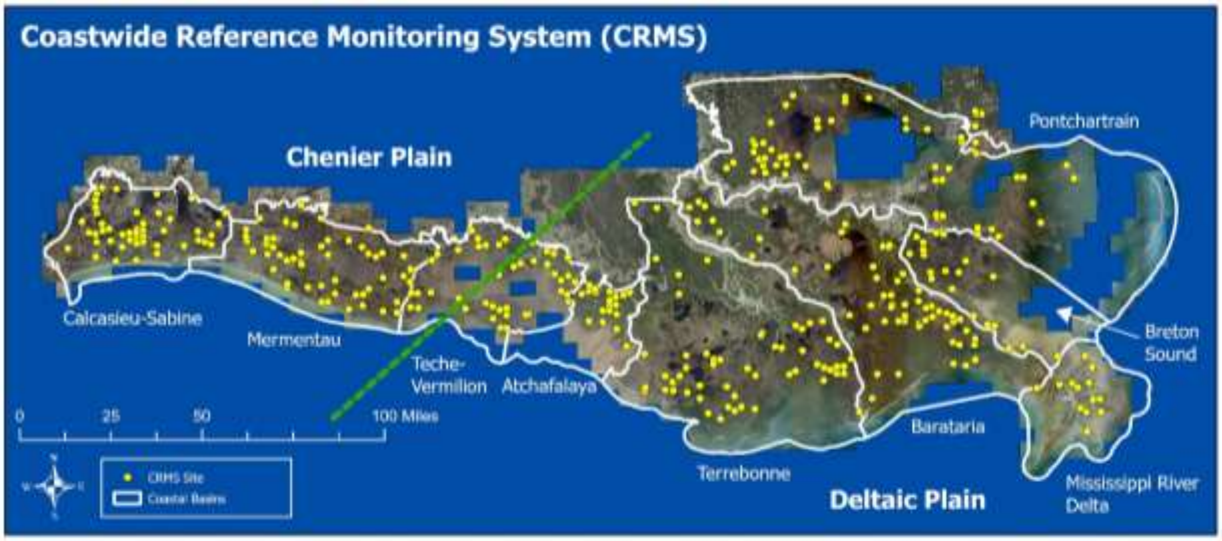


Figure 1. CRMS Sites, geomorphic provinces, and coastal basins.

1.2 CRMS METRICS

Land loss is the primary issue in coastal Louisiana and as such, all CRMS variables measure processes associated with land loss (Couvillion et al., 2017). Inundation and saltwater intrusion cause land loss so CRMS provides trends in water elevation, inundation and salinity. Erosion and subsidence cause land loss so CRMS provides trends in vertical accretion and surface elevation that help assess changing elevation capital. Restoration projects target specific vegetation communities and marsh types so CRMS measures vegetation and classifies species data to communities and marsh types (Snedden et al., 2019; Visser and Sasser, 1998). The ultimate response variable is land and land change so CRMS measures land and land change at multiple scales. Satellite derived estimates that capture historical trends (currently 1985-2020; Couvillion, 2021a) are paired with higher precision spatial analyses performed by USGS every three years (Couvillion, 2021b). Annual vegetation monitoring provides additional detail and context necessary to interpret restoration impacts on a changing coastal landscape. The CRMS data collection methodology is described in detail in the CRMS/SWAMP SOP (Folse et al., 2023).

1.3 ABOUT THE 2005 TO 2023 COASTWIDE DATA SYNTHESIS

This report is the first in a series of reports intended to highlight emerging trends and improve public utilization of the CRMS dataset. Detailed appendices with site level data used in each report are provided to help CRMS data users distill and utilize this valuable coastal resource generously made publicly available by the CWPPRA program to the benefit of Louisiana and its coastal citizens.

This report is limited to CRMS spatial datasets and aims to frame the conversation about the location and types of land change observed on the landscape during the CRMS monitoring timeframe. Future reports will feature trends in hydrology, surface elevation and vegetation that help interpret these land change groupings.

2.0 LAND CHANGE ANALYSIS - METHODS

The Louisiana coast is always changing. Land change patterns are spatially complex and express the net effect of coastal processes on vegetation. Land change is captured at different resolutions both temporally and spatially via satellite imagery (30m) and aerial photography (1m) from CRMS 1-km^2 data collection areas (Figure 2). Satellite data has been captured between 1985 and 2020 with 37 collection dates analyzed during that time span (Couvillion 2021a). CRMS one kilometer high resolution aerial photography has been collected and analyzed between 2005 and 2021 at approximately three year intervals; 2005, 2008, 2012, 2015-2016, 2018, and 2021 post Hurricane Ida (Couvillion 2021b). This data along with some derivatives of it including change rates were assessed using multivariate techniques to form functional groups and synthesize coastwide CRMS sites based on land water statistics.

Along the coastal zone of Louisiana there are 390 CRMS sites spread across basin, hydrologic subunits, and marsh types. In order to group sites in an ecologically meaningful manner for further analysis, a Principal Component Analysis was performed on five variables from 390 sites, which yielded two Principal Components that were used in a Hierarchical Cluster analysis to form eight clusters, which lastly were tested via a Discriminant analysis of the raw variables. Some manual CRMS site assignment was done post analysis via the results of the Discriminant assessment.

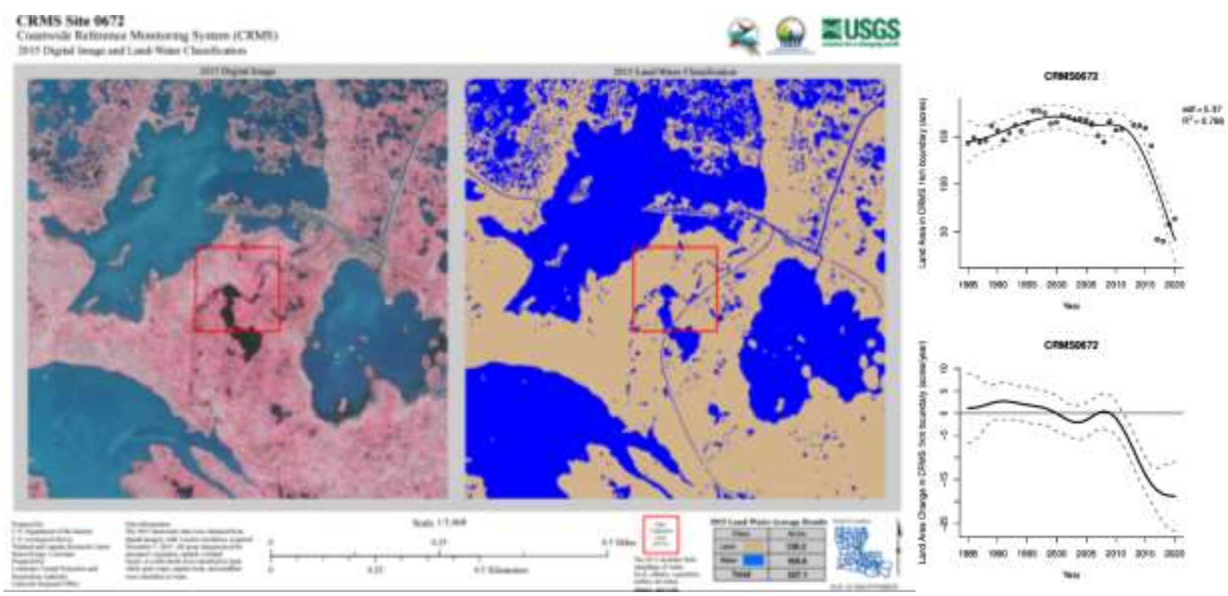


Figure 2. Examples of CRMS spatial data products available online. Left, 2021 land:water classification. Right, satellite derived land trend (top) and land change rate (bottom). https://www.lacoast.gov/crms_viewer/Map/CRMSViewer

2.1 CLUSTER ANALYSIS INTO FUNCTIONAL GROUPINGS

In order to extract information from similar variables within the land/water dataset for the cluster analysis exercise, CRMS variables, which were correlated and potentially collinear, were formed into Principal Components (Table 1, Figure 3). These variables were introduced into a Principal Component Analysis (PCA) in JMP 13.2.1 using a Row-wise method for calculating the correlation matrix (SAS Institute Inc. 2016). The dataset was log transformed to correct for normality and skewness; however, this did not alter the final results and was removed to reduce interpretive complexity. The original five variables yielded two components with eigenvalues equal to or greater than ~1.0, known as the Kaiser Rule (Hair et al., 1998), 2.76 and 1.00 capturing 75.4% of the variation in the data set. This was done to reduce multicollinearity (i.e. the inter-association among variables). The two above mentioned PCAs were conserved for usage in the cluster analysis (Table 2).

