VEGETATION ANALYSIS AND SPATIAL VISUALIZATION OF A TIDAL SALT MARSH

by

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Abstract

Mitchell Marsh, a tidal salt marsh in the Salmon River Estuary, was diked in the early 1960s. Restoration of the marsh, which began in late 1978, consisted of partial dike removal. Several studies have been conducted in the marsh, addressing the status of the developing salt marsh plant communities. Species composition data have been collected in the marsh for the years 1978, 1979, 1980, 1984, 1988, 1993, 1999, and 2004.

Previous studies used multivariate methods, which did not address the spatial variation present in the developing communities. This study introduces an innovative method for representing spatial and temporal variation present in plant community distributions. To achieve this, several methods were used. First, cluster and indicator species analyses were performed in PCORD to identify plant assemblages for each year. Second, universal kriging was performed using the Geostatistical Analyst in ArcGIS. This resulted in a prediction map representing the spatial distribution of the plant assemblages. Third, an animation of the kriged plant assemblages was created to display continuous spatial plant assemblages from 1978 through 2004.

The vegetation analysis results were very similar to those found in previous year-by-year studies conducted in the marsh. Initially the marsh was composed of wet pasture assemblages that mostly died off by 1980. The only assemblage that persisted beyond 1980 was a high marsh assemblage identified by *Argentina egedii.* By 1984 the salt marsh assemblages identified by *Carex lyngbyei, Distichlis spicata,* and *Argentina egedii* were developing. These assemblages varied slightly in composition and distribution over the years but presently appear much like they did in 1984.

The innovative methods introduced in this study allow the interpretation of spatial and temporal distributions of plant communities. The results from this study may be added to the wealth of data on salt marsh ecosystems and will provide a building block for creating and interpreting visual representations of landscapes, ecosystems, and communities. In combination with many other studies, this one may help in the management and protection of this highly productive ecosystem.

Introduction

Of the many ecosystems around the world, salt marshes are one of the most productive (Mitsch and Gosselink, 1993; Keddy, 2000). Plant biomass and cover is often a significant measure of this productivity, and the vegetation forms distinct assemblages referred to as communities. Tidal salt marshes throughout the world have been diked, drained, and filled to provide new areas for farming or in more recent years, for commercial or residential development.

In the 1970s as society began to recognize the value of estuarine ecosystems protective regulations were enacted and fewer marshes were diked and some were even restored. The restoration of Mitchell Marsh began in 1978 by partial dike removal, reinstituting the many estuarine processes that tidal inundation supports. Monitoring of the marsh began in 1978 and continued through 1980 by Mitchell (1981) and later by Frenkel and Morlan (1990) through 1988. Frenkel further monitored the marsh and others in the estuary, through 2003.

Much data have been collected regarding composition and physical habitat of the marsh. Included in these data is the species percent cover for the years 1978, 1979, 1980, 1984, 1988, 1993, and 1999. Data of this type have been analyzed in many ways in the past (Mitchell, 1980; Frenkel and Morlan, 1990; Frenkel, 2001; Frenkel, 2003). One method that has been prominent is vegetation analysis by multivariate methods (Mitchell, 1980; Frenkel and Morlan, 1990; Frenkel, 2001; Frenkel, 2003). A relatively new technique used in vegetation science is geostatistics, particularly kriging. Geostatistics yields a visual product through the interpolation of real data. In this study a typical vegetation analysis will be combined with kriging analysis to produce a series of images representing the plant assemblages present in the Mitchell Marsh from 1978 through 2004.

Site Description

The site used in this study is the Mitchell Marsh, in the Salmon River Estuary. The estuary is located in northern Lincoln County on the central Oregon coast. Mitchell Marsh is located along the northern shore of the estuary, approximately two kilometers from the estuary mouth (Figure 1). The 800 ha area of the estuary and the surrounding 3400 ha of forested and non-forested headland comprise the Cascade Head Scenic Research Area (CHSRA), which was established in 1974 to provide an area for research and recreation. In 1980, the CHSRA and neighboring Cascade Head Experimental Forest were designated a Biosphere Reserve as part of the United Nations Biosphere Reserve system.

Historically, both Native Americans and settlers used the estuary as a source of food and livelihood. Settlers did not begin to use the estuary until the mid 1800s, and this early use consisted primarily of grazing. As roads began to be constructed in the 1920s, it is presumed that the activity such as grazing and mowing increased. In the early 1960s the first dikes were built in the estuary, converting 133 hectares (60%) of high salt marsh to diked pasture and managed pasture (Mitchell, 1981).

Following the mandate of Congress (Public Law 93-535), the first dike was removed on the north shore of the Salmon River in September 1978, initiating the restoration process of what is now called the Mitchell Marsh. Most of the remaining dikes in the estuary were removed by the year 1996. Several studies have been conducted in the various marshes and monitoring has taken place since the inception of each restoration effort (Frenkel, 2001; Frenkel, 2003).

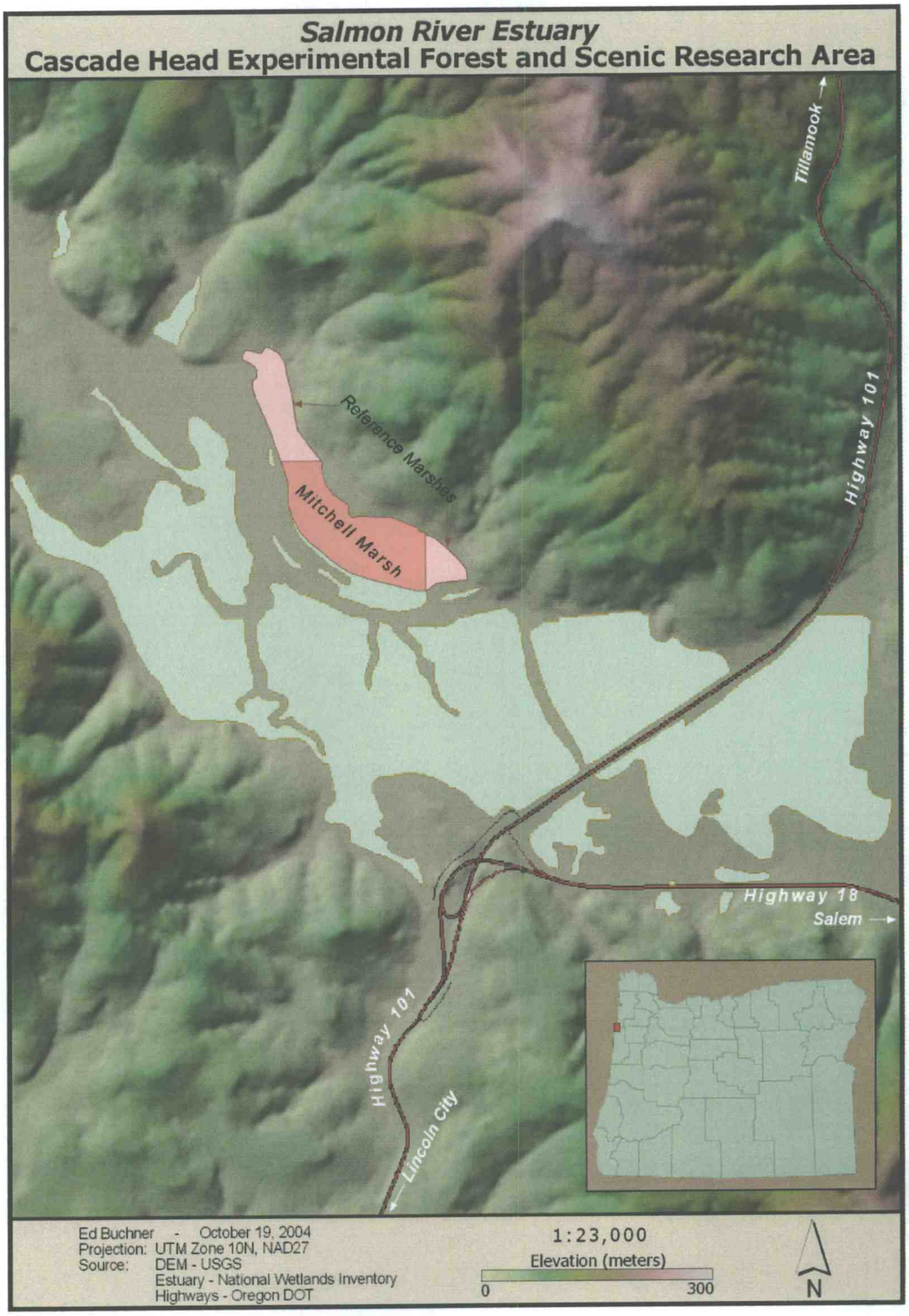

Figure 1. Salmon River Estuary and vicinity.

Background

In this study, the work at Mitchell Marsh was continued using ideas and methods from various disciplines, including: community ecology, landscape ecology, and geostatistics. Dianne Mitchell (1981) performed the initial study at Mitchell Marsh; and Robert Frenkel and Janet Morlan (1990) continued the study in 1990.

Community Ecology

A system of plants and/or animals living together and linked by their influences on one another and their response to the surrounding environment is termed a community (Whittaker, 1975). Community ecology is the study of communities and the dynamics occurring within them. Species composition, species biomass, dominance, growth forms, and species diversity are some of the pertinent information collected and studied in this field. The vegetation in Mitchell Marsh is only now developing through successional processes to what could be referred to as communities. The vegetation in the marsh is currently organized as assemblages, which do not possess long-term stable species composition and are in a constant state of change during successional sequences.

The classification and mapping of plant communities and assemblages can be accomplished using specific criteria (Forman and Godron, 1986). In broad classifications appearance, species composition, species dominance, and habitat are often used (Forman and Godron, 1986). At finer scales, species composition is used most often (Forman and Godron, 1986).

There are many different approaches to classifying communities and assemblages and there is no single correct way (Whittaker, 1975). These different approaches may include classification by structure, dominance, strata and dominance, or measurements of relative similarity (Whitaker, 1975).

Landscape Ecology

The spatial approach of geographers and the functional approach of ecologists come together with the development of landscape ecology (Forman and Godron, 1986). Two aspects of landscape ecology separate it from other ecological disciplines. First, as recognized by Turner et al (2001), landscape ecology addresses the importance of spatial arrangement of operative ecological processes. Second, landscape ecology focuses on a larger spatial extent than is traditionally recognized in ecology. Although a relatively new science, landscape ecology studies have increased recently due to the need to assess the impact of rapid, broad-scale changes in the environment (Turner et al, 2001).

Geostatistics

Spatial continuity is present in many natural environments, but is not addressed by most traditional statistical methods. Geostatistical methods provide the means for describing spatial relationships inherent in many data sets (Isaaks and Srivastava, 1989). These methods can produce a continuous prediction map from individual data points that represent the variables of interest. This map is interpolated from known observations. There are various geostatistical methods within the realm of geostatistics that may be used to produce a surface, one of the more popular being universal kriging. Detrending and other transformations can be used in universal kriging. Either the semivariogram or covariogram can be used to model the spatial relationships, which in turn can be used to make predictions at locations where there are no observed data. In addition to the predictions, error estimates are available.

Previous Studies

Dianne Mitchell's work at the beginning of the restoration process focused on "evaluating the potential for natural salt marsh reestablishment after dike breaching..." (Mitchell, 1981). In the first stages of the study, wet pasture plant communities were described and mapped prior to the breaching of the dikes. A comparison between diked and undiked areas was also performed. The dikes were then partially breached and tidal creeks reconnected with the main river channel. Vegetation was resampled for two years and residual species along with colonizers were described together with permanent plot elevation.

In 1978, 20 permanent transects were installed in the Mitchell Marsh and the adjoining undiked reference marshes. On these transects, 102 m^2 permanent plots were established. At these plots all plant species and their cover classes were collected in one-meter square quadrats. In addition to this relatively simple data collection effort, Mitchell collected additional vegetation data every five meters along the permanent transects and every ten meters along belt transects oriented perpendicular to the permanent transects. Other data included stream profiles, biomass, elevation, tide gauge data, soil salinity, and pH.

Mitchell reported that most upland plant species cover diminished to zero in nearly all plots within a year of dike breaching, while the previously scarce or absent salt marsh colonizers slowly increased progressively (Mitchell, 1981). Mitchell hypothesized, based on elevation estimates and initial species composition, that the expansion of salt marsh species would fill in all "bare soil" in 5 to 10 years. The most successful initial colonizers consisted of the low salt marsh species, *Salicornia virginica*, *Spergularia salina*, and *Carex lyngbyei*. This is due to the 30 cm subsidence of the marsh surface after dike breaching due to compaction, oxidation of organic matter in the soil, and settling of sediments during the 17 years of diked pasture (Mitchell, 1981). Mitchell and others have found the following factors to be important in natural marsh reestablishment: elevation of the site with respect to the range of elevation of adjacent salt marshes; type of drainage system, including tidal creek location and morphology; salinity of estuarine inundation; and availability of colonizing species off the site.

Frenkel and Morlan (1990) assessed the Mitchell Marsh restoration site 11 years after the dike was removed. Their study used Mitchell's (1981) sampling system and continued the research by evaluating the composition, structure, function, and long-term outlook for the site.

Carex lyngbyei, *Salicornia virginica*, *Distichlis spicata*, and *Juncus balticus* were found to be important colonizers, which by 1988 characterized most of the developing salt marsh communities (Frenkel and Morlan, 1990). By 1988 the marsh surface had subsided by 35 cm with the lowest areas occurring in the upriver portions of Mitchell Marsh. These areas were dominated by *Carex lyngbyei*. Narrow bands of high marsh communities only occurred on the elevated former dike, which did not substantially subside.

Objectives

There were several objectives for this project. The first objective was to conduct a simple vegetation analysis. The second objective was to visually represent the plant assemblages and their distribution across the Mitchell Marsh in successive years, from prior to dike breaching to present. The final objective was to animate the changes that have occurred in the Mitchell Marsh over the last 26 years.

By fulfilling the objectives, this study will have introduced an innovation to the traditional methods of vegetation analysis. The relative usefulness of this new method may not be known immediately, but it is felt that future landscape ecology and vegetation analyses may benefit from it.

Justification

Although the restoration of disturbed ecosystems is a valued endeavor in today's society, a measure of success is often overlooked. In any restoration activity it will be impossible to return the ecosystem to its natural conditions prior to the disturbance. Monitoring of the vegetation is the one way to assess the relative success of restoration. Often the monitoring is only pursued for a short time after restoration and no long-term efforts are made. Without long-term monitoring the actual results of any restoration cannot be known. The monitoring of the Mitchell Marsh vegetation is one of the longest running tidal salt marsh monitoring projects on the west coast. The continuation of this program will provide a great wealth of data and insight into the long-term effects of diking tidal salt marshes.

