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Error Analysis in Tidal Wetland Inventory Change Detection: Comparison of Historical Mapped Wetlands of the Achilles Quadrangle between 1976 to 1989

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Error Analysis in Tidal Wetland Inventory Change Detection:

Comparison of Historical Mapped Wetlands of the Achilles Quadrangle between 1976 to 1989

A Thesis

Presented to

The Faculty of the School of Marine Science,

The College of William and Mary in Virginia

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

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by

Stacy A. C. Nelson

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of

the requirements for the degree of

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To my family... your belief, encouragement, love and support is truly the only thing that got me through all these years. I love you.

ABSTRACT

Current wetland status and trend analysis has become a valuable tool for policy makers, regional planners, resource managers and also the public. This information allows for the development and implementation of best management practices.

Although technological advances have provided increased levels of accuracy in compiling spatial data, often this information is applied and presented without any consideration of accuracy and the estimate of reliability associated with final product(Goodchild et al., 1989). The illusion of accurately assessed change detection gains and losses can really confuse zoning and planning projects, and qualitative assessment of wetland and upland areas. Applying cumulative errors allow for some fair indication of the amount of real detectable geomorphological changes that can be accurately assessed using the best available best techniques.

Taking into account all the quantifiable estimated potential errors of the 1976 Achilles, VA topographic inventory, the USGS National Map Accuracy Standards of +/-12.2m remains the greatest estimated error. This compounded with a +/-6.0m pen line width error and the +/-6.0m digitizer operator error, can account for an accumulated error of plus or minus approximately +/-24.2m.

Using the best available practices, including remote sensing, GIS, and ERDAS, such high error estimates would not be expected. The newer inventory, using computer aided analysis with minimum amounts of accuracy limited only to the +/-1.5m resolution of the digitally scanned NAPP photographs, combined with +/-1.5m photography resolution from the AUTOCAD files, had a total maximum accumulated error of at least +/-3.0 meters

To reduce cumulative mapping positional errors, it is important to compare actual inventory changes from inventories developed or assessed from like media, such as NAPP to NAPP, or media exhibiting comparable estimates of maximum allowable error. This would establish a common frame of reference from old to new inventories, and substantially decrease the degree of lost accuracy that found in incorporating older techniques.

Error Analysis in Tidal Wetland Inventory Change Detection:

Comparison of Historical Mapped Wetlands of the Achilles

Quadrangle between 1976 to 1989

INTRODUCTION

Purpose

Wetlands have been declared to be a critical natural resource. In coastal areas wetlands are facing the pressure of major population increases. Protection of this resource conflicts directly with the need for additional agricultural, industrial and residential "space". One aspect of this conflict is a determination of the actual changes (particularly losses) in wetlands. This study examines the problems of accurately measuring changes on amounts of coastal wetlands through time.

Activities such as agriculture, construction, industrialization, and increasing residential development have traditionally threatened resources such as tidal wetlands. Society's activities have led to the degradation of water and air quality, chemical loading of storm and watershed runoff, increased suspended sediment in runoff, and agricultural and industrial drainage problems. All of these can result in changes in wetland resources. Natural factors also lead to changes in resource boundaries. Natural pressures affecting wetlands include episodic storm events, shoreline erosion, sediment supply, land subsidence and sea level rise.

Although urbanization and natural processes produce real changes in land boundaries over a period of years, detection and documentation of these changes must consider accuracy and cumulative errors inherent in the mapping process. Detailed mapping of approximate wetland boundaries has fast become an important tool for policy makers, regional planners, land and wetland managers, and the public. Mapping can provide site specific information which is valuable in making appropriate decisions regarding proper use and management of the resource (Pywell and Wilen, 1991). The purpose of this study was to determine if accurate assessment of tidal wetland changes can be made by comparison of tidal wetland maps produced with modern digital photogrammetry techniques to tidal wetland maps based upon USGS topographic maps.

Ecologists or resource planners have attempted to relate declines in commercial fisheries to wetland quality and quantity status and trends (see Tiner, 1984). Coastal managers and planners face the inevitable task of resolving the competing demands on wetlands. An accurate definable method of accessing real losses can help resolve disputes over wetland resource management.

This study compares 1976 and 1989 tidal wetland inventories in the Achilles, Virginia Quadrangle in order to achieve a better understanding of error sources and estimates in historical (1976) and new (1989) inventories by considering quantifiable errors inherent in the mapping, classification and inventory composition of tidal wetland. The 1976 inventory (old inventory) was developed by conventional classification and mapping methods. The 1989 inventory (new inventory) was developed by supervised automated classification of digitally scanned vertical aerial photographs. Mapping errors for both inventories were assessed using the best available information. An image processing software package, Earth Resources Data Analysis System (ERDAS) and the Geographic Information System ARC/INFO, was used to overlay the two inventories and evaluate the landcover differences in the study area. From this study general observations about accuracy of old and new inventories, possibilities for change detection in light of these accuracies, and management implications can be derived.

The Resource

Wetland Trends

George E. M. Newbury (1981), in a Department of the U.S. Army Corps of Engineers Topographic Laboratories Report, stated;

> "... wetland habitats of North America have changed greatly since the colonization by the Europeans. Man has drained marshes, filled swamps and laid bare hillsides. Nature has altered sea level and filled bays with sediments eroded from the denuded hillsides. The interaction of man and nature often alters wetlands more quickly than either would when acting separately. The results of the interaction between man and nature may be easily viewed in many areas."

Wetlands, originally viewed as only breeding grounds for rats and mosquitoes, and as nonfunctional wastelands, are today understood to be invaluable natural resources essential to the productivity of coastal and marine systems (Virginia Council on the Environment, 1989). Wetland functions include: production of oxygen and conversion of atmospheric nitrogen into a form that could be readily used by plants and animals to make proteins; trapping of sediment to improve water quality; removal of coliform bacteria, heavy metals, pesticides, and toxic chemicals from run-off; providing flood protection; serving as a feeding and nursery ground for fish, waterfowl, and other wetland inhabitants; and providing shoreline stability by dissipating current and wave energy (Council on Environmental Quality, 1989). Wetlands also have social/economic importance for their support of activities such as hunting, fishing and trapping.

The number of wetlands existing in the United States since settlement has declined rapidly. According to reports by the U.S. Fish and Wildlife Service (Tiner, 1984; Tiner et al., 1994; Wilen and Frayer, 1990; Dahl 1990; Dahl et al., 1991) and the National Wildlife Federation (Feierabend and Zelazny, 1987), an estimate of over 200 million acres of wetlands were present in the conterminous United States in the early 1700's. The numbers dwindled to somewhere between 86 to 99 million acres between the 1950's and the 1970's. From 1954 to 1974 the Fish and Wildlife Service (FWS) reported that wetland losses averaged 550,000 acres per year (Feierabend and Zelazny, 1987). By the mid-1980's total wetland acreage constituted approximately 5.0 percent of the conterminous U.S. (Dahl et al. 1991).

Wetland loses have been attributed to a number of causes such as agricultural land conversions, urbanization, and erosive natural pressures. Large agricultural drain and fill conversions account for as much as 54 percent of total wetland losses between the mid-1950's and the 1970's (Dahl et al. 1991). Urban land use conversions, within this period, have accounted for approximately 5 percent of wetland losses. FWS estimates that of the 86 to 99 million remaining acres of wetlands within the continental United States, 30 million acres are polluted or contaminated that their functionality is so limited that they are essentially useless (Feierabend and Zelazny, 1987).

A study conducted by Cashin et al. (1992) investigated the alteration trends of North Carolina coastal plain wetlands. The author found that over 50% of the historical wetlands within the study area no longer performed their original roles since being altered during the early eighties. From the 1950's to 1980's approximately 15.9% of the historical wetlands endured alteration such that they could no longer support their original wetland functions and values. Over 50% of the alteration was caused by the conversion of these wetlands for forestry purposes, and 40% by conversion agriculture. Remaining changes were attributed to urbanization, road construction and rural residential development.

Kiraly (1989) proposed that the key to future ecosystem research is to understand cumulative effects on the quantity and quality of coastal habitats and ecosystems. Since the U.S. Fish and Wildlife Service estimates of wetland loss rates are as much as ten years out of date they do not adequately provide information on rapidly changing areas. Kiraly (1989) also pointed out that we do not have a clear understanding of how human activity and natural processes effect the habitats. Without this information our understanding of these areas remains speculative at best.

According to Stachecki (1987), considerable wetland losses have resulted from agricultural and intensive development activities. Specifically wetlands in particular are being filled or dredged for construction without legal authorization or without sound environmental planning. Deegan et al. (1984) found that in the Mississippi River Deltaic Plain region of southern Louisiana, natural factors and human modifications have led to an estimated annual loss of 10,200 acres of coastal marsh.

Scaife et al. (1983) determined that annual coastal land loss in the sedimentary deltaic plain of southern Louisiana is related to impacts caused by man-made canals, which interrupt the regional hydrologic regimes. For Virginia, Wright (1988) cited an example of the loss of an environmentally important wetland habitat that supported a number of local plants and animal species, as a result of economic development pressure in the 1950's.

The only way to accurately determine the significant occurrence of different types of land loss, according to Penland (1990), is to develop a suitable classification for quantitatively mapping the spatial distribution and contribution of each morphologic type lost to the total amount of land lost over a given interval of time. Land-use change studies have characterized three classes of impacts associated with urbanization including: nonpoint source pollution associated with runoff from urbanized areas; preemption of wetland habitats for local, state, and federal acquisition; and modification of stream environment zones, including ditching, draining, burning, logging, stand conversion, etc. of adjacent wetland or upland areas (McCreary et al., 1992).

Quantifying the Resource

Surveying, line transets, and aerial photography, are among the mapping techniques used as early as 1929 to map the present distribution of wetland habitats (Newbury, 1981). However, since the 1980's, remote sensing techniques have become more popular in the delineation of wetlands. Tortell (1992) believes that one of the most effective instruments for providing successful management of the coastal zone are resource maps and atlases. Computer technology and digital analysis applications support development of maps and atlases using remote sensing techniques.

With available technological advances, many attempts are now being made to compile data from a collage of sources using a suite of techniques to form a "best available information" approach. Geographic Information Systems (GIS) are widely being applied to critical coastal resource management issues. Compared to traditional means, GIS provides researchers with the ability to make rapid and appropriate decisions affecting the environment (Ricketts, 1992).

Other authors have fused processes together in an effort to provide better approaches to collecting data from remotely sensed sources, such as photogrammetry. Williams and Lyon (1991), evaluating historical wetland changes in the St. Marys River, Michigan, incorporated GIS with a digital data base constructed by photo interpretation, mapping, and digitization of aerial photographs. It was found that the greatest variations occurred in the areas of emergent wetlands and scrub-shrub populations, which seemingly corresponded to variations in the water level.

Photogrammetry

Maps and charts, derived solely from field measurements, have proven valuable for coastal research, but alone they generally fail to provide accurate accounts of boundary or coastline changes (Jones, 1969). However, mapping techniques coupled with aerial photography have been used by scientists such as McBride et al. (1991), to document rapidly changing shoreline positions.

The use of photographic records allowing observers easier access to information as compared to single or very limited opinions complied from laborious field collected data

(Williams and Lavelle, 1990). Another advantage of aerial photographs over maps or charts is that the photographs capture ground details, whereas maps and charts show only selected details that have been subjected to human interpretation (Stafford and Langfelder, 1971).

Silberbauer and King (1991) found that a combination of both photogrammetry and field surveys tends to be the most accurate method of mapping wetlands. According to Fuller et al. (1986) aerial photointerpretation incorporated in the mapping process has resulted in maps that show the distributions and patterns of coastal changes to a standard and accuracy not possible with conventional map analysis techniques. Although field verification can not completely be eliminated or substituted, high-resolution, color infrared photography has been proven useful in delineation of both tidal and non-tidal wetland and upland boundaries (Anderson and Roos, 1991).

In a study of spatial and temporal changes in Louisiana's Barataria Basin Marshes, between 1945 and 1980, Sasser et al. (1986) discovered that marsh loss rates have increased yearly. By examining aerial photographs over the study period using modified versions of software applications developed by the National Aeronautics and Space Administration (NASA), it was revealed that marsh loss was seen to be highest where tidal marshes were subjected to extensive saltwater inundations. In more recent work Hefner and Moorehead (1991) showed, through the use of conventional wetland maps developed from high altitude color infrared photography, that the study area had experienced large wetland losses and that pocosin wetlands have been particularly susceptible to conversions.

