Causes of Submerged Aquatic Vegetation Declines in Tangier Sound, Chesapeake Bay

Report prepared for the Chesapeake Bay Program

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Table of Contents

Table of Figures

Tables

Chapter 1: Causes of submerged aquatic vegetation (SAV) decline in the Tangier Sound region of Chesapeake Bay

1.1: Introduction

Straddling the border between Maryland and Virginia, the Tangier Sound region is an extremely important habitat area of Chesapeake Bay. The Sound covers approximately 250 square miles, is bounded on the west by a series of islands and by the Delmarva Peninsula on the east, and is fed by several rivers draining off Maryland's lower eastern shore (Figure 1.1). It is home to the Bay's largest submerged aquatic vegetation (SAV) community and contains nearly 57,000 acres of critical habitat shallower than two meters. Because of the presence of these extensive SAV covered, shallow water flats, Tangier Sound is also home to numerous watermen communities.

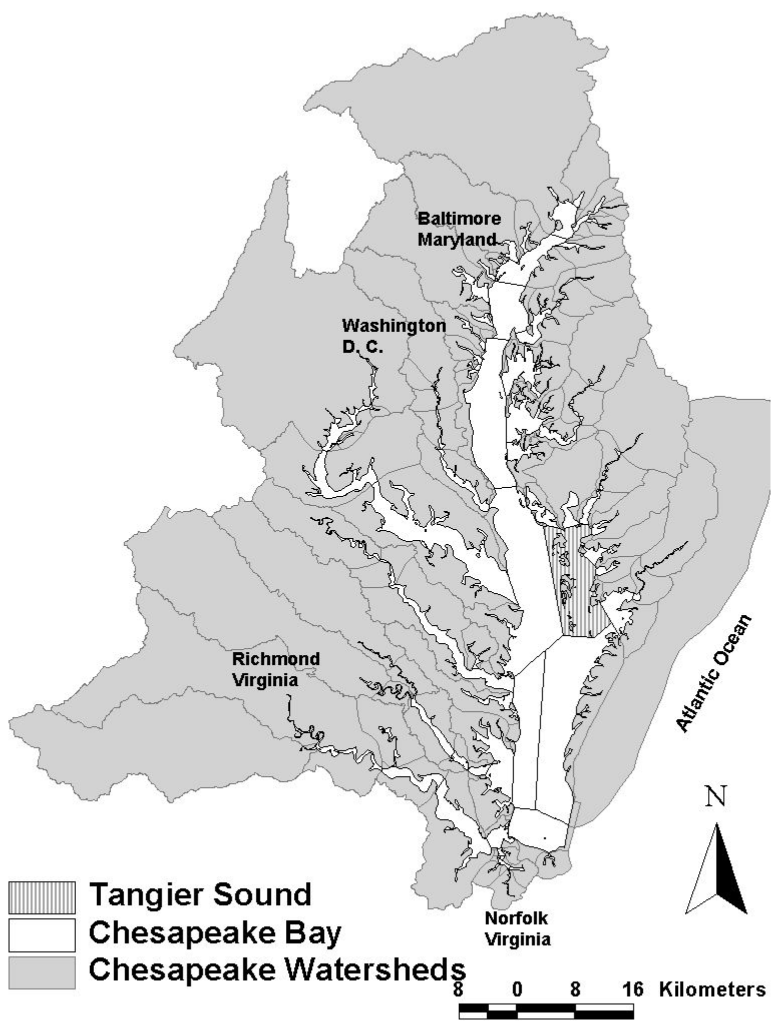


Figure 1.1: Map of Chesapeake Bay, identifying Tangier Sound

SAV are vital to the Chesapeake Bay's health because they produce oxygen, reduce wave action and erosion, absorb nutrients and trap sediments. They also provide food and habitat for many bay organisms, including *Callinectes sapidus* (blue crab), an important part of the Tangier Sound region economy. While research has shown that post-larval blue crabs (megalopi) greatly prefer SAV beds over non-vegetated areas (Orth & Montfrans, 1990), the Tangier Sound region SAV beds are especially important for the settlement of blue crab post-larvae and have been specifically identified by the Maryland Blue Crab Fisheries Management Plan as critical to the survival of the blue crab (Fisheries Management Plan Workgroup, 1997).

Two species dominate the seagrass community of SAV in Tangier Sound: *Zostera marina* (eelgrass) and *Ruppia maritima* (widgeon grass). While both species inhabit similar areas, they have different water temperature, light and salinity requirements. *Zostera marina* growth is optimal during the cooler months (spring & fall). Conversely, *Ruppia maritima* typically grows best during the warmer months (April through October).

Following a steady increase of SAV from 1978 to 1992, 1993 marked the beginning of a six-year decline in coverage in the Tangier Sound region. By 1998, SAV had declined over 63% to 6,612 acres since its maximum coverage of 18,112 acres in 1992. The majority of SAV loss occurred in the northern portions of the Tangier Islands. These recent declines were cause for alarm not only regionally, but also their impact on the entire Chesapeake Bay. Since the recent SAV surveys began in the late 1970s, the Tangier Sound region has consistently contained at least 25% of the total Bay-wide SAV coverage (Figure 1.2).

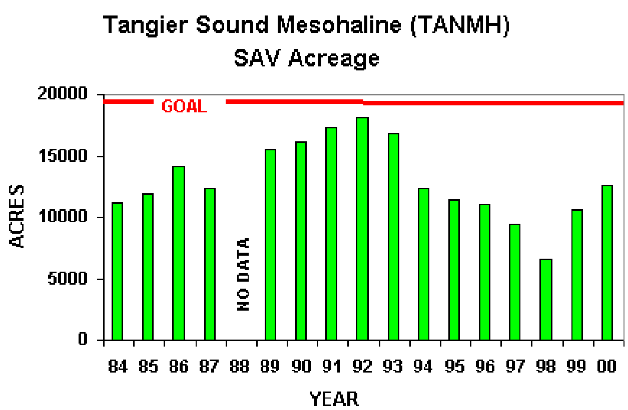
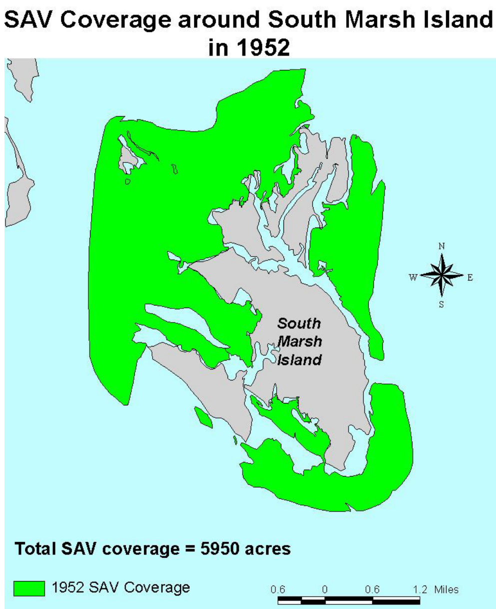
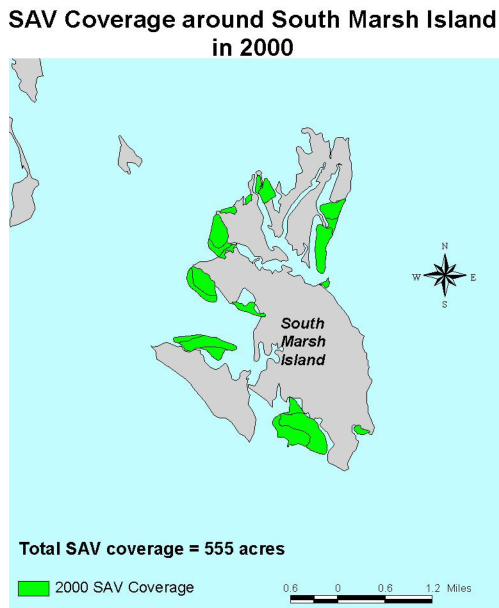


Figure 1.2: Tangier Sound SAV acreage - (1984-2000)

While current declines in SAV acreage are dramatic, these losses pale when viewed in the historical context. An analysis of South Marsh (one of the Tangier islands) in the early 1950s, prior to tropical storm Agnes (1972), reveals 5,950 acres of SAV (Figure 1.3; Naylor, in prep). Currently, SAV covers less than 10% of that historic area (Figure 1.4). Adjacent islands show similar trends.





Figures 1.3 and 1.4: 1952 and 2000 South Marsh Island SAV coverage.

1.2: STUDY APPROACH

Recent losses of SAV initially appeared to be tied to decreases in water clarity due to increases in total suspended solids and chlorophyll a from high flow years in the Chesapeake Bay between 1993 and 1998 (Figure 1.5).

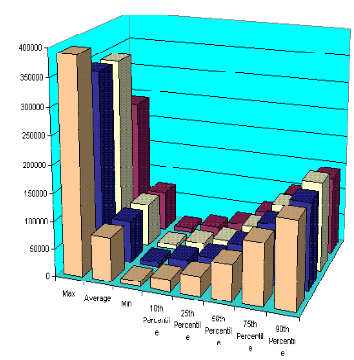


Figure 1.5: Annual flow to the Chesapeake Bay (U.S. Geological Survey)

In addition to water quality declines, a species shift from *Zostera marina,* a plant with relative stable population dynamics to *Ruppia maritima*, a plant characterized by large population swings may have influenced the coverage of SAV in the region. Other alternate hypotheses include; increases in fisheries impacts in the region, erosion of the offshore islands, and biological disturbances.

1.3: FOCUS OF STUDY

In 2000, the Chesapeake Bay Foundation held a summit to outline possible causes for the SAVdecline in this region. Their list of potential factors agrees with those identified by other Bay scientists.

Possible causes of SAV decline in Tangier Sound,(CBF Summit, 2000)

- Decreased water clarity
- Natural fluctuations in *Ruppia maritima* (widgeon grass)
- Increased macro-algae and epiphytic communities
- Increased clam dredging in SAV beds
- Changes in hydrodynamics and sediment processes
- Increased biological disruptions

This study examines large scale and site-specific factors, and improves our understanding of how water quality and other ecological processes have impacted the Tangier Sound region SAV during the recent and long term SAV declines. The results of this study identify the factors that can be attributed to natural variability and those that have an anthropogenic origin. The study was divided into five components that each comprise a chapter in this report:

- Examination of SAV community changes over time
- Examination of shoreline loss and effects on SAV
- Comparison of current versus historic water quality relative to the loss of SAV
- Evaluation of regional water quality in Tangier Sound relative to the loss of SAV
- Utilization of water quality interpolation to evaluate changes in SAV abundance

Chapter 2: SAV Community Changes Over Time

2.1: Introduction

In order to fully understand the causes of SAV declines in Tangier Sound, the community dynamics require examination. Different species of SAV have different tolerances to water quality conditions and inhabit different microclimates (Orth and Moore, 1988). Changes in speciation can also indicate changes in habitat conditions.

2.2: Methods

From 1971 until 1990, the Maryland Department of Natural Resources (DNR) and the United States Fish and Wildlife Service (USFWS) conducted Submerged Aquatic Vegetation (SAV) surveys of Maryland's portion of the Chesapeake Bay to assess relative species abundance of SAV (data available from www.chesapeakebay.net). A set of 642 stations were randomly selected throughout the Bay. Once annually at each station, 3 replicate 1 square meter quadrants were quantitatively sampled for species composition, biomass and percent cover. Of the 642 stations, 86 were located in the Tangier Sound mesohaline segment (Figure 2.1) with a total of 224 observations used for analysis. From these data, a percent occurrence of each species of SAV found in the segment was generated to assess if there was any temporal variation in speciation. This was calculated by dividing the number of observations per year containing species *X* by total number of observations for a given year in that Bay Program segment. The analysis was narrowed to the Tangier Sound mesohaline Chesapeake Bay Program (TANMH) segment, and only *Ruppia maritima* and *Zostera marina* were considered, as these two species are the only ones to occur throughout the time period in this mesohaline region. Percent occurrence data for each species were plotted by year, and then analyzed using a linear regression (Zar, 1984) (Figure 2.2).

In addition to the DNR/USFWS survey, the Virginia Institute of Marine Science (VIMS) has conducted "ground-truthing" surveys to compliment the annual aerial survey (Orth *et al.*, 1986) beginning in 1985 and running to the present day. The purpose of these surveys is to provide species information at SAV beds identified by the annual aerial survey. These data only indicate areas containing SAV as identified by citizens, and sites were selected haphazardly. Because of the survey design, it was not possible to have a 0% occurrence. Therefore, these data are not directly comparable to the DNR/USFWS survey (Figure 2.2). For the purposes of this study, only data from 1985 to 1999 were considered. There were 614 observations in the TANMH segment during this time frame (Figure 2.1). Using the procedure above, these data were converted to percent occurrence of each species in the TANMH segment and analyzed in the same matter.

2.3: Results

The DNR/USFWS survey data indicate that there was a species dominance shift in TANMH over the time period of the survey. For most of the 1970s, *Ruppia maritima* and *Zostera marina* both showed similar percent occurrence (Figure 2.3), oscillating near the 50% occurrence line. Beginning in 1979, the percent occurrence data began to diverge,

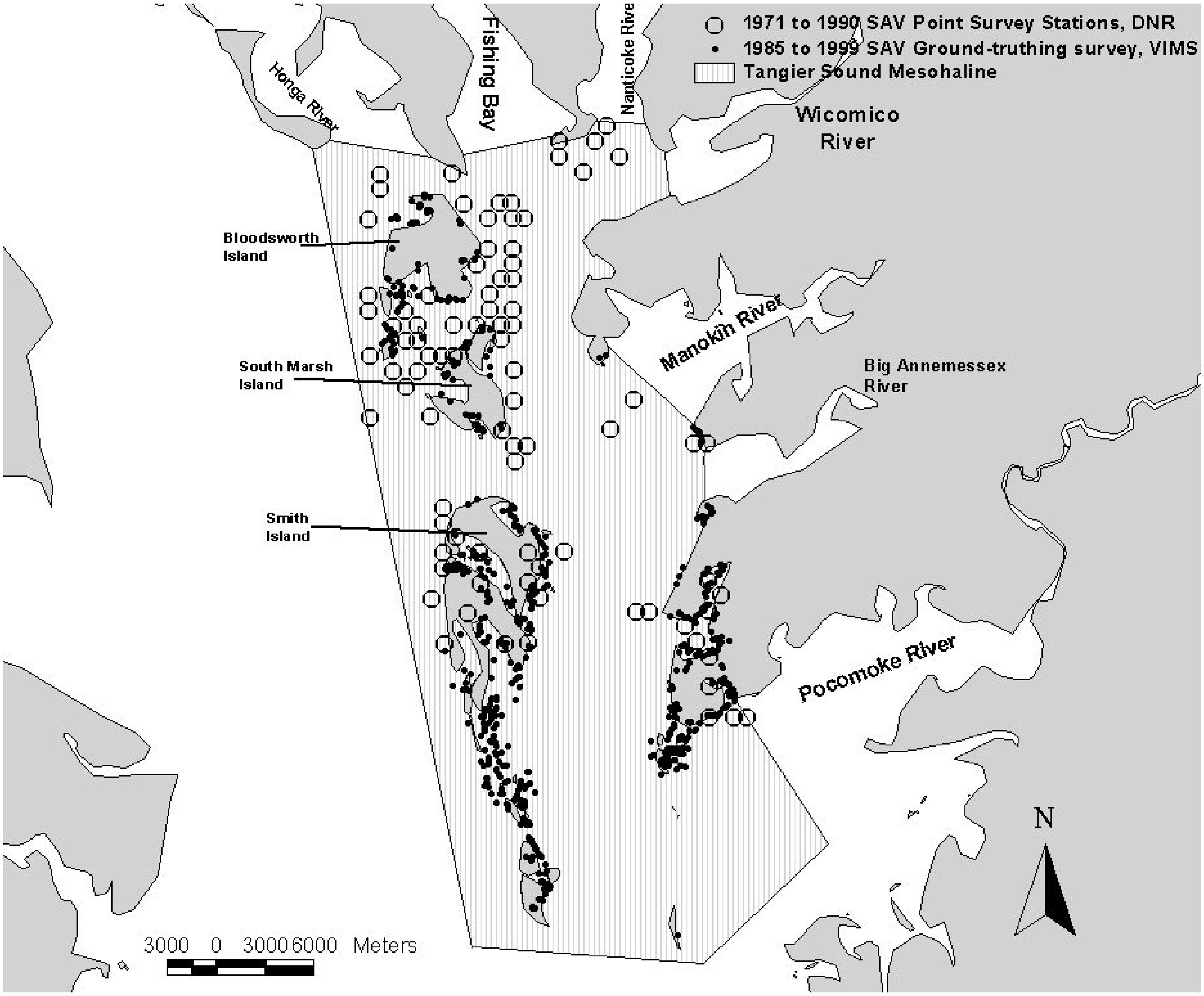


Figure 2.1: Location of SAV point survey and SAV ground-truthing observations. The DNR/USFWS stations are represented by open circles, and the VIMS observations by hollow squares.

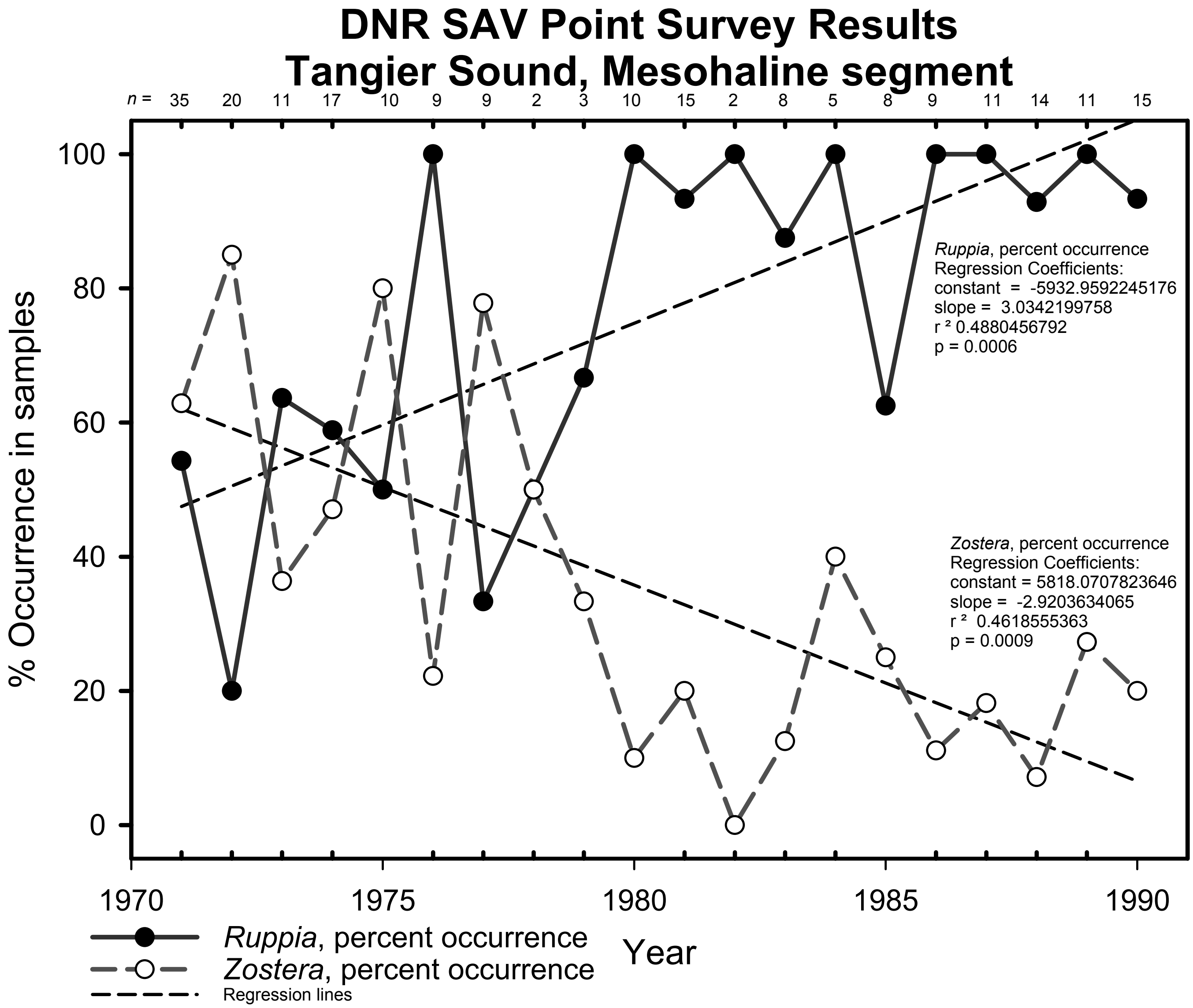


Figure 2.2: Percent occurrence of *Ruppia maritima* and *Zostera marina* from 1971 to 1990. The y-axis is the percent occurrence in the Tangier Sound Mesohaline segment, the x-axis is the year of observation. The number of observations (*n*) from which the percent occurrence is generated appears above the graph frame. The solid symbols and line represent the *Zostera marina* data, and the dashed line with open symbols represents the *Ruppia maritima* data. The two linear dashed lines identify the regression equation.

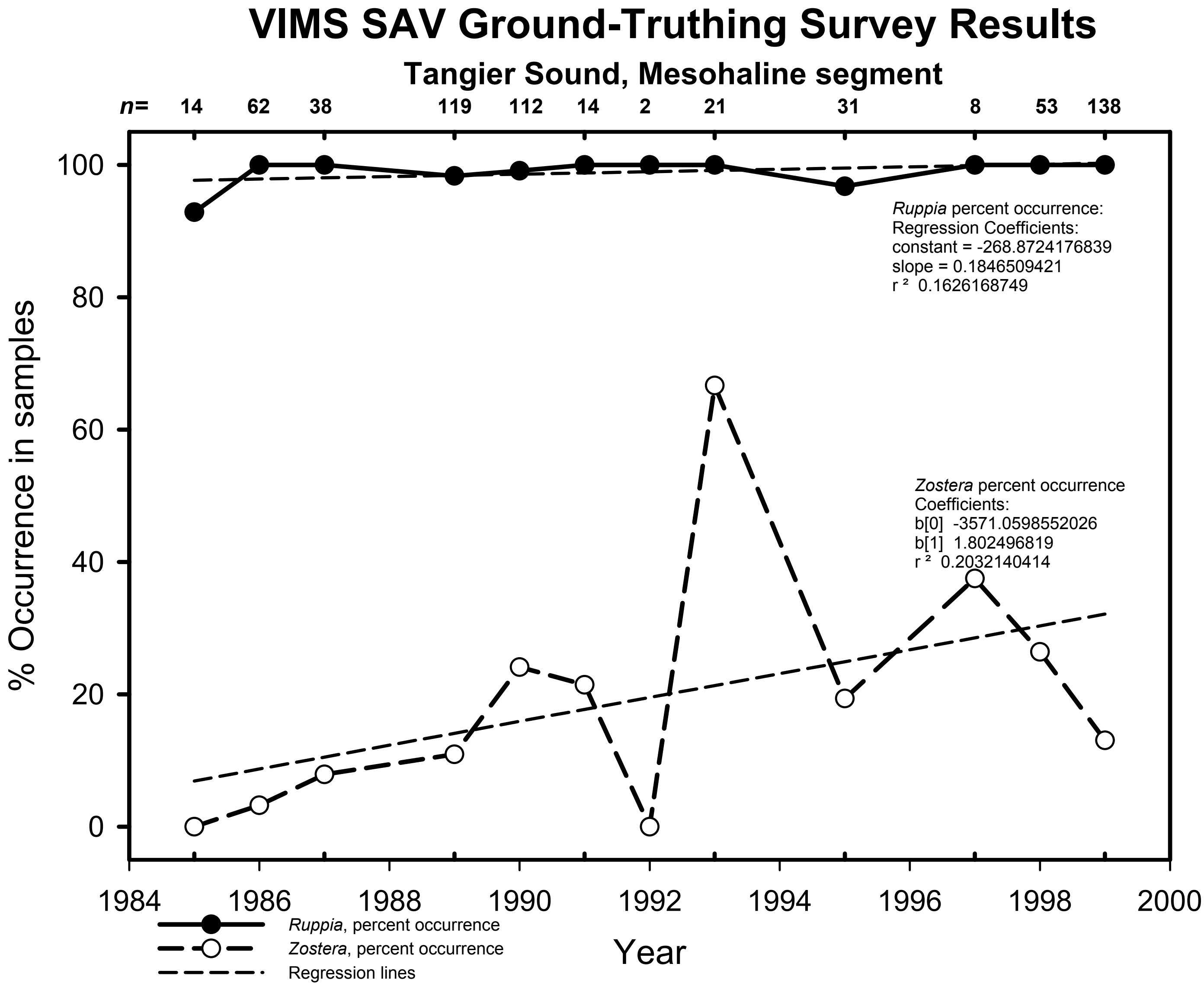


Figure 2.3: Percent occurrence of *Ruppia maritima* and *Zostera marina* from 1985 to 1999. The y-axis is the percent occurrence in the Tangier Sound Mesohaline segment, the x-axis is the year of observation. The number of observations (*n*) from which the percent occurrence is generated appears above the graph frame. The solid symbols and line represent the *Zostera marina* data, and the dashed line with open symbols represents the *Ruppia maritima* data. The two linear dashed lines identify the regression equation.

Ruppia maritima showed a significantly increased percent occurrence over time, with usually greater than 80% occurrence after 1980. Over the same time frame, *Zostera marina* showed a significant decreased in percent occurrence, oscillating near the 20% occurrence line. The VIMS ground-truthing survey data indicate that *Ruppia maritima* continued to have a significantly higher percent occurrence (near 100%, Figure 2.3) The VIMS percent occurrence regression slopes are not significantly different from zero, though the occurrence of *Zostera* does appear to be trending upward.

2.4: DISCUSSION

It appears, from the dramatic changes after 1978, that a "threshold" of water quality conditions may have been crossed, leading to the observed shift from an *Zostera marina* to *Ru*ppia maritima dominated community. This species dominance shift from *Zostera marina* to *Ruppia maritima* may help explain some of the loss of SAV in the Tangier Sound region.

An apparent water quality decline (see chapters 4, 5 and 6) may explain the dramatic changes in SAV species composition and SAV coverage in Tangier Sound. Orth and Moore (1988) established that *Ru*ppia maritima generally dominates shallower water (< 40 cm, mean low water), while *Zostera marina* is typically the dominant species in waters deeper than 60cm mean low water. If water quality conditions, particularly light availability, were to decline, SAV in the deeper waters would be the first to be affected. As *Zostera marina* is usually in greater relative abundance in deeper waters, this species would have a disproportional decline. *Ruppia maritima* generally has higher light requirements and high temperature tolerance than *Zostera marina* (Batiuk *et al.*, 2000), and is better able to exploit the shallower waters, where a reduction in water clarity would not be as catastrophic as in deeper waters. In chapter 6 of this report, it is observed that the extent of SAV beds has become shallower over time, in addition to having smaller beds. That is supported by the population dynamics in the area, where a species better adapted to shallow waters has become the dominant.

Chapter 3: Shoreline Loss and Effects on SAV

3.1: Introduction

One hypothesis suggests that shoreline loss and erosion are contributing to the decline of SAV in Tangier Sound. The mode of action for disruption of SAV could be either burial of SAV or a degradation of water quality due to the suspension of eroded material. Shoreline loss and erosion data are limited, complicating the investigation of this hypothesis. In Chesapeake Bay, extensive shoreline surveys are performed on long time scales (40 or more years), while SAV surveys are conducted annually. To further complicate analyses, the SAV survey does not span the entire interval between recent shoreline surveys.

3.2: Methods

In order to assess how shoreline loss and erosion are contributing to the decline of SAV, spatial data were obtained from Maryland Geological Survey (metadata in appendices) containing the 1942 and 1988 shorelines for much of the Tangier Sound region, including most of the Chesapeake Bay Program Tangier Sound Mesohaline segment. While these data were originally created as line files, polygons were created from the lines to represent landmasses. From each survey, these landmasses were then converted to grid format using an "assign distance" function, which populates a grid composed of 50 foot cells with each cell given a value as to how far away from the nearest shoreline that cell is located. The cells that fall within a landmass have a value of zero. Once the grids were created, the 1988 grid was subtracted from the 1942 grid, as the assumption is that the 1942 landmasses would extend further seaward. The resultant output grid had cells populated with values for the difference between the two surveys, providing total shoreline loss values extending beyond the original shoreline (Figure 3.1). It is possible that the values in these cells can be positive (indicating shoreline loss) or negative (indicating accretion of "new" shorelines). The grid was converted to a shapefile, retaining the values for shoreline loss.

Considering the large time period between shoreline surveys (46 years), it was difficult to directly compare the annual SAV coverages to the shoreline loss grid. While shoreline loss between 1942 and 1988 can be determined; it was assumed that the shorelines that had receded the most (or least) would continue to recede at high (or low) rates beyond the end of the latest survey. Using this assumption as a guiding principal, each SAV coverage for the region from 1992 to 1998 was converted to grid, again with 50 foot cells, with each cell having a value of either one (SAV present) or zero (SAV absent). The 1992 grid was used as the baseline, since it was the maximum spatial coverage of any year. Each cell in this grid was multiplied by 6, which established the maximum value for the subsequent step. Each cell from the following years' grids was subtracted from the 1992 grid (each cell has a value of one or zero). The resultant grid shows where SAV loss (or gain) occurred. The values ranged from –6 to 6 (Figure 3.2). A cell value of zero indicates no change over the 7 years, a positive value indicates that a loss of SAV has occurred (the larger the number, the longer that particular cell has been unvegetated)

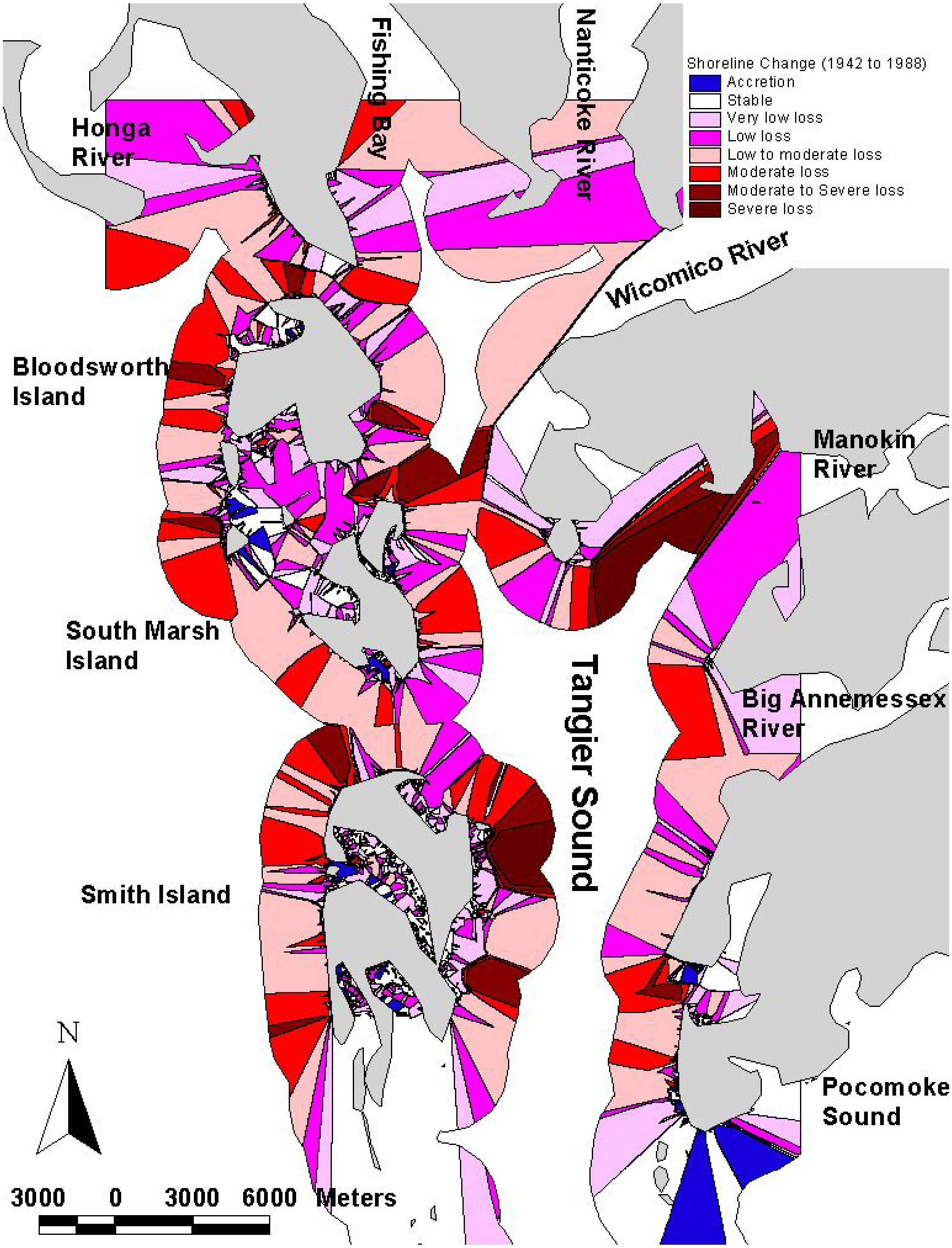


Figure 3.1: Map of the output of the shoreline loss grid. The grid is limited to 2.5 kilometers from shore, for ease of interpretation.

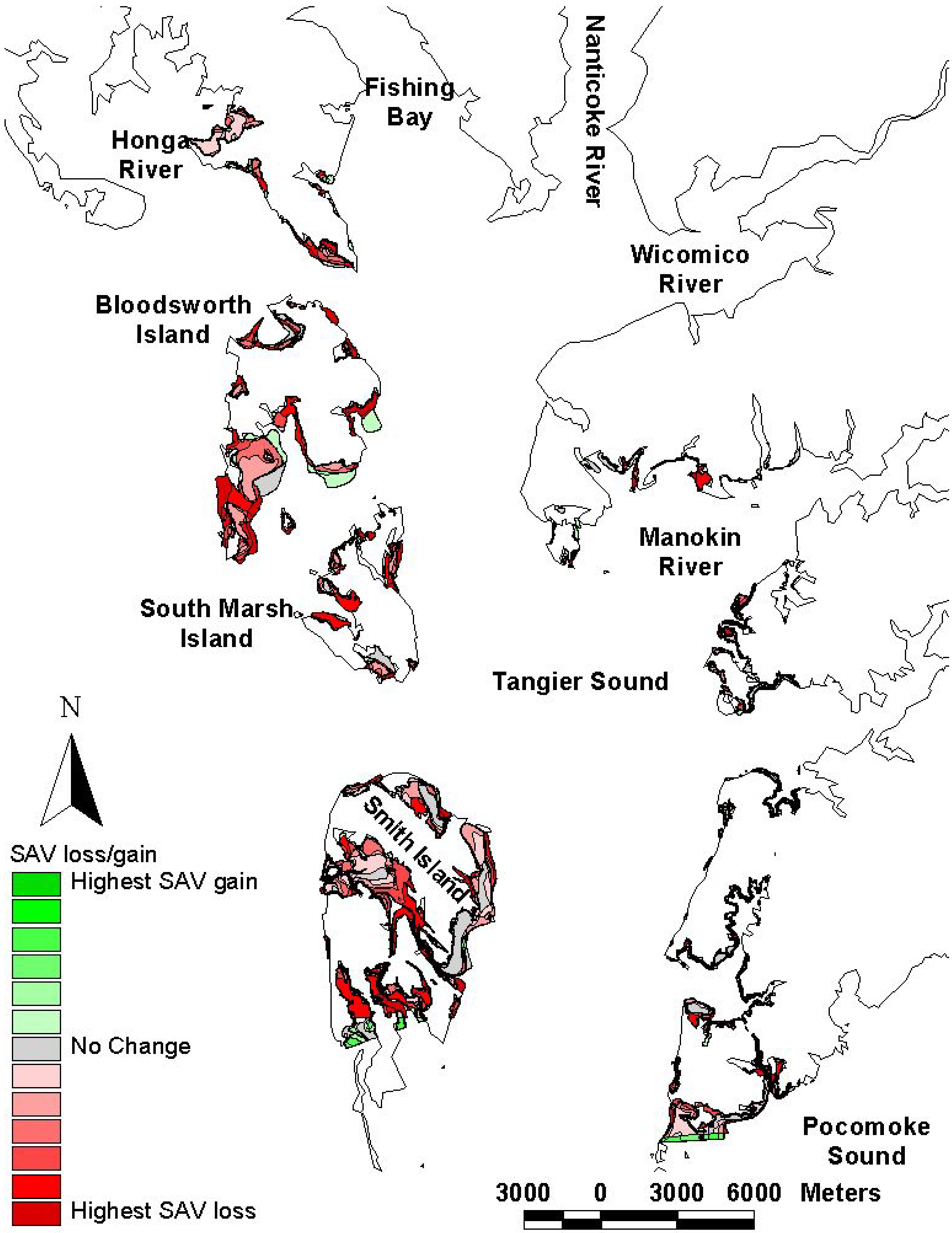


Figure 3.2: Map of SAV loss and gain over the 1992 to 1998 time period. SAV loss relative to the 1992 coverage is represented in red. The more red an area is, the more years vegetation has been absent from that area since 1992. Green areas represent gains over the 1992 SAV coverage (areas unvegetated in 1992 becoming vegetated later). The more green the area, the more years SAV has been present.

and a negative value indicates areas where SAV colonized after 1992 (the more negative the number, the more years that cell has been vegetated). The resulting grid was intersected with the 1992 SAV coverage.

The final step was to intersect the shoreline loss shapefile and the SAV loss shapefile to generate one coverage where each polygon contained a SAV loss value and a shoreline loss value. In order to assess whether there was a significant relationship between shoreline erosion and SAV loss, the shoreline loss data were compared with a Type-II ANOVA for unequal *n* (SAS Institute) with 13 classes representing each of the SAV loss values. Tukey "Honestly Significant Difference" multiple comparison tests (HSD) were performed (Table 3.1, Figure 3.3). The operating hypothesis was that there would be higher SAV loss in areas with the most shoreline loss.

Table 3.1: Results of Tukey HSD multiple comparison tests on shoreline loss data, classed by SAV Code. NS = non-significant, A = significant, with title row having higher mean, B = significant, with title column

SAV CODE	**-6**	**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**
-6		NS	NS	NS	NS	A	NS	A	NS	NS	NS	A	NS
-5			A	A	NS	A	NS	NS	NS	NS	NS	NS	NS
-4				NS	A	A	A	A	A	A	A	A	A
-3					A	A	A	A	A	A	A	A	A
-2						A	A	A	NS	A	NS	A	NS
-1							B	B	B	B	B	B	B
0								A	B	A	B	A	B
1									B	B	B	B	B
2										A	NS	A	NS
3											B	A	B
4												A	NS
5													B
-6													

having higher mean. All results were evaluated at $p<0.05$.

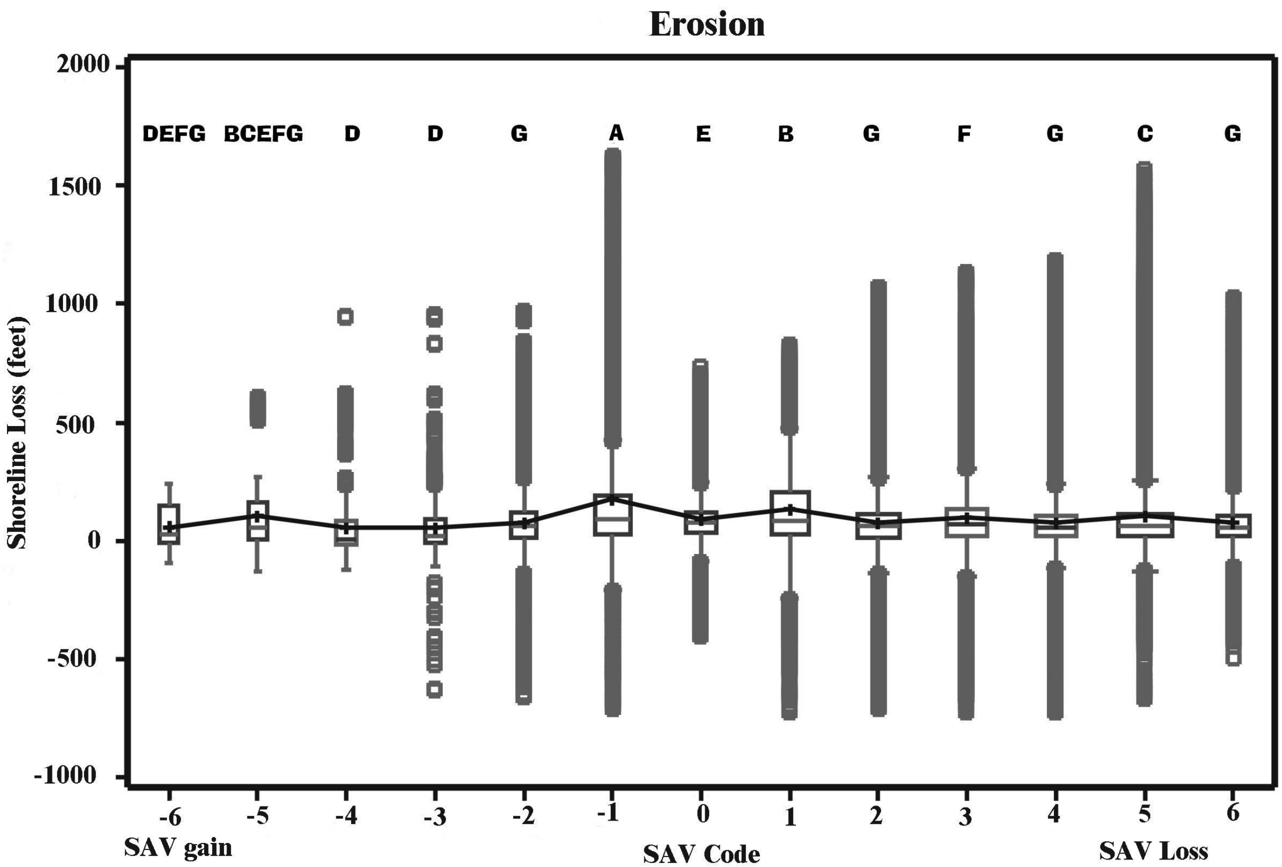


Figure 3.3: Box plots of shoreline loss data, plotted by SAV loss (gain). The greater the SAV code number, the longer that area has been unvegetated since 1992. The more negative the number, the more years SAV has been present in areas not vegetated in 1992. The letters above each box are the results of the Tukey HSD multiple comparisons. Box plots with different letters are significantly different from each other. The solid line through each box plot connects the means shoreline loss for each SAV gain/loss class.

3.3: Results and Discussion

While there were many significant differences (Table 3.1), there is no clear pattern of SAV loss vs. shoreline loss (Figure 3.3). These large-scale results indicate that the shoreline loss is not affecting the SAV loss or gain from 1992 to 1998 in the Tangier Sound region. However, that does not mean that shoreline erosion does not have major impacts on SAV distribution, either negatively affecting the vegetation by smothering or increased local turbidity or positively affecting it by converting intertidal zones or uplands into shallow water flats (Batiuk *et al*., 1992). The relationship of SAV distribution and shoreline erosion needs more detailed examination than is possible with data currently available.

Chapter 4: Comparison of “Current” vs. “Historic” Water Quality Data in the Tangier Sound Region

4.1: Introduction

One of the fundamental questions of this study is whether or not the recent declines in submerged aquatic vegetation (SAV) abundance in Tangier Sound are a reflection of long- or short-term water quality degradation. In 1952, there were approximately 24,827 acres of SAV (Naylor, in prep) in the Maryland section of the Tangier Sound Mesohaline segment. Since the beginning of yearly SAV surveys in 1984 (Orth *et al.*, 1984-2000), the maximum SAV coverage recorded by Virginia Institute of Marine Science was 9,154 acres in 1992. By 1998 there were only 1,948 acres remaining. This is a total decline from 1952 to 1998 of over 92%. The principal factor in the large decline in SAV coverage was hypothesized to be a reduction in water quality. Water quality conditions prior to the creation of the Chesapeake Bay Program have yet to be examined in relation to this problem. To assess whether long-term water quality degradation can explain the decline in SAV, historical water quality data (earlier than 1984) were compared with post 1984 conditions.