In addition to extending the monitoring period, this project has addressed the challenge of spatially visualizing plant assemblages. Presently, plant communities and assemblages are represented descriptively via multivariate statistics; however, their spatial distribution is not effectively conveyed. By representing assemblages visually, spatial interactions and distributions will be more evident, and will provide a new way to interpret the dynamics present in the estuary. To complement the spatial visualization of assemblages, the animation presented in this paper will provide a temporal context. By visualizing the temporal changes in assemblage distribution, the direction of change may be more easily recognized and studied.

Methods

The data analyzed with these methods consisted of the species percent cover for the years 1978, 1979, 1980, 1984, 1988, 1993, 1999, and 2004. Each year of data is a separate dataset. Each analysis procedure was performed on an individual dataset and treated independently of the other datasets. The species are taxonimcally recognized using the Kartesz nomenclature as found on the National Plant Data Center's online database, PLANTS (USDA, 2004).

Previously Collected Data

Mitchell (1981) designed a monitoring network of permanent transects and plots (Figure 2). In the years 1978, 1979, 1980, 1984, 1988, 1993 and 1999 extensive data pertaining to the marsh were collected at the permanent plots situated along the transects. In the restored marsh there are a total of 50 plots on 10 transects with at least 3 plots per transect. Transects occur at key positions that were identified by Mitchell (1981), and are roughly perpendicular to the Salmon River. The first plot is within 10 meters of the upland, in what was deemed at the time by Mitchell to be representative vegetation. Subsequent plots are near evenly spaced, with small variations to avoid placement in tidal streams and to capture vegetation variability at the time; shorter transects also required short plot intervals to ensure 3 plots per transect. The final plot spacing varies from 25 to 45 meters. The data of interest were species percent cover, collected in a 1x1 meter plot at the northwest corner of the permanent plot. In the years of 1978, 1979, 1980, 1984, and 1988 the data were collected as cover class, which was later converted to mid-point percent cover value. From 1993 on, the data were collected as species percent cover.

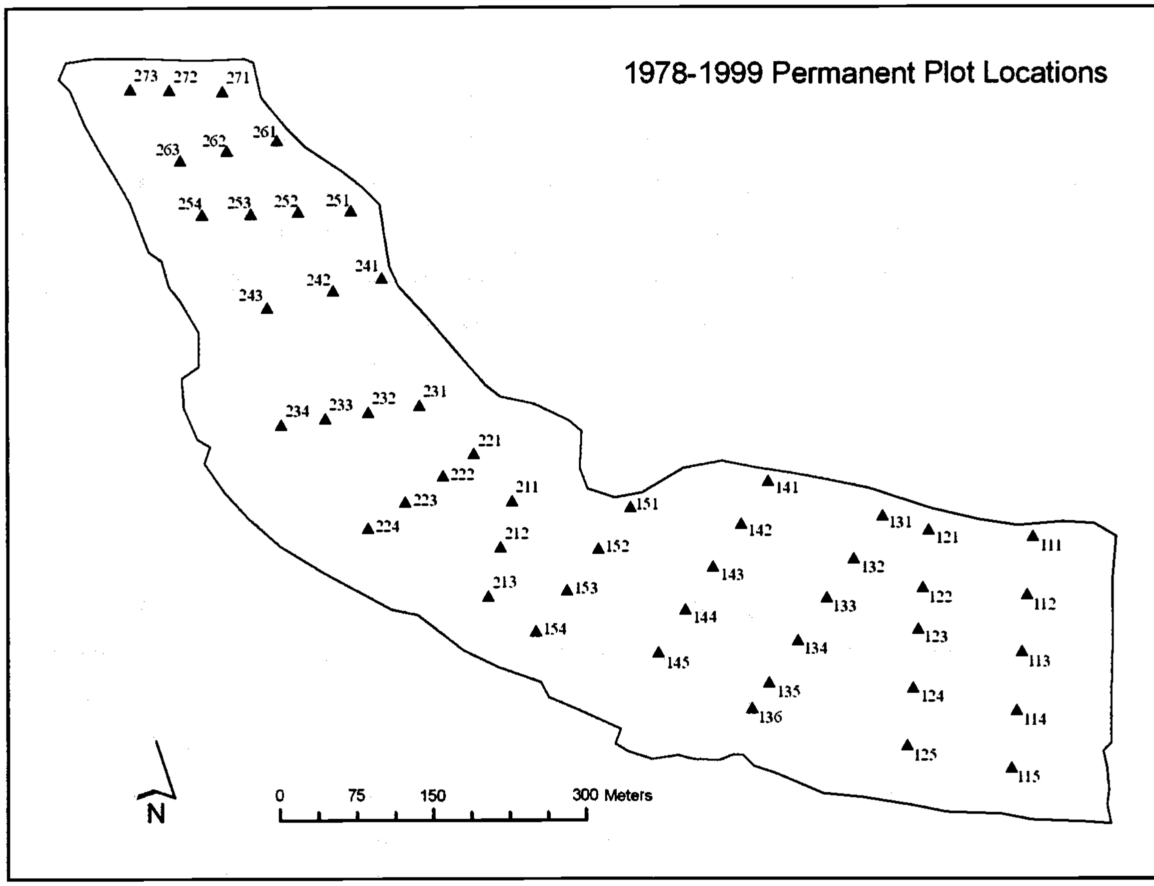

Figure 2. Permanent plot diagram for 1978-1999.

2004 Data

During the summer of 2004 additional species percent cover data were collected in Mitchell Marsh. These data were collected using a sampling design similar to Mitchell's. The existing permanent plot transects were utilized, but sampled at a fifteen-meter interval, starting at the transition between salt marsh vegetation and upland vegetation and extending to the base of the remnant dike. Additional, intermediate, transects were placed at approximately half the distance between the permanent transects and sampled in the same manner as the first transects. This sampling design produced

235 1x1 meter plots (Figure 3). These plots were temporary, not marked, and cannot be exactly relocated for further sampling.

The intermediate transect starting and ending points were placed with respect to coordinates of the existing permanent transect end points. The upland end point was located in the field using two consumer-grade Garmin GPS units (eTrex Venture and Map76). This point was sampled and the GPS unit was set to navigate to the dike end of the transect. Every 15-meters, as determined from the GPS, a new temporary plot was installed and read until the base of the dike was encountered.

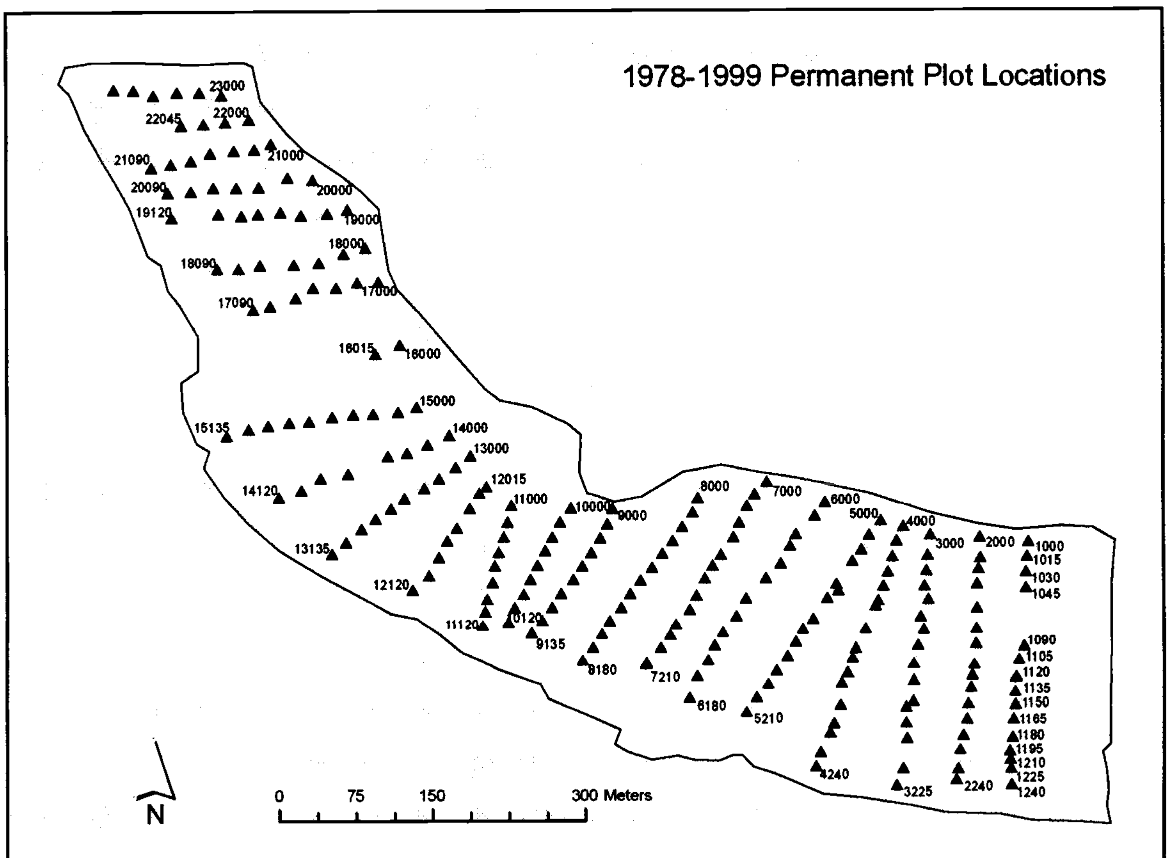

Figure 3: 2004 fine scale plot locations at a 15-meter interval.

Vegetation Analysis

For each year, the species percent cover for each plot was analyzed using the ecological software package PCORD. Columns (species) with less than 2 entries were removed and rows (plots) with less than 1 entry were also removed. Outliers, as determined by PCORD, were removed from each dataset at a standard deviation of 2.00. Once these tasks were complete, cluster analysis, indicator species analysis, and multi-response permutation procedure tests (MRPP) were performed on the data. No standardizations or relativizations were applied.

The objectives of this analysis require that there be only three assemblages, one for each band of a three-color image. Each year of data was processed individually using cluster analysis in PCORD. The Euclidean (Pythagorean) distance measure was used along with the Ward's group linkage method for computing the assemblages and displaying the relationships as a cluster dendrogram.

Following the cluster analysis, indicator species analysis was performed to identify the species of significance for each assemblage. From the indicator species analysis, those species with larger values for percent of perfect indication and low p-values from the Monte Carlo test were identified. In addition to these statistical methods for selecting indicator species, non-statistical methods were used. Several species were ignored as indicators, as these species were found in many plots and appeared to be quite cosmopolitan in distribution.

The previously discussed methods for vegetation analysis resulted in individual, unique assemblages for each year of data. To animate changes in assemblage distribution over the last 26 years, a single, standardized set of assemblages had to be identified. The assemblages identified in the 2004 data were chosen for this, based on my interest in how the distributions came to be the way they are at present. To create a single metric identifying each assemblage, the values of each indicator species in each assemblage were totaled for each plot. This value was then linearly stretched from 0 to 255. The 0 to 255 scale was selected on the basis of the number of values in an 8-bit grayscale image. This value, therefore, provided a spectral signature for each assemblage.

Universal Kriging

The assemblage data, including latitude and longitude as determined by the GPS unit, were imported into ArcGIS. The Geostatistical Analyst was used to perform universal kriging. Each assemblage for each year was analyzed individually. Second order detrending was used to account for spatial relationships resulting from unknown, influential gradients in the marsh. A spherical model was fit and the automatic values for the range, partial sill, nugget, lag size, and number of lags were accepted. When making predictions a reduced kriging neighborhood was used to reduce computational requirements.

Image manipulation

The prediction map, representing each assemblage, resulting from the kriging process was converted to grayscale and exported to a raw 8-bit image format (.RAW). The same was done for the data point file and area boundary. Both the unique assemblage images for each year and the standardized assemblage images were optimized using a 0-255 linear stretch performed in the image processing software ENVI. The area boundary image was manipulated in ENVI so that it could be used as a clipping layer. These images were then exported to Adobe Photoshop. In Photoshop, the unique assemblage images were layer stacked, clipped to the area boundary, and overlain with the data points. The standardized assemblage images for the animation had a ten pixel Gaussian blur applied to smooth the jagged edges inherent to the kriging process.

Animation

The final product of the analysis is the animation. To create a smooth interpretable animation the real time interval between frames needed to be constant. This required that there be at least one image for each year from 1978 through 2004. To accomplish this, Dr. Kimerling assisted by writing a simple C-language program to linearly interpolate from one image to the next. Using this program, images were created for each assemblage for each year.

The C program created single grayscale images for each assemblage for each year. These were placed into the RGB channels of an image to create a 24-bit color image. Assemblage 1 was placed in the red channel, assemblage 2 in the green channel, and assemblage 3 in the blue channel. The resulting RGB images were smoothed using a 10-pixel Gaussian blur filter. This was done to visually smooth the transitions from one assemblage to another. The area boundary mask was used to crop the assemblage images and a legend was placed in the resulting image.

Each one-year interval was morphed using WinMorph at twelve frames per second, resulting in a single month per frame. This was done for each of the 26 one-year intervals. The resulting 26 one-second videos were linked together to form a single video 25 seconds long, at a rate of 1 month per frame and 1 year per second.

Results

In 1978 Mitchell (1981) found the marsh dominated by three wet pasture assemblages consisting of *Agrostis stolonifera, Holcus lanatus*, and *Argentina egedii.* After the dike was breached, upland pasture species suffered high and rapid mortality, while the more salt tolerant species such as *Agrostis stolonifera* and *Argentina egedii* expanded into the previously occupied areas or died back, depending on the degree of salinity and flooding. Successful colonizers of the marsh in 1979 and 1980 included the salt tolerant species; *Atriplex gmelinii, Hordeum brachyantherum, Carex lyngbyei, Spergularia salina,* and *Salicornia virginica.*

Frenkel and Morlan (1990) found that by 1988 *Carex lyngbyei, Salicornia virginica, Distichlis spicata,* and *Juncus balticus* were the important colonizers that characterized many of the new assemblages in the salt marsh that began to form in 1984. In 1988 Frenkel and Morlan identified five salt marsh assemblages that had replaced the original pasture assemblages. In the upriver two thirds of the marsh there was a nearly monotypic low elevation *Carex lyngbyei* assemblage. The downriver third of the marsh was composed of a low elevation *Salicornia virginica* and *Distichlis spicata* assemblage. Along the upland margin the marsh were assemblages composed of *Carex lyngbyei, Agrostis stolonifera, Argentina egedii,* and *Juncus balticus.*

1978 Vegetation Analysis

The three wet pasture assemblages this study identified from 46 plots in the 1978 data, prior to dike removal, were very similar to those identified by Mitchell (1981). The first assemblage consisted of the dominant species *Holcus lanatus* and *Trifolium repens. Argentina egedii* dominated the second assemblage and *Alopecurus geniculatus* dominated the third assemblage. Indicator species analysis in PCORD identified these species as having an indicator value of 50 or greater (Table 1) and a p-value of 0.01 or lower (Appendix B).

