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Status and Trends of Phragmites australis invasion within constructed wetlands in Virginia

Kirk J. Havens
Virginia Institute of Marine Science

Harry Berquist
Virginia Institute of Marine Science

Walter I. Priest III
Virginia Institute of Marine Science

James E. Perry
Virginia Institute of Marine Science

John Anderson

See next page for additional authors

Authors
Kirk J. Havens, Harry Berquist, Walter I. Priest III, James E. Perry, John Anderson, and Libby Norris

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Virginia Institute of Marine Science
College of William & Mary
P.O. Box 1346
Gloucester Point, Virginia 23062

Part I. Field GPS Mapping of P. *australis* Populations.
Kirk J. Havens, Harry Berquist, and Walter I. Priest, III

Part II. Evaluating the Use of Multispectral Imagery for Identifying and Quantifying P. *australis* Populations in Created Wetlands.
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Part III. A Summary of Methods for Controlling *Phragmites australis*.
Libby Norris, James E. Perry, and Kirk J. Havens

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Part I. Field GPS mapping of *P. australis* populations.

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Introduction

Phragmites australis is a cosmopolitan plant found throughout the world. *P. australis* is an aggressive colonizer of disturbed sites and is rapidly gaining ground in North America displacing more desirable species such as *Spartina cynosuriodes*, *Zizania aquatica* and *Spartina patens*. *P. australis* is considered native to North America and was probably a minor component of the wetland plant community in the past. *P. australis* has been found in archeological sites in the west and peat cores in the east. Stems of *P. australis*, used as cigarettes, were found in Arizona at the Red Bow Cliff Dwellings dating to 1325-1400 A.D. (Adams 1990). *P. australis* was used in the construction of mats in Anasazi communities in Colorado dating to 880-900 A.D. (Breternitz et al. 1986). Niering et al. (1977) found Phragmites rhizomes in soil profiles from a marsh in Connecticut that were estimated from submergence rates to be from 500-1000 years old. Paleoecology studies by Orson (1999) in New England have dated *P. australis* rhizomes to 3000 years old. *P. australis* was first recorded in New England in colonial times and became a concern with resource managers in Virginia about 40-50 years ago (Silberhorn 1991). However, more recent evidence suggests that aggressive, nonnative genotypes now occur in the United States (Saltonstall, 2002).

P. australis can survive in most wet habitats. Its rapid vegetative propagation and its ability to suppress other graminoids by shading and litter mat formation (Haslam 1973, Windham and Lathrop 1999) gives *P. australis* a distinct advantage over other species. A single plant of *Phragmites* can spread over 1/8 acre in 2 years (Fanshawe 1972). Once established it is extremely difficult to eradicate. Numerous methods for eradication or control have been researched such as herbicides, flooding, burning, biological control, and discing with mixed results (Marks et al. 1994).

P. australis is an aggressive colonizer of disturbed sites and tends to form monodominant communities, and it has become a serious concern in the construction of compensatory wetland mitigation sites. Some studies suggest that *P. australis* lacks the functional equivalency of other marsh species (Chambers et al. 1999). Resource managers attempting to offset the loss of wetland functions from destruction of natural wetlands often require the construction of new wetlands. *P. australis* colonization of these constructed sites may result in a net loss of function and a step back from the national policy of "no net loss" of wetlands.

In an earlier study it was demonstrated that 73 percent of the largest constructed wetlands sites in Virginia had been colonized by *P. australis* (Havens et. al 1997). In addition, it was shown that the rate of *P. australis* expansion within these sites suggested the areas would be dominated by *P. australis* in about 40 years. While this information is dramatic, it was also noted during the earlier study that certain construction activities such as; subtidal perimeter ditches, planting desirable herbaceous species at high stem densities, and, in polyhaline systems, concentrating restoration efforts to areas at or below mean high water, may inhibit the colonization of wetlands by *P. australis.*

The objective of this investigation was to provide additional information to resource managers regarding the colonization and expansion rate of *P. australis* in wetland mitigation sites by revisiting the sites from the earlier study.

Methods

The fifteen wetland creation sites from the previous study were revisited and ground surveyed (Havens et al. 1997). Low altitude vertical imagery was photographed with a Computerized Airborne Multicamera Imaging System (CAMIS). Each site was visited and the vegetated community types identified and mapped. After each visit, equipment was washed to prevent accidental introduction of an invasive plant species into the next wetlands site. All *P. australis* communities were kinematically surveyed using satellite-based Trimble receivers. Differential GPS survey methods will be used to obtain accurate positioning to within 2 cm. Dominant community types (more than 50% one species) were delineated by walking the perimeter of specific vegetated communities. Each digital image was rectified using GPS ground control points and then overlain with the ARC/INFO polygon vector coverage created from the 1994 and 2000 GPS survey data. Areas for each vegetated community type were calculated using ARC/INFO software.

Results

Colonization of the sites by *Phragmites australis* increased from 73% in 1994 to 80% in 2000. Total area of *P. australis* within the sites increased from 34,708 m^2 (8.6 acres) in 1994 to 49,647 m^2 (12.3) acres in 2000 (Table 1). However, in four sites the area of *P. australis* decreased an average of 28% and was replaced with scrub/shrub vegetation (Figures 1-4)(Pearson Correlation, 0.986, $p = 0.014$). Similar to the earlier study, tidal sites that are surrounded by subtidal perimeter ditches have significantly less *P. australis* (Mann-Whitney, $p < 0.019$) than those sites without perimeter ditches (Table 2). The regression equation percent area *P. australis* = -5.33 + 2.02 (age in years) [R^2 (adj) = 67.9%, df = 12, $p < 0.001$], indicates that 67.9% of the average percent area of *P. australis* can be explained by the linear relationship to the age of the wetland (Figure 5) and suggests that if conditions remain favorable for *P. australis* colonization, then the sites could become dominated by *P. australis* in approximately 50 years. This is a shift of about 10 years later from the previous study analysis.

Discussion

Due to the disturbance resulting from the excavation and construction of a wetlands site, constructed wetlands are inherently more susceptible to invasion by unwanted opportunistic plant species than natural communities (Daiber 1986). Construction activity that leaves open, oxidized soils, restricts or disrupts hydroperiod, or establishes well-drained berms low in sulfides can leave a wetland site vulnerable for invasion by *P. australis* (Pyke and Havens 1999, Bart and Hartman 2000).

Phragmites australis has colonized 12 of the 15 reviewed constructed sites, up one from the previous study. However, the new colonization is limited to approximately 9 square meters. In some sites *P. australis* expanded considerably (Figures 6-9), while in three sites *P. australis* area remained approximately the same (Figures 10-12) and in others actually decreased (Figures 1-4,13).

The sites where *P. australis* decreased in area are of particular interest. Specific patches of *P. australis* that were dominant in 1994 are now predominately sapling, mid-story trees, and shrub communities. Seedlings of *Phragmites australis* are susceptible to shading (Haslam 1971, Kudo and Ito 1988, Ostendorp 1989) and shading by shrubs and trees can reduce the density, height, and the proportion of flowering shoots, and can increase the number of dead tips (Lambert 1946, Kassas 1952, Haslam 1971). In Europe, deforestation of lakeshore woods in the Bronze Age and Roman period is believed to have promoted expansion of *P. australis* (Rösch 1987). In more recent times, these areas have been re-colonized by bushes and trees resulting in a reduction of *P. australis* (Ostendorp 1989). Small stressed patches of *P. australis* still remain underneath the scrub/shrub layer in some sites.

The establishment of perimeter ditches still appear to be inhibiting rhizomal propagation into the constructed wetland interior. Expansion on, and from, the wetland berm continues to be the predominate mechanism for *P. australis* encroachment into constructed wetlands sites. Bart and Hartman (1999) demonstrated the ability of *P. australis* to expand from well-drained soils, such as constructed berms, that are low in sulfides to marsh interiors. *P. australis* maintains itself in adverse environmental conditions through translocation of essential substances from the berm colony to the expanding rhizomes. On one site, *P. australis* rhizomes were so heavily covered in feathery root hairs that the rhizome was floating across the perimeter ditch. It seems evident that subtidal perimeter ditches do have the ability to delay the expansion of *P. australis* into marsh interiors. However, if the marsh interiors are bare, sparsely vegetated or experience continued disturbance then *P. australis* will ultimately succeed in expanding into these interior marsh areas.

Conclusion

Constructed wetland sites remain susceptible to invasion from *P. australis*. Resource managers should weigh the loss of a natural system against the potential loss of function of a constructed site that may be invaded by *P. australis*. Some mechanisms can be employed to reduce the likelihood of invasion such as subtidal perimeter ditches, dense planting of the targeted species, elimination of bare, well-drained berms, and the planting of scrub/shrub species along the site perimeter. In addition, in some cases simply waiting for the scrub/shrub species to mature may reduce *P. australis* to a minor component of the plant community..

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Literature cited:

Adams, K.R. 1990. Prehistoric reedgrass (*Phragmites*) "cigarettes" with tobacco (*Nicotiana*) contents: A case study from Red Bow Cliff Dwelling, Arizona. J. Ethnobiol. 10: 123-139.

Bart, D. and J.M. Hartman. 2000. Environmental determinants of *Phragmites australis* expansion in a New Jersey salt marsh: an experimental approach. OIKOS 89: 59-69.

Breternitz, D.A., C.K. Robinson, and G.T. Gross. 1986. Dolores archaeological program: final synthetic report. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado.

Chambers, R.M., L.A. Meyerson, K. Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. Aquatic Botany 64: 261-273.

Daiber, F.C. 1986. Conservation of Tidal Marhes. Van Nostrand Reinhold Co., New York, NY, USA.

Fanshawe, D.B. 1972. The biology of the reed - *Phragmites mauritanus* Kunth. Kirkia 8: 147-150.

Haslam, S. M. 1971. Community regulation in *Phragmites communis* Trin. II. Mixed stands. J. Ecol. 59:75-88.

Haslam, S.M. 1973. Some aspects of the life history and autecology of *Phragmites communis*. Polish Archives of Hydrobiology: 2079-2100.

Havens, K.J., W.I. Priest, H. Berquist. 1997. Investigation and long-term monitoring of *Phragmites australis* within Virginia's constructed wetland sites. Environmental Management 21: 599-605.

Kassas, M. 1952. Studies in the ecology of Chippenham fen. III. The Forty Acre wood. J. Ecol. 40:50-61.

Kudo, G. and K. Ito. 1988. Rhizome development of *Phragmites australis* in a reed community. Ecological Research 3: 239-252.

Lambert, J. M. 1946. The distribution and status of *Glyceria maxima* (Hartm.) Holmb. In the region of Surlingham and Rockland Broads, Norfolk. J. Ecol. 33:230-67.

Marks, M., B. Lapin and J. Randall. 1994. *Phragmites australis* (P. communis): threats, management, and monitoring. Natural Areas Journal 14: 285-294.

Niering, W.A., R.S. Warren, and C. Weymouth. 1977. Our dynamic tidal marshes: vegetation changes as revealed by peat analysis. Connecticut Arboretum Bulletin 22.

Orson, R.A. 1999. A paleoecological assessment of *Phragmites australis* in New England tidal marshes: change in plant community structure during the last few millenia. Biological Invasions 1: 149-158.

Ostendorp, W. 1989. 'Die-back' of reeds in Europe - a critical review of literature. Aquatic Botany 35: 5-26.

Pyke, C.R., and K.J. Havens. 1999. Distribution of the invasive reed *Phragmites australis* relative to sediment depth in a created wetland. Wetlands 19: 283-287.

Saltonstall, K. 2002. Native or introduced? Genetic variation in North American populations of *Phragmites australis*. *Phragmites australis*: A sheep in wolf's clothing? A special technical forum and workshop, January 6-9, 2002, Cumberland County College, Vineland, New Jersey, New Jersey Marine Sciences Consortium and the U.S. Environmental Protection Agency, Mid-Continent Ecology Division.

Silberhorn, G. 1991. Reed grass *Phragmites*. Technical Report, wetland flora. Wetlands Program, College of William and Mary, School of Marine Science, Virginia Institute of Marine Science, 2 pp.

Windham, L. and R. Lathrop. 1999. Effects of *Phragmites australis* (common reed) invasion on above-ground biomass and soil properties in brackish tidal marsh of the Mullica River, New Jersey. Estuaries 22: 927-935.

Table 1. *Phragmites australis* colonization of constructed wetlands sites in 1994 and 2000.

			1994	2000			
Site	**Age**	**Total area (m2)**	**Area (m2)**	**Area (m2)**	**% (1994)**	**% (2000)**	
PA	7	39688.5	259.8	5042.6	0.7	12.7	
BM	7	53487.9	0.0	0.0	0.0	0.0	
MD1	7	5568.6	1.2	2.9	0.0	0.0	
KF	8	11726.1	0.0	0.0	0.0	0.0	
BR	9	9346.3	0.0	0.0	0.0	0.0	
CS	10	14178.5	49.3	175.4	0.4	1.2	NM
	13	18726.0	11538.4	10640.2	61.6	56.8	
SP	13	7686.3	358.0	83.9	4.7 (0.0[a])	1.1 (0.0[a])	
LY	13	4908.8	143.9	520.5	2.9	10.6	
FL	13	6475.0	0.0	8.7	0.0	0.1	
MCD	15	8273.0	5191.6	4572.9	62.8	55.3	
MD2	15	4295.9	588.4	505.0	13.7	11.8	
MB	16	27919.3	2589.7	4689.1	9.3 (1.0[a])	16.8 (0.9[a])	
HB	18	32589.0	2295.0	449.2	7.0	1.4	
GC	18	31731.9	11693.4	22956.4	36.9	72.3	
TOTAL		276601.1	34708.3	49646.8			

[a]Percent of *P. australis* within ditched area.

Table 2. Percent *P. australis* area in marsh interior in constructed wetland sites with and without perimeter ditches.