The National Aerial Photography Program (NAPP) was initiated in 1987 to acquire and archive photographic coverage of the coterminous United States at 1:40,000 scale using either color infrared or black and white film (Light, 1993). The resolution, geometric quality, and flight parameters produced from the operation are used to produce orthophotoquads, digital elevation models, topographic maps, and digital information to meet National Map Accuracy Standards and to serve as a GIS resource.

Although the use of air photos and wetland mapping techniques have been employed since the 1930's, the combination of photogrammetry, boundary mapping, and computer based GIS has only recently been developed. The combined methods provide an effective and accurate means of assessing humanity's and nature's impact on our wetland resource. This new methodology will allow for better decision making, planning, and management of these areas for years to come.

Many historical tidal wetland inventory map boundaries have been developed from the digitization and classification of USGS topographical maps. This method has margins of error that could be critical when classifying small wetlands, such as fringe or pocket marshes. These marshes cover a much smaller area than extensive marsh systems; however, in some ways their ecological importance may be equal to larger systems.

Presently there is little literature available pertaining to map accuracy and potential cumulative errors associated with detection of tidal wetland and shoreline changes. However, accurate change detection may be critical in determining the stability or impermanence of an area, giving clues to the effects of local current and drift processes, storm events, long-term erosion and accretion, and the adaptive changes vegetation have made over time. Historical shoreline change maps have been developed for much of the U. S. coastline, from maps and nautical charts dating back to the mid-1800s. Although earlier maps and inventories were complied from state of the art techniques at the time of composition, large differences in accuracy have proved the majority of this information unreliable (Leatherman, 1983, Dolan et al., 1980).

Many authors such as Dolan et al. (1980), Anders and Byrnes (1991), Leatherman (1983), and Anderson and Roos (1991) have determined that maps and charts tend to be of questionable accuracy and are frequently restricted in temporal coverage, providing at best only supplemental information in determining historical changes in coastal areas. Aerial photography can generate large data bases which can be utilized in change detection, and multi-temporal analysis (Anderson and Roos, 1991).

The high water line (HWL) has become recognized as the best indicator of the land-water interface (Crowell et al., 1991). This mark is easily recognized in the field and can accurately be located in aerial photographs, as it is distinguished by a change in shore line sediment color, or darken, wet sand. The HWL, representing the landward extent of the last high tide, is often confused with the mean high water line (MHW). The HWL is determined by averaging the height of the high water line over a nineteen-year period (Shallowitz, 1964).

Aerial photogrammetry techniques may prove useful in that truer references or stable points may be evidenced through aerial photogrammetric scanned maps (Anderson and Roos, 1991). Although vertical aerial photographs in the past have not been considered the photogrammetric equivalent of maps due to scale variances (Dolan et al., 1980), new techniques have been developed to reduce these problems.

The scale variations include: (1) radial distortion, which contributes to scale variations away from the photograph's principle point (center of the photograph); (2) camera tilt and pitch distortion, which may be caused by the aircraft's roll, pitch or vibrations at the time of film exposure; (3) scale variations caused by changes in the aircraft's altitude along a flight line; and (4) relief or elevation distortion, which can occur when topographic elevations or depressions occur within the flight track, causing features farther from the lens to appear at a smaller scale than features closer to the lens. However, this last variation is generally not a problem when observing low relief areas such as many coastal areas (Anders and Byrnes, 1991).

Corrective techniques for scale variations have included improved camera optics for reduction of radial distortion, and the use of contact prints to eliminate stretching and shrinking during printing and lens distortions associated with optical enlargements. Tilt and radial distortion can be minizied by only using the center or principle area of the photograph. Image rectification procedures remove scale variations and tilt by using stereoscopic systems to obtain orthophotographic images (rectified aerial photographs). These processes produce vertically rectified aerial photographs (orthophotos) that can be used as regular topographical maps (Anders and Byrnes, 1991).

Rectified vertical aerial photographs converted to digital images and coupled with computer based analysis programs provide a complete method of synoptic area coverage, and also may be useful in determining short term geomorphological changes, such as coastal erosion and accretion (Moffitt, 1969). In addition, aerial photography does not require labor intensive field surveys or extensive data collection procedures to create useful data sets (Anders and Byrnes, 1991). However, other factors of error may still exist, including errors in photograph pixel resolution and interpretation, and digitizing error. Nevertheless, photogrammetric procedures, coupled with available computer software systems, have made it possible to assess accurately areas more readily than conventional methods.

With respect to historical shoreline inventories, carefully rectified and aligned aerial photography can provide accurate determination of past shoreline changes (Crowell et al., 1991). In search of more accurate methods of change assessment, it is important for researchers to understand error sources and estimates in valued classification and mapping in both historical and new inventories.

Regulatory Framework

To combat the loss impending wetland and coastal habitat losses, in 1972, Congress passed the Coastal Zone Management Act. The law provides incentive for coastal states to develop management plans for the use of their coastal regions. The management plans detail all sources of potential coastal-threatening activities, including development and natural factors (Atkin, 1977). The 1972 introduction of Section 404 of the Federal Water Pollution Control Act Amendments and the 1985 Food Security Act's "swampbuster" provisions stipulated that all wetlands and associated boundaries be identified and delineated in agreement with applicable statutes and regulations (Adams et al., 1987).

Introduction of protective policy has led to a number of wetland fair use, permitting, and zoning problems. This is especially true when trying to manage government, state, and local planning of these areas. Status and trend estimates must acknowledge potential error factors, from historical to recent data, or rely on data media or collection procedures with increased accuracy to provide reliable estimates of present or anticipated wetland changes.

Wetland Trends in the Chesapeake Region

A study was initiated by the Fish and Wildlife Service (Tiner et al., 1994) to assess the estimates of wetland status and trends in the 1980's in the Chesapeake Bay watershed. This study employed a stratified random sampling technique also utilized in national wetland trends studies and also in the original Chesapeake Bay watershed wetland trends study (Tiner et al., 1994). This technique involved the selection of 760 four square mile plots for sampling out of the 63,000 square mile watershed. State boundaries, physical subdivisions, and coastal zone boundaries, composed the twelve initial sampling sites for this study. An additional ten sites, based on further physical characteristics of the areas, were established to improve efficiency.

Each plot was analyzed and classified for the type and extent of wetlands it contained, through interpretation of aerial photography corresponding to the seven year span of the study (1982-1989). The present wetland status was recorded on existing National Wetland Inventory maps derived from black and white and color infrared aerial photos. 1:40000 color infrared photos were examined to detect wetland boundary or cover type changes. Wetland status and trends data were exhibited by overlaying base inventory plots with recent ones and scan-digitized for computer analysis. Wetland change was determine for class levels within each system, class aggregations, and for wetland losses or gains. Within the seven year review period of this report, overall recent wetland trends showed a net loss of 23,110 acres of the total 670,000 acres in the Chesapeake watershed at a standard error of >54%. A Net gain of five percent (5,634 acres) in freshwater ponds was reported at a standard error of 55.4%. With such high standard error, a 95 percent confidence limit cannot be achieved to assert positively that the true value is not zero. However, this report remains the most up-to-date information and accuracy on the status and trends of wetlands in the Chesapeake watershed. Use of trend analysis of wetlands change without consideration of errors inherent within the wetland delineation techniques give a false sense of certainty to the results which leave them open to challenge when dealing with specific management issues.

Types of Errors

Standards of accuracy are necessary for the appropriate assessment of cumulative errors. Quantitative measurement errors can broadly be classified into five types; blunders, constant errors, systematic errors, random errors, and potential errors (Table 1.) (Slama,1980).

Blunders are caused completely by human carelessness, and thus are not predictable. A blunder can range from an accidental mistake in normal procedure to an inadvertent miscalculation. This type of error is very common, even among skilled professionals, and may be reduced or detected by repeating the procedure or stringent quality control measures.

Constant errors are attributable to either a measuring instrument or an observer's personal bias. A measuring instrument, perhaps not calibrated properly, can provide a constant error every time it's used to measure the same quantity. These errors produce the same consistent magnitude of inaccuracy that can only be controlled by precise calibrations. Individual bias also may produce this type of error in that an observer may view a certain measurement or factor, as significant or insignificant, based on personal views. It is difficult to correct for personal bias which can only be minimized with proper training, quality control guidelines or consensus building among different interpreters.

Systematic errors, as with constant errors, also may occur in measuring equipment. However, whether these errors are known or not, they tend to occur in more definite patterns. This pattern allows for known systematic errors to be mathematically corrected by modeling expressions and exposing measurements to a wide range of operating conditions to account for environmental influences.

Random errors usually occur from uncontrollable variations in actual measuring instruments as well as human observation. This type of error normally very small, and can be reduced through carefully repeated individual observations and repeated calibrations of measurement equipment. Also, as in systematic errors, measurements should be exposed to a wide range of operating conditions to account for environmental influences.

Potential errors occur in all shoreline change source materials and compilation techniques (McBride et al., 1991). These errors are time-independent and consist of variables such as sources of data, measurement techniques, high water line interpretations and tracing pen line width.

The largest amount of potential error is found in high water line delineation (Table 2), which has been recognized as the best indicator of the land-water interface (Crowell et al., 1991; McBride et al.,1991; Langfelder et al., 1968). Field measured inventories have been found to accumulate approximately a 3 to 4 meter potential measurement error. As much as 10 to 12 meters of potential error is found in some aerial photography interpretations (Anders and Byrnes, 1991).

According to McBride et al. (1991), HWL delineation through photointerpretation is complicated in low relief areas. These areas are problematic due to extremely gentle sloping beaches, poorly developed berms, subtle elevation differences, time of photo vs. tidal phase, wind and wave shifts causing horizontal land-water interface changes, and emergent vegetation growths which can hide the actual upland boundary. Nevertheless, proper ground truthing and adequate photointerpretation experience can minimize these problems. Additional potential errors may be associated with measuring shoreline position from maps and aerial photographs (Table 3) (Anders and Byrnes, 1991).

National Map Accuracy Standards for USGS topographical maps, at a scale of 1:24,000, currently allow a maximum error of +/- 12.2m for 90% of the stable points (Anders and Byrnes, 1991; Council on Information Management, 1992; Leatherman, 1983; U.S. Department of Commerce, 1976). Land/sea interface changes, assessed from the comparison of both present and historical maps, can only be as accurate as the original maps (Crowell et al., 1991). If boundary changes occur within a measured distance less than the sum of the two map's allowable accuracy standards (<+/-24.4m), significance is difficult to prove. Wetland areas smaller than the accuracy standard sum may not even be included in some of the early mapping inventories (Anders and Byrnes, 1991).

Other sources of potential error in these inventories may occur in the mapping and classification process itself. This includes errors in the actual boundary classification or identification, and mapping errors such as scale interpretations and plotting accuracy. Also, errors in historical inventories may be attributable to early unsatisfactory map accuracy standards due to the lack of or few fixed identifiable points, and debate as to the correct location of the actual land-water boundary.

Another source of potential error occurring in HWL delineation stems from pen line width (McBride et al., 1991). A pen line width of 0.25 mm will provide a potential error +/- 2.5 meters at 1:10,000 scale, +/-6.0 meters at 1:24,000, and +/-16.3 meters at 1:65,000 scale. McBride's study showed that using a thinner pen line can reduce this potential error as much as 25% or more. For instance, a pen line width of 0.18 mm will provide a potential error of

+/-3.6 meters at 1:20,000 scale, +/-4.3 meters at 1:24,000 scale, and +/-5.9 meters at 1:33,000.

The study also pointed out that digitizing operator error is also reduced when tracing the thinner outlined shorelines. Operator error, which can be as much as +/-6.0 meters at 1:24,000 scale, may also be decreased by employing the use of large format cursors and digitizers. This equipment can increase the precision of computer digitizing hardware and software to approximately 0.1 mm, producing a potential error of +/-2.0 meters at 1:20,000 scale and +/-2.4m at 1:24,000 scale.

A final source of error is attributable to the selection of inappropriate ground control points for ground truthing and/or georectification procedures. It is important that the selected sites are represented by stable landmarks that guarantee a level of permanency. These are particularly difficult to find in rural or undeveloped regions.