	1978			1979			1980			1984			1988			1993			1999			2004		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Agrostis stolonifera	-	-	-	-	69	-	-	85	-	-	77	-	-	97	-	-	-	-	-	-	-	-	60	-
Alopecurus geniculatus	-	-	91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Argentina egedii	-	85	-	-	-	82	-	-	78	-	78	-	-	87	-	-	65	-	-	63	-	-	67	-
Carex lyngbyei	-	-	-	-	--	-	-	-	-	96	-	-	91	-	-	93	-	-	86	-	-	71	-	-
Deschampsia caespitosa	-	-	-	-	-	-	-	-	-	-	-	39	-	-	-	-	-	-	-	-	-	-	-	-
Distichlis spicata	-	-	-	-	-	-	-	-	-	-	-	79	-	-	99	-	-	76	-	-	95	-	-	93
Holcus lanatus	54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hordeum brachyantherum	-	-	-	-	-	-	-	-	-	-	-	-	-	65	-	-	-	-	-	-	-	-	-	-
Juncus balticus	-	-	-	-	-	-	-	-	-	-	-	-	-	69	-	-	-	-	-	47	-	-	30	-
Salicornia virginica	-	-	-	25	-	-	58	-	-	-	-	97	-	-	69	-	-	98	-	-	-	-	-	22
Symphytotrichum subspicatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67	-	-	-	-
Trifolium repens	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triglochin maritimum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20

Table 1. Indicator values for each species with p-values less than 0.02, indicating a specific plant assemblage in each year.

<u>1979 Vegetation Analysis</u>

The analysis of the 48 plots from the 1979 data resulted in slightly different assemblages than Mitchell (1981) reported. The first assemblage was identified by *Salicornia virginica* with a low indicator value of 25. Traces of *Carex lyngbyei* and *Holcus lanatus* were also indicated in the assemblage but with a low probability, p-values of 0.0620 and 0.5010, respectively. *Agrostis stolonifera* identified the second assemblage with an indicator value of 69. Identifying the third assemblage was *Argentina egedii* with a value of 82.

<u>1980 Vegetation Analysis</u>

The 1980 assemblages were approximately the same as those identified for 1979, with slightly different species composition and indicator values. The data consisted of 48 plots in which *Salicornia virginica* identified the first assemblage with an indicator value of 58. *Agrostis stolonifera* identified the second assemblage with an indicator value of 85. The third assemblage was identified by *Argentina egedii* with an indicator value of 78.

1984 Vegetation Analysis

The 1984 assemblages, derived from 49 plots, differed highly from those found in 1980 and earlier. The first assemblage was identified by *Carex lyngbyei* with an indicator value of 96. The second assemblage was identified by both *Agrostis stolonifera* and *Argentina egedii,* each with indicator values greater than 75. Three species identified the third assemblage; *Salicornia virginica* with a value of 97, *Distichlis spicata* with a value of 79, and *Deschampsia caespitosa* with a value of 39. This was the first year after dike removal that the marsh composition that exists today became apparent.

1988 Vegetation Analysis

The assemblage identified for 1988 from 48 plots were very similar to those found by Frenkel and Morlan (1990) for the same year by a different analysis. The first assemblage was identified by *Carex lyngbyei* with an indicator value of 91. The four species *Agrostis stolonifera, Argentina egedii, Juncus balticus,* and *Hordeum brachyantherum* identified the second assemblage, each with values of 65 or greater. The third assemblage was identified by *Distichlis spicata* and *Salicornia virginica* with indicator values of 99 and 69, respectively.

1993 Vegetation Analysis

The assemblages for 1993 from 45 plots were similar to those found in 1984 and 1988. The first assemblage was identified by *Carex lyngbyei* with an indicator value of

93. The second assemblage was identified by *Argentina egedii* with an indicator of 65. *Salicornia virginica* and *Distichilis spicata* identified the third assemblage with values of 98 and 76, respectively.

<u>1999 Vegetation Analysis</u>

The 1999 assemblages derived from 46 plots were similar to those found in 1984 through 1993. The first assemblage was identified by *Carex lyngbyei* with an indicator value of 86. The second assemblage was identified by three species; *Symphytotrichum subspicatum, Argentina egedii,* and *Juncus balticus.* The indicator values were 67, 63, and 67, respectively. The third assemblage was identified by *Distichilis spicata* with a value of 94.

<u>2004 Vegetation Analysis</u>

These results are based on the fine resolution data coming from 232 plots. As found in the years from 1984 to 1999 *Carex lyngbyei* identified the first assemblage with an indicator value of 71. The second assemblage also resembled that of previous years with the indicators *Argentina egedii, Agrostis stolonifera,* and *Juncus balticus.* The indicator values were 67, 60, and 30, respectively. The third assemblage differed from the previous years by adding *Triglochin maritimum,* to *Distichlis spicata* and *Salicornia virginica.* The values for these were 20, 93, and 22, respectively.

<u>Plant Assemblage Kriging Analysis and Animation</u>

Appendix D, Part 1 contains the set of prediction maps resulting from the kriging of individual assemblages from each year. These images represent the assemblages' spatial distribution across the Mitchell Marsh. The species are denoted by a symbol, which is often the first two letters of the genus followed by the first two letters of the species. A full species list including the symbol can be referred to in Appendix A.

The kriging results from the standardized assemblages can be found in Appendix D, Part 2. These images represent the spatial distribution of the assemblage presently existing in the marsh. From the sequence of these images it is possible to see how the current groupings developed.

The animation of the standardized assemblages can be found in Appendix E. There are two animations, the only difference being the length. The first (MM78-04_1.wmv) is 26 seconds long with one year per second and 12 frames per second. The second (MM78-04_2.wmv) is 52 seconds long with one year every 2 seconds and 12 frames per second. These files can be played using Windows media player version 10.0.

Discussion

The vegetation analyses for the years 1978, 1979, 1980, 1984, and 1988 closely resemble those from Mitchell (1981) and Frenkel and Morlan (1990). For the purpose of this spatial study the number of assemblages was constrained to three for each year.

1978 Assemblages

The freshwater pasture assemblages that existed in the marsh at this point in time are quite different from those discussed later in the study, which developed after the dike was breached. In comparing and contrasting this study's results to those found by Mitchell in 1981 there were many similarities and a few dissimilarities. Mitchell identified three freshwater pasture assemblages in 1978; these included an *Argentina egedii* assemblage, a *Holcus lanatus* assemblage, and an *Agrostis stolonifera-Holcus lanatus* assemblage. In this study the results differed in that the previously mixed

Agrostis stolonifera-Holcus lanatus assemblage was identified as a *Holcus lanatus-Trifolium repens* assemblage and the original *Holcus lanatus* assemblage was dissolved and dispersed among the other three assemblages, which included an *Argentina egedii* assemblage, an *Agrostis stolonifera-Holcus lanatus,* and an *Alopecurus geniculatus* assemblages, which was not identified by Mitchell. The only species to persist after dike breaching were *Argentina egedii* and *Agrostis stolonifera.*

<u>1979 Assemblages</u>

At this point most of the freshwater pasture assemblages were dying off and not significantly contributing to subsequent assemblages as they developed. Although Mitchell did not report a vegetation analysis for the years of 1979 and 1980, her field observations and species composition and distribution were reported. From these data, the results from the present study's vegetation analysis can be assessed. Mitchell reports that of the species contributing to the assemblages found in 1978, only two persist after dike breaching, *Agrostis stolonifera* and *Argentina egedii.* However, with the reestablishment of saline tidal circulation, Mitchell found several developing assemblages identified by the colonizing species, *Juncus balticus, Hordeum brachyantherum,* and *Atriplex gmelinii.* These colonizing species were identified within this study's plant assemblages, which were indicated by *Agrostis stolonifera, Argentina egedii,* and *Salicornia virginica.* The *Agrostis stolonifera* assemblage included *Atriplex gmelinii* and *Juncus balticus;* whereas *Hordeum brachyantherum* was found in the *Salicornia virginica* assemblage. As a side note, *Carex lyngbyei,* which later became the most important species in the marsh, appeared for the first time in 1979.

1980 Assemblages

In 1980 much of the marsh was algal covered bare ground or decomposing vegetation litter and relatively few plots had 100% cover. However, Mitchell reported that *Argentina egedii* and *Agrostis stolonifera* were still prevalent and that the colonizing species *Juncus balticus, Atriplex gmelinii, Spergularia salina, Carex lyngbyei, Hordeum brachyantherum,* and *Salicornia virginica* were important. The present study's analysis resulted in similar results, identifying three assemblages denoted by the species *Argentina egedii, Agrostis stolonifera,* and *Salicornia virginica.* Included in the *Argentina egedii* assemblage was the colonizing species *Juncus balticus.* The colonizers *Atriplex gmelinii* and *Carex lyngbyei* were found in the *Agrostis stolonifera* assemblage. The *Salicornia virginica* assemblage also included the colonizers *Spergularia salina* and *Hordeum brachyantherum*.

1984 Assemblages

Many changes occurred between 1980 and 1984, the most significant being the establishment of the *Carex lyngbyei* assemblage. The first assemblage was identified by *Carex lyngbyei* and was nearly homogeneous. The second assemblage was identified by both *Argentina egedii* and *Agrostis stolonifera* with other species such as *Juncus balticus* and *Hordeum brachyantherum.* A much more heterogeneous assemblage identified by *Salicornia virginica, Distichlis spicata,* and *Deschampsia caespitosa* included remnant patches of *Spergularia salina* and colonizing patches of *Triglochin maritimum.* These general assemblages persist through 2004 with slight changes occurring from year to year as well as their spatial distribution.

1988, 1994, 1999, and 2004 Assemblages

From 1984 through 2004 the general composition of the assemblages stayed relatively constant. The first and most important through these years was always a homogeneous *Carex lyngbyei* assemblage. The second was a more heterogeneous assemblage, which always included *Argentina egedii*. Other species that frequently found membership with the *Argentina* assemblage included *Agrostis stolonifera* in 1988 and 2004, *Holcus lanatus* in 1988, *Juncus balticus* in 1988, 1999, and 2004, and *Symphytotrichum subspicatum* in 1999. The third assemblage was also somewhat heterogeneous and always included *Distichlis spicata*. *Salicornia virginica* and *Triglochin maritimum* often found membership in the *Distichlis* assemblage.

Kriging Analysis

The kriging analysis resulted in highly interpretable displays for each year of data. From these images the spatial distribution of each assemblage can be assessed for each year. Beyond simply showing the location of each assemblage, the images also show the areas where the assemblages begin to coalesce. In Figure 4, the assemblages for 1984 are shown, the areas of pure red indicating the *Carex lyngbyei* assemblage. Areas in green indicate the developing *Agrostis stolonifera* and *Argentina egedii* assemblage, whereas those areas in blue represent the developing *Salicornia virginica, Distichlis spicata,* and *Deschampsia caespitosa* assemblage. At the margins of each assemblage the blending of the two colors represent transitions.

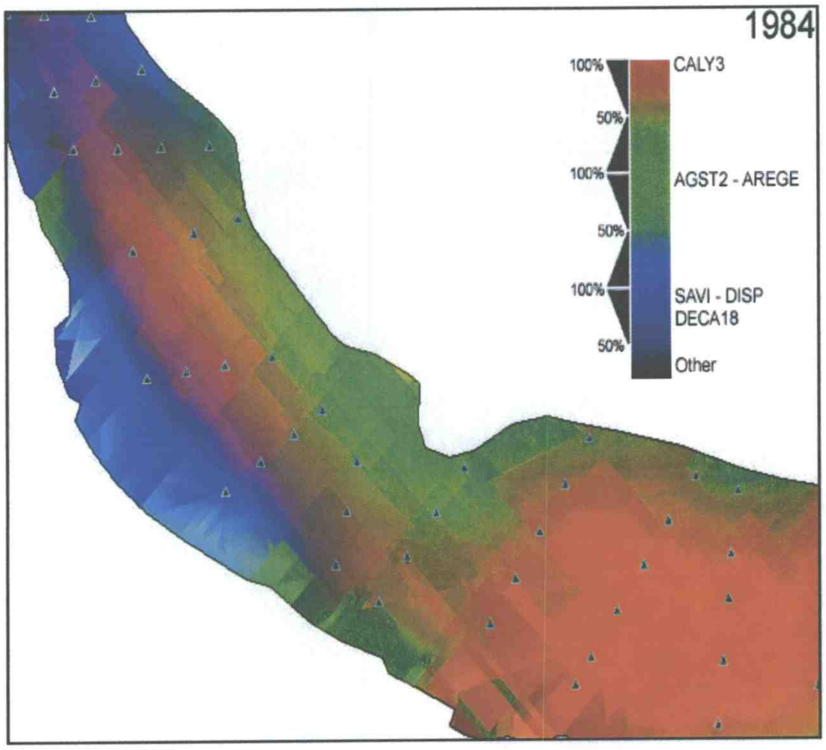

Figure 4. Kriging results for 1984 unique assemblages.

The entire set of kriging results can be found in Appendix D, Part 1. By studying these results it is evident how the plant assemblages have changed composition and distribution over the last 26 years. The *Argentina egedii* assemblage was the only one to persist beyond 1978, but in a different location. The areas previously inhabited by the *Holcus lanatus-Trifolium repens* assemblage later became dominated by *Agrostis stolonifera.* The *Salicornia virginica* assemblage of 1979 took over the low south-west shore where the *Alopecurus geniculatus* assemblage had been in 1978. The 1980 results show large areas of disaggregated assemblages, possibly "bare" ground. Other than the areas of black, the 1980 image resembles that of 1979 with identical assemblages and areas of disaggregation and only slight variations in their distribution.

From the 1984 image the beginning of aggregation can be seen. This includes the establishment of a large area of the *Carex lyngbyei* assemblage in the eastern portion of the marsh, and a well-established *Salicornia virginica-Distichlis spicata-Deschampsia caespitosa* assemblage along the west shore extending towards the north. Also evident in 1984 is the aggregation and spatial differentiation of the *Agrostis stolonifera* and *Argentina egedii* assemblages. Little to no change in the spatial extent of the *Salicornia virginica-Distichlis spicata* assemblage is evident in 1988. However, the *Carex lyngbyei* assemblage has expanded up into and displaced much of the higher elevation area where the *Argentina egedii* assemblage had been previously. In 1993, very little change can be interpreted. The zone of transition between all the assemblages shifted slightly, the core distribution remained constant with no dramatic changes. Slight changes occurred in the *Argentina egedii* and *Distichlis spicata* assemblages between 1993 and 1999. The former tail, towards the east, that occurred in the *Argentina egedii* assemblage is not apparent in the 1999 results. This may be the result of development and destruction of a beaver dam in the area. In the *Distichlis spicata* assemblage there is an area that does not belong to any of the assemblages. This patch may be attributed to an area dominated by *Salicornia virginica,* which did not appear to be an indicator for this year and was not included in the analysis.