		Percent Area *P. australis*	
Site	**Age**	**1994**	**2000**
PA (ditched)	7	0.02	3.6
SP (ditched)	13	0.0	0.0
FL (ditched)	13	0.0	0.1
MB (ditched)	16	1.0	0.9
HB(ditched)	18	7.0	1.2
NM (no ditch)	13	61.6	56.8
LY (no ditch)	13	2.9	10.6
MD (no ditch)	15	13.7	11.8
GC (no ditch)	18	36.9	72.3

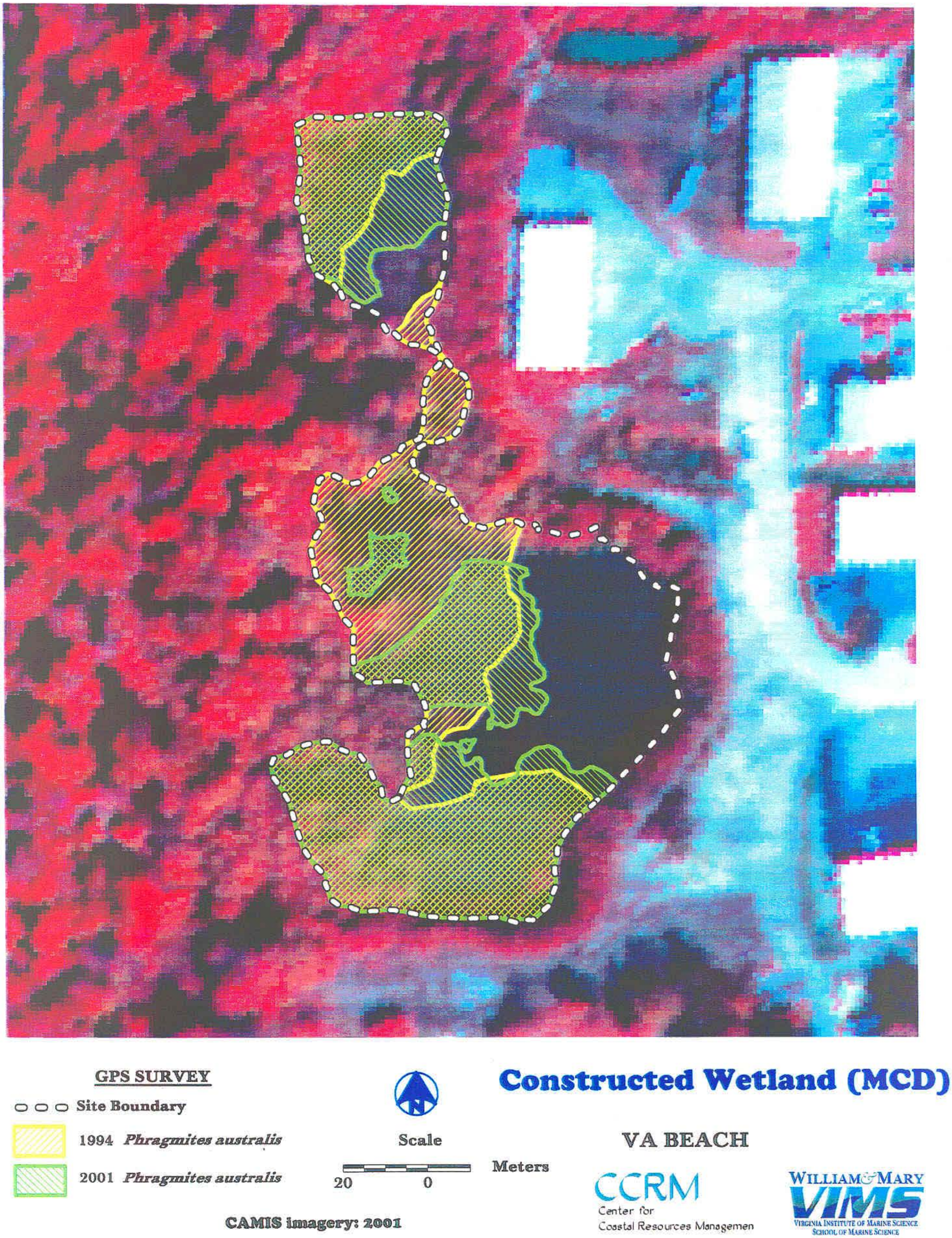
Constructed Wetland (MCD)
GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
Scale
20
0
Meters
VA BEACH
CAMIS imagery: 2001
CCRM
Center for
Coastal Resources Managemen
WILLIAM&MARY
VIMS
VIRGINIA INSTITUTE OF MARINE SCIENCE
SCHOOL OF MARINE SCIENCE

Figure 1.

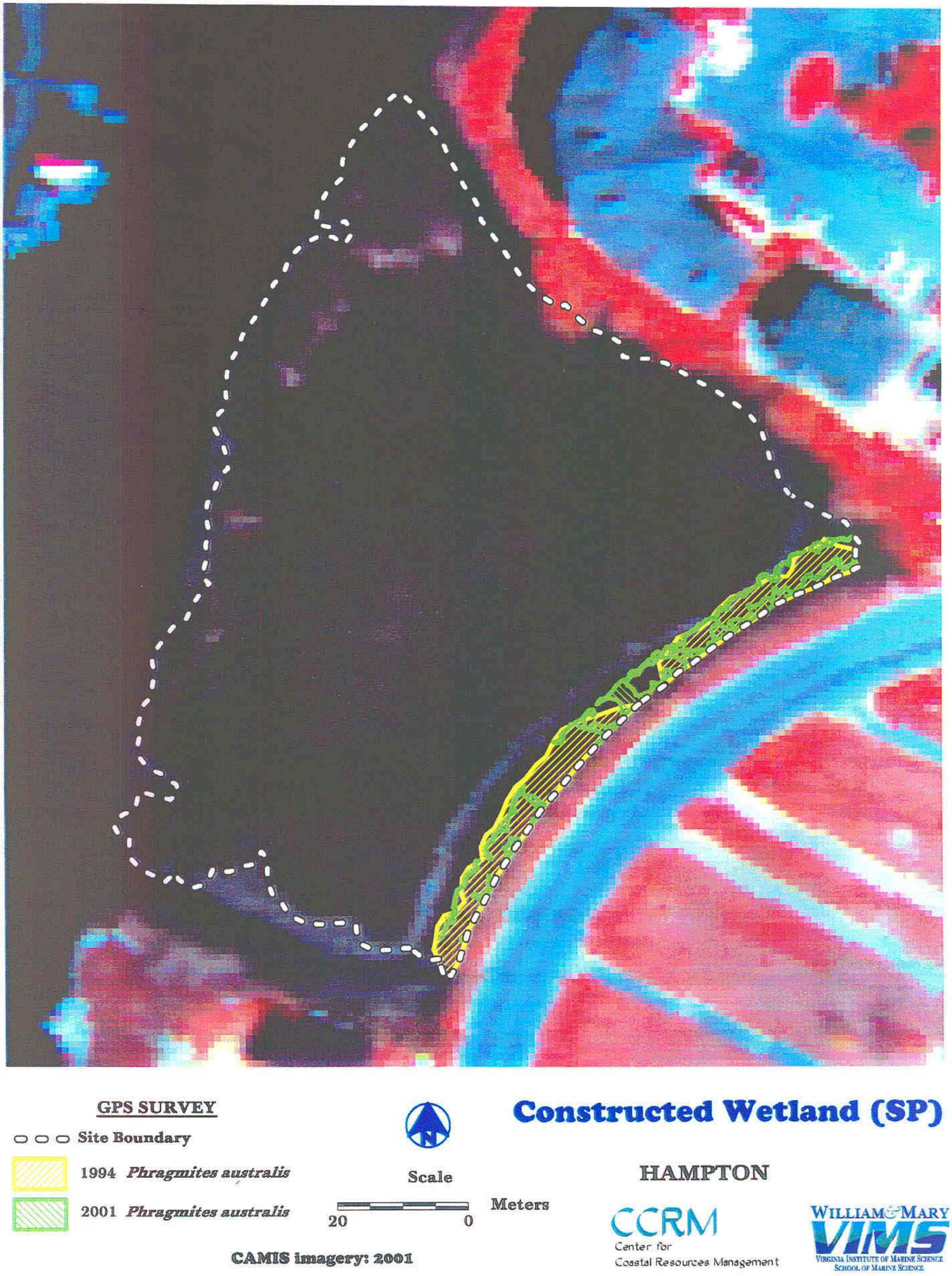
GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
Scale
20
0
Meters
CAMIS imagery: 2001
Constructed Wetland (SP)
HAMPTON
CCRM
Center for
Coastal Resources Management
WILLIAM&MARY
VIMS
VIRGINIA INSTITUTE OF MARINE SCIENCE
SCHOOL OF MARINE SCIENCE

Figure 2.

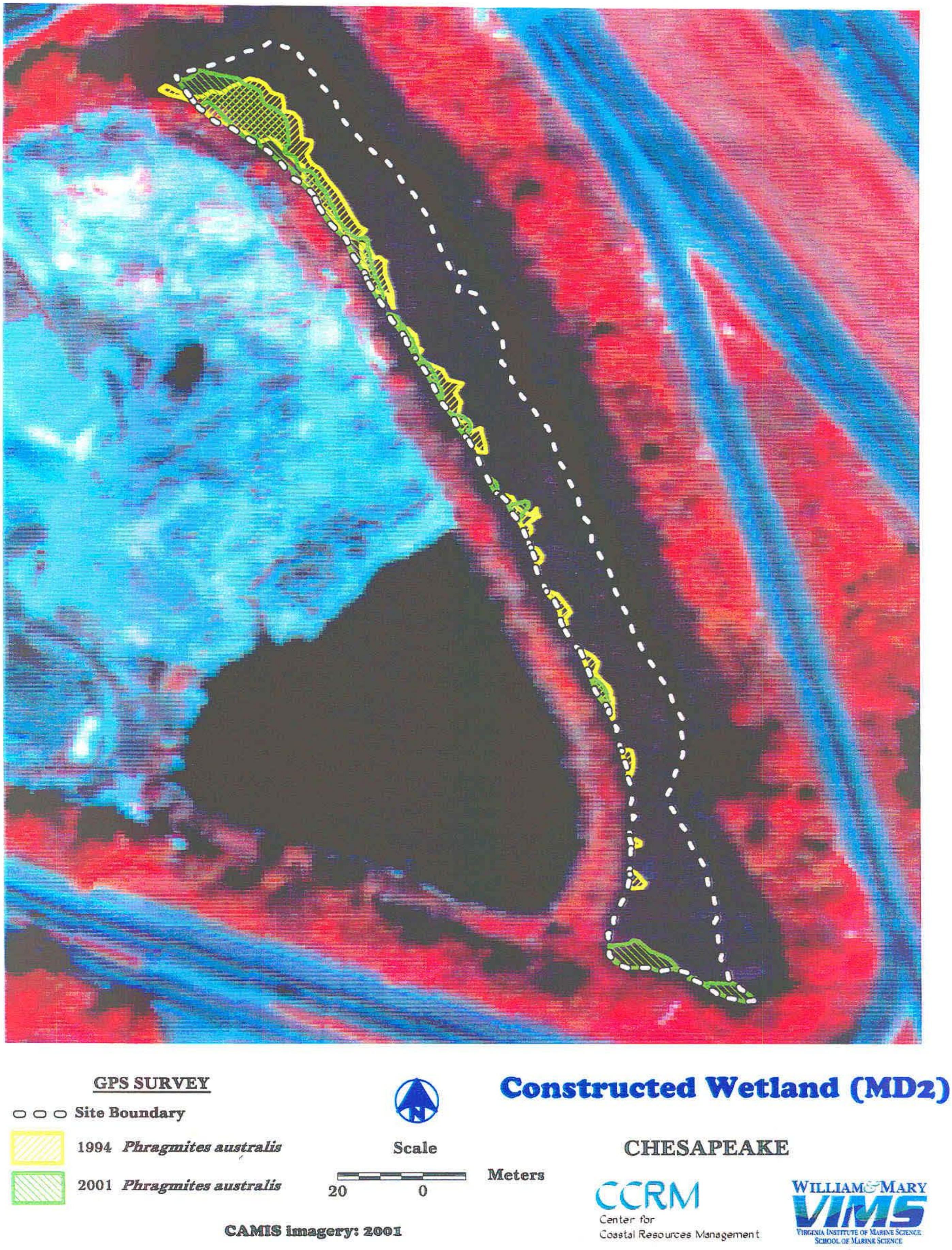
GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
Scale
20
0
Meters
CAMIS imagery: 2001
Constructed Wetland (MD2)
CHESAPEAKE
CCRM
Center for
Coastal Resources Management
WILLIAM&MARY
VIMS
VIRGINIA INSTITUTE OF MARINE SCIENCE
SCHOOL OF MARINE SCIENCE

Figure 3.

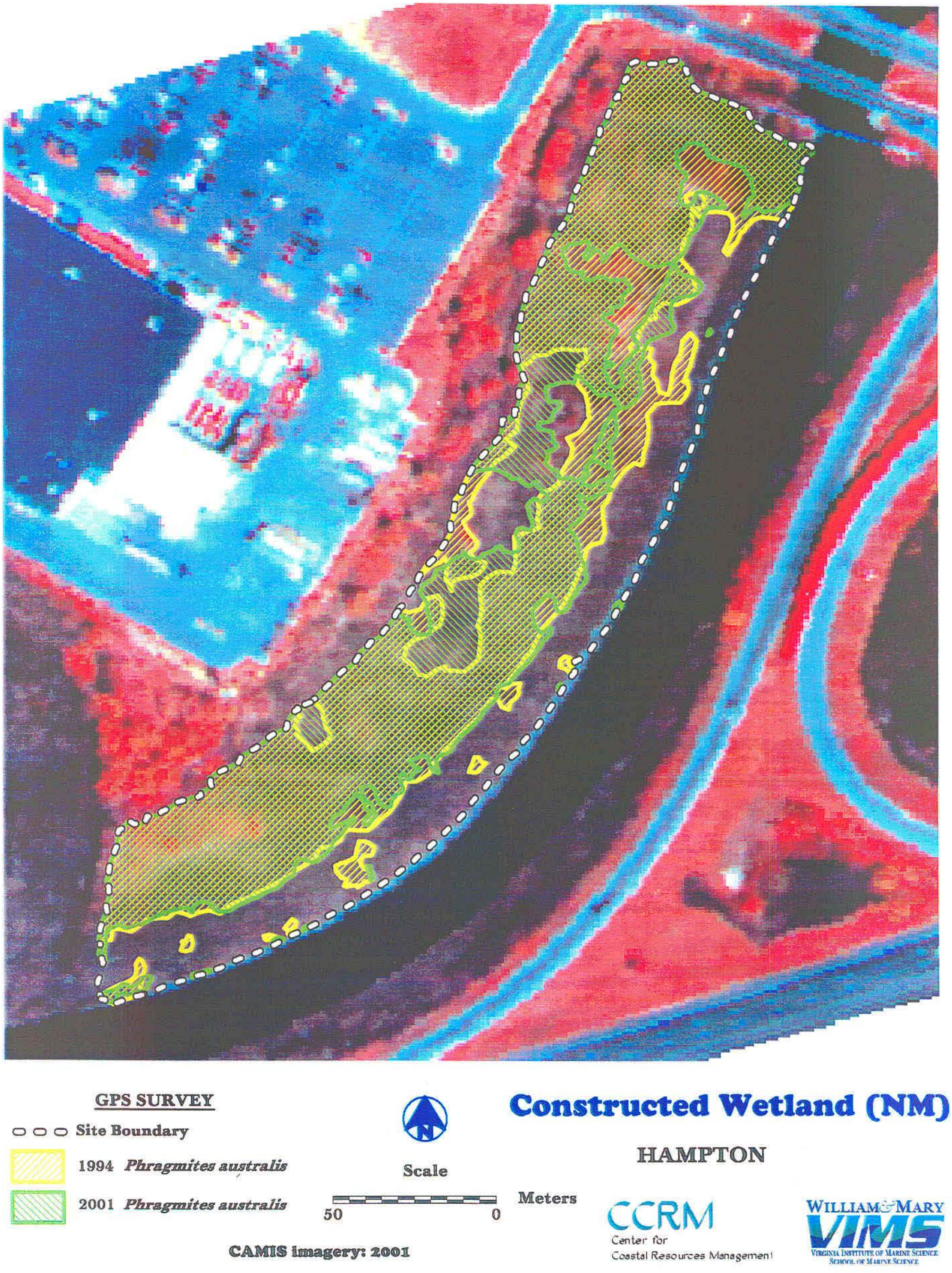
GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
CAMIS imagery: 2001
Scale
50
0
Meters
Constructed Wetland (NM)
HAMPTON
CCRM
Center for
Coastal Resources Management
WILLIAM & MARY
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Figure 4.