McBride's (et al., 1991) work found that long-term shoreline change rates have a significantly lower potential error than short-term shoreline change rates. When comparing a long-term shoreline change (i.e. greater than 100 years) to a short-term shoreline change study (10-15 years), it was found that the maximum potential error for long term rates was +/- 0.4 to 0.5 meters/year, whereas short-term rates yielded a potential error of as much as +/- 3.4 to 5.1 meters/year.

METHODS

Study Area

Gloucester County, Virginia, has seen a progressive population growth over the last twenty years, from 14,059 people in 1970 to 30,131 in 1990 (Virginia Power,1994). The county's economic base has centered around some agriculture, but timber and seafood harvesting have remained major components (U.S. Department of Agriculture, 1992, Virginia Power, 1994). However, with the county's ever increasing population, the area is now moving towards more of a retail sales and service economy (Virginia Power,1994).

The coastal zone of Gloucester County is composed of over 330 miles of shoreline. This region also includes more than 12,000 acres of wetlands containing numerous swamps, marshes, and submerged grassbeds producing a natural shoreline buffer from erosive conditions (Marcellus and Waas, 1972).

The Achilles area (figure 1)(USGS 7.5-Minute Achilles VA, Quadrangle Topographic Map) is characterized by an abundance of tidal marshes. These marsh areas are made up of several intricate marsh types from Gloucester Point to the Guinea Marshes, and numerous fringing, pocket and creek marshes along the Severn and Ware Rivers to the extensive broad and embayed marshes of Mobjack Bay (Moore, 1976).

Error Analysis of 1976 Inventory

The original Gloucester County Tidal Marsh Inventory (Moore, 1976) was produced as part of Virginia's 1972 Tidal Wetlands Management Act (Figure 2). Inventories were generated to assist in the preservation of the state's tidal marshes and shoreline habitats. The Gloucester County inventory provided comprehensive maps of tidal wetlands, detailing marsh types, locations, boundaries, and vegetative patterns. Although very accurate for its time, the Gloucester inventory didn't have the advantage of today's sophisticated technological advances, such as remote sensing and computer based geographical information systems now widely in use.

Wetland boundaries were delineated from 1:24,000 USGS topographical maps. Field visits, low altitude overflights, and the few available air photos were used to confirm the boundary identifications. Difficulties occurred in estimating area in small regions, such as pocket or narrow fringing marshes, approximately less than one acre, which were not present on topographic maps. These areas were exaggerated and not indicated to scale (Moore, 1976).

Cumulative errors were found in the USGS topo maps which were used as base maps for recording the 1976 inventory (Table 4.). The maximum allowable error for USGS topo maps is plus or minus 12.2m. Boundary changes occurring within a measured distance less than the topo map's 12.2m maximum allowable accuracy standard, may be an insignificant change when detected by the use of a comparable map.

The use of paper topographic maps caused problems in area calculations because differential shrinkage and stretching of maps could not be assessed, especially older maps. Paper shrinkage and stretching occur with age and inadequate care of maps printed on paper medium. Paper tends to shrink and stretch unevenly. Thus, scale changes due to shrinkage or stretching are not the same in both directions. Folds, creases or tears also may impede accurate interpretation. Other equipment that may have attributed to loss of accuracy included planimeters and range finders used for estimating area size. Range finder readings were commonly taken from boats as they were bouncing up and down on the water within sight of the inventory land. It was said by contemporary wetland scientists that it was common for some researchers, after developing some precision in using this instrument, to estimate an area's size without even applying the device, thus introducing a bias error.

Pressure to deliver initial inventories may have caused procedural changes in inventory methods which led to additional errors (Table 5.). Inventory completion deadlines may have limited allowable project time for locating adequate numbers of fixed identifiable points and/or may have produced rushed decisions.

Few low altitude aerial photographs were available. These photos were most likely not vertically rectified aerial photographs (orthophotos), necessary for the reduction of scale variations: radial and elevation distortion, camera tilt and pitch, and scale variations caused by altitude changes (Dolan et al., 1980).

Interpreter accuracy or bias may have caused problems such as map transcription errors and inaccurate land-water boundary delineations. Also, guessing may have provided another source for error accumulation, although a historical inventory provided some room for experienced assumptions. Often it is the investigator's own inductive and deductive reasoning, formulated from personal experience or expertise, that allows for some areas of estimation pertaining to distinguishable wetland and upland boundaries (Anderson and Roos, 1991; McCrain, 1991).

In an attempt to develop a digital based inventory from the tidal wetland information produced in Moore's (1976) work, ten of Moore's original paper tidal marsh inventory (TMI) maps were traced onto a mylar USGS topographic map of the Achilles quadrant and then digitized into ARC/INFO (see appendix I). The ten separate paper tidal marsh maps from Moore's work constituted the entire Achilles quadrant, however due to publication specifications this work was printed in separate 8.5" x 11" page size sections at a scale equal to 1:24,000. The TMI file was digitized into a single USGS quadrant coverage containing all the inventory data. The TMI file was then partitioned to correspond to the ten NAPP image files matching the study area (Figure 3).

Development of the New Inventory

Image Scanning

Composition of the new tidal marsh inventory for the Gloucester County Achilles, VA topo, utilizing current (1995) best available techniques required the use of digitally scanned National Aerial Photography Program (NAPP) photographs and the implementation of ERDAS and ARC/INFO digital mapping software packages. The ten most recent 1989 color IR photographs were acquired through the NAPP. These photographs corresponded to the USGS 7.5 Minute Achilles topo quadrant (see appendix I). These photographs were digitally scanned into the Earth Resources Data Analysis System (ERDAS) as digital image files at 1,000 dpi (25 um). This scanning resolution, greater than the +/-1.5m NAPP photographic resolution, minimized and pixel degradation or loss of resolution from this process. These files were then georectified by aligning coordinate values from highly accurate Gloucester County Planning District AUTOCAD computer files (see appendix II). After careful analysis of the ERDAS digital images, all tidal wetlands within the Achilles study area were classified by highlighting the regions of the images that represented the determined spectral signature for tidal wetlands (Figure 4). Recent low altitude aerial photographs were examined to confirm physical wetland boundary classifications. Tidal wetland vegetative patterns were considered in comparing wetland landward boundary classifications. These files were transferred into ARC/INFO for new versus old inventory comparison and cumulative error analysis.

Detection of Change

The ten image files were then overlaid with the ten matching TMI files. A 54.4m (+/-27.2m) cumulative error buffer zone was calculated for the ten Achilles tidal marsh inventory files. These buffers files were then overlain with the combined TMI/Image files (Figure 5). Tidal wetland areas exceeding the +/-27.2m total maximum allowable estimate of error were evaluated for the possibility of potential real detectable change.

Because of computer hardware and software problems limitations (i.e. low processor speeds, inadequate directory and swap spaces, the inability to handle extremely large file sizes, application crashes or failures, etc.) only one inventory area (corresponding to NAPP photography 1627-144 of the Four Point Marsh Region) was subjected to full analysis (Figure 3). Site inspection of 10 areas with major discrepancies between inventories (Figure 8) were conducted to evaluate if these changes might be attributable to classification, registration changes or real changes.

RESULTS AND DISCUSSION

Cumulative error assessment of the entire Achilles topo region was not possible due to several computer software limitations (i.e., low processor speeds, inadequate directory and swap spaces, the inability to handle extremely large file sizes, application crashes or failures, etc.), the learning curve necessary to implement all procedures, and the time constraints in this project. These limitations should be viewed as an important consideration when critical time lines are being considered. The processing of vectorized raster imagery (as compiled to form the new inventory) has proven to be extremely slow and the most time-consuming element of this project.

The inventory area corresponding to NAPP photography (Four Point Marsh) was processed to demonstrate the potential error associated with cumulative inventory analysis (Figure 3). Error buffers generated for the cumulative mapping errors of the original and new 1627-144 inventories produced a total of 184 hectares (455 acres) within the 54.4m (+/- 27.2m) wide buffer. Ten hectares (24 acres) fell outside of the buffer limits (Figure 6.).

These ten hectares of tidal wetland remain the only detectable areas of potential change within the 1627-144 region. Difficulties occur in accepting these areas of change due to further considerations of potential error. These errors include: **1. Classification Changes,** which result from the dissimilar techniques used to compose the individual new and old inventories, also the variations in tidal wetland upland definitions at the time of the individual inventories. **2. Registration Changes**, which include processes inherent in the computerized classification procedures, such as mapping artifacts and pixel shifts. **3. Potential Real Changes**, including the physical geomorphological changes resulting from processes such as erosion and accretion as well as anthropogenic conversions. Although technological advances have increased the accuracy in compiling spatial data, often this information is applied and presented without any consideration of accuracy and the estimate of reliability associated with the final product (Goodchild and Gopal, 1989). To look at the combined overlay of the two inventories without a regard to errors, there appear to be significant erosional and accretional changes (Figure 7; Table 7). This has a potential to cause a number of management and regulatory problems. The illusion of fine resolution in detection of gains and losses can misguide planning and management of inventoried resources. Consideration of cumulative errors delimits the amount of real detectable geomorphological changes that can be accurately assessed using the best available techniques.

Interpreter accuracy or bias continues to play an important role in accurate image registration. At present there is no clear estimate of this potential error within the GIS/ERDAS registration procedure. Nevertheless, the error attributable to pixel resolutions would appear to be relatively small, and as a result registration errors should be very small. Computer aided image classification may introduce additional error because raster-based systems define precision by cell size. This can be limiting because all cells in a particular classification are assumed to be homogeneous. However, again with high pixel resolutions, such as +/-1.5m, the degree of accuracy loss would be minimal when considering moderate scale levels of change detection.

Changes in base data and methodology can result in large differences in accuracy, and this can complicate appropriate interpretation of apparent change. Consistency in base data and methodology would limit the amount of potential classification error found in the delineation of the upland edge of inventoried tidal wetlands.

Land use changes within the modified study site could largely account for potential change classification errors. The implementation of the different inventory compilation techniques may have also led to misclassification of tidal marsh areas. To resolve some of these uncertainties ten sites of potential change tidal marshes were visited to examine localized changes in these areas (Figure 8).

Site 1 represented an area that was not classified as wetland in the old inventory but appeared as tidal wetland in the new inventory. This land may have been mowed and used for livestock grazing during the compilation of the old inventory. Subsequently the land was allowed to revert to its natural condition. The return of halophytic vegetation produced a signature that was identified spectrally as tidal marsh in the new inventory. This suggests that this area may have been misclassified by the original inventory due to land use practices. Additionally, this area may not have been visible from the survey boats and platforms used in the original inventory; a mature tree line obscures the area from the shore, making it visible only from an aerial perspective.

Site 2 contained a mixed vegetative community composed of *Disticlis spicata*, *Spartina patens*, and large encroachments of salt bush. This area was characterized in the old inventory as tidal wetland, but not in the new inventory. This may be a misclassification error of the new inventory due to a mixed spectral signature resulting from the varied vegetative community; the extensive shrub growth may have caused the area to appear to be upland. Localized ground truthing is necessary to correct for this type of misclassification error.

Site 3 was largely characterized as tidal wetland by the old inventory. The new inventory demonstrated that much of this region is now non tidal and no longer contained the vegetative signatures require for tidal marsh categorization. This area's vegetative community is currently primarily comprised of salt bush, suggesting that the differences between inventories may be either misclassification in the new inventory or a vegetative successional change, where the area may have represented a larger tidal marsh community during the old inventory assessment.

Site 4 as in Site 1 represented an area of tidal wetland in the new inventory. This area may have simply been missed by the old inventory, but it is more likely a misclassification in the new inventory. The site was forested in the early 1970's and has since been cleared and converted to pasture, a very wet but nontidal pasture.

Site 5 appeared on the old inventory as tidal marsh. However, due to land use change, this area did not show up on the new inventory. This area is now comprised of private home, a horse ranch and pasture land. This may have actually been correctly classified as wetland in the old inventory, evident by the amount of standing water currently visible in the center of the livestock pastures.

Site 6 and 7 appeared in Figure 8 as showing coastal retreat based on the comparison of the comparison of the 1976 and 1989 surveys. Field investigation at site 6, however, showed no evidence of erosional or accretional variations. Inventory overlay differences suggest registrational pixel shift errors, occurring in the small scale shoreline contour areas.