Many changes in the assemblage distribution are evident when comparing the 1999 and 2004 results, the overriding factor being the change in scale between these years. The tail to the east of the *Argentina egedii* assemblage reappears and many small patches along the fringes of the marsh begin to show evidence of this assemblage. The *Argentina egedii* assemblage also displaces some of the *Distichlis spicata-Salicornia virginica-Triglochin maritimum* assemblage, which in place displaced much of the *Carex lyngbyei* assemblage in the western portion of the marsh.

In Part 2 of Appendix D are the results for the standardized assemblage kriging. From these images it is evident how the present assemblages came to have the distribution that is currently present in the marsh. The results for 1978 and 1979 show only one assemblage in the marsh, the *Agrostis stolonifera-Juncus balticus-Argentina egedii* assemblage. Very slight patches of the *Distichlis spicata-Salicornia virginica-Triglochin maritimum* assemblage are present in the 1979 image. In the 1980 results the distribution of the *Agrostis stolonifera-Juncus balticus-Argentina egedii* assemblage changes drastically and several areas are showing association of the *Distichlis spicata, Salicornia virginica,* and *Triglochin maritimum* assemblage. The spatial pattern shown for the period 1979-1980 show the disaggregation during these years related to a new set of environmental factors. The *Carex lyngbyei* assemblage is evident in the 1984 results. Also interpreted from these results is the displacement of much of the *Agrostis stolonifera-Juncus balticus-Argentina egedii* assemblage by the *Carex lyngbyei* assemblage, and the expansion of the *Distichlis spicata-Salicornia virginica-Triglochin maritimum* assemblage into areas of previously disaggregated assemblages. The standardized assemblage analysis results from 1988 through 2004 closely resemble the results from the unique assemblage analysis. The general assemblages are the same and the distributions follow the general trends found in the previously discussed results.

Many of the differences seen between the 1999 and 2004 data can be attributed to the scale change. As discussed in the methods section, the meter square plots used for the analysis of the data from 1978 through 1999 had a plot interval of 25-45 meters along ten transects. In 2004 the plot interval was 15 meters along 19 transects. In 1999 there were 46 plots used and in 2004 there were 232 plots in the analysis. Areas most affected by the change in scale are those where species integration was poorly defined in space and time near the dike and along the upland fringe at the bend in the marsh. The 1999 transects did not get as close to the dike as those in 2004. As a result the high marsh species on the dike, partially expressed by *Argentina egedii* presence, appear along the marsh shore in the western area and in the southeast corner. Another result of the fine-scale data can be seen in the center of the image where the *Argentina egedii-Agrostis stolonifera-Juncus balticus* assemblage has appeared to retreat towards higher elevation. However, the changes observed in the *Distichlis spicata-Salicornia virginica-Triglochin maritimum* assemblage are not the direct results of finer-scale data. Field observations of this assemblage found these species to have increasing frequency and cover.

Sources of Error

In a project such as this there can be many sources of error. The first source could be random errors, which include field observation and data recording errors. Over the years different observers have estimated, by eye, the species percent cover, and although training areas were used to "calibrate" the investigator to the conditions, errors are inevitable. In the field, the second error could be simple misrecording of data. This could include entering the data into the wrong cell in the data sheet or misreporting the value. Similar errors can occur when entering the data into the spreadsheets. Observing all outliers in the data and referring back to the original datasheets to be sure no values appeared to be erroneous helped to address these errors.

The second set of errors are systematic in nature, and include errors arising from the process of performing the vegetation analysis, kriging prediction error, image manipulation, or animation. Although these errors may not be erroneous, the effect on the study could be substantial.

In the vegetation analysis only three assemblages were identified when in fact there were could be several more. The various smaller assemblages were forced together in three broader assemblages. This clumping does not actually result in an error but rather misrepresents the assemblages in the marsh by generalizing the finer-scale variations present. The cluster dendrograms (Appendix C) display the smaller homogeneous assemblages and from them a general idea can be interpreted importance.

The interpolated surfaces resulting from the kriging analysis contain inherent errors. During the modeling phase of the study, attempts were made to minimize the prediction error. Error sources in the image manipulation phase of the project could only be attributed to user error. These errors would be evident from the misalignment of images, masks, and plots or the general appearance of the results would not be what was expected. Another error was introduced by the smoothing of the results for the animation. However, this error does not provide false results but, rather, simply smoothes the transition between assemblages.

Conclusion

The objectives of this study were (1), to continue the vegetation monitoring at the Mitchell Marsh; (2) visually represent the plant assemblages and their corresponding distribution; and (3) to animate these changes in assemblage structure and distribution that lead to the existing conditions in the marsh. All of these objectives have been successfully completed and the results have met the expectations of the project. The continued monitoring of the marsh has made it possible to conduct further analysis in the future using similar time intervals and will provide additional data regarding the status of salt marsh restoration in Oregon. Interpretation of the plant assemblages and their distributions can be made more readily from the results of the kriging and the animation provides an interpretable display of the marsh over time. In addition, the animation makes it possible to identify possible trajectories in the distribution of plant assemblages.

There are many possible studies that could address a large number of questions still unanswered regarding the Mitchell Marsh. It is known that many environmental factors influence plant distribution in salt marshes and this study could not address all of these due to various constraints. Elevation and the related inundation frequency and duration, and salinity are two of the additional factors that could be included in a future analysis. Also, not addressed by this study were the roles played by the many marsh creeks present in the marsh and their relatively important role in the distribution of plant assemblages.

The results from this study may be added to the wealth of data on salt marsh ecosystems and will provide a building block for creating and interpreting visual representations of landscapes, ecosystems, and communities. In combination with the many other studies conducted in the estuaries of Oregon and the world, this study may help in the management and protection of this highly productive ecosystem.

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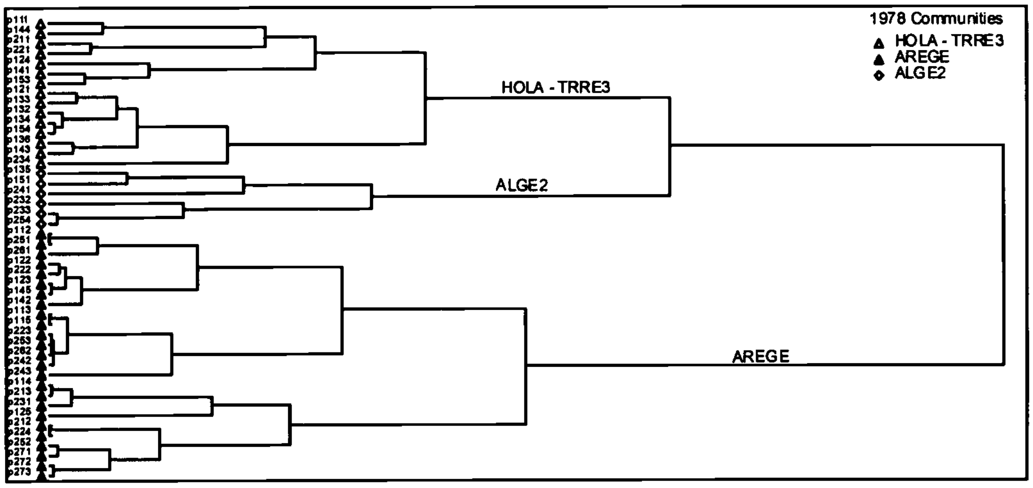
Appendix A
Species list

New Symbol	Genus species (Kartesz nomenclature)	Genus species (Hitchcock nomenclature)	Old Symbol
AGST2	*Agrostis stolonifera*	*Agrostis alba var. stolonifera*	*AGAL*
AGCA5	*Agrostis capillaris*	*Agrostis tenuis*	*AGTE*
ALGE2	*Alopecurus geniculatus*	*Alopecurus geniculatus*	*ALGE*
AREGE	*Argentina egedii ssp. egedii*	*Potentilla pacifica*	*POPA*
ATGM	*Atriplex gmelini*	*Atriplex patula var. obtusa and hastata*	*ATPA*
BRHOH	*Bromus hordeaceus ssp. hordeaceus*	*Bromus mollis*	*BRMO*
CALY3	*Carex lyngbyei*	*Carex lyngbyei*	*CALY*
COCO7	*Cotula coronopifolia*	*Cotula coronopifolia*	*COCO*
DECA18	*Deschampsia caespitosa*	*Deschampsia caespitosa var. longiflora*	*DECE*
DISP	*Distichlis spicata*	*Distichlis spicata*	*DISP*
ELPA3	*Eleocharis palustris*	*Eleocharis palustris*	*ELPA1*
EPCIW	*Epilobium ciliatum ssp. watsonii*	*Epilobium watsonii var. watsonii*	*EPWA*
FERUR2	*Festuca rubra ssp. rubra*	*Festuca rubra ssp. rubra*	*FERU*
GRSTS2	*Grindelia stricta var. stricta*	*Grindelia integrifolia*	*GRIN*
HOLA	*Holcus lanatus*	*Holcus lanatus*	*HOLA*
HOBR2	*Hordeum brachyantherum*	*Hordeum brachyantherum*	*HOBR*
JUBA	*Juncus balticus*	*Juncus balticus*	*JUBA*
LOPE	*Lolium perenne*	*Lolium perenne*	*LOPE*
LOPEM2	*Lolium perenne ssp. multiflorum*	*Lolium multiflorum*	*LOMU*
LOPR7	*Lolium pratense*	*Festuca pratensis*	*FEPR*
LOCO6	*Lotus corniculatus*	*Lotus corniculatus*	*LOCO*
PLLA	*Plantago lanceolata*	*Plantago lanceolata*	*PLLA*
POAN	*Poa annua*	*Poa annua*	*POAN*
POTR2	*Poa trivialis*	*Poa trivialis*	*POTR*
PUTEA	*Puccinellia tenella ssp. alaskana*	*Puccinellia pumila*	*PUPU*
RARE3	*Ranunculus repens*	*Ranunculus repens var. repens*	*RARE*
RUAC3	*Rumex acetosella*	*Rumex acetosella*	*RUAC*
RUAQF	*Rumex aquaticus var. fenestratus*	*Rumex occidentalis*	*RUOC*
RUCO2	*Rumex conglomeratus*	*Rumex conglomeratus*	*RUCO*
RUOB	*Rumex obtusifolius*	*Rumex obtusifolius*	*RUOB*
Rumex	*Rumex spp.*	*Rumex spp.*	*RUMEX*
SAVI	*Salicornia virginica*	*Salicornia virginica*	*SAVI*
SCMA8	*Schoenoplectus maritimus*	*Scirpus maritimus var. paludosis*	*SCMA*
SEJA	*Senecio jacobaea*	*Senecio jacobaea*	*SEJA*
SPSA5	*Spergularia salina*	*Spergularia marina*	*SPMA*
SYSUS	*Symphytotrichum subspicatum var. subspicatum*	*Aster subspicatus*	*ASSU*
TRRE3	*Trifolium repens*	*Trifolium repens*	*TRRE*
TRMA4	*Triglochin maritimum*	*Triglochin maritimum*	*TRMA*
Vicia	*Vicia spp.*	*Vicia spp.*	*VICI*
VUBR	*Vulpia bromoides*	*Festuca bromoides*	*FEBR*