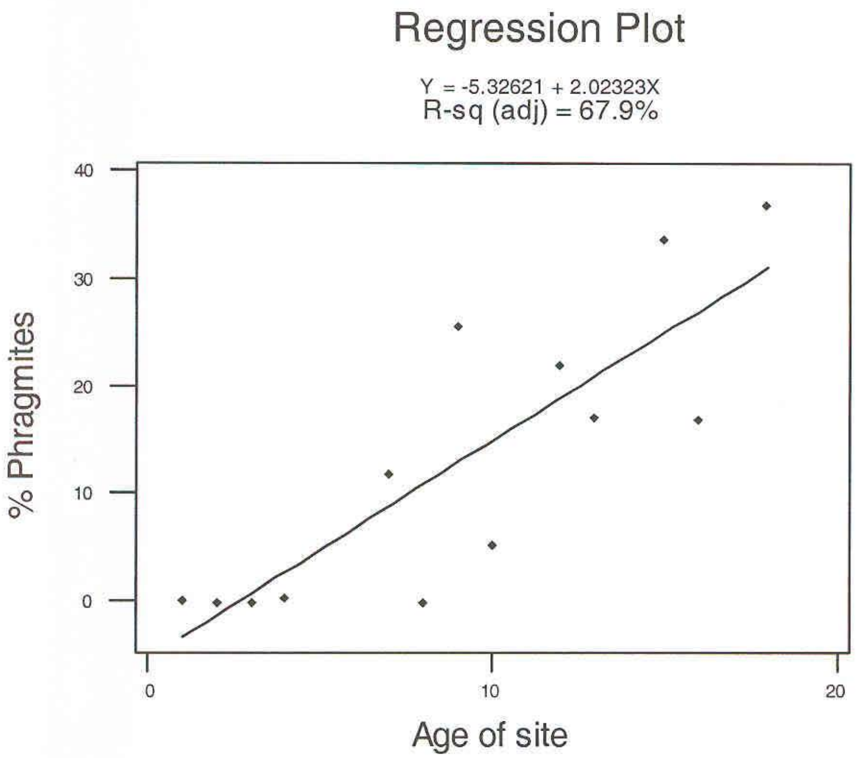

Figure 5. Regression plot of average percent *P. australis* with age of site.


GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
CAMIS imagery: 2001
N
Scale
50
0
Meters
Constructed Wetland (GC)
CHESAPEAKE
CCRM
Center for
Coastal Resources Management
WILLIAM&MARY
VIMS
VIRGINIA INSTITUTE OF MARINE SCIENCE
SCHOOL OF MARINE SCIENCE

Figure 6.


GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
CAMIS imagery: 2001
Scale
50
0
Meters
Constructed Wetland (PA)
CHESAPEAKE
CCRM
Center for
Coastal Resources Management
WILLIAM & MARY
VIMS
VIRGINIA INSTITUTE OF MARINE SCIENCE
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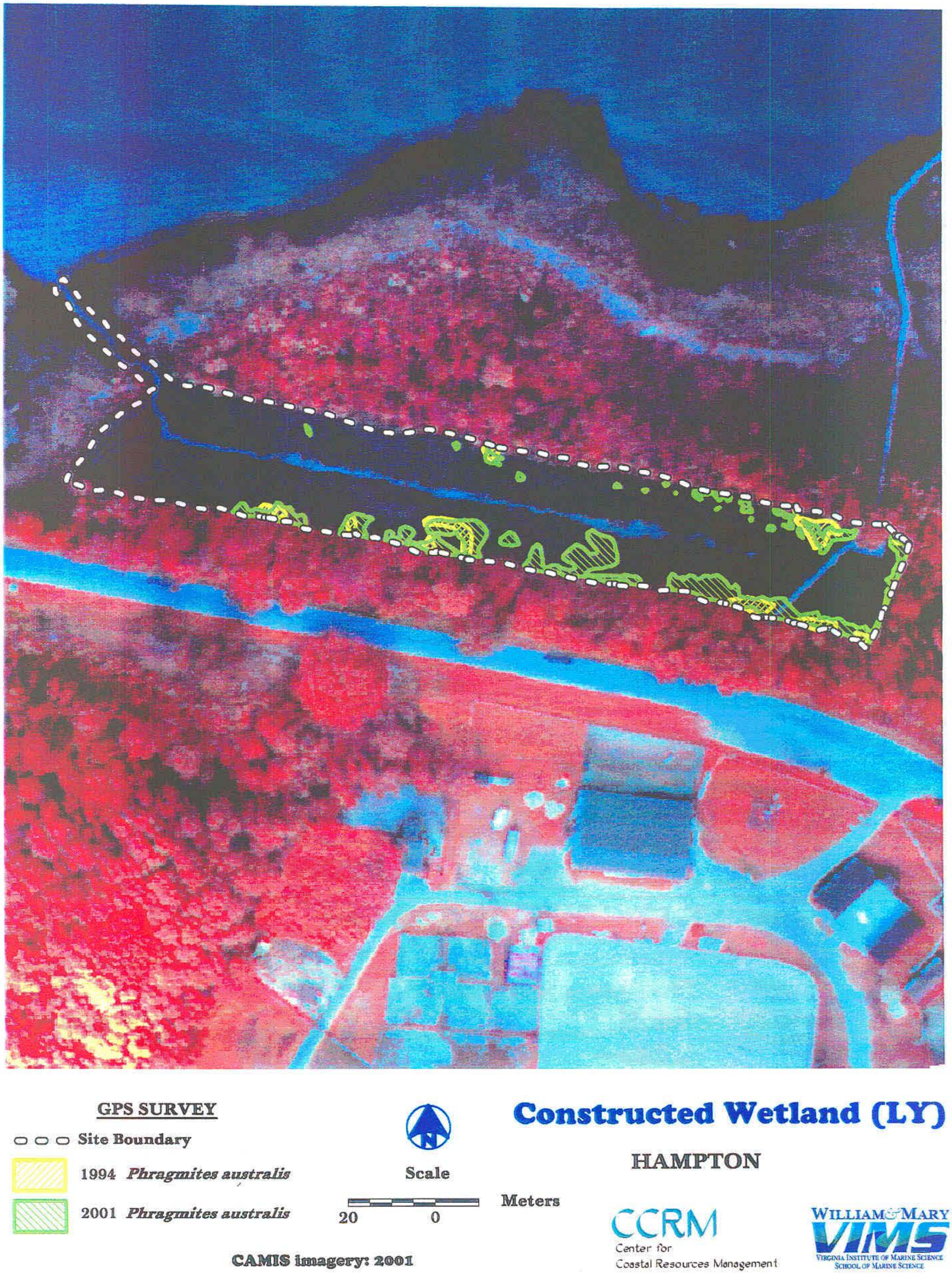
Figure 7.



GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
Scale
20
0
Meters
CAMIS imagery: 2001
Constructed Wetland (LY)
HAMPTON
CCRM
Center for Coastal Resources Management
WILLIAM & MARY
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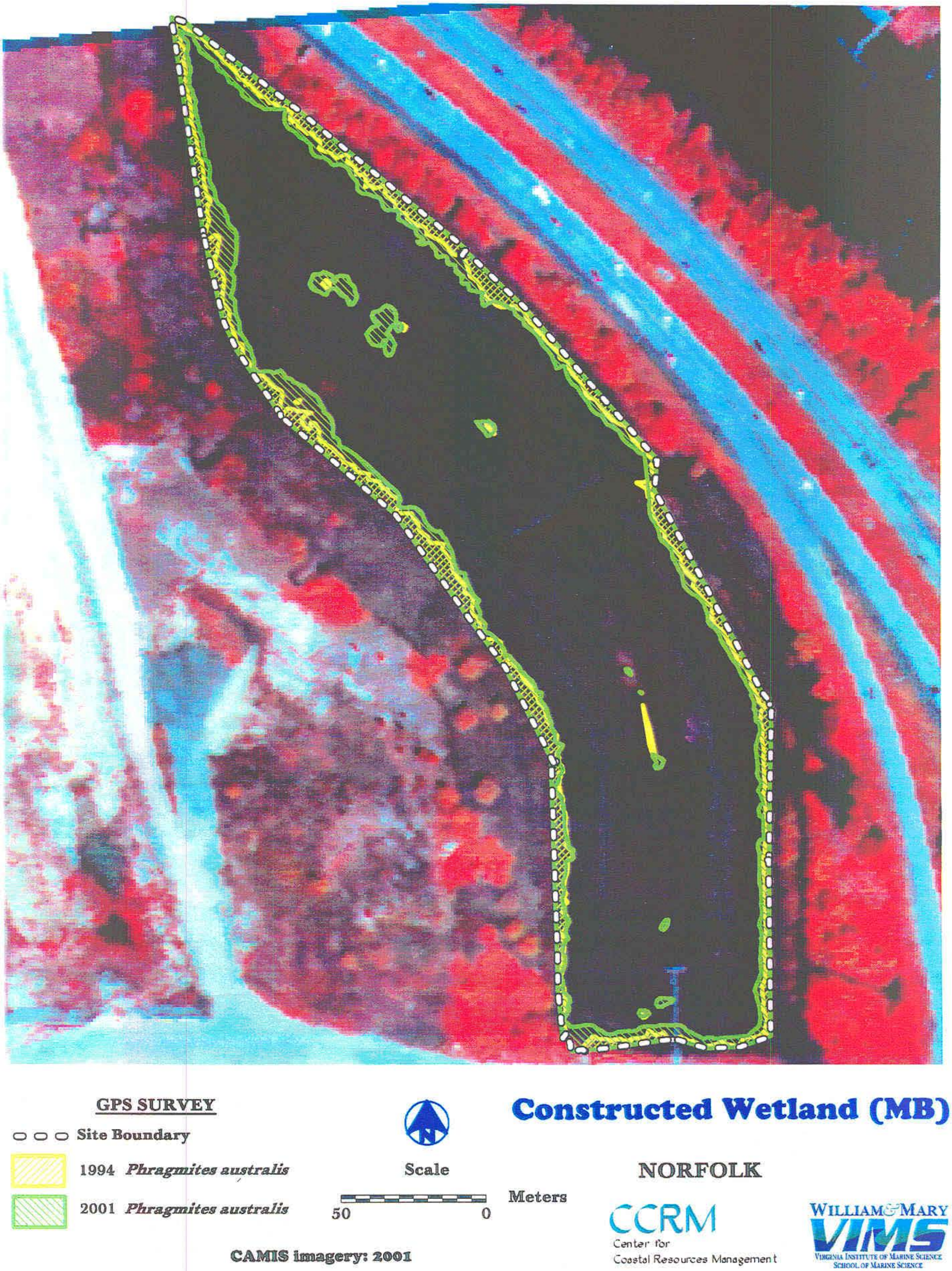
Figure 8.



GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
Scale
50
0
Meters
CAMIS imagery: 2001
Constructed Wetland (MB)
NORFOLK
CCRM
Center for
Coastal Resources Management
WILLIAM&MARY
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Figure 9.