Registrational changes occurring within small scale meandering shoreline or creek areas produced a shadow-like change classification.

In contrast, site 7 appeared to contain large erosional shoreline loss areas and large tidal marsh landward encroachments. Site observation revealed historic evidence of relic peat and forest material extending well into the intertidal zone. This, coupled with the fetch across Mobjack Bay, suggests that there has been actual shoreline erosion within the tidal wetland leading edge. The upland expansion may be attributable to salt intrusion and sea level rise, as this area is characterized by high marsh vegetation and forest die-back.

Site 8 appeared to be another location of land use change. This area was classified as a tidal wetland in the old inventory. It has subsequently been developed as a residential subdivision.

Site 9 appeared as tidal wetland in the new inventory but not in the old. Field observation of this location revealed a slow encroachment of *Phragmites communis* communities into the upland hardwood tree line. This upland vegetative expansion may be to sea level encroachment and consequently produced a tidal wetland vegetation spectral signature in the new inventory.

Site 10 may have not been considered in the old inventory due to interior landward location, and low visibility from the shoreline. There is evidence of landward wetland encroachment (*Phragmites communis* especially) , suggesting the new inventory may be correct in indicating expansion of wetlands in this area.

Non-random erosional changes occurring on open water leading marsh edges (site 6 and 7), suggest potential real changes less then the potential error do exist (Figure 8).

However, given such large estimates of cumulative error associated with the cumulative inventory overlay, these changes occur well within the estimated error limits (Figure 6). Precise assessment of these changes would require site specific studies involving reduced cumulative error or higher resolution in the base information.

Taking into account all the quantifiable estimated errors of the original inventory, the USGS National Map Accuracy Standards of +/-12.2m remains the greatest estimated error. This, compounded with a +/-6.0m pen line width error and the +/-6.0m digitizer operator error, can account for an accumulated error of approximately +/-24.2m. An additional +/-2 to 4 meters or more may be added to account for other incidental or inadequate measurements, contributing to an approximate total error of up to +/-28 meters or greater.

Using current (1995) best available practices, with high-resolution aerial photography and state-of-the-art image processing software, such high error estimates would not be expected in modern inventories. The new inventory, using computer aided analysis with minimum amounts of accuracy limited only to the +/-1.5m resolution of the digitally scanned NAPP photographs, combined with +/-1.5m photography resolution from the AUTOCAD files, had a total maximum accumulated error of at least +/-3.0 meters (Table 6.). In effect, the older inventory used in this study is approximately eight times less accurate than the newly composed inventory.

Cumulatively the estimates of potential error can be as large as +/-27m or greater, when contrasting old and new inventories. In a status and trend analysis, changes occurring within this limit may not be confidently assessed as real changes since they may only represent combined inaccuracies of the inventories. Only changes exceeding the +/-27 meter error buffer may be confidently viewed as real geomorphological variations. Specific localized changes less than the +/-27m cumulative error may only be detected by comparing their positions against stable features that can provide a fixed point of reference, such as roads or buildings. Local changes, such as shoreline recessions, might be determined by virtue of their position relative to some fixed object. However, difficulties occur in comprehensive determination of change in boundaries, such as shorelines, when precision depends on the accuracy of successive maps.

With the average rate of natural shoreline erosion in Gloucester County, VA of approximately 0.3m/yr (Marcellus and Wass, 1972), it would take over 80 years to detect a shoreline change exceeding 27 meters. Good management practices require re-inventory frequencies to be determined from inventory accuracies and local average rates of change. Developing status trend analysis with inventories generated from comparisons of like media, providing total cumulative errors of +/-6.0m or less, could be effectively demonstrated with a re-inventorying frequency of about every 10 to 20 years given this rate of change for Gloucester County, VA.

Evaluating changes in resources is generally assumed to require continual updating of the resource inventory. An appropriate interval is 5-10 years (Hershner and Berman, 1993). This frequency allows for current anthropogenic and natural changes to be expressed as well as evaluation of longer term status and trends. In order for this practice to be effective, it is necessary for each consecutive inventory to be as accurate as possible. This enables reputable determinations of current and anticipated changes within the resources (Hershner and Berman, 1993).

High levels of accuracy also will provide a method of accounting for historical errors as newer, more precise techniques become available. However, only by using the most accurate, best available techniques can reliable assessments be made as to the success or inadequacies of current management practices.

Table 1. Types of Errors.

Error Types	**Causes**
Blunders	Human carelessness
Constant Errors	Flaw in measuring equipment or personal bias
Systematic Errors	Flaw in measuring equipment occurring in more systematic patterns
Random Errors	Uncontrollable variations in instruments
Potential Errors	Time independent/consists of variables such as sources of data, measurement techniques, HWL-interpretations and tracing pen line width

Compiled from: Slama, 1980.

Table 2. Potential Errors.

Source	**Amount of Error**
HWL delineation	+/- 10.0-12.0m (field measurements) +/- 3.0-4.0m (aerial photography interpretation)
Pen line width (0.25mm)	+/- 6.0m at 1:24,000 scale
Pen line width (0.18mm)	+/- 4.3m at 1:24.000 scale
Digitization operator error	+/- 6.0m at 1:24,000 scale
Digitization operator error (large format cursor)	+/- 2.4m at 1:24,000 scale
Control point selection	+/- 6.0m at 1:24,000 scale

Compiled from: Anders and Byrnes, 1991; Crowell et al., 1991; McBride et al.,1991; Langfelder et al., 1968; Slama, 1980.

Table 3. Potential Errors Associated with Shoreline Mapping.

ACCURACY		PRECISION
Maps and Charts	**Air Photos**	
scale	interpretation of HWL	annotation of HWL
datum changes	location of control points	digitizing equipment
shrink/stretch	quality of control points	temporal data consistency
surveying standards	aircraft tilt and pitch	media consistency
publication standards	altitude changes (scale)	----
photogrammetric standards	topographic relief	----
projection	negative vs contact prints	----

Complied from: Anders and Byrnes, 1991.

Table 4. Cumulative Errors Associated with Historical Inventory

Source	Amount of Error
Topographic Maps	+/- 12.2m
Pen line width error (0.25mm pen)	+/- 6.0m
Digitizing error	+/- 6.0m
TOTAL	**+/- 24.2m**

Complied from: Anders and Byrnes, 1991, Crowell et al., 1991, and McBride et al., 1991.

Table 5. Additional Potential Error Sources*

Source	**Amount of Error**
Air Photos	+/- 10.0m-12.0m
Rough estimates	+/- 3.0m- 5.0m
Map transcription	+/- 1.0m- 3.0m
TOTAL	**+/- 14.0m-20.0m**

Complied from: Anders and Byrnes, 1991, McBride et al., 1991.

*These additional sources of potential error produces a grand total of approximately +/- 38.2-44.2m. This is just an indication of how large these errors can get. Other factors, if considered could still drive these numbers even higher; however, for the purpose of this study a total maximum allowable error of +/-24.2m assumed for the historical inventory.

Table 6. New Inventory

Source	Amount of Error
NAPP orthophotos	+/- 1.5m resolution
ERDAS boundary classification	+/- 1.5m resolution
TOTAL	**+/- 3.0m**

Complied from: Light, 1993 and Smith et al. 1994.

Table 7. Achilles Tidal Wetland Acreage without estimates of cumulative inventory error

Corresponding NAPP Coverage Areas	1976 Inventory (hectares)	1989 Inventory (hectares)	Area of Agreement (hectares)
1630-15	149	71	45
1627-88	100	71	49
1627-90	187	127	84
1627-91	52	21	14
1627-92	52	18	10
1627-141	98	64	49
1627-142	472	403	328
1627-143	314	289	214
1627-144	248	225	180
1627-145	31	20	13
TOTAL	**1703**	**1309**	**986**

Table 8. Estimated combined inventory with cumulative error buffer.

Corresponding NAPP Coverage Area	Old and New Inventory (Hectares)	Potential Real Change (Hectares)
1627-144	184	10

Figure 1. A map of the Achilles Quadrant, Gloucester County, Virginia.

THE STUDY SITE

USGS 7.5' Achilles Quadrangle

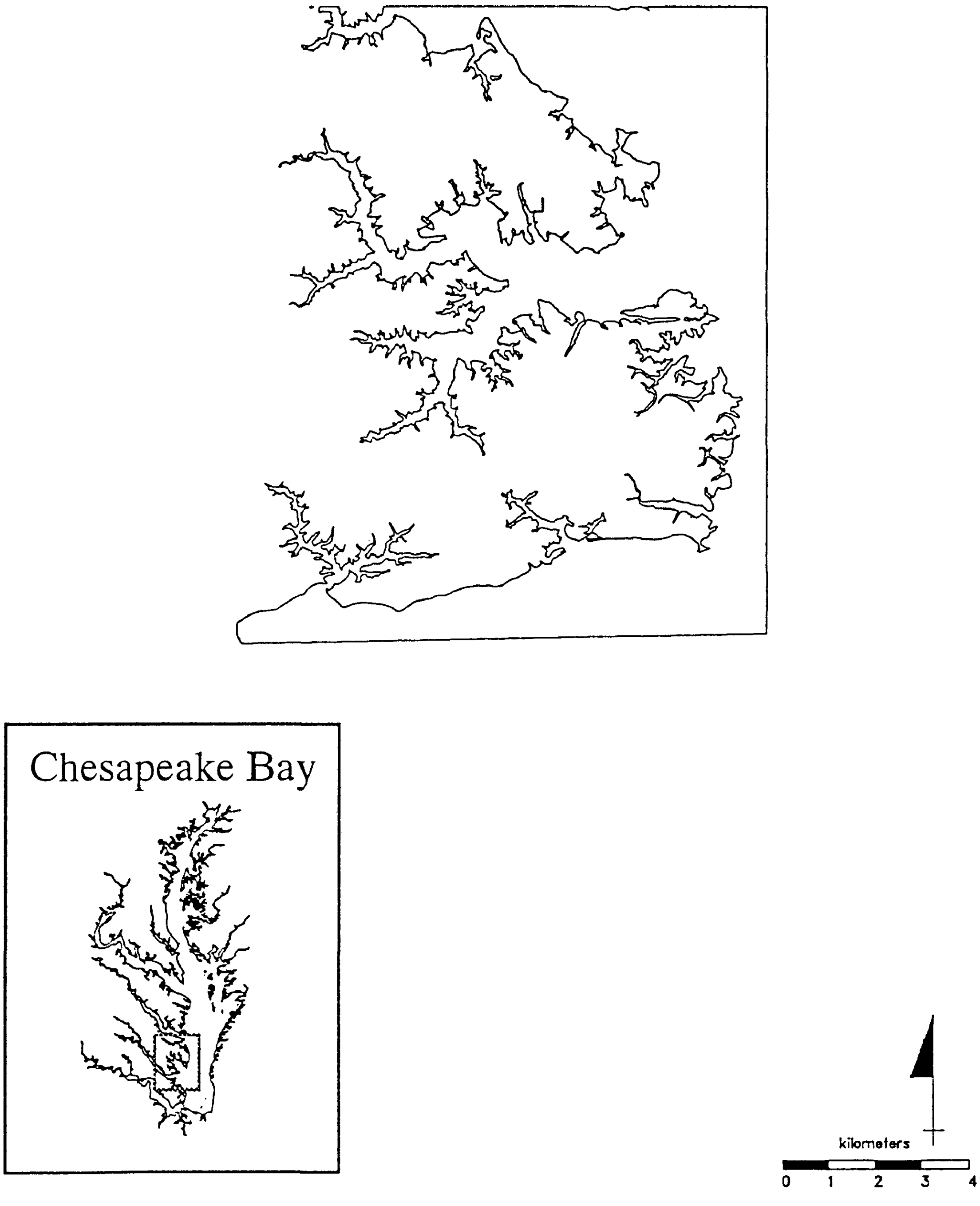


Fig. 1

Figure 2. The original Tidal Marsh Inventory (Moore, 1976).