The Chesapeake Bay Institute (CBI) of Johns Hopkins University collected water quality data from 1949 to 1982 throughout Chesapeake Bay. SAV related parameters collected include; dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorous (DIP), chlorophyll *a*, Secchi depth and total suspended solids (TSS), with percent light through the water column (PLW) and percent light at leaf (PLL) calculated by the method of Batiuk *et al.* 2000, and salinity, as a surrogate for freshwater input. Data and metadata are available online at http://www.chesapeakebay.net/data/index.htm. In this dataset, there are 178 stations located in the Chesapeake Bay Program (CBP) segments associated with the Tangier Sound area (Figure 4.1). These stations were not sampled regularly, or over long time periods (Table 4.1). Most of these data are from the 1970s, with limited data prior to 1971. The CBI dataset was compared to the CBP water quality monitoring data (1984-2000), in the same geographic area (13 stations total).

4.2: Methods

Data from all stations within a given CBP segment were “lumped” together for analysis, due to the high temporal and spatial variability of the CBI data. In addition, comparisons of individual stations would have insufficient sample size for robust analyses (Table 4.1). The data were limited to March through November to represent the growing seasons of both *Ruppia maritima* (widgeon grass) and *Zostera marina* (eelgrass). Only samples taken at the surface were analyzed. Qualitative analysis consisted of graphing the older CBI data by CBP segment, with time as the independent variable and each water quality parameter as the dependent. The SAV habitat requirement (Batiuk *et al.*, 1992, Batiuk *et al.*, 2000) for each parameter, and the long-term median of the more modern 1984-2000 Chesapeake Bay Program dataset were included (Figures 4.2-4.8). While there is not a habitat requirement for salinity, this parameter was included to provide some indication of fresh water input to the system. Quantitatively, the CBI data were compared to the CBP water quality data with a *t-test* for unequal *n* (SAS Institute), testing chlorophyll *a*,

Table 4.1: Years sampled and Maximum *n* for each segment analyzed. Maximum *n* is the highest total number of observations over the time series for one of the SAV habitat requirements and the number in parentheses shows how many stations were "lumped" into the analysis.

Segment	CBI Years Sampled	Maximum *n* (# of stations)	CBP Years Sampled	Maximum *n* (# of stations)
CB5MH	1949-1951, 1965, 1966, 1968 to 1971, 1973 to 1981	935 (78)	1984 to 2000	1020 (4)
FSBMH	1974 to 1978	58 (24)	1986 to 2000	253 (1)
MANMH	1974 to 1976	12 (13)	1986 to 2000	254 (1)
BIGMH	1976 and 1977	4 (8)	1986 to 2000	256 (1)
POCMH	1949, 1974, 1976, 1977	945 (15)	1986 to 2000	504 (2)
TANMH	1949-1951, 1968, 1970, 1971, 1973 to 1978	153 (40)	1984 to 2000	1056 (4)

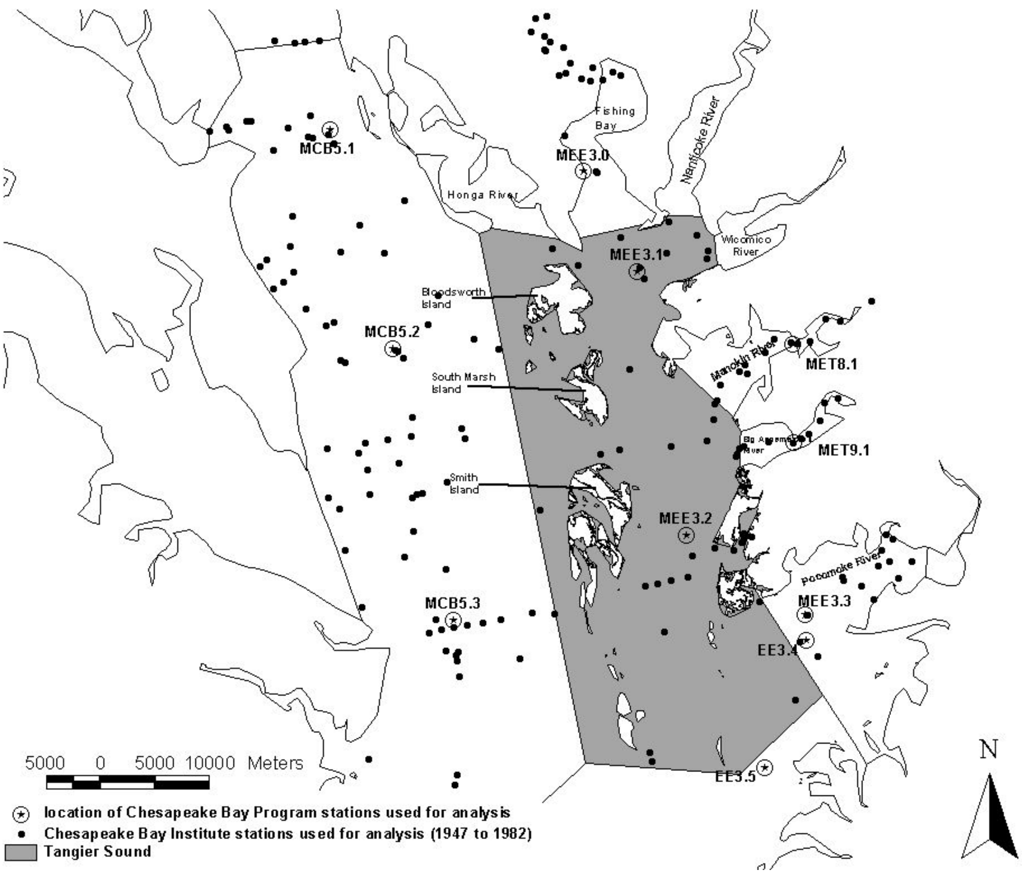


Figure 4.1: Location of stations used in the "Current" vs. "Historic" water quality data analysis;

DIN, DIP, Secchi depth, TSS, PLW (1 meter), PLL (1 meter) and salinity. PLW and PLLare modeled parameters. Calculations were only performed if each observation had DIN, DIP and TSS (annual medians were not used).

The following segments were analyzed: Big Annemessex Mesohaline (BIGMH), Mid Chesapeake Bay Mesohaline (CB5MH), Fishing Bay Mesohaline (FSBMH), Manokin Mesohaline (MANMH), Pocomoke Mesohaline (POCMH) and Tangier Sound Mesohaline (TANMH). These segments were chosen because they are the ones in the region that have SAV coverage recorded by the VIMS SAV survey, and all experienced losses after 1992. The Nanticoke (NANMH) and Wicomico (WICMH) Mesohaline segments have not had SAV recorded since 1984, so these were not considered in order to simplify the analysis. The results are summarized in Table 4.2.

Table 4.2: Results of *t-test* for unequal sample sizes. Blank cells indicate that there was insufficient data to perform the test. **NS** indicates a non-significant result for the comparison. If a cell contains **CBI**, the 1949-1982 dataset (Chesapeake Bay Institute) had a significantly greater value for that parameter. If the cell contains **CBP**, the 1984-2000 dataset (Chesapeake Bay Program) had a significantly greater value for that parameter. If no asterisk follows the dataset designation, this indicates that the p-value was less than 0.05 and greater than or equal to 0.01. A single asterisk indicates that the p-value was less than 0.01 and greater than or equal to 0.001. Two asterisks indicate that the p-value was less than 0.001.

Parameter	**CB5MH**	**FSBMH**	**MANMH**	**BIGMH**	**POCMH**	**TANMH**
Chlorophyll	NS					
DIN	NS	CBI**	NS	NS	CBI**	CBI*
DIP	CBI**	NS	CBI**		CBI**	CBI**
Secchi	CBI**				CBP**	NS
TSS	CBI**	CBI**	NS		NS	CBI**
PLL (1m)	CBI*					
PLW (1m)	CBI**					
Salinity	CBI**	CBP**	CBP	CBP**	CBP**	NS

4.3: RESULTS

Chlorophyll *a*: only CB5MH had sufficient data for analysis of chlorophyll *a* (which showed no significant differences between the datasets (Figure 4.2).

DIN: Levels of DIN were either the same (BIGMH, CB5MH, and MANMH) or significantly higher (FSBMH, POCMH and TANMH) in the historic (CBI) data than in the recent (CBP) data (Figure 4.3).

DIP: There is a similar pattern with each segment having higher DIP in the historic data than in the modern sampling effort (except FSBMH which showed no difference). This is expected since the phosphate ban was instituted in 1986 in Maryland and 1987 in Virginia, so more recent data would show the effect of decreased phosphorous loads (Figure 4.4).

Light penetration: For Secchi depth, there were only 3 segments with sufficient data for analysis and of those, the historic dataset showed greater light penetration than the recent data at CB5MH, TANMH showed no difference and the recent, CBP, dataset showed greater clarity than the CBI data in POCMH (Figure 4.5).

TSS: TSS also showed a similar pattern, with either no difference between the two datasets (MANMH, POCMH) or the CBI data significantly higher (CB5MH, FSBMH and TANMH). There were no data for BIGMH (Figure 4.6).

PLL and PLW: CB5MH was the only segment that had sufficient data to perform an analysis on PLL and PLW calculations. For both of these parameters, the historic (CBI) dataset had significantly greater light penetration than the recent CBP data. In light of the higher TSS values in the older dataset, this is a surprising result, as usually higher TSS results in poor water clarity. Differences in algal populations between the two time periods may explain this result. However there is not a significant difference between the chlorophyll *a* concentrations between the older and new datasets for segment CB5MH, and there are no chlorophyll *a* data for the other segments to assess if algae populations are greater in the modern dataset, thus explaining the lower light penetration (Figure 4.7).

Salinity: Salinity was greater in the CBP dataset in most segments, except CB5MH had greater salinity in the earlier dataset and in TANMH where there was not a significant difference. This suggests that before 1984 there may have had more rainfall and thus higher flows into the region. This may explain the higher DIN and TSS levels in the CBI dataset (Figure 4.8).

4.4: DISCUSSION

The water quality conditions as a whole were worse prior to the 1984 to 2000 time period. This may explain the loss of SAV over the larger time scales. The majority of the CBI data are from the 1970s, which from anecdotal evidence is after the large SAV declines of the 1960s, so assessing a "before" state is not possible. Lastly, the high spatial and temporal variability in the data, which coupled with the low *n* in a many areas, make drawing meaningful conclusions difficult.

The general conclusions of these analyses are:

- Chlorophyll *a*, PLL and Secchi depth data are lacking
- Dissolved inorganic nitrogen concentrations have either been stable or decreased.
- Dissolved inorganic phosphorous concentrations have decreased.
- Total Suspended Solids levels have decreased.
- Salinity levels have increased, indicating that the more recent time period may have been more dry, with less freshwater input.

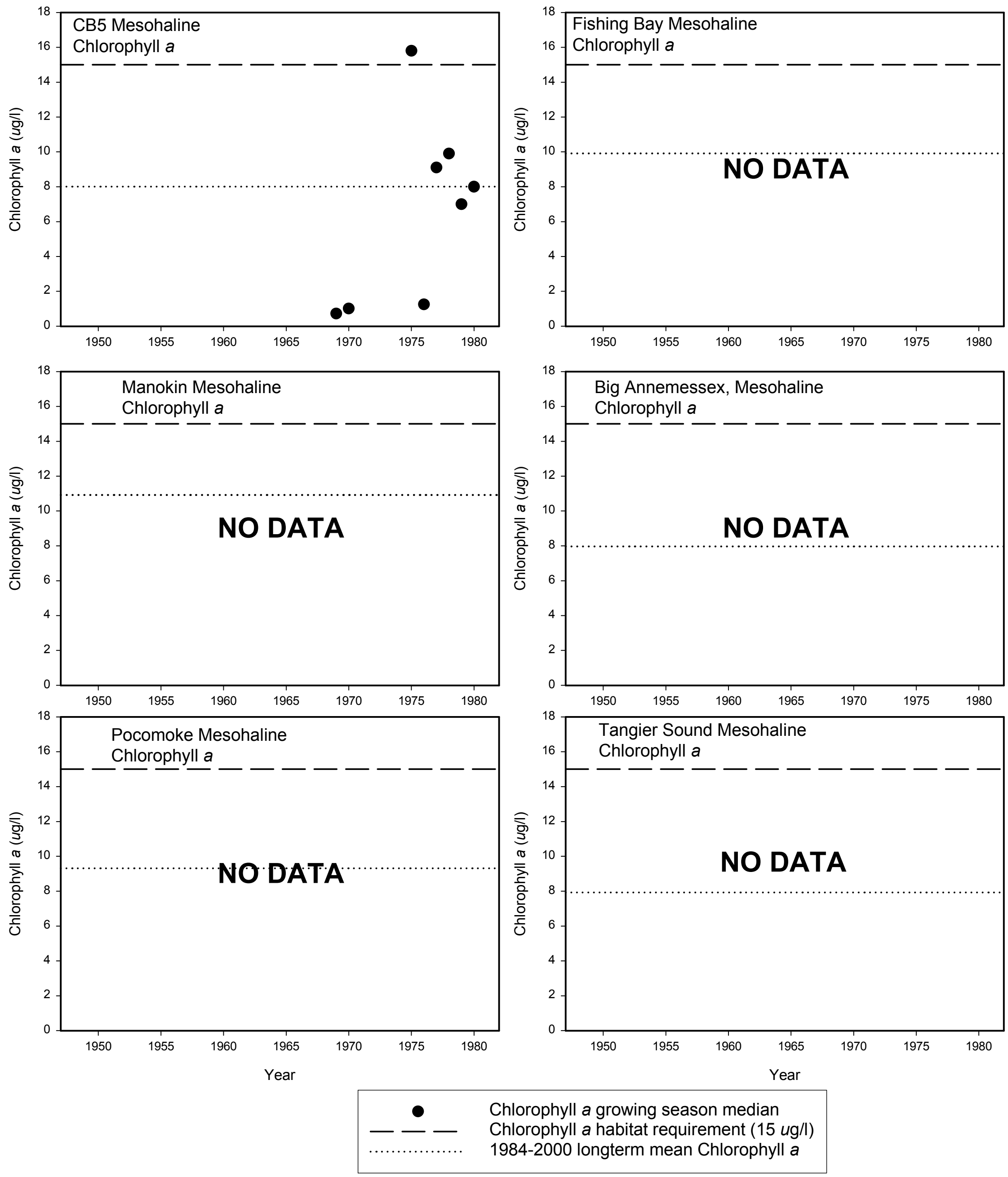


Figure 4.2: Graphs of Chlorophyll *a*, CBI time series data and long-term median of CBP data and SAV habitat requirement for each segment analyzed.

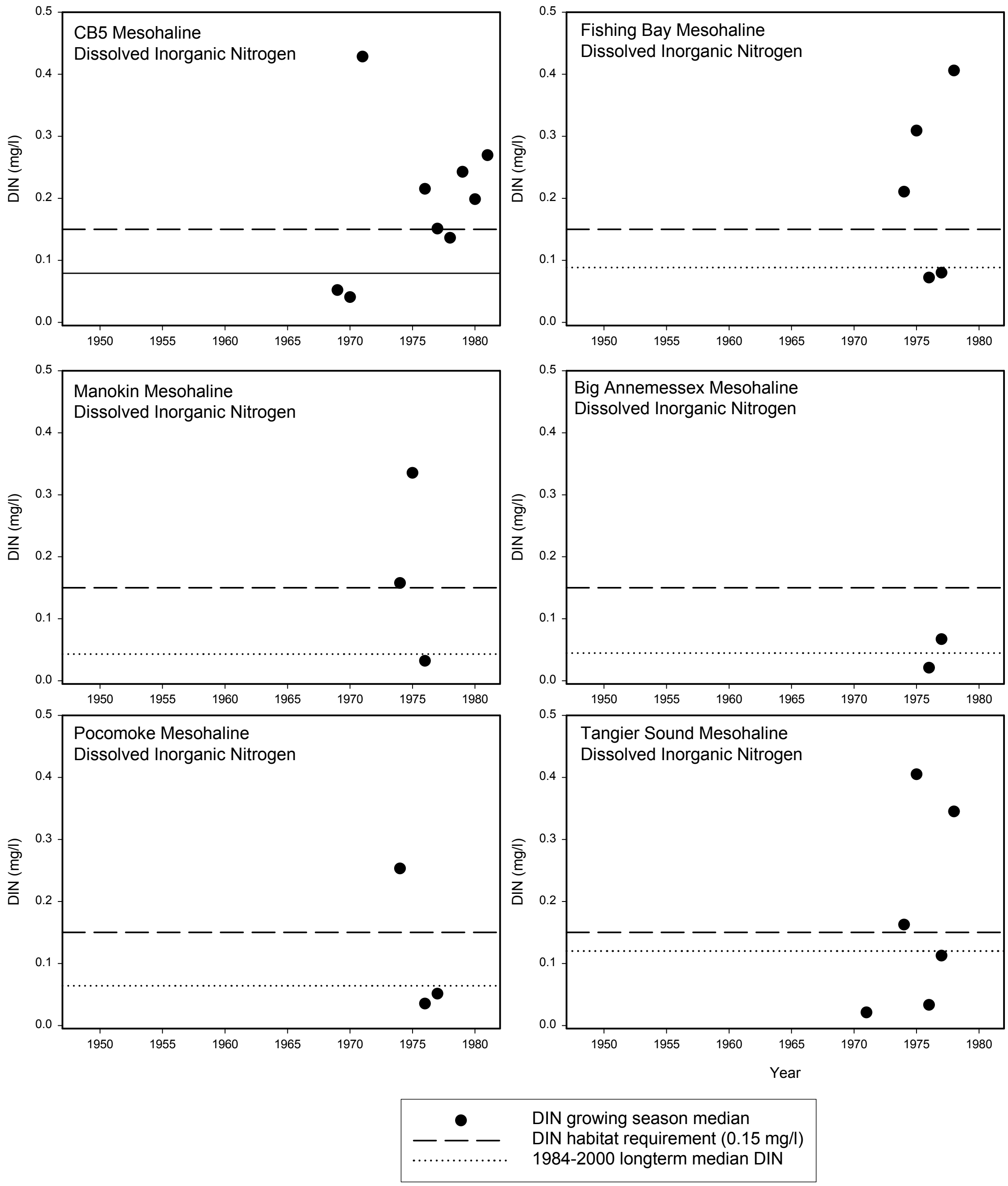


Figure 4.3: Graphs of dissolved inorganic nitrogen (DIN), CBI time series data and long-term median of CBP data and SAV habitat requirement for each segment analyzed.

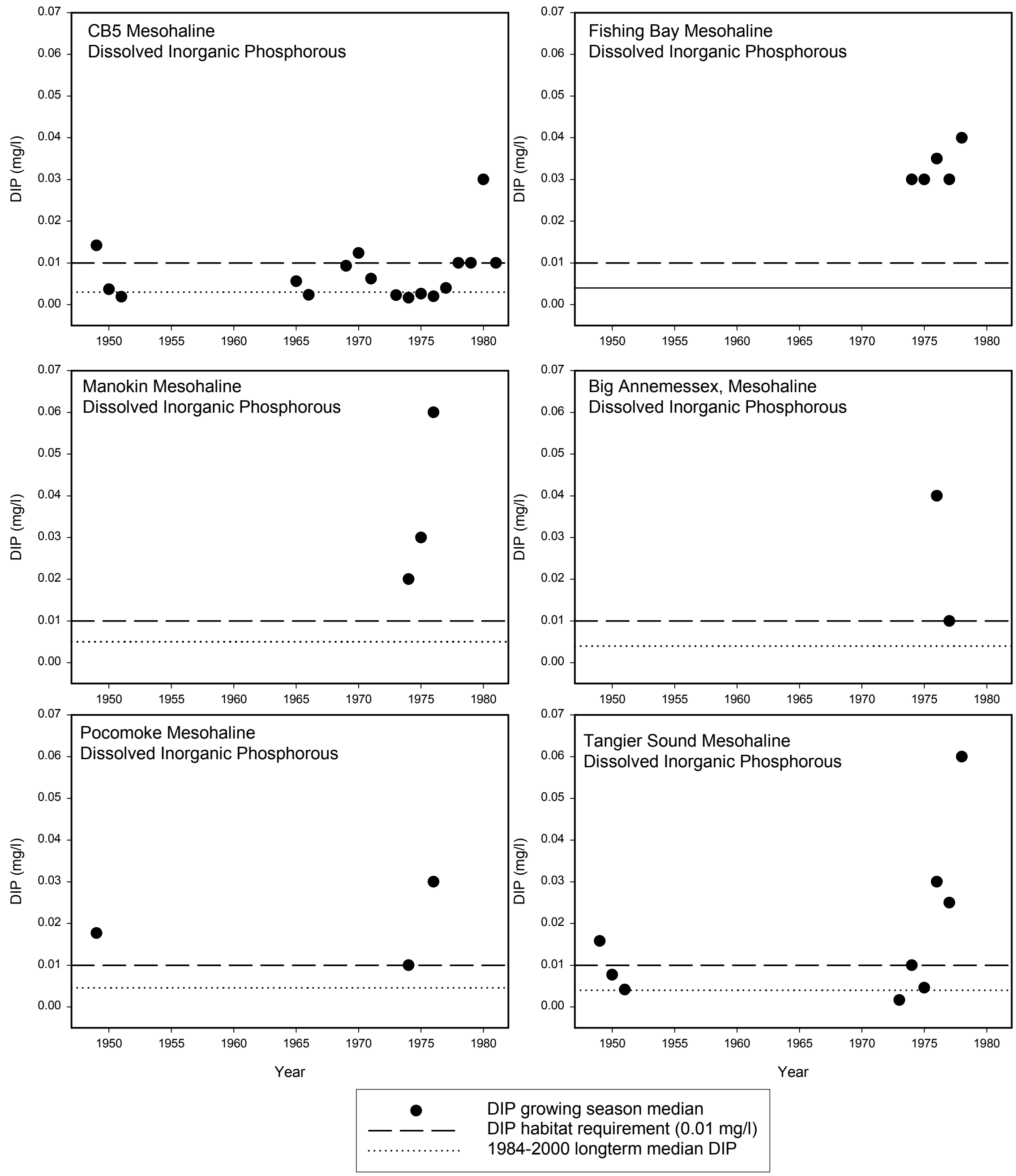


Figure 4.4: Graphs of dissolved inorganic phosphorous (DIP), CBI time series data and long-term median of CBP data and SAV habitat requirement for each segment analyzed.

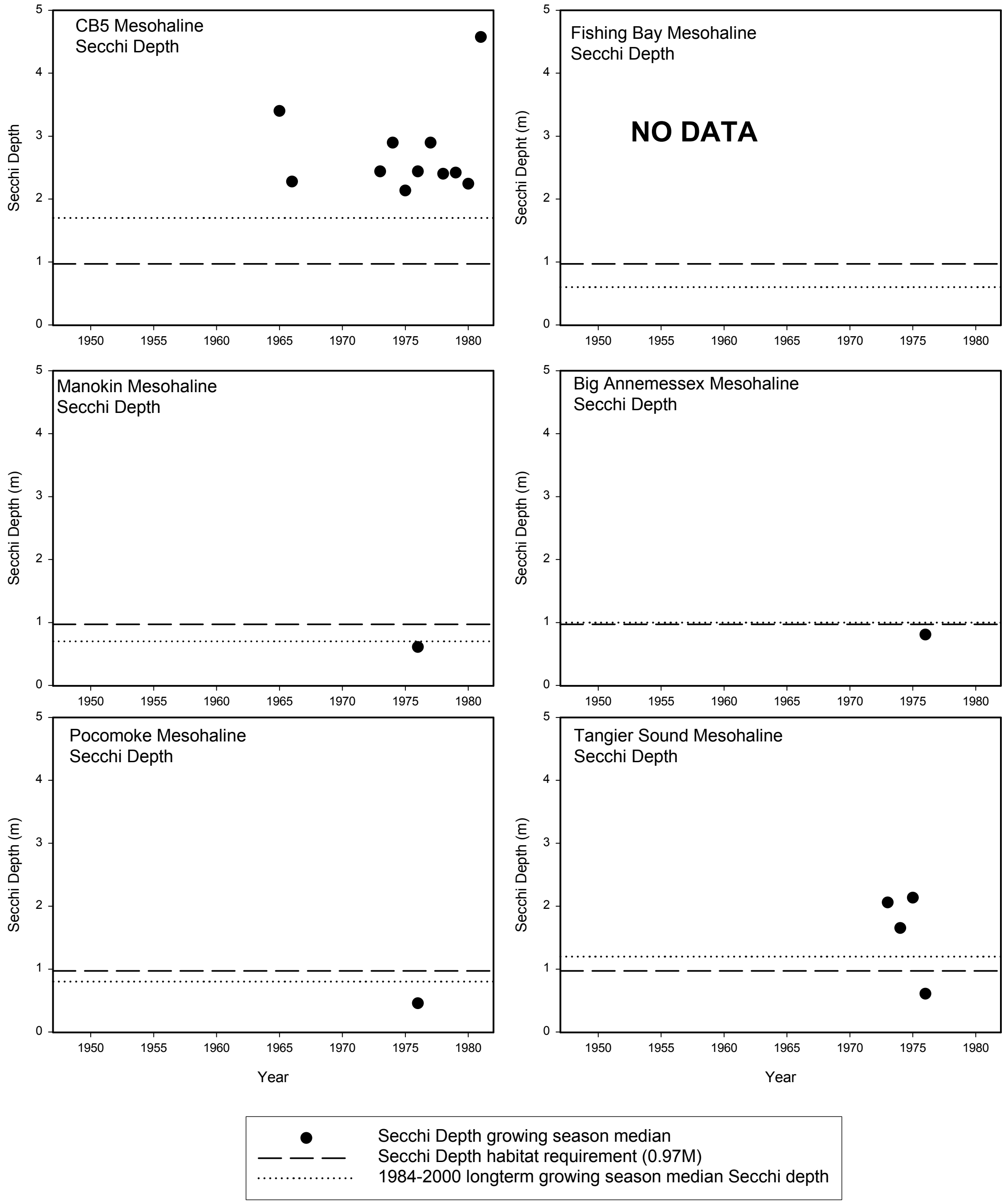


Figure 4.5: Graphs of Secchi depth, CBI time series data and long-term median of CBP data and SAV habitat requirement for each segment analyzed.

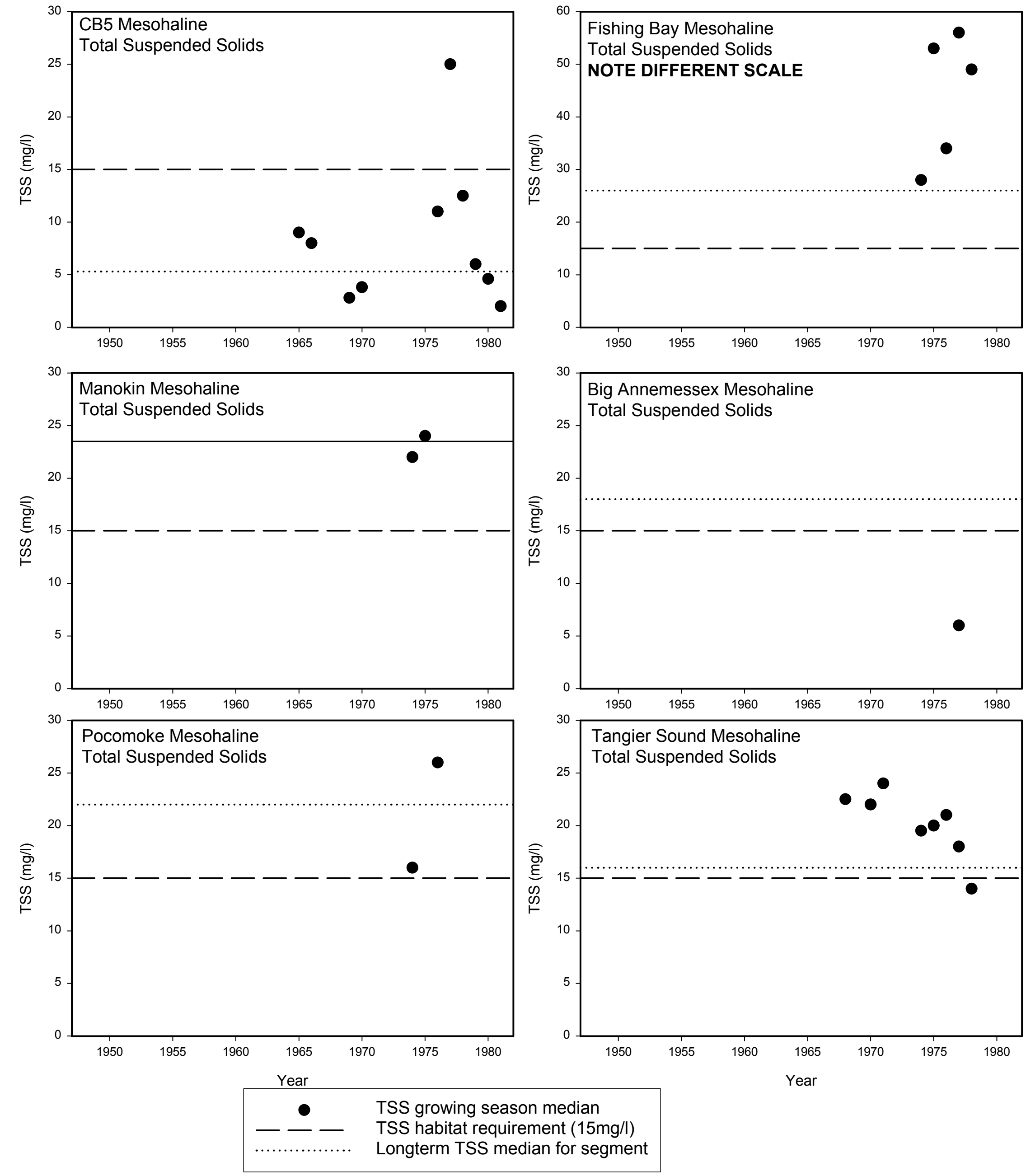


Figure 4.6: Graphs of Total Suspended Solids (TSS), CBI time series data and long-term median of CBP data and SAV habitat requirement for each segment analyzed.

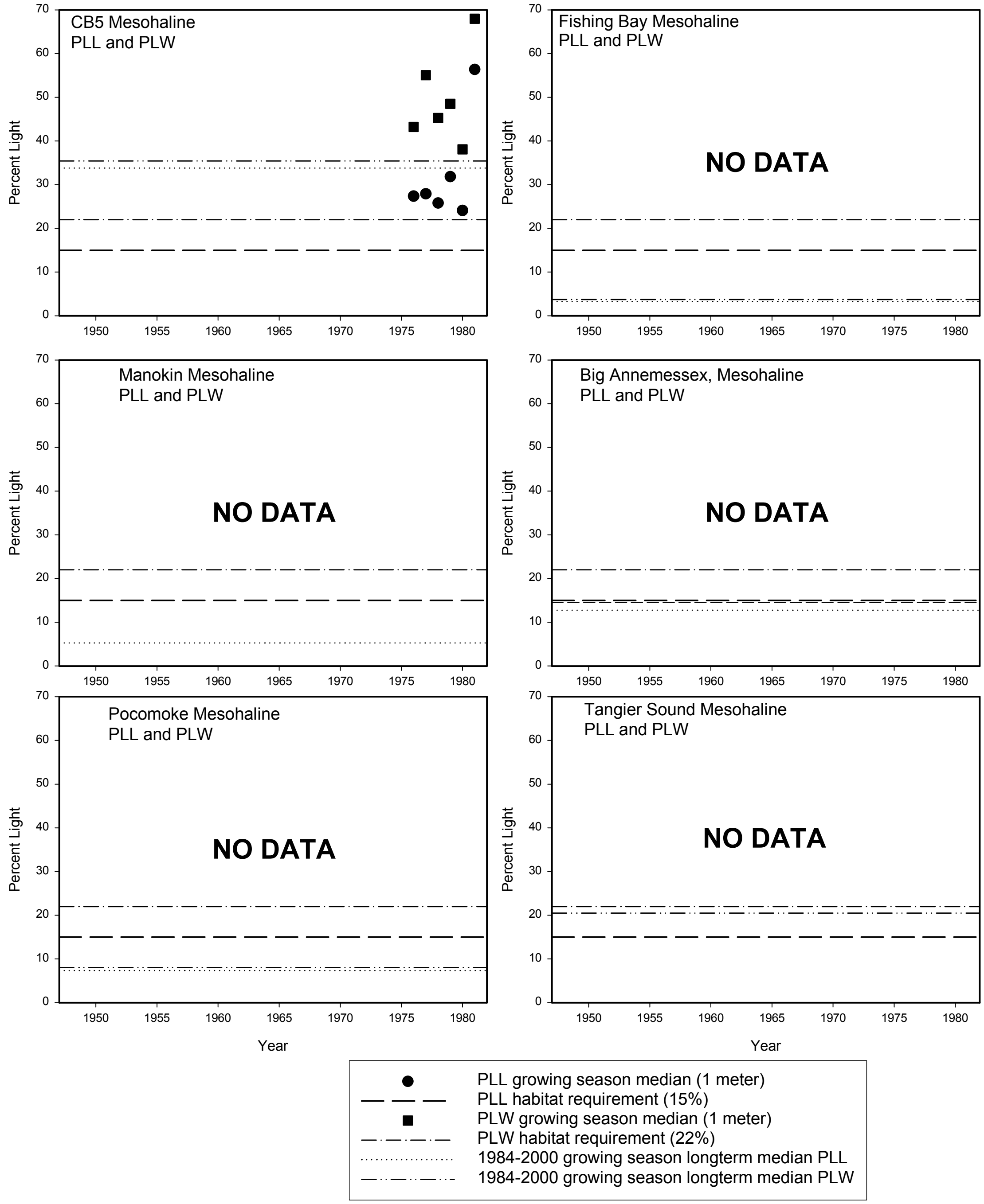


Figure 4.7: Percent light through water column and percent light at leaf (PLW and PLL), CBI time series data, long-term median of CBP data and SAV habitat requirement for each segment analyzed.

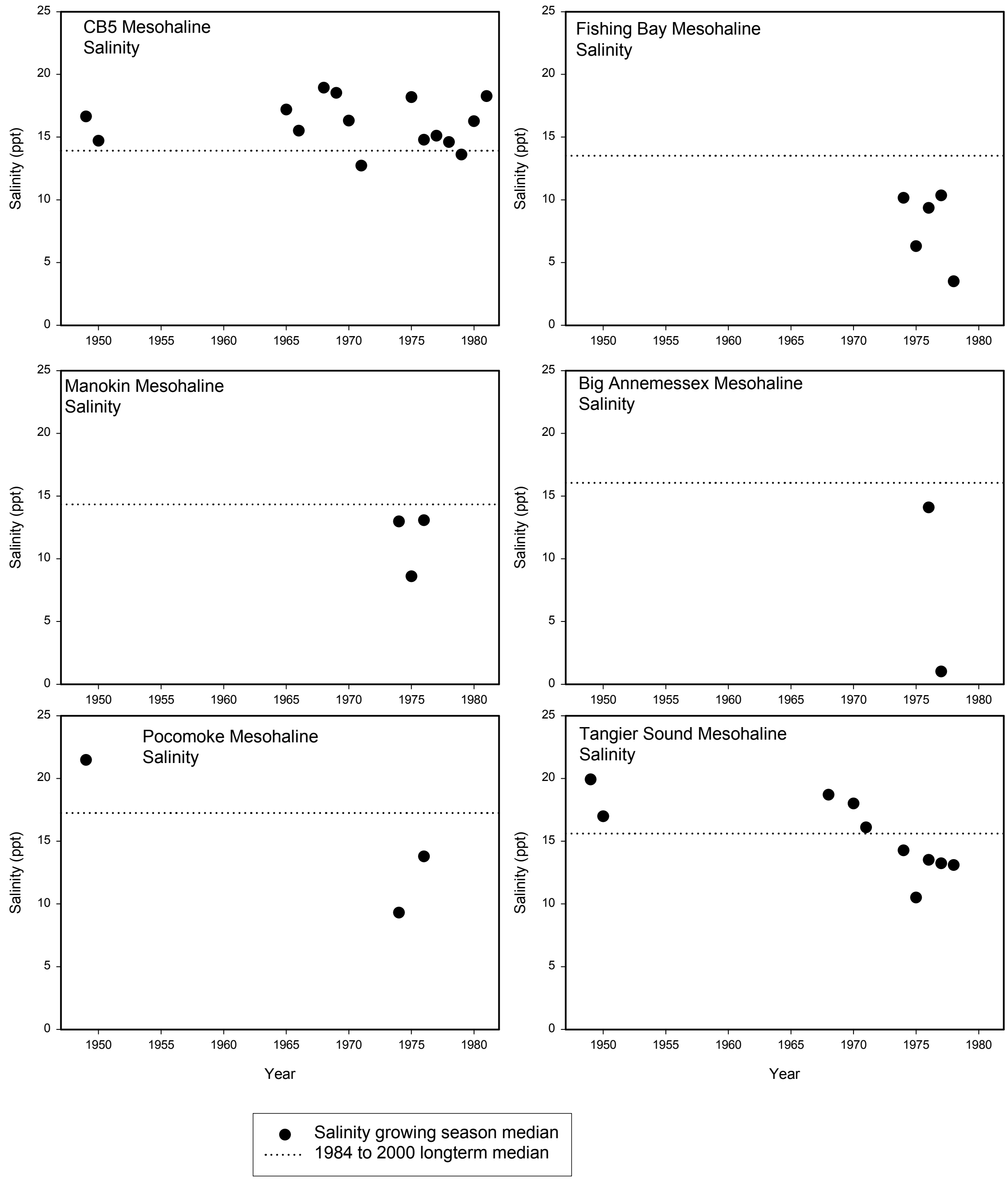


Figure 4.8: Graphs of salinity, CBI time series data and long-term median of CBP data for each segment.

Chapter 5: Evaluation of Regional Water Quality in Tangier Sound Relative to the Loss of SAV

5.1: Status and Trends

5.1.1: Introduction

The Maryland Department of Natural Resources, and the Chesapeake Bay Program have been collecting water quality data throughout the Lower Eastern Shore region since 1984 (Figure 5.1). Annually, these data are analyzed to assess status and trends of water quality conditions in these areas. A component of these analyses assess parameters relevant to the survival and growth of SAV (DIN, DIP, Chlorophyll *a*, TSS, Secchi depth, and percent light at leaf, Batiuk *et al*., 1992; Batiuk *et al*., 2000).

5.1.2: Methods

Status is assessed by a Wilcoxon Rank Sum test using 1998 to 2000 data, and trends are assessed with a Season Kendall test using 1984 to 2000 data. Only surface data are used, limited to the SAV growing season, April through October for most areas, and March to May and September to November for areas containing *Zostera marina* (eelgrass).

5.1.3: Results

DIN and DIP: The status of nutrient concentrations (dissolved inorganic nitrogen and phosphorous, DIN and DIP) are passing or borderline with respect to the SAV habitat requirements (Batiuk *et al.*, 1992) in the all of the Lower Eastern Shore mesohaline segments; Chesapeake Bay 5 Mesohaline (CB5MH), Fishing Bay Mesohaline (FSBMH), Nanticoke River Mesohaline (NANMH), Wicomico River Mesohaline (WICMH), Manokin River Mesohaline (MANMH), Big Annemessex Mesohaline (BIGMH), Pocomoke Sound Mesohaline (POCMH), and Tangier Sound Mesohaline (TANMH) (Maryland DNR, http://www.dnr.state.md.us/bay/sav/acreage/les.html). DIP concentrations show no trend in most segments (TANMH, FSBMH, NANMH, WICMH, MANMH and BIGMH) while POCMH, and MANMH show improving trends (i.e. DIP concentrations are dropping over time). DIN conditions are improving (i.e. DIN concentrations are dropping over time) in CB5MH, FSBMH, MANMH, POCMH and TANMH, while segments NANMH, WICMH, and BIGMH have no DIN trend (Table 5.1). It is important to note that for DIN, segment CB5MH has a significant trend with no slope, as do MANMH and POCMH for DIP. This is an artifact of the Seasonal Kendal test, due to the method by which concentrations below the detection limit of these parameters are assigned discrete values.

Chlorophyll *a*: Chlorophyll *a* concentrations are either borderline (CB5MH, FSBMH and NANMH) or meet the SAV habitat requirements (WICMH, MANMH, BIGMH, POCMH and TANMH; MD-DNR, http://www.dnr.state.md.us/bay/sav/acreage/les.html). CB5MH, FSBMH, NANMH, BIGMH, and POCMH have no trend in chlorophyll *a*

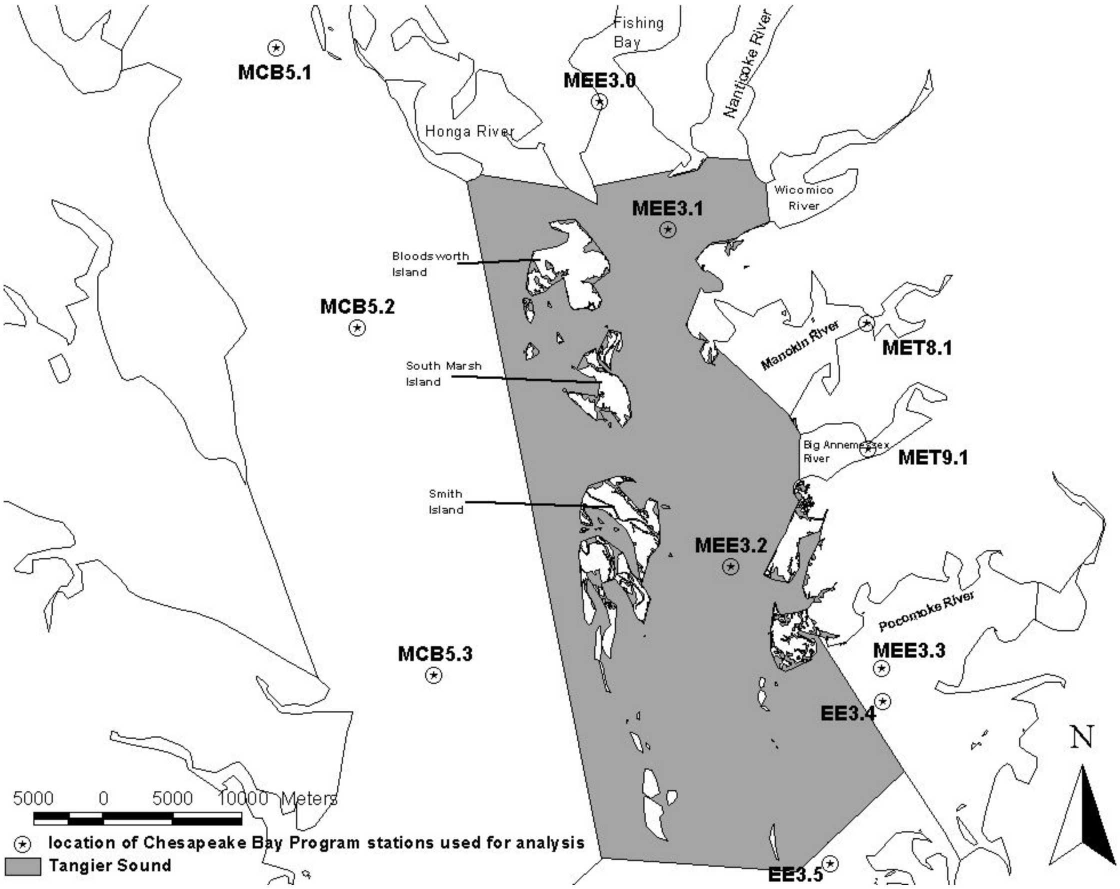


Figure 5.1: Locations of stations used for status, trend and discrete time interval analysis.

Table 5.1: Results of 1984-2000 trend analyses, (Marcia Olson, Chesapeake Bay Program, Annapolis, MD, personal communication) with significant results in shaded rows.