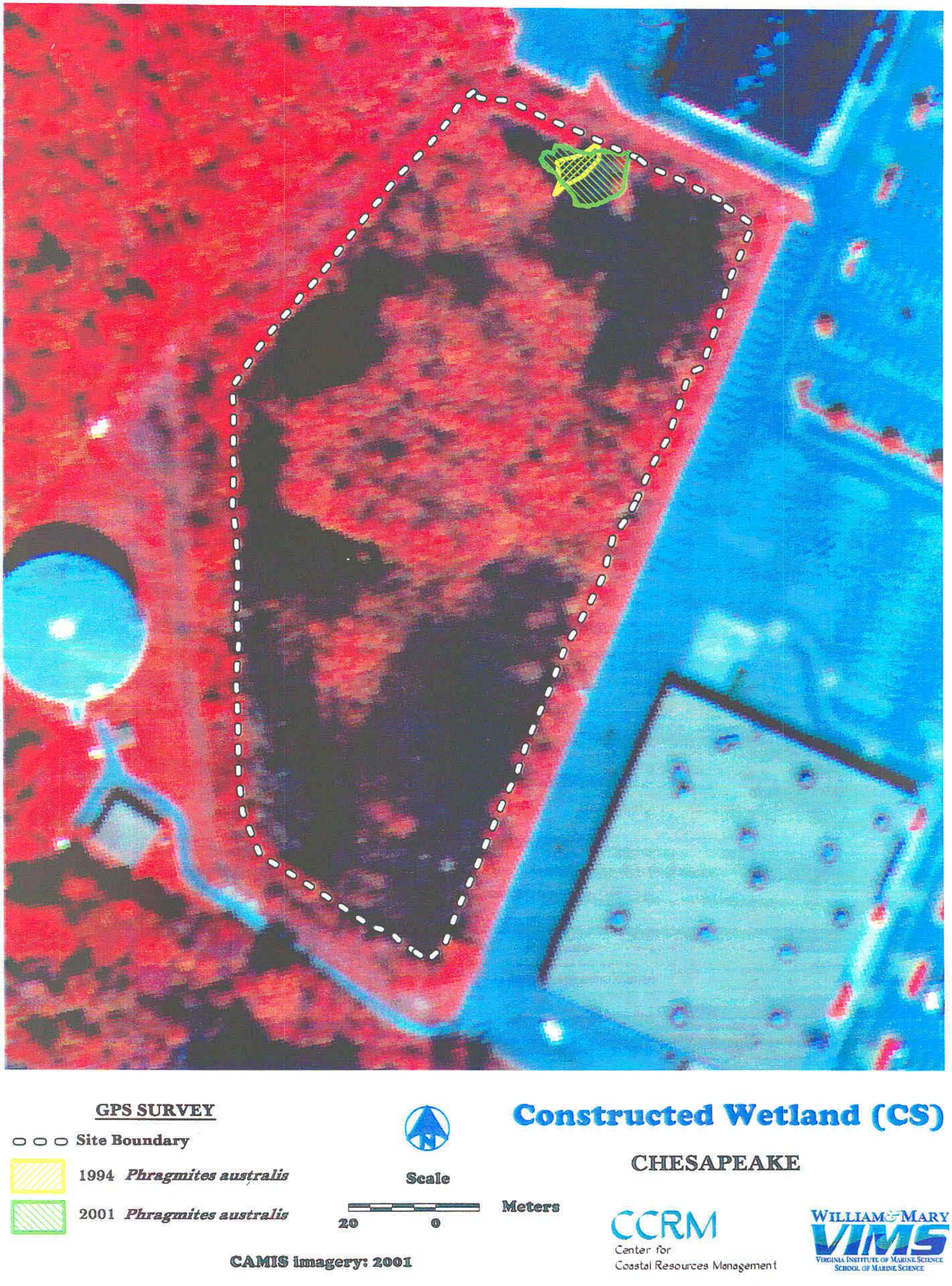
GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
Scale
20 0
Meters
CAMIS imagery: 2001
Constructed Wetland (CS)
CHESAPEAKE
CCRM
Center for Coastal Resources Management
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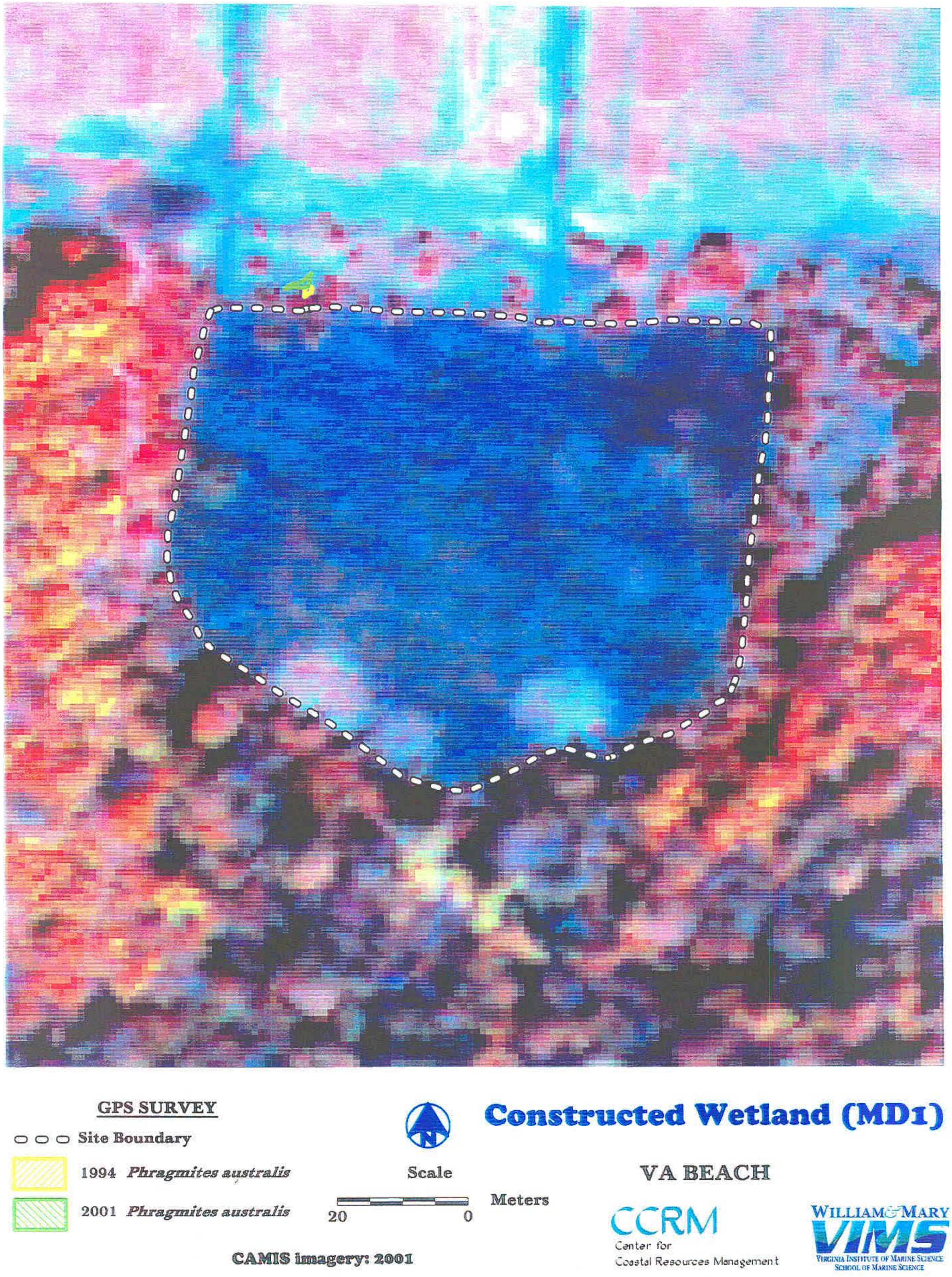
Figure 10.


GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
N
Scale
Meters
20
0
CAMIS imagery: 2001
Constructed Wetland (MD1)
VA BEACH
CCRM
Center for
Coastal Resources Management
WILLIAM&MARY
VIMS
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SCHOOL OF MARINE SCIENCE

Figure 11.

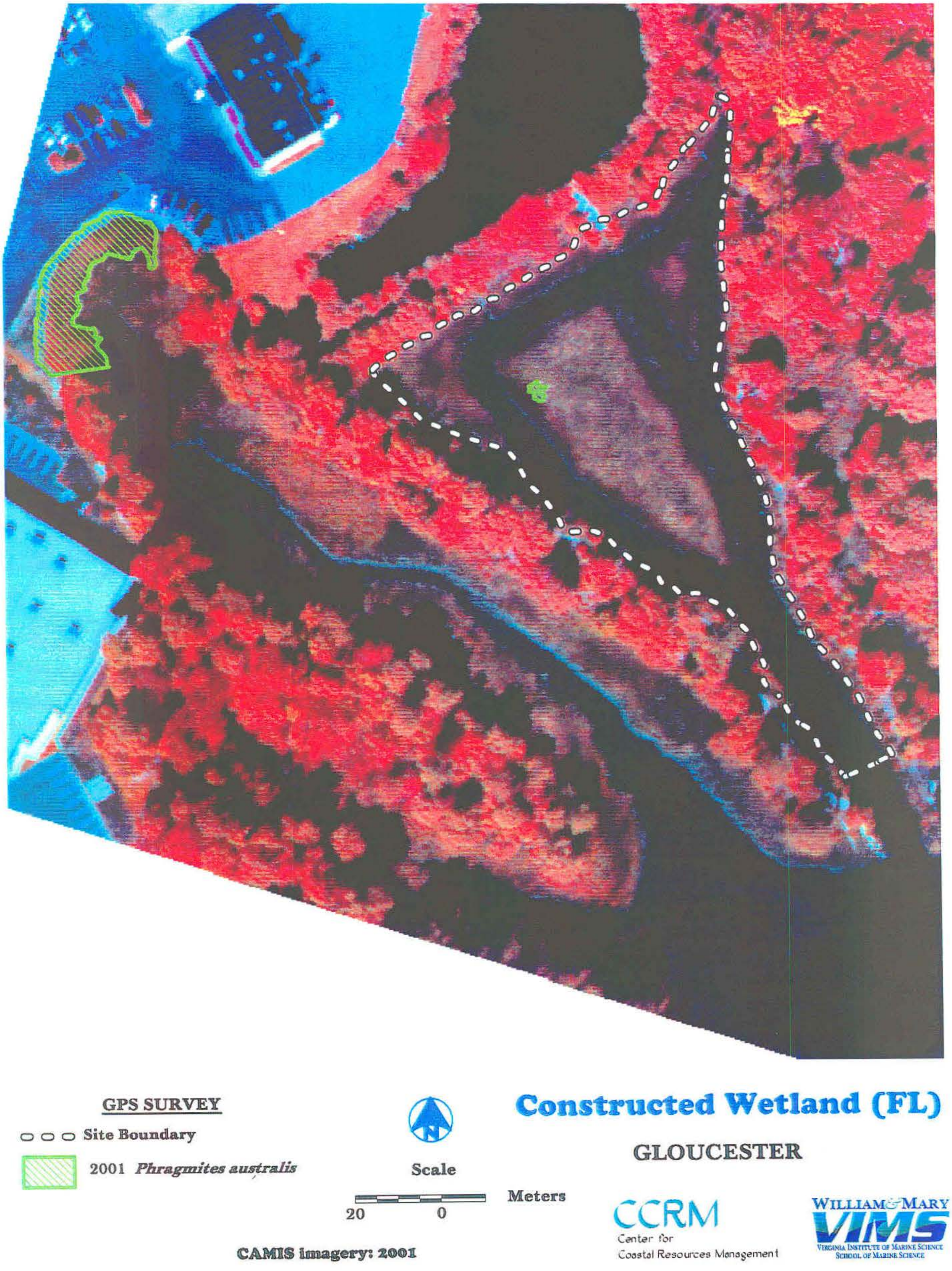
GPS SURVEY
Site Boundary
2001 Phragmites australis
Scale
Meters
20
0
CAMIS imagery: 2001
Constructed Wetland (FL)
GLOUCESTER
CCRM
Center for Coastal Resources Management
WILLIAM&MARY
VIMS
VIRGINIA INSTITUTE OF MARINE SCIENCE
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Figure 12.

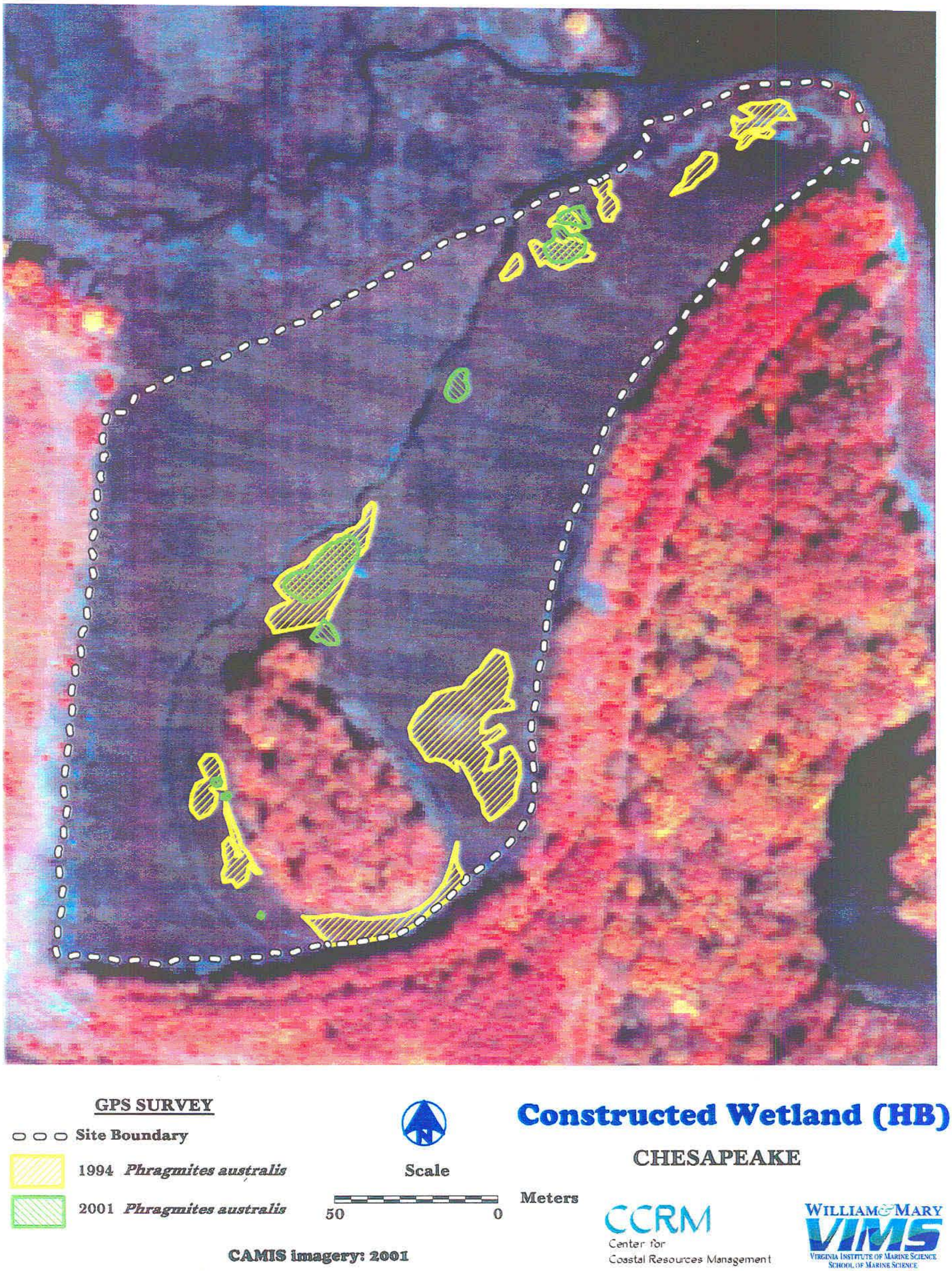
GPS SURVEY
Site Boundary
1994 Phragmites australis
2001 Phragmites australis
Scale
50
0
Meters
CAMIS imagery: 2001
Constructed Wetland (HB)
CHESAPEAKE
CCRM
Center for
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Figure 13.

Chapter 2

Evaluating the Use of Multispectral Imagery for Identifying and Quantifying *P. australis* Populations in Created Wetlands

By: James E. Perry and John Anderson

INTRODUCTION

One of the original recommendations identified by previous wetlands work was to investigate the ability for resource managers to evaluate wetland sites using remote sensed imagery data sets (RSI). RSI could be particularly useful in identifying sites that contain specific management oriented plant species such as invasive and/or endangered plants and/or habitat. If proven to be feasible and accurate, RSI could provide a powerful tool that could be used in the decision-making process. This work seeks to test the accuracy of using RSI to evaluate the presence of *Phragmites australis* (common reed grass), an invasive plant species in created wetlands of the mid-Atlantic region of the continental U.S. The goal of the project was to produce a RSI generated *P. australis* map of 12 created wetlands located throughout eastern Virginia (Table 2.1). Each map was then field tested for accuracy.

Table 2.1. Site location. See Chp.1 for location maps.