1976 Tidal Wetland Inventory

Achilles Quadrangle

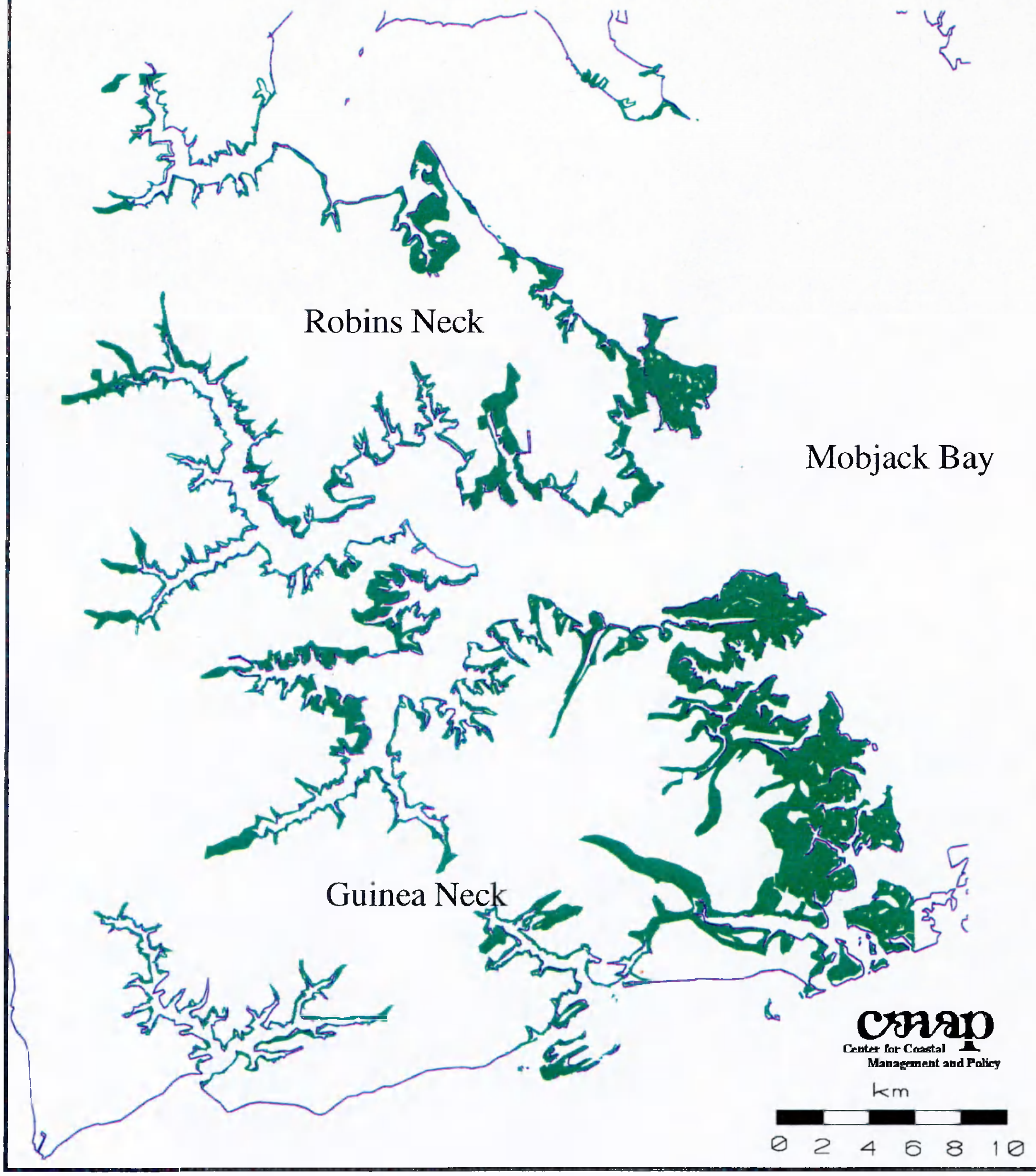


Figure 3. NAPP photography coverage of the Achilles Quad.

Index of NAPP Photography

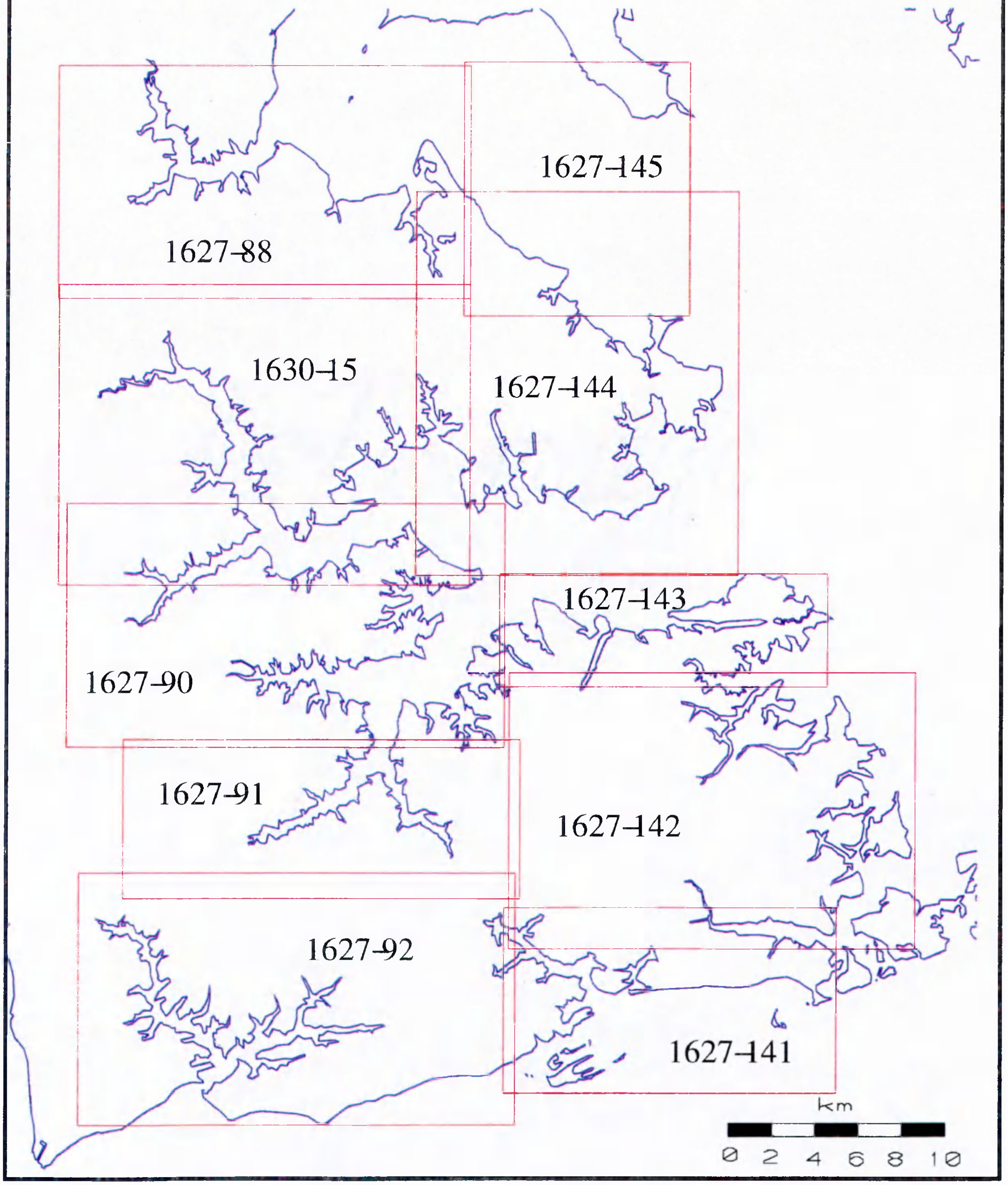


Figure 4. The newly developed 1989 Achilles Quad Tidal Marsh Inventory.

1989 Tidal Wetland Inventory

Achilles Quadrangle

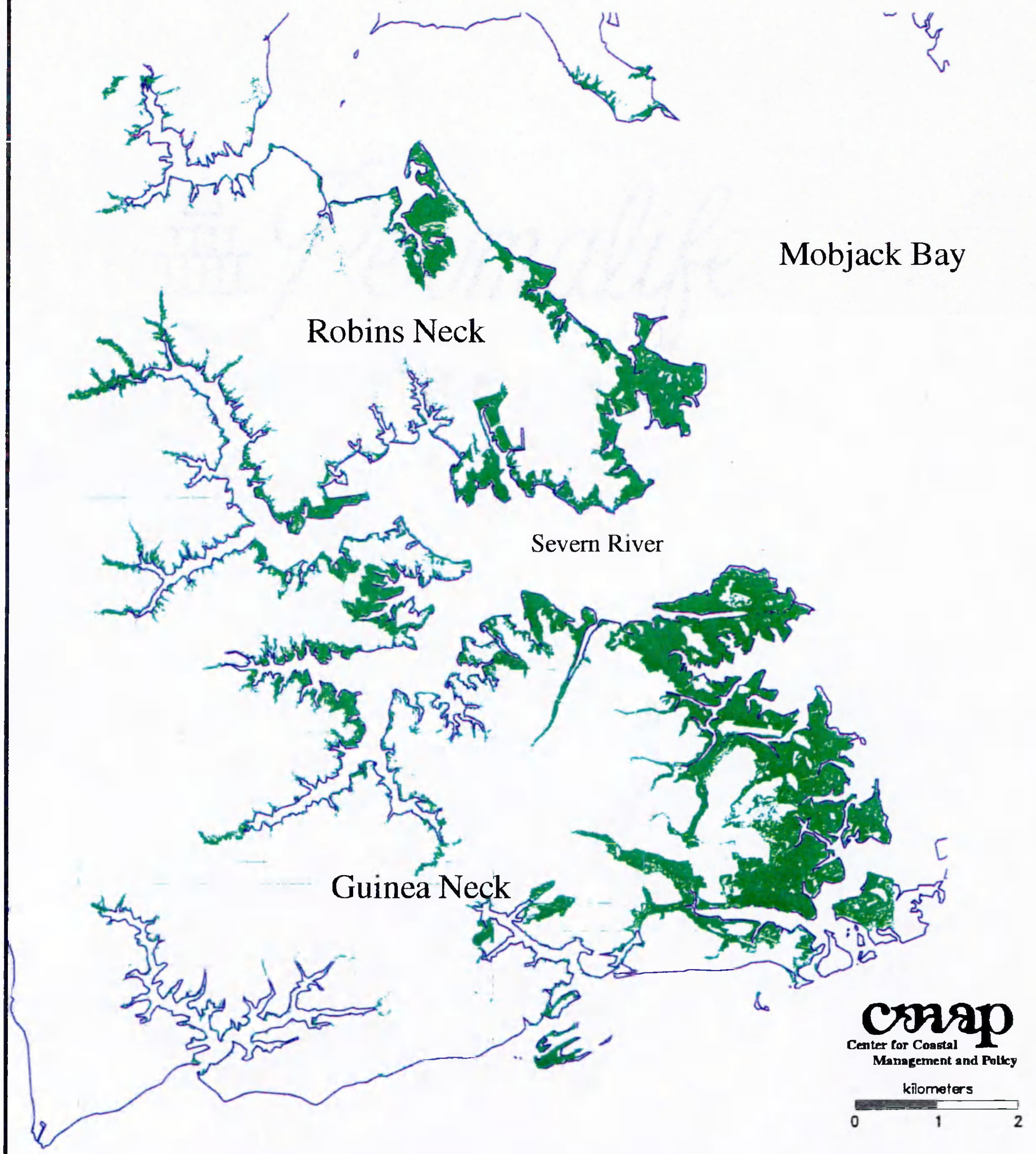


Figure 5. A map of the Old and New Inventories combined without estimates of error.