Parameter	Segment	# Yrs	Probability	Slope	Base median	% Change
DIN	**CB5MH**	**16**	**0.022s**	**-0.001**	**0.072**	**-13.4**
DIN	**FSBMH**	**16**	**0.014s**	**-0.003**	**0.146**	**-32.9**
DIN	NANMH	16	0.664	-0.001	0.15	.
DIN	WICMH	16	0.464	-0.001	0.14	.
DIN	**MANMH**	**16**	**0.043s**	**-0.001**	**0.042**	**-22.9**
DIN	BIGTF	16	0.55	0	0.036	.
DIN	**TANMH**	**16**	**0.019s**	**-0.005**	**0.156**	**-46.1**
DIN	**POCMH**	**16**	**0.003s**	**-0.001**	**0.065**	**D**
DIP	**CB5MH**	**16**	**0.021s**	**0**	**0.005**	**Z**
DIP	FSBMH	15	0.082	0	0.002	.
DIP	NANMH	15	0.259	0	0.006	.
DIP	WICMH	15	0.831	0	0.014	.
DIP	**MANMH**	**15**	**0.037s**	**0**	**0.005**	**0**
DIP	BIGMH	15	0.079	0	0.002	.
DIP	TANMH	16	0.788	0	0.005	.
DIP	**POCMH**	**16**	**0.003s**	**0**	**0.005**	**Z**
CHLOROPHYLL	CB5MH	16	0.196	0.083	5.8	0
CHLOROPHYLL	FSBMH	16	0.104	0.145	5.7	.
CHLOROPHYLL	NANMH	16	0.574	0.073	9.6	.
CHLOROPHYLL	**WICMH**	**16**	**0.032s**	**-0.312**	**10.4**	**-48**
CHLOROPHYLL	MANMH	16	0.275	-0.117	11.6	.
CHLOROPHYLL	BIGMH	16	0.519	0.043	7.3	.
CHLOROPHYLL	**TANMH**	**16**	**0.000s**	**0.22**	**4.1**	**86.5**
CHLOROPHYLL	POCMH	16	0.358	0.064	9	0
TSS	CB5MH	16	0.268	0.042	7	0
TSS	FSBMH	16	0.377	0.25	21	.
TSS	NANMH	16	0.335	0.374	25	.
TSS	WICMH	16	0.316	0.25	20	.
TSS	MANMH	16	0.844	0	21	.
TSS	BIGMH	16	0.752	0.057	12	.
TSS	TANMH	16	0.453	0.125	10	.
TSS	POCMH	16	0.148	0.259	13	0
SECCHI	**CB5MH**	**16**	**0.000s**	**-0.021**	**1.8**	**-18.5**
SECCHI	**FSBMH**	**16**	**0.042s**	**0**	**0.7**	**0**
SECCHI	**NANMH**	**16**	**0.006s**	**0**	**0.5**	**0**
SECCHI	WICMH	16	0.239	0	0.6	.
SECCHI	**MANMH**	**16**	**0.003s**	**-0.017**	**0.7**	**-38.2**
SECCHI	**BIGMH**	**16**	**0.030s**	**-0.011**	**1.1**	**-16.9**
SECCHI	**TANMH**	**16**	**0.001s**	**-0.013**	**1.5**	**-13.8**
SECCHI	**POCMH**	**16**	**0.001s**	**-0.013**	**1.1**	**-18.6**
PLL	**CB5MH**	**16**	**0.000s**	**-0.004**	**34.8**	**-17.9**
PLL	FSBMH	16	0.057	-0.001	5.1	.
PLL	**NANMH**	**16**	**0.023s**	**0**	**1.6**	**-41**
PLL	WICMH	16	0.257	0	2.7	.
PLL	**MANMH**	**16**	**0.007s**	**-0.003**	**5.4**	**-79.7**
PLL	**BIGMH**	**16**	**0.048s**	**-0.003**	**14.3**	**-35.8**
PLL	**TANMH**	**16**	**0.001s**	**-0.003**	**22.7**	**-21.1**
SALINITY	**CB5MH**	**16**	**0.000s**	**-0.191**	**16.1**	**-19**
SALINITY	**FSBMH**	**16**	**0.001s**	**-0.252**	**15.1**	**-26.7**
SALINITY	**NANMH**	**16**	**0.027s**	**-0.19**	**10.3**	**-29.5**
SALINITY	WICMH	16	0.584	-0.052	9	.
SALINITY	**MANMH**	**16**	**0.012s**	**-0.146**	**15.7**	**-14.8**
SALINITY	**BIGMH**	**16**	**0.002s**	**-0.167**	**17.1**	**-15.6**
SALINITY	**TANMH**	**16**	**0.004s**	**-0.115**	**16.6**	**-11.1**
SALINITY	**POCMH**	**16**	**0.002s**	**-0.135**	**19.1**	**-11.3**

concentrations, MANMH has an improving trend (Table 5.1). However, TANMH has a significant degrading trend.

TSS: For total suspended solids, FSBMH, NANMH, MANMH and POCMH fail the SAV habitat requirement (Batiuk *et al.*, 1992), while BIGMH and TANMH are borderline. Only TSS concentrations in CB5MH pass the habitat requirement. No significant trends have been identified in these 8 bay program segments.

Light penetration: The most compelling of all the parameters' status is that for light penetration, as measured by Secchi depth. Only CB5MH passes the habitat requirement (Batiuk *et al.*, 1992), BIGMH and TANMH are borderline and the other 5 segments fail. In addition to the poor current water clarity, CB5MH, MANMH, BIGMH, POCMH and TANMH have degrading trends, indicating that conditions may be worsening (Table 5.1). FSBMH and NANMH again have significant trends with zero slopes. This is due to Secchi depth typically being reported as discrete values rounded to the nearest 10 centimeters.

PLL: For percent light at the leaf, TANMH and BIGMH pass the habitat requirement, CB5MH, MANMH and POCMH are borderline, and FSBMH, NANMH, WICMH fail the habitat requirement. CB5MH, MANMH, BIGMH, POCMH and TANMH have degrading trends, while FSBMH, NANMH and WICMH have no trend (NANMH has a significant trend, but the slope is zero and the reason for this is unclear).

Salinity: Salinity was analyzed as a diagnostic parameter. While there isn't a habitat requirement for salinity, this parameter can be used as a surrogate for freshwater input. In all segments, except WICMH, the trend analysis indicates that the water has become less saline over time.

5.1.4: Discussion

Overall, the most likely suspect for the decline in SAV coverage from 1992 to 1998 appears to be low water clarity. The increasing chlorophyll *a* concentrations in TANMH may account for the decrease in water clarity in this segment, coupled with the borderline TSS levels. The decreasing trend in salinity (i.e. higher freshwater inflow) is a complicating factor, and reflected in the nutrient trends to date. Typically increased nutrient concentrations result from increased freshwater flow, due to higher terrestrial inputs. The exception to this is in areas of high primary production, where phytoplankton consume the additional nutrients coming into the system. However, this would be more obvious in the chlorophyll trends for the other segments.

5.2: Discrete Time Interval Analysis

5.2.1: Introduction

Trend analyses are not sensitive to short time scale changes in water quality, typically requiring 8 or more years of data to have robust analyses. The SAV dynamics in the Tangier Sound region have been of typically shorter time frames. SAV increased from 1984 to 1992, then decreased dramatically between1993 to 1998, and has rebounded in 1999 and 2000. In order to more precisely analyze the water quality conditions in these three distinct time periods, Chesapeake Bay Program (CBP) data were analyzed using an "Intervention" model, with the beginning of the decline in 1993 as one intervention and the recovery in 1999 as the other.

5.2.2: Methods

The water quality data between 1984 and 2000 were broken into classes based on the time periods of SAV recovery, decline and subsequent recovery. These data were analyzed with a Type-II ANOVA for unequal *n* (SAS Institute) with 3 classes, 1984 to 1992 (Recovery1) = class 0, 1993-1998 (Decline) = class 1 and 1999 and 2000 (Recovery2) = class 2. The following segments were used for analysis, CB5MH, FSBMH, MANMH, BIGMH, POCMH and TANMH. NANMH and WICMH were excluded, as they have never had SAV recorded in them in the modern surveys. Significance was evaluated at p <= 0.05. Results are summarized in table 5.2.

5.2.3: Results of Discrete Time Interval Analysis

Table 5.2: Results of the discrete time period analysis (Type II ANOVA for unequal *n* with Tukey multiple comparison tests). **A** = the pre-1993 time period, **B** = 1993 through 1998 time period and **C** = 1999 and 2000 time period. Cells with **NS** indicate no significant difference between time periods. A single asterisk indicates a significant result with a probability between 0.01 and 0.05. Two asterisks indicate a significant result with a probability less than 0.01 and greater than 0.001. Three asterisks indicate a probability less than 0.001. The >, < and = symbols show how each time period's mean related to the others for each parameter. The time period listing (A, B or C) that is in bold indicates the time period that had the "worst" mean relative to the others, for SAV growth and survival.

Parameter	CB5MH	FSBMH	MANMH	BIGMH	POCMH	TANMH
Chlorophyll *a*	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
DIN	*****B**> (A=C)	**(**A=B**)>C	**(**A=B**)>C	*****B**>C>A	*****A**>(B=C)	***(**A=B**)>C
DIP		**(**A=B**)>C		***(**A=B**)>C	*****A**>B>C	***A>B>**C**
Secchi depth	***A>B>**C**	***(A=B)>**C**	***A>(**B=C**)	**A>(**B=C**)	**(A=C)>**B**	***A>(**B=C**)
TSS	*****C**>B>A				***(**B**>A)=C	*****B**>(A=C)
PLL (1m)	***A>B>**C**	**(A>**C**)=B	**A>(**B=C**)		***A>(**B=C**)	***(A>**B**)=C
PLW (1m)	***A>B>**C**	***(A=B)>**C**	**A>(**B=C**)	**(A>**C**)=B	***A>(**B=C**)	***(A>**B**)=C
Salinity	***(A=C)>B	**(A>B)=C	***(A=C)>B	**(A=C)>B	***(**A=B**)>C	***(A=C)>B
Water temp.	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Chlorophyll *a*: Chlorophyll *a* does not show any significance differences over time in any of the Bay Program segments analyzed. This contradicts the trend results in MANMH (improving) and in TANMH (degrading). However, trends are time-series analyses, where this analysis is converting time periods into discrete units, so any difference between the two analyses can be expected (Figure 5.2).

DIN: Dissolved inorganic nitrogen concentrations were generally better in the 1999 to 2000 time periods than in the other two time periods, except in BIGMH where pre-1993 had lower DIN concentrations than the later time periods. In FSBMH, MANMH and TANMH, the period before 1993 had equal DIN to the 1993 to 1998 time period and was

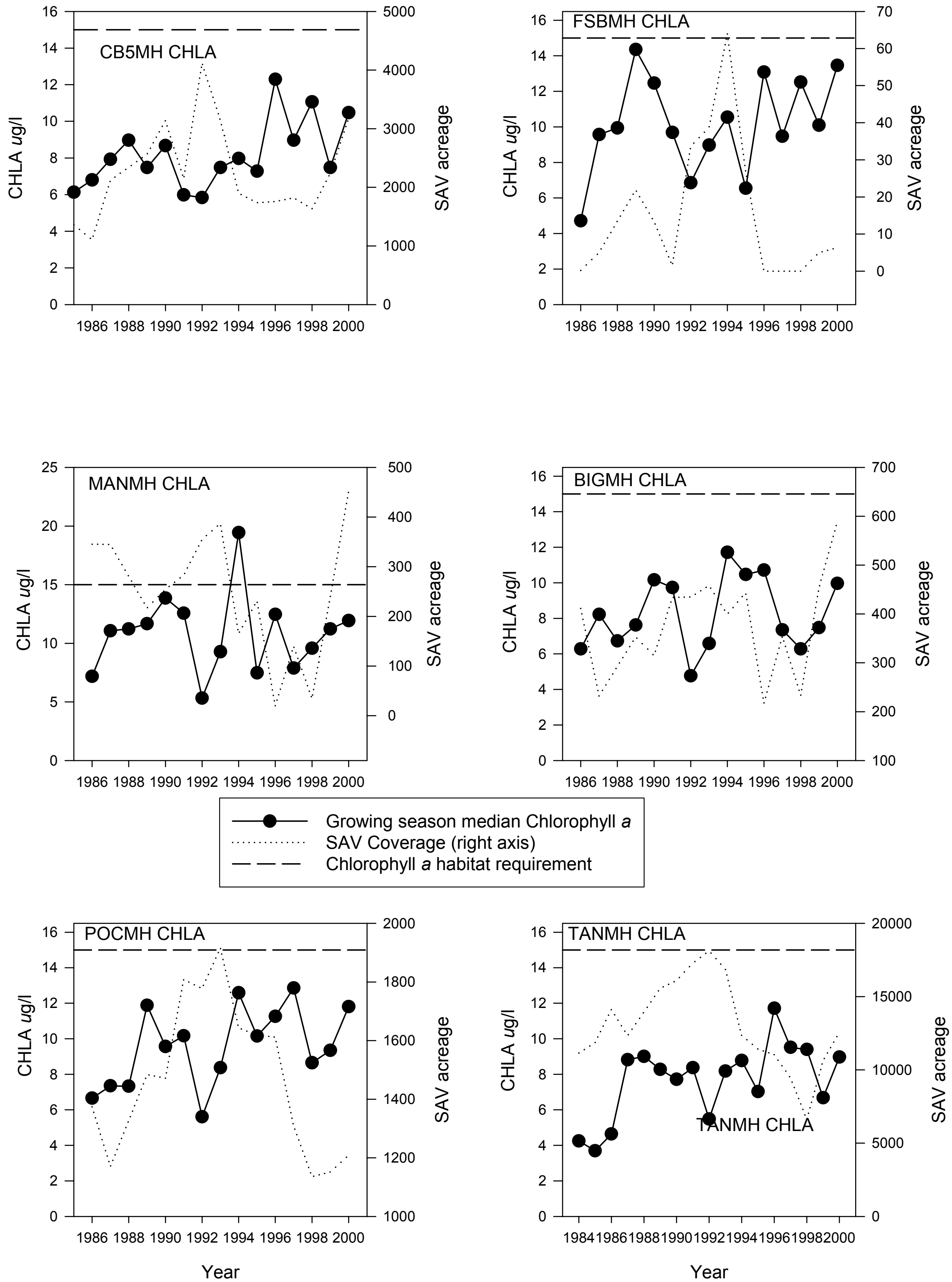


Figure 5.2: Graphs of Chlorophyll *a* showing growing season median of CBP data and SAV coverage by year and SAV habitat requirement for each segment analyzed.

greater than those in 1999-2000. The 1993 to 1998 time period had the highest DIN levels in BIGMH and CB5MH, and there was not a significant difference between the pre-1992 and 1999-2000 time periods in POCMH and CB5MH. This agrees with the trend analyses, showing either no significant or improving trends (Figure 5.3).

DIP: Dissolved inorganic phosphorous concentrations were generally better (lower) in the 1999 to 2000 time periods than in the other two time periods, except in CB5MH and MANMH, were all time periods were statistically similar. The 1993 to 1998 time period had lower DIP concentrations than the before 1993 time period in POCMH and TANMH. The DIP concentrations between the time period before 1993 and the 1993-1998 period were equal in FSBMH and BIGMH. These results are expected as the phosphate ban was instituted in 1986 in Maryland and 1987 in Virginia (Figure 5.4).

Light Penetration: Secchi depth is generally worse in later time periods, except in POCMH, where the 1999-2000 condition is similar to that before 1993. CB5MH has shown steady degradation over time. In MANMH, BIGMH and TANMH, Secchi depth in the 1993 to 1998 time period is similar to the 1999 to 2000. FSBMH had similar conditions between the 1993 to 1998 time period and pre-1993. Water clarity is the most important factor in SAV growth and survival, so these results give a good indication as to why SAV declined. However, with the exception of POCMH, there was no dramatic improvement in water clarity to explain the resurgence in the 1999 and 2000 (Figure 5.5).

TSS: Total suspended solids showed no significant differences in FSBMH, MANMH or BIGMH. In CB5MH, TSS levels have steadily increased (degraded) over time. POCMH had higher TSS concentration in the 1993 to 1998 time period than before 1993, and the 1999 to 2000 period was statistically similar to both time periods. TSS levels in TANMH were higher between 1993 and 1998 than the other periods, which were statistically similar to each other (Figure 5.6).

PLL and PLW: Percent light at the leaf (PLL) and percent light through the water (PLW) have generally been worse (lower) in later time periods. CB5MH has shown a steady decrease in both PLL and PLW. In FSBMH, PLL was lower in the 1999 to 2000 period than in the pre-1993 time period, while both time periods were indistinguishable from the 1993 to 1998 time period. PLW in this segment was lowest in the 1999 to 2000 time, while the two earlier time periods were similar. MANMH and POCMH both had the highest values for PLL and PLW in the pre-1993 time period, with the 1993-1998 and 1999 to 2000 periods being indistinguishable from each other. PLL in BIGMH had no significant difference between time periods, while PLW was better (higher) pre-1993 than in the 1999 to 2000 time period, though neither were different from the 1993 to 1998 values. TANMH was slightly different for both PLL and PLW, where the pre-1993 condition was better than the 1993 to 1998 time periods were, with both similar to the 1999 to 2000 period (Figure 5.7).

Salinity: Most segments had higher salinities in the pre-1993 and 1999 to 2000 time period than between 1993 and 1998. The exception was FSBMH, where pre-1993 salinity was significantly greater than between 1993 and 1998 and both were statistically similar to the 1999 to 2000 period (Figure 5.8).

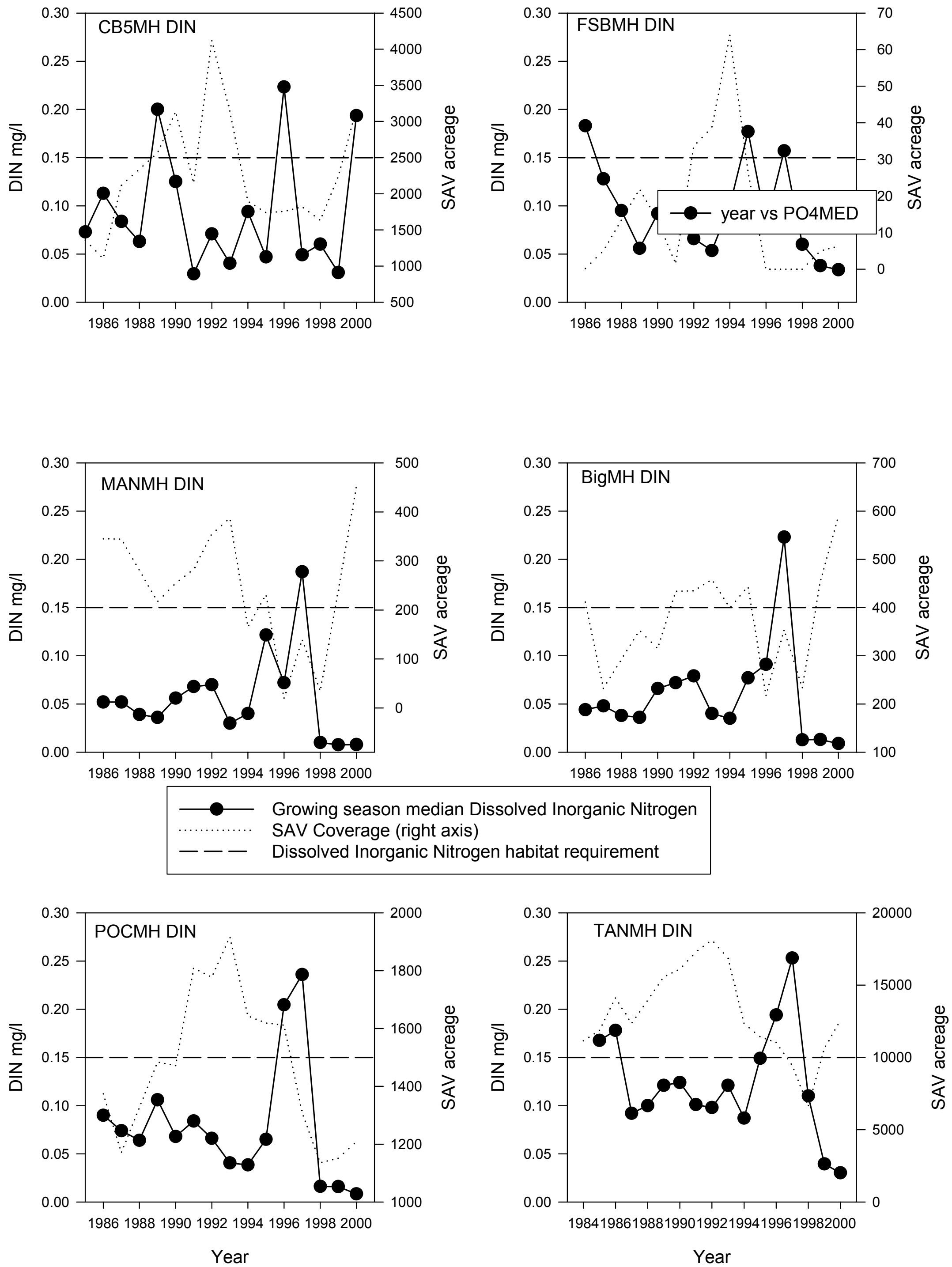


Figure 5.3: Graphs of dissolved inorganic nitrogen showing growing season median of CBP data and SAV coverage (right axis) by year and SAV habitat requirement for each segment analyzed.

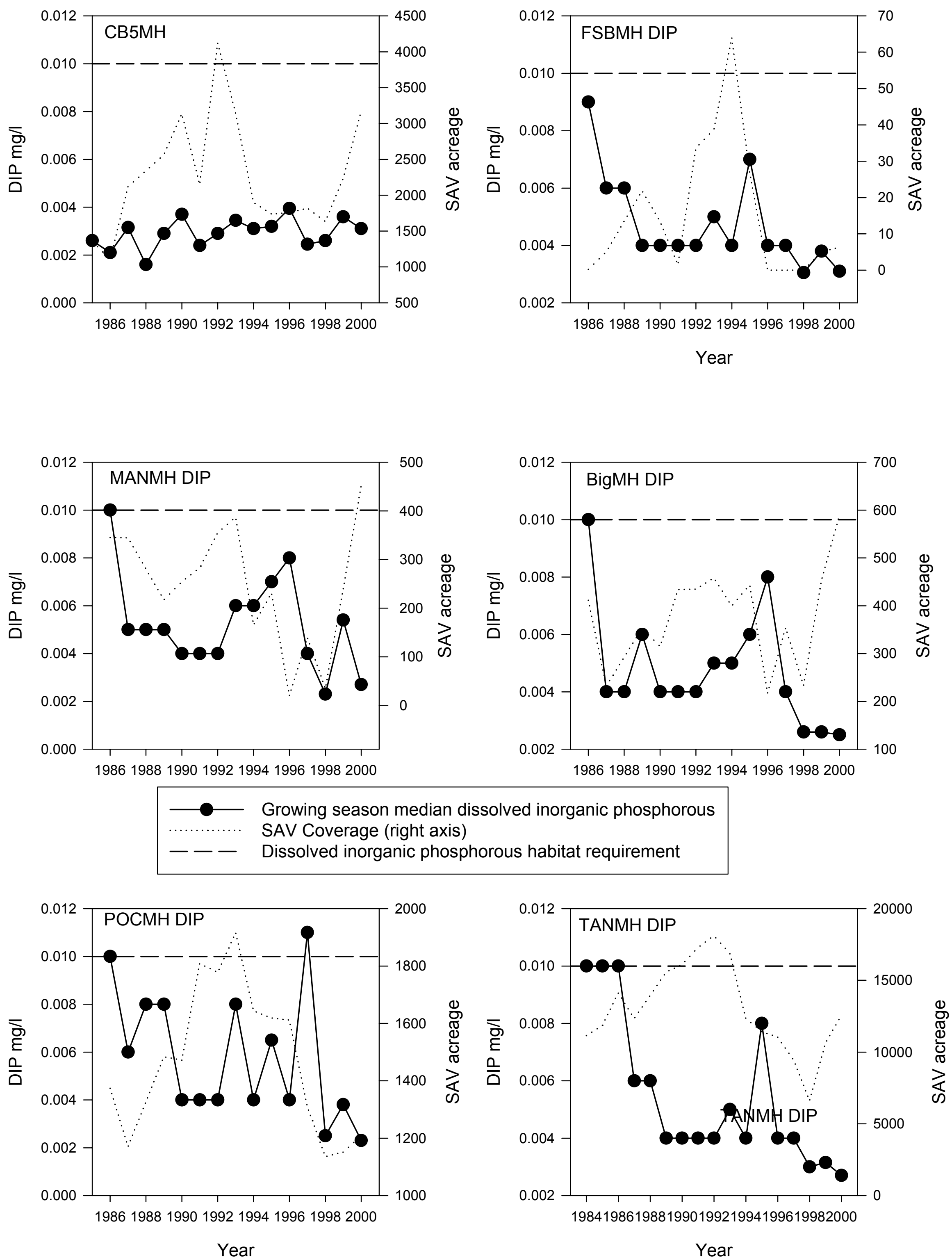


Figure 5.4: Graphs of dissolved inorganic phosphorous showing growing season median of CBP data and SAV coverage (right axis) by year and SAV habitat requirement for each segment analyzed.

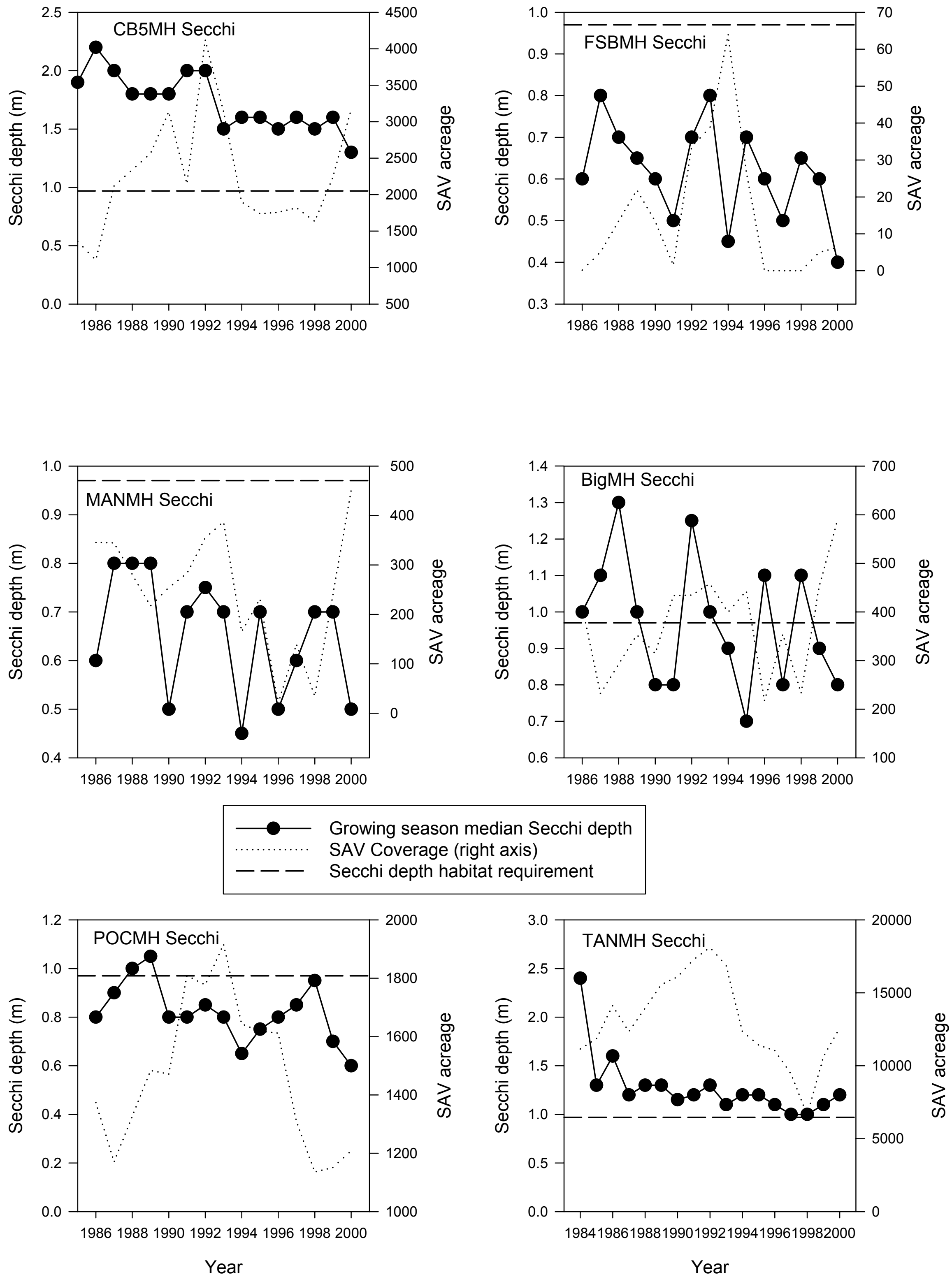


Figure 5.5: Graphs of Secchi depth showing growing season median of CBP data and SAV coverage (right axis) by year and SAV habitat requirement for each segment analyzed

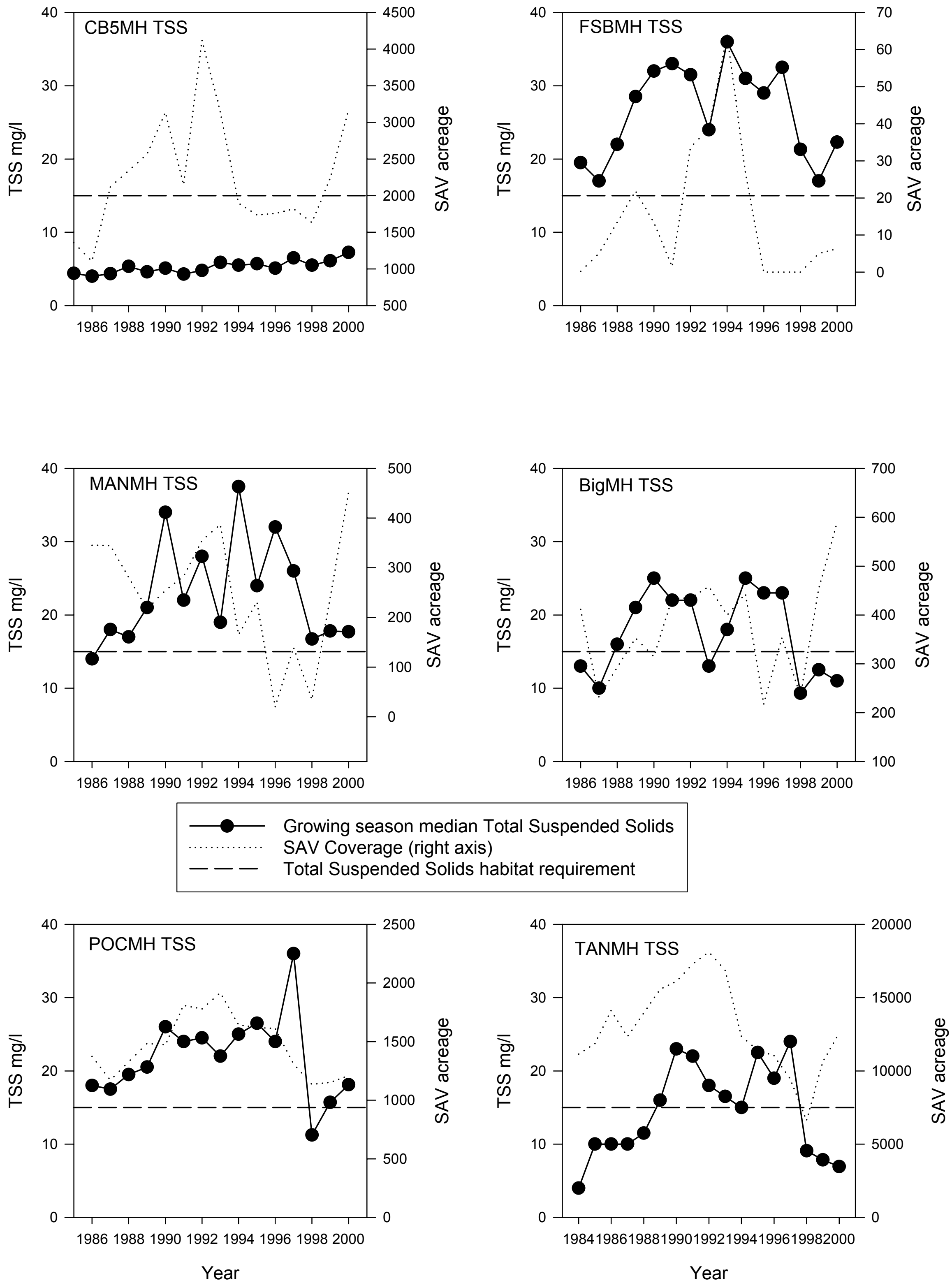


Figure 5.6: Graphs of total suspended solids showing growing season median of CBP data and SAV coverage (right axis) by year and SAV habitat requirement for each segment analyzed.

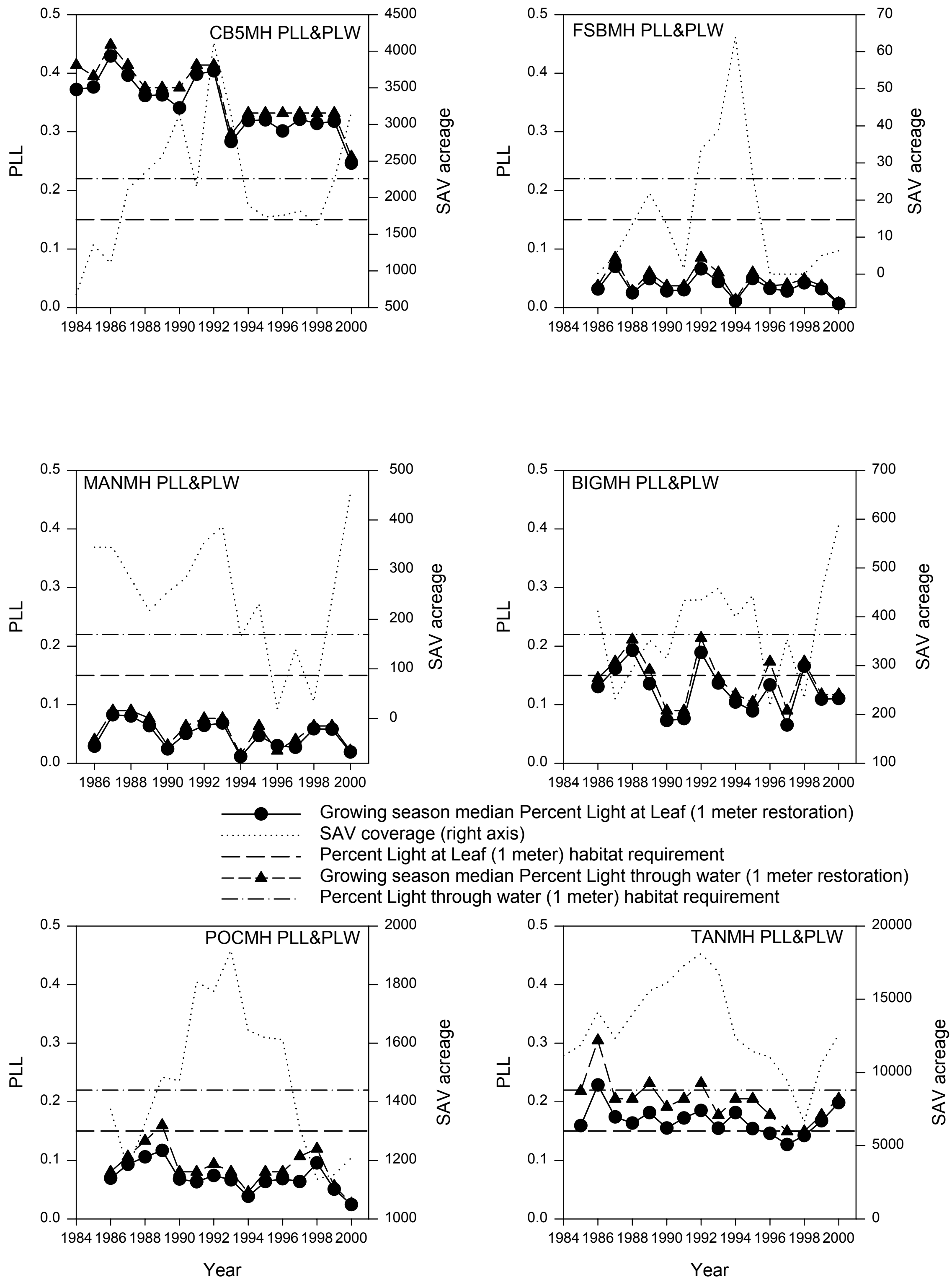


Figure 5.7: Graphs of percent light at leaf and percent light through water column showing growing season median of CBP data and SAV coverage (right axis) by year and SAV habitat requirement for each segment analyzed.

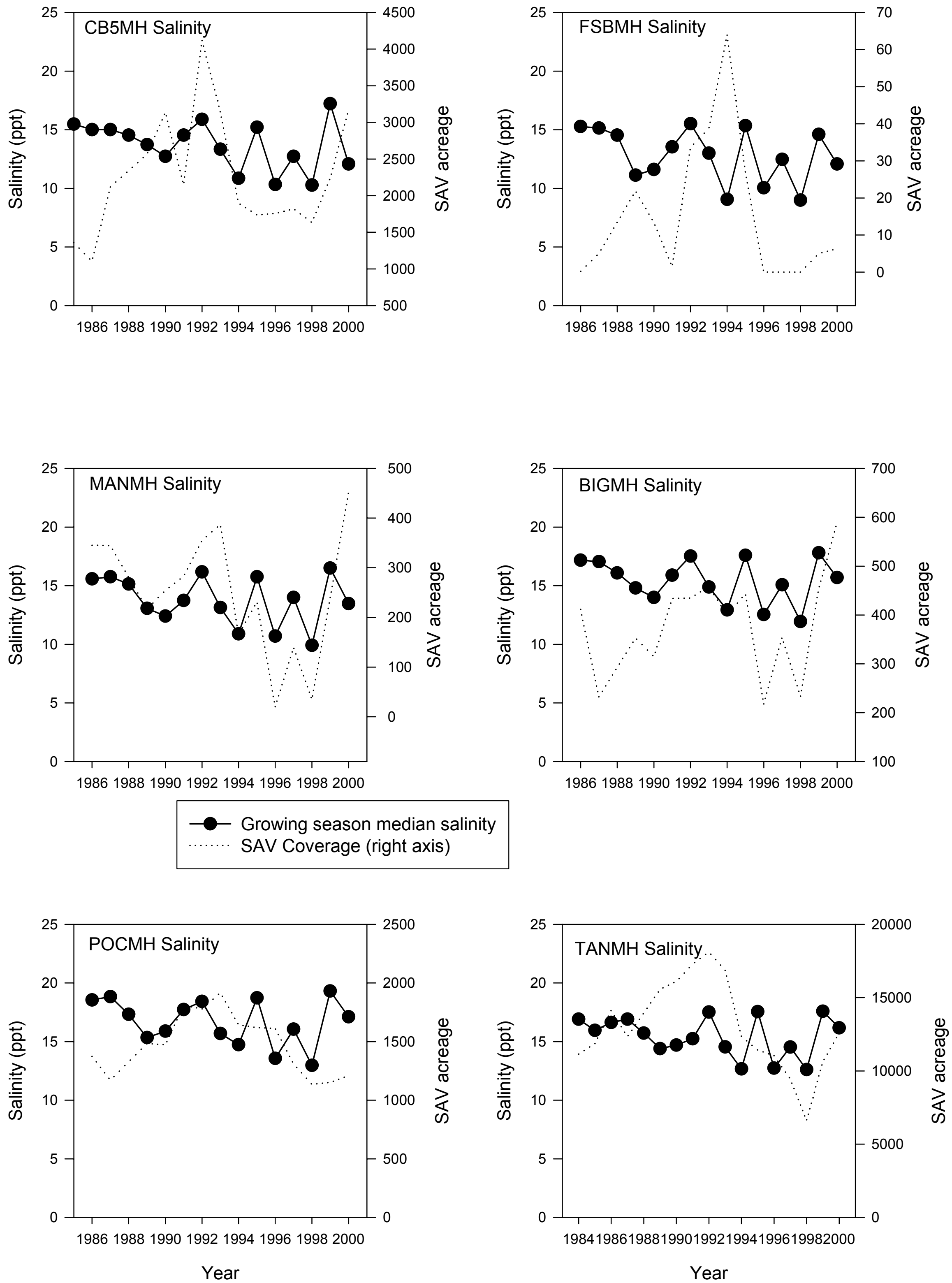


Figure 5.8: Graphs of salinity showing growing season median of CBP data and SAV coverage (right axis) by year and SAV habitat requirement for each segment analyzed.

5.3: Freshwater Inflow and SAV Abundance

Generally, water quality degrades with increasing flow of freshwater into an estuary. As more freshwater enters the system, nutrient and suspended solid loads are increased as well. With the additional nutrients fueling algal growth and higher loads of suspended solids, water clarity is reduced, with potentially adverse impacts on SAV communities. Therefore, it is not possible to adequately examine the causes of SAV declines and resurgence in Tangier Sound without considering how freshwater inflow relates to the SAV community.

5.3.1: Methods

To assess whether variation in freshwater inflow into the Tangier Sound area has a demonstrable affect on SAV abundance, flow data were obtained from the Chesapeake Bay Program (http://www.chesapeakebay.net/index.cfm) for the major rivers on the Bay (Susquehanna, Choptank, Patuxent, Potomac, Rappahannock, York and James) from 1984 through 2000. These data were summed (to give a Bay wide picture of flow by year) and divided into season (spring, summer, autumn and winter). Means were calculated for each season and year. Each year's data were then subtracted from the overall mean for each season. This yielded a "deviation from mean" number for each year's annual and seasonal data. If a year's data was greater than the mean (a positive value) it was considered a relatively wet year, while years that were less than the mean (a negative value) were considered dry years.

The 1984 to 2000 annual SAV coverage data were analyzed for the Tangier Sound Mesohaline segment. Using each year's SAV data, starting in 1985, an annual coverage change index was calculated by subtracting the previous year's SAV coverage. For example, the 1985 coverage in TANMH was 4,796 hectares and in 1984 it was 4,509 hectares. Subtracting the 1984 coverage from the 1985 coverage yields a 287-hectare increase between 1984 and 1985. This procedure was repeated for each year. If the value of the difference was positive, that means that SAV increased between the two years, if the value is negative, than the SAV coverage decreased. There are no 1988 SAV data, so this index for 1989 is the 1989 coverage minus the 1987 data.

The flow deviations from mean indexes, by season and annually, were placed into bar graphs (Figures 5.9 to 5.13), and then overlaid with the SAV change data. A reference line was drawn at the zero value. The expectation is that the relatively wetter years (a positive deviation from mean) would correspond with a decrease in SAV coverage (a negative SAV change index value) and vice versa. The graph for each season was visually assessed to determine how often this expectation was met. These data are summarized in Table 5.3.

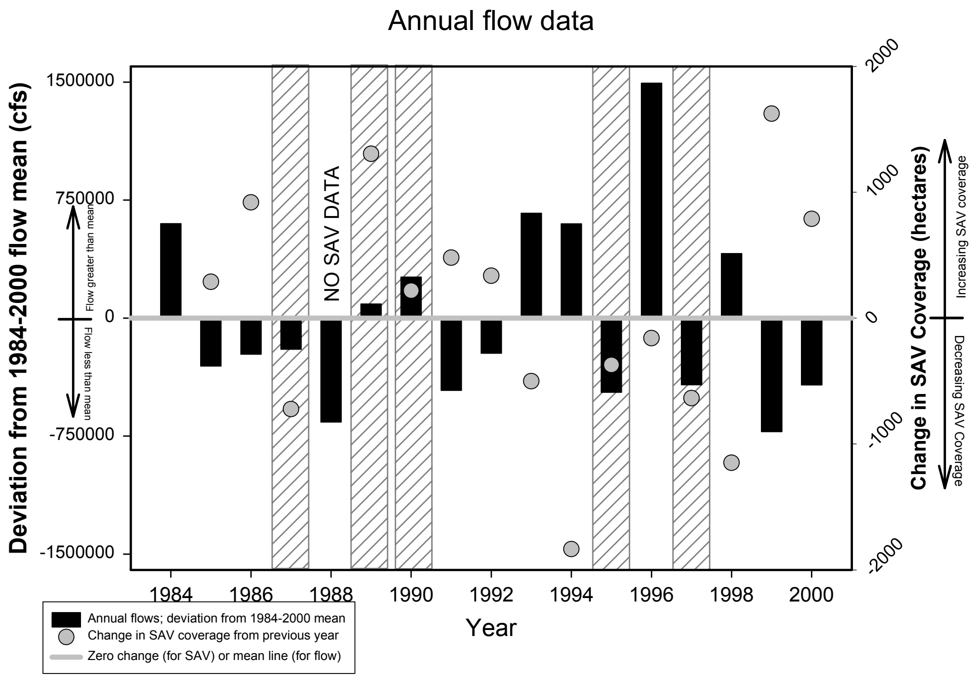


Figure 5.9: Bar graph of annual flow deviation from mean (left axis) and scatter plot of SAV coverage change by year (right axis). The hatched areas show where the expectation that high flows would yield a decrease in SAV coverage (or vice versa) is **not** met.