A cluster analysis of CRMS sites was performed on the two PCAs in order to define functional groupings of the CRMS sites across the Louisiana coast. This cluster analysis used Wards Method of Hierarchical Clustering, to aggregate the CRMS sites into classes for analysis purposes (Ward 1963). Ward's minimum variance criterion minimizes the total within-cluster variance while maximizing the between cluster variance; this increase is a weighted squared distance between cluster centers. Eight potentially distinct clusters were originally chosen to represent the majority of land/water conditions found along the coast.

A linear discriminant analysis featuring the quadratic method was applied to the raw data and the PCA derived clusters to assess the predicted membership of categories based on the observed continuous variables. This yielded a misclassification percentage of 6.2, with the most misclassification between cluster five and six (Table 3). Post analysis group assignment focused on combining cluster seven and eight into a single land gaining category, along with condensing cluster five to CRMS sites with between 95%-100% land as of the most recent data capture (Figure 4). This reduced cluster five from 106 CRMS sites to 75; minor other site level group reassignment took place but was very minimal with a guise on interpretation and discussion.

The primary clustering division was between sites experiencing land loss, 20.8% (Groups 1-3), and all other CRMS sites (79.2%, Groups 4-7) (Figure 5). The next division was between locations gaining land (5.6%, Group 4) and stable sites (73.6%, Groups 5-7), after which stable sites were split into variable and non-variable groups (65.9%, Groups 6 and 7). The next break separates land loss sites into variable loss (7.7%, Group 5) and continuous loss (15.4%, Groups 1 and 2) categories. Stable sites were further divided into sites with nearly 100% land (19.2%, Group 7) and areas averaging closer to 70% land (46.7%, Group 6), both with minimal variability. The final break was between land loss sites with no land remaining (1.8%, Group 1) and those with some land remaining (13.6%, Group 2) as of the 2021 data collection period. The next break would have separated land gain into sub-categories that were not particularly informative.

The statistically derived clusters were fashioned into descriptive groups for further examination. Further augmentation of the groupings were carried out based on the results from a discriminant analysis to reduce complexity for discussion clarity. Land loss/gain was classified as continuous, variable, or stable. Remaining land within study area was identified as a distinguishing characteristic for the outermost clusters on both ends: all water, some land, some water, and all land. These descriptive land change groups, 1-7, will be referenced throughout the rest of the land change section.

Table 1. CRMS site spatial variables entered into the Principal Component Analysis (PCA) model to determine clusters.

Variable Name	**Temporal Range**	**Resolution**
Land Change (%)	2005 - 2021	One meter
Satellite Land Change (ac/y)	1985 - 2020	30 meter
Land (%) 2021	2021	One meter
Percent of 2005 Land Remaining (%)	2005 - 2021	One meter
Satellite Land Change Standard Deviation (ac/y)	1985 - 2020	30 meter

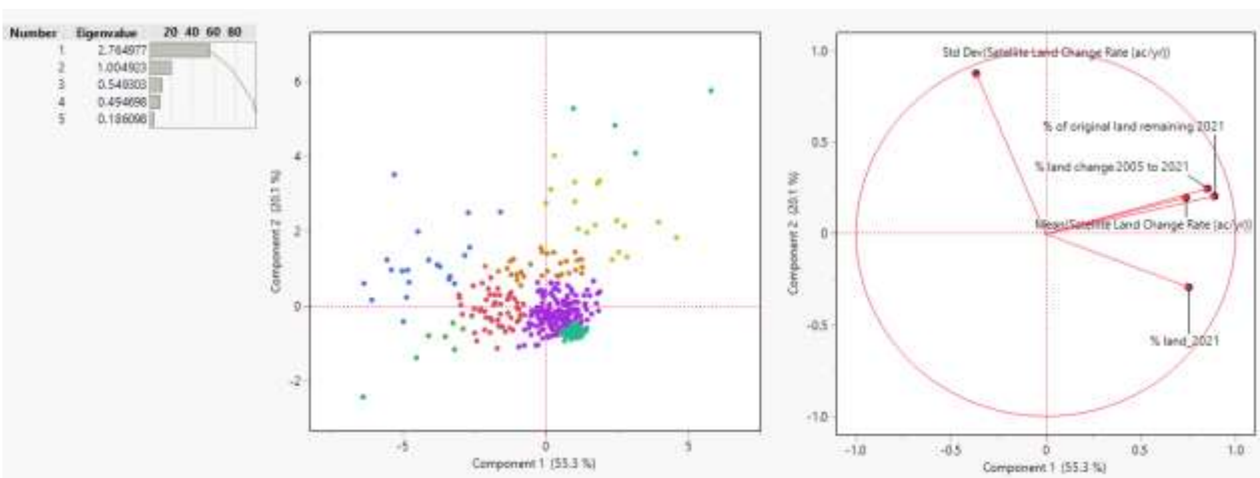


Figure 3. Results from the PCA showing the Score Plot and the Loadings Plot. The Score Plot graphs each component's calculated values in relation to the other, adjusting each value for the mean and standard deviation. Representative colors are as followed: Continuous Loss, All Water (Green), Continuous Loss, Some Land (Red), Variable Loss (Blue), Variable Gain (Black), Variable Stable (Orange), Stable, Some Water (Purple) and Stable, All Land (Teal). The Loadings Plot graphs the un-rotated loading matrix between the variables and the components. The closer the value is to one, the greater the effect of the component on the variable.

Table 2. Eigen values and vectors loading matrix.

Eigenvalues

Number	Eigenvalue	Percent	Cum Percent
1	2.7650	55.300	55.300
2	1.0049	20.098	75.398
3	0.5493	10.986	86.384
4	0.4947	9.894	96.278
5	0.1861	3.722	100.000

Eigenvectors

	Prin1	Prin2	Prin3	Prin4	Prin5
Mean(Satellite Land Change Rate (ac/yr)	0.44424	0.19884	-0.82481	0.28738	-0.01461
Std Dev(Satellite Land Change Rate (ac/yr)	-0.22086	0.87811	0.21650	0.35869	0.06791
% land_2021	0.45297	-0.29167	0.41496	0.70314	0.20774
% land change 2005 to 2021	0.51250	0.24831	0.14961	-0.50249	0.63309
% of original land remaining 2021	0.53482	0.20654	0.27971	-0.20458	-0.74244

Table 3. Misclassification metrics and number of CRMS sites by original cluster assignment based on the raw land water analytics.