Tidal Marsh Inventory: 1976 vs. 1989

Achilles, VA Quadrangle

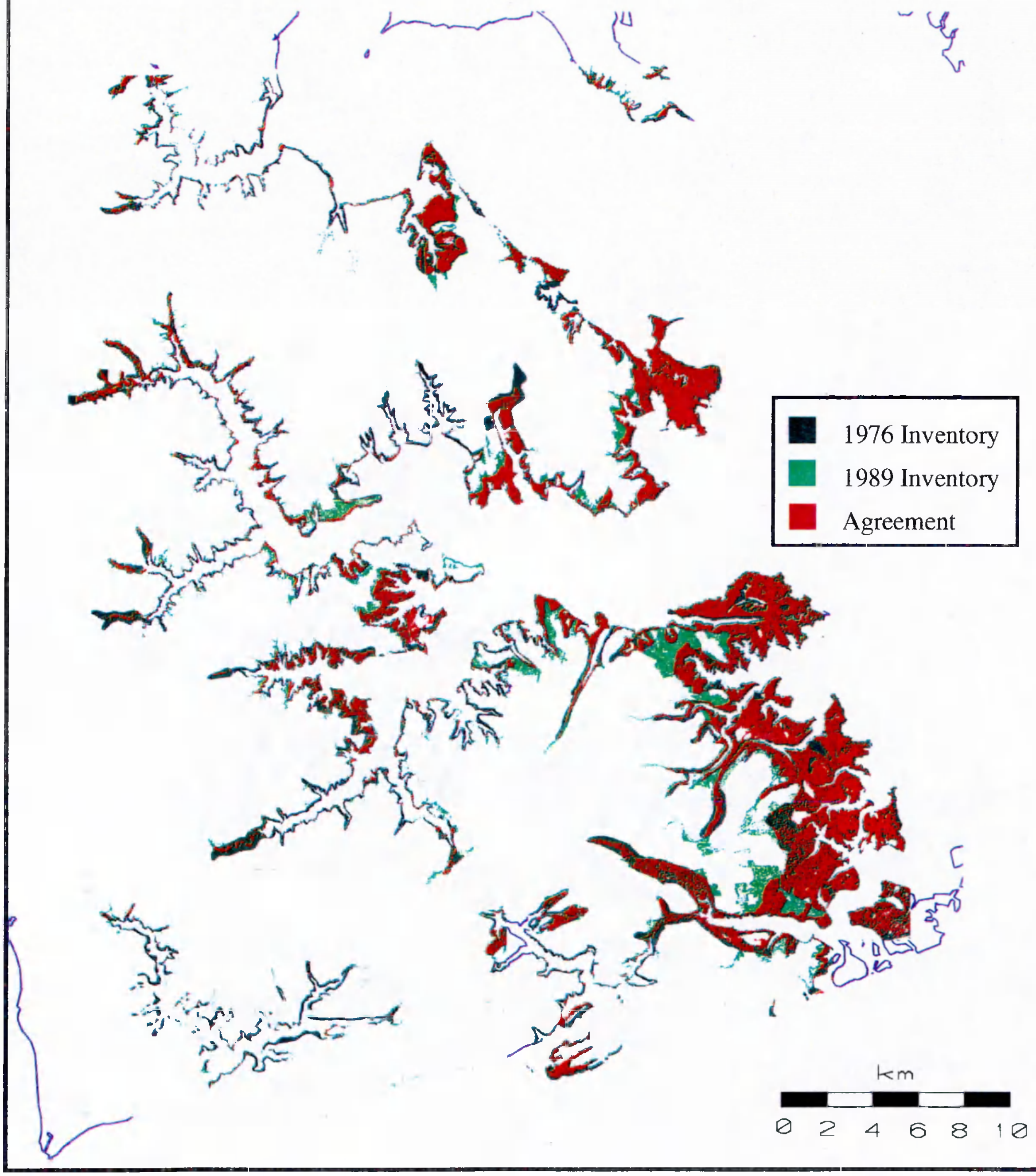


Figure 6. Cumulative Error Buffer associated with Four Point Marsh combined inventory.

Cumulative Error Buffer Associated with Combined Inventory

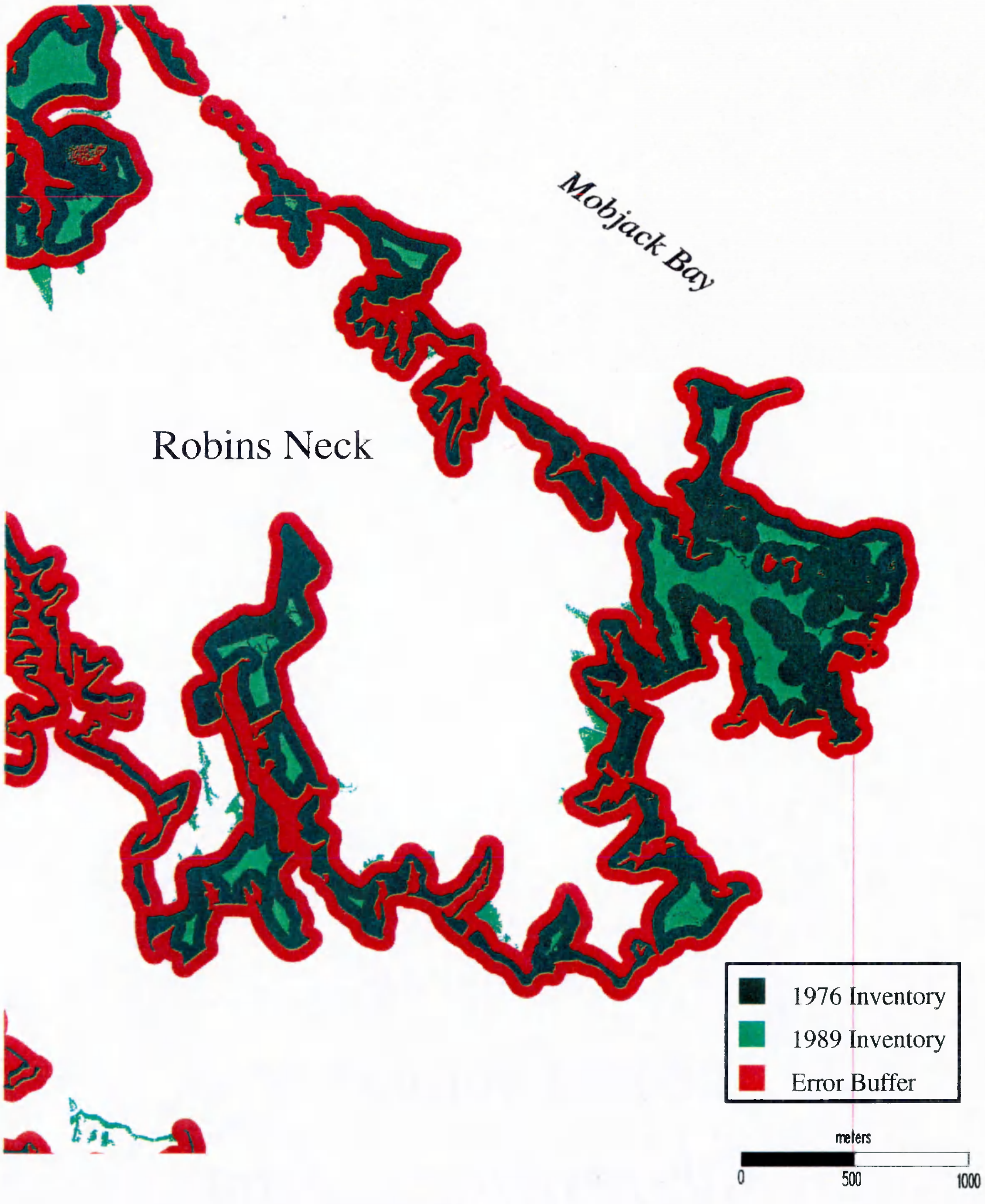


Figure 7. Four Point Marsh Old and New Inventories combined without estimates of error.

Four Point Marsh Tidal Wetland Inventory

Old vs. New

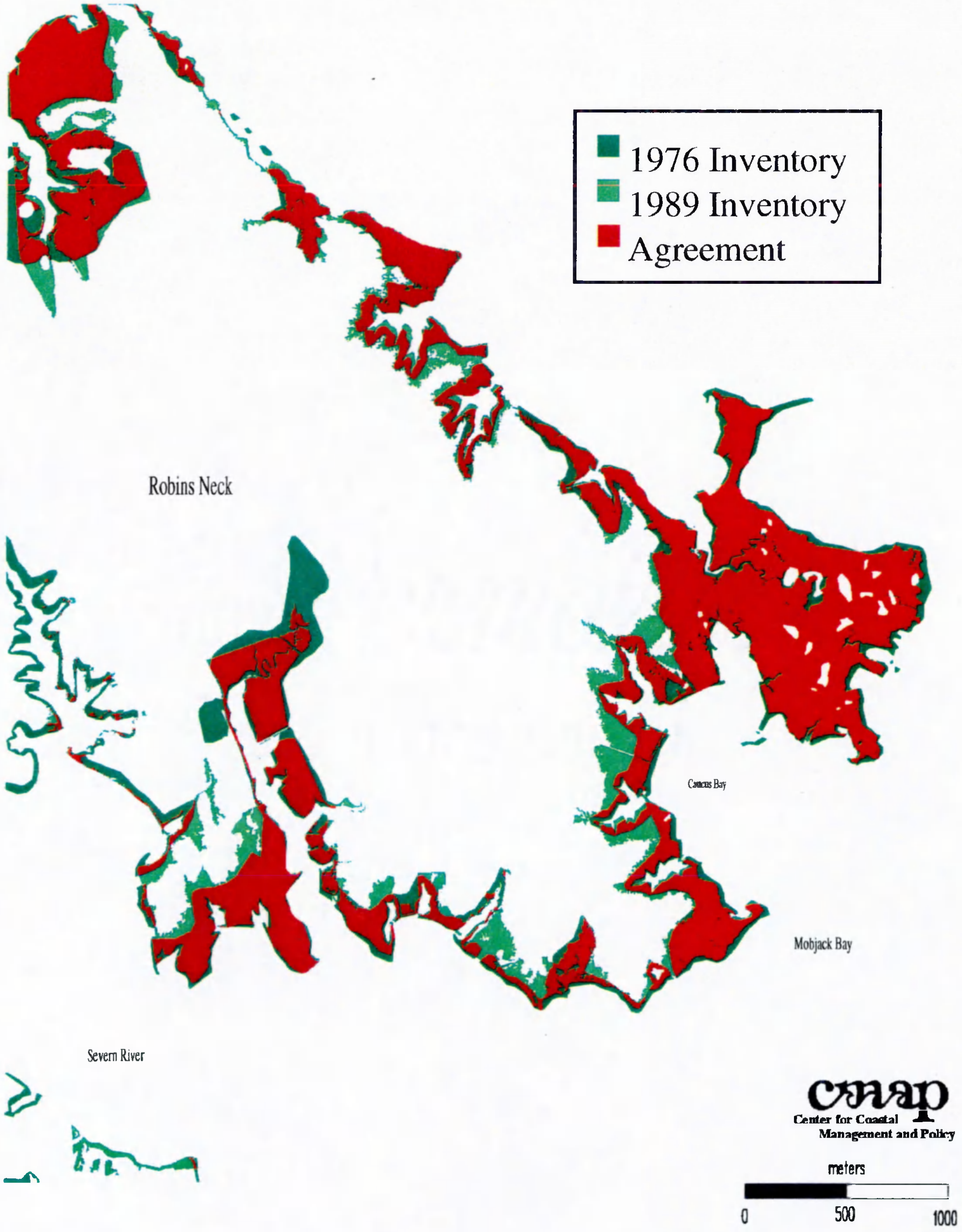
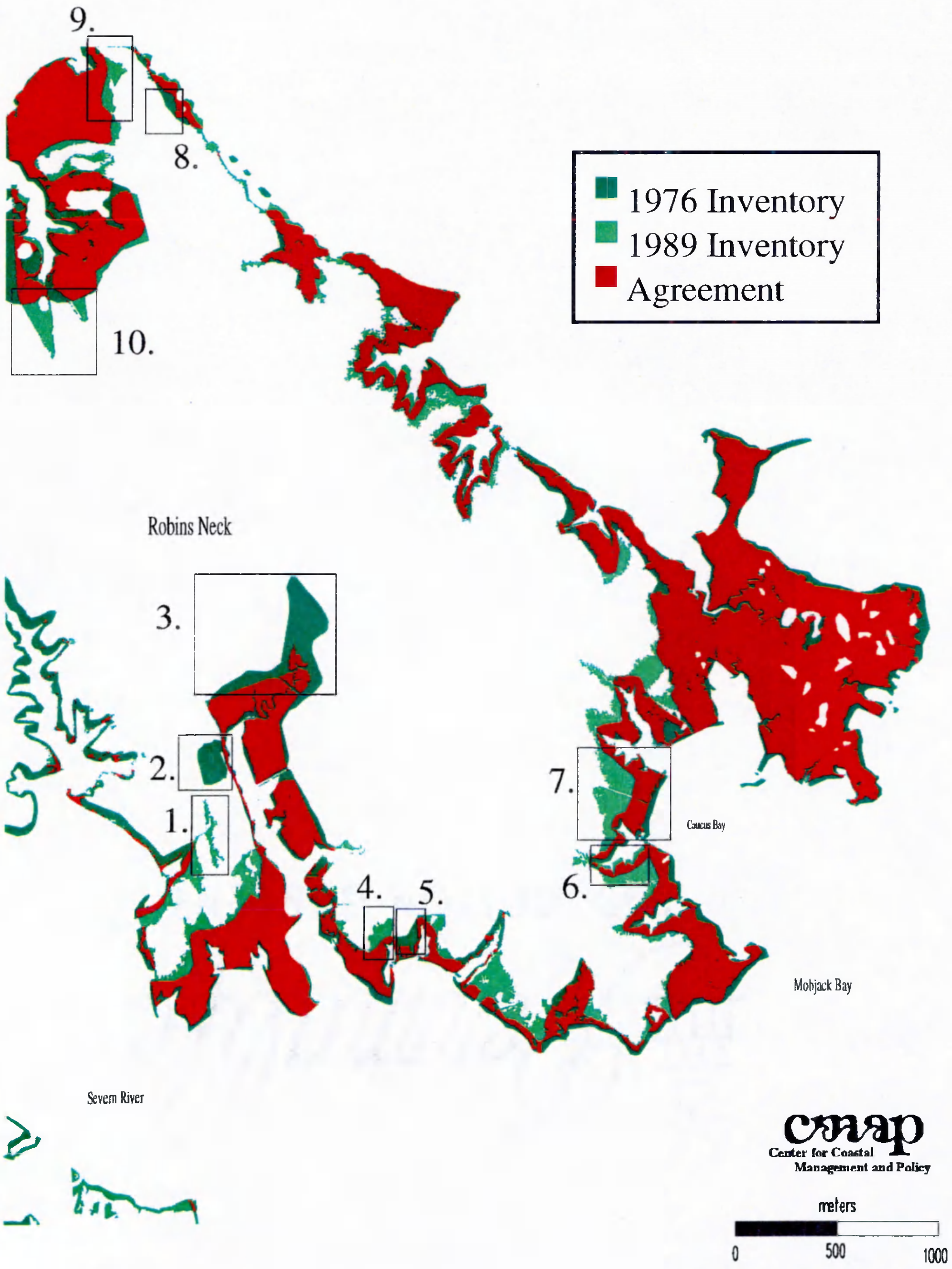