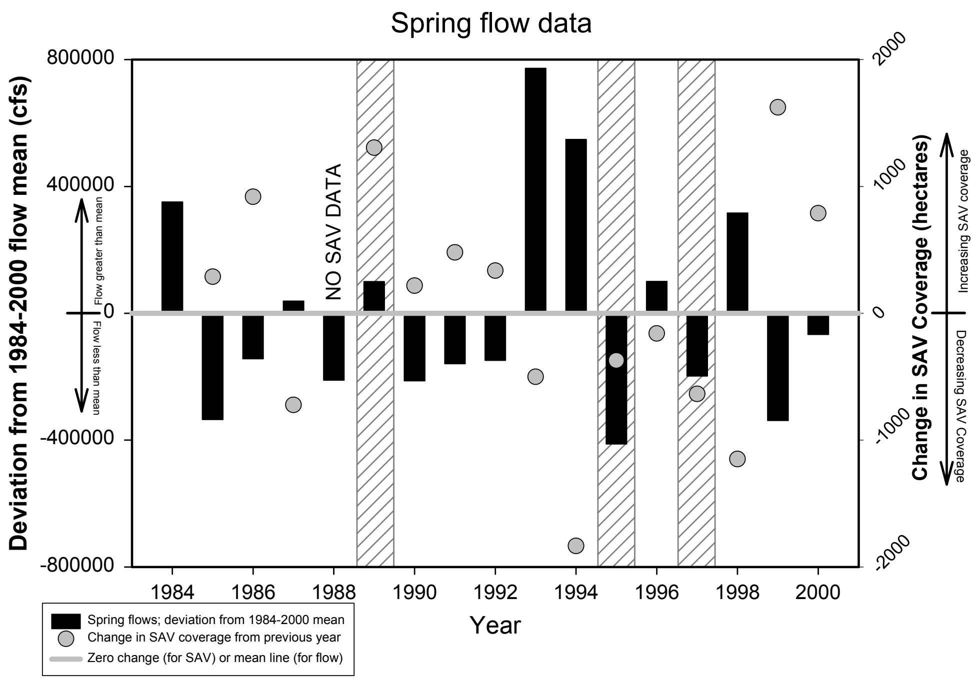


Figure 5.10: Bar graph of Spring flow deviation from mean (left axis) and scatter plot of SAV coverage change by year (right axis). The hatched areas show where the expectation that high flows would yield a decrease in SAV coverage (or vice versa) is **not** met.

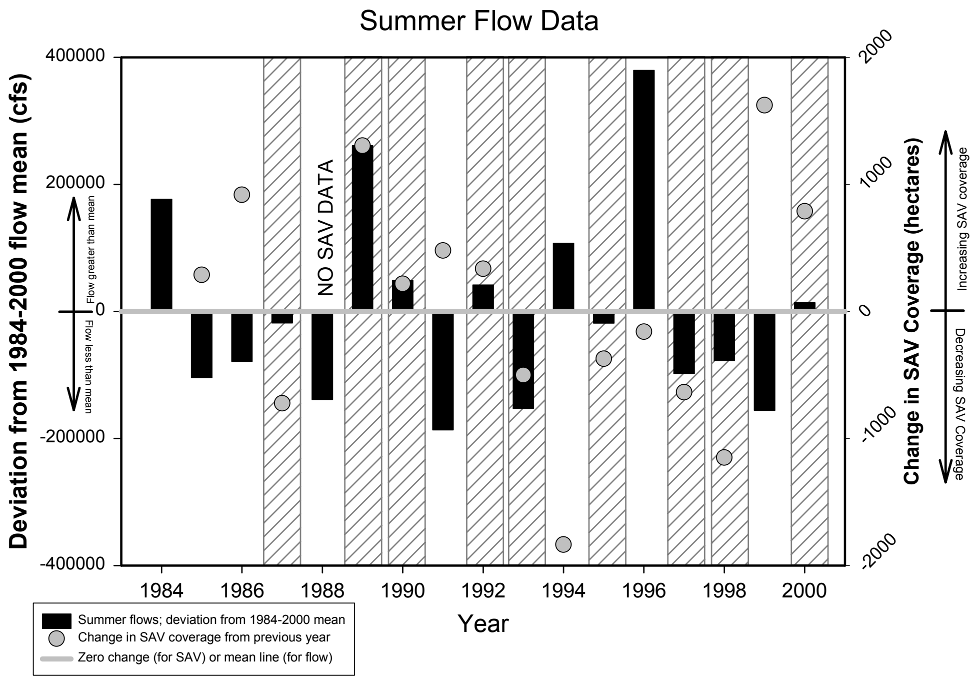


Figure 5.11: Bar graph of Summer flow deviation from mean (left axis) and scatter plot of SAV coverage change by year (right axis). The hatched areas show where the expectation that high flows would yield a decrease in SAV coverage (or vice versa) is **not** met.

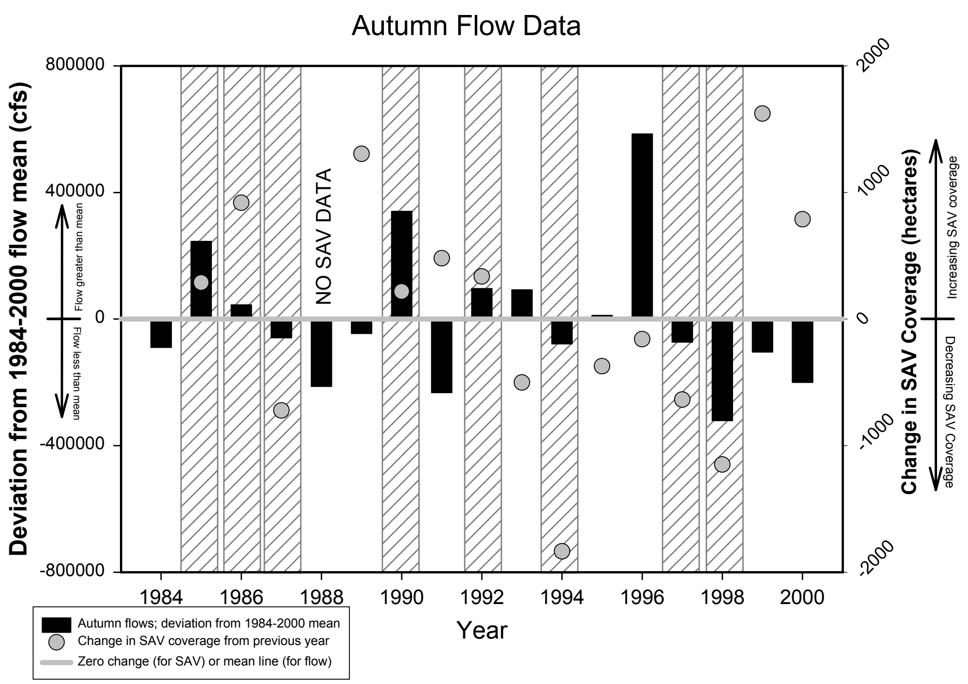


Figure 5.12: Bar graph of Autumn flow deviation from mean (left axis) and scatter plot of SAV coverage change by year (right axis). The hatched areas show where the expectation that high flows would yield a decrease in SAV coverage (or vice versa) is **not** met.

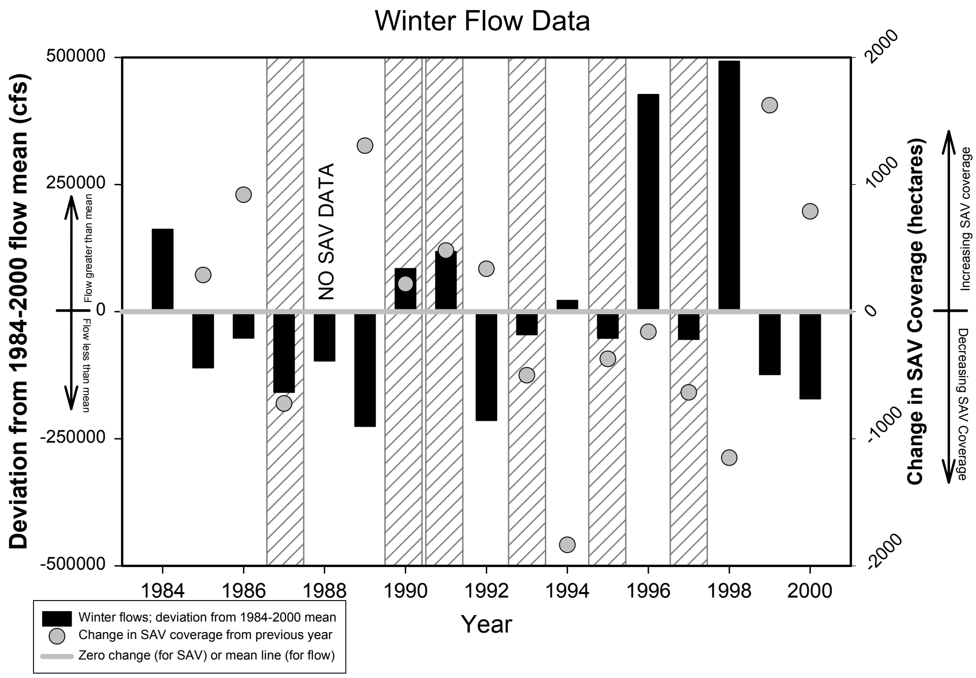


Figure 5.13: Bar graph of Winter flow deviation from mean (left axis) and scatter plot of SAV coverage change by year (right axis). The hatched areas show where the expectation that high flows would yield a decrease in SAV coverage (or vice versa) is **not** met.

Table 5.3: Results of graphical analysis comparing flow deviation from mean data to SAV coverage change data. The total number of observations is 15.

Season	**Observations meeting expectation**	**Observations not meeting expectation**	**Percent meeting expectation**
Annual	10	5	66%
Spring	12	3	80%
Summer	6	9	40%
Autumn	7	8	47%
Winter	9	6	60%

More robust statistical analysis is not possible for these data, as they are highly variable and not directly comparable. Additionally, each year's SAV change index is dependent on the previous year's data, which further complicates quantitative analysis. Correlations were performed on each season and annual flow deviation from mean versus change in SAV coverage to determine if changes in SAV coverage can be predicted based on flow data (Table 5.4).

Table 5.4: Pearson correlation coefficient matrix of flow deviation from mean and change in SAV coverage data. Coefficients in bold and larger font are significant at $\alpha = 0.05$. All flow data are deviation from mean.

Parameter	SAV Change	Annual Flow	Spring Flow	Summer Flow	Autumn Flow	Winter Flow
SAV Change	1.0	-0.45254	**-0.54354**	-0.03679	0.05488	-0.42497
Annual Flow		1.0	**0.70724**	**0.68326**	**0.52520**	**0.65163**
Spring Flow			1.0	0.25285	-0.07342	0.32359
Summer Flow				1.0	**0.49777**	0.25458
Autumn Flow					1.0	**0.65163**
Winter Flow						1.0

5.3.2: Results of Flow Analysis

Considering Figures 5.9 through 5.13 and Table 5.3, the flows in the Spring season tend to provide the best indication of changes in SAV coverage, with 80% of the observations meeting the expected pattern of high flow resulting in SAV declines and low flow resulting in SAV gains (Figure 5.10). In seven of nine years of below mean flows, SAV coverage increased, with 1995 and 1997 being the exception. In five of six years of above mean flows showed SAV declines, with the exception being 1989, keeping in mind that there is not a 1988 data point, which may skew that result. The winter, summer and autumn flows don't match the expected patterns nearly as well as Spring flows, and the annual flow is only marginally better than those other seasons.

Additionally, SAV change data are significantly and negatively correlated with spring flows. Descriptively, annual flows are significantly correlated with all other seasons' flows (not surprisingly), as the annual flow is comprised of the other seasons' flows. Additionally, summer and winter flows are correlated with autumn flows.

5.4: DISCUSSION

Overall, the trends and discrete time period analysis indicate;

- Chlorophyll *a* concentrations did not change over time.
- DIN and DIP conditions were higher (worse) before the 1999 to 2000 period.
- Secchi depths are generally lower in the 1999 to 2000 period than prior time periods, except in POCMH, where conditions were poorest in the 1993 to 1998 time period.

- TSS levels hadn't changed in FSBMH, MANMH or BIGMH, but have degraded steadily in CB5MH. TANMH and POCMH had highest (worse) levels during the 1993 to 1998 time period,

- PLL and PLW conditions have generally declined since 1993.

- Salinity levels were generally lower during the 1993 to 1998 time periods.

- Change in SAV coverage is best indicated by spring flow's deviation from mean with declines in SAV coverage occurring in springs that are wetter than average. There is a significant and negative correlation between spring flows and SAV change.

5.5: CONCLUSIONS

From both the trends and the discrete time period analyses, the most consistent factor that could explain the loss of SAV in TANMH from 1993 to 1998 is a reduction in water clarity. This is reflected in the Secchi depth as well as PLL and PLW parameters. Trend analyses indicate that chlorophyll *a* concentrations are increasing in TANMH, but the intervention analysis indicates no difference between time periods, which agrees with the trends in the other segments analyzed. Additionally, TSS does not have any significant trends in the lower Eastern Shore region, though the intervention analysis does hint at worsening conditions in the mainstem of the Bay (CB5MH) and that conditions were worse in Tangier and Pocomoke sounds during the SAV declines. Additionally, the annual status reports indicate that TSS either fails or is borderline relative to the habitat requirements in all but CB5MH, which is currently the only segment in the lower Eastern Shore area to exceed the habitat requirements. For parameters with borderline conditions, slight improvements or degradations in TSS levels could drive the resurgence or loss of SAV. Salinity has generally decreased over time, with the lowest salinities occurring during the period of the SAV declines. Run-off from the land could have transported unusually high sediment loads into the region, thus increasing TSS and reducing water clarity. Nutrient concentrations seem to have no relationship with the SAV declines. Lastly, SAV coverage has a negative correlation with spring flows, meaning that springs that are wetter than average usually result in SAV declines, while springs that are drier tend to correspond with SAV increases.

Chapter 6: Utilization of Water Quality Interpolation to Evaluate Changes in SAV Abundance

6.1: Introduction

This chapter investigates in detail the relationship of water quality changes in the Tangier Sound area to the changes in SAV distribution and abundance in the region. The linkages between water quality conditions and SAV distribution and abundance are well known (Dennison et al. 1993, Moore et al. 1996, Moore et al. 1997). As discussed in the previous chapter, water quality (particularly light) over the entire region had been observed to decline in the 1990s, coinciding with the declining SAV abundance over large spatial scales. However, the scale at which SAV beds grow or decline is much smaller than the scale of most water quality monitoring programs. To better understand how SAV in the Tangier Sound region has been affected by water quality conditions, finer estimates of water quality at SAV bed locations is required.

Most existing water quality data is collected from sparsely distributed points that are primarily located in deeper water, several kilometers from the nearest grass bed. This data must be spatially interpolated to provide an estimate of the conditions experienced by SAV beds. The existing three-dimensional water quality interpolator (VOL3D) from NOAA is commonly used to estimate water quality parameters from point data, particularly from the Chesapeake Bay Water Quality Monitoring Program (Bahner 2001). However, this interpolator is best suited for main channel estimations of water quality in the Chesapeake mainstem and tributaries, and is not ideal for finer scale interpolations, particularly in areas with complex shorelines.

In this chapter, we utilize a revised water quality interpolator that uses the shortest distance across water during its calculations and integrates the interpolations into a GIS system. The error of interpolated data is evaluated by comparing interpolated results with high-resolution water quality sampling (DATAFLOW—Madden and Day 1992, Maryland Department of Natural Resources 2001). Once water quality estimates are determined for SAV bed locations, comparisons to SAV bed growth and decline can show large-scale effects of changing water quality on SAV, and particularly how such changes have affected the grass beds in the Tangier and Pocomoke Sound areas.

This study is comprised of two main parts. First is the development and testing of the interpolator. Second is the application of the interpolator to analyze water quality and SAV changes. There are three main objectives:

1. Extensively test and modify as necessary the GIS water quality interpolator to assess accurately its capabilities as a tool for research and management.

2. Use the GIS water quality interpolator to estimate water quality conditions at grass bed locations mapped by the annual VIMS SAV aerial survey for the Tangier and Pocomoke Sound areas.

3. Analyze major trends in SAV growth or decline in relation to water quality conditions at grass bed locations.

If water quality is a determining factor regulating the distribution and abundance of SAV in the Tangier Sound region, we hypothesize the following responses of SAV to water quality changes:

1. As light conditions decline, SAV abundance will decrease.

2. As light conditions decline, SAV beds will respond by retreating from deeper waters.

3. In areas where SAV has been mapped, areas supporting SAV will have different water quality than unvegetated shallow water areas.

6.2: Interpolation and Sensitivity Analyses

6.2.1: Interpolator Methods

A new water quality interpolator was developed and tested using ArcInfo GIS software. (See Appendix A for the interpolator program code). A standard inverse distance squared interpolator was implemented using over-water distances instead of straight-line distances. The interpolator accepts as input water quality station locations, a single observation for each station, a shoreline GIS layer, a study region GIS layer, and a maximum distance for interpolation. With these inputs, the interpolator uses grid-based analysis to produce an interpolated grid of the requested cell size.

For this project, the cell size was set to 250 meters in a region centered on the mid-bay islands. Distances used in the interpolation were restricted to 20 kilometers, and the four nearest neighbor stations were used in the interpolation for each cell. Interpolator output was a grid of 404 row and 346 column cells for each parameter.

6.2.2: Methods- Sensitivity and Error Analysis

High-resolution spatial data from four Dataflow water quality cruises (Maryland DNR 2001) were used to evaluate the quality of interpolated data (see Madden and Day 1992 for description of Dataflow sampling method). Each cruise (6/99, 10/99, 5/01, and 6/01) covered the Tangier Sound region and generated between 6,000 and 10,000 data points.

To evaluate the interpolation of the EPA long-term water quality stations, nine Dataflow points were selected for each cruise. These points were selected based on their proximity to the long-term EPA stations and were of similar depth to those stations. The water quality measurements at these nine Dataflow points were interpolated using the new interpolator to generate a grid of estimates for each parameter at a 250-meter cell resolution. These estimates were then compared to actual measurements at the remaining Dataflow points to evaluate the error in the interpolation.

The over-water distance from each interpolated point to the nearest Dataflow station was computed to evaluate the change in error with interpolation distance. In addition, the points were classified by depth to evaluate whether there is a difference in error between the shoals and deeper waters.

Semivariograms were computed for the full Dataflow datasets using straight-line distances with the ArcInfo kriging tool to measure spatial auto-correlation within the Dataflow data. Although these semivariograms do not precisely match the over-water interpolation, they provide insight into the spatial character of the different water quality parameters

6.2.3: Results- Sensitivity and Error Analysis

The dataflow semivariograms demonstrate that most of the water quality parameters have marked spatial auto-correlation on each of the four sampling dates (Appendix B). TSS and turbidity semivariograms have a fairly clear sill, indicating a possible interpolation limit at around five kilometers. The continuous increase and lack of a sill in the salinity and chlorophyll semivariograms reflect a spatial trend in the region for these two parameters.

The results of the interpolation analyses are shown graphically in Appendix C. The difference between the interpolated value at each Dataflow location and the actual measured value is symbolized from black (underestimation) to white (overestimation). There are clear spatial patterns in the error for each parameter and on most of the sampling dates. For the May and June 2001 dates, salinity tended to be underestimated in the Nanticoke and overestimated in north Fishing Bay and along the mid-bay islands. For all dates, TSS and turbidity were underestimated around the mid-bay islands and overestimated on the Eastern Shore. Errors in chlorophyll were more evenly distributed. However, during the June 1999 sampling, interpolation underestimated chlorophyll in the Nanticoke and overestimated it in the Wicomico, while during the October sampling interpolation underestimated chlorophyll along the mid-bay islands and at the mouth of the Nanticoke, and overestimated it in the north and eastern embayments.

To evaluate interpolator error with over-water distance rather that the straight line distance used by the semivariograms, the mean error was plotted against distance to the nearest Dataflow station (Appendix D1). The pattern is not as clear as it is in the semivariograms. Error increases with distance for TSS and turbidity for all dates, and salinity for all dates except October 1999. The error levels off slightly at around five km for TSS and turbidity except for the October 1999 date, which has spikes in error at 10 and 14 km.

In order to further investigate how well the interpolator is estimating conditions in the shoals, root mean squared error (RMSE) was computed for the entire area (all depths), for areas less than two meters deep (shoals), and for deeper waters (channel). In most cases error in the shoals exceeded error for deep regions (Table 6.1). Overall TSS and Turbidity error in the shoals for each date was up to three times the error in the channel. While errors in the chlorophyll estimate for both depth regions were similar on all dates and salinity was similar on the two 1999 dates, salinity error for the 2001 dates was worse in the shoal. This pattern is also clear when interpolation error is plotted against depth (Appendix D2). Turbidity and TSS error drops as the water gets deeper up to a depth of between 10 and 15 meters. Salinity follows a similar pattern for the October 1999 and June 2001 dates.

Table 6.1: Interpolator RMSE calculated for all depths, the area shallower than 2 meters (MLW) and the area deeper than 2 meters (MLW).

		6/99	10/99	5/01	6/01
Salinity (ppt)	All depths	0.56	1.00	0.74	1.14
	Shoal (< 2m)	0.55	0.98	0.84	1.30
	Channel (> 2m)	0.57	1.04	0.54	0.81
TSS (mg/l)	All depths	5.89	8.03		
	Shoal (< 2m)	6.39	9.89		
	Channel (> 2m)	4.92	3.02		
Turbidity (NTU)	All depths			9.36	14.16
	Shoal (< 2m)			11.11	16.96
	Channel (> 2m)			5.28	7.43
Chlorophyll (ug/l)	All depths	1.64	2.58	2.04	1.69
	Shoal (< 2m)	1.67	2.33	2.15	1.88
	Channel (> 2m)	1.59	2.96	1.82	1.31

In this chapter it is assumed that a spatially interpolated estimate will be closer to the actual value at a location than simply using the value of the nearest water quality station. To check that new the interpolator is producing useful estimates, interpolator estimates were compared to the value from the nearest long-term station (Table 6.2). In all cases except TSS on 10/99, the interpolator produced a more accurate estimate of the water quality.

Table 6.2: Interpolator RMSE compared to RMSE based on using the nearest station value.

		6/99	10/99	5/01	6/01
Salinity (ppt)	Nearest Station	0.85	1.15	1.32	1.77
	Interpolator	0.56	1.00	0.74	1.14
TSS (mg/l)	Nearest Station	6.75	7.83		
	Interpolator	5.89	8.03		
Turbidity (NTU)	Nearest Station			10.19	14.90
	Interpolator			5.28	7.43
Chlorophyll (ug/l)	Nearest Station	1.99	2.98	2.25	1.81
	Interpolator	1.64	2.58	2.04	1.69

6.2.4: Conclusions- Sensitivity and Error Analysis

The comparison of estimates produced by the new interpolator with actual Dataflow measurements shows an increase in TSS and turbidity estimation error with distance and in shallower water. Mean RMSE was approximately 1 ppt for salinity, 6-8 mg/l for TSS, 5-7 NTU for Turbidity, and 2 ug/l for Chlorophyll. Even with this level of error the interpolator performed considerably better than simply using the nearest fixed station. The interpolator provides a better estimate of water quality conditions, but the error in the estimate can be large in the shoals and at a distance greater than approximately five kilometers from the sample stations.

6.3: WATER QUALITY AND SAV ABUNDANCE

6.3.1: Methods- Water Quality and SAV Abundance

6.3.1.1 SAV Data

SAV distribution and abundance data was obtained from the VIMS annual aerial SAV monitoring survey (Orth et al. 2001). This survey uses over 2,000 black and white photographs of Chesapeake Bay annually since 1984 (excluding 1988), taken at an altitude of approximately 12,000 feet each year, producing 1:24,000 scale prints. SAV beds are then outlined and digitized into a geographic information system.

6.3.1.2 Large Scale Water Quality Data

Water quality data was obtained from the Chesapeake Bay Program's Water Quality Monitoring Program (Chesapeake Bay Program, 2001). This program samples water quality at bi-monthly or monthly intervals at 49 stations in the mainstem and approximately 150 stations in the tributaries of Maryland and Virginia.

Batiuk et al.(2000) describes the SAV growing season as April-October in tidal fresh, oligohaline and mesohaline areas, and March- May and September-November in polyhaline areas. Although the Chesapeake Bay Program segmentation system labels most of the Tangier and Tangier Sound area as mesohaline (DAWG, 1997), we used the combination of mesohaline and polyhaline growing seasons (including summer) for analysis. Since aerial photography in this region of the bay is usually obtained in the late spring and early summer (usually before July 1) of each year, that year's water quality growth season was considered to be July 1 through November 30 of the previous calendar year and March 1 through June 30 of the current year. For example, 1996 growth season incorporates water quality data from July 1-November 30, 1995 and March 1 – June 30, 1996. Water quality parameters were interpolated for each semi-monthly sampling period within the growth season.

Water quality from semi-monthly cruises between July 1985 and July 2000 were extracted from the data set. Replicate cruise data within each semi-monthly period were averaged together. Only data from surface depths equal to or shallower than 1 meter (MLW) were utilized for interpolation (usually the "S" layer of the dataset). If a sampling point had several depths shallower than 1 meter for a given day, (e.g. samples at 1 m and at 0.1 m), the deeper sample was used. The following data was extracted to be used as input for interpolation (See CBP, 1993 for definitions and methodology of sampling):

- Salinity
- Water temperature
- Secchi depth
- Chlorophyll a
- Total suspended solids
- NO23 (filterable)

- NH4 (filterable)
- PO4

The following fields were added to the dataset:

- Kd = Light Attenuation Coefficient = Secchi/1.45 (Batiuk et al. 1992)
- DIN = NO23 (filterable) + NH4 (filterable)

Water depths were sampled from TIN bathymetry (Chesapeake Bay Program) at a 25 meter cell size. Mean tidal height values were obtained from Batiuk et al. 2000.

6.3.1.3 Zonal categorization

The interpolations showed strong spatial gradients from north to south and east to west (Appendices E1-E5). These gradients occurred within individual Chesapeake Bay Program Segments (DAWG, 1997.). As a result, we decided to subjectively subdivide the region into smaller, more detailed water quality and SAV zones (Figure 6.1). Zone boundaries were placed to divide obvious water bodies and island complexes (e.g. Bloodsworth and South Marsh Islands vs. Tangier and Smith Islands). Boundaries also took into account natural unvegetated breaks in the SAV coverage of areas that had SAV at any time between 1984 and 1999.

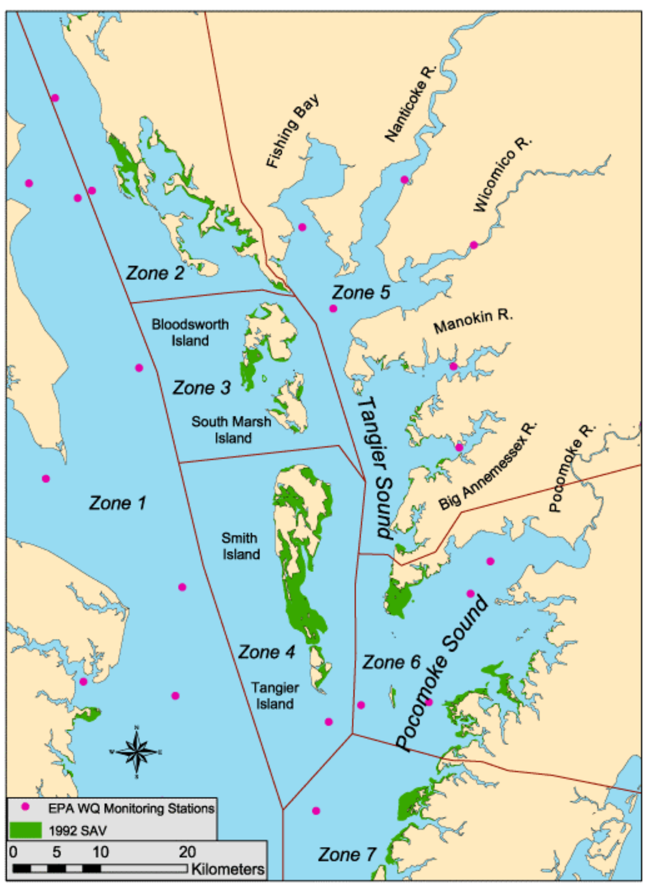


Figure 6.1: Map of zonal delineation for fine scale interpolated water quality analysis.

The result was a subdivision of the region into 7 zones:

- Zone 1- Western Shore
- Zone 2- Honga River
- Zone 3- Bloodsworth and South Marsh Islands
- Zone 4- Tangier and Smith Islands
- Zone 5- Tangier Sound and Nanticoke Sound (from Bishops Head Point to south of the Little Annemessex River
- Zone 6- Pocomoke Sound (Southern Part of Cedar Island to the northern half of Parker's Marsh
- Zone 7- Lower Eastern Shore (southern half of Parker's Marsh to Occohannock Creek)

The area of SAV in each zone each year (1986-2000, excluding 1988) was calculated, as well as the change in SAV area between years.

6.3.1.4 Post-Interpolation water quality data manipulations

Median annual water quality values by cell were calculated for each 250 m cell for each year from the semi-monthly interpolated output during that year. Because the depth gradient was finer than the 250 m cell size, calculating the amount of light through the water column or reaching the leaf surface was problematic. We therefore subset all 250 m cells which contained SAV at some point between 1984 and 2000, or had mean depths less than 2 meters MLW. Each of these 250 m cells was then subdivided into 25 m subcells. Using the interpolated data from the original 250 m cell (Kd, TSS, DIN, DIP), and the depth estimate for each 25 m subcell, we calculated the following for each 25 m subcell:

- PLW= Percent of incident light reaching through the water column, as calculated via Batiuk et al. 2000). This value is a function of Kd and depth (including half the mean tidal range)

- PLL = Percent of incident light reaching through water column and material on plant leaves to be available for photosynthesis by the plant. This value is a function of PLW, calculated epiphytic light attenuation, and calculated attenuation of particulates on a leaf surface (see Batiuk, et al. 2000).

We first sampled water quality at all 25 m cells in each zone at 0.5m, 1.0m, and 2.0m depths, regardless whether that cell ever had SAV in order to characterize conditions over the entire zone.

To analyze water quality in areas where SAV fluctuated, we focused only on those 25 meter cells at the deeper edges of SAV beds. This was based on the assumption that changes in SAV abundance due to changing light regime (due to water quality) would first occur at the deeper edges of the beds, where light is lowest. To accomplish this, we analyzed water depths of the 25 meter cells containing SAV for each year. Cells shallower than 0 meters and deeper than 2 meters (MLW) were not used due to apparent errors in bathymetric or shoreline data. Of the remaining cells, those vegetated cells which were neighbored by unvegetated cells on one of 4 sides were considered "edge" cells. These "edge" cells were ranked by depth and the deepest quartile sampled as "deep edge" cells. The deep edge cells were grouped into two categories with which to sample water quality each year. The first category was the deep edge of the SAV from a specific year ("specific year edge"). The second category was the deep edge of the SAV from the year of maximum SAV abundance ("maximum abundance edge"). By comparing the water quality at these different locations during each year, we analyzed how water quality differed between an area with SAV in a particular year (specific year's edge) and an area which was known to be able to support SAV but was unvegetated during that particular year (maximum abundance edge). Water depth and seasonal median water quality were sampled for each cell in these two categories for each year. The resulting set of cells for each zone were then analyzed by cell, as well as averaged together to obtain mean data per zone per year.

6.3.1.5 Partitioning of Kd

Suspended sediment and chlorophyll components of Kd were calculated using interpolated Chlorophyll and TSS values with the following equation from Batiuk et al. 2000:

Calculated Kd = 0.32 + 0.016 [Interpolated Chl] + 0.094 [Interpolated TSS]

Comparisons of the calculated Kd with the interpolated Kd showed that the equation tended to overestimate Kd relative to the interpolation estimate of Kd (data not shown). Therefore, Kd partitioning was not used for correlation analysis. However, the percent of calculated Kd for each partition was useful to qualitatively identify relative increases or decreases in the importance of inorganic suspended sediments or chlorophyll for light attenuation.

6.3.1.6 Water quality statistical analysis

All statistics were conducted within each zone. Zone 1 and Zone 2 were not analyzed due to low confidence in the accuracy of the interpolation in these areas (i.e. few data stations used in the interpolations).

Differences in PLW and PLL as well as depth between a specific year's edge cells and the maximum abundance edge cells were detected via ANOVA for each year and each zone between 1986 and 2000 (excluding 1988). PLW and PLL were arcsine square root transformed for analysis of variance.

Spearman Rank correlations were used to identify any significant correlations in each zone between median water quality at the maximum edge cells and SAV area or SAV change per year. For salinity, correlations were analyzed between SAV area and SAV change per year using the seasonal median salinity values, the seasonal maximum salinity, and seasonal minimum salinity values for each cell. Correlations of depth with SAV area or SAV change per year were conducted using data from the specific year's edge cells.

6.3.2: Results- Water Quality and SAV Abundance

6.3.2.1 Overall water quality descriptions

For most water quality parameters, interpolations show a general gradient from east to west, with worse water quality along the Eastern Shore in the rivers and sounds, and better water quality towards the west (Appendix E). The mid-bay islands (Bloodsworth, South Marsh, Smith, and Tangier) appear to be a boundary line between these water quality conditions.

Seasonal median light attenuation (Kd) was mostly below 1.5 in the mid bay islands (zones 3 and 4), and consistently higher in the sounds and rivers (zones 5 and 6). There were substantial differences in PLW and PLL depending on depth (0.5m, 1.0m, or 2.0 m MLW) along the shoals of the entire zone (Appendix E1, Appendix F). Partitioning of Kd into Ks (suspended sediment fraction) and Kc (chlorophyll fraction) (Figure 6.2) show apparent trends that the percentage of Kd attributed to light attenuation of sediments is generally increasing from 1986, reaching a maximum around 1992 and maintaining high percentages afterwards (over 70% of Kd). Meanwhile, the chlorophyll fraction apparently follows the opposite trend (decreasing to 5-10% of Kd).

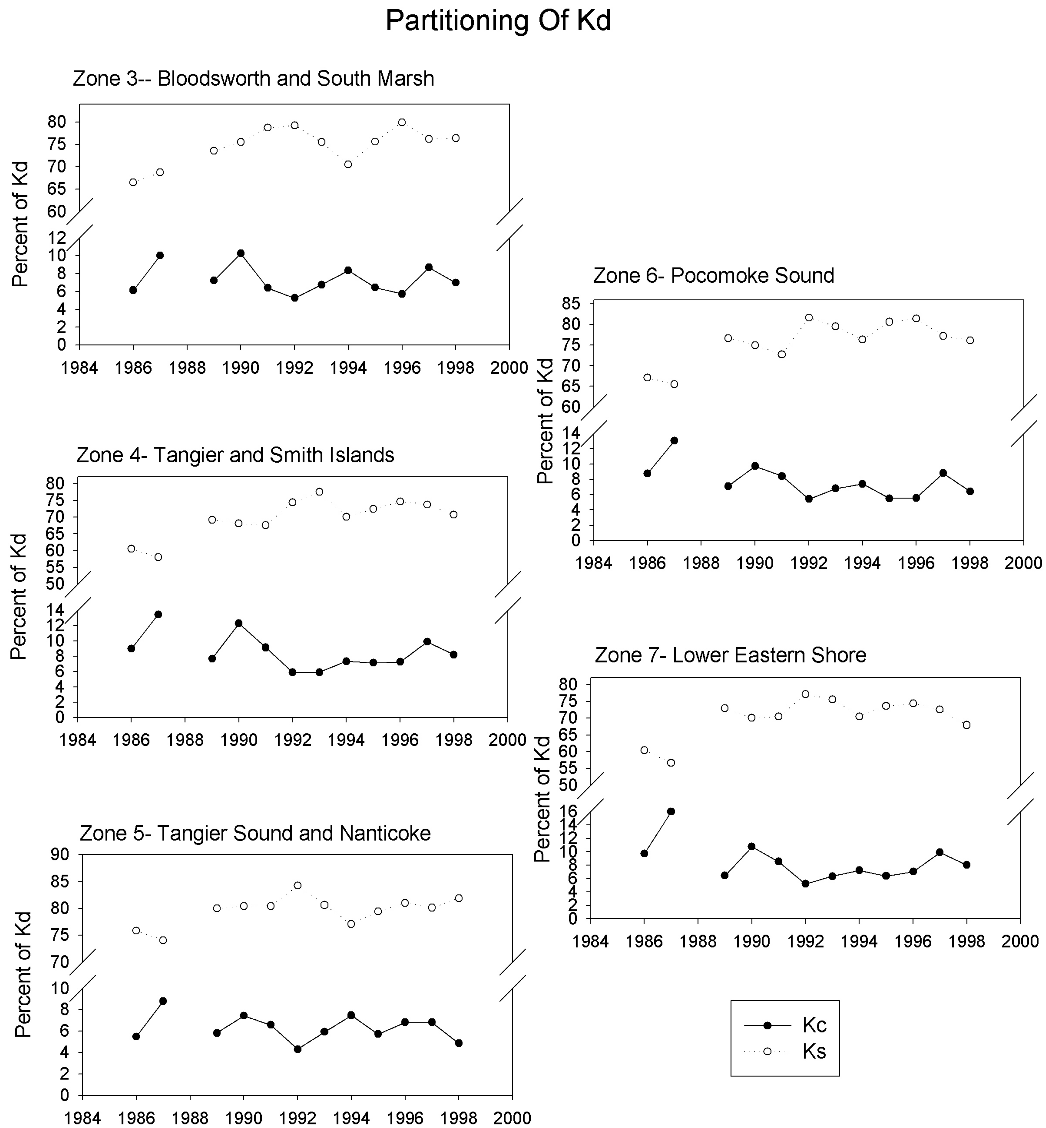


Figure 6.2: Partitioning of Kd in each zone into Kc (solid circles) and Ks (hollow circles)

However, total suspended solids are low in most zones until 1989, when TSS levels begin to rise (Appendix E2, Appendix F). In the mid bay islands, although the overall mean TSS values are less than 20 mg/l, values on the eastern side of the islands are consistently above 20 mg/l TSS after 1989, with lesser values on the western side of the islands (Appendix E2). It is important to note the median chlorophyll a values in most of the region remain relatively low throughout all years, below the SAV habitat requirement, as do concentrations of dissolved inorganic phosphorous. Dissolved inorganic nitrogen, however, becomes extremely high in the rivers and sounds, particularly after 1995 (Appendix E4). Fishing Bay, Nanticoke, Wicomico, Manokin, Big Annemessex, and Pocomoke Rivers all show high amounts of nitrogen, which in recent years is consistent with results from recent more detailed sampling occurring in these areas by Maryland DNR. However, these levels decline with distance from these river sources.

6.3.2.2 SAV abundance, depth trends, and water quality at bed edges

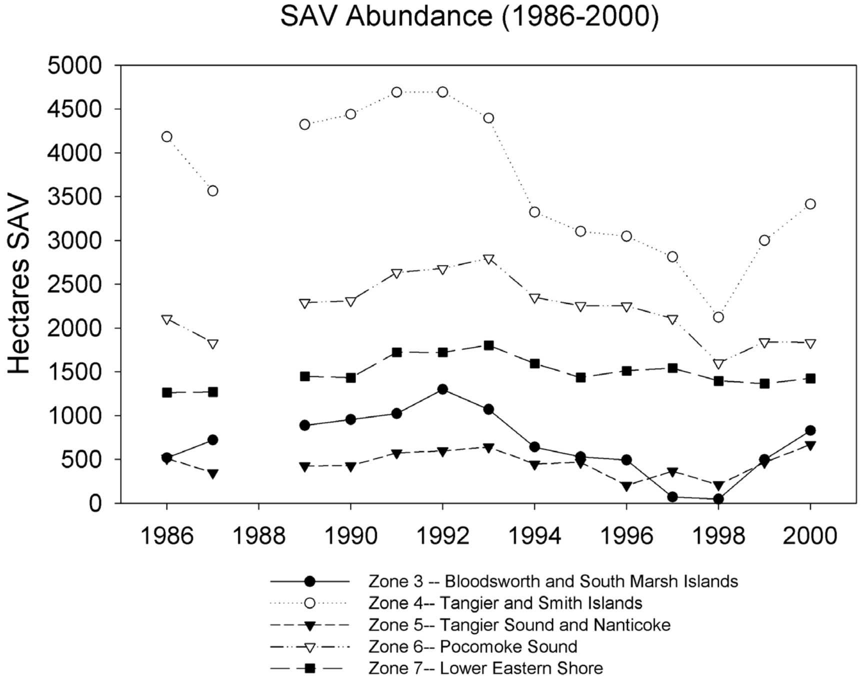


Figure 6.3: SAV abundance in each zone between 1986 and 2000

Zone 3: Bloodsworth and South Marsh Islands (Figure 6.4):

SAV consists primarily of *R. maritima* in this region. Between 1986 and 1992, SAV increased from 519 hectares to a maximum of 1,300 hectares in this zone. In 1993, SAV began to decline, reaching a minimum of 49 hectares in 1998. After six years of decline, some recovery was apparent in 1999 and 2000 (497 and 829 hectares, respectively) (Figure 6.3). Before the decline, SAV beds were colonizing deeper waters, with depths increasing from 0.78 m below MLW (1987) to 0.98 m below MLW. During the decline, the edges of the beds significantly shallowed in most years (Appendix G3). However, there was no overall significant correlation between total SAV abundance and depth at the bed edges (Appendix G1).

Median light levels (Kd, PLW, and PLL) values remained better than the habitat requirement except in 1997. There were no correlations of SAV area with either Kd, PLW, or PLL (Appendix G2). Total suspended sediments did increase to a level above the habitat requirement (18.19 mg/l) during the years of SAV expansion, however, TSS was not significantly correlated to SAV area (Appendix G2). Median chlorophyll levels were not significantly correlated with SAV area, and did not exceed the habitat requirement (Appendix G2**.** After the SAV decline, there were no consistent PLW or PLL differences between the each year's edge cells and the maximum abundance year's edge cells (Appendices G4 & G5).