Source	Count	Number Misclassified	Percent Misclassified	Entropy RSquare	-2LogLikelihood
Training	390	24	6.15385	0.84312	196.015

Actual	Predicted Count							
Cluster	1	2	3	4	5	6	7	8
1	50	0	0	1	0	2	0	0
2	0	7	0	0	0	0	0	0
3	0	0	21	0	0	0	0	0
4	0	0	0	30	0	0	1	0
5	0	0	0	0	97	4	0	0
6	3	0	0	4	9	140	0	0
7	0	0	0	0	0	0	17	0
8	0	0	0	0	0	0	0	4

Discriminant Analysis of CRMS Sites as Originally Clustered

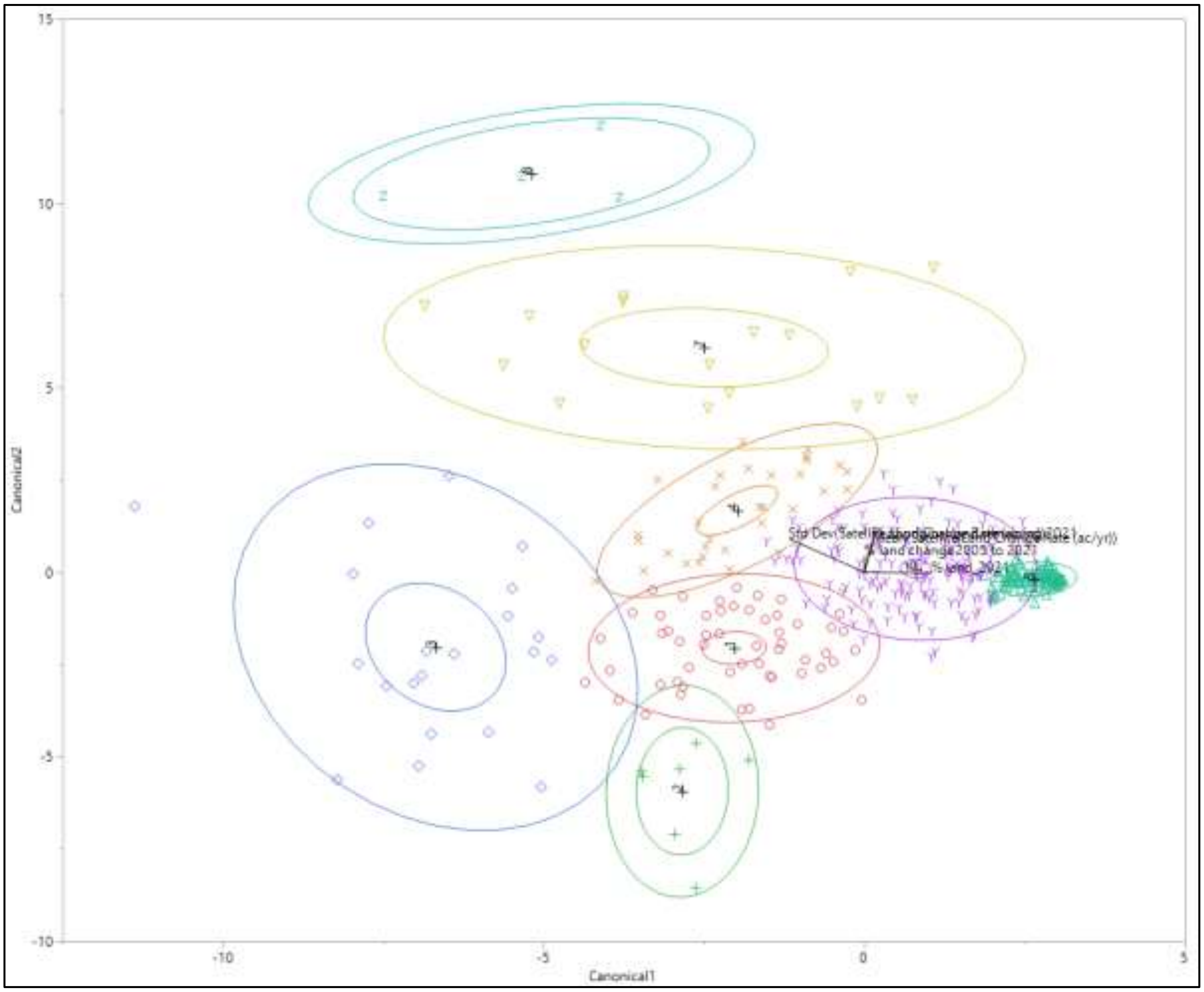


Figure 4. Discriminant analysis using a quadratic method on CRMS sites raw cluster assignment, land gaining clusters were combined, and the two stable clusters were adjusted for interpretation clarity post analysis.

Dendrogram of CRMS Sites as Originally Clustered

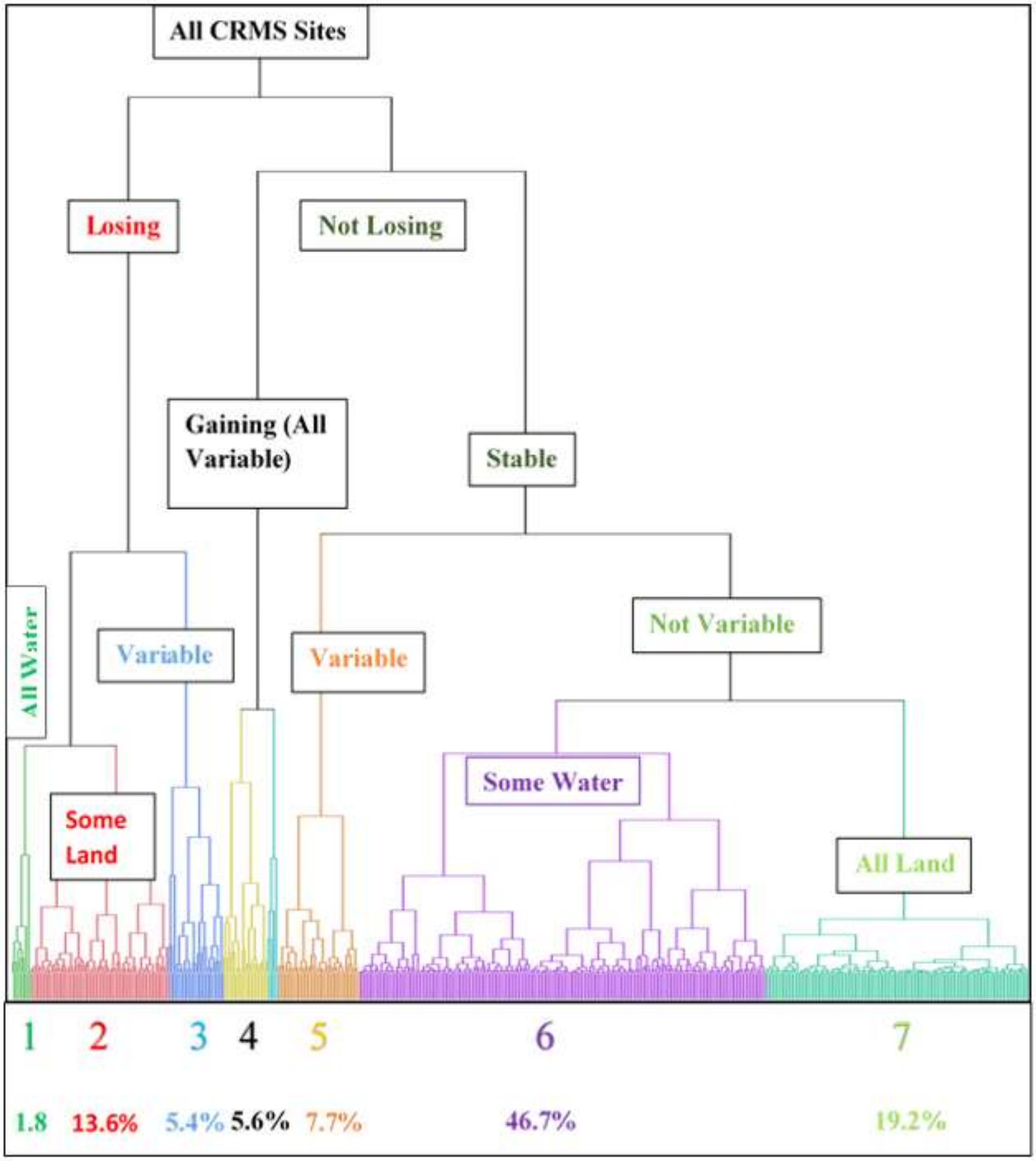


Figure 5. Dendrogram of a hierarchical clustering algorithm using Ward's method of variance augmentation to cluster CRMS sites coastwide. Gaining sites (yellow and blue of Group 4) were grouped back together, reducing from eight clusters to seven groups. The percentage of CRMS sites coastwide falling into each functional group is displayed below the group number, which is used throughout the rest of the land change section.