Figure 8. Four Point Marsh Old and New Inventories Potential Change Field Sites.

Four Point Marsh Tidal Wetland Inventory

Potential Change Field Sites



APPENDIX I. Procedural Methods

The ten most recent (1989) digitally scanned National Aerial Photography Program (NAPP) color infrared aerial photographs comprising the Achilles quadrangle, Gloucester County, VA, were used to distinguish wetland and upland boundaries, to create a new, remotely sensed tidal wetlands inventory of the Achilles quadrant. The color infrared photography was acquired through the National Aerial Photography Program at a set scale of 1:40,000 (Light, 1993). These were digitally scanned at 1,000 dpi (25 um) to yield a +/- 1.5m photographic resolution. Only the photograph's principle area, consisting of a center region of approximately 10 cm x 10 cm, was used in this study to minimize photographic error. The photos completely cover the entire Achilles quadrant, with a 60% overlap between each consecutive picture and an approximately 10% overlap between each photograph's principle area.

Stable points were identified within each photo's principle area to provide the necessary georectification coordinate references. This procedure was accomplished by using ground-truthed and rectified Gloucester County computerized AUTOCAD digital map files of the corresponding area, obtained from Gloucester County's Office of Public Works. These data included high resolution (1:2,400) delineations of roadways, buildings, piers, shorelines, etc. (appendix II). The aerial photography used to generate the county's database were taken with highly precise Wilde RC-10 photogrammeteric cameras. These cameras lacked forward motion compensation capabilities, but they were equipped with instrument-guided lens-calibrating monitors for eliminating all camera distortions. These photographs were taken at a 1'= 200" scale with a 1.5m resolution. Since the county database was at scale resolutions equal to or better than the NAPP photography, they provided a highly accurate framework in the absence of a full scale GPS survey.

Georectification (New Inventory)

The rectification process included linking the digitally scanned ERDAS images to corresponding stable points from the corresponding AUTOCAD coverages in an Earth Science Resource Institute ARC/INFO geographic information management system program. AUTOCAD files were identified and selected that correspond to the Achilles study area (see appendix II). These files then were transferred from original DOS based media into a UNIX based ARC/INFO format by use of the DOS2UNIX command. The computer system employed was the SUNN SPARC computer system, containing both ARC/INFO and ERDAS software packages. At this point, the ARC formatted digital files, containing highly accurate shoreline and land use information, were created by the use of the DXFARC command and selecting the following 12 coverage layers;

:0
:Water
:Proad
:Droad
:Dock
:Bridge
:CL-EW-P
:CL-NS-P
:CL-EW-D
:CL-NS-D
:Lakes
:Routes

These files were then appended to correspond with the NAPP photos and imported into ERDAS as vector coverages (.LAN). Corresponding fixed identifiable points were selected from the .LAN and .IMG files. Once in ERDAS the "Transformation Editor" was used to georectify the .IMG files with coordinates selected from the .LAN files, creating highly accurate .IMG files limited only by the resolutions of each media (+/-1.5m).

Duplicate ARC files were created, consisting of only shoreline information, by selecting the following 4 coverage layers;

:0 :Water :Lakes :Docks

These files were appended to duplicate the ten NAPP digitally scanned image files and imported into ERDAS. All arc or line dangles and breaks were snapped or weeded together. These files were then used as templates for removing the open water areas from the .IMG files. This procedure was accomplished by manually selecting Areas of Interest (AOIs) containing only the water with the "Image Interpreter Subset" command. All open water AOIs were removed or cut from the digital images to reduce the broad spectral variance that is encountered when assigning tidal wetland classifications to the images. This broad spectral variance was due to possible scanning or sunglint contrasts, open water in the digitally displayed images comprised an extensive spectral range encompassing signatures partly or totally equal to all broad order classes (i.e.: Wetland, Urban, Agriculture, Forest, etc.)

ERDAS Image Classification (New Inventory)

AOIs were then applied to .IMG files containing only terrestrial areas. This was done by creating a signature editor for all wetland classes. The signature editor consists of the spectral ranges within the red, green, and blue radiometric bans in the wetland or marsh region of the images. This procedure was performed utilizing the "Feature Space Command". Once a signature satisfactorily encompassed the tidal marsh area it was applied to the images as an AOI by employing the "Feature Space to Mask" command. This process was repeated until the signature editor contained all available tidal marsh signatures.

The "Feature Space to Mask" command, once applied to the .IMG files, created highlighted classified regions referred to as marsh masks. The marsh mask files were edited for upland pixel spreads, by creating AOIs of the upland areas, as evidenced by vegetative variations. These AOIs were then deleted, leaving the marsh mask files containing only the highlighted tidal wetland areas.

ERDAS classification was within +/-3.0m minimum accuracy due to AUTOCAD coverage resolution and NAPP photography resolution.

The next step was to classify the rectified image. This involved creating a supervised ERDAS Imagine "Signature Editor". There are a number of ways in Imagine that this technique can be performed; however, after numerous trial and error attempts, the most effective format for this study was to compose an editor by collecting signatures from the "Feature Space" application. The feature space classification signature is a method of grouping area of interest (AOI) pixels into a spectral range that may then be applied to the image by a "FEATURE SPACE TO IMAGE" command. Here wetland signatures were collected and applied to the images as a mask.

The wetland mask's upland edge was then edited to conform to the general physical boundary of the specified AOIs. 1990 low altitude aerial photos were used to confirm boundary classifications. The wetland imagine mask files were then converted to vector coverages and imported into ARC/INFO and transformed into a GRID format. The wetland mask values were changed to a single number to facilitate identification of this particular inventory during the overlay comparisons.

TMI Coverage Preparation (Old Inventory)

The USGS Achilles, VA Topo 7.5 minute mylar map was used to delineate the upland tidal wetland boundary. This was done by tracing tidal wetlands from Moore's (1976) historical Tidal Marsh Inventory directly onto the mylar map for digitizing. All wetland annotations were made using a mechanical drawing pen, with a pen line width of .25mm.

The wetlands were then digitized as individual polygons onto an existing Achilles Quad TMI shoreline file in ARC/INFO. Digitizing error was reduced to 0.001 inch by implementing the use of small scale cursors. The tidal marsh polygons were then edited for dangles, nodes, breaks, or any other inconsistencies in the coverage. Each polygon was then labeled, corresponding to the numerical scheme used by Moore (1976). The TMI was then rechecked for errors. The box enclosing the displayed coverage, along with any shoreline not comprising a tidal marsh polygon's leading edge, was deleted, leaving a TMI file composed of only the tidal marsh polygons corresponding to the Achilles Quadrant.

TMI Coverage and Image Overlay

The Achilles TMI coverage was divided into ten corresponding sections equal to the ARC/INFO grid converted ERDAS wetland mask files. The ten corresponding pairs were then overlaid by using the "INTERSECT" command. To demonstrate the +/-27.2m cumulative error associated with the tidal wetland inventory, a buffer representing this amount of error was created and applied to each intersect file using the "Buffer" command. However, four of these files proved to contain greater than 80,000 vertices, which is the current system file size limitation for these applications to run successfully. As a result, the four files containing more than 80,000 vertices required further divisions before they could be overlaid.

These files were each subdivided into four smaller files using the "GENERATE" command.

This command developed box outlines according to the specified coordinates of each quartered file. The general boundary coordinates were obtained by listing the larger file's X_{min}, Y_{min}, X_{max}, and Y_{max} coordinates and then calculating the corresponding X_2 and Y_2 values. These values were obtained using the following formulae:

$$X_2 = (X_{max} - X_{min})/2 + X_{min}$$

$$Y_2 = (Y_{max} - Y_{min})/2 + Y_{min}$$

Once the box outlines were completed they were then used to clip the corresponding area from the larger files by applying the "CLIP" command. The clipped files were then buffered to create the +/-27.2 error buffer and then intersected with original intersect files for consistency. "MFIPS" values were calculated for each individual inventory and buffer distance and the "POLYGONSHADES" command was used to assign the selected inventory colors.

APPENDIX II. Selection of NAPP and AUTOCAD Files

NAPP Photograph Selection

USGS Achilles, VA 7.5 minute quadrant topographical map was used a base map to find the corresponding NAPP photos. This quadrant consisted of ten high resolution 1989 color infrared NAPP photographs:

1627-88
1630-15
1627-90
1627-91
1627-92
1627-141
1627-142
1627-143
1627-144
1627-145

AUTOCAD File Selection

AUTOCAD system data files, used for georectification in this study, consisted of a total of 52 precisely scanned, PC-based, Gloucester County digital files:

GCJ18
GCJ19
GCJ20
GCJ21
GCJ22
GCJ23
GCJ24
GCJ25
GCJ26
GCJ27
GCK18
GCK19
GCK20
GCK21
GCK22
GCK23
GCK24
GCK25
GCK26
GCK27
GCL18
GCL19
GCL20
GCL21
GCL22
GCL23
GCL24
GCL25
GCL26
GCL27
GCM18
GCM19
GCM20
GCM21
GCM22
GCM23
GCM24
GCM25
GCM26
GCM27
GCN20
GCN21
GCN22
GCN23
GCN24
GCN25
GCN26
GCO23
GCO24
GCO25
GCP24
GCP25

APPENDIX III. Acronyms

AOI: Area of Interest

ERDAS: Earth Resources Data Analysis System

FWS: (U. S.) Fish and Wildlife Service

GIS: Geographic Information System

HWL: High Water Line

MHW: Mean High Water

NAPP: National Aerial Photography Program

NASA: National Aeronautics and Space Administration

NWF: National Wildlife Federation

TMI: Tidal Marsh Inventory

TOPO: Topographic (map)

USGS: United States Geological Survey

APPENDIX IV. Glossary

Arc: an ordered string of vertices (x, y, coordinate pairs) that begin at location and end at another.