Appendix B

Assemblage indicator values and Monte Carlo p-values from PCCORD

Appendix C
Cluster Dendrograms from PCCORD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ALGE2
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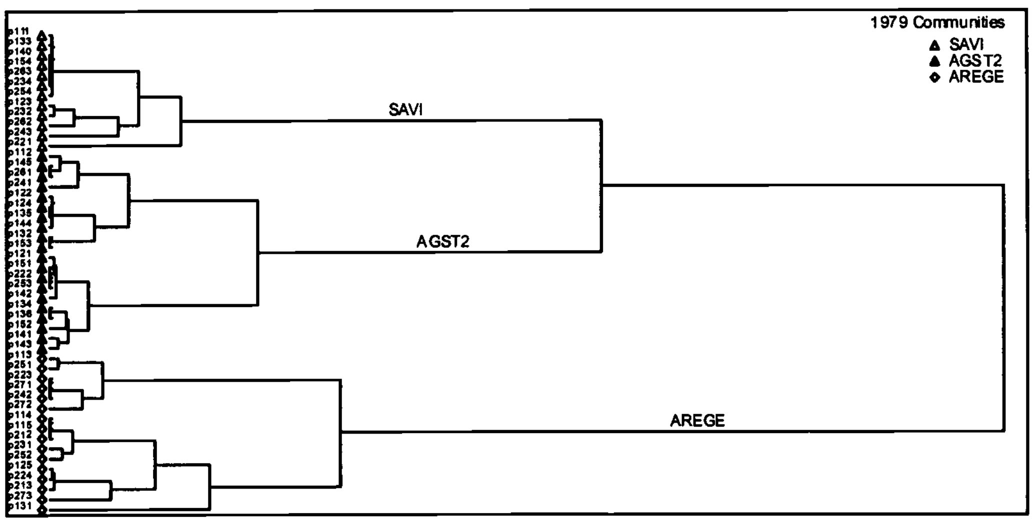
ALGE2
AREGE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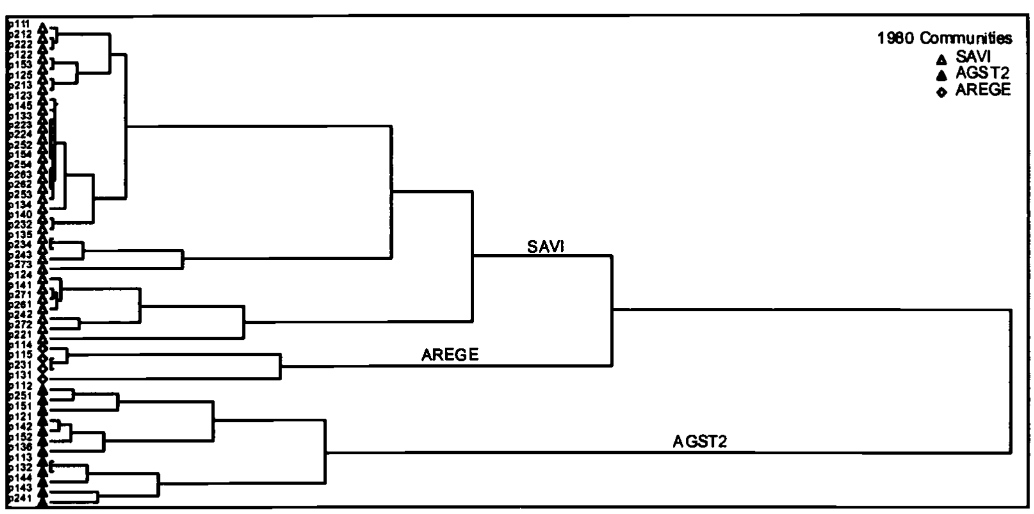
SAVI
AGST2
AREGE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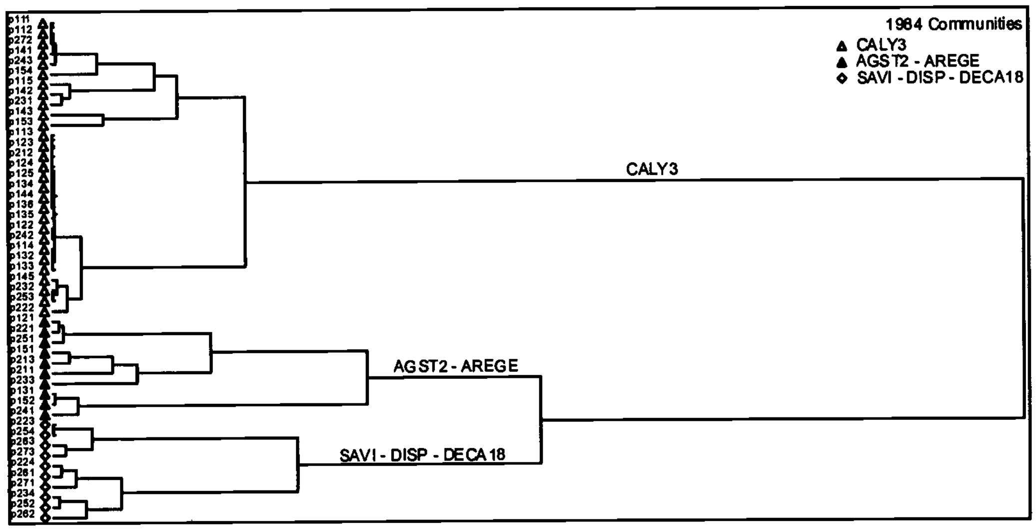
AGST2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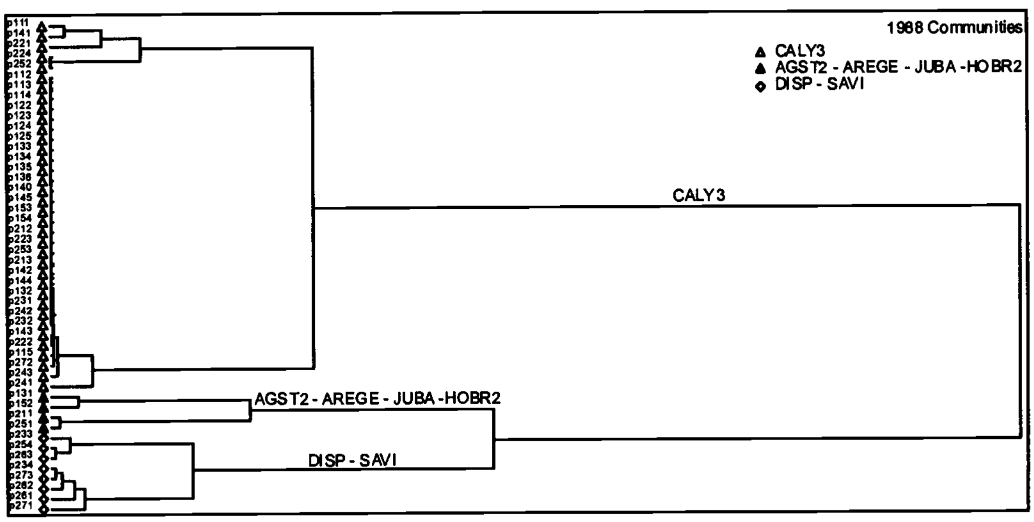
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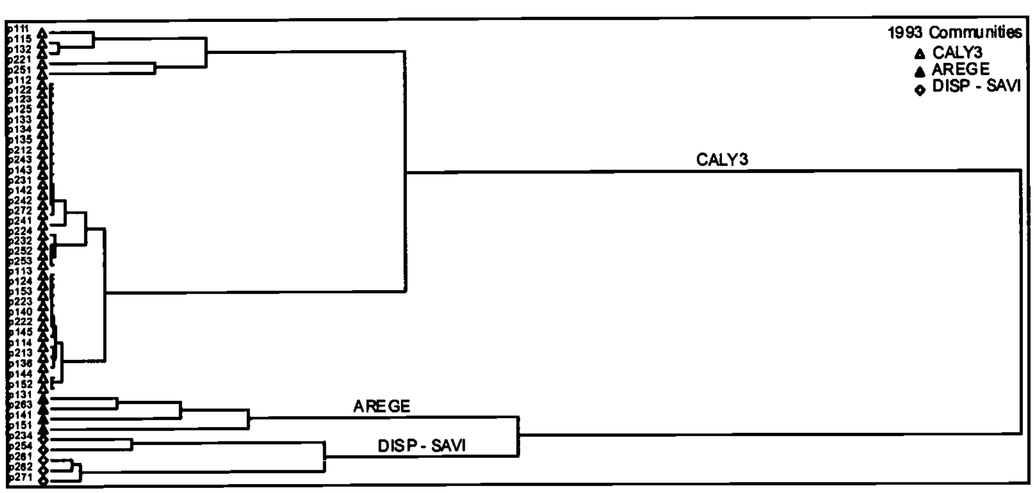
DISP - SAVI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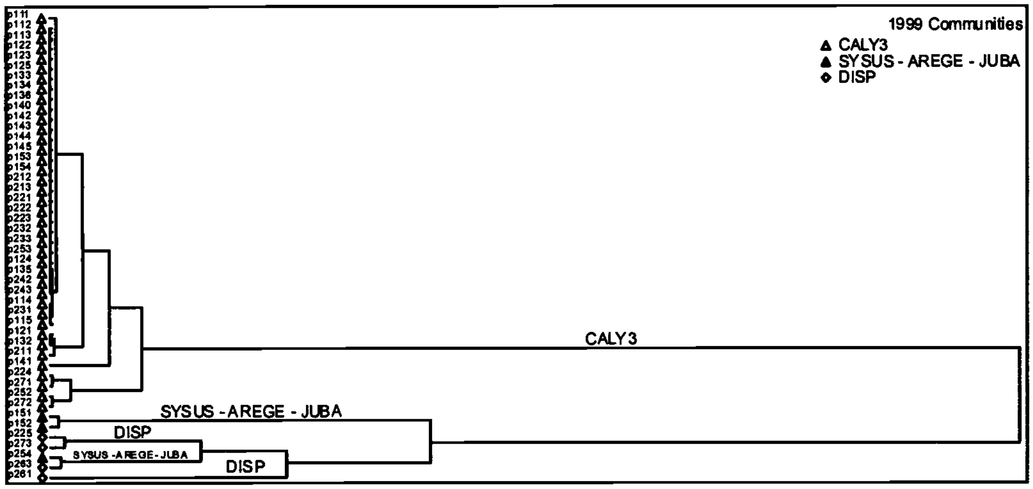
AREGE
DISP - SAVI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p144
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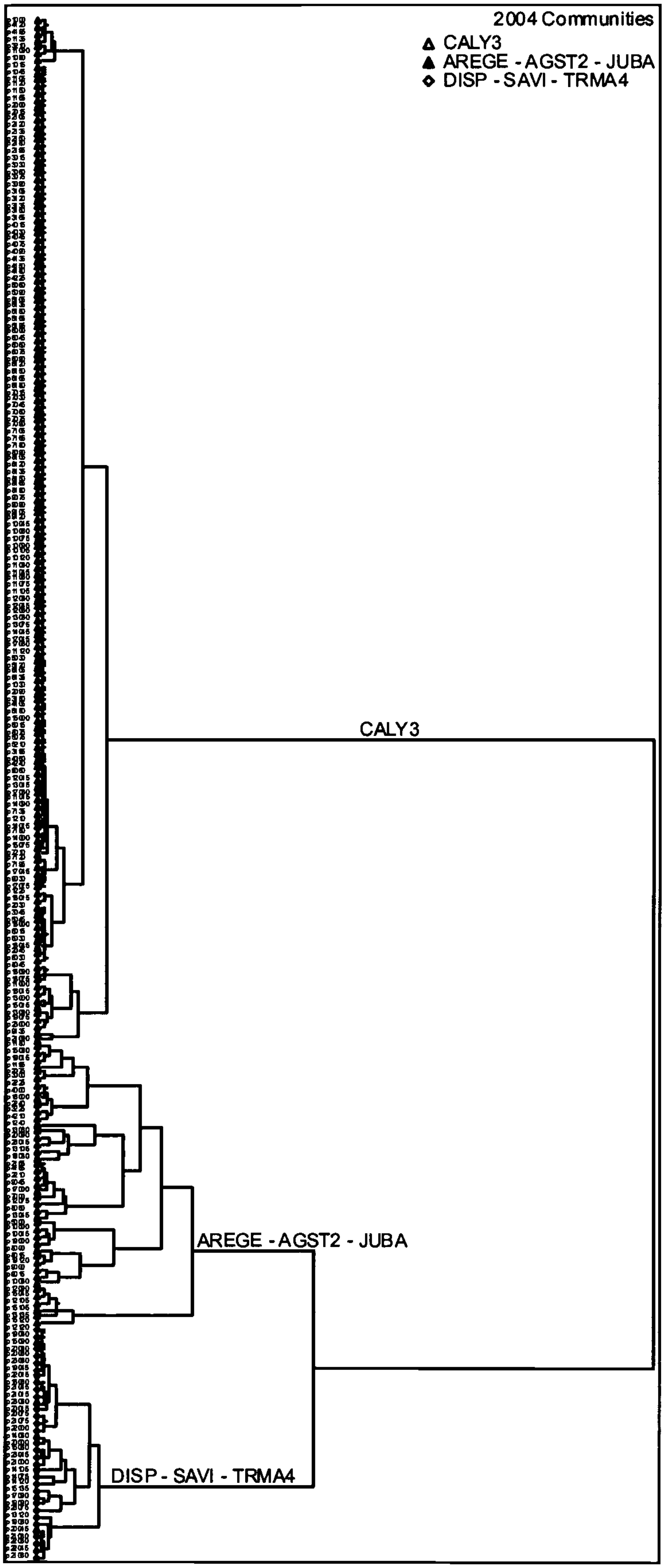
SYSUS - AREGE - JUBA
DISP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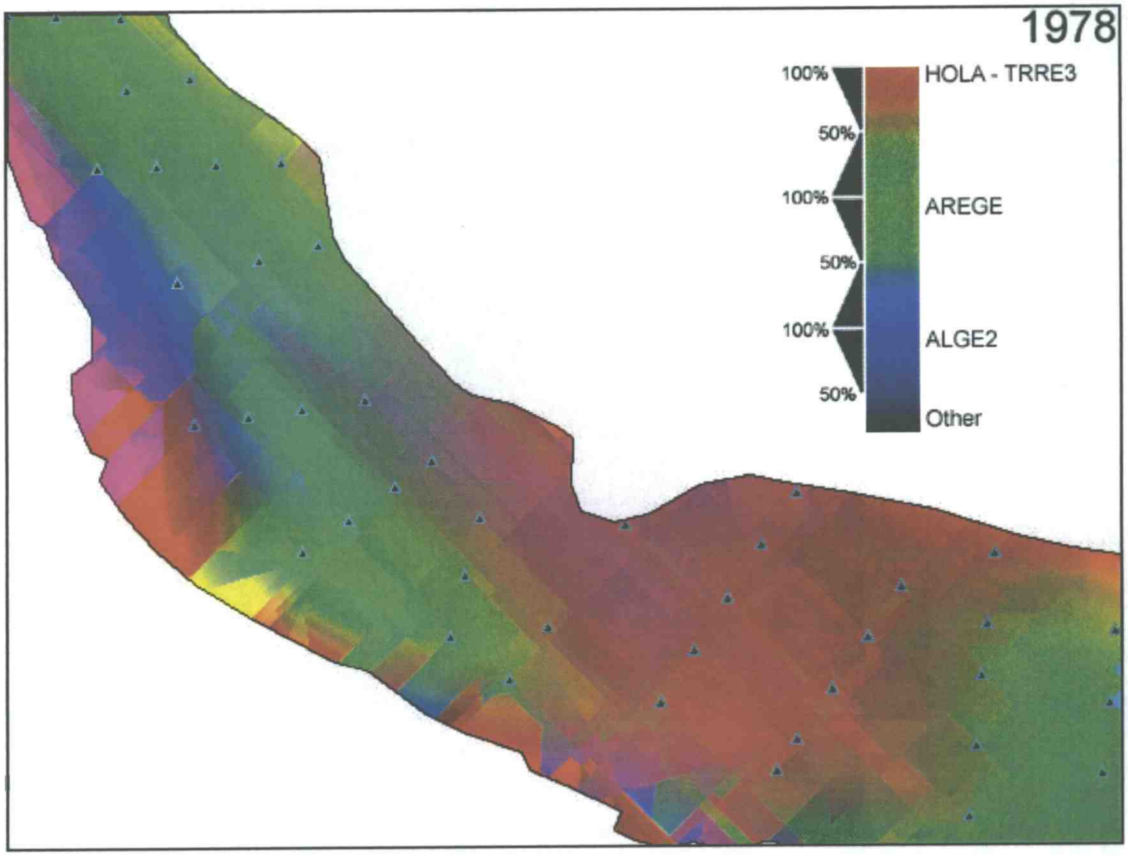
Appendix D

Part 1. Unique Plant Assemblage Kriging Results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Other


