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# Advances in Wetland Status and Trends Monitoring Cumulative Error Comparisons

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## Advances in Wetland Status and Trends Monitoring— Cumulative Error Comparisons

*Stacy A. C. Nelson*

### Introduction

The number of wetlands existing in the United States since colonial 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), it is believed that over 200 million acres of wetlands were present in the conterminous United States in the early 1700's. Estimates of wetland area made during the 1950's to 1970's indicate the numbers have dwindled to somewhere between 86 to 99 million acres. Feierabend and Zelazny (1987) reported that wetland losses have totaled an average of 550,000 acres a year from 1954 to 1974. By the mid-1980's, total wetland acreage constituted approximately 5.0 percent of the co-extensive U.S. (Dahl et al., 1991).

Wetland losses have been attributed to a number of causes such as agricultural land conversions, urbanization, and natural erosion. Agricultural drain and fill conversions account for as much as 54.0 percent of total wetland losses between the mid-1950's and the 1970's (Dahl et al., 1991). Urban land use conversions, during the same period, have accounted for approximately 5.0 percent of wetland losses. The U.S. Fish and Wildlife Service estimates that of the 86 to 99 million remaining acres of wetlands within the continental United States, 30 million acres are polluted or contaminated to such an extent that natural function is limited and they are essentially useless (Feierabend and Zelazny, 1987).

Fragile and vulnerable coastal zones have suffered from adverse impacts associated with the country's increasing population. These areas have been the target of everything from filling and draining for agricultural uses to resort area complexes, usually with little regard to ecological, cultural, historic, and aesthetic coastal zone values.

To combat these problems, in 1972, Congress passed the Coastal Zone Management Act. The law provides incentives for coastal states to develop management plans for the use of their coastal regions. The law allows each state to detail all potential threats to the coastal zone, including development and natural factors (Atkin, 1977). Section 404 of the Federal Water Pollution Control Act (as amended in 1972) and the 1985 Food Security Act's "swampbuster" provisions required that all wetlands and associated boundaries be identified and delineated in agreement with applicable statutes and regulations (Adams et al., 1987).

Technically, wetland delineation has largely focused around a three parameter approach of identifying hydrophytic vegetation, hydric soils, and hydrologic indicators (Newling et al., 1982). Historically wetlands and coastal boundary demarcation has consisted of intensive field labor with the aid of topographic maps and aerial photography. These methods were largely employed for United States wetland status and trend reports from the 1950's through the 1970's (Wilen and Frayer, 1990). However, map interpretations,

ground surveys, line transects, and aerial photography are among the methods used as early as 1929 to map the present distribution of wetland habitats (Newbury, 1981).

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 expands the accessibility of information about any given area, allowing more observers access to the information as compared to single or very limited opinions compiled 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 which have been subjected to human interpretation (Stafford and Langfelder, 1971).

Aerial photo-interpretation incorporated into the mapping process has resulted in maps which show the distributions and patterns of coastal changes to a standard and accuracy not possible

with conventional map analysis techniques (Fuller et al., 1986). Although ground truth verification can not be completely limited 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).

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. This paper examines the limitations of certain mapping techniques with special emphasis on cumulative error problems.

## Discussion

Since the early 1980's, remote sensing techniques have become more popular and efficient in the delineation of wetlands. With the technological advances available today, many attempts are now being made to compile data from a collage of techniques to form a "best available information" approach. Geographic Information Systems (GIS) are being widely 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).

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 estimate the system's cartographic potential 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 aerial photos and wetland mapping techniques have been employed since roughly the 1930's, the combination of photogrammetry, boundary mapping, and computer based GIS has only recently been developed. This poses an intricate set of problems as errors involved in developing this data accumulate.