Base Map: a map containing geographic features used for locational reference.

Buffer: a zone of a specified distance around coverage features.

Cartography: the art or technique of making maps or charts.

Change Detection: the process of evaluating amount or percentage of wetland area loss within a specified region.

Classification: the process of assigning a category or identifiable name to a specific type of land cover or use; i.e.: wetland, agricultural land, forested land, urban.

Color Infrared Photography: the photography employing the use of electromagnetic radiation having wavelengths greater than those of visible light and shorter than those of microwaves.

Coverage: the digital version of a map forming the basic unit of vector data storage.

Cumulative Error: an experimental error or mistakes in calculations that increase in magnitude with each successive measurement.

Dangles: an excess or stray line unconnected to any polygon or node usually resulting from digitization.

Delineation: the process of marking or sketching a classification or land use boundary for map transcription.

Digitization: the process of encoding geographic features in digital form as x, y coordinates

ERDAS: a raster based computer imaging software package used for area classification.

Fixed or Stable Points: a permanent identifiable features on a location on the earth which may be used to assign corresponding map coordinates.

Geographic Information System (GIS): a vector based computer software package used for the entry, storage, analysis, management, and display of data associated with physical locations on the earth.

Georectification: the process of assigning map coordinates to physical locations on the earth.

Ground Truthing: the process of examining or surveying a region or area fixed points for correlation with corresponding maps or charts.

Inventory: complied map data representing an area or specific location demonstrating some or all of the land uses, covers, types, etc within the region.

Maximum Allowable Error: the greatest amount of error associated with a fixed point on a map or inventory.

Mitigation: the process of reducing the impacts of changes brought about usually from anthropogenic effects or alterations.

Nodes: intersections of arcs or lines within a digitized coverage.

Orthophotos: aerial photographs vertically rectified to reduce error associated with distortion and scale variations.

Photogrammetry: the process of making precise maps or scale drawings by aerial or other photography.

Polygon: a coverage feature class composed of arcs, used to represent an area.

Potential Error: the possible error associated with the mapping or measuring processes.

Raster Image: pertaining to a GIS digital image composed from multi-dimensional media; i.e. satellite imagery or aerial photography.

Registration: the process of digitally recording map data or fixed points into a computer based mapping package.

Remote Sensing: the process of accessing map information, photography, or image data without contacting it physically. Remote sensing platforms include: satellite, aircraft, radar, etc.

Resolution: the accuracy at which a given map scale can depict the location and shape of geographic features.

Scanning: the process of capturing data in a raster format for digital display with a device called a scanner.

Status and Trends: the present or anticipated conditions of an area as evidenced from past recorded conditions.

Tidal Wetland: wetlands subjected tidal inundations and recessions .

Topographic Map: a map containing contours indicating lines of equal surface elevations.

Vector Image: pertaining to a GIS digital image composed from one-dimensional media; i.e. maps or charts.

Wetland: an area or location extending to elevations greater than 1.5 times the mean tide range above mean low water.

Wetland Boundary : usually refers to landward limit or upland edge of a wetland.

LITERATURE CITED

Adams, D.A., M.A. Buford, and D.M. Dumond. 1987. In Search of the Wetland Boundary. 1987. Wetlands, 7:59-70.

Anders, F.J. and M.R. Byrnes. 1991. Accuracy of Shoreline Change Rates as Determined from Maps and Aerial Photographs. Shore and Beach, 16:(1):17-26.

Anderson, J. and M. Roos. 1991. Using Digital Scanned Aerial Photography for Wetlands Delineation. Earth and Atmospheric Remote Sensing, SPIE vol. 1492, pp 252-262.

Atkin, D. 1977. Decision Time for the Coastal Zone. Underwater Naturalist, 10(4):4-8.

Cashin, G.E., J.R. Dorney, and C.J. Richardson. 1992. Wetland Alteration Trends on the North Carolina Coastal Plain. Wetlands, 12:63-71.

Council on Environmental Quality. 1989. Executive Office of the President/Interagency Advisory Committee on Environmental Trends. Environmental Trends, 4: 97-127.

Council on Information Management/Commonwealth of Virginia. 1992. Model Virginia Map Accuracy Standards. COV ITRM Guideline 92-1.

Crowell, M., S.P. Leatherman, and M.K. Buckley. 1991. Historical Shoreline Change: Error Analysis and Mapping Accuracy. J. of Costal Research, 7(3):839-852.

Dahl, T.E. 1990. Wetland Losses in the United States 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. pp 2-10.

Dahl, T.E., Johnson, C.E., Frayer, W.E. 1991. Wetlands Status and Trends in the Conterminous United States, Mid-1970's to Mid-1980's. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. pp 1-15.

Deegan, L.A., H.M. Kennedy, and C. Neill. 1984. Natural Factors and Human Modifications Contributing to Marsh Loss in Louisiana's Mississippi River Deltaic Plain. Envir. Man., 8(6): 519-528.

Dolan, R., B.P. Hayden, P. May, and S. May. 1980. The Reliability of Shoreline Change Measurements from Aerial Photographs. Shore and Beach, 48: (4): 22-29.

Feierabend, J.S., and J.M. Zelazny. 1987. Status Report on Our Nation's Wetlands. National Wildlife Federation, Washington, D.C. pp 22-46.

Fuller, R.M., N.J. Brown, and M.D. Mountford. 1986. Taking Stock of Changing Broadland. I. Air Photointerpretation and Digital Cartography. J. of Biogeography, 13: 313-326.

Goodchild, M. and S. Gopal. 1989. The Accuracy of Spatial Databases. Taylor and Francis Publishing, New York, N. Y., pp 3-67.

Hefner, J.M., and K.K. Moorhead. 1991. Mapping Pocosins and Associated Wetlands in North Carolina. Wetlands, 11: 377-389.

Hershner, Carl, and M. Berman. 1993. The Importance of Natural Resource Inventories. Wetlands Technical Report, no. 93-10. pp 1. Virginia Institute of Marine Science. Gloucester Point, VA.

Jones, D.A. 1969. Mapping the Coastal Zone for Boundary Demarmarcation. Shore and Beach, 17:(8): 34-38.

Kiraly, S.J. 1989. Understanding the Effects of Habitat Loss or Modification: A Plan for Federal Research. Oceans '89: The Global Ocean, 1: 203.

Langfelder, J., Stafford, D., and Amein, M. 1968. A Reconnaissance of Coastal Erosion in North Carolina. Dept. of Civil Engineering, North Carolina State University, Raleigh, NC, pp 127.

Leatherman, S.P. 1983. Shoreline Mapping: Comparison of Techniques. Shore and Beach, 7:(1):28-33.

Light, D.L. 1993. The National Aerial Photography Program as a Geographic Information System Resource. Photogrammeteric Engineering and Remote Sensing, 59:(1): 61-65.

Marcellus, K., and M. Waas. 1972. Gloucester County Coastal Zone. Special Report in Applied Marine Science and Ocean Engineering, no. 26. Virginia Institute of Marine Science, Gloucester Point, VA.

McBride, R.A., M.W. Hiland, S. Penland, S.J. Williams, M.R. Byrnes, K.A. Westphal, B.E. Jaffe, and A.H. Sallenger, Jr.1991. Mapping Barrier Island Changes in Louisiana: Techniques, Accuracy, and Results. Coastal Sediments '91 Proceedings Specialty Conference/WR Div./ASCE Seattle, WA, June 25-27, pp 1011-1026.

McCrain, G.R. 1991. Highways and Pocosins in North Carolina: An Overview. Wetlands, 11: 481-487.

McCreary, S., R. Twiss, B. Warren, C. White, S. Huse, K. Gardels, and D. Roques. 1992. Land Use Change and Impacts on the San Francisco Estuary: A Regional Assessment with National Policy Implications. Coastal Man., 20: 219-253.

Moffitt, F. H. 1969. History of Shore Growth from Aerial Photographs. Shore and Beach, 37:(1): 23-27.

Moore, K. 1976. Gloucester County Tidal Marsh Inventory. Special Report in Applied Marine Science and Ocean Engineering no. 64, pp 1-12, 42-92. Virginia Institute of Marine Science. Glouster Point, VA.

Newbury, G.E.M., III. 1981. Changes in the Wetlands of Hunting Creek Fairfax County, Virginia. Wetlands, 1:183-196.

Penland, S. 1990. A Review of Coastal Erosion and Wetland Loss in Louisiana. Proceedings: Long Term Implications of Sea Level Change for the Mississippi and Alabama Coastlines, Biloxi, MS, pp 27-28.

Pywell, H.R. and B.O. Wilen. 1991. Remote Sensing the Nation's Wetlands. U.S. Fish and Wildlife Service/National Wetland's Inventory, St. Petersburg, FL, pp 7-18.

Ricketts, Peter J. 1992. Current Approaches in Geographic Information Systems for Coastal Management. Marine Pollution Bulletin, 25:(1-4): 82-87.

Sasser, C.E., M.D. Dozier, J.G. Gosselink, and J.M. Hill. 1986. Spatial and Temporal Changes in Louisiana's Barataria Basin Marshes, 1945-1980. Envir. Manage., 10:(5):671-680.

Scaife, W.W., R.E. Turner, and R. Costanza. 1983. Coastal Louisiana Recent Land Loss and Canal Impacts. Envir. Man., 7:(5):433-442.

Shallowitz, A.L. 1964. Shore and Sea Boundaries. U.S. Department of Commerce, vol. 2, publication 10-1, pp 749.

Silberbauer, M.J. and J.M. King. 1991. The distribution of Wetlands in the South-Western Cape Province, South Africa. South Africa J. of Aquatic Science, 17:(1-2):65-81.

Slama, Chester C. 1980. Manual of Photogrammetery, ed. 4. American Society of Photogrammetery, Falls Church, VA. ed. 4, pp 69,73,86, 470,475,580.

Smith, C., N. Brown, N. Pyden, and D. Wormer. 1994. The ERDAS Field Guide. ERDAS, Inc. Atlanta, GA ed. 3, pp 16-20.

Stachecki, D. 1987. Sussex mapping aimed at aiding land use decisions. Delaware-Conserv., 30:(3):17-18.

Stafford, D.B. and J. Langfelder. 1971. Air Photo Survey of Coastal Erosion. Photogrammetric Engineering, pp 565-575.

Tiner, R.W. 1984. Wetlands of the United States: Current Status and Recent Trends. U.S. Fish and Wildlife Service, Habitat Resources, Newton Corner, MA. pp 1-3, 21-24.

Tiner, R.W., I. Kenenski, T. Nuerminger, J. Eaton, D.B. Foulis, G.S. Smith, and W.E. Frayer. 1994. Wetlands of the Chesapeake Watershed: Status and Trends from 1982 to 1989. U.S. Fish and Wildlife Service, Region 5, Ecological Services, Hadley, MA. Technical Report R5ES, pp 7-9, 11-17.

Tortell, P. 1992. Coastal Zone Sensitivity Mapping and Its Role in Marine Environmental Management. Mar. Pol. Bul., 25:88-93.

U.S. Department of Agriculture. 1992. U.S. Almanac and Report. pp 16-23, 76-77, 233-235.

U.S. Department of Commerce/NOAA and U.S. Department of Interior/USGS. 1976. Coastal Mapping Handbook. pp 421-430.

Virginia Council on the Environment. 1989. Chesapeake Bay and Susquehanna River and Its Tidal Tributaries Public Access Guide. pp 7-9,16,42,47,52,60.

Virginia Power. 1994. Gloucester County Community Profile. August.

Wilen, B.O. and W.E. Frayer, 1990. Status and Trends of the U.S. Wetlands and Deepwater Habitats. For. Ecol. Manage., 33/34:181-192

Williams, A.T., and C.D. Lavalle. 1990. Coastal Landscape Evaluation and Photography. J. of Coastal Research, 6:(4):1011-1020.

Williams, D.C., and J.G. Lyon. 1991. Use of a Geographic Information System Data Base to Measure and Evaluate Wetland Changes in the St. Mary's River, Michigan. Remote Sensing Env., 23:111-135.

Wright, R.A.S. 1988. The Historical Floristics and Ecology of Lea's Meadow and the Clopton Bog in Richmond, Virginia. Virginia J. of Science, 39:(2):133-145.