SITE NAME	LONGITUDE	LATITUDE
Chesapeake Square	76:25:14.10	36:49:31.66
Foodlion	76:29:41.7	37:16:27.5
Goose Creek	76:25:32.06	36:47:44.72
Higgerson/Buchanon	76:18:03.31	36:44:44.15
Langley	NA	NA
McDonnell	76:00:13.67	36:50:05.88
Mill Dam 1	76:04:53.62	36:34:49.42
Mill Dam 2	76:16:50.81	36:46:36.17
Monkey Bottom	76:16:00.70	36:57:35.97
Newmarket	76:21:57.83	37:02:02.48
Port Authority	76:18:43.59	36:45:10.15
Salt Ponds	76:17:16.65	37:03:02.41

METHODS

A. CAMIS System Configuration.

To accomplish the remote sensing required by this project, a four - channel multispectral camera system was used. The computer-assisted multispectral imaging system is a portable remote sensing system consisting of a matrix of four Sony digital cameras, a Pentium III computer, flat screen LCD display, and a keyboard. To detect single channel information the spectral wavelengths are controlled by placing bandpass interference filters in front of the camera optics (fore lens). This permits the passage of only a single spectral band of data to be captured by the system. Each camera is filtered independently and four single wavelength images are multiplexed via a frame grabber. The result is four panchromatic spectral channels merged into one data file that can be manipulated using computer image processing routines.

For the VIMS missions, the wavelength band centers were 450 nm (blue), 550 nm (green), 680 nm (red), and 770 nm (near infrared) at a resolution of 25 nm full-wave half-maximum. These band assignments allowed the creation of both natural color and false color infrared composites. The narrow bands (25 nm) used by the system make discriminating different soil and vegetation features more. This is in contrast to film-based imagery and satellite data which is typically broad-banded (100 nm).

The lens architecture of the CAMIS incorporates 12 mm focal length lenses fixed at infinity. In addition, each silicon detector for each of the four cameras has a rectangular array size of 740-by-578 pixels. Given the flying height of the aircraft, the pixel size of the CCD arrays in each camera (8 microns), and the lens focal length (12 mm), the spatial resolution, or ground sample distance (GSD), was computed and is presented in table 2.2.

Table 2.2. CAMIS Flying height and GSD.

740 m	.5 meters	106 km^2
1650 m	1 meter	430 km^2
3000 m	2 meters	km^2

B. Data Acquisition.

The VIMS missions were flown at an altitude of 1650 m (5500 ft.). All representative data sets have a GSD of 1 meter. The DMSV was configured and installed in a Cessna 172 Skyhawk operated by Airborne Research and Services (ARS) of Manassas, Virginia. The optical head containing the four cameras was leveled and mounted over the open port in the floor of the aircraft at a nadir view angle (see figure 1). The DMSV was spectrally configured with the filter suite (450 nm, 550 nm , 680 nm, 770 nm) to achieve both natural and false color infrared data in the final imagery. As noted bandpass interference filters (by Corion) were used having full-wave, half maximum FWHM resolutions of 25 nm.

Prior to each mission, all sites were located using a global positioning system (GPS) through ground surveys (see Table 1). GPS points were sent to ARS for input into the on-board navigation system via electronic mail. During data acquisition, the CAMIS was triggered automatically by the GPS signal. A sequence of frames was captured to the computer at two-second intervals and, depending upon the coverage needed, flying height and aircraft speed, stereo images were acquired. This effectively created data sets having 40 to 60% overlap. For large, complex sites this capability was important since the frame sequence was mosaicked (tied together digitally) using the common points within each scene. All flights occurred at an altitude of 1650 m under nominally clear sky conditions.

C. Field Verification.

Two site visit were conducted for the study: the first to verify the signature file used to create the supervised classification of *Phragmites australis* and, second, a post classification visit to check the supervised classification accuracy. Prior work has shown that signature files do not transfer well from site to site, therefore, a new *P. australis* signature files was created for each site. Accuracy was judged as high (>80%), medium (50-80%), or low (<50%) as determined by field verification of easily identifiable target areas.

RESULTS

Of the 12 sites classified, one site (Foodlion) did not have a *P. australis* population large enough to create a signature file. Therefore one was created from a population located in the headwaters of an adjacent marsh.

Only the Foodlion site, with its small population, had a classification that was ranked as high. All others were not acceptable for management purposes (Table 2.3) (Figures 2.1-2.12). Attempts to improve classifications by varying the standard deviation (SD) of pixtels accepted by the classification found that a SD of 2.5 accepted almost all pixtels (i.e. colored entire frame) while a SD of 1.5 lost both small and low density populations. With a 2.0 SD most problems occurred with similar species. For example, in Goose

Creek the classification could not separate the *P. australis* populations from those dominated by *Spartina cynosuroides* or *Typha angustifolia.* The Monkey Bottom site classification did not successfully picked out the P. australis population found in the interior of the marsh, problems occurred as well in separating high density *P. australis* and low density shrubs such as *Myrica cerifera* and *Iva frutescens* along the high marsh border.

TABLE 2.3. Ranking of classification for each site. Accuracy was based on field verification of supervised classification using *P. australis* populations within or adjacent to the marsh as the training.

SITE NAME	RANK
Chesapeake Square	Low
Foodlion	High
Goose Creek	Medium
Higgerson/Buchanon	Low
Langley	Low
McDonnell	Low
Mill Dam 1	Low
Mill Dam 2	Low
Monkey Bottom	Low
Newmarket	Medium
Port Authority	Low
Salt Ponds	Low

CONCLUSIONS AND RECOMMENDATIONS

The results of this work points to the weakness of using four channel digital multispectral video data for individual species identification. Complications arose with separating *P. australis* with other species, some of similar structure, but also with others, such as the shrubs at Monkey Bottoms, that were quite different not only in structure, but in growth habit as well. Attempts to refine the supervised classification by field verification of the training pixtels and by adjusting the SD to define the pixtels acceptable to the classification did not improve the overall supervised classifications. Therefore, the

CAMIS data used for this study was not appropriate for identifying and/or quantifying *P. australis* populations on the test sites and, therefore, would be of limited value to resource managers.

Current work with hyperspectral video systems is more promising and has shown a much higher success rate of identifying *P. australis* populations in coastal wetlands. Also, this work only tested four channel multispectral data on *P. australis* and did look at the ability of the system to identify other invasive species such as *Pueraria lobata* (kudzu) or *Typa latifolia* (broadleaf cat-tails) in the southeast.

Figure 2.1. Chesapeake Square. Accuracy for site was low (3%). Supervised classification of *P. australis* (right) represents 404 training pixtals taken from the site.

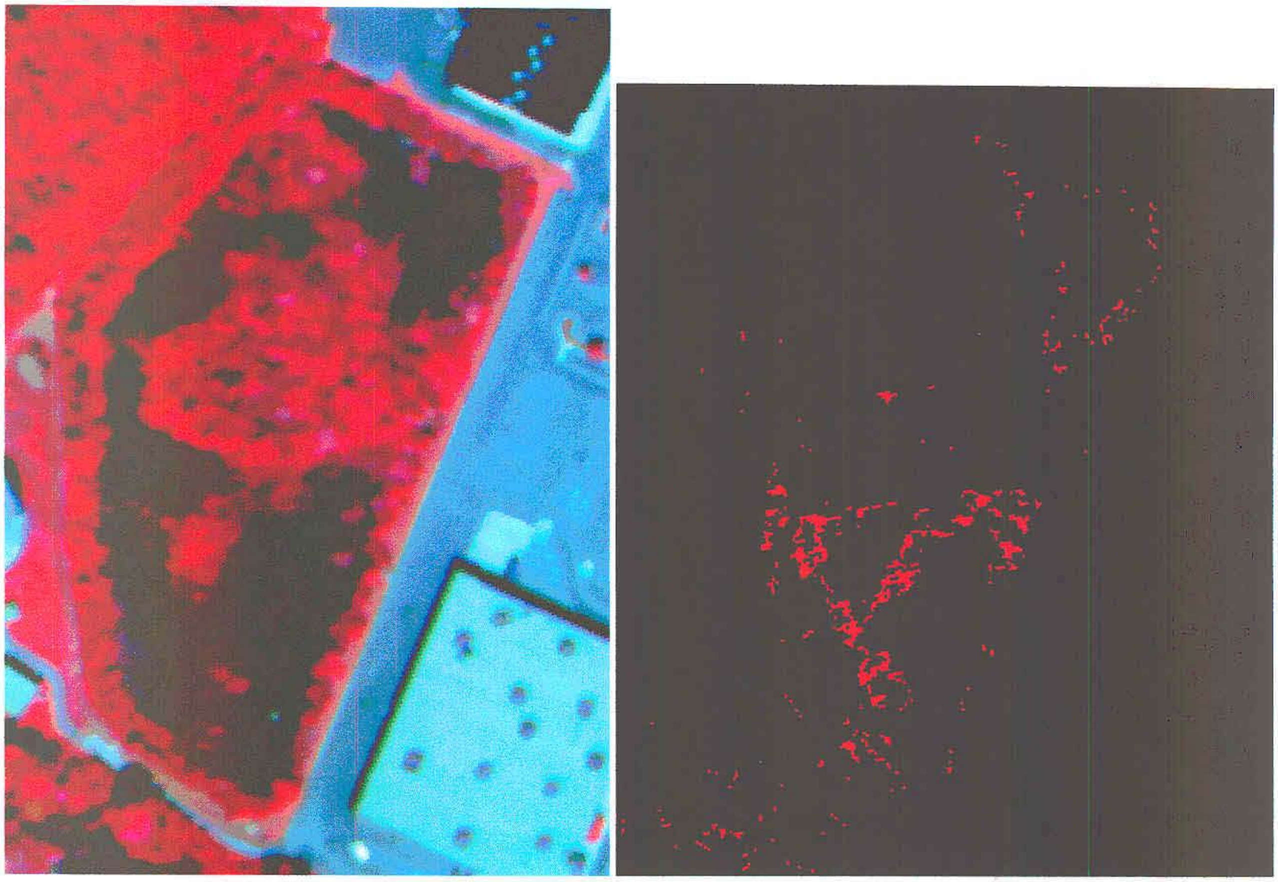


Figure 2.2. Foodlion. Accuracy for site was high (100%) due to small population. Supervised classification of *P. australis* (bottom) represents 518 training pixtals taken from an adjacent site.

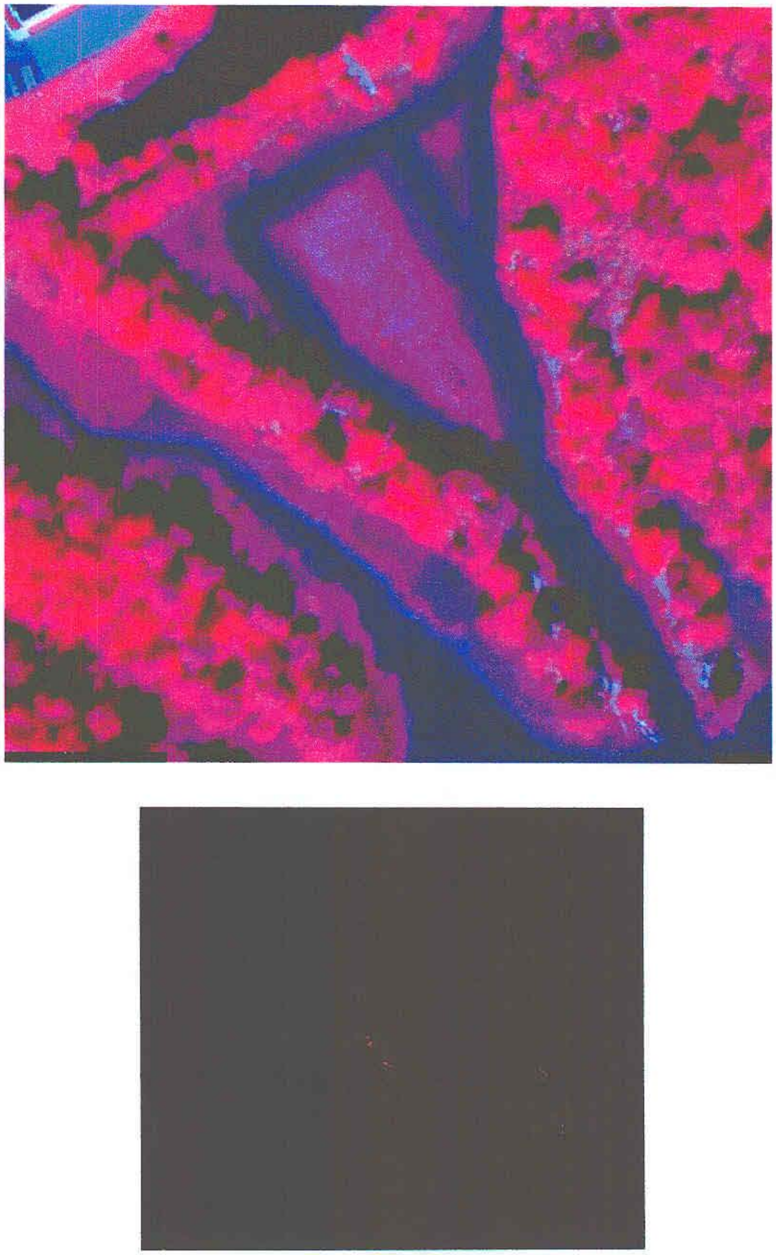


Figure 2.3. Goose Creek. Accuracy for site was medium (60%) due to high species richness and species of similar structure and growth habit. Supervised classification of *P. australis* (bottom) represents 2700 training pixtals taken from the site.