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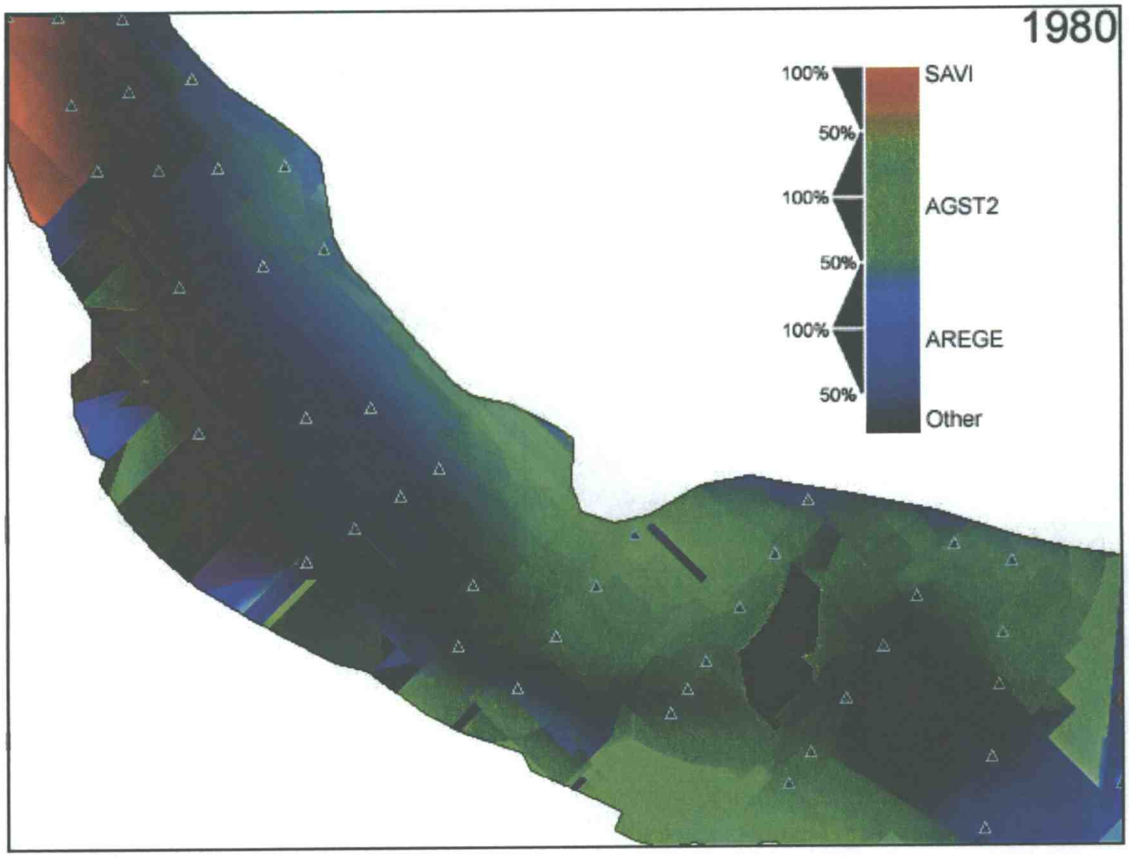
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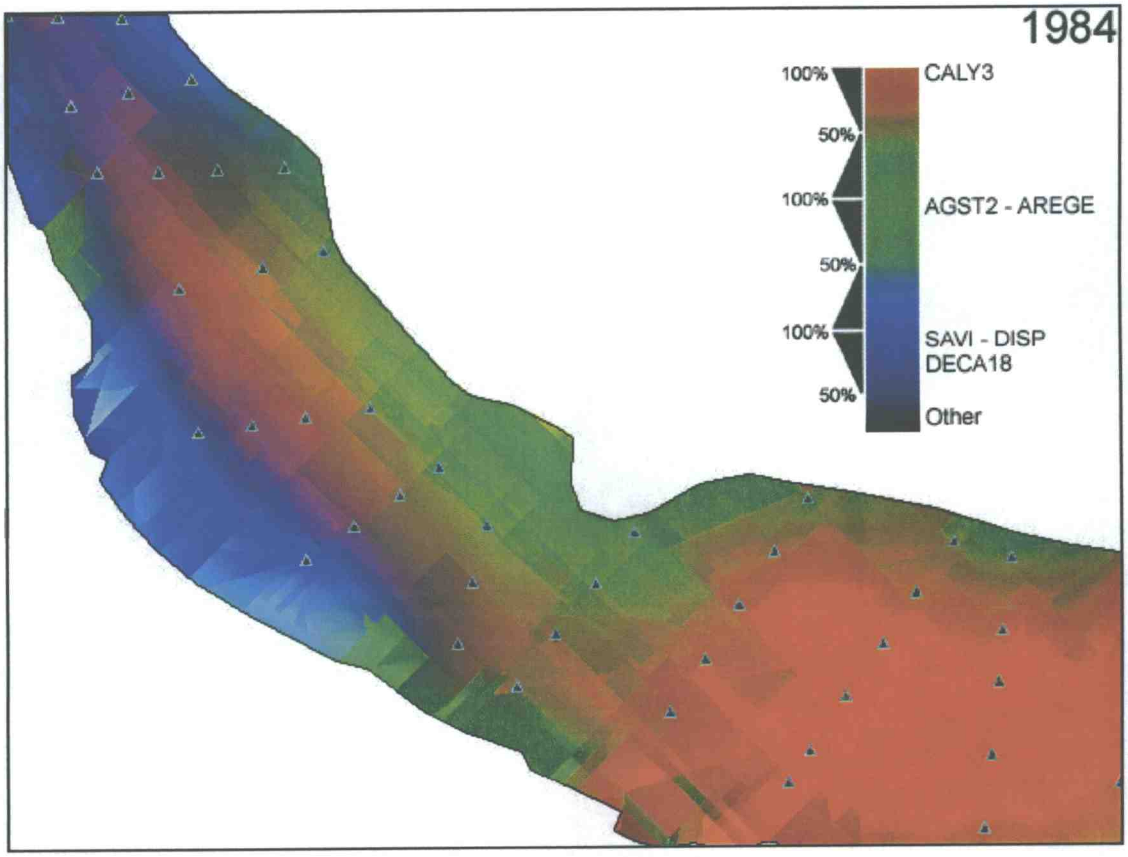
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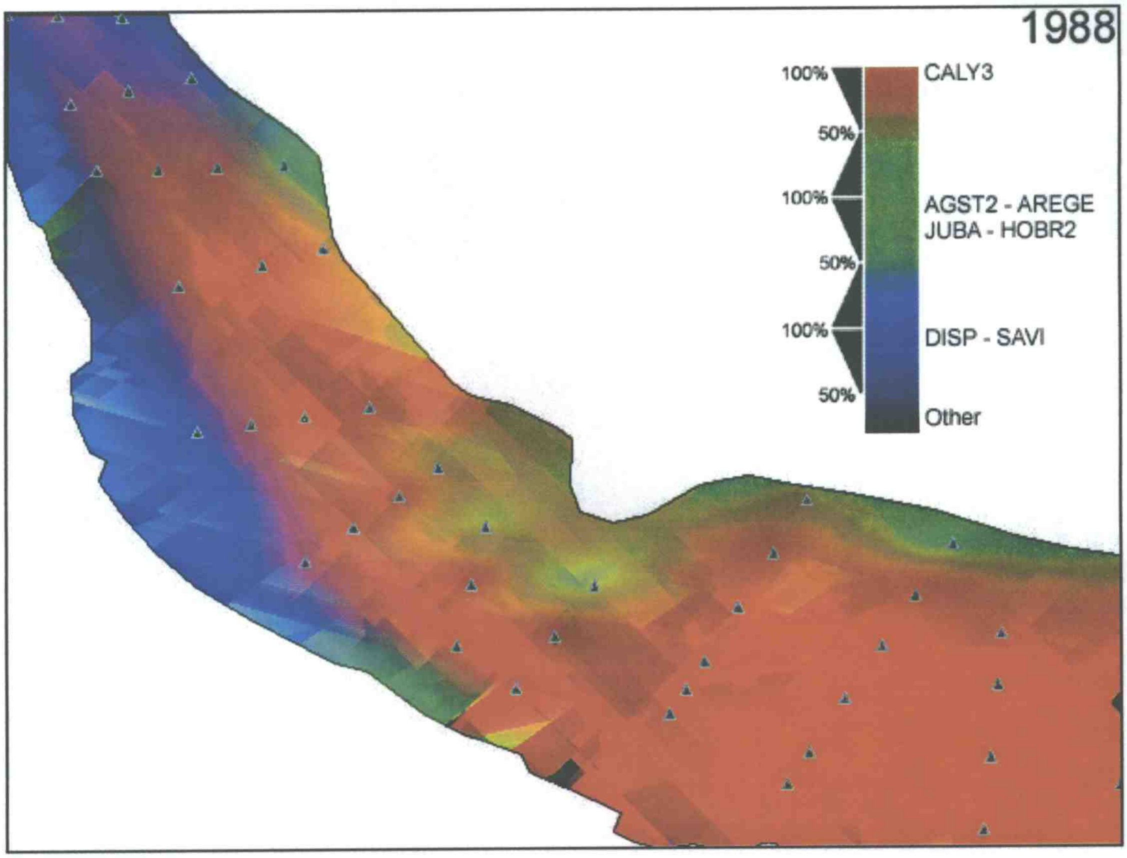
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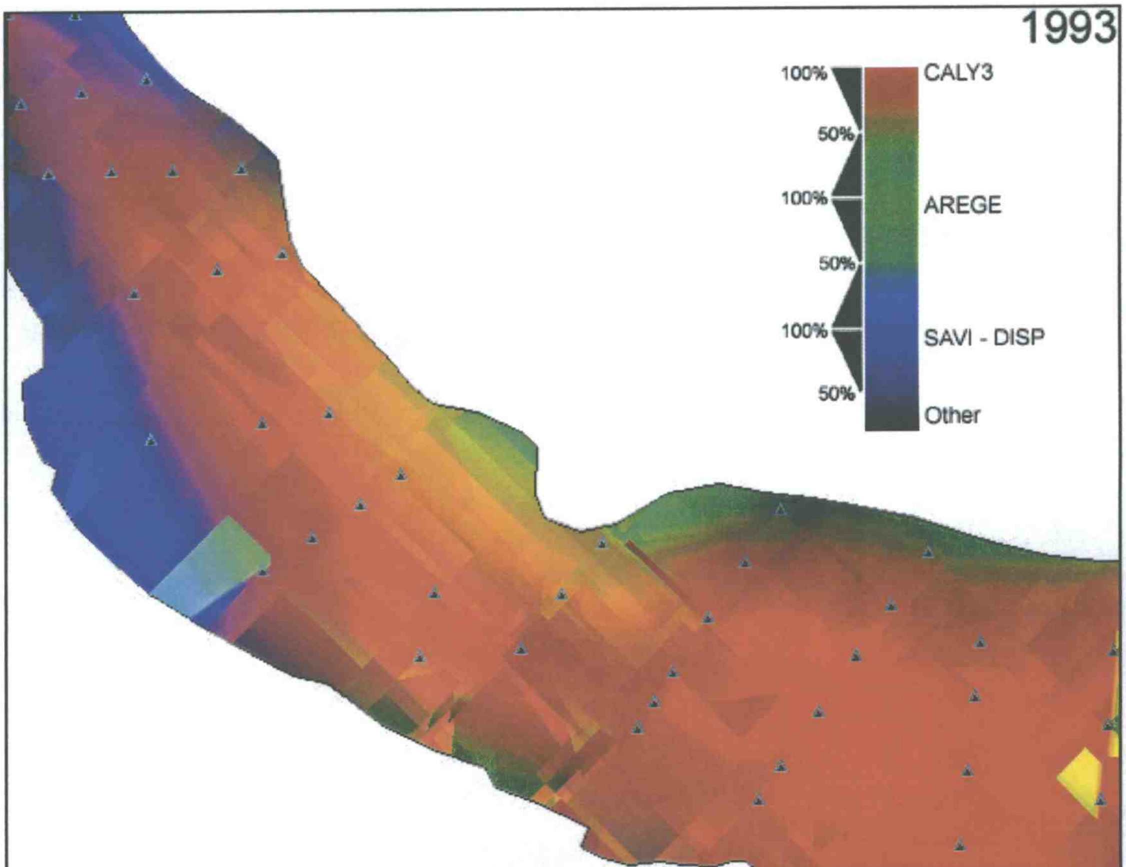
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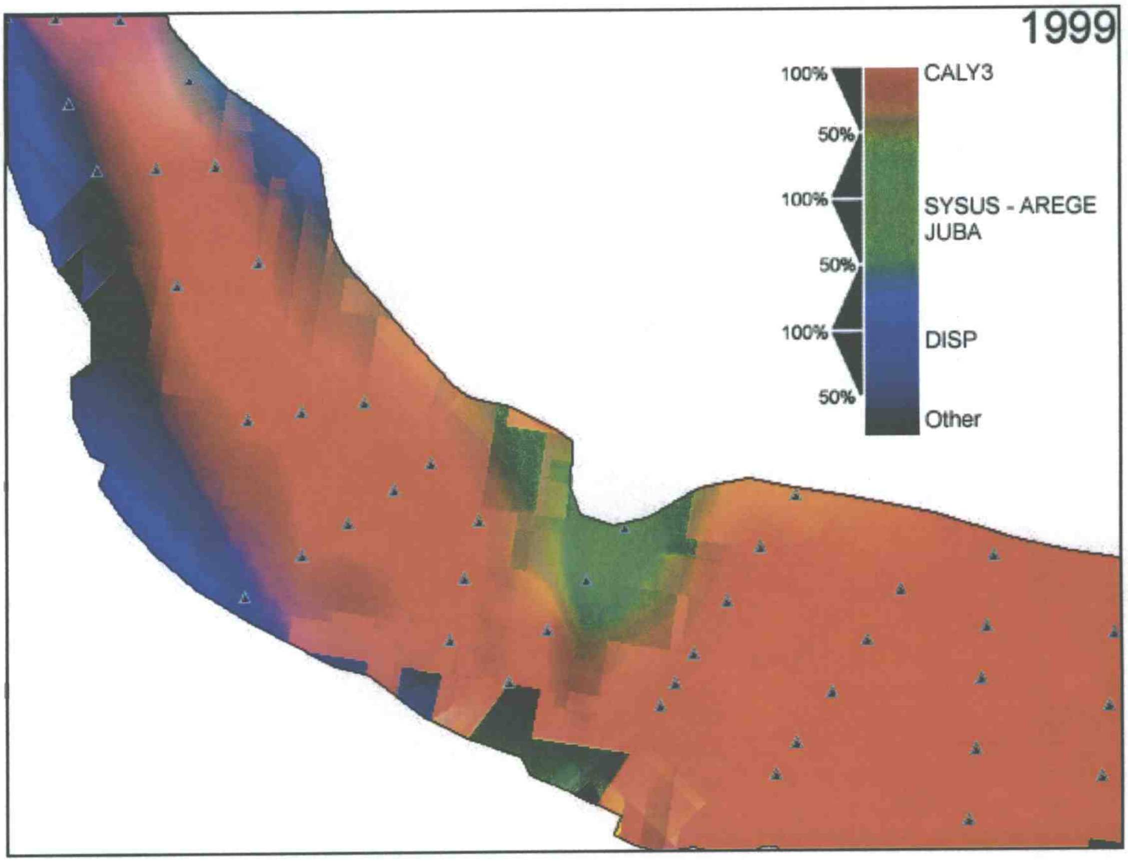
AREGE
SAVI - DISP
Other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50%
100%
50%
100%
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CALY3
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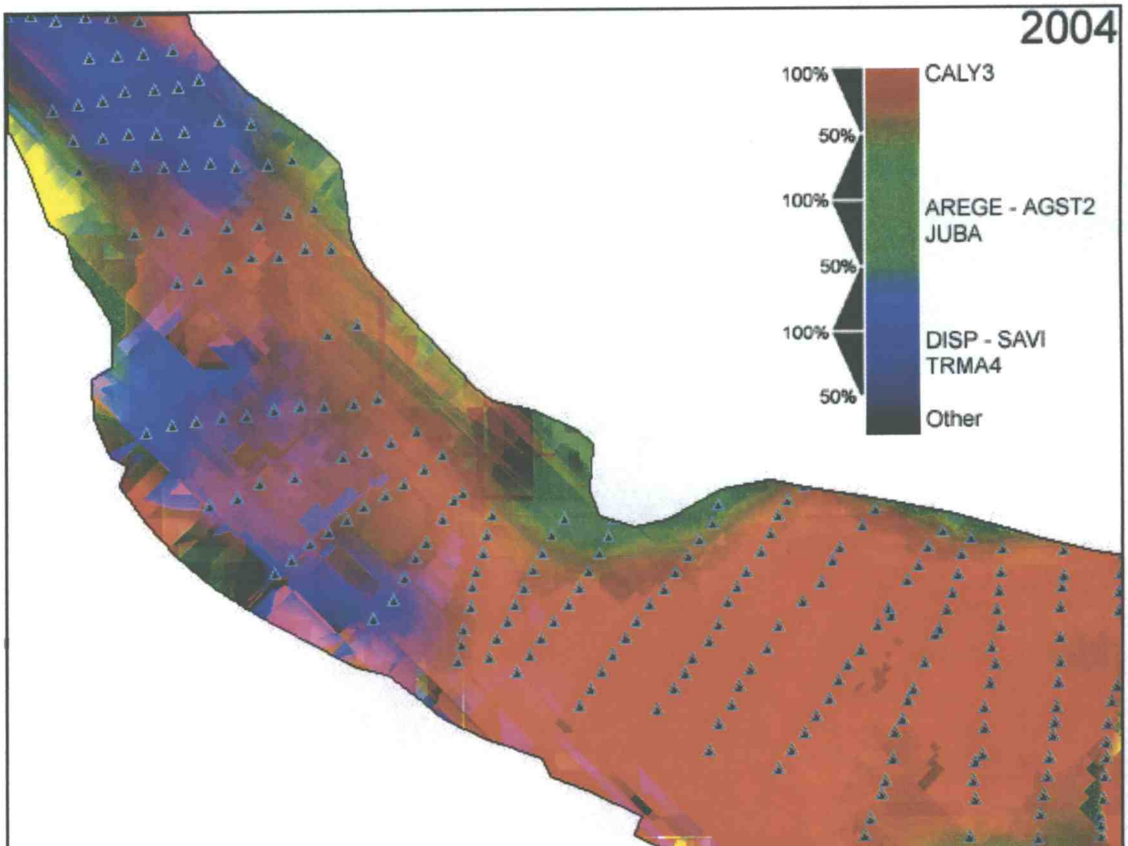
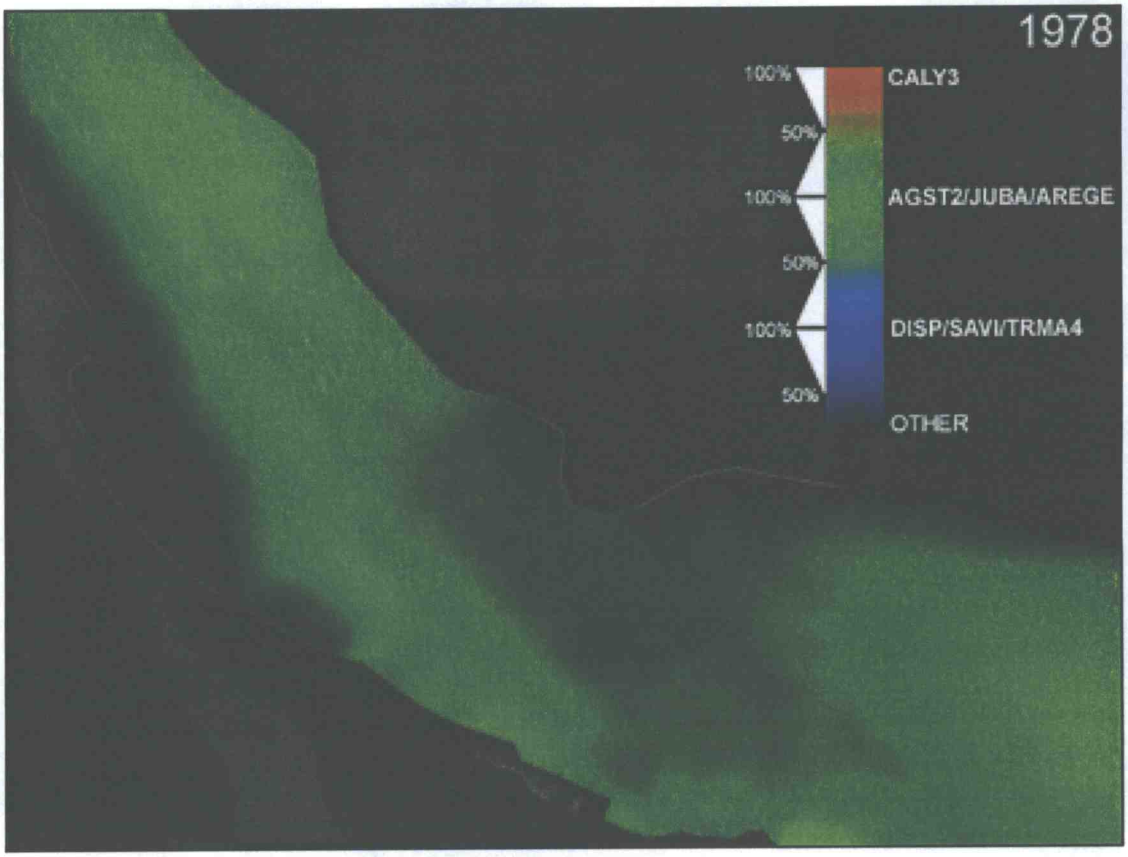
JUBA
DISP
Other