Cumulative errors occur as the sum of combined potential errors within a mapped or delineated

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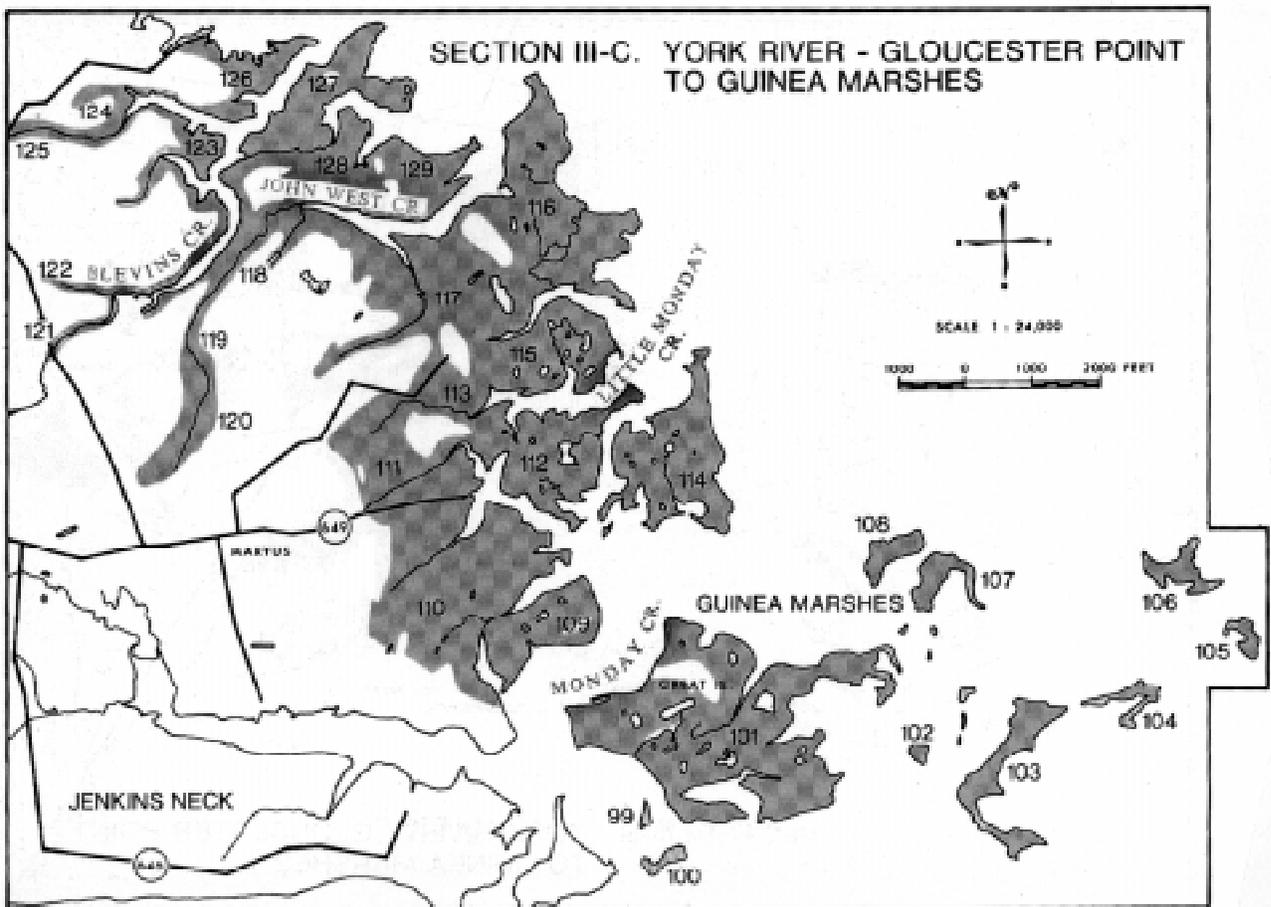
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*Commonwealth's Declared Policy: "to preserve the wetlands and to prevent their despoliation and destruction..."*

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1976 Gloucester County Tidal Marsh Inventory - Guinea marshes.

wetland inventory. The largest sources of potential error include the estimated errors which fall within the National Map Accuracy Standard's allowable error estimate, the photogrammetry process, wetland boundary and high water line interface delineations, scale interpretations, plotting and digitizing, and interpreter bias.