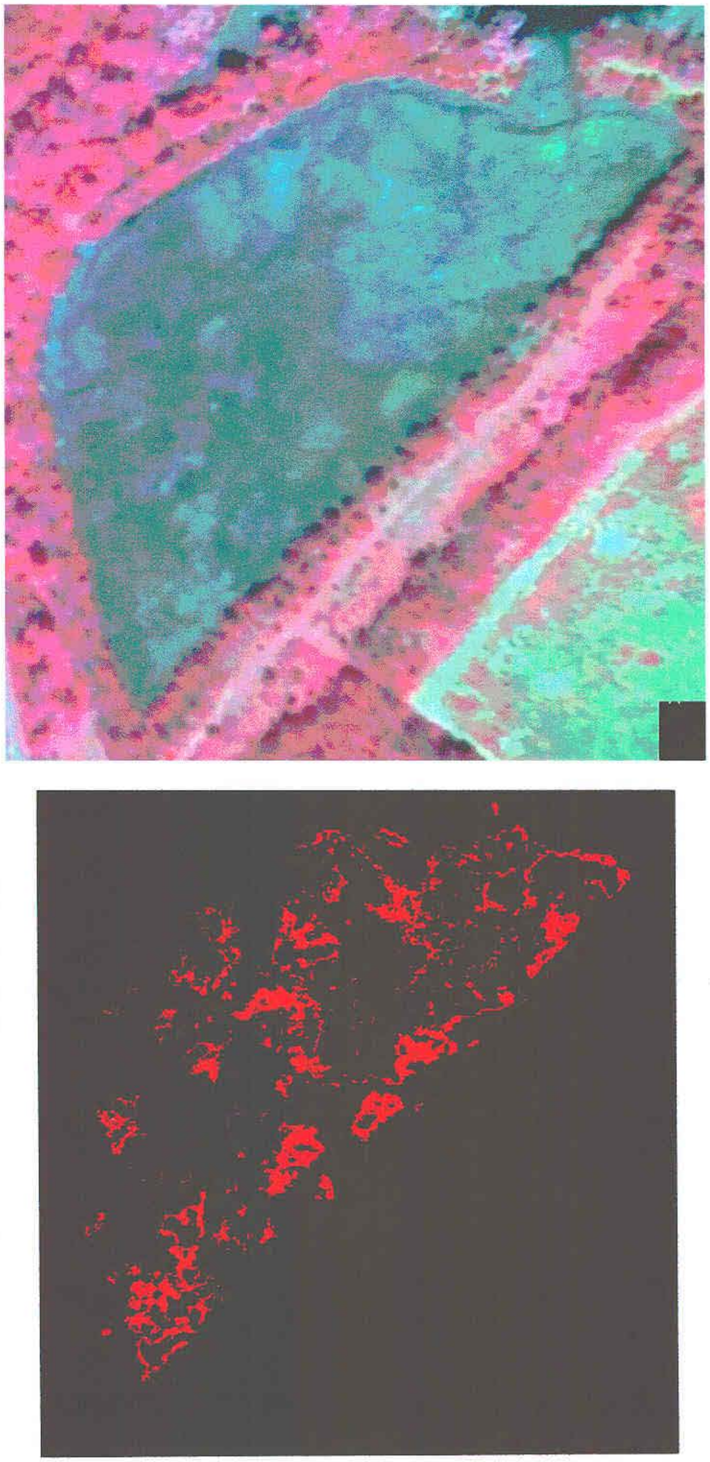


Figure 2.4. Higgerson-Buchanon. Accuracy for site was low (40%) due to the presence of species of similar structure and growth habit. Supervised classification of *P. australis* (bottom) represents 598 training pixtals taken from the site.

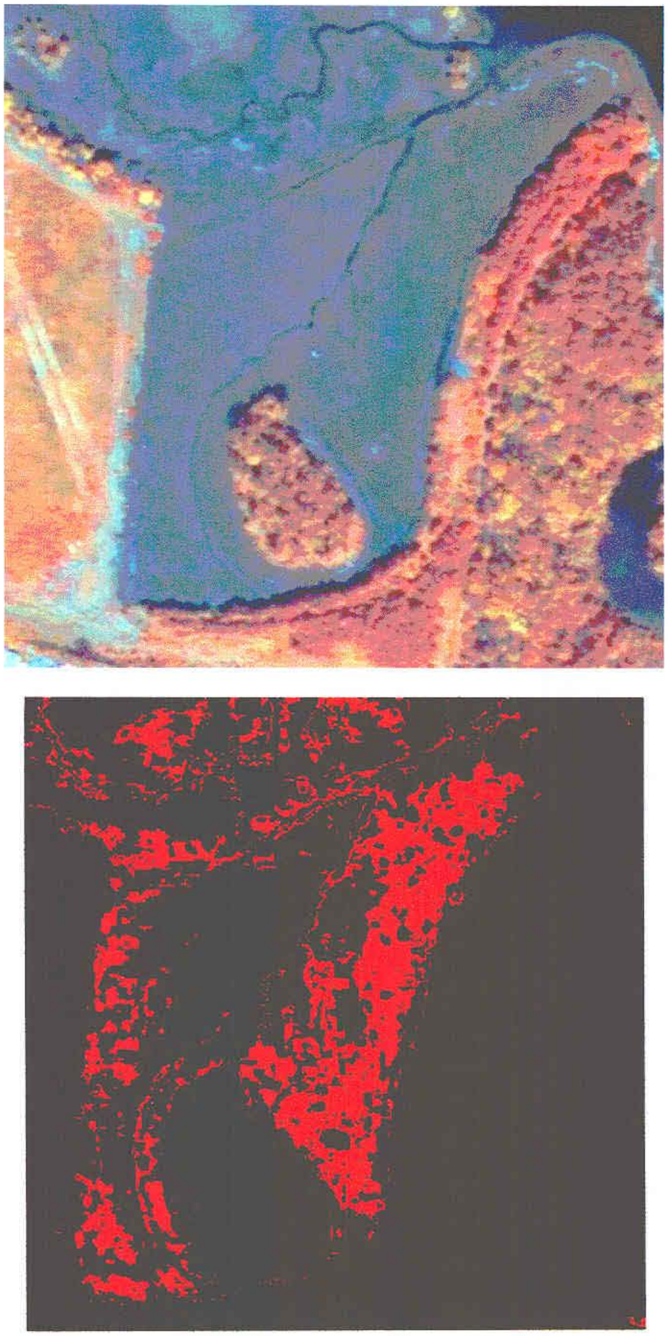


Figure 2.5. Langley. Accuracy for site was low (30%) due to species of similar structure and growth habit. Supervised classification of *P. australis* (bottom) represents 712 training pixtals taken from the site.

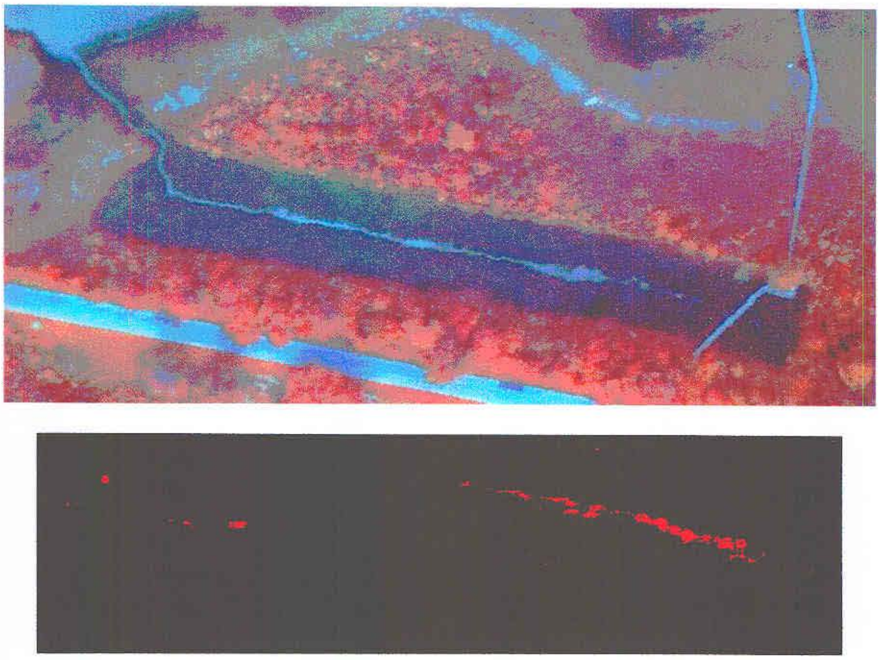


Figure 2.6. McDonnell. Accuracy for site was low (40%) due to species of similar structure and growth habit. Supervised classification of *P. australis* (bottom) represents 113 training pixtals taken from the site.

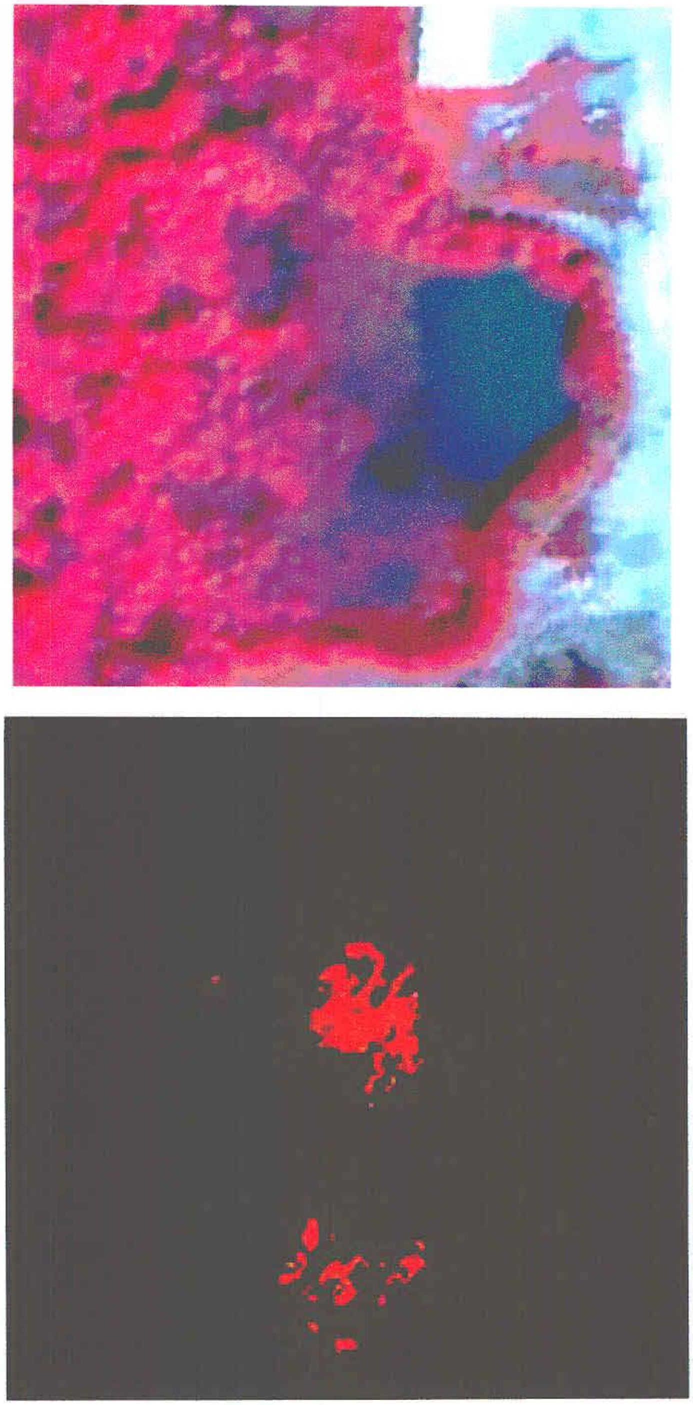


Figure 2.7. Mill Dam 1. Accuracy for site was low (40%) due to high species richness and species of similar structure and growth habit. Supervised classification of *P. australis* (bottom) represents 323 training pixtals taken from the site.

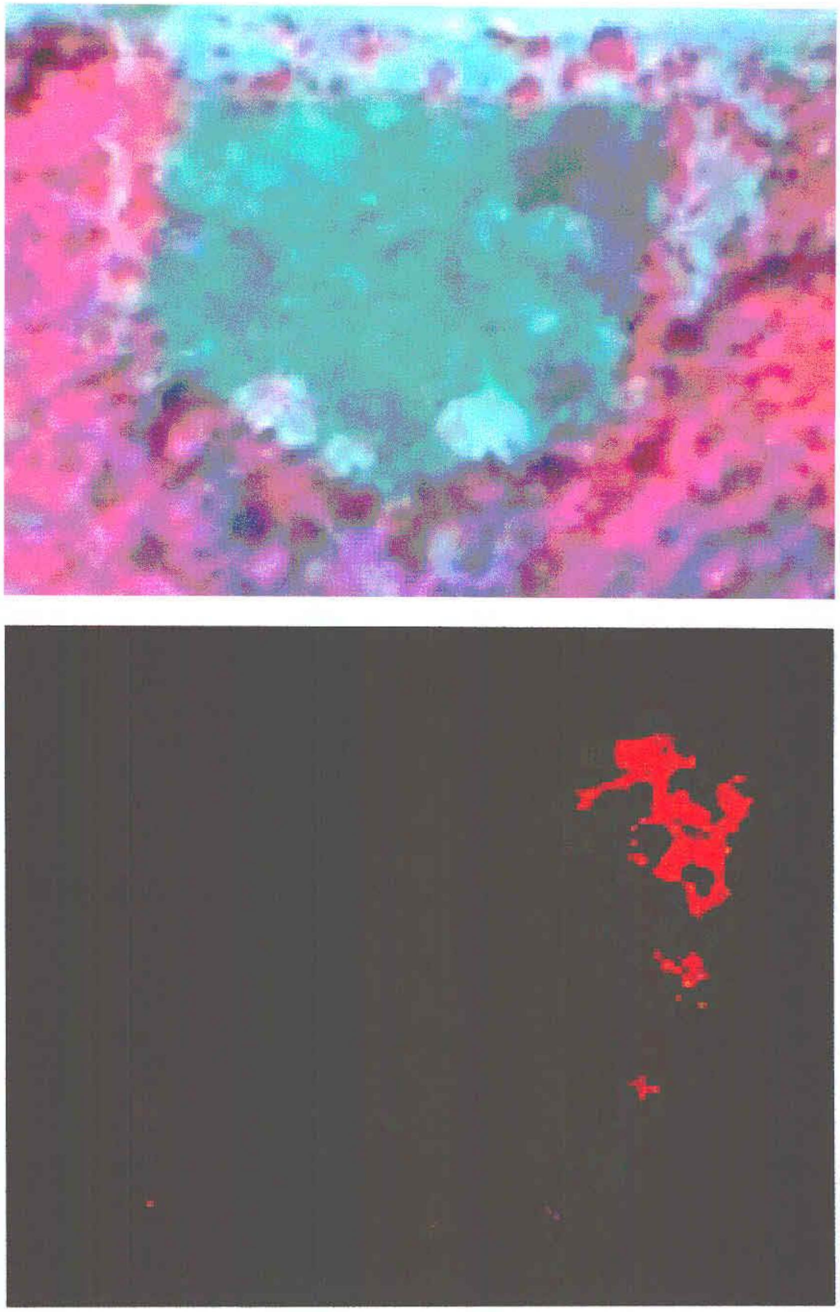


Figure 2.8. Mill Dam 2. Accuracy for site was low (30%) due to high species richness and species of similar structure and growth habit. Supervised classification of *P. australis* (right) represents 793 training pixtals taken from the site.