3.0 LAND CHANGE ANALYSIS – RESULTS AND DISCUSSION

3.1 REVIEW INPUT DATASETS

LAND CHANGE 2005 TO 2021

The original percentage of land at each CRMS site, calculated using the 2005 flight, is depicted alongside the most recent flight from 2021 (Figures 6 and 7). A cursory examination of the 2005 data indicates the majority of sites along the coast were intact, with greater than 80% of the land area remaining within the CRMS 1-km^2. This was not the case for the sites in the lower Deltaic Plain, which was already highly fragmented and had just been impacted by Hurricanes Katrina and Rita when CRMS data collection began in 2006.

Between 2005 and 2021 coastal Louisiana experienced drought (2005-2006, 2010-2011, 2018), river floods (2008, 2011, 2016, 2018, 2019, 2020), and hurricanes (2008, 2012, 2017, 2019, 2020 and 2021). The 2021 percent land classification includes the combined effect of all of these coast-shaping events.

Land change between 2005 and 2021 is presented in Figure 8 as the percent of original land (2005 acres) remaining in 2021. Land loss continued in this timeframe on the lower Deltaic Plain in the Terrebonne (TE), Barataria (BA) and Breton Sound (BS) basins where tidal erosion seems to be the dominant process (Stagg et al., 2024). Land loss extends into the Teche-Vermilion (TV), Mermentau (ME) and Calcasieu-Sabine (CS) basins with little land loss occurring in the central coast Atchafalaya (AT) and Terrebonne (TE) basins beyond the tidal fringe.

Inland swamps and freshwater marshes in the Pontchartrain (PO), BA, TE and AT basins are stable. Land gain is evident in both the Mississippi (MR) and Atchafalaya (AT) deltas with deltaic processes expanding on the east side of the river in Breton Sound (BS) due to crevasse induced land building. Land building outside of active deltas is either recovery from previous storm damage (BS) or marsh creation (CS and PO).

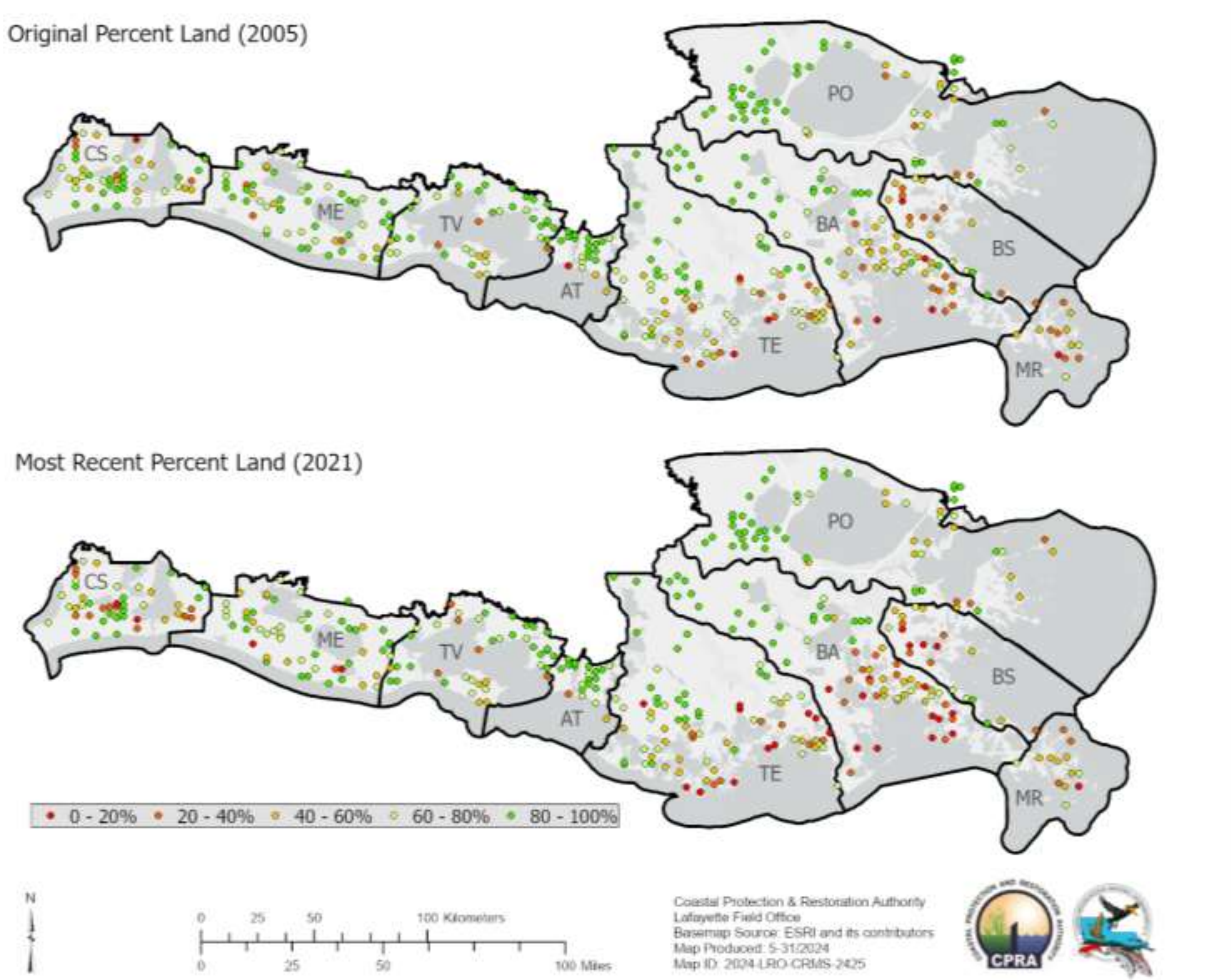
An area of more rapid and unanticipated land loss has emerged on the Chenier Plain. From 2005 to 2021, land loss within CRMS sites in the Calcasieu/Sabine (CS) basin was at the same scale as ongoing land loss on the lower Deltaic Plain (Figures 8 and 9). In total, CRMS sites in the CS basin have lost 7.6% of the area that was land at program inception (2005) while sites in the BA and TE basins have lost 8.6% and 5.4% respectively. The Mermentau (ME) basin is also comparable to TE land loss with 5.1% of the area lost during the CRMS monitoring timeframe. The Chenier Plain was destabilized by Hurricane Rita and has suffered from persistent inundation in the most recent high water period starting in 2016 (McGinnis et al., 2019). Land loss adds up in the Mermentau basin but at the site level, loss is around 10-25%. In the CS basin, there are several impoundments that have seen near complete loss of land over a relatively short timeframe which amplifies the need for large scale hydrologic restoration in this region.

LAND CHANGE 1985 TO 2000

Recent land loss largely captures the same trend as historic land loss from Landsat data (Figure 10). High land loss rates are observed on the Deltaic Plain in lower TE, BA and BS basins. The longer-term data also identifies loss in areas that occurred prior to CRMS monitoring. Loss rates of -0.5-2 acres/yr occurred in the eastern ME, central TV, BS and eastern PO basins. Higher loss rates of greater than -4 acres/year occurred at one site in the CS, ME, MR and BS basins.