It is important to note that there was a significant correlation between the change in SAV area per year and median salinity, as well as with minimal salinity over the growing season (Appendix G2**).**

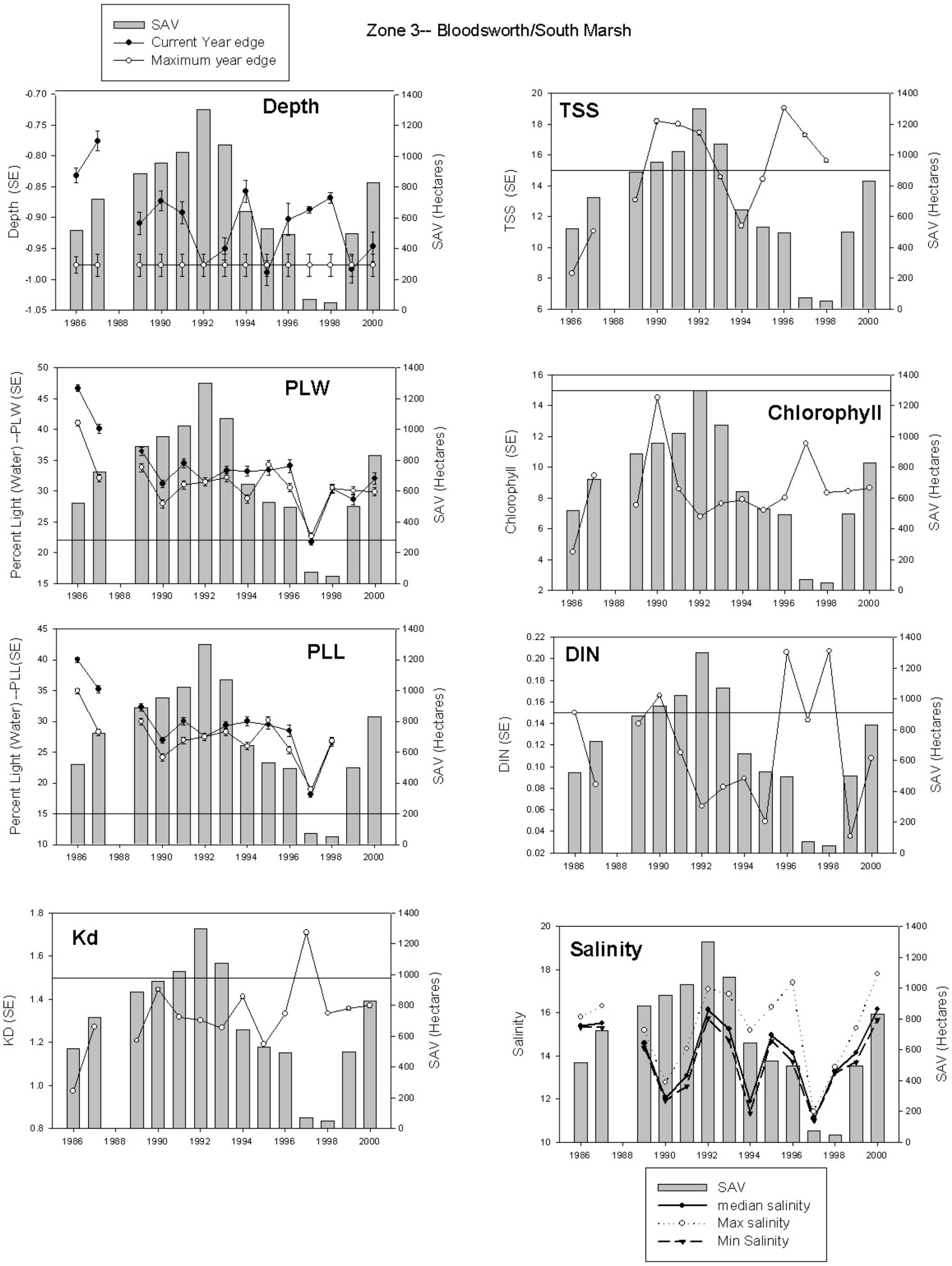


Figure 6.4: Zone 3 (Bloodsworth and South Marsh Island) water quality and SAV area. Horizontal line represents SAV Habitat Requirement (Batiuk et al. 2000). For Depth, PLW and PLL, water quality values are zonal, annual means (±SE) of current year's edge cells' seasonal median values and annual means of maximum year's edge cells' seasonal median values. All other water quality parameters are sampled from the maximum year's edge cells. For salinity, the means of the seasonal medians, seasonal minimums and seasonal maximum values from the maximum edge cells are shown.

Zone 4: Tangier and Smith Islands (Figure 6.5):

SAV consists of both *Z. marina* and *R. maritima* in this region. SAV increased from 3,564 ha in 1987 to a maximum of 4,690 ha in 1992. Declines occurred in 1993 and more sharply in 1994. After a minimum in 1998 (2,123 ha), SAV began to recover in 1999 and 2000 (Figure 6.3). There was a significant correlation of SAV abundance and depth (Appendix G6) and a significant difference between depths at the edge of the maximum year's SAV (1992) and each particular year (Appendix G8). This indicates that as SAV area increased before 1992, the beds were encroaching into deeper water (maximum depth of 1.36 m below MLW). After 1992, as abundance decreased, the bed edges were retreating to shallower waters. Beds in this zone were the deepest of all the zones throughout the entire time period studied.

Kd, PLW, and PLL were all significantly correlated with SAV area (Appendix G7). Kd fluctuated between 0.85 m^{-1} and 1.02 m^{-1} before 1992, but increased to as high as 1.14 m^{-1} in 1998. However, this is still consistently better than the habitat requirement. PLW was high in the years of SAV increase (26.27% - 32.57%) but was lower after the decline (as low as 22.42%). PLL followed similar trends, as low as 19.59% and was also correlated with SAV Change (Appendix G7). During the SAV decline, PLW and PLL in the maximum edge cells were significantly different than current year edge values (Appendices G9 & G10). TSS increased before 1992 and then fluctuated just below the habitat requirement in the years following the decline. However, TSS levels were not significantly correlated with SAV area. Chlorophyll remained lower than the habitat requirement, as did DIN for most years (except 1996 and 1997).

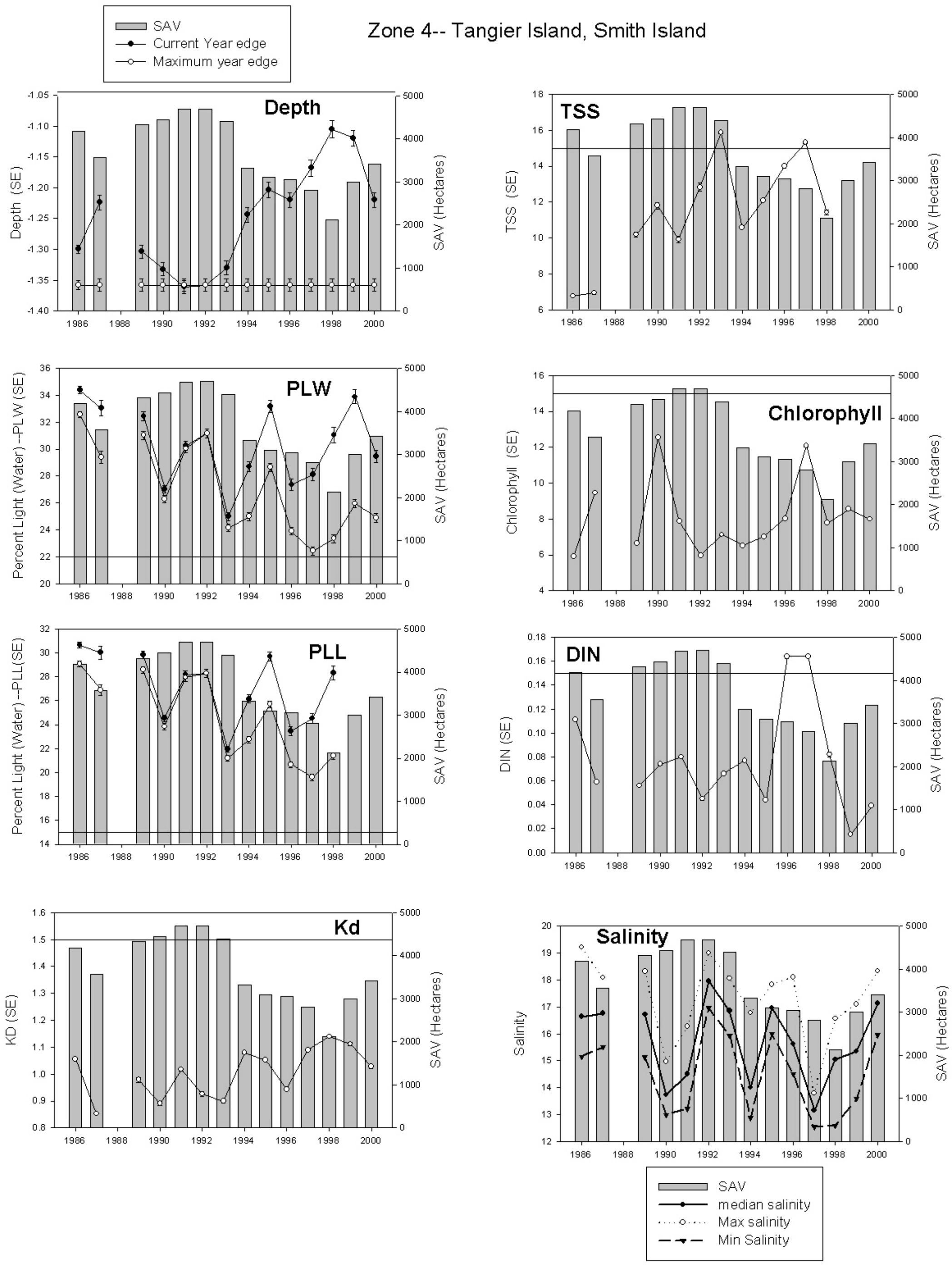


Figure 6.5: Zone 4 (Tangier and Smith Islands) water quality. Horizontal line represents SAV Habitat Requirement (Batiuk et al. 2000). For Depth, PLW and PLL, water quality values are zonal, annual means (±SE) of current year's edge cells' seasonal median values and annual means of maximum year's edge cells' seasonal median values. All other water quality parameters are sampled from the maximum year's edge cells. For salinity, the means of the seasonal medians, seasonal minimums and seasonal maximum values from the maximum edge cells are shown.

Zone 5: Tangier Sound and Nanticoke Sound (Figure 6.6):

SAV (primarily *R. maritima*) fluctuated between 1986 and 1993, with a general increase to 642 ha by 1993. In 1994, a decline was observed reaching a minimum of 204 ha in 1996. Between 1997 and 2000, SAV again fluctuated in abundance (Figure 6.3). There was no significant correlation between SAV abundance and SAV depth, nor were there any significant differences between each specific year's edge depth and the maximum year's depth (1993) in most of the years after the decline (Appendices G11 & G13). The SAV beds in this zone were shallower than in any other zone.

None of the water quality parameters were significantly correlated with SAV area (Appendix G12). Although Kd fluctuated above and below the habitat requirement, PLW and PLL remained better than the habitat requirements throughout the period (>31.58% PLW and >26.56% PLL) . Before the decline, PLW and PLL were significantly different between the each year's edge cells and the maximum year's edge cells (Appendices G14 & G15). TSS was consistently worse than the habitat requirements after 1987 (16.97-25.09 mg/l) and had the highest values of all the zones. Chlorophyll remained below the habitat requirement, as did DIN in most years. Although DIN in the entire zone was very high in most years, the levels were not as high where the bed edges were located.

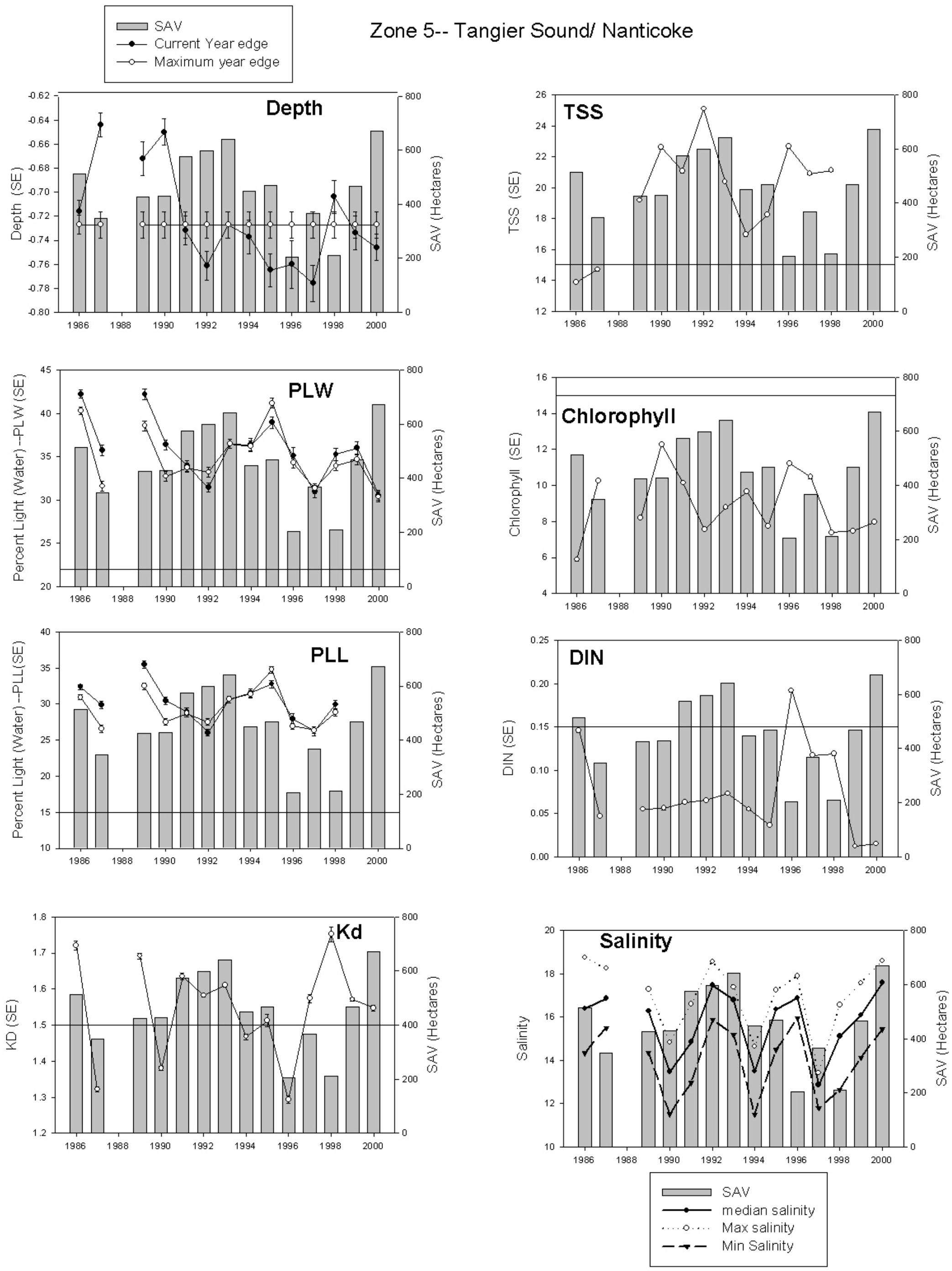


Figure 6.6: Zone 5 (Tangier Sound and Nanticoke) water quality. Horizontal line represents SAV Habitat Requirement (Batiuk et al. 2000). For Depth, PLW and PLL, water quality values are zonal, annual means (±SE) of current year's edge cells' seasonal median values and annual means of maximum year's edge cells' seasonal median values. All other water quality parameters are sampled from the maximum year's edge cells. For salinity, the means of the seasonal medians, seasonal minimums and seasonal maximum values from the maximum edge cells are shown.

Zone 6: Pocomoke Sound (Figure 6.7):

SAV (primarily *R. maritima*) abundance increased from 1,831 ha in 1987 to a maximum of 2,797 ha in 1993. In 1994 a decline was observed reaching a minimum in 1998 (1,601 ha). Slight recovery has been observed since 1999 (Figure 6.3). SAV area and depth were significantly correlated, with beds reaching as deep as 1.00 meters by 1992, and shallowed to 0.88 m during subsequent years (Appendix G16). Before 1991 and after 1996, the depth of the bed edge each year was significantly different than the 1993 maximum abundance depth (Appendix G18), but only by a few centimeters.

Water quality values were not significantly correlated with absolute SAV area, but Kd, PLW and PLL were significantly correlated with change in SAV area (Appendix G17). Kd values tended to increase over time, eventually surpassing the habitat requirement by 1996. As a result, PLW and PLL values at the maximum edge cells tended to decrease over time, (to a minimum of 24.18% PLW and 20.47% PLL in1996) and were significantly different from PLW and PLL values at each specific years' edge (Appendices G18 & G19). TSS values after 1987 were greater than the habitat requirement in most years, reaching as high as 21.46 mg/l. Chlorophyll levels were significantly lower than the habitat requirements, as were DIN levels. It is important to note that although nitrogen levels in the entire zone may have been high, levels at the grass beds were lower.

SAV change was also correlated with the maximum salinity in this zone (Appendix G17). As maximum salinity increased, the change in SAV from one year to the next also increased.

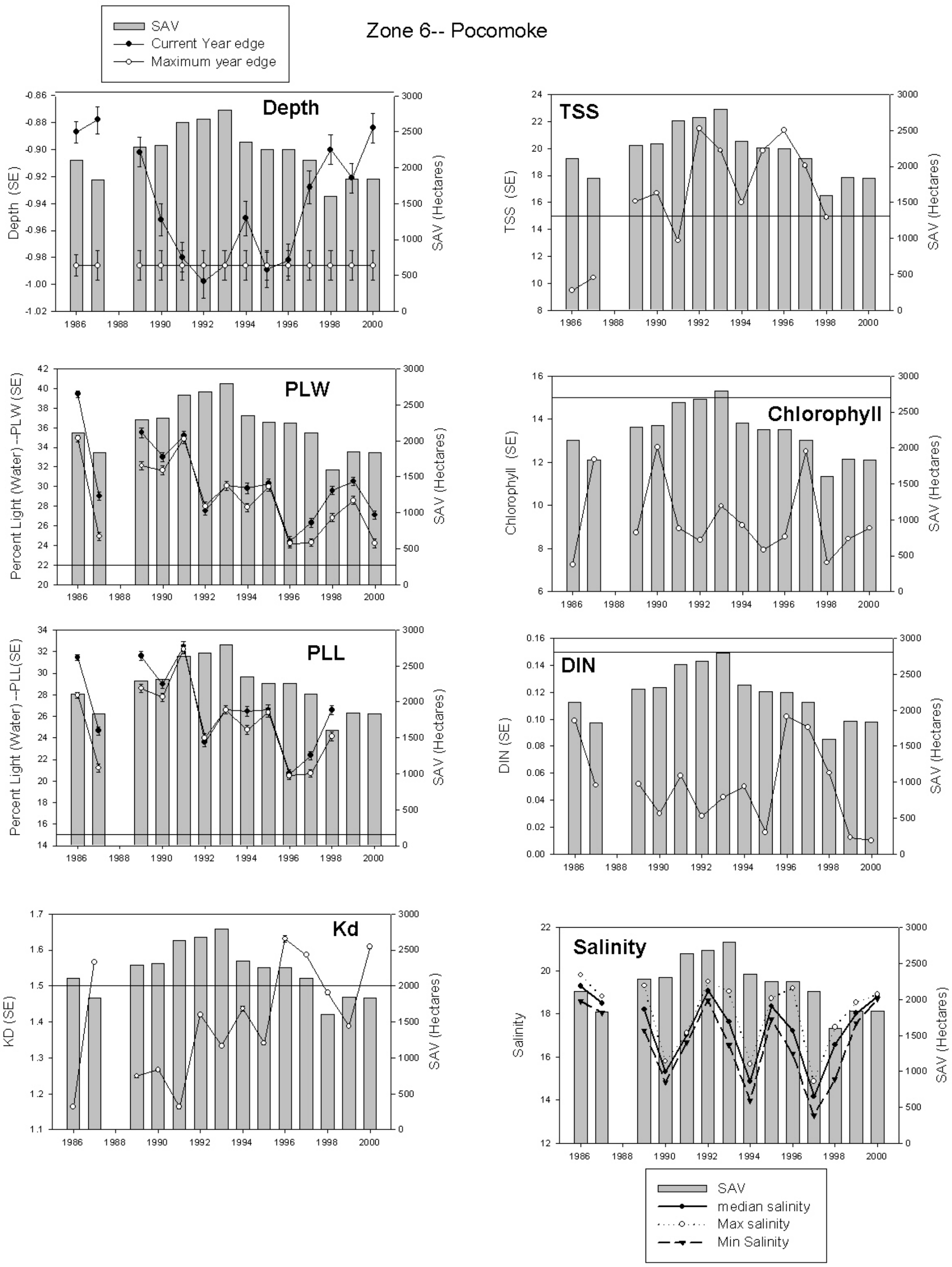


Figure 6.7: Zone 6 (Pocomoke Sound) water quality. Horizontal line represents SAV Habitat Requirement (Batiuk et al. 2000). For Depth, PLW and PLL, water quality values are zonal, annual means (±SE) of current year's edge cells' seasonal median values and annual means of maximum year's edge cells' seasonal median values. All other water quality parameters are sampled from the maximum year's edge cells. For salinity, the means of the seasonal medians, seasonal minimums and seasonal maximum values from the maximum edge cells are shown.

Zone 7: Lower Eastern Shore (Figure 6.8)

SAV in this region is primarily *Z. marina*, which increased to a maximum of 1,803 ha by 1993. After an initial decline in 1994, SAV abundance has fluctuated steadily (Figure 6.3). Depth was significantly correlated with SAV area, with the beds significantly shallower than the maximum depth before 1992 and after 1996 (Appendices G21 & G23).

No water quality parameters were significantly correlated with SAV area except for TSS (Appendices G22). There appears to have been a trend for increasing Kd, and therefore a decreasing trend for PLW and PLL, although this zone consistently had the highest levels of PLW and PLL of all the zones. TSS, Chlorophyll, and DIN all remained below the habitat requirements.

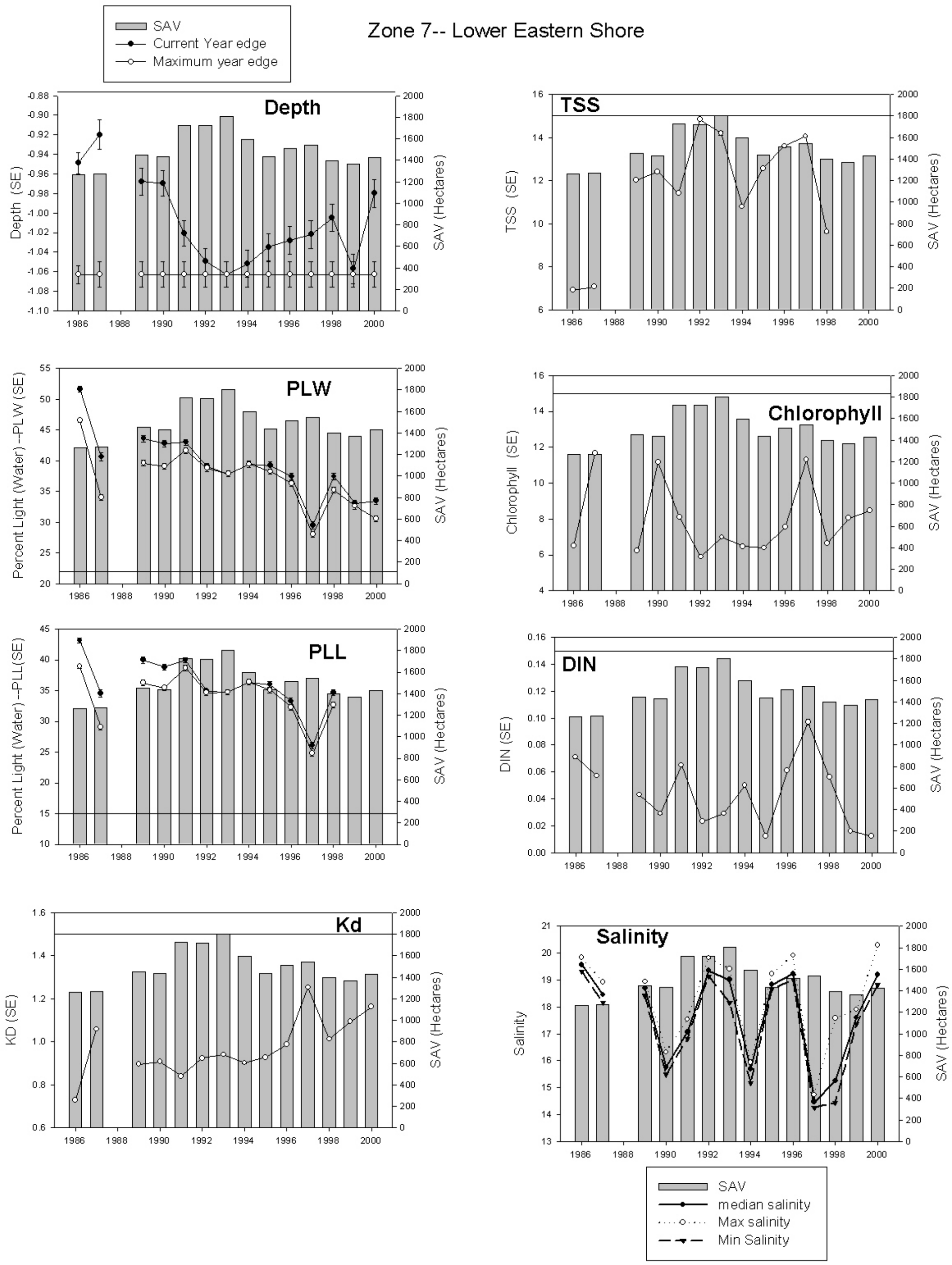


Figure 6.8: Zone 7 (Lower Eastern Shore) water quality. Horizontal line represents SAV Habitat Requirement (Batiuk et al. 2000). For Depth, PLW and PLL, water quality values are zonal, annual means (±SE) of current year's edge cells' seasonal median values and annual means of maximum year's edge cells' seasonal median values. All other water quality parameters are sampled from the maximum year's edge cells. For salinity, the means of the seasonal medians, seasonal minimums and seasonal maximum values from the maximum edge cells are shown.

6.4: DISCUSSION

The Dataflow analysis shows that interpolation of mid-channel data is more precise than solely assigning data from the nearest mid-channel station to estimate shoal conditions, i.e. interpolation results have smaller variances than nearest mid channel values. However, neither method successfully predicts **actual** shoal conditions (< 2m depth) with an acceptable level of precision. Interpolation tends to underestimate shoal turbidity and other factors, and variance from observed data is higher in the shoals. This is likely because of the variety of physical and biological factors affecting the water column in shallow water. First, as waves enter shallow water, their energy begins impinging on the bottom, which can resuspend sediments (Ward et al. 1984), increasing local turbidity. Also, adjacent eroding marshes can increase sediment loads near the shore, with these suspended particles settling out of the water column with increasing distance from the shore. Shallow water also has greater spatial and temporal variance in light levels, suspended solids, and nutrient remineralization (Moore et al. 1995) compared to deeper water. However, large SAV beds can offset some of these turbidity effects by slowing water velocities, which will allow larger suspended sediment particles to settle to the bottom, thereby clearing the water (Ward et al. 1984, Moore et al. 1995). However, some recent studies have suggested that some grassbeds may even act as sources of suspended sediments under certain physical conditions (Koch 1999). Reduction of suspended sediments was not apparent in the dataflow data, as that data exhibited high turbidities in the shoals, even over existing grassbeds. The dataflow data exhibited a high degree of small spatial scale patchiness, particularly in the shallow waters. Since the interpolation is using deep water data, these extreme conditions are not measured.

However, this does not mean that the interpolation cannot be used to evaluate regional water quality, as overall spatial and temporal trends in water quality are still apparent. The interpolator is providing an estimate of water quality at shoal locations, and if the water quality at the shoals is already poor, shallow water processes would likely degrade water quality even more, particularly if there is little or no SAV present. Therefore, it is still valid to analyze trends in water quality and correlations with SAV abundance, as long as the interpolated values in the shoals are considered relative and not absolute.

Interpolation underestimation and high variance may also explain why much of the interpolated water quality at the SAV beds in each zone are better than the SAV habitat requirements (lower Kd, TSS, Chl, DIN, DIP, higher PLW and higher PLL). Actual values are likely worse than the interpolator values.

Besides the mid-channel/shoal condition issues, the values used to analyze SAV trends were median values over the growing season. This may miss extreme events such as spikes in suspended sediments, chlorophyll or nutrients, or sudden drops in salinity, all of which may have effects on SAV abundance, and which might occur during extreme runoff periods or storm events. However, median values do give estimations of longer-term changes in water quality, and utilizing minimum and maximum salinity in the analysis along with median values provides a surrogate measure of the intensity of these extreme events.

Given these constraints on shallow water interpolated values, the interpolations show that there are many areas, primarily along the Eastern Shore rivers, which consistently have had insufficient water quality to support SAV (Appendix E). Both high nitrogen loads and high levels of suspended solids appear to be the main water quality issues in these regions. Further from these sources, water quality improves enough to support SAV in at least some years.

The declines in the Tangier/Smith Islands region (zone 4) are apparently due to diminishing light conditions. As Kd increased over time, PLW and PLL were decreasing. The beds apparently responded to worsening light conditions by retreating from deeper waters, as evidenced through the shallowing of the deep edges of the beds after 1992. This is consistent with light limitation of *Zoster*a marina. TSS levels were rising and accounted for a growing percentage of Kd (58.0% in 1987 vs. 77.5% in 1993), suggesting that inorganic suspended sediments were of increasing importance. However, overall levels of Kd and TSS were still at or better than the habitat requirements, and PLW and PLL were consistently above the established habitat requirements.

The changes in SAV at Bloodsworth and South Marsh Islands (Zone 3) are more complicated. Unlike the Tangier/Smith Island zone (zone 4) which contained primarily *Z. marina* or *Z.marina/R .maritima* mix, Bloodsworth and South Marsh Islands are primarily *R. maritima* which fluctuates greatly from year to year. In this zone, the mean depth of the grassbeds increased during the period of decline, counter to what is expected given light limitation. This seems to be caused by the disappearance of shallow beds around the islands, resulting in only deeper beds remaining with which to sample depth. There are several possible explanations for this phenomenon, including storm excavation in the shallower, high energy environments. Another possibility is that light limitation may be occurring, caused by a potentially high epiphytic load or a local increase in turbidity from resuspension in the shallow waters or erosion from the land. Such local turbidity is not apparent from mid-channel data from which the interpolation is based, although it is apparent in the high resolution dataflow sampling. This is also supported by the significant correlations between SAV change from year to year and salinity at Bloodsworth and South Marsh.

SAV declines in the Pocomoke zone (zone 6) and in the lower Eastern Shore (zone 7) may also be due to light limitation, as these areas also show significant correlations with depth. Light levels in the Pocomoke zone are also significantly correlated to the change in SAV, further suggesting light limitation.

The cause of this light limitation remains uncertain. As discussed in a previous chapter, there were no consistent patterns between shoreline erosion and SAV gain or loss. However, given the uncertainties of the shoreline datasets, particularly during the small time frame of 1992-1998, the potential of shoreline erosion as a source of turbidity remains unidentified.

According to USGS provisional data, the period of decline (1992 or 1993 through 1998) encompassed three years of unusually high river flows into the Chesapeake Bay (1993, 1994, 1998) and one year with the highest flow on record (1996) (Figure 1.5). Increased precipitation decreases salinities, and increases nutrient and sediment loads via runoff and groundwater. All of these factors can stress *Z. marina* and *R. maritima*. Together with sediment resuspension in shallow water, these factors may be the cause of the light limitation apparent around the mid-bay islands and the correlations between SAV abundance and light levels (Kd, PLW, PLL). Two of those high flow years were consecutive (1993 and 1994), which may have stressed the plants with low light conditions beyond their ability to survive, while plants may have been able to recover if the high precipitation years were interspersed with low stress years. It is during these two years that the largest SAV declines were observed. It is important to note that 1999 and 2000 were unusually dry years, and SAV significantly recovered in that time.

6.5: SUMMARY

Interpolation of mid channel data in Tangier Sound and mid-bay island region has been found effective in analyzing relative effects of water quality on spatial and temporal changes of SAV abundance. However, the interpolations are less accurate and less precise in areas shallower than 2m, due to the higher variation of measured variables in shallow waters. Yet, given these constraints, the interpolations confirm that areas along the eastern shore rivers have higher TSS and nutrient loads (and less light), with most shoals not capable of supporting populations of SAV. Conditions improve towards the west, however water quality on the eastern side of the mid bay islands is worse than the western side. This analysis also shows that interpolated water quality data from mid-channel, when used with high resolution depth data, can differentiate between where SAV was growing in a particular year and where it could potentially grow but was unvegetated during that year. The data identifies light limitation as a correlating factor with SAV area and SAV changes in area from year to year. In most zones, there was significantly less light (PLW, PLL) at the locations where beds have been shown to grow (maximum abundance edge) relative to the edge of the bed in each year. Beds were also significantly shallower during the declining years compared to the maximum abundance depth, which is consistent with light limitation. In some regions, salinity also correlated with SAV distribution, further suggesting that the high precipitation years since 1993 and resultant increased inputs of sediments and nutrients were a likely factor causing the declining local light conditions at the SAV beds around the islands, resulting in a loss of SAV.

Chapter 7: Conclusions

Large-scale declines in SAV in the Tangier Sound region of the Chesapeake Bay from 1950s to the present have resulted in SAV coverages are approximately only 10% of the 1938-1952 abundances. In addition, smaller scale declines in SAV from 1993 to 1998 are cause for alarm not only for the regional impacts but also because of the ecological and economic importance of these extensive SAV covered, shallow water flats. Tangier Sound was examined to identify the primary factor(s) causing these alarming declines.

7.1: Study Focus

- Examination of SAV community changes over time
- Examination of shoreline loss and affects on SAV
- Comparison of current versus historic water quality relative to the loss of SAV
- Evaluation of regional water quality in Tangier Sound relative to the loss of SAV
- Utilization of water quality interpolation to evaluate changes in SAV abundance

Examination of large and small scale water quality and other ecological processes have revealed that Tangier Sound region SAV declines can be grouped into causes of recent and long term SAV declines.

7.2: Long term SAV declines (1950s to 1994)

There have been large declines in SAV coverage since the 1950s. While the data are sparse, there is some indication of elevated nutrient and suspended solid concentration in the lower eastern shore tributaries during the 1970s as a result of increased flows. The 1970s had 5 years of above average flow including the record flows from Agnes in 1972. In addition, a species dominance shift occurred around the late 1970s from *Zoster*a marina to a *Ru*ppia maritima. Since *Ru*ppia maritima generally dominates shallower water than *Zoster*a marina, this may be a response to a generally poorer water quality during this time period.

There does not appear to be a clear pattern of SAV loss or gain versus shoreline loss.

7.3: Recent SAV declines (1994-1998)

Increased spring flows since 1993 during critical SAV growth periods appear to have contributed to declining light levels in the Tangier Sound region. This is supported by regionally decreasing salinity levels, increased suspended solids as well as generally poorer water quality originating from lower Eastern shore tributaries. In response to the degraded water quality conditions during 1993-1998, Tangier Sound SAV beds appeared to be retreating to shallower water.

7.4: Management Implications

While the cause of the short and long term declines in Tangier Sound SAV appear to be weather (flow) related, overall reductions in sediment and nutrient loading will help minimize what is eventually carried into the Chesapeake Bay. In addition, due to the close proximity of the Tangier Sound region to the lower Eastern Shore tributaries, special emphasis should be placed on improving water quality conditions in these locations.

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Appendix A: Interpolator Code

ArcInfo AML source code for the new over-water inverse-distance squared interpolator.

```
/****************************************************/
/*  Name: interp.aml
/*  Date: March, 2001
/*  ARC 8.1
/*  Author:      David Wilcox
/*               Virginia Institute of Marine Science
/*               Gloucester Point, VA
/*               (804)684-7088
/*  Purpose: Inverse distance squared interpolator using
/*           over-water distances
/*           Created for the Tangier WQ project
/*
/*****************************************************
&args routine arglist:rest

&severity &error &routine  bailout
&messages &off &all

/* Coverages created by this aml. These will be automatically created
&s rgncov = region
&s statcov = stations
&s stations = stations_used
&s rngrid = region_grid
&s watergd = water_grid

/* A polygon coverage used to identify water and land areas
&s shorecov = shore100

/* A weight table used to assign a higher weight to water
&s watertab = WATER.TAB

/* Call the requested routine or return in none was specified
&if ^ [null %routine%] &then
  &call %routine%
&else
  &return error

&messages &on

&return

/*****************************************************
&routine setup
/*
/* Sets up all the distance grids for a set of stations
/* and a region. This needs to be run only once for multiple
/* interpolations.
/*
/* args: stationfile region cellsize max_dist
/*
/* Stationfile is a comma delimeted text file with station ids
/* and lat/long coordinates:
/*
/*    CB1.0,76.1740036,39.6585999
/*    CB1.1,76.0810013,39.5447006
/*    CB2.1,76.0250015,39.4399986
/*    CB2.2,76.1750031,39.3466988
/*
/* Region is a shapefile with a polygon identifying the region
/* to interpolate
/*
/* Cellsize is the cellsize to use in meters (assuming a utm
/* projection
/*
/* Maxdist is the maximum distance to use in the interpolation
/*
```

```
/****************************************************

&s stnfilename = [extract 1 [unquote %arglist%]]
&s rgnfilename = [extract 2 [unquote %arglist%]]
&s cellsize = [extract 3 [unquote %arglist%]]
&s maxdist = [extract 4 [unquote %arglist%]]

&call readstn
&call readrgn
&call pickstns
&call calcstndists
&call calcmindists

&return

/****************************************************
&routine process
/*
/* Process a parameter value to produce an interpolated
/* grid. Assumes that setup has been run first.
/*
/* args: valuefile numstns outputgrid
/*
/* Valuefile is a comma-delimeted text file with station ids
/* and parameter values. Negative values are treated as missing
/* data.
/*
/*    CB1.0,-9
/*    CB1.1,1.385
/*    CB2.1,1.81
/*    CB2.2,1.81
/*
/* Numstns is the number of nearby stations to use in the
/* interpolation at each cell.
/*
/* Outputgrid is the name of the interpolated grid that will
/* be created
/*
/****************************************************

&s valfilename = [extract 1 [unquote %arglist%]]
&s numstns = [extract 2 [unquote %arglist%]]
&s outputgrid = [extract 3 [unquote %arglist%]]

&if [exists %rgngrid% -grid] &then &do
    &describe %rgngrid%
    &s cellsize = %grd$dx%
&end
&else
    &return 'Run setup first!'

&call readvalues
&call setminvalues
&call makemasks
&call interpolate

&return

/****************************************************
&routine readstn
/* Read station file
/****************************************************

&s statcovgeo = [scratchname -prefix nn -directory]
CREATE %statcovgeo%

BUILD %statcovgeo% POINT
ADDITEM %statcovgeo%.PAT %statcovgeo%.PAT STATION 32 32 C

&s stnfile = [open %stnfilename% ok -READ]
&if %ok% <> 0 &then
    &return I could not open the station file!
```

```
ARCEDIT
EDIT %statcovgeo%
COORDINATE KEYBOARD
EDITFEATURE POINT

&s numlines = 0
&s numpts = 0
&s line = [read %stnfile% ok]
&s line = [read %stnfile% ok]
&do &while %ok% = 0
   &s numlines = %numlines% + 1
   &s id = [extract 1 %line%]
   &s long = [extract 2 %line%]
   &s lat = [extract 3 %line%]
   &s numpts = %numpts% + 1
   ADD
   1,[calc 0 - %long%],%lat%
   9,0,0
   CALC station = [quote [unquote %id%]]
   &s line = [read %stnfile% ok]
&end

&s ok = [close  %stnfile%]

SAVE
COORDINATE MOUSE
QUIT

&if [exists %statcov% -coverage] &then
    KILL %statcov%

PROJECT COVER %statcovgeo% %statcov%
INPUT
PROJECTION GEOGRAPHIC
UNITS DD
DATUM NAD83
PARAMETERS
OUTPUT
PROJECTION UTM
ZONE 18
UNITS METERS
DATUM NAD83
PARAMETERS
END

KILL %statcovgeo% ALL

&type Read %numlines% lines. Accepted %numpts% stations.

&return

/******************************************************
&routine readrgn
/* Read region shapefile
/******************************************************
&if [exists %rgncov% -coverage] &then
    KILL %rgncov%

SHAPEARC %rgnfilename% %rgncov%
BUILD %rgncov% POLY

PROJECTDEFINE COVER %rgncov%
PROJECTION UTM
ZONE 18
UNITS METERS
DATUM NAD83
PARAMETERS

&describe %rgncov%
&s gridxmin = [round [calc %dsc$xmin% / %cellsize%]] * %cellsize%
&s gridymin = [round [calc %dsc$ymin% / %cellsize%]] * %cellsize%
```

```
&s gridxmax = [round [calc %dsc$xmax% / %cellsize%]] * %cellsize%
&s gridymax = [round [calc %dsc$ymax% / %cellsize%]] * %cellsize%
&s gridcols = [round [calc ( %gridxmax% - %gridxmin% ) / %cellsize%]]
&s gridrows = [round [calc ( %gridymax% - %gridymin% ) / %cellsize%]]

&if [exists %rngrid% -grid] &then
    KILL %rngrid%

POLYGRID %rgncov% %rngrid%
%cellsize%
N
%gridxmin%,%gridymin%
%gridrows%,%gridcols%

&return


/*****************************************************
&routine pickstns
/*  pick the stations that are in the region plus the buffer
/*****************************************************
&s rgnbuff = [scratchname -prefix nn -directory]

BUFFER %rgncov% %rgnbuff% # # %maxdist% 0.1 poly round full

&describe %rgnbuff%
&s buffxmin = [round [calc %dsc$xmin% / %cellsize%]] * %cellsize%
&s buffymin = [round [calc %dsc$ymin% / %cellsize%]] * %cellsize%
&s buffxmax = [round [calc %dsc$xmax% / %cellsize%]] * %cellsize%
&s buffymax = [round [calc %dsc$ymax% / %cellsize%]] * %cellsize%
&s buffcols = [round [calc ( %buffxmax% - %buffxmin% ) / %cellsize%]]
&s buffrows = [round [calc ( %buffymax% - %buffymin% ) / %cellsize%]]

&if [exists %stations% -coverage] &then
    kill %stations%

CLIP %statcov% %rgnbuff% %stations% point 0.1

KILL %rgnbuff% all

&s tempgd = [scratchname -prefix nn -directory]
POLYGRID shorecov %tempgd% LAND # watertab
%cellsize%
N
%buffxmin%,%buffymin%
%buffrows%,%buffcols%

GRID
&if [exists %watergd% -grid] &then
    kill %watergd% all

%watergd% = SETNULL(%tempgd% ^= 1,1)
QUIT

KILL %tempgd% ALL

&return

/*****************************************************
&routine calcstndists
/*     Calculate the distance grids
/*****************************************************
ADDXY %stations% POINT

CURSOR ptcur DECLARE %stations% POINT RO
CURSOR ptcur OPEN
&s id = 0
&do &while %:ptcur.aml$next%
    &s id = %id% + 1
    &s stn%id%x = %:ptcur.x-coord%
    &s stn%id%y = %:ptcur.y-coord%
    CURSOR ptcur NEXT
```

```
&end
&s cntstns = %id%
CURSOR ptcur CLOSE
CURSOR ptcur REMOVE

&type %cntstns% stations are within the max distance of the data region.
&type
&type Calculating distances...
GRID
&do id = 1 &to %cntstns%
    &type Station %id%
    &s stncov = [scratchname -prefix nn -directory]
    ARC RESELECT %stations% [value stncov] POINT
    RES %stations%# = %id%
~
N
N

    &s stngd = [scratchname -prefix nn -directory]
    ARC POINTGRID %stncov% %stngd% %stncov%#
%cellsize%
N

/* round to cell border
&s x = [value stn%id%x] - %maxdist%
&s y = [value stn%id%y] - %maxdist%
&s x = [round [calc %x% / %cellsize%]] * %cellsize%
&s y = [round [calc %y% / %cellsize%]] * %cellsize%

%x%,%y%
[round [calc %maxdist% * 2 / %cellsize%]],[round [calc %maxdist% * 2 / %cellsize%]]
NODATA

    &s stn%id%dist = [scratchname -prefix nn -directory]
    SETCELL %cellsize%
    SETWINDOW %stngd%
    [value stn%id%dist] = COSTDISTANCE(%stngd%,%watergd%,#,#,%maxdist%,#)

    KILL %stncov% ALL
    KILL %stngd% ALL
&end
QUIT

KILL %watergd% ALL

&return

/*******************************************************
&routine calcmindists
/*    Calculate the minimum distance to all locations
/*******************************************************
GRID

&s stn = 1
&s done = .False.
&do &until %done%

    &type Calculating minimum distances (%stn%)
    SETWINDOW %gridxmin% %gridymin% %gridxmax% %gridymax%
    SETCELL %cellsize%
    &s mindist = min%stn%dist
    &if [exists %mindist% -grid] &then
        KILL %mindist% ALL
    %mindist% = %stn1dist%
    ARC PROJECTDEFINE GRID %mindist%
PROJECTION UTM
ZONE 18
UNITS METERS
DATUM NAD83
PARAMETERS

    &s minid = min%stn%id
```

```
    &if [exists %minid% -grid] &then
        KILL %minid% ALL
    %minid% = con(%mindist% >= 0,1)
    ARC PROJECTCOPY GRID %mindist% GRID %minid%

    &do id = 2 &to %cntstns%
        &type Checking station %id%
        &s stndist = [value stn%id%dist]

        &s tempgd = [scratchname -prefix nn -directory]

        %tempgd% = con(isnull(%stndist%),%minid%,con(isnull(%mindist%),%id%,con(%stndist%
< %mindist%,%id%,%minid%)))
        KILL %minid% all
        RENAME %tempgd% %minid%

        /* Copy distance value
        &s tempgd = [scratchname -prefix nn -directory]
        %tempgd% = con(%minid% == %id%,%stndist%,%mindist%)
        KILL %mindist% ALL
        RENAME %tempgd% %mindist%

    &end

    /* remove from possible choices
    &do id = 1 &to %cntstns%
        &s stndist = [value stn%id%dist]
        SETWINDOW %stndist%
        &s tempgd = [scratchname -prefix nn -directory]
        %tempgd% = setnull(%minid% == %id%,%stndist%)
        KILL %stndist% ALL
        RENAME %tempgd% %stndist%
    &end

    SETWINDOW %gridxmin% %gridymin% %gridxmax% %gridymax%

    &describe %minid%
    &if %grd$nclass% = -1 &then
        &s done = .True.
    &else
        &s stn = %stn% + 1

&end

&s maxstns = %stn% - 1
kill %minid% ALL
kill %mindist% ALL

QUIT

&type Cleaning up..
&do id = 1 &to %cntstns%
    KILL [value stn%id%dist] ALL
&end

&return

/*****************************************************
&routine readvalues
/*    Read the parameter values text file
/*****************************************************

&s valfile = [open %valfilename% ok -READ]
&if %ok% <> 0 &then
    &return I could not open the value file!

&s numlines = 0
&s numpts = 0
&s line = [read %valfile% ok]
&s line = [read %valfile% ok]
&dv stnval_*
&do &while %ok% = 0
```