Changes in natural resources, 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, significance is difficult to prove. In fact, wetland areas smaller than the accuracy standard may not even be included in some of the early mapping inventories (Anders and Byrnes, 1991). As an example, National Map Accuracy Standards for USGS topographical maps, at a scale of 1:24,000, currently allow a maximum error of plus or minus 12.2m for 90% of the stable points, thus creating an allowable accuracy of plus or minus 24.4 meters when comparing information from two maps (Anders and

Byrnes, 1991; Council on Information Management, 1992; Leatherman, 1983; U.S. Department of Commerce, 1976).

Other sources of potential error in wetland (or other natural resource) inventories may occur with both classification and boundary 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.

The high water line (HWL) has become recognized as the best indicator of the land-water interface (Crowell et al., 1991). The HWL, representing the landward extent of the last high tide, is often confused with the mean high water line (MHW). This line is determined by averaging the height of the high water line over a nineteen year period (Shalowitz, 1964). It is important to explore the best methods available for the determination of the land-water interface.

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## Wetland and Shoreline Monitoring

Aerial photogrammetry techniques may prove useful for this purpose 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.

There are several problems with scale variation associated with aerial photography. 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) 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 further from the lens to appear at a smaller scale than features closer to the lens. However, topographic relief distortion is generally not a problem when observing low relief areas typical of many coastal areas (Anders and Byrnes, 1991).

Corrective techniques for scale variations have included improved camera optics for reduction of radial distortion, the use of contact prints to eliminate the variations caused by stretching and shrinking during printing, and lens distortions associated with optical enlargements. Tilt and radial distortion can be minimized by using only 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 in place of regular topographical maps (Anders and Byrnes, 1991).

The recent use of digital images and computer analysis in natural resource inventories introduces other factors of error, including photograph pixel resolution, interpretation and digitizing. Nevertheless, photogrammetric procedures, coupled with available computer software systems, have made it possible to accurately assess areas more readily than conventional methods. In search of more accurate methods of classification, it is important for researchers to understand error sources and estimates in both historical and new inventories.

Urbanization and natural processes produce real changes in land boundaries over a period of years, however detection and documentation of these changes must consider accuracy and cumulative errors inherent in the mapping and classification process. Although very accurate for its time, historical inventories didn't have the advantage of today's sophisticated technological advances such as remote sensing and computer based geographical information systems.

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 but cumulatively contribute a significant percentage of wetlands.

Rectified vertical aerial photographs converted to digital images and coupled with computer based analysis programs provide a complete method of synoptic area coverage, and may also be useful in determining short term geomorphological changes such as coastal erosion and accretion (Moffitt, 1969). 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 addition, aerial photography does not require labor intensive field surveys or extensive data collection procedures to create useful data sets (Anders and Byrnes, 1991).

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 pressures, erosion and accretion rates and the adaptive changes vegetation has 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. However, large differences in accuracy have proved the majority of this information unreliable (Leatherman, 1988 and Dolan et al., 1980). Therefore it is neces-