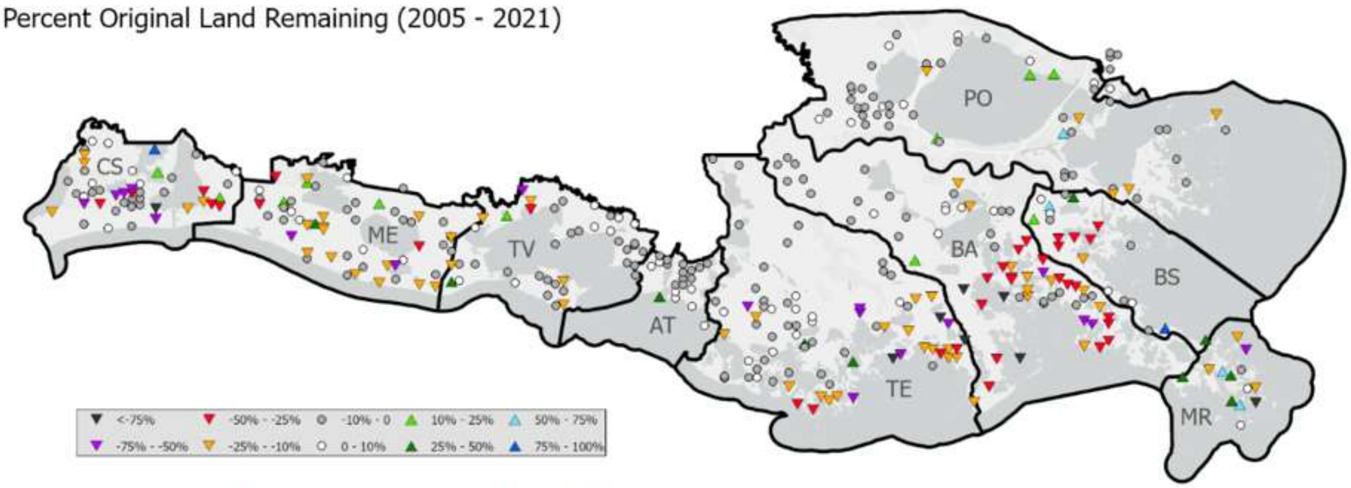
Landscape stability is also apparent in the longer-term dataset. Swamps, interior freshwater wetlands, and freshwater impoundments on the Chenier Plain (interior ME basin) were all stable between 1985 and 2020. Land gain is also observed with the highest rates occurring in active deltas. High land gain outside of deltas is either marsh creation (CS, PO) or recovery from previous land loss (ME). Land gain of 0.5-2 acres/yr was observed throughout the coastal zone including the upper CS, TE, AT and BA basins, western ME and TV basins, and the BS and MR basins.

The variability of land change is presented the standard deviation of the mean of Landsat derived land change rate (Figure 11). Again, the typical trend is for sites to be more stable in the upper reaches of the coast and become more variable from north to south. In the parts of the coast that are losing land over this time frame, lower Deltaic Plain land loss is much less variable than Chenier Plain land loss which makes sense because tidal erosion is continuous and ongoing while Chenier Plain land change is related to cycles of flood and drought.

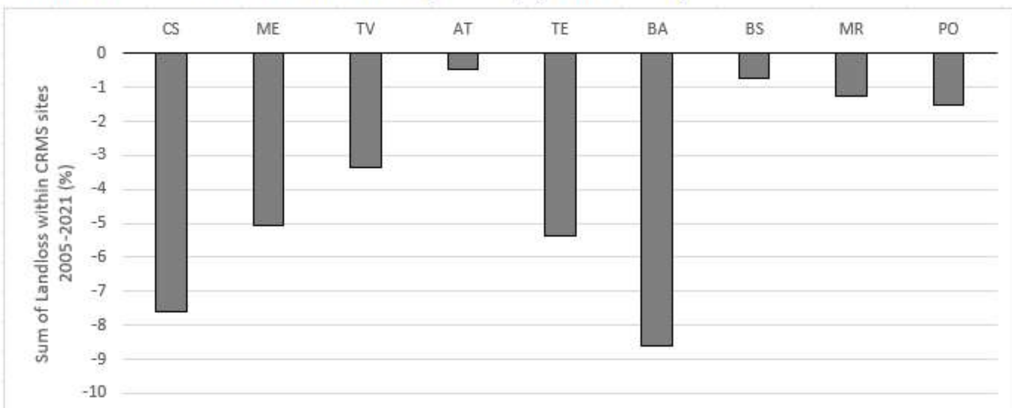


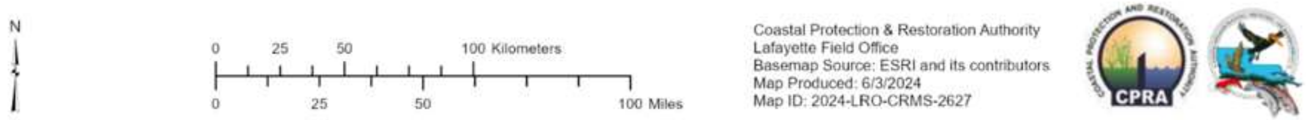
Figures 6 & 7. Percent land within CRMS sites at program inception (2005) and most recently (2021).

Percent Original Land Remaining (2005 - 2021)

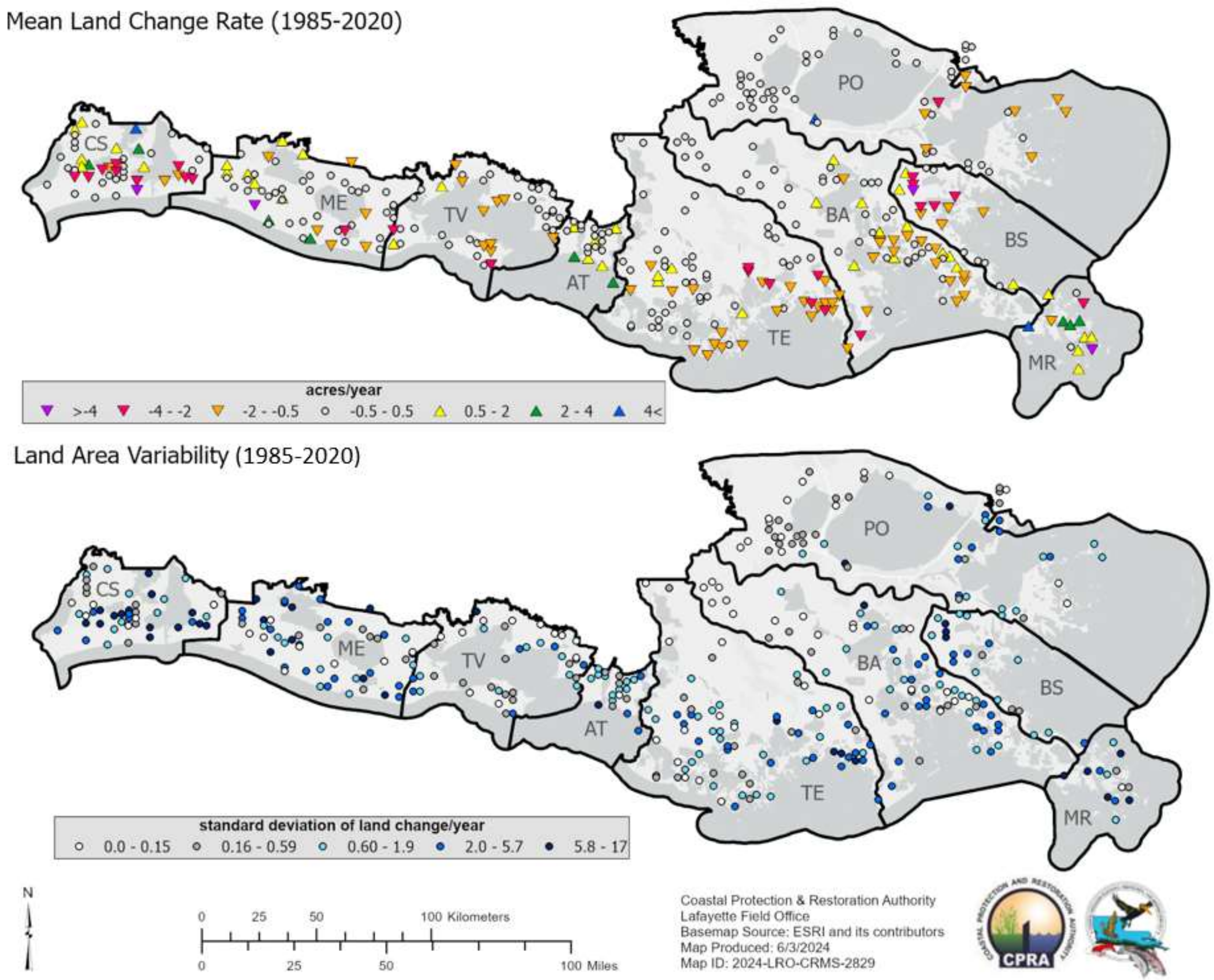


Sum of Landloss within CRMS sites by Basin (%, 2005-2021)





Figures 8 & 9. Percent Original (2005) land remaining in 2021 and the sum of land loss within CRMS sites by Coastal Basin.



Figures 10 & 11. Land change rate derived from satellite data (1985-2020) and variability in satellite data (std dev).