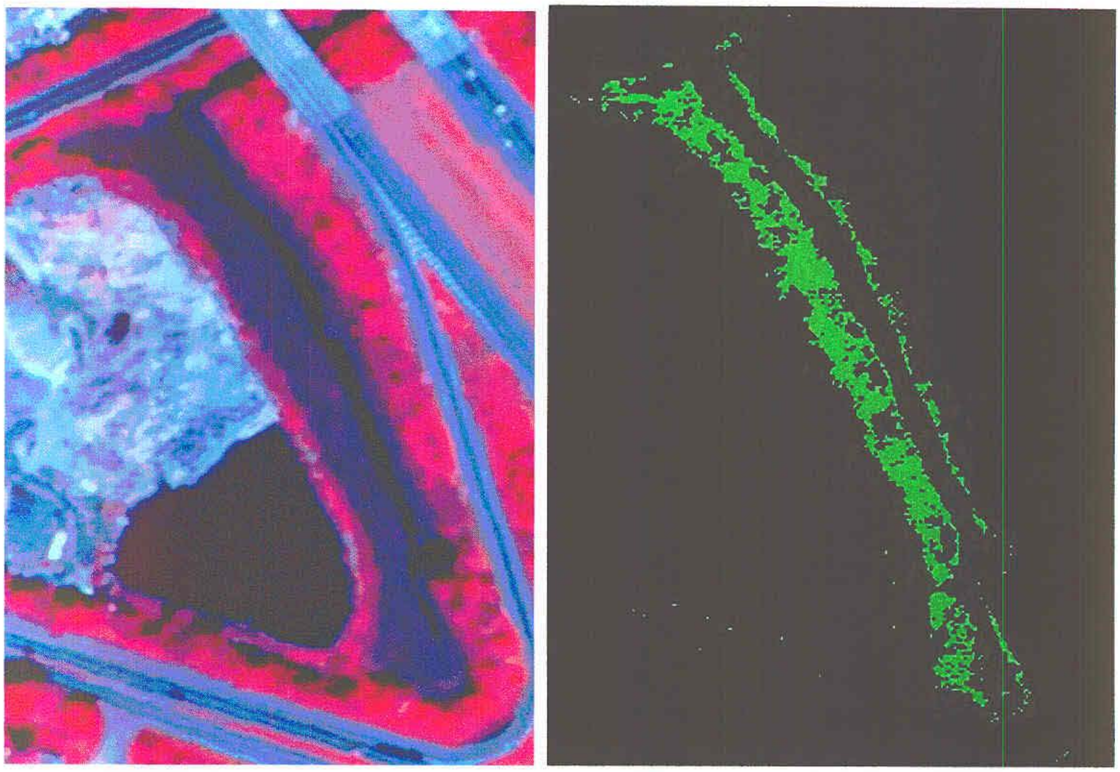


Figure 2.9. Monkey Bottom. Accuracy for site was low (20%) due to presence of species similar in grown habit and highmarsh shrubs. Supervised classification of *P. australis* (bottom) represents 2750 training pixtals taken from the site.

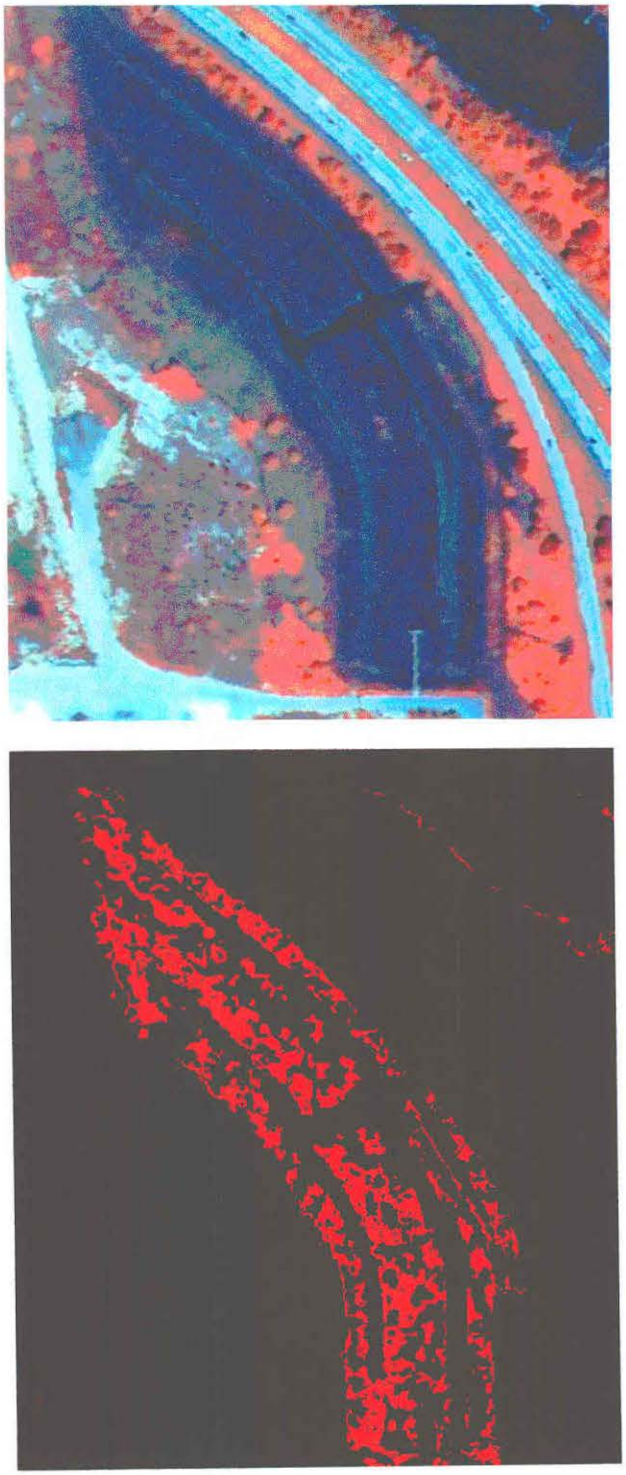
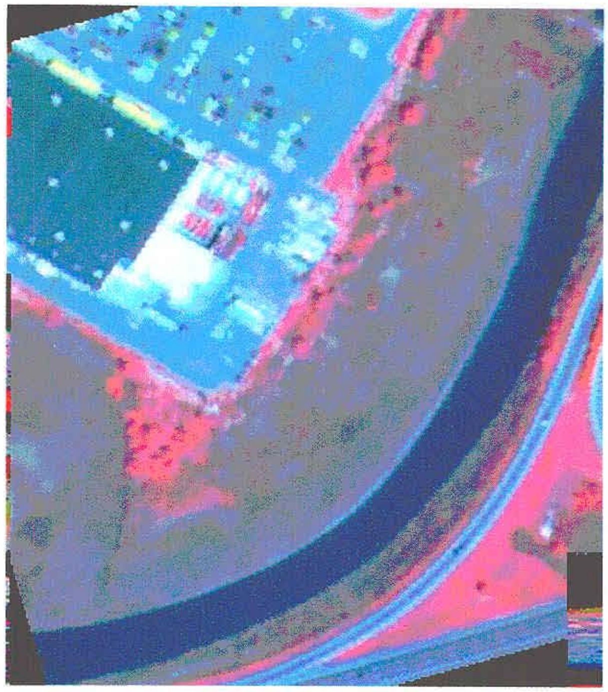


Figure 2.10. Newmarket. Accuracy for site was medium (60%) due to species of similar structure and growth habit. Supervised classification of *P. australis* (bottom) represents 266 training pixtals taken from the site.



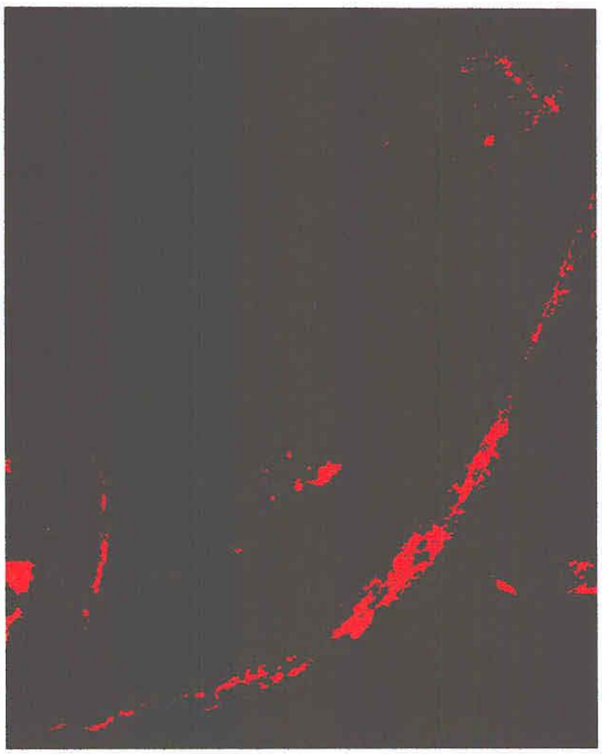


Figure 2.11. Port Authority. Accuracy for site was low (40%) due to high species richness and species of similar structure and growth habit. Supervised classification of *P. australis* (bottom) represents 729 training pixtals taken from the site.

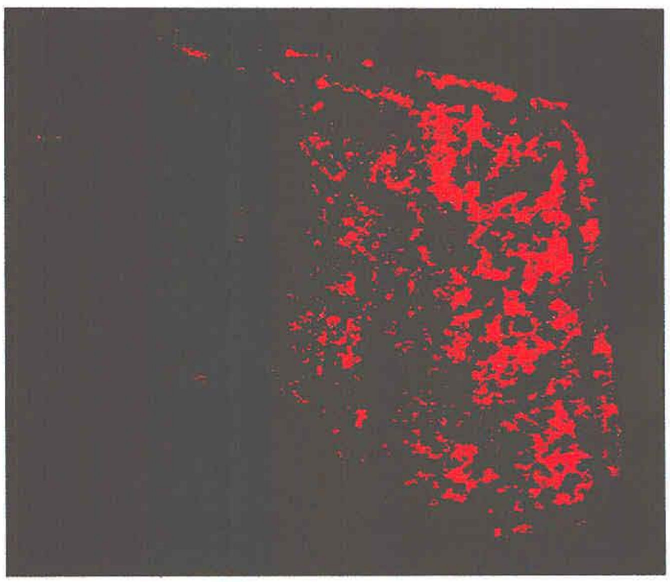
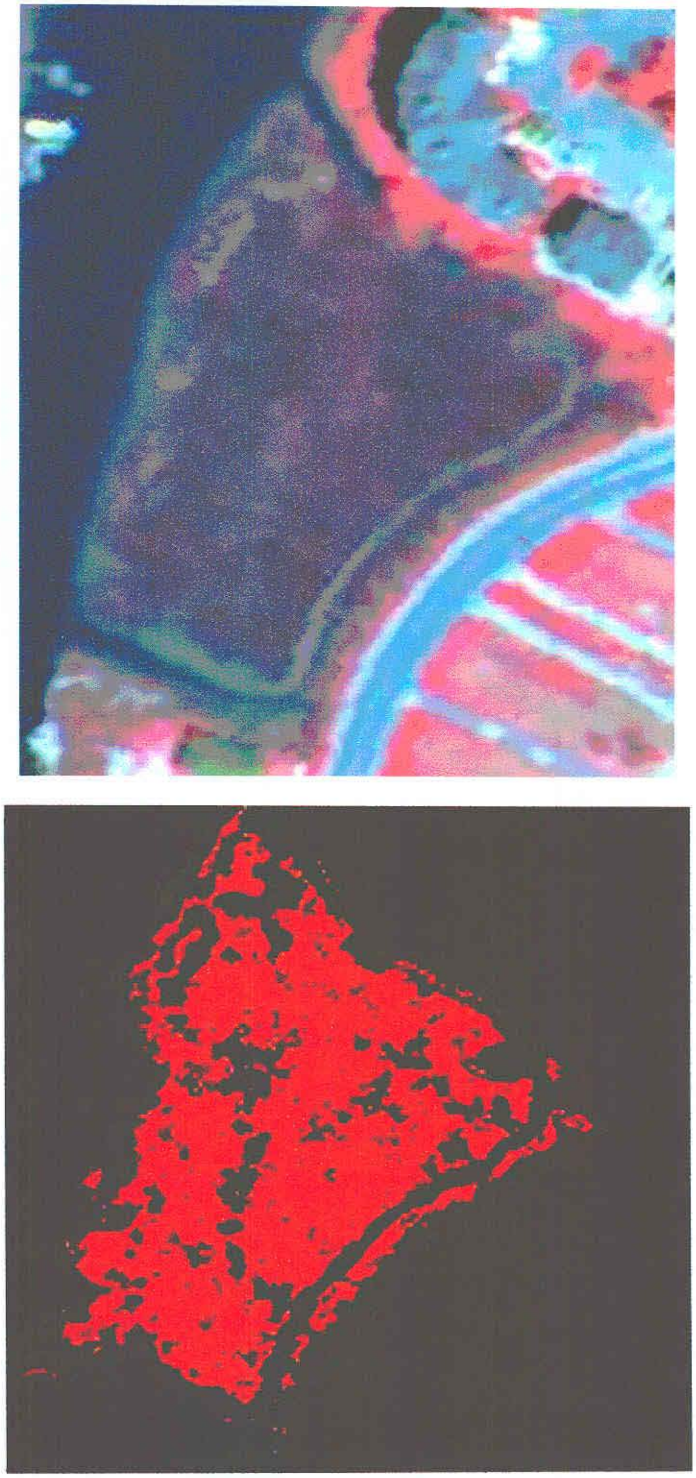


Figure 2.12. Salt Ponds. Accuracy for site was low (<50%) due to species of similar structure and growth habit. Supervised classification of *P. australis* (bottom) represents 524 training pixtals taken from the site.



Part III. A Summary of Methods for Controlling *Phragmites australis*

Libby Norris, James E. Perry, and Kirk J. Havens

I. Chemical Control

Spraying

Chemical spraying is one of the most popular choices of habitat managers. Translocation of the chemical to the root system can successfully kill the entire plant. The challenge lies in correctly timing the spraying application. Chemical spraying is most effective if applied in the fall, when a majority of the plants are in full bloom and leaves are fully open. During this time, the plant is actively moving stored energy from leaves to the complex rhizome system. Taking advantage of this energy shift insures the highest opportunity that the selected chemical will reach the rhizomes. In addition, in temperate zones, more desirable species such *Spartina alterniflora* and *Spartina cynosuroides* may have already begun to senesce reducing the potential for impacts to non-targeted species.

Glyphosate (N-(phosphonomethyl) glycine), sold under the trade name Rodeo ® or Rodeo Pro ® by Monsanto, is the most common herbicide used to control Phragmites. It should be noted, however, that using a high concentration of chemical designed to translocate in the rhizomes (such as glyphosate), can result in top kill of the plant before the herbicide can be translocated properly, thus decreasing the effectiveness of the treatment. It is noted that split applications of glyphosate (at 1/2 dosages) can work better that a single, full strength application. The second dosage should be applied 15-30 days after the first (Cross and Fleming 1989).