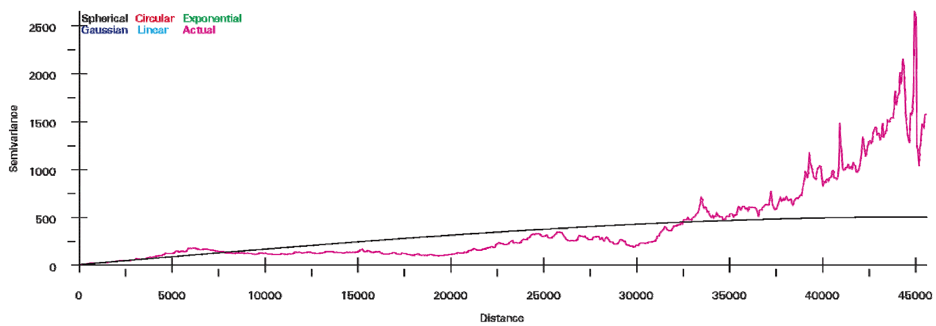
```
   &s numlines = %numlines% + 1
   &s id = [extract 1 %line%]
   &s value = [extract 2 %line%]
   CURSOR stncur DECLARE %stations% POINT RO station = [quote [unquote %id%]]
   CURSOR stncur OPEN
   &if %:stncur.aml$nsel% <> 0 and %value% >= 0 &then &do
       &s stnval_[value :stncur.%stations%#] = %value%
       &s numpts = %numpts% + 1
   &end
   &else
       &type %numlines%: %line%  Skipped
   CURSOR stncur CLOSE
   CURSOR stncur REMOVE
   &s line = [read %valfile% ok]
&end
&s ok = [close  %valfile%]

&describe %stations%
&s cntstns = %dsc$points%

&dv ndstn*
&s ndstn_cnt = 0
&do stn = 1 &to %cntstns%
    &if ^ [variable stnval_%stn%] &then &do
        &s ndstn_cnt = %ndstn_cnt% + 1
        &s ndstn_%ndstn_cnt% = %stn%
    &end
&end
&type Read %numlines% lines. Accepted %numpts% stations. %ndstn_cnt% stations do not have
a value.

&return

/*****************************************************
&routine setminvalues
/*  Greate tje minimum value grids
/*****************************************************
grid
setwindow min1id
setcell min1id

&s stn = 1
&do &while [exists min%stn%id -grid]
    &s stn = %stn% + 1
&end
&s maxstns = %stn% - 1

&do min = 1 &to %maxstns%
    &s min%min%value = [scratchname -prefix nn -directory]
    &s minvalue = min%min%value
    &if [exists %minvalue% -grid] &then
    KILL %minvalue% ALL
    %minvalue% = -9999
    ARC PROJECTCOPY GRID min1dist GRID %minvalue%
    &s minid = min%min%id
    &do stn = 1 &to %cntstns%
        &if [variable stnval_%stn%] &then &do
            &s tempgd = [scratchname -prefix nn -directory]
            %tempgd% = con(%minid% == %stn%,[value stnval_%stn%],%minvalue%)
            KILL %minvalue% ALL
            RENAME %tempgd% %minvalue%
        &end
    &end
&end
quit
&return

/*****************************************************
&routine makemasks
/*  Create masks to deal with missing data
/*****************************************************
GRID
```

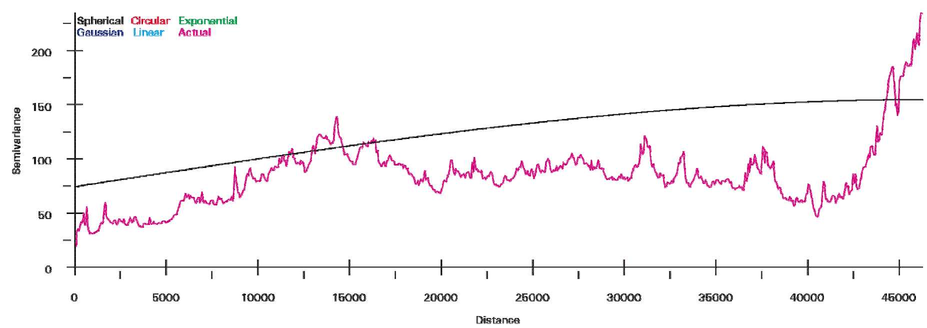
```
SETWINDOW min1id
SETCELL min1id

&do stn = [calc %numstns% + 1] &to %maxstns%
    &s mask%stn% = [scratchname -prefix nn -directory]
    [value mask%stn%] = 0
    ARC PROJECTCOPY GRID min1dist GRID [value mask%stn%]
&end
&if %numstns% < %maxstns% &then
    &s lastmask = [value mask[calc %numstns% + 1]]

&do stn = 1 &to %numstns%
    &s mask%stn% = [scratchname -prefix nn -directory]
    &s maskstn = [value mask%stn%]
    &s minid = min%stn%id
    %maskstn% = 1
    ARC PROJECTCOPY GRID min1dist GRID %maskstn%
    &do ndstn = 1 &to %ndstn_cnt%
        &s tempgd = [scratchname -prefix nn -directory]
        %tempgd% = con(isnull(%minid%),%maskstn%, con(%minid% == [value ndstn_%ndstn%],
0, %maskstn%))
        KILL %maskstn% ALL
        RENAME %tempgd% %maskstn%
    &end
    &if %numstns% < %maxstns% &then &do
        &s tempgd = [scratchname -prefix nn -directory]
        %tempgd% = %lastmask% + 1 - %maskstn%
        KILL %lastmask% ALL
        RENAME %tempgd% %lastmask%
    &end
&end

&do stn = [calc %numstns% + 1] &to [calc %maxstns% - 1]
    &s maskstn = [value mask%stn%]
    [value mask[calc %stn% + 1]] = con(%maskstn% > 0, %maskstn% - 1)
    &s tempgd = [scratchname -prefix nn -directory]
    %tempgd% = con(%maskstn% > 0,1,0)
    KILL %maskstn% ALL
    RENAME %tempgd% %maskstn%
&end
&s tempgd = [scratchname -prefix nn -directory]
%tempgd% = con([value mask%maxstns%] > 0,1,0)
KILL [value mask%maxstns%] ALL
RENAME %tempgd% [value mask%maxstns%]

QUIT

&return

/******************************************************
&routine interpolate
/*    Compute the interpolated grid
/******************************************************
GRID

&if [exists %outputgrid% -grid] &then
    KILL %outputgrid% ALL

SETWINDOW min1dist
SETCELL min1dist

&s tw = [scratchname -prefix nn -directory]
%tw% = float(setnull(1 == 1,1))
ARC PROJECTCOPY GRID min1dist GRID %tw%

&s tval = [scratchname -prefix nn -directory]
%tval% = float(setnull(1 == 1,1))
ARC PROJECTCOPY GRID min1dist GRID %tval%

&type Interpolating...
&do stn = 1 &to %maxstns%
```

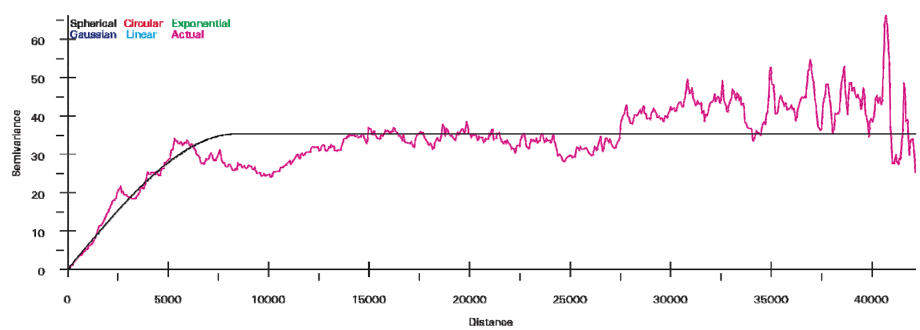
```
    &type Summing values (%stn% of %maxstns%)
    &s mindist = min%stn%dist
    &s minid = min%stn%id
    &s minvalue = min%stn%value
    &s mask = [value mask%stn%]

    &s tempgd = [scratchname -prefix nn -directory]
    %tempgd% = con(isnull(%tval%),%minvalue% / ( %mindist% * %mindist% ) *
%mask%,con(isnull(%minvalue%),%tval%,%tval% + %minvalue% / ( %mindist% * %mindist% ) *
%mask% ))
    KILL %tval% ALL
    RENAME %tempgd% %tval%
    &s tempgd = [scratchname -prefix nn -directory]
    %tempgd% = con(isnull(%tw%),1 / ( %mindist% * %mindist% ) *
%mask%,con(isnull(%minvalue%),%tw%,%tw% + 1 / ( %mindist% * %mindist% ) * %mask% ))
    KILL %tw% ALL
    RENAME %tempgd% %tw%

&end

/* Set cells that contain stations to the station value (if a value exists)
&s tempgd = [scratchname -prefix nn -directory]
%tempgd% = con(min1dist == 0 && %mask1% == 1,min1value,%tval%)
KILL %tval% ALL
RENAME %tempgd% %tval%
&s tempgd = [scratchname -prefix nn -directory]
%tempgd% = con(min1dist == 0 && %mask1% == 1,1,%tw%)
KILL %tw% ALL
RENAME %tempgd% %tw%

&type Computing interpolated values
SETMASK %rgngrid%
%outputgrid% = %tval% / %tw%
QUIT
&return


/*******************************************************
&routine EXIT
/*******************************************************
&type Finished!
&messages &on
&severity &error &fail
&return


/*******************************************************
&routine BAILOUT
/*******************************************************
&type [quote An error has occurred in %aml$errorfile%!]
&call exit
&return &error
```

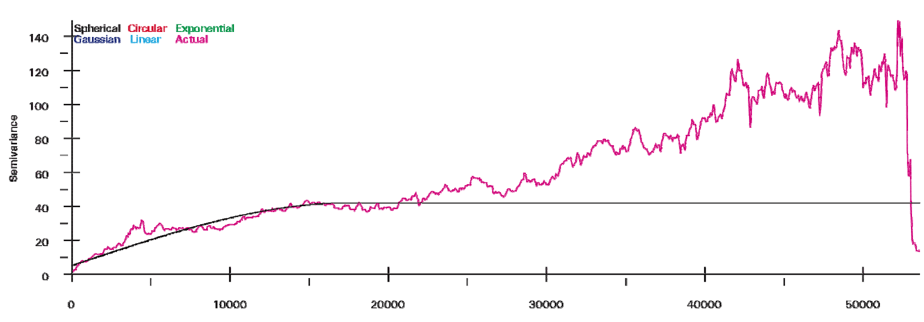
Appendix B: Semivariograms calculated in ESRI ArcInfo from the Dataflow cruise data using straight-line distances.

B1: Salinity

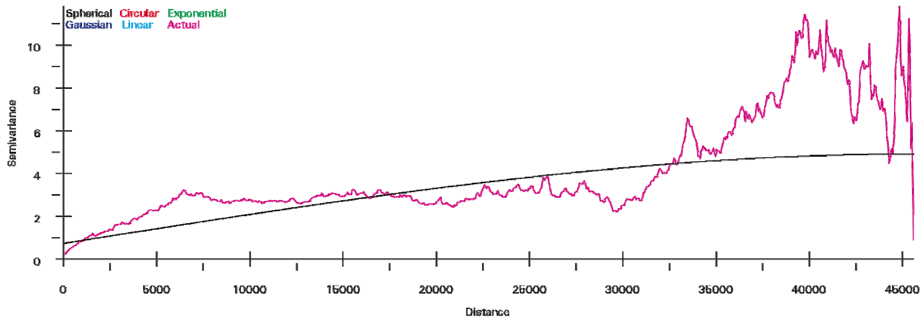


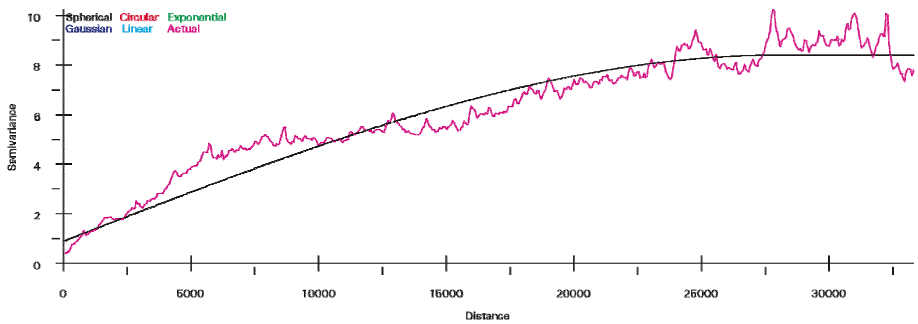


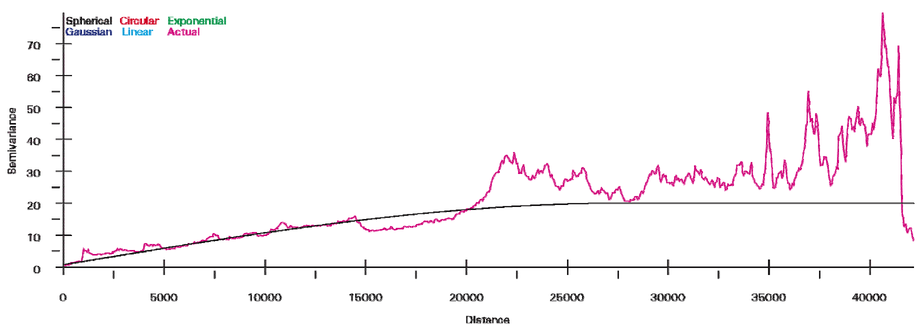


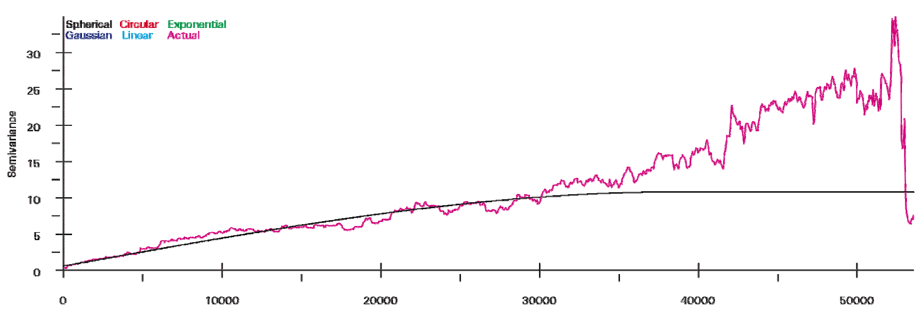


B2: Chlorophyll Semivariogram

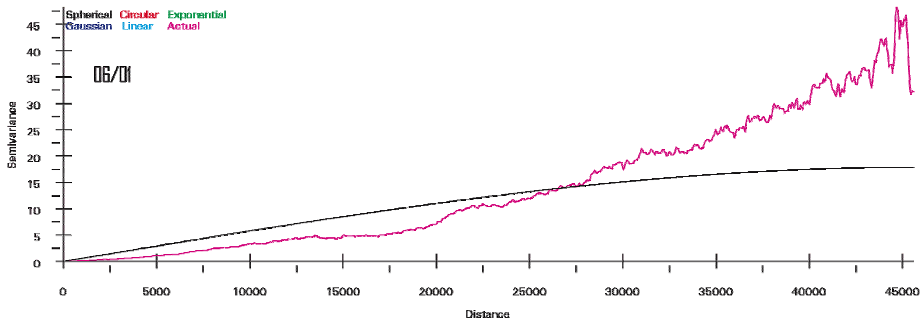


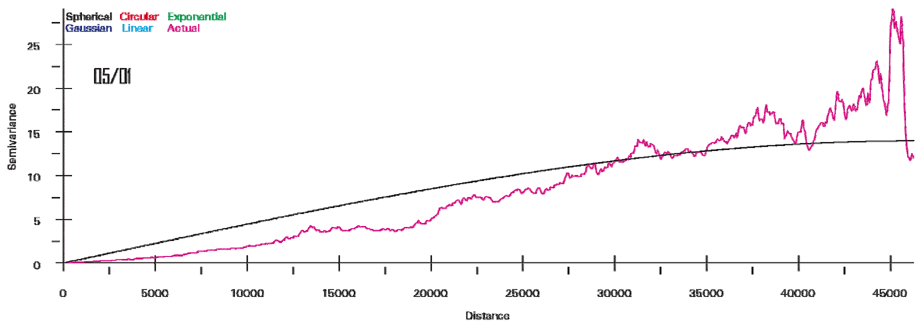


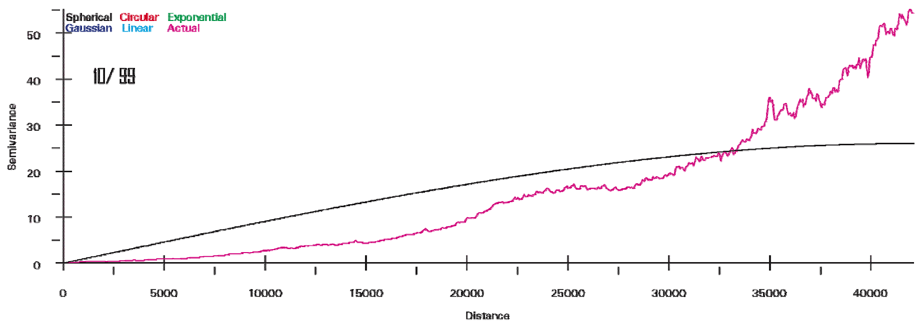


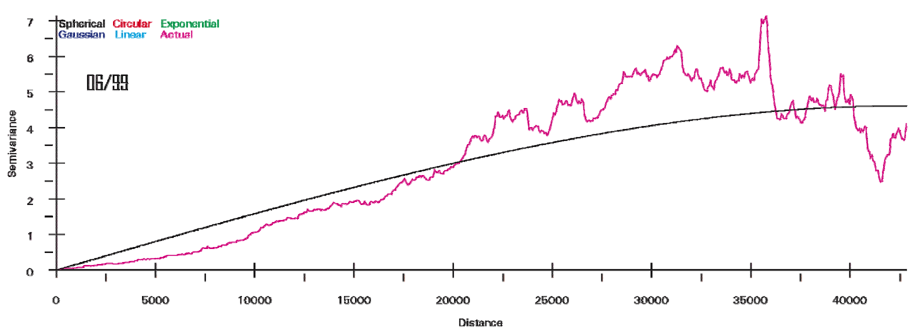


B3: Turbidity/TSS Semivariogram



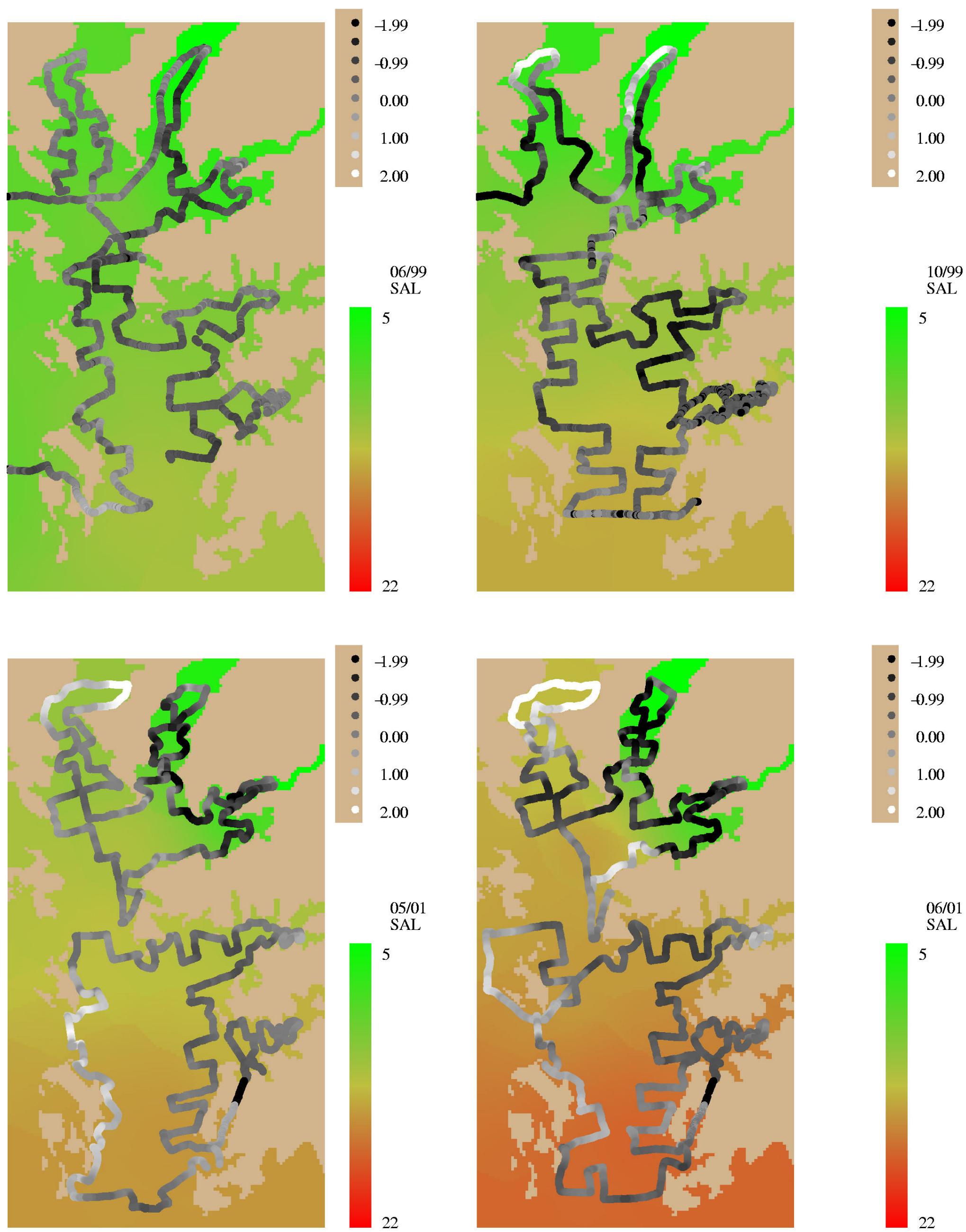




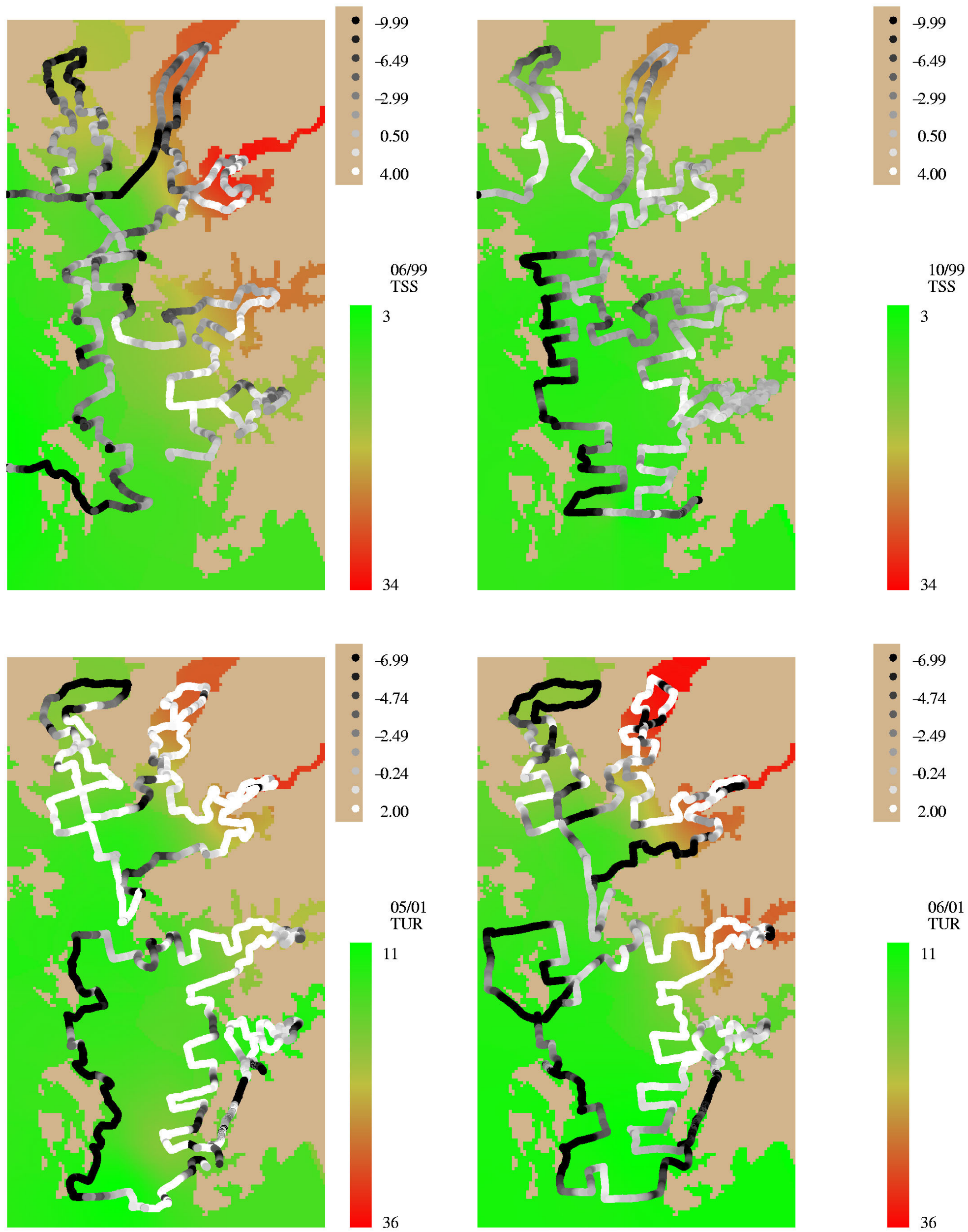


Appendix C: Dataflow Interpolations

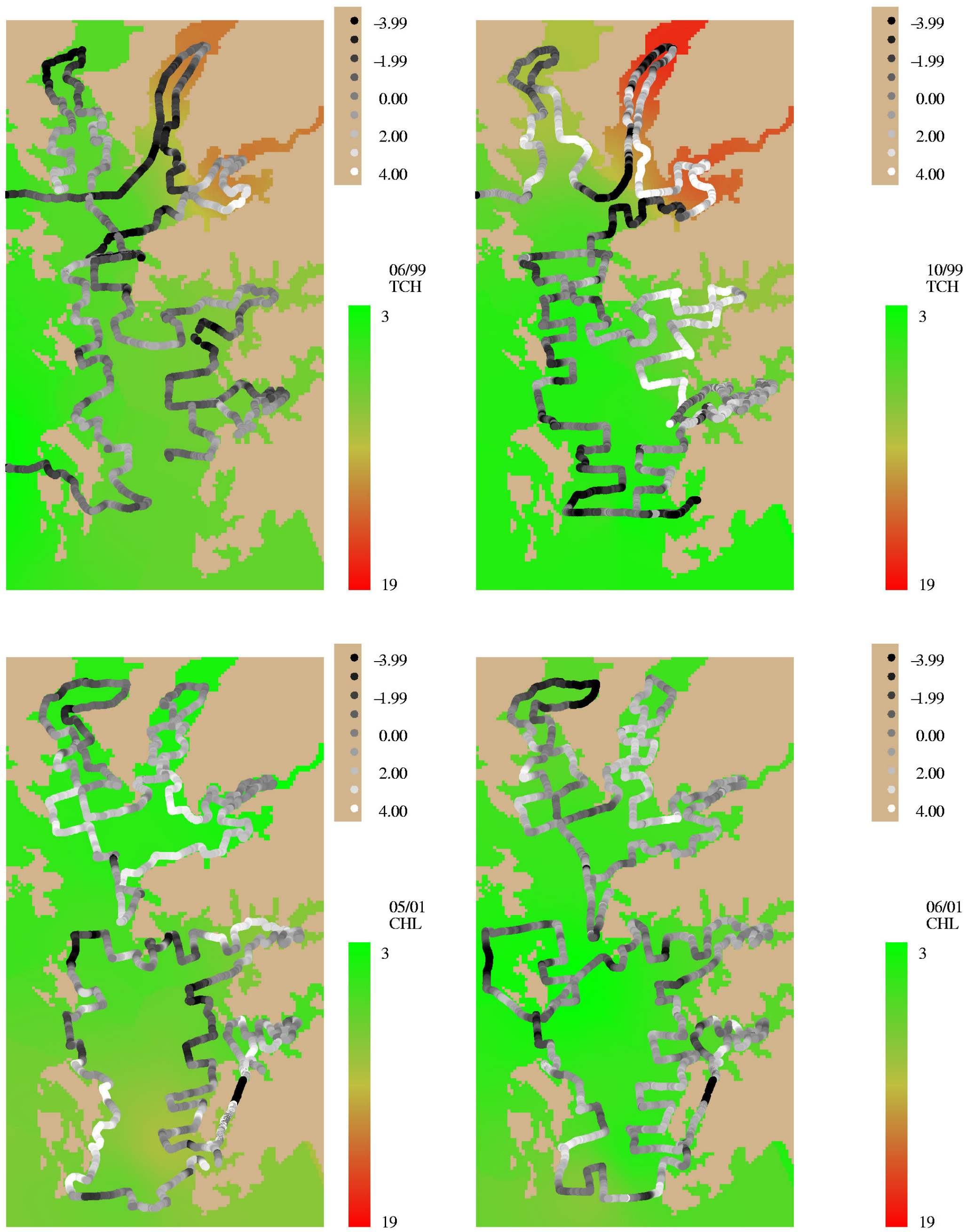
C1: Interpolated Dataflow Salinity compared with actual measured values. The dots represent RMSE (ppt). Black dots denote where interpolation underestimated actual measured values. White dots denote areas where interpolation overestimated actual measured values.



C2: Interpolated Dataflow TSS (6/99, 10/99) and Turbidity (5/01, 6/01) compared with actual measured values. The dots represent RMSE (mg/l and NTU). Black dots denote where interpolation underestimated actual measured values. White dots denote areas where interpolation overestimated actual measured values.

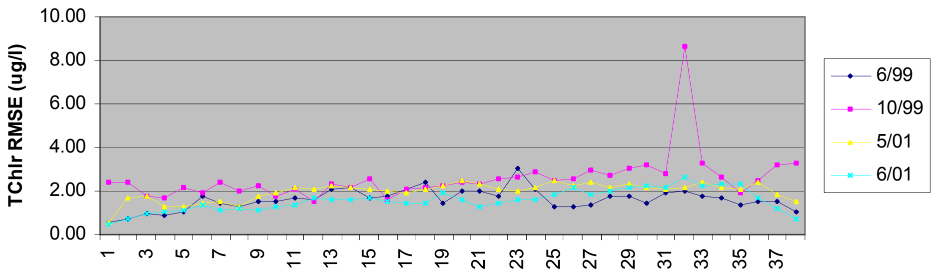


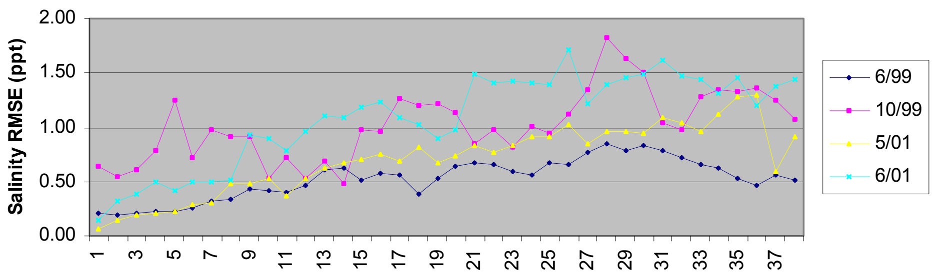
C3: Interpolated Dataflow Chlorophyll compared with actual measured values. The dots represent RMSE (ug/l). Black dots denote where interpolation underestimated actual measured values. White dots denote areas where interpolation overestimated actual measured values.

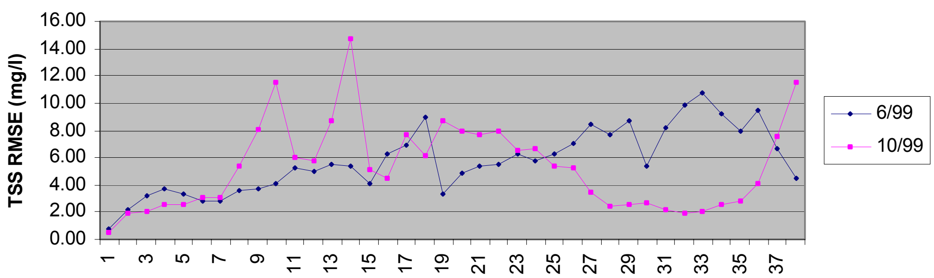


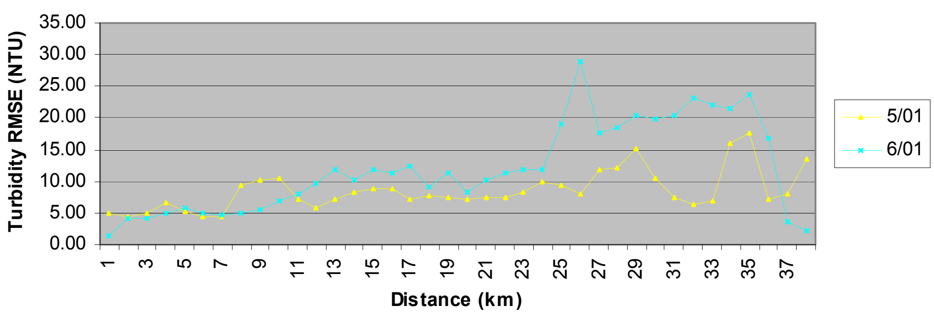
Appendix D: Dataflow RMSE Error

D1: Interpolation of Dataflow data versus actual RMSE computed for Distance (kilometers) for chlorophyll, salinity, TSS and Turbidity.

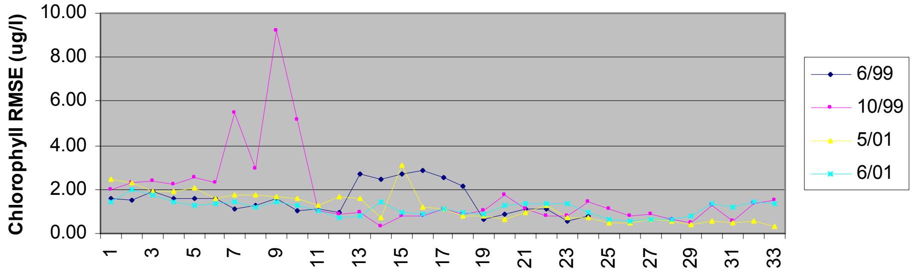


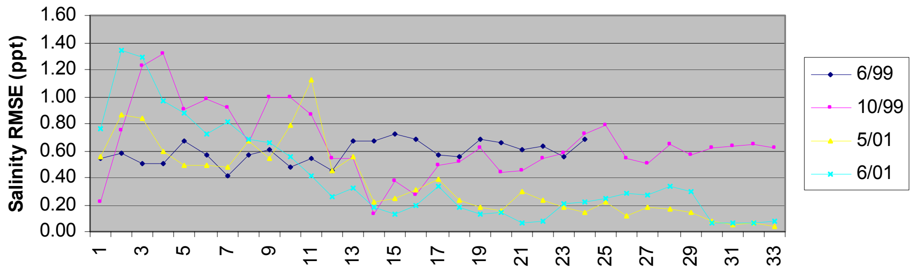


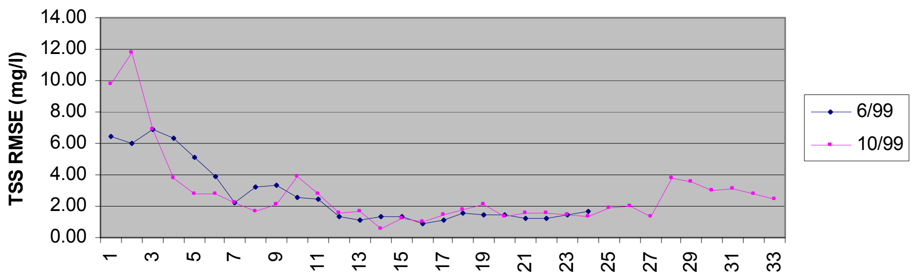


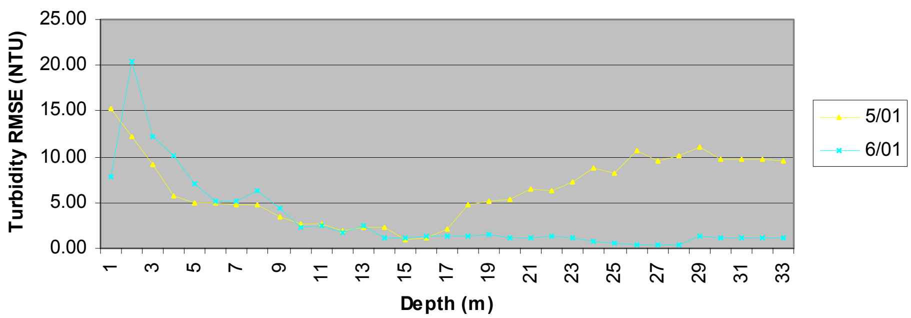


D2: Interpolation of Dataflow data versus actual RMSE computed for each depth for chlorophyll, salinity, TSS and Turbidity. Error for most depths is consistent, except error in the shallowest 2-3 meters is higher for TSS and Turbidity.