2004
100%
50%
100%
50%
100%
50%
CALY3
AREGE - AGST2
JUBA
DISP - SAVI
TRMA4
Other

Appendix D

Part 2. Standardized Plant Assemblage Kriging Results


1978
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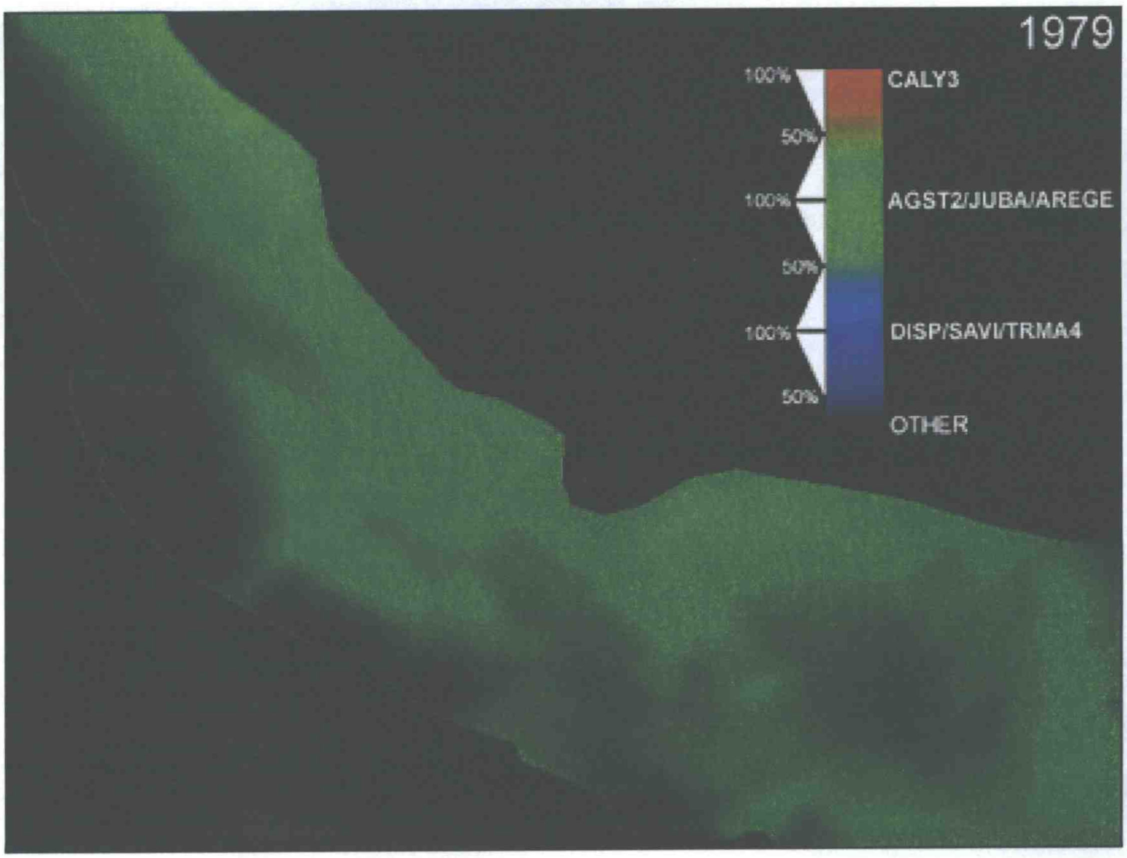
50%
100%
50%
100%
50%
CALY3
AGST2/JUBA/AREGE
DISP/SAVI/TRMA4
OTHER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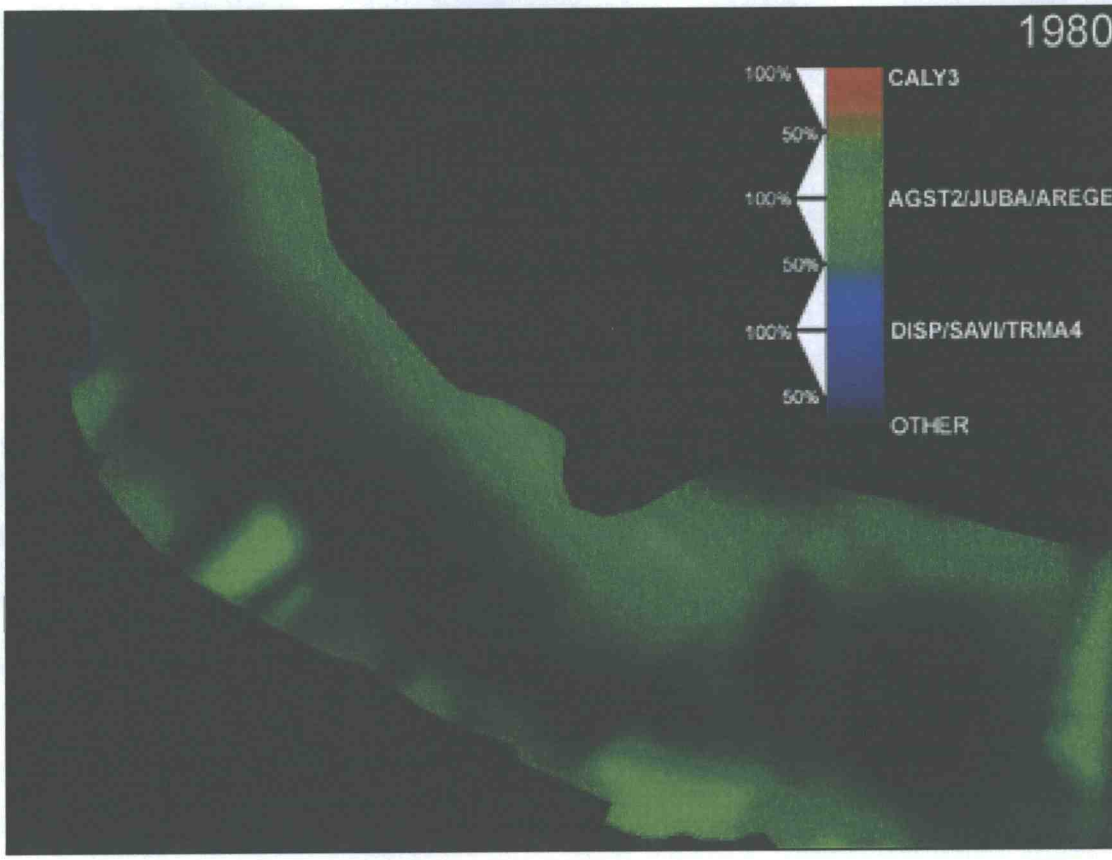
100%
50%
100%
50%
CALY3
AGST2/JUBA/AREGE
DISP/SAVI/TRMA4
OTHER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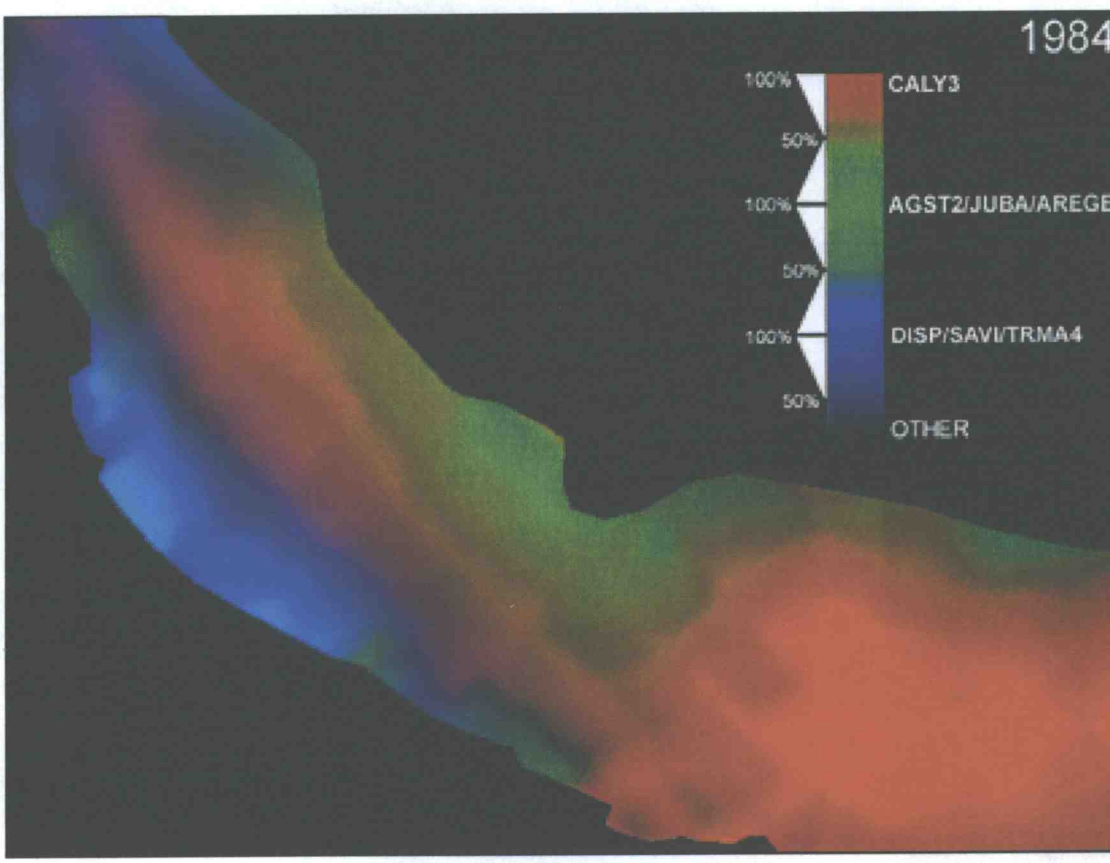
CALY3
AGST2/JUBA/AREGE
DISP/SAVI/TRMA4
OTHER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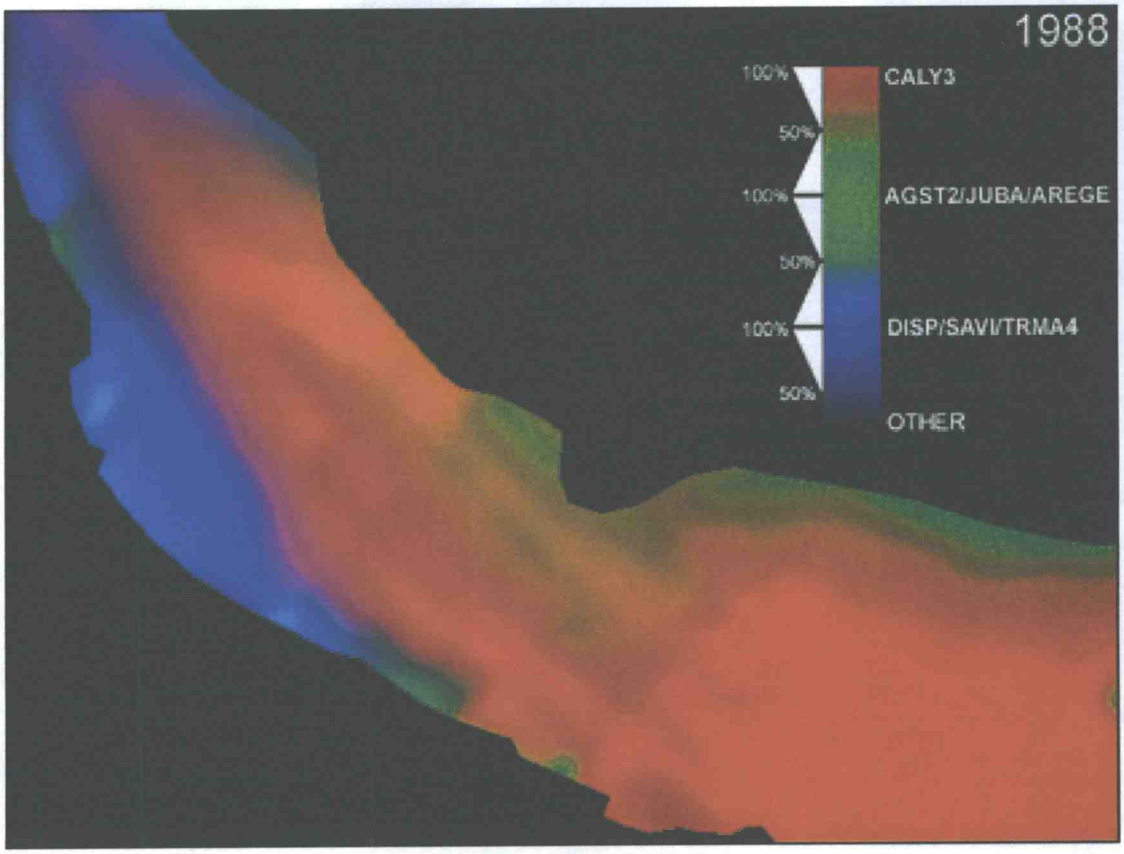