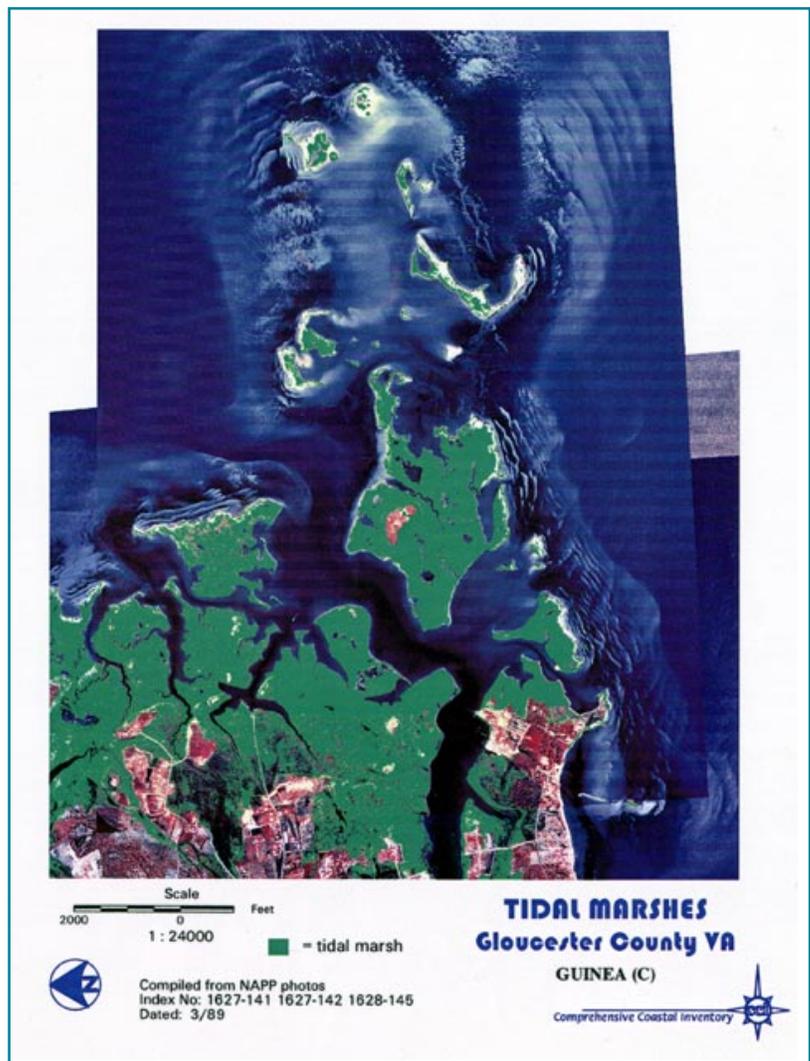
sary to consider all estimates of error, especially when employing less accurate data as a base reference.

## Gloucester County Inventory

An inventory effort initiated by the Virginia Institute of Marine Science in the early 1970's had the goal of creating a tidal marsh inventory for each Tidewater locality named in the Virginia Wetlands Act (28.2-1300 Va Code Ann.). As one in the series of inventories produced as part of that effort, the Gloucester County Tidal Marsh Inventory provides insight into some of the common problems associated with inventory efforts in the past. Recently, a new effort was begun to update the tidal marsh inventory series using new technologies. The Gloucester County Inventory was selected to be the first in the new series and is being used to identify and develop the necessary procedures and protocols.

In the original Gloucester County, Virginia Tidal Marsh Inventory (Moore, 1976), 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 the area of small wetlands such as pocket or narrow fringing marshes. These were usually less than one acre and were not present on the topographical maps. Such wetland areas were exaggerated and not indicated to scale in the inventory.

Area errors may have accumulated due to the compounded cumulative errors from the USGS topographic maps themselves. Real boundary changes occurring within a measured distance less than the topographic map's 12.2m maximum allowable accuracy standard may be an insignificant change when compared to another map with comparable accuracy. In order for a point or boundary to show change, as evidenced by a comparison of topographic maps, the boundary must be greater than the sum of the two maps'



1989 Gloucester County Tidal Marsh Inventory - Guinea marshes.

maximum allowable error. In this case of comparison using two topographic maps, the change must be greater than 24.4m. Significant changes of less than this distance may be difficult to prove, and smaller areas may not even be included in some inventories (Anders and Byrnes, 1991).

The use of paper topographic maps caused problems in area calculations because it is not possible to account for the error associated with differential shrinkage and stretching, especially in older maps. Paper shrinkage and stretching occurs with age and handling 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 may also impede accurate interpretation.