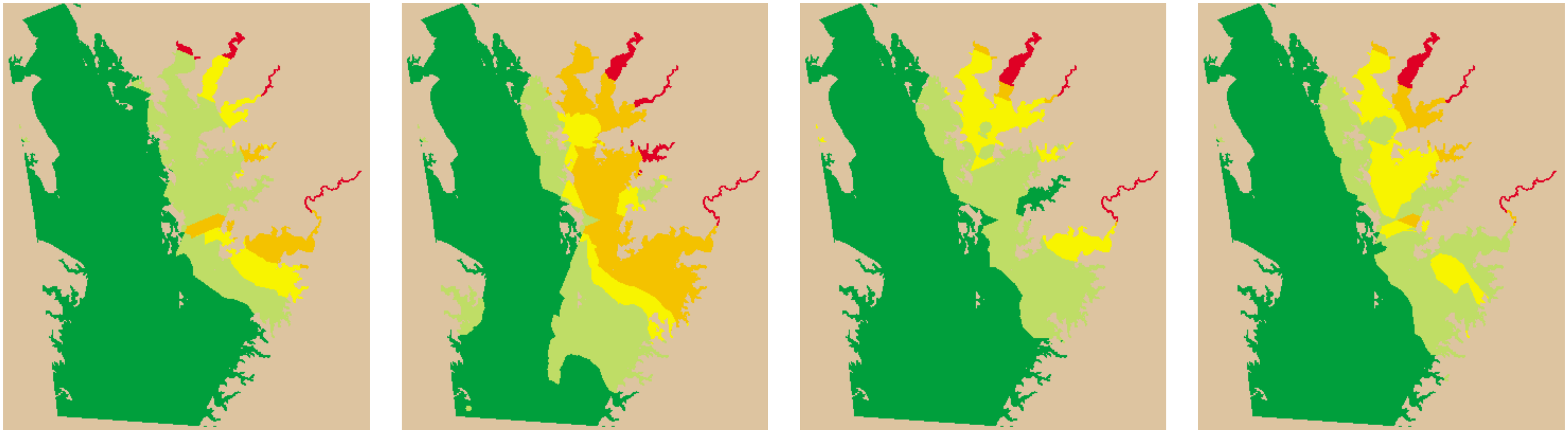


Appendix E: Water Quality Interpolations of EPA Monitoring

App. E1: Light attenuation (Kd)

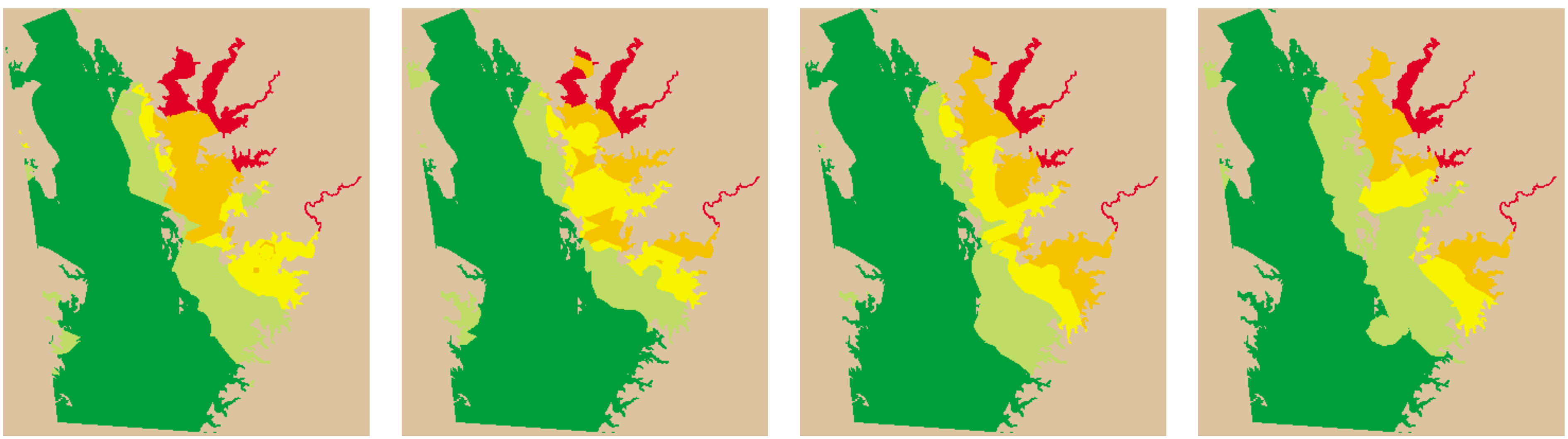
KD (m^{-1}): < 1.0 | 1.0 - 1.4 | 1.4 - 1.6 | 1.6 - 2.0 | > 2.0

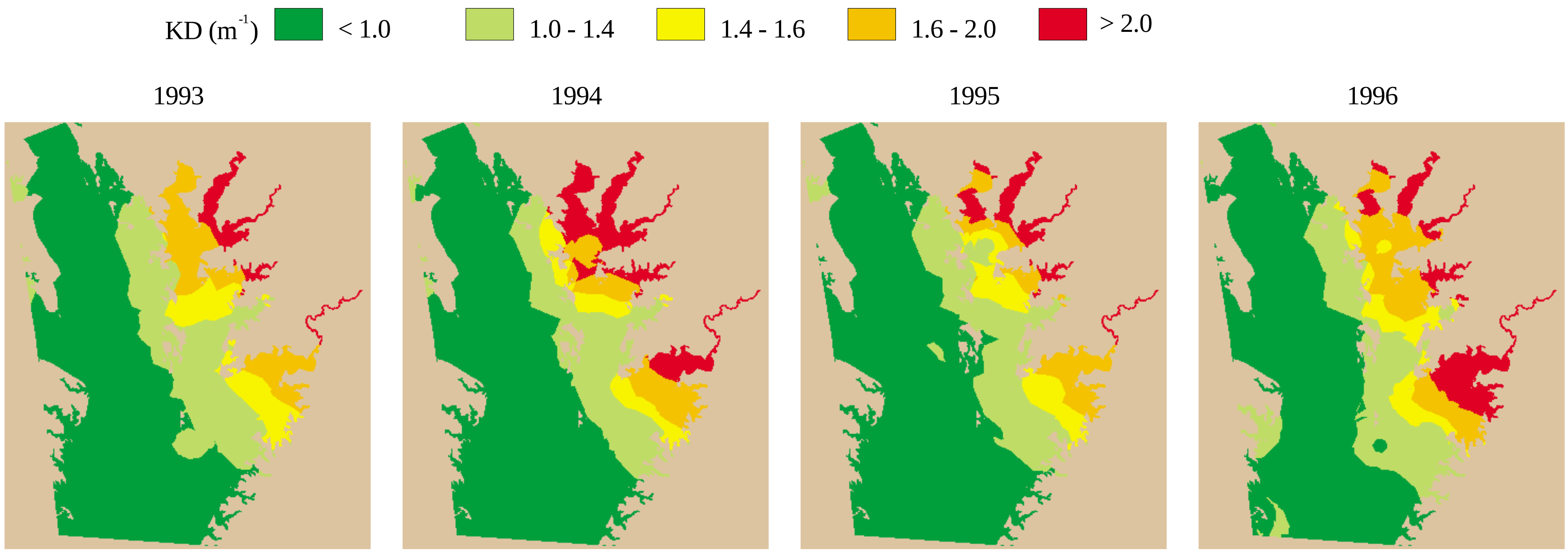
1986 | 1987 | 1988 | 1989



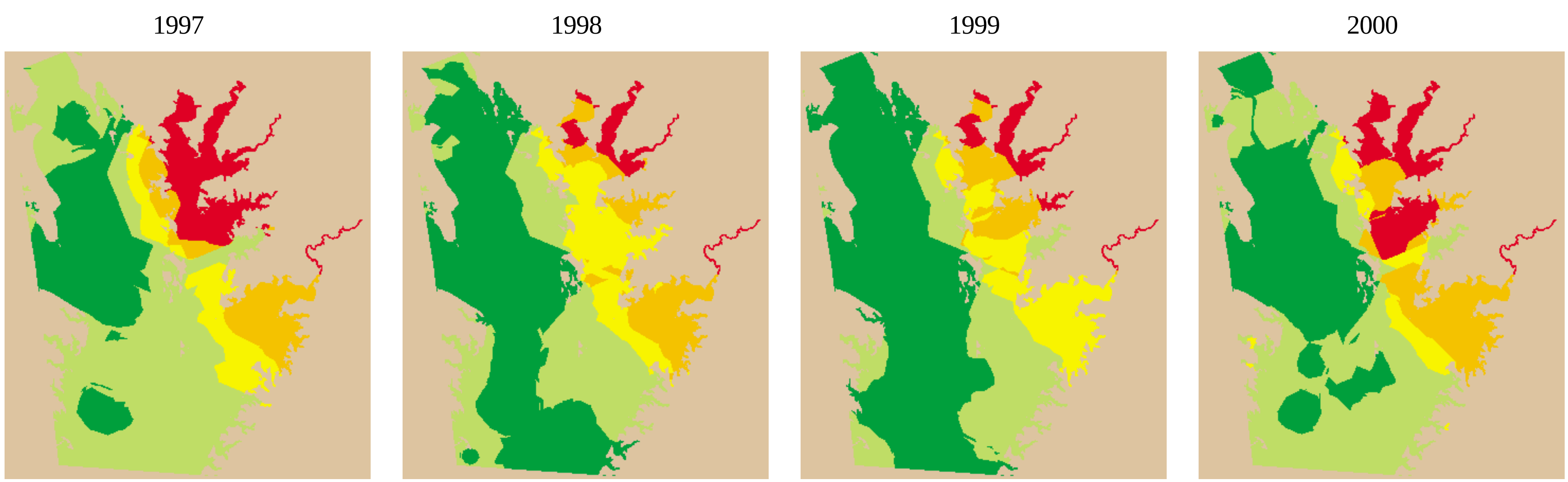
Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.

1990 | 1991 | 1992 | 1993



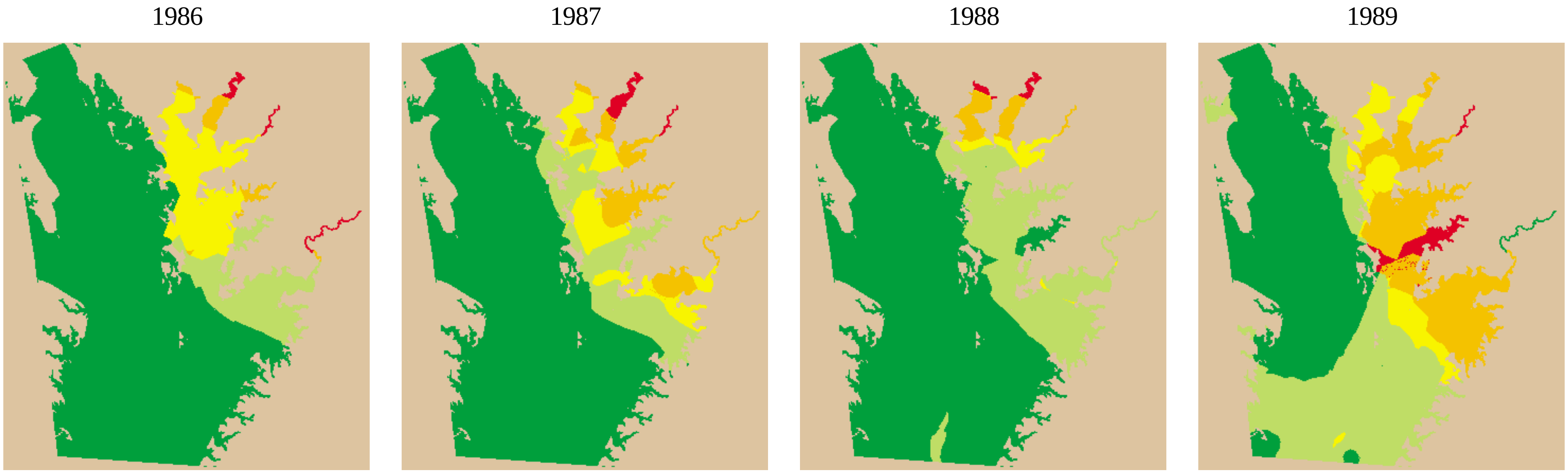


Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.

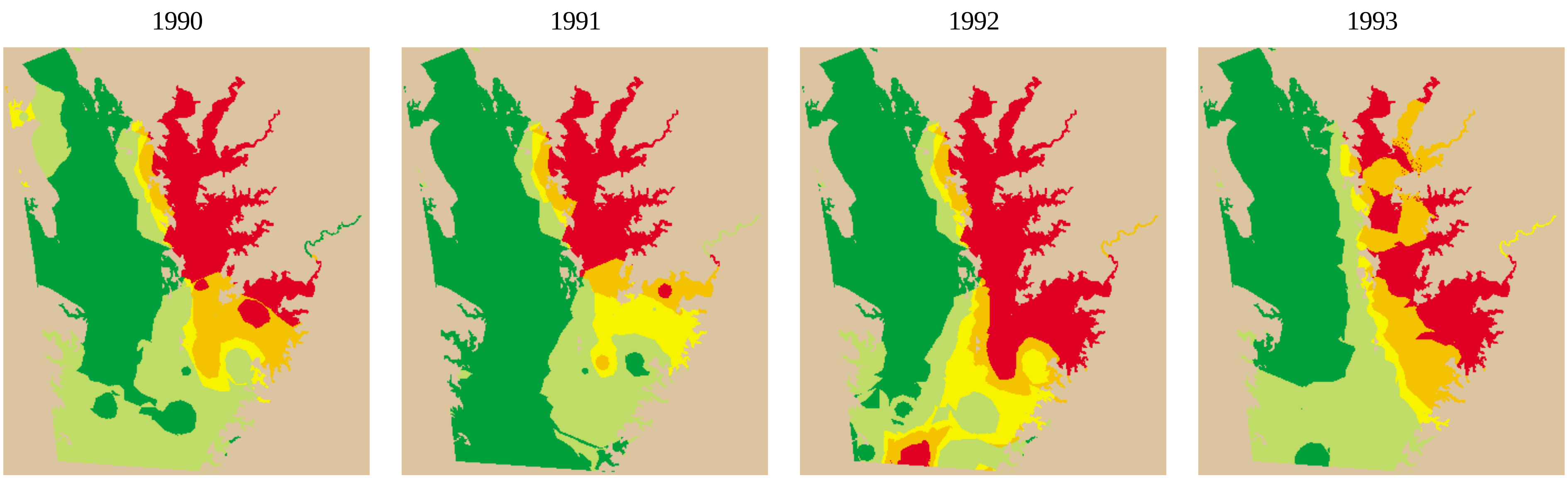


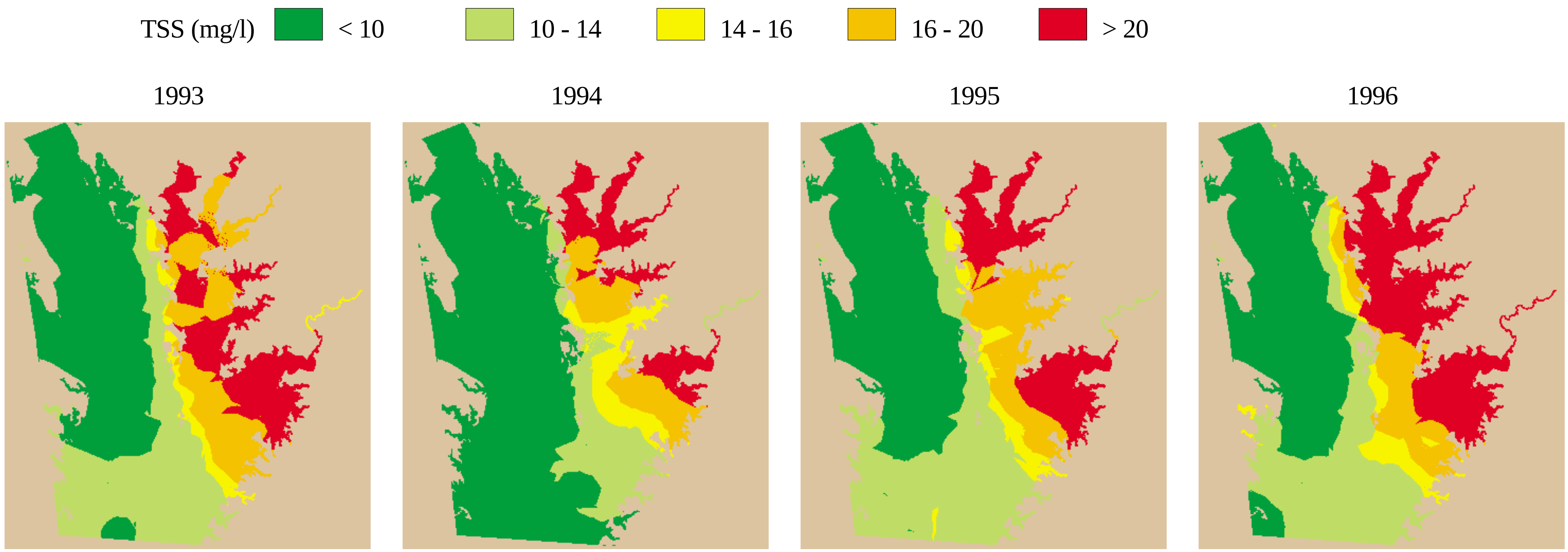
App. E2: Total Suspended Solids (TSS)

TSS (mg/l): < 10 | 10 - 14 | 14 - 16 | 16 - 20 | > 20

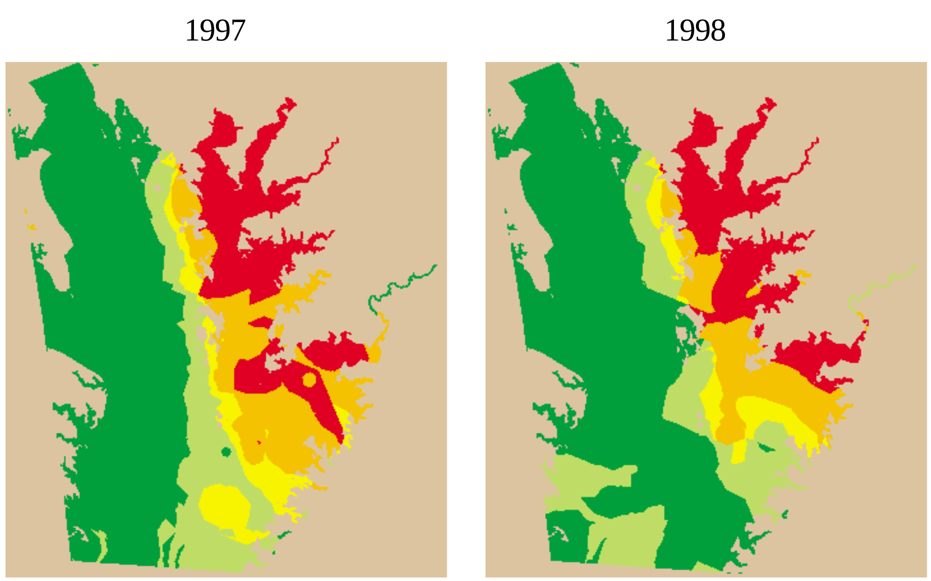


Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.

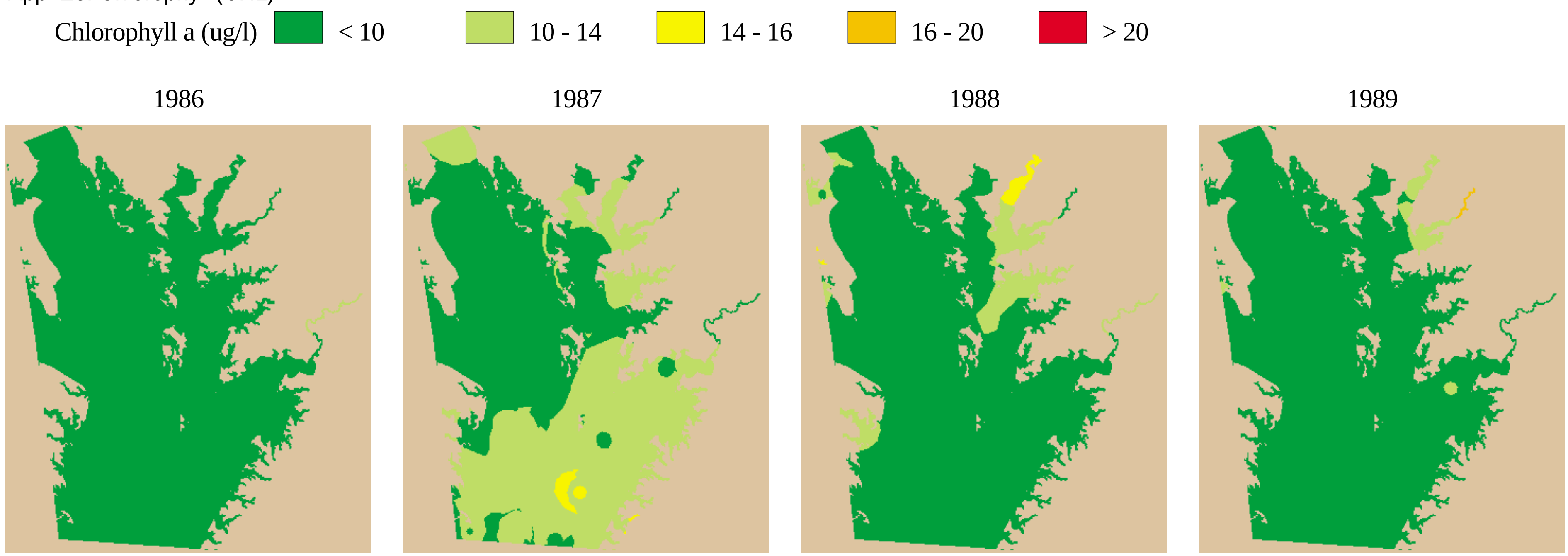




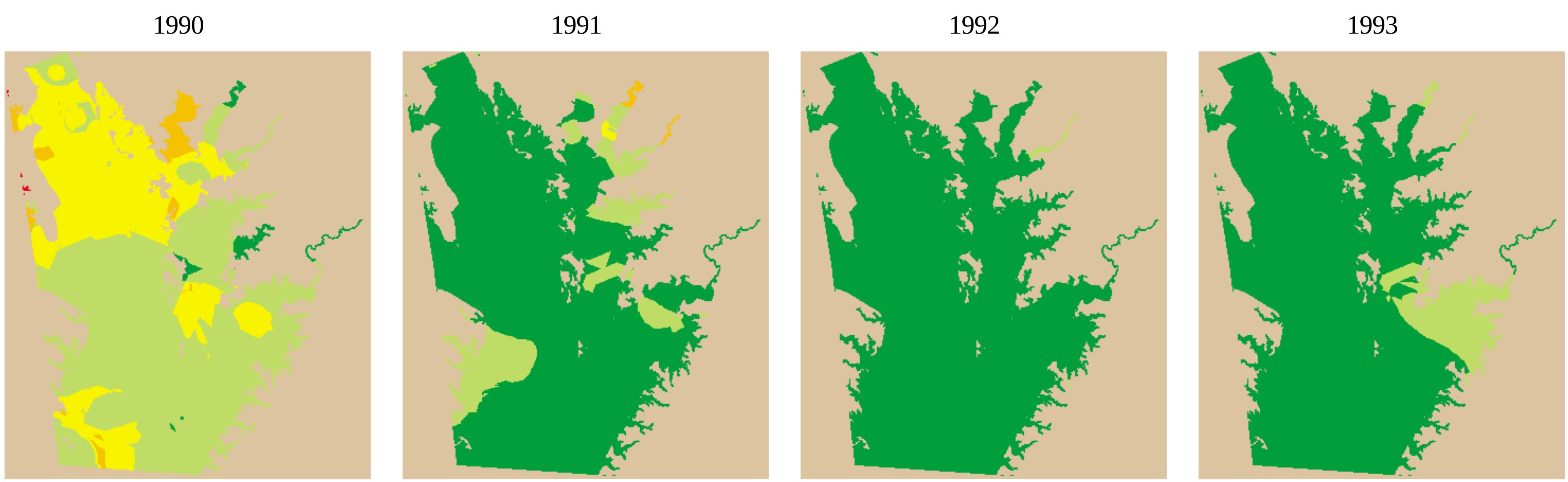
Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.

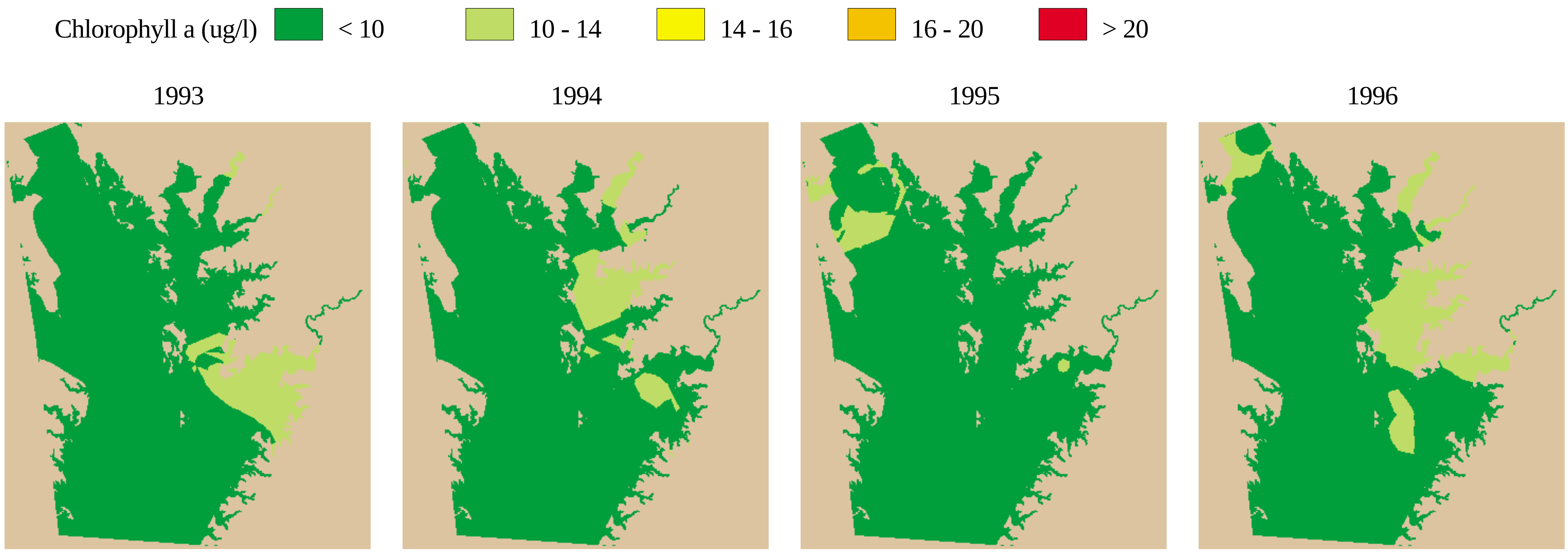


App. E3: Chlorophyll (CHL)

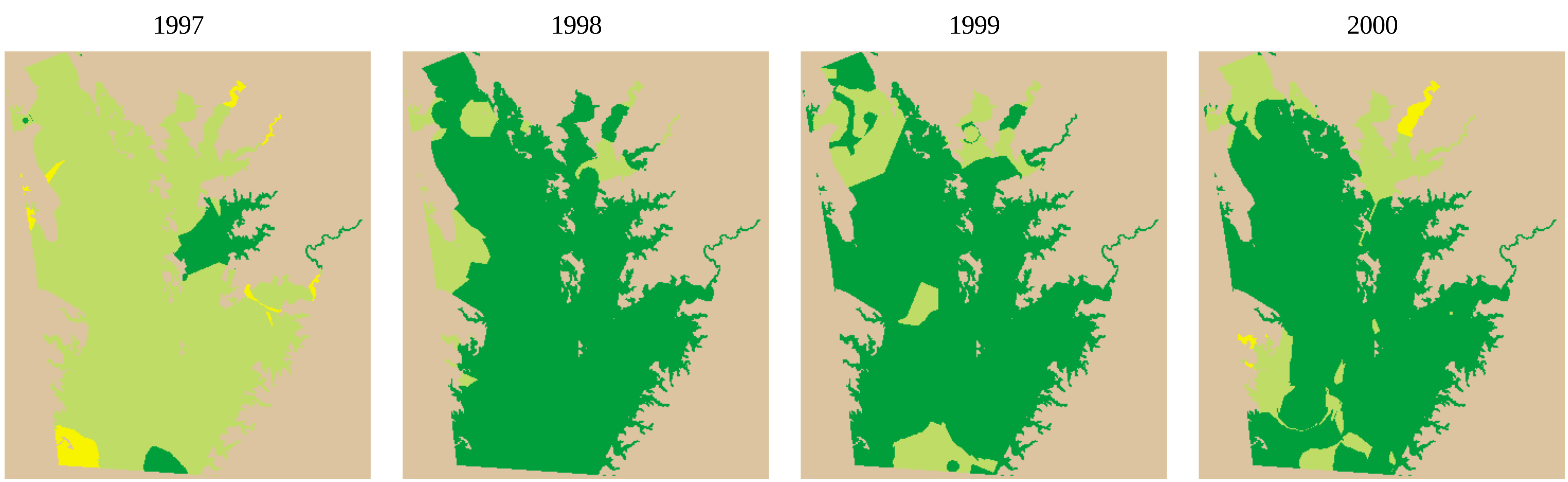


Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.

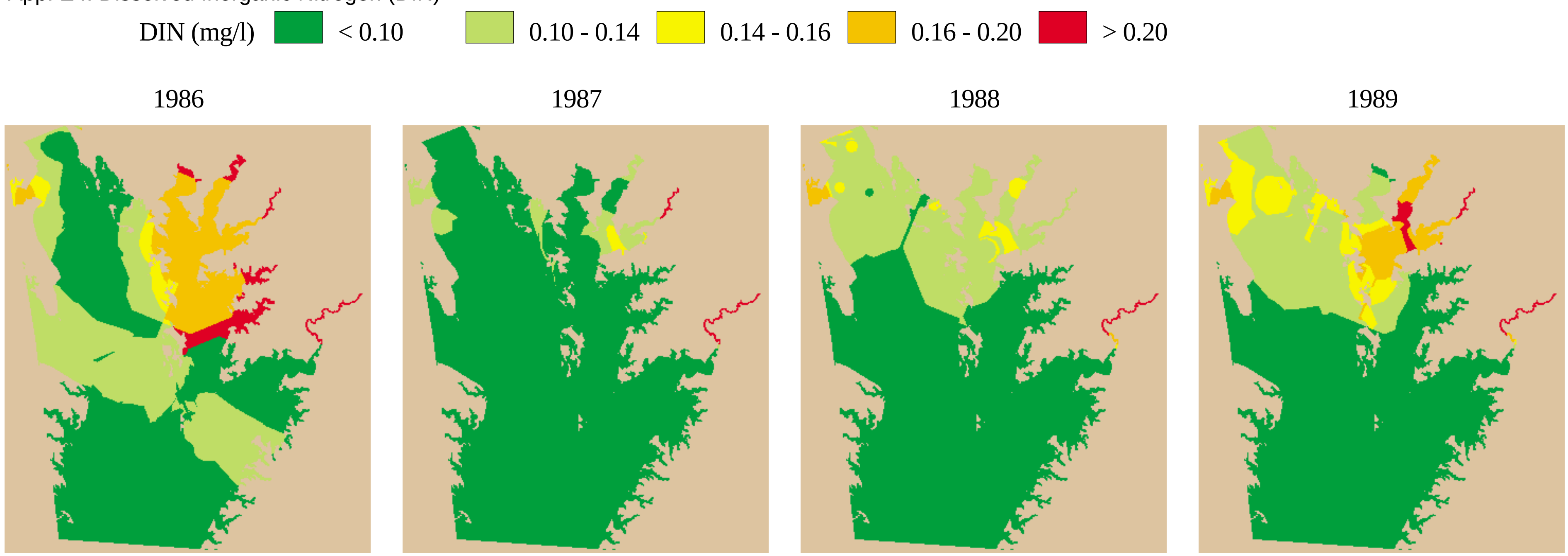




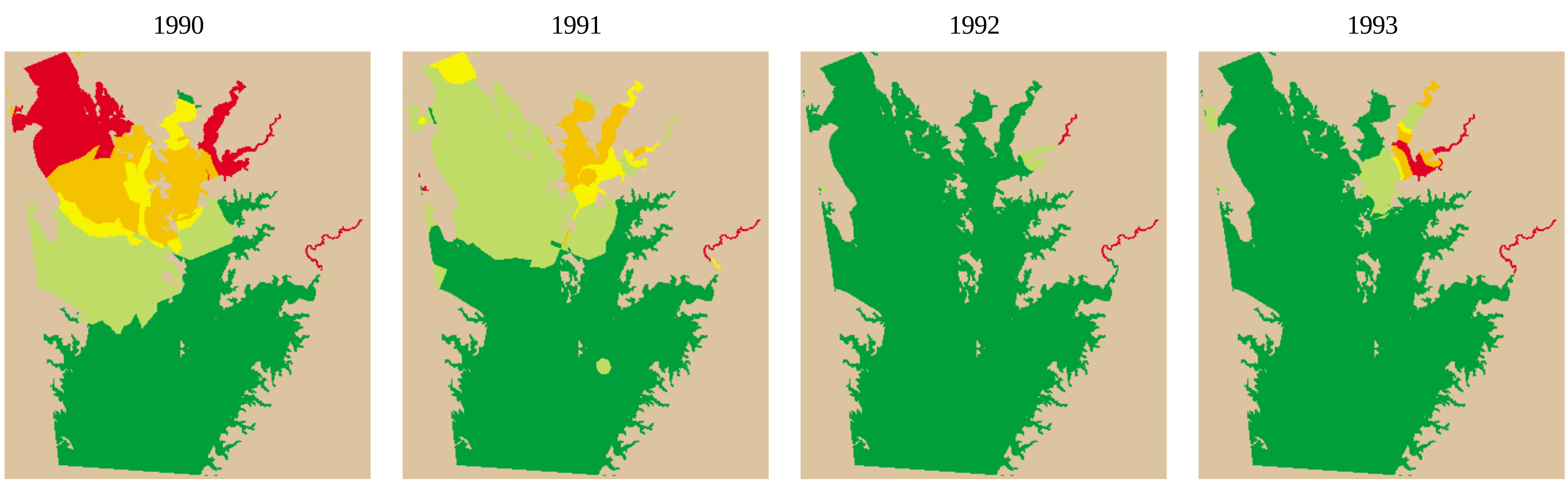
Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.

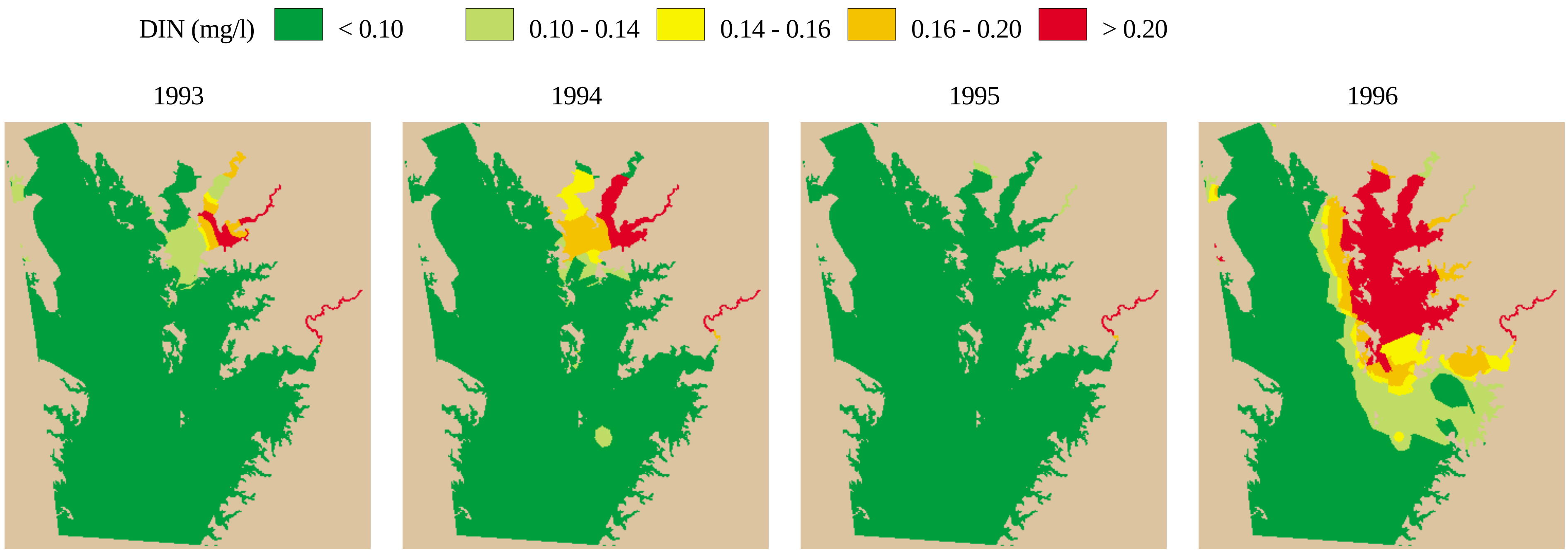


App. E4: Dissolved Inorganic Nitrogen (DIN)

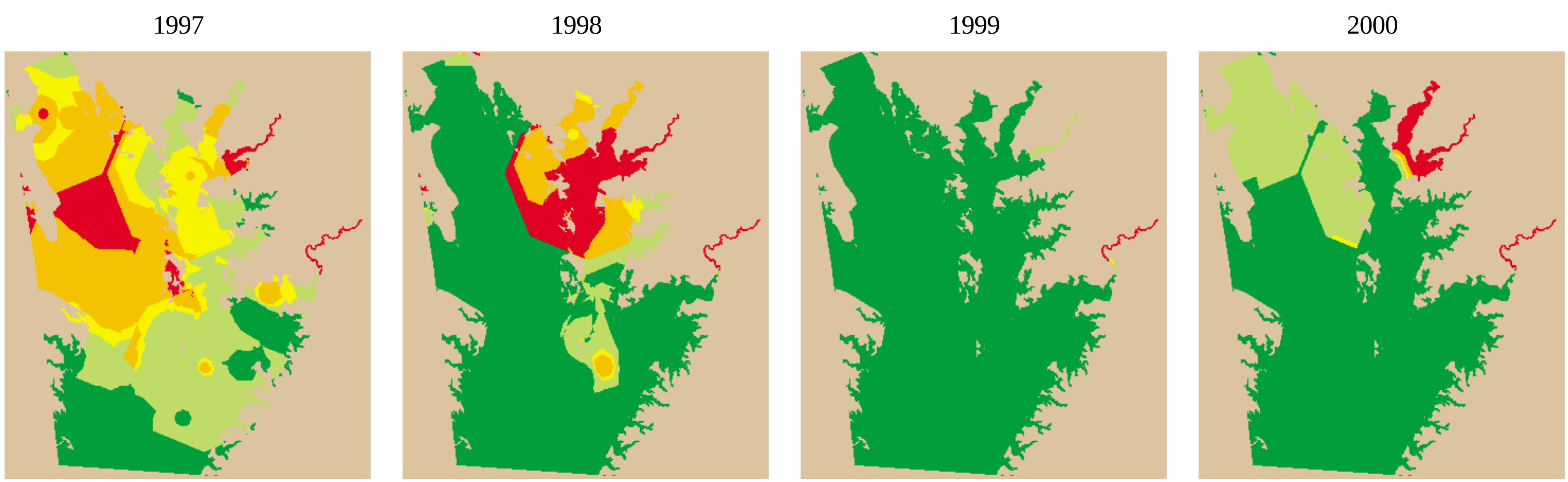


Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.



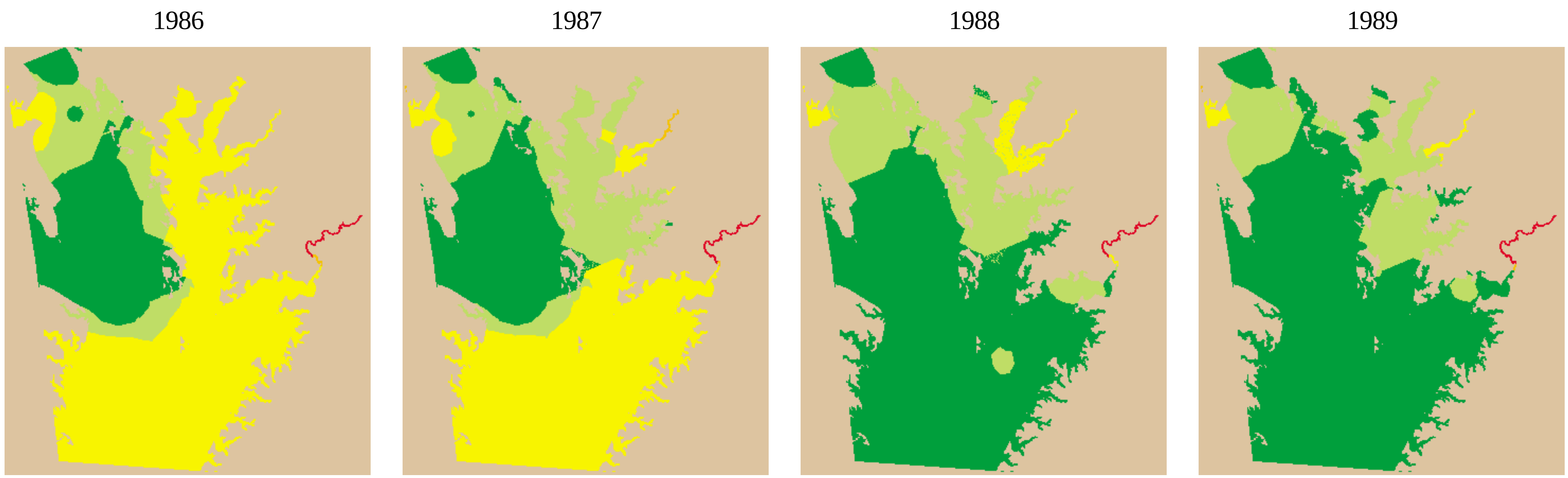


Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.

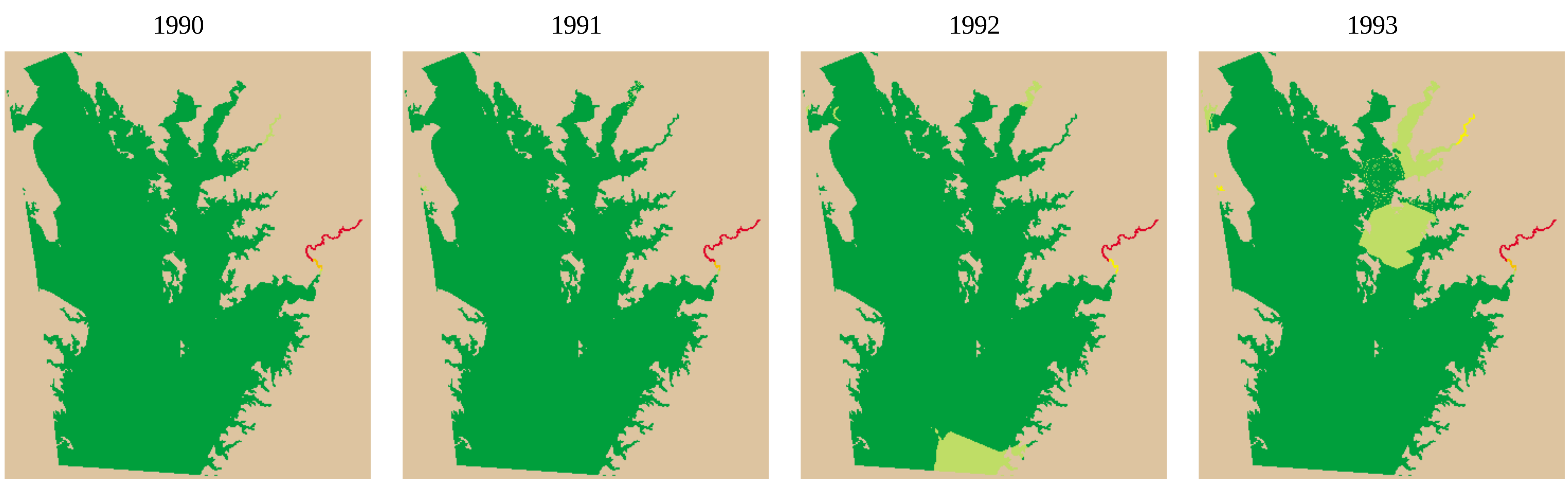


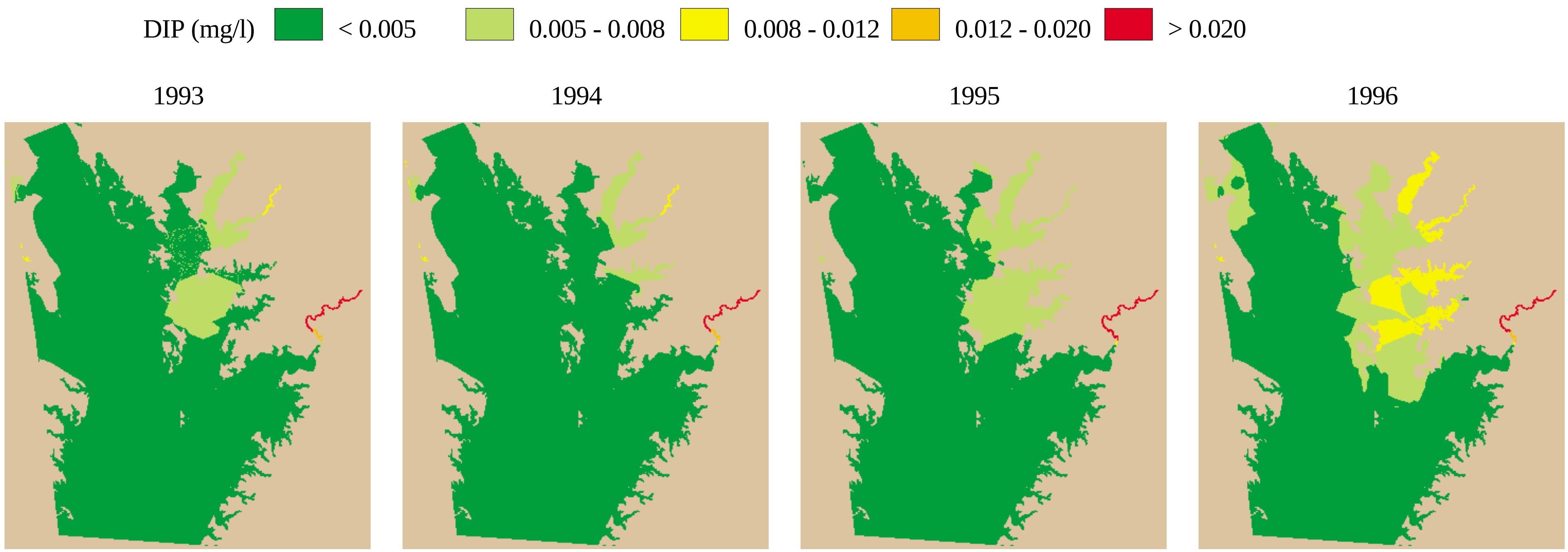
App. E5: Dissolved Inorganic Phosphorous (DIP)

DIP (mg/l) < 0.005 | 0.005 - 0.008 | 0.008 - 0.012 | 0.012 - 0.020 | > 0.020

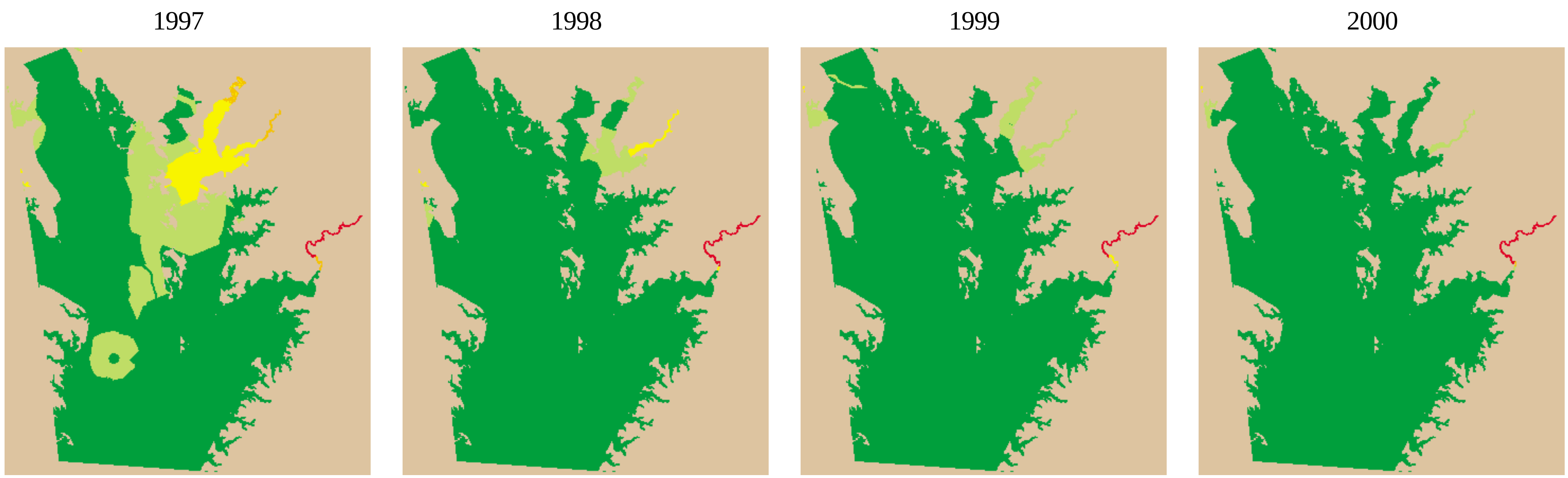


Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.