The dense nature of *Phragmites* may prevent complete chemical coverage and result in uneven stages of growth. So, repeat treatments may be necessary to maintain control (Brooker 1976). Seasonal burning, used in combination with spraying the vegetation, has been shown effective in reducing the above ground biomass thus increasing the opportunity for complete coverage when spraying (Cross and Fleming 1989).

Wicking

Wipe-on herbicide application, or wicking, has been investigated as a more environmentally acceptable alternative to spray applications. The method utilizes canvas-covered, Speidel ® applicators attached to a boom on each side of the boat or low ground pressure application equipment. The chemical saturates the canvas strips and is only applied to the plants that come in direct contact with the fabric. Chemical application through wicking allows for the targeting of *Phragmites* without affecting the other, often shorter, plant species present in the treatment area. This method can be useful in areas where complete eradication of all vegetation is not desired.

However, care should be taken when using wicking equipment. The equipment can bend and break the plant, reducing the opportunity the chemical will reach the rhizomes and thus reducing the effectiveness of the treatment (Kay 1995). In addition to breaking plant stalks during application, the application boom also may cause much of the taller stalks to bend over and cover the shorter *Phragmites* plants. This can effectively shield the shorter plants from the chemical, therefore reducing the rate of contact with the desired vegetation. In heavy weed stands, a double application in opposite directions may improve the results (Monsanto 1995). Yet, double applications will increase the treatment cost, effort and likelihood of stem breakage.

Sulfide Treatments

Studies have shown that sulfides react with salinity to greatly impact *Phragmites* communities. Many of the die-back symptoms associated with field sites, namely stunted adventitious roots and laterals, bud death, callus blockages of the gas-pathways, and vascular blockages, were particularly acute at higher concentrations of acetic acid and sulfides (Armstrong et al. 1996). It has also been shown that an increase in sulfide in the rhizosphere reduces the ability of *Phragmites* to take up nutrients relative to species such as *Spartina alterniflora* that are better-adapted to sulfuric soil conditions, thus restricting the distribution of *Phragmites* in tidal saltmarshes (Chambers 1998).

II. Mechanical Control

Water Management

Regulating the water level within the treatment area can be used to controlling *Phragmites*. *Phragmites* roots require little oxygen and have well-developed mechanisms of flood tolerance. Therefore, flooding an established colony of *Phragmites* may not be effective (Gries et al. 1990). However, if a water level greater than 30 cm is maintained, colonies will not expand and further increasing water levels can easily kills seedlings.

Tidal flushing can be effective in preventing *Phragmites* from becoming established. But, a coastal location is required and increasing the salinity is more likely to hurt competing plants and the freshwater biota than control *Phragmites* to the desired levels (Cross and Fleming 1989). Due to the dense nature of root and rhizome systems, wave action has been shown to have no effect on established stands of *Phragmites*. In fact, the presence of *Phragmites* actually reduced the amount of erosion normally caused by repeated wave action.

Disking

Disking is more effective than plowing because the chopped rhizome pieces that result are often too small to be viable. The most effective time for cutting rhizomes is late in the growing season. In dry areas, the rhizome fragments may remain above ground to dry out or freeze. Disking in the summer or fall has shown a reduction in stem density during the next growing season. But, disking in late winter to mid-summer has actually stimulated bud production and resulted in *Phragmites* stands with greater stem density (Cross and Fleming 1989).

Bulldozing

Bulldozing can be destructive to *Phragmites* under certain conditions. Removal of vegetation can expose rhizome fragments to killing frosts, or fragments can dry out in non-flooded areas. However, this level of disturbance can also provide ideal growing conditions for *Phragmites*

(Cross and Fleming 1989).

Dredging

Complete removal of *Phragmites* through dredging can be difficult and destructive to the surrounding area. Rhizomes can reach depths of 2 m or more (Haslam 1970). Horizontal rhizomes must be removed and the area must remain deeply flooded (more than 1.5 m) following dredging or regrowth will almost certainly occur (Cross and Fleming 1989).

Seasonal Mowing

Mowing a stand of *Phragmites* has been shown to reduce biomass and increase the available sunlight to competing plant species within the stand. Spring mowings have produced shorter, but more dense, *Phragmites* stands within the same growing season. Yet, mowing for three consecutive summers in Canada resulted in a reduction of *Phragmites* and a replacement of a short grass-sedge-sowthistle meadow (Cross and Fleming 1989).

Cutting

Reducing the above ground biomass through labor intensive cutting has produced mixed results. In one study, fall cutting did not increase species richness (Thompson and Shay 1989). Yet, hand cutting 30-40 cm below the water level in June resulted in total eradication of the *Phragmites* stand (Kay 1995). The level of the cut must be made below water level and a high water level maintained, to allow the shoot bases to become flooded with water from the top. This has been shown to result in the plant rotting beneath the water, especially when the cut is applied twice during one growing season (Husak 1978).

Short-term results were also obtained by cutting the vegetation at the onset of flowering. However, within two years, no significant differences were detected in the above ground biomass between treatment and control plots (Husak 1978).

Plastic Barriers

Applying large plastic sheets to a treatment area can be an effective, non-herbicide option for eradicating *Phragmites*. The site should first be mowed or burned to reduce the height of above ground biomass. Large sheets of 6-mm plastic can then be applied and held in place with stakes, sandbags or chains. As the under plastic temperatures increase, complete surface kill can be achieved in only 3-4 days. An increased application time could eventually kill the rhizomes as their energy storage is depleted and soil temperatures remain high (Boone et al. 1988). Using a clear plastic has been shown effective and it is suggested that using a black plastic could further increase under plastic temperatures.

However, large plastic sheets can be difficult to manage and hold in place, particularly in tidal marshes. Extended time in the sun can also increase the possibility of the plastic to deteriorate into hundreds of tiny pieces, making clean up difficult. Small animals located in the wetland area may be drawn to the warm temperatures located under the plastic sheeting and can potentially tear the material. The sharp tips of *Phragmites* rhizomes have also been known to easily penetrate plastic sheeting.

Perimeter Ditching
During construction of a new tidal wetland site, ditching around the perimeter may be effective in preventing the spread of rhizomes (Havens et al. 1997). While designing a new tidal wetland site, special attention should be given to elevation. In polyhaline areas much of the potential for *Phragmites* invasion can be eliminated by concentrating restoration efforts to below mean high water (Priest 1989). Bare oxidized soils that do not experience regular tidal flooding may be more susceptible to invasion (Pyke and Havens 1999, Bart and Hartman 2000). The project should also include additional steps to eliminate areas available for *Phragmites* development. These steps include planting a high density of vegetation, using mature scrub/shrub species and plantings along the upland berm.

Burning
Controlled burning has traditionally been used by habitat managers as a quick and efficient method for removing above ground biomass and increasing soil nutrients. In fact, it is commonly used in combination with other *Phragmites* control methods such as chemical spraying. However, new discussions are taking place concerning annual burns to control *Phragmites* on wetland properties. Most professionals agree that removing the above ground biomass does indeed allow more sunlight to reach the soil surface and thus increases the opportunity for more desirable plants to sprout and grow. However, it is suggested that removing the above ground biomass on an annual basis may not allow the build up of nutrients to be returned to the wetland soil. In addition, the bare soil following a burn often provides prime disturbed conditions for the establishment of *Phragmites.*

Shading
Seedlings of *Phragmites* are susceptible to shading (Haslam 1971, Kudo and Ito 1988, Ostendorp 1989). Shading by shrubs and trees can reduce the density, height, and the proportion of flowering shoots, and can increase the number of dead tips (Lambert 1946, Kassas 1952, Haslam 1971). In created or restored areas, simply allowing scrub/shrub vegetation to mature can reduce *Phragmites* to a minor component of the vegetative community (Havens et al. 2001).

III. Biological Control

Classical biological weed control is the introduction of host specific natural enemies (usually insects, less often pathogens) from the native range of the pl ant. Over 100 insect species are known to attack *Phragmites* in Europe and about 50% of these are *Phragmites* specialists. This provides ample opportunity to assess their potential as biological control agents (Blossey 2000).

The most promising potential biological control agents are rhizome and shoot mining moths and flies. The highest priority for investigation lies in the rhizome feeding insects, and is followed by the stem and leaf feeders. If an insect is discovered to destroy the rhizomes, the entire *Phragmites* plant will be killed. When the desired control level is met, a controlled burn of the area destroys the insects along with the above ground biomass. Some of the insect species being investigated have recently been introduced to North America and the destructive potential of these species on *Phragmites* is very promising (Blossey 2000).

Summary

Although *Phragmites* is considered to be an invasive wetland species in North America, it can play a positive role in wetland habitat management. Waterfowl species benefit from *Phragmites* when the plant stands are interspersed with open water or with other vegetation. *Phragmites* stems provide cover and nesting habitat, and rhizomes provide a food source for waterbirds and small mammals. Its dense root systems have also been used to strengthen dikes and roads and reduce beach erosion.

The key may lie in integrated management of *Phragmites*. The first important step is deciding what level of control is needed for a stand. In some cases, although a monoculture of *Phragmites* exists, the best decision may be not to apply any control methods to the area. Yet, if it is decided that *Phragmites* control is part of an overall management plan, careful steps should be taken to select a control method.

When it is decided that action must be taken to decrease the amount of *Phragmites* in an area, having a plan and clear objectives is important. It is also crucial that the management plan include a long term monitoring program to insure the desired results are maintained. It was once thought that a 5-year monitoring plan was sufficient. However, monitoring for a longer time period is more likely the case (Mitsch and Wilson 1996, Havens et al. 1997).

Literature Cited

Ailstock, M.S. 2000. Adaptive Strategies of Common Reed *Phragmites australis*. *Phragmites* in Virginia: A Management Symposium; 2000 December 14; Library of Virginia, Richmond, Virginia.

Armstrong, J., F. Afreen-Zobayed and W. Armstrong. 1996. *Phragmites* die-back: sulfide-and acetic acid-induced bud and root death, lignifications, and blockages within aeration and vascular systems. New Phytologist 134(4): 601-614.

Barnard Jr., T.A., C.H. Hershner, and M. Greiner. 1997. The Oldest Operating Wetland Mitigation Bank in The U.S. Technical Report 97-7. Virginia Institute of Marine Science, College of William and Mary.

Bart, D. and J.M. Hartman. 2000. Environmental determinants of *Phragmites australis* expansion in a New Jersey salt marsh: an experimental approach. OIKOS 89: 59-69.

Boone, J., E. Furbish, K. Turner, and S. Bratton. 1988. Clear plastic. A non-chemical herbicide. Restoration & Management Notes 6(2): 101.

Brooker, M.P. 1976. The Ecological Effects of the Use of Dalapon and 2,4-D for Drainage Channel Management. Arch. Hydrobiol. 78(3): 396-412.

Caffrey, J.M. 1996. Glyphosate in fisheries management. Hydrobiologia 340: 259-263.

Chambers, R.M. 1997. Porewater Chemistry Associated with *Phragmites* and *Spartina* in a Connecticut Tidal Marsh. Wetlands 17(3): 360-367.

Cross, D.H. and K.L. Fleming. 1989. Control of *Phragmites* or Common Reed. USFWS Leaflet 13.4.12.

Gries, C., L. Kappen, and R. Losch. 1990. Mechanism of flood tolerance in reed, *Phragmites australis* (Cav.) Trin. Ex Steudel. The New Phytologist 114: 589-593.

Haslam, S.M. 1970. The performance of *Phragmites* communis in relation to water supply. Annals of Botany 34: 867-877.

Haslam, S. M. 1971. Community regulation in *Phragmites communis* Trin. II. Mixed stands. J. Ecol. 59:75-88.

Havens, K.J., J. Perry, J. Anderson, H. Berquist, L. Norris, W.I. Priest. 2001. Status and trends of *Phragmites australis* invasion within constructed wetlands. Final Report to the U.S. Environmental Protection Agency. College of William and Mary, School of Marine Science, Virginia Institute of Marine Science.

Havens, K.J., W. I. Priest, III and H. Berquist. 1997. Investigation and Long-Term Monitoring of *Phragmites australis* Within Virginia's Constructed Wetland Sites. Environmental Management 12(4): 599-605.

Husak, S. Control of Reed and Reed Mace Stands by Cutting. 1978. In D. dykyjova and J. Kvet eds. Pond Littoral Ecosystems, Structure and Functioning. New York: Springer-Verlag, 1978: 404-408.

Kassas, M. 1952. Studies in the ecology of Chippenham fen. III. The Forty Acre wood. J. Ecol. 40:50-61.

Kay, S. 1995. Efficacy of Wipe-on Applications of Glyphosate and Imazapyr on Common Reed in Aquatic Sites. Journal of Aquatic Management 33: 25-26.

Kudo, G. and K. Ito. 1988. Rhizome development of Phragmites australis in a reed community. Ecological Research 3: 239-252.

Lambert, J. M. 1946. The distribution and status of *Glyceria maxima* (Hartm.) Holmb. In the region of Surlingham and Rockland Broads, Norfolk. J. Ecol. 33:230-67.

Mitsch, W.J., and R.F. Wilson. 1996. Improving the Success of Wetland Creation and Restoration with Know-How, Time, and Self-Design. Ecological Applications 6(1): 77-83.

Monsanto. 1995. Rodeo ® Emerged Aquatic Weed and Brush Herbicide; Complete Directions for Use in Aquatic and Other Noncrop Sites. Leaflet 1995-1: 21061T1-1/CG, 8pp.

Orson, R.A. 1999. A paleoecological assessment of *Phragmites australis* in New England tidal marshes: change in plant community structure during the last few millennia. Biological Invasions 1: 149-158.

Ostendorp, W. 1989. 'Die-back' of reeds in Europe - a critical review of literature. Aquatic Botany 35: 5-26.

Priest, W.I. 1989. Wetlands mitigation evaluation vegetation studies, Monkey Bottom disposal area. Final report to the City of Norfolk. College of William and Mary, School of Marine Science, Virginia Institute of Marine Science. 20pp.

Pyke, C.R., and K.J. Havens. 1999. Distribution of the invasive reed *Phragmites australis* relative to sediment depth in a created wetland. Wetlands 19: 283-287.

Silberhorn, G. 1991. Reed Grass *Phragmites*. Technical report, wetland flora. Wetlands Program College of William and Mary, School of Marine Science, Virginia Institute of Marine Science, 2 pp.

Thompson, D.J. and J.M. Shay. 1989. First-year response of a *Phragmites* marsh community to seasonal burning. Canadian Journal of Botany 67: 1448-1455.

Virginia Natural Heritage Program (VA NHP) Invasive Plant Species of Virginia Fact Sheet. Common Reed (*Phragmites australis* (Cav.) Trin. Ex Steud.) Virginia Department of Conservation & Recreation, Richmond, Virginia USA.