Equipment employed in these studies may also have attributed to loss of accuracy, such as

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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 area. 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. Inventory completion deadlines may have limited allowable project time for locating adequate numbers of fixed identifiable points and/or may have produced rushed decisions.

Older tidal marsh inventories were digitized years later, as modern technologies became available, in order to allow comparison with newer inventories. Digitizing the old inventories increased the potential for error. Digitizer error or human interpretation error could account for as much as plus or minus 6.0 meters. During digitization, even the pen line width could account for a potential error of 6.0 meters with a 0.25mm pen line and 4.3 meters with a pen line width of 0.18mm at a scale of 1:24,000.

Finally, guessing may have provided another source for error accumulation. The 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).

Taking into account all the quantifiable estimated errors of the original inventory, the USGS National Map Accuracy Standards of plus or minus 12.2m remains the greatest estimated error. This compounded with a plus or minus 6.0m pen line width error and the plus or minus 6.0m digitizer operator error, can account for an accumulated error of plus or minus 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 plus or minus 28 meters or greater.

## Chesapeake Bay Watershed Inventory

A study was conducted by Tiner et al. (1994) to assess the estimates of wetland status and trends from the early 1980's to the late 1980's, for the Chesapeake Bay watershed. This study employed a stratified random sampling technique which has also been utilized in national wetland trends studies and was used in the original Chesapeake Bay watershed wetland trends study (Tiner et al., 1994). This technique required the selection of 760, four square mile sample plots out of the 63,000 square mile watershed. State boundaries, physical subdivisions, and coastal zone boundaries composed the twelve initial sampling strata for this study. An additional ten strata, 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. Color infrared photos at scale of 1:40,000 were examined to detect wetland boundary or cover type changes. Wetland change data was generated by overlaying base inventory plots with recent ones and scan-digitizing for computer analysis. Wetland change was determined 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 errors, a 95 percent confidence limit cannot be achieved to positively assert 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 Bay watershed.

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## Conclusion

Although technological advances have provided an increased level of accuracy, interpreter accuracy or bias continues to play an important role in accurate image registration. Additionally, it is important to compare actual inventory changes from inventories developed or assessed from like media such as NAPP to NAPP. This reduces cumulated mapping positional errors by establishing a common frame of reference from old to new inventories.

The application of some modern techniques, such as computer aided classification, may also cause problems. Computer aided classification commonly employs raster based systems which define precision by cell size. As such, the method requires the assumption that all cells in a particular classification are homogeneous, and this is not always the case. However, due to ever increasing pixel resolutions, the estimates of potential error may be effectively minimized.

The use of best available practices decreases the likelihood of high error estimates. The newer inventories, using computer aided analysis may produce minimum amounts of cumulative error, limited only to scanning and pixel resolutions generating a total maximum cumulative error of at least plus or minus 3.0 meters.

For instance, an inventory utilizing digitally scanned NAPP photos and an image processing package, such as ERDAS Imagine, for wetland classification, with a maximum allowable error of plus or minus 3.0 meters, could establish a reduced estimate of potential error. This approach creates a more accurate base reference for future status and trend analysis when overlaying recent inventories composed of similar or better estimates of error.

It has been suggested that effective evaluation of changes in wetland resources requires repeated updating of the resource information every 5 to 10 years. This frequency allows for current anthropogenic and natural changes to be considered and noted for accurate inventory mapping as well as evaluation of long term status and trends. In order for this practice to be as effective as possible, it is necessary for each collective 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 will also 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 of current wetland management efforts.

## Editor's Note

Stacy A. C. Nelson is a recently graduated Master's student in the Resource Management and Policy Department of the Virginia Institute of Marine Science, School of Marine Science, College of William and Mary. This paper was presented at the Wetlands Workgroup of the Chesapeake Bay Program, October 30 - 31, 1995.

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