3.2 REVIEW LAND CHANGE GROUPS

The hierarchical clustering analysis utilized the land change datasets described above to create seven land change groups (Figure 12 A and B, Table 4) which were ordered from worst case (continuous loss, all water) to best (stable, all land). Coastwide, most sites fell into one of the two stable groups (66%) with 19% of those being completely vegetated. This condition is primarily found in swamps and inland freshwater wetlands that change slowly through this spatial analysis lens.

The continuous loss groups make up 15.4% of the network. The majority still have some land remaining (13.6%) while 2% have seen all vegetation removed in the 2005 to 2021 timeframe. Continuous loss is primarily found on the lower deltaic plain in the TE, BA, and BS basins. Recent work has shown land loss in this part of the coast is occurring in a depositional environment with an increase in sediment deposition as the eroding edge gets closer to the CRMS site (Stagg et al., 2024).

There are three Variable groups in between the Stable and Continuous Loss groups that all have relatively high variability and different land change outcomes. Variable loss captures non-continuous land loss where loss is episodic, typically due to hurricanes, and the landscape is stable in between storms (net land loss; 5.4%). This type of loss is most frequently found in the CS basin which has seen both hurricane induced land loss and loss related to inundation stress.

Variable gain (5.6%) occurs in deltas, recovering marshes and created wetlands. Land gain is episodic with periods of gain followed by stability (net gain). The last group is the Variable stable group (7.7%) which includes sites with high variability in land change and no net change overall. This type of land change is primarily found in the ME basin which is known to be both dynamic and robust (Mouledous et al., 2016). Here fresh and intermediate marshes are under hydrologic management that controls salinity so changes in hydrologic conditions cause habitat shifts instead of land loss. The CS basin is similarly impounded and is losing land under the same boundary conditions that ME is experiencing. The difference appears to be salinity where ME is relatively fresh and CS is more saline.

Figure 13a displays only the sites from the groups that are losing land as well as the associated land change through time from both satellite and aerial photography (Figure 13b). Within the Chenier Plain, loss at CRMS sites is predominantly episodic and related to Hurricanes Rita and Ike in 2005 and 2008. These sites remained relatively stable to recovering until Hurricanes Laura and Delta in 2020 caused further loss. The losing sites of the Deltaic Plain fall within the lower basins toward the Gulf and have been losing land since monitoring began. Those that have no land remaining were ultimately lost to Hurricane Ida in 2021. The sites in the Variable loss group lost land in 2005 due to Hurricane Katrina and further lost in Hurricane Ike in 2008.

Figure 14a displays only the sites from the groups that are stable and gaining land as well the associated land change through time from satellite and aerial photography (Figure 14b). Sites in these stable/land gain groups did still see some acute land loss due to hurricanes in 2005 and 2021. They differ from the land loss groups in that they recovered from 2005 storms though at different rates. The two stable groups both recovered quickly to pre-2005 percentages and maintained high land values to present with little variability. The Variable stable group was able to recover some but not all of the lost land, with varying land values through time. This group also had another loss event due to Hurricane Ida in 2021. The Variable gain group regained the land that was lost in 2005 and more.

Variable gain is found within active deltas, recovering wetlands, and in marsh creation areas.

LAND CHANGE GROUPS BY BASIN

Table 5 includes percent of sites falling into each land change group within basins for discussion. The CS basin has seen a lot of Variable Loss (22% of sites in the basin), mostly related to hurricane damage though inundation stress has also been implicated as a mechanism causing land loss (McGinnis et al., 2019). Variable Gain in the CS basin is due to marsh creation at two sites and hurricane recovery at a third. Continuous loss is occurring in the center of the basin which is unique among coastal basins as typically continuous loss is on the eroding edge. The interior loss here is related to storm surge and subsequent landscape deterioration caused by storms (in the CS basin, canals remained clogged after Hurricane Rita which has caused land loss within impoundments; see McGinnis et al., 2019). Stable sites make up 61% of the basin and there are stable sites within the same region as destabilized sites. Large-scale hydrologic restoration could reverse the destabilization occurring now in the central CS basin.

The ME basin sites have been largely stable since 2005 (64%). Continuous loss is occurring at a few sites in the southeast corner of the basin (6%) in the absence of tidal erosion indicating potential destabilization there. The ME basin has the most sites in the Variable stable group coastwide meaning that the landscape is changing without losing land. Here we see storm damage with recovery and habitat switching related to flood/drought cycles. There is some Variable gain from marsh management practices and hurricane recovery.

The majority of sites within the TV and AT basins fall within the two stable groups (>85% of sites are stable). These sites have had little to no variability, are stable, and have a large amount of land remaining. Two sites in TV fall within Continuous loss, some land (5%); the site on northern Vermilion Bay that saw edge erosion before it was lost as a result of Hurricane Barry and the site along Freshwater Bayou as a result of ongoing land loss that began in the late 1990’s. One site falls within Variable loss group and is losing land due to impoundment and land management practices (2.5%). All of the sites of the AT basin fall within groups that are either stable (85%) or are gaining land (10%) and reflects the basin’s properties as an active delta.

The TE and BA sites show a consistent pattern of stability with little variability in the upper basin (63% and 52%) to continually losing land and becoming more fragmented towards the Gulf (23% and 32%). Many of these sites were already highly fragmented at the onset of the CRMS program. Three sites in TE and four sites in BA have completely washed away during this time frame (4% and 6%). Two sites within the TE basin fall into the Variable loss group, having lost much of the land at the site due to hurricanes (6%).

A number of sites in southeastern Terrebonne Basin (lower Penchant sub-basin) are remarkably stable. The region has the same open tidal connectivity as eroding marshes to the west but is not losing land. The difference appears to be related to freshwater conveyed east from the Atchafalaya and protection from provided by restored barrier islands. Two sites within the TE basin have gained land, the one to the west due to natural land gain and the other due to a marsh creation project.

The BS basin sites reflect the trends seen in lower TE and BA basins, continually losing land and being fragmented from the inception of the CRMS program. There are a few sites near the river that are stable and even gaining land due to crevasse influence. In fact, the Variable gain group is mostly in the MR basin but is expanding into the BS basin on the east side of the river due to crevasse influence.

The MR basin sites are mostly stable (84.5%) or gaining land (38.5%) due to high sediment availability, but a few sites on the extremity of the delta are losing land continuously or acutely due to erosion (Variable loss; 15%). One site was observed to lose land to water hyacinth rafting (CRMS0161).

The sites in the PO basin appear to be the most stable of the Deltaic Plain (85%) with only a few losing land continuously on the tidal fringe around Lake Borgne (5%). A large proportion of sites in the basin are swamps that change much more slowly than marshes. Land gain around Lake Pontchartrain is due to marsh creation projects (Variable gain 5%).

Table 4. CRMS Land Change Groups and percent of total CRMS network (n=390) assigned to each group split by basin. Highlighted cells indicate maximum value for each land change group. Basins ordered West to East.

		Percent of CRMS Monitoring Network									
Group #	**Land Change Group Name**	**CS**	**ME**	**TV**	**AT**	**TE**	**BA**	**MR**	**BS**	**PO**	**Total**
1	Continuous loss, all water					0.8	1.0				**1.8**
2	Continuous loss, some land	0.5	0.5	0.5		4.4	5.4	0.3	1.3	0.8	**13.6**
3	Variable loss	2.6	0.8	0.3		0.5		0.5	0.8		**5.4**
4	Variable gain	0.8	0.8	0.3	0.5	0.5		1.3	0.8	0.8	**5.6**
5	Variable stable	0.8	2.8	0.3	0.3	1.0	1.5	0.3		0.8	**7.7**
6	Stable, some water	4.6	6.2	7.4	3.8	9.5	4.6	1.0	2.1	7.4	**46.7**
7	Stable, all land	2.6	2.6	1.5	0.5	2.6	4.1		0.3	5.1	**19.2**

Table 5. CRMS Land Change Groups and percent of sites within each basin assigned to each group.