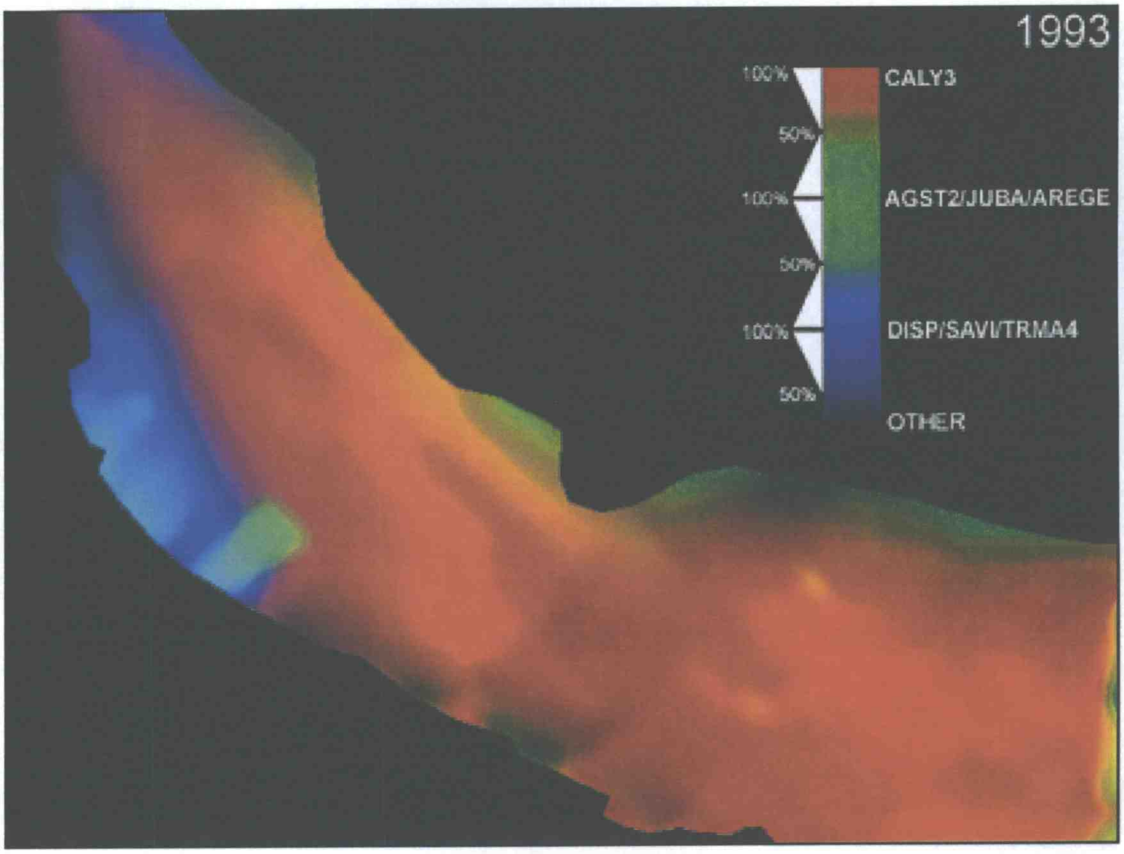
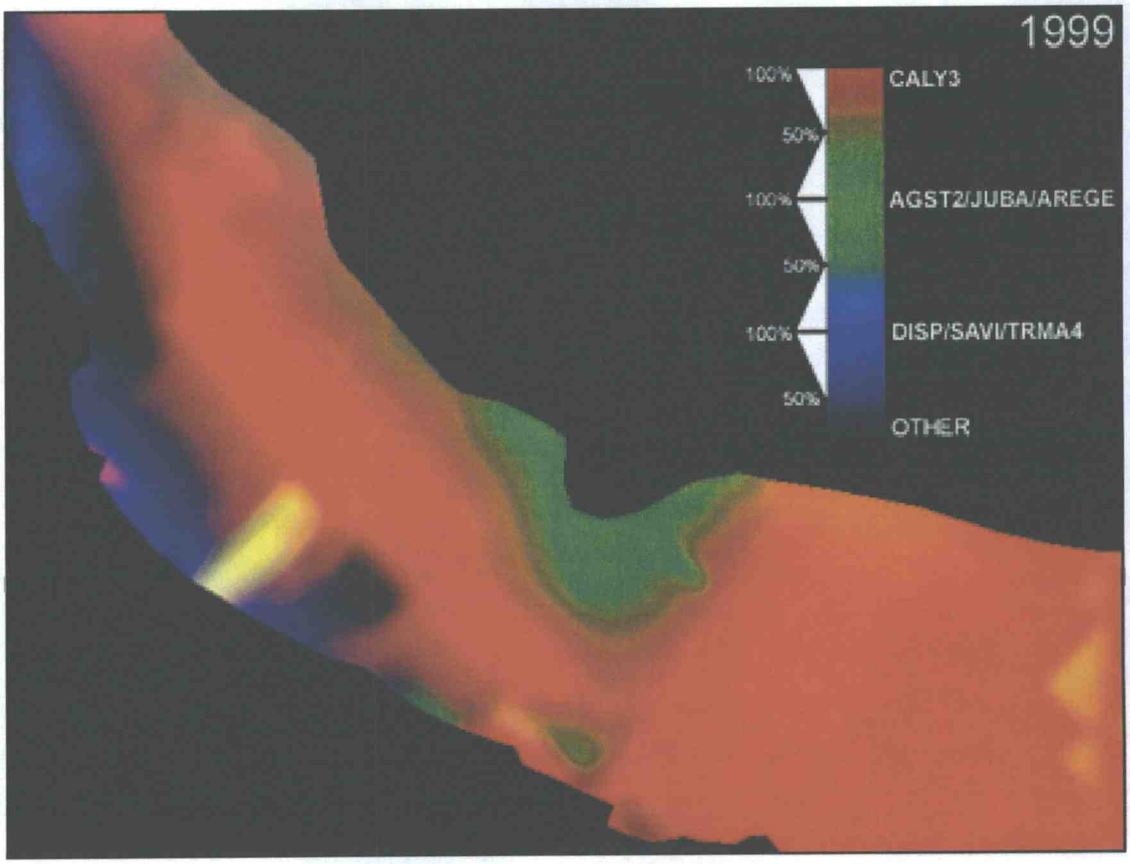
50%
100%
50%
100%
50%
CALY3
AGST2/JUBA/AREGE
DISP/SAVI/TRMA4
OTHER


1988
100%
CALY3
50%
100%
AGST2/JUBA/AREGE
50%
100%
DISP/SAVI/TRMA4
50%
OTHER


1993
100%
CALY3
50%
100%
AGST2/JUBA/AREGE
50%
100%
DISP/SAVI/TRMA4
50%
OTHER


1999
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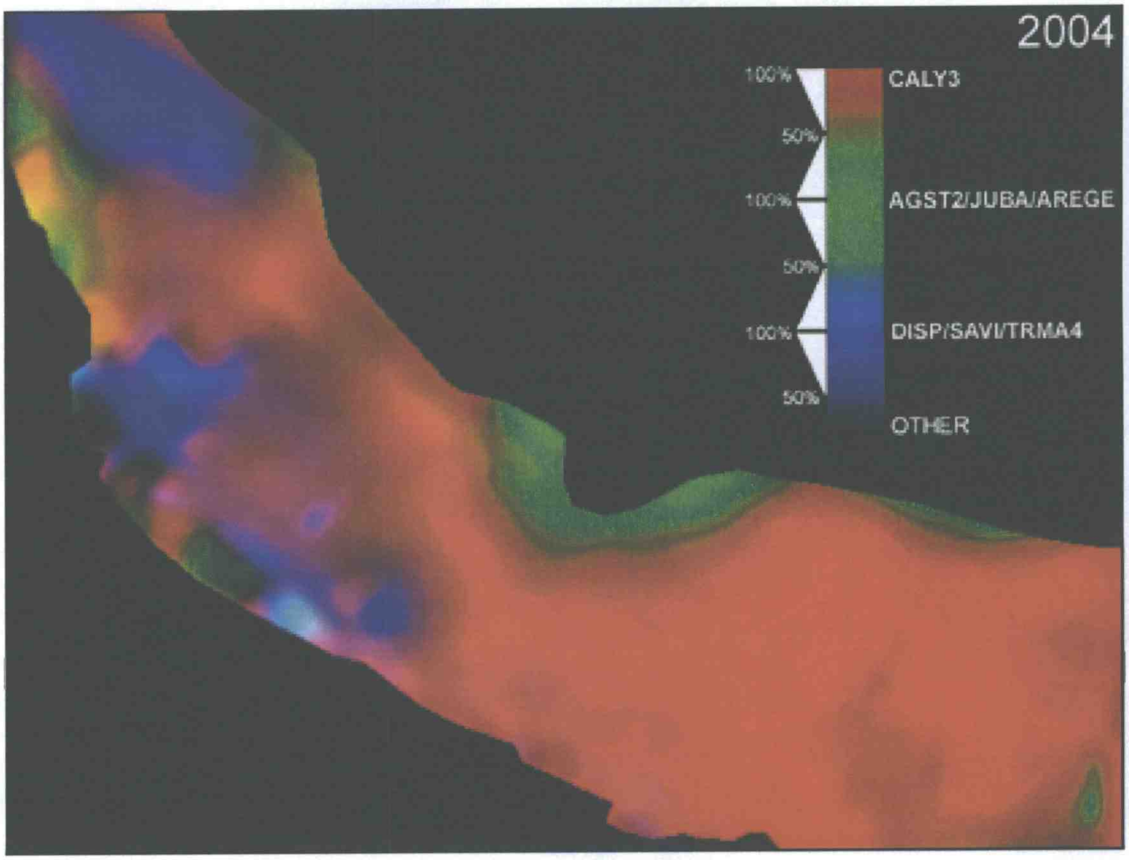
100%
50%
100%
50%
CALY3
AGST2/JUBA/AREGE
DISP/SAVI/TRMA4
OTHER


2004
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50%
100%
50%
100%
50%
CALY3
AGST2/JUBA/AREGE
DISP/SAVI/TRMA4
OTHER

Appendix E
CD on the back cover
Animations

Appendix F
CD on the back cover
Raw Data