		Percent of CRMS Monitoring Network within Basin								
Group #	Land Change Group Name	**CS**	**ME**	**TV**	**AT**	**TE**	**BA**	**MR**	**BS**	**PO**
1	Continuous loss, all water					4	6.2			
2	Continuous loss, some land	4.3	3.8	5		22.7	32.3	7.7	25	5.2
3	Variable loss	21.7	5.7	2.5		2.7		15.4	15	0.0
4	Variable gain	6.5	5.7	2.5	10	2.7		38.5	15	5.2
5	Variable stable	6.5	20.8	2.5	5	5.3	9.2	7.7		5.2
6	Stable, some water	39.1	45.3	72.5	75	49.3	27.7	30.8	40	50
7	Stable, all land	21.7	18.9	15	10	13.3	24.6		5	34.5

3.3 FUTURE PLANS

The 2024 coastwide imagery dataset was collected and is being classified by USGS. Changes between 2021 and 2024 will capture impacts from the 2022/2023 drought and Hurricane Francine (2024).

Future data summaries will reference this analysis and will provide additional context into processes that drive coastal change.

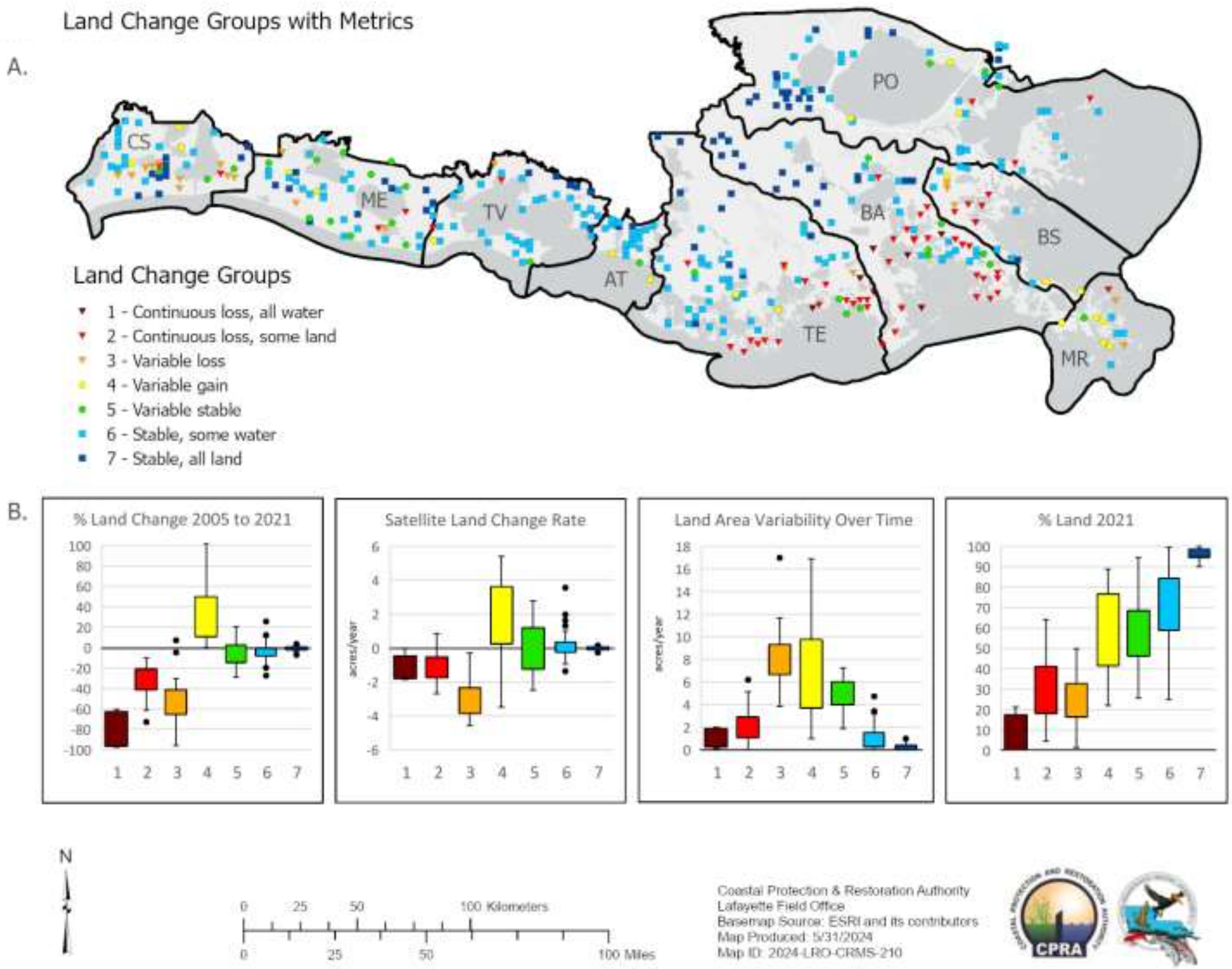


Figure 12. A) CRMS Land Change Groups and B) associated metrics. Box and whiskers indicate data range excluding outliers (black dots).

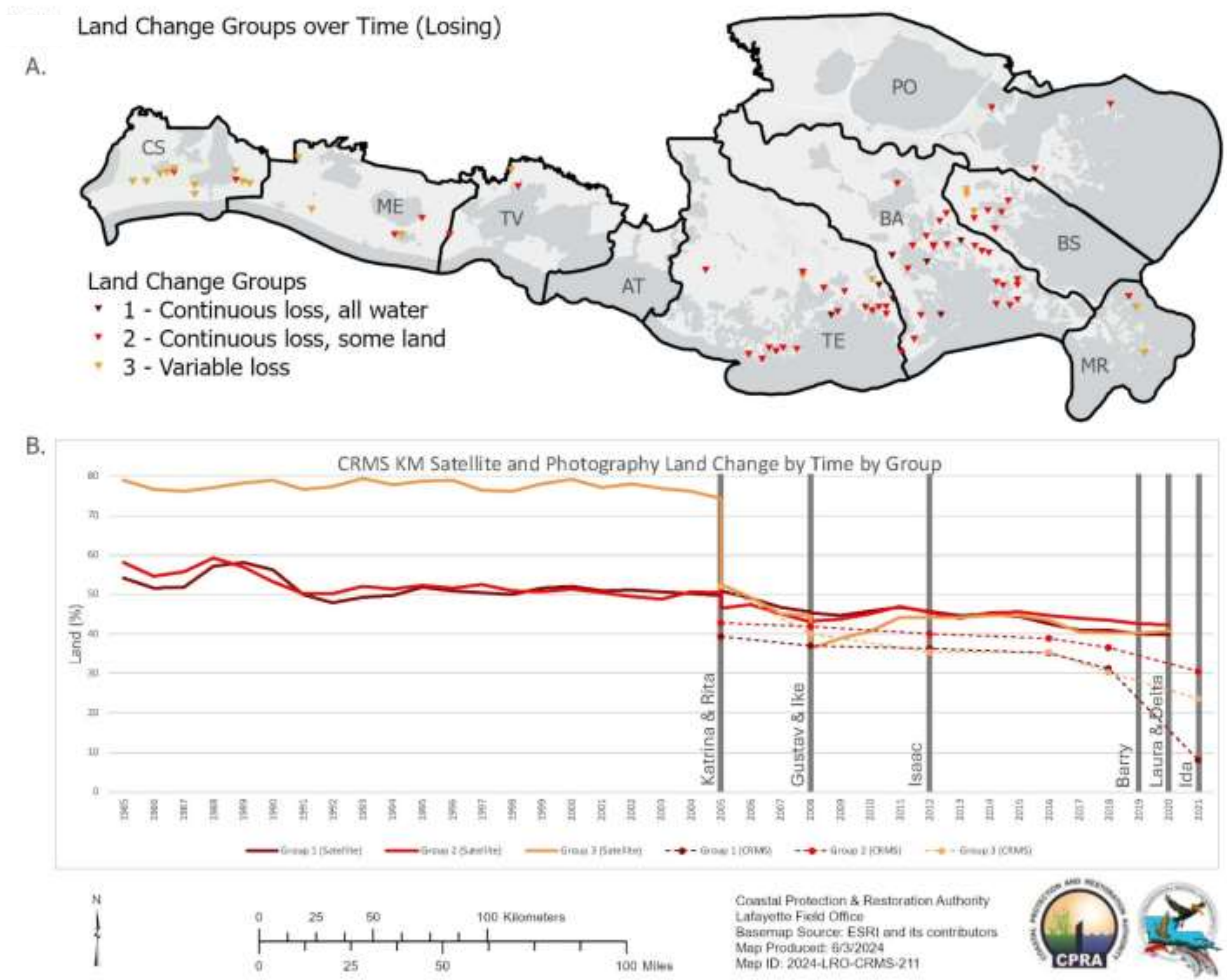


Figure 13. A) Location of CRMS sites allocated to groups that capture land loss and B) trends in land change by group (% land by year).

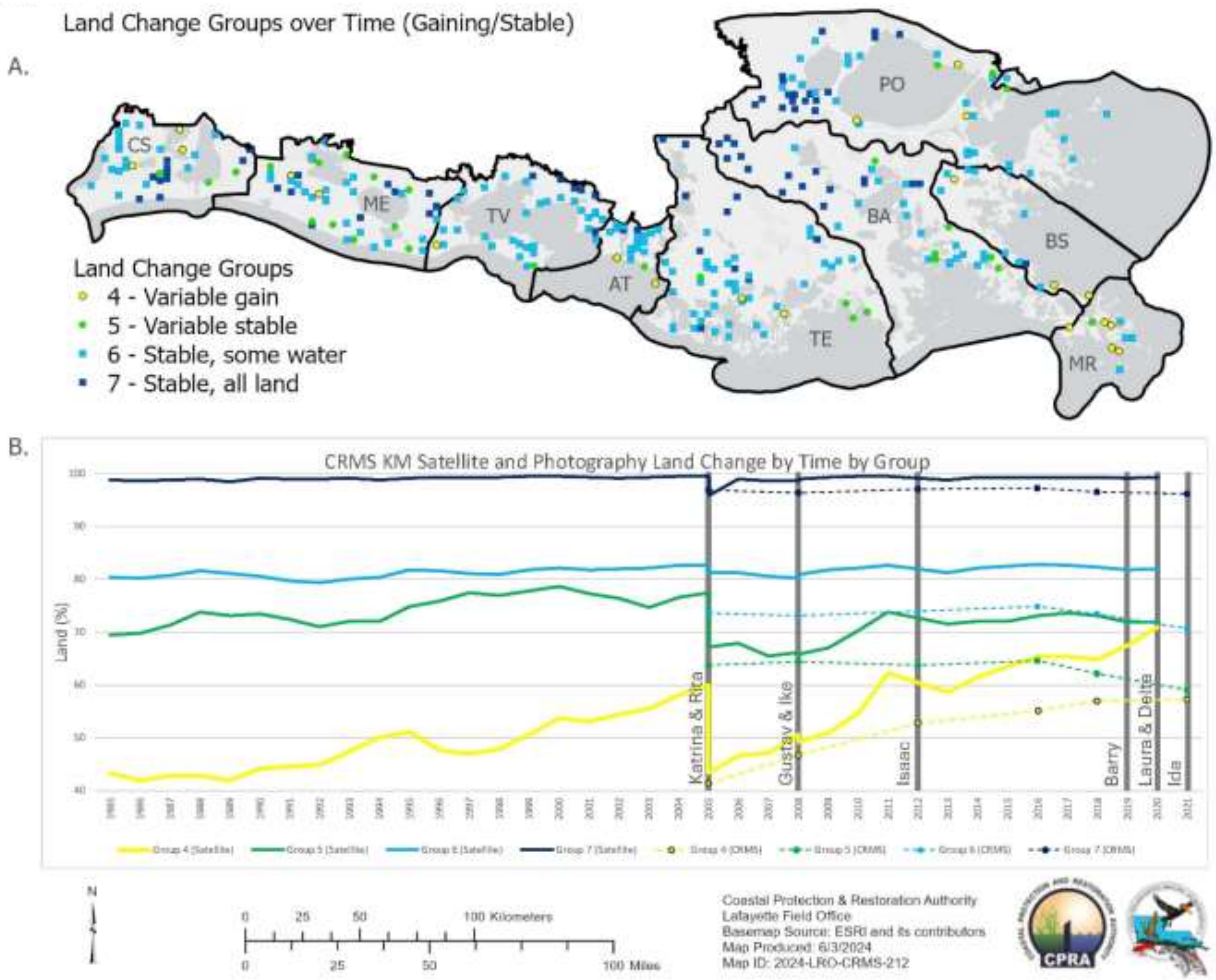


Figure 14. A) Location of CRMS sites allocated to groups that capture stability and land gain and B) trends in land change by group (% land by year).

4.0 REFERENCES

Couvillion, B. R., Beck, H., Schoolmaster, D., & Fischer, M. (2017). Land area change in coastal Louisiana (1932–2016). Scientific Investigations Map 3381. https://doi.org/10.3133/sim3381

Couvillion, B.R., (2021a), Coastal wetland area change in the Gulf of Mexico, 1985-2020: U.S. Geological Survey data release, https://doi.org/10.5066/P9ZQI7ZW.

Couvillion, B. (2021b). Gulf of Mexico Land Area Change in Wetland Possible Zone by Hydrologic Unit Code (HUC) Graphs: U.S. Geological Survey data release, https://doi.org/10.5066/P9ZQI7ZW.

Coastal Protection and Restoration Authority (CPRA) of Louisiana. (2025) Coastwide Reference Monitoring System-Wetlands Monitoring Data. Retrieved from Coastal Information Management System (CIMS) database. http://cims.coastal.louisiana.gov.

Todd M. Folse, Thomas E. McGinnis, Leigh A. Sharp, Jonathan L. West, Melissa K. Hymel, John P. Troutman, Dona Weifenbach, William M. Boshart, Laurie B. Rodrigue, Danielle C. Richardi, W. Bernard Wood, C. Mike Miller, Elizabeth M. Robinson, Angelina M. Freeman, Camille L. Stagg, Brady R. Couvillion, and Holly J. Beck. (2023). A Standard Operating Procedures Manual for the Coastwide Reference Monitoring System-*Wetlands* and the System-Wide Assessment and Monitoring Program: Methods for Site Establishment, Data Collection, and Quality Assurance/Quality Control. Louisiana Coastal Protection and Restoration Authority. Baton Rouge, LA. 255 pp.

Hair Jr., J. F. et al. (1998). Multivariate Data Analysis with Readings. Englewood Cliffs, NJ: Prentice-Hall.

McGinnis, T.E., W.B. Wood, M. Luent, M. Mouledous, M. Miller, and L.A. Sharp. (2019) 2019 Basin Summary Report for the Calcasieu-Sabine Basin. Coastal Protection and Restoration Authority of Louisiana, Lafayette, Louisiana. 59 pp plus Appendix.

Mouledous, M, Wood, W.B. and Sharp, L.A. (2016) 2016 Basin Summary Report for the Mermentau Basin, Coastal Protection and Restoration Authority of Louisiana, Lafayette, Louisiana. 57 pp

Snedden GA. Patterning emergent marsh vegetation assemblages in coastal Louisiana, USA, with unsupervised artificial neural networks. Appl Veg Sci. (2019) 22:213–229. https://doi.org/10.1111/avsc.12425

Stagg, C.L., Sharp, L.A., Fromenthal, E. *et al*. Correction: Accelerating Elevation Gain Indicates Land Loss Associated with Erosion in Mississippi River Deltaic Plain Tidal Wetlands. *Estuaries and Coasts* **47**, 2119 (2024). https://doi.org/10.1007/s12237-024-01330-1

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

SAS Institute Inc. (2016). SAS/ETS® 14.2 User's Guide. Cary, NC: SAS Institute Inc.

Visser, J.M. and C.E. Sasser. (1998) 1997 Coastal vegetation analysis. Louisiana State University: Coastal Ecology Institute. Baton Rouge, LA.

Ward, J. H. (1963) Hierarchical grouping to optimize an objective function. Journal of the American Statistical Association, 58(301), 236–244. {1, 7, 10}

5.0 APPENDIX

5.1 CRMS LAND CHANGE DATASET