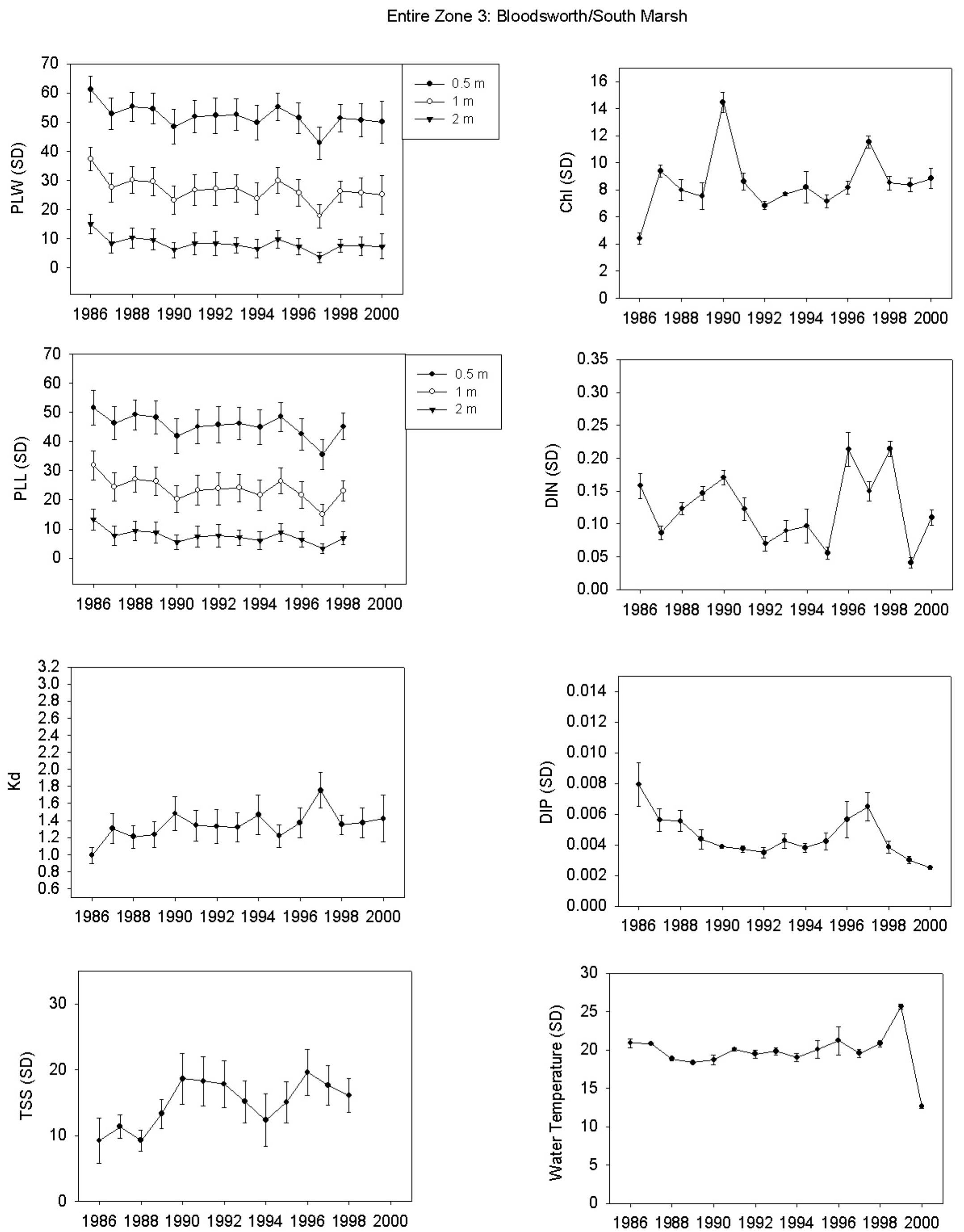


Green colors indicate values better than the SAV habitat requirement. Red colors indicate values worse than the habitat requirement. Areas in yellow are close to the habitat requirement.

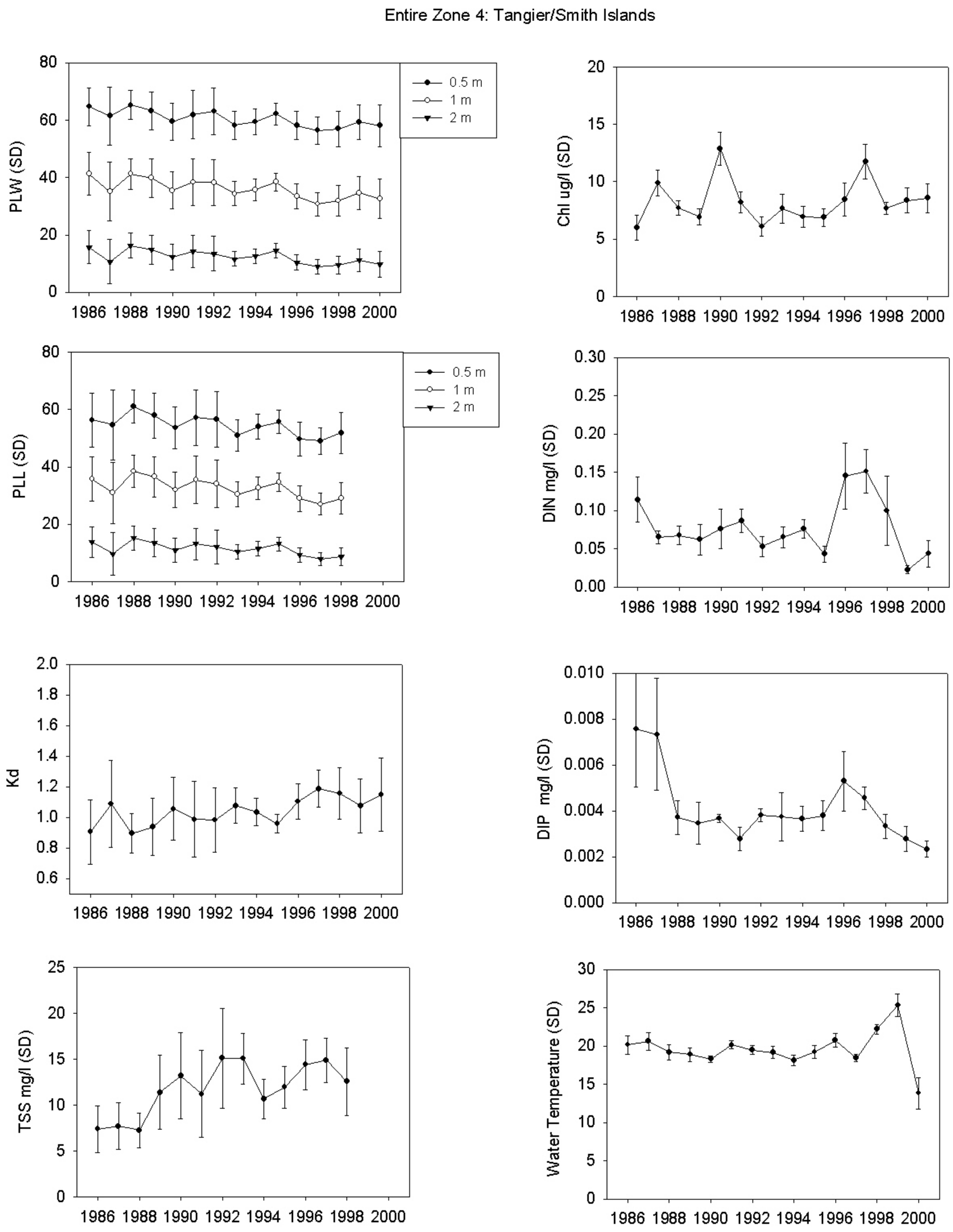


Appendix F: Water Quality of Each Zone

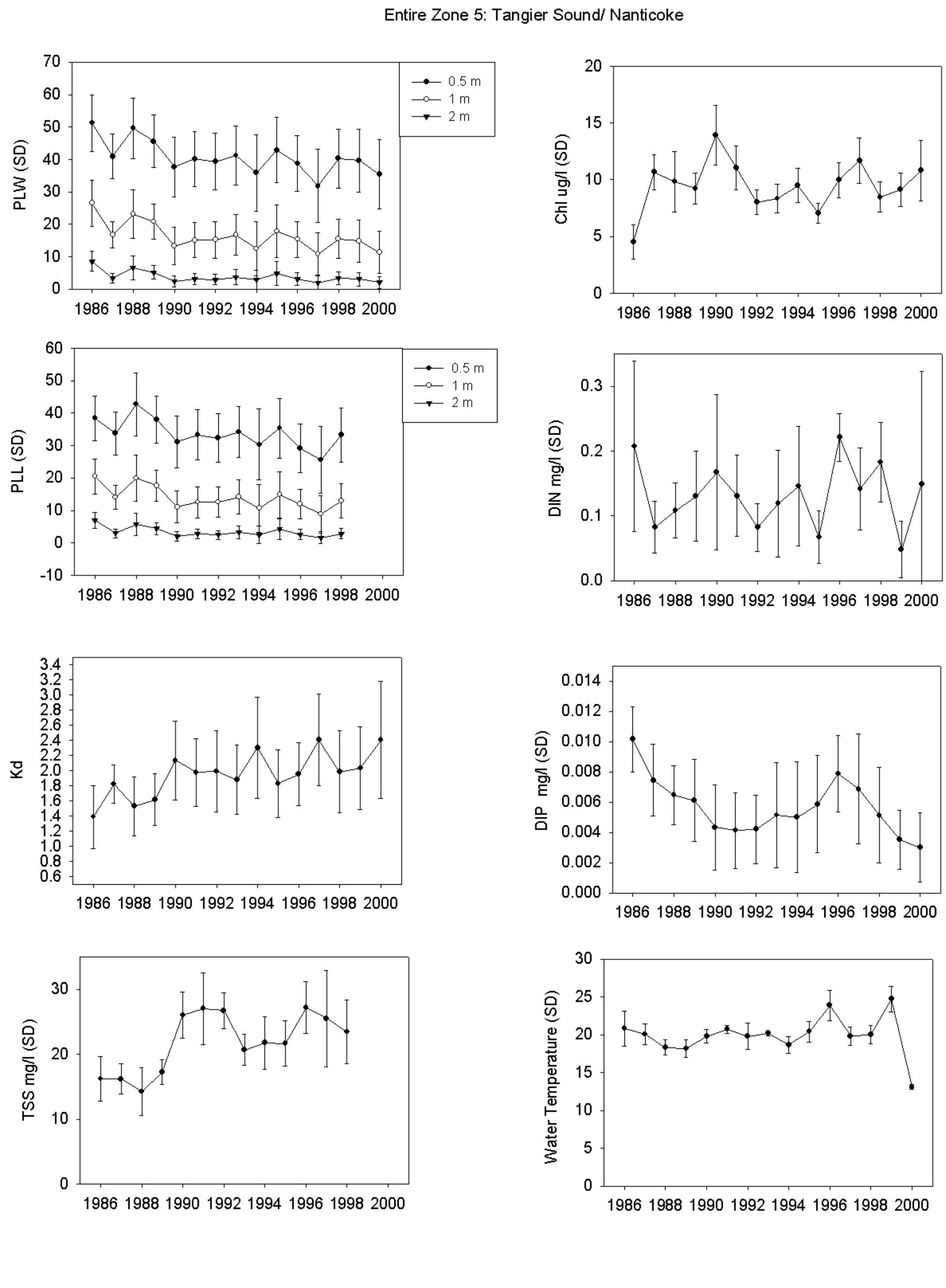
F1: Zone 3 (Bloodsworth and South Marsh Islands) water quality over the entire zone. For PLW and PLL, values are calculated at the 0.5m, 1m and 2m depth cells. For all other parameters, values are sampled from the 1m depth cells.



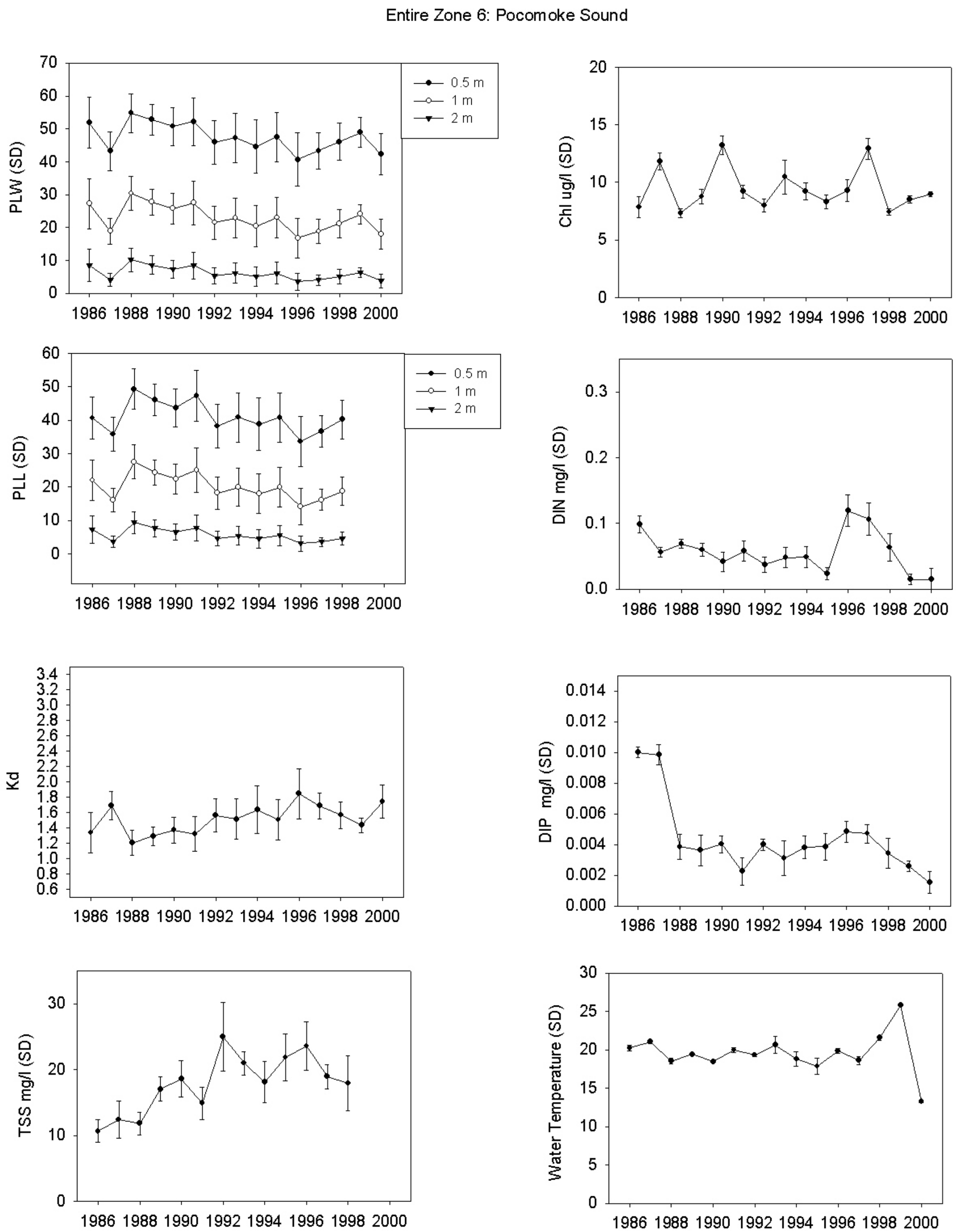
F2: Zone 4 (Tangier and Smith Islands) water quality over the entire zone. For PLW and PLL, values are calculated at the 0.5m, 1m and 2m depth cells. For all other parameters, values are sampled from the 1m depth cells.



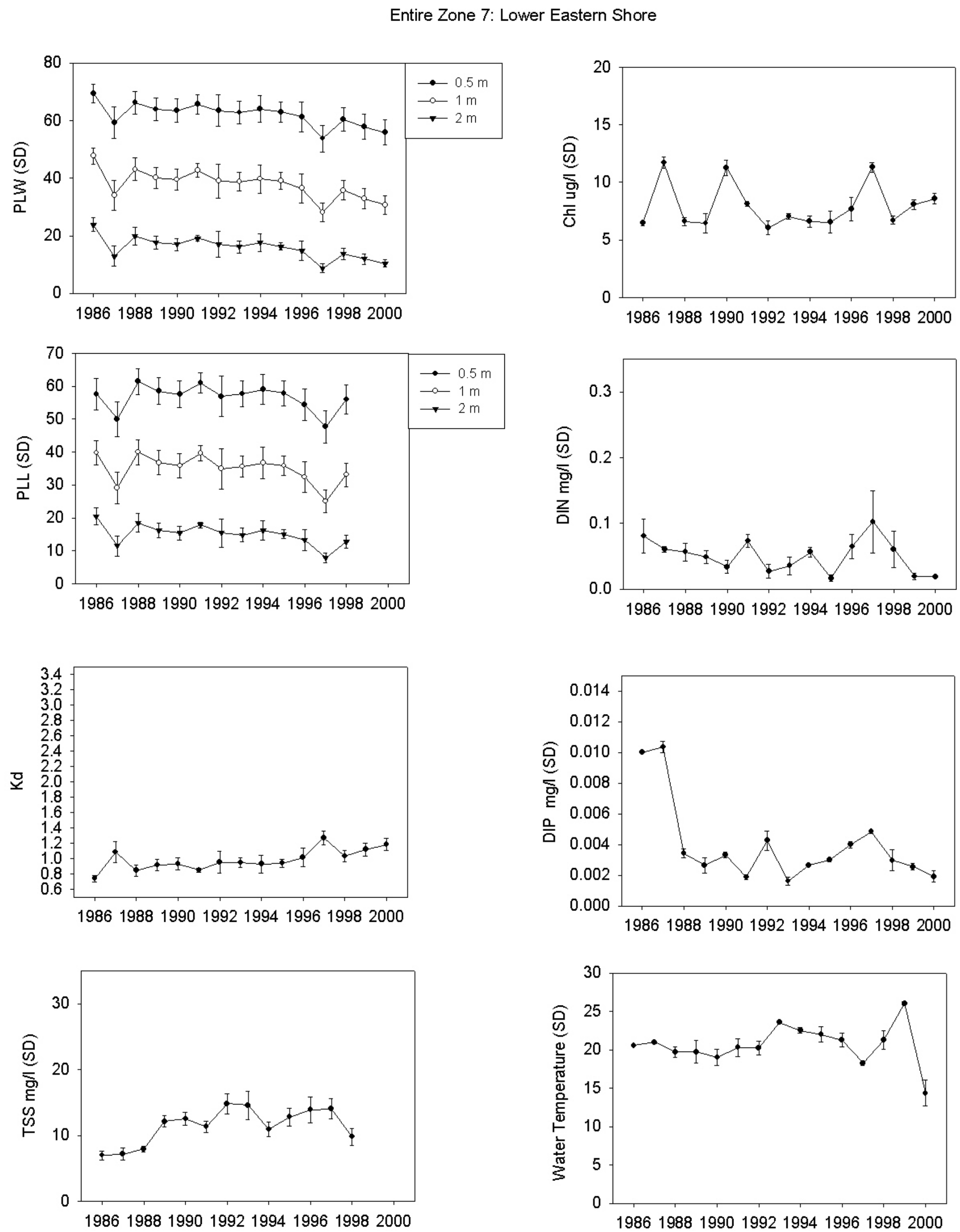
F3: Zone 5 (Tangier Sound and Nanticoke) water quality over the entire zone. For PLW and PLL, values are calculated at the 0.5m, 1m and 2m depth cells. For all other parameters, values are sampled from the 1m depth cells.



F4: Zone 6 (Pocomoke Sound) water quality over the entire zone. For PLW and PLL, values are calculated at the 0.5m, 1m and 2m depth cells. For all other parameters, values are sampled from the 1m depth cells.



F5: Zone 7 (Lower Eastern Shore) water quality over the entire zone. For PLW and PLL, values are calculated at the 0.5m, 1m and 2m depth cells. For all other parameters, values are sampled from the 1m depth cells.



Appendix G: Statistical Analyses of Water Quality and SAV Abundance

G1: Zone 3—Bloodsworth and South Marsh Islands. Spearman correlations of depth of the deepest edge each year vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
DEPTH & SAV	14	-.252747	-.904923	.383315
DEPTH & SAV CHANGE	13	-.153846	-.516398	.615799

G2: Zone 3—Bloodsworth and South Marsh Islands. Spearman correlations of water quality (at maximum abundance cells) vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
SAV & PLW	14	.235165	.83814	.418334
SAV & PLL	12	.230769	.75000	.470532
SAV & KD	14	-.235165	-.83814	.418334
SAV & TSS	12	.125874	.40124	.696683
SAV & CHL	14	-.129670	-.45302	.658619
SAV & DIN	14	-.380220	-1.42407	.179906
SAV & DIP	14	-.429851	-1.64918	.125023
SAV & WTEMP	14	-.490110	-1.94777	.075220
SAV & SAL	14	.384615	1.44338	.174509
SAV & SALMIN	14	.470847	1.84883	.089260
SAV & SALMAX	14	.243956	.87142	.400625
SAV CHANGE & PLW	13	.148352	.49753	.628609
SAV CHANGE & PLL	11	.363636	1.17108	.271638
SAV CHANGE & KD	13	-.148352	-.49753	.628609
SAV CHANGE & TSS	11	.018182	.05455	.957685
SAV CHANGE & CHL	13	.087912	.29270	.775195
SAV CHANGE & DIN	13	-.241758	-.82633	.426176
SAV CHANGE & DIP	13	-.454257	-1.69115	.118910
SAV CHANGE & WTEMP	13	.225275	.76686	.459305
SAV CHANGE & SAL	13	.598901	2.48036	.030554
SAV CHANGE & SALMIN	13	.613481	2.57650	.025751
SAV CHANGE & SALMAX	13	.318681	1.11508	.288583

G3: Zone 3—Bloodsworth and South Marsh Islands. ANOVA results of DEPTH at the current year's edge vs. DEPTH at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	7.346	7.346	62.432	<.0001
	Residual	1466	172.499	0.118		
1987	edgetype	1	7.925	7.925	66.018	<.0001
	Residual	795	95.435	0.12		
1989	edgetype	1	0.941	0.941	6.875	0.0089
	Residual	831	113.789	0.137		
1990	edgetype	1	2.439	2.439	18.417	<.0001
	Residual	907	120.137	0.132		
1991	edgetype	1	1.552	1.552	11.207	0.0009
	Residual	864	119.627	0.138		
1992	edgetype		MAXIMUM YEAR			
	Residual					
1993	edgetype	1	0.145	0.145	1.014	0.3143
	Residual	872	124.704	0.143		
1994	edgetype	1	2.557	2.557	20.651	<.0001
	Residual	743	92.016	0.124		
1995	edgetype	1	0.03	0.03	0.226	0.6348
	Residual	728	96.532	0.133		
1996	edgetype	1	0.791	0.791	5.466	0.0197
	Residual	664	96.083	0.145		
1997	edgetype	1	0.441	0.441	3.479	0.0627
	Residual	510	64.676	0.127		
1998	edgetype	1	0.526	0.526	4.029	0.0453
	Residual	496	64.752	0.131		
1999	edgetype	1	0.007	0.007	0.057	0.812
	Residual	665	88.063	0.132		
2000	edgetype	1	0.158	0.158	1.024	0.3119
	Residual	747	115.135	0.154		

G4: Zone 3—Bloodsworth and South Marsh Islands. ANOVA results of PLW at the current year's edge vs. PLW at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	1.231	1.231	61.469	<0.0001
	Residual	1466	29.351	0.02		
1987	edgetype	1	1.488	1.488	68.373	<0.0001
	Residual	795	17.307	0.022		
1989	edgetype	1	0.177	0.177	7.945	0.0049
	Residual	831	18.553	0.022		
1990	edgetype	1	0.34	0.34	15.738	<0.0001
	Residual	907	19.586	0.022		
1991	edgetype	1	0.315	0.315	12.835	0.0004
	Residual	863	21.172	0.025		
1992	edgetype			MAXIMUM YEAR		
	Residual					
1993	edgetype	1	0.036	0.036	1.439	0.2307
	Residual	872	21.74	0.025		
1994	edgetype	1	0.495	0.495	20.022	<0.0001
	Residual	743	18.365	0.025		
1995	edgetype	1	0.015	0.015	0.683	0.409
	Residual	728	16.392	0.023		
1996	edgetype	1	0.214	0.214	8.05	0.0047
	Residual	664	17.679	0.027		
1997	edgetype	1	0.0001275	0.0001275	0.005	0.9415
	Residual	510	12.077	0.024		
1998	edgetype	1	0.002	0.002	0.068	0.7947
	Residual	496	11.662	0.024		
1999	edgetype	1	0.029	0.029	1.264	0.2612
	Residual	665	15.188	0.023		
2000	edgetype	1	0.082	0.082	2.92	0.0879
	Residual	747	20.963	0.028		

G5: Zone 3—Bloodsworth and South Marsh Islands. ANOVA results of PLL at the current year's edge vs. PLL at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	1.056	1.056	79.852	<.0001
	Residual	1466	19.387	0.013		
1987	edgetype	1	1.208	1.208	73.313	<.0001
	Residual	795	13.099	0.016		
1989	edgetype	1	0.145	0.145	8.427	0.0038
	Residual	831	14.294	0.017		
1990	edgetype	1	0.284	0.284	17.047	<.0001
	Residual	907	15.085	0.017		
1991	edgetype	1	0.272	0.272	14.391	0.0002
	Residual	863	16.334	0.019		
1992	edgetype		MAXIMUM YEAR			
	Residual					
1993	edgetype	1	0.03	0.03	1.556	0.2126
	Residual	872	16.556	0.019		
1994	edgetype	1	0.431	0.431	22.104	<.0001
	Residual	743	14.492	0.02		
1995	edgetype	1	0.009	0.009	0.503	0.4786
	Residual	728	12.698	0.017		
1996	edgetype	1	0.183	0.183	9.893	0.0017
	Residual	664	12.313	0.019		
1997	edgetype	1	4.00E-04	4.00E-04	0.023	0.8785
	Residual	510	8.736	0.017		
1998	edgetype	1	0.002	0.002	0.099	0.7528
	Residual	496	8.989	0.018		

G6: Zone4—Tangier and Smith Islands. Spearman correlations of depth of the deepest edge each year vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
DEPTH & SAV	14	-.968097	-13.3836	.000000
DEPTH & SAV CHANGE	14	-.176018	-.6194	.547224

G7: Zone4—Tangier and Smith Islands. Spearman correlations of water quality (at maximum abundance cells) vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
SAV & PLW	14	.687912	3.28330	.006540
SAV & PLL	12	.587413	2.29530	.044609
SAV & KD	14	-.709890	-3.49153	.004451
SAV & TSS	12	-.153846	-.49237	.633091
SAV & CHL	14	-.283516	-1.02415	.325966
SAV & DIN	14	-.195820	-.69173	.502271
SAV & DIP	14	.076497	.26577	.794925
SAV & WTEMP	14	-.243956	-.87142	.400625
SAV & SAL	14	.305495	1.11140	.288170
SAV & SALMIN	14	.446154	1.72692	.109807
SAV & SALMAX	14	.090110	.31342	.759339
SAV CHANGE & PLW	14	.450549	1.74825	.105933
SAV CHANGE & PLL	12	.636364	2.60875	.026097
SAV CHANGE & KD	14	.006593	.02284	.982153
SAV CHANGE & TSS	12	-.272727	-.89642	.391097
SAV CHANGE & CHL	14	.006593	.02284	.982153
SAV CHANGE & DIN	14	-.402641	-1.52376	.153479
SAV CHANGE & DIP	14	-.396396	-1.49568	.160565
SAV CHANGE & WTEMP	14	.010989	.03807	.970258
SAV CHANGE & SAL	14	.178022	.62670	.542597
SAV CHANGE & SALMIN	14	.248352	.88814	.391920
SAV CHANGE & SALMAX	14	.151648	.53147	.604791

G8: Zone 4—Tangier and Smith Islands. ANOVA results of DEPTH at the current year's edge vs. DEPTH at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	2.945	2.945	32.415	<.0001
	Residual	3466	314.895	0.091		
1987	edgetype	1	7.394	7.394	72.922	<.0001
	Residual	1659	168.205	0.101		
1989	edgetype	1	1.264	1.264	13.541	0.000
	Residual	1735	161.958	0.093		
1990	edgetype	1	0.296	0.296	3.140	0.077
	Residual	1708	161.102	0.094		
1991	edgetype	1	0.003	0.003	0.033	0.855
	Residual	1666	155.732	0.093		
1992	edgetype			MAXIMUM YEAR		
	Residual					
1993	edgetype	1	0.312	0.312	3.269	0.071
	Residual	1642	156.621	0.095		
1994	edgetype	1	5.076	5.076	52.332	<.0001
	Residual	1564	151.699	0.097		
1995	edgetype	1	8.904	8.904	87.925	<.0001
	Residual	1499	151.796	0.101		
1996	edgetype	1	6.978	6.978	75.697	<.0001
	Residual	1494	137.721	0.092		
1997	edgetype	1	14.272	14.272	136.407	<.0001
	Residual	1589	166.250	0.105		
1998	edgetype	1	24.129	24.129	217.576	<.0001
	Residual	1521	168.677	0.111		
1999	edgetype	1	23.420	23.420	206.433	<.0001
	Residual	1643	186.401	0.113		
2000	edgetype	1	7.741	7.741	79.110	<.0001
	Residual	1627	159.204	0.098		

G9: Zone 4—Tangier and Smith Islands. ANOVA results of PLW at the current year's edge vs. PLW at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	0.321	0.321	28.148	<.0001
	Residual	3438	39.233	0.011		
1987	edgetype	1	0.640	0.640	25.338	<.0001
	Residual	1647	41.603	0.025		
1989	edgetype	1	0.098	0.098	10.541	0.001
	Residual	1720	15.936	0.009		
1990	edgetype	1	0.031	0.031	3.496	0.062
	Residual	1692	14.811	0.009		
1991	edgetype	1	0.002	0.002	0.180	0.671
	Residual	1644	17.445	0.011		
1992	edgetype		MAXIMUM YEAR			
	Residual					
1993	edgetype	1	0.037	0.037	4.094	0.043
	Residual	1632	14.764	0.009		
1994	edgetype	1	0.665	0.665	61.567	<.0001
	Residual	1556	16.811	0.011		
1995	edgetype	1	0.864	0.864	69.861	<.0001
	Residual	1493	18.465	0.012		
1996	edgetype	1	0.556	0.556	49.528	<.0001
	Residual	1489	16.704	0.011		
1997	edgetype	1	1.622	1.622	110.598	<.0001
	Residual	1578	23.136	0.015		
1998	edgetype	1	2.651	2.651	150.436	<.0001
	Residual	1516	26.717	0.018		
1999	edgetype	1	3.004	3.004	184.386	<.0001
	Residual	1629	26.540	0.016		
2000	edgetype	1	1.005	1.005	65.349	<.0001
	Residual	1607	24.721	0.015		

G10: Zone 4—Tangier and Smith Islands. ANOVA results of PLL at the current year's edge vs. PLL at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	0.243	0.243	23.017	<.0001
	Residual	3438	36.224	0.011		
1987	edgetype	1	0.484	0.484	19.284	<.0001
	Residual	1647	41.363	0.025		
1989	edgetype	1	0.079	0.079	9.236	0.002
	Residual	1720	14.742	0.009		
1990	edgetype	1	0.027	0.027	3.488	0.062
	Residual	1692	13.196	0.008		
1991	edgetype	1	0.003	0.003	0.255	0.614
	Residual	1644	16.804	0.010		
1992	edgetype		MAXIMUM YEAR			
	Residual					
1993	edgetype	1	0.034	0.034	4.700	0.030
	Residual	1632	11.977	0.007		
1994	edgetype	1	0.594	0.594	64.485	<.0001
	Residual	1556	14.324	0.009		
1995	edgetype	1	0.705	0.705	70.929	<.0001
	Residual	1493	14.843	0.010		
1996	edgetype	1	0.394	0.394	44.530	<.0001
	Residual	1489	13.179	0.009		
1997	edgetype	1	1.285	1.285	113.676	<.0001
	Residual	1578	17.831	0.011		
1998	edgetype	1	2.208	2.208	136.765	<.0001
	Residual	1512	24.414	0.016		

G11: Zone 5—Tangier Sound and Nanticoke. Spearman correlations of depth of the deepest edge each year vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
DEPTH & SAV	14	-.221978	-.788629	.445630
DEPTH & SAV CHANGE	14	-.156044	-.547256	.594235

G12: Zone 5—Tangier Sound and Nanticoke. Spearman correlations of water quality (at maximum abundance cells) vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
SAV & PLW	14	.072527	.25191	.805376
SAV & PLL	12	.363636	1.23443	.245265
SAV & KD	14	.261538	.93867	.366411
SAV & TSS	12	-.090909	-.28868	.778725
SAV & CHL	14	-.362637	-1.34797	.202565
SAV & DIN	14	-.292629	-1.06010	.309969
SAV & DIP	14	-.372944	-1.39237	.189074
SAV & WTEMP	14	-.323077	-1.18259	.259874
SAV & SAL	14	.375824	1.40488	.185410
SAV & SALMIN	14	.226374	.80508	.436435
SAV & SALMAX	14	.367033	1.36683	.196739
SAV CHANGE & PLW	14	-.046154	-.16005	.875503
SAV CHANGE & PLL	12	.118881	.37862	.712884
SAV CHANGE & KD	14	.481319	1.90217	.081418
SAV CHANGE & TSS	12	-.195804	-.63141	.541936
SAV CHANGE & CHL	14	-.424176	-1.62259	.130637
SAV CHANGE & DIN	14	-.264027	-.94826	.361702
SAV CHANGE & DIP	14	-.293352	-1.06297	.308720
SAV CHANGE & WTEMP	14	-.046154	-.16005	.875503
SAV CHANGE & SAL	14	.050549	.17533	.863742
SAV CHANGE & SALMIN	14	-.098901	-.34429	.736585
SAV CHANGE & SALMAX	14	.243956	.87142	.400625

G13: Zone 5—Tangier Sound and Nanticoke. ANOVA results of DEPTH at the current year's edge vs. DEPTH at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	0.063	63.000	0.899	0.343
	Residual	1946	136.170	0.070		
1987	edgetype	1	1.467	1.467	29.201	<0.0001
	Residual	859	43.161	0.050		
1989	edgetype	1	0.654	0.654	9.704	0.002
	Residual	884	59.609			
1990	edgetype	1	1.328	1.328	24.209	<0.0001
	Residual	901	49.439	0.055		
1991	edgetype	1	0.007	0.007	0.104	0.747
	Residual	951	60.063	0.063		
1992	edgetype	1	0.270	0.270	4.490	0.034
	Residual	913	54.823	0.060		
1993	edgetype			MAXIMUM YEAR		
	Residual					
1994	edgetype	1	0.020	0.020	0.324	0.569
	Residual	825	51.924	0.063		
1995	edgetype	1	0.304	0.304	4.785	0.029
	Residual	848	53.894	0.064		
1996	edgetype	1	0.136	0.136	2.218	0.137
	Residual	638	39.231	0.061		
1997	edgetype	1	0.420	0.420	6.773	0.009
	Residual	755	46.818	0.062		
1998	edgetype	1	0.067	0.067	1.264	0.261
	Residual	658	34.715	0.053		
1999	edgetype	1	0.013	0.013	0.175	0.676
	Residual	884	63.486	0.072		
2000	edgetype	1	0.097	0.097	1.523	0.217
	Residual	1010	64.236	0.064		

G14: Zone 5—Tangier Sound and Nanticoke. ANOVA results of PLW at the current year's edge vs. PLW at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	0.183	0.183	8.215	0.004
	Residual	1936	43.109	0.022		
1987	edgetype	1	0.453	0.453	26.122	<0.001
	Residual	856	14.846	0.017		
1989	edgetype	1	0.304	0.304	17.660	<0.001
	Residual	881	15.181	0.017		
1990	edgetype	1	0.353	0.353	21.033	<0.001
	Residual	898	15.080	0.017		
1991	edgetype	1	0.0005	0.0005	0.028	0.868
	Residual	943	16.977	0.018		
1992	edgetype	1	0.085	0.085	5.314	0.021
	Residual	909	14.576	0.016		
1993	edgetype			MAXIMUM YEAR		
	Residual					
1994	edgetype	1	0.0002	0.0002	0.001	0.973
	Residual	821	16.821			
1995	edgetype	1	0.129	0.129	7.744	0.006
	Residual	846	14.133			
1996	edgetype	1	0.010	0.010	0.608	0.436
	Residual	634	10.540			
1997	edgetype	1	0.002	0.002	0.097	0.756
	Residual	752	14.646			
1998	edgetype	1	0.034	0.034	2.262	0.133
	Residual	656	9.739			
1999	edgetype	1	0.034	0.034	1.700	0.193
	Residual	881	17.398	0.020		
2000	edgetype	1	0.001	0.001	0.031	0.861
	Residual	1008	19.515	0.019		

G15: Zone 5—Tangier Sound and Nanticoke. ANOVA results of PLL at the current year's edge vs. PLL at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	0.105	0.105	8.193	0.004
	Residual	1936	24.795	0.013		
1987	edgetype	1	0.319	0.319	24.490	<0.001
	Residual	856	11.133	0.013		
1989	edgetype	1	0.215	0.215	17.183	<0.001
	Residual	881	11.021	0.013		
1990	edgetype	1	0.258	0.258	20.747	<0.001
	Residual	898	11.155	0.012		
1991	edgetype	1	0.001	0.001	0.051	0.821
	Residual	943	12.729	0.013		
1992	edgetype	1	0.064	0.064	5.322	0.021
	Residual	909	10.883	0.012		
1993	edgetype			MAXIMUM YEAR		
	Residual					
1994	edgetype	1	0.000	0.000	0.000	0.994
	Residual	821	13.765	0.017		
1995	edgetype	1	0.105	0.105	8.383	0.004
	Residual	846	10.601	0.013		
1996	edgetype	1	0.015	0.015	1.235	0.267
	Residual	634	7.455	0.012		
1997	edgetype	1	0.003	0.003	0.002	0.964
	Residual	752	11.659	0.016		
1998	edgetype	1	0.028	0.028	2.492	0.115
	Residual	656	7.379	0.011		

G16: Zone 6—Pocomoke Sound. Spearman correlations of depth of the deepest edge each year vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
DEPTH & SAV	14	-.771429	-4.19965	.001233
DEPTH & SAV CHANGE	14	-.125275	-.43741	.669582

G17: Zone 6—Pocomoke Sound. Spearman correlations of water quality (at maximum abundance cells) vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
SAV & PLW	14	.494505	1.97086	.072250
SAV & PLL	12	.419580	1.46172	.174519
SAV & KD	14	-.520879	-2.11377	.056154
SAV & TSS	12	.440559	1.55189	.151735
SAV & CHL	14	.164835	.57892	.573346
SAV & DIN	14	-.112088	-.39075	.702833
SAV & DIP	14	-.255365	-.91495	.378238
SAV & WTEMP	14	-.213187	-.75588	.464303
SAV & SAL	14	-.098901	-.34429	.736585
SAV & SALMIN	14	-.151648	-.53147	.604791
SAV & SALMAX	14	.103297	.35975	.725282
SAV CHANGE & PLW	14	.723077	3.62613	.003475
SAV CHANGE & PLL	12	.671329	2.86433	.016831
SAV CHANGE & KD	14	-.714286	-3.53553	.004104
SAV CHANGE & TSS	12	-.006993	-.02211	.982792
SAV CHANGE & CHL	14	-.230769	-.82158	.427336
SAV CHANGE & DIN	14	.024176	.08377	.934619
SAV CHANGE & DIP	14	-.107522	-.37464	.714465
SAV CHANGE & WTEMP	14	.178022	.62670	.542597
SAV CHANGE & SAL	14	.410989	1.56170	.144333
SAV CHANGE & SALMIN	14	.389011	1.46279	.169217
SAV CHANGE & SALMAX	14	.538462	2.21359	.046976

G18: Zone 6—Pocomoke Sound. ANOVA results of DEPTH at the current year's edge vs. DEPTH at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	10.322	10.322	82.119	<0.0001
	Residual	4138	520.140	0.126		
1987	edgetype	1	5.672	5.672	49.011	<0.0001
	Residual	1956	226.357	0.116		
1989	edgetype	1	3.539	3.539	28.551	<0.0001
	Residual	1993	247.014	0.124		
1990	edgetype	1	0.582	0.582	4.282	0.039
	Residual	2002	272.253	0.136		
1991	edgetype	1	0.019	0.019	0.143	0.706
	Residual	2086	283.163	0.136		
1992	edgetype	1	0.074	0.074	0.541	0.462
	Residual	2090	286.258	0.137		
1993	edgetype	MAXIMUM YEAR				
	Residual					
1994	edgetype	1	0.633	0.633	4.496	0.034
	Residual	1987	279.596	0.141		
1995	edgetype	1	0.003	0.003	0.019	0.891
	Residual	1941	266.073	0.137		
1996	edgetype	1	0.011	0.011	0.082	0.775
	Residual	1947	258.044	0.133		
1997	edgetype	1	1.650	1.650	12.688	0.0004
	Residual	1923	250.131	0.130		
1998	edgetype	1	3.488	3.488	28.411	<0.0001
	Residual	1893	232.381	0.123		
1999	edgetype	1	2.000	2.000	16.056	<0.0001
	Residual	1909	237.825	0.125		
2000	edgetype	1	4.804	4.804	40.798	<0.0001
	Residual	1879	221.274	0.118		

G19: Zone 6—Pocomoke Sound. ANOVA results of PLW at the current year's edge vs. PLW at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	2.599	2.599	94.155	<0.0001
	Residual	4116	113.614	0.028		
1987	edgetype	1	1.292	1.292	52.030	<0.0001
	Residual	1948	48.368	0.025		
1989	edgetype	1	0.725	0.725	29.527	<0.0001
	Residual	1979	48.579	0.025		
1990	edgetype	1	0.110	0.110	4.378	0.037
	Residual	1983	49.982	0.025		
1991	edgetype	1	0.0060	0.006	0.225	0.635
	Residual	2073	58.052	0.028		
1992	edgetype	1	0.018	0.018	0.698	0.404
	Residual	2073	53.675	0.026		
1993	edgetype		MAXIMUM YEAR			
	Residual					
1994	edgetype	1	0.2440	0.244	8.023	0.005
	Residual	1978	60.053	0.030		
1995	edgetype	1	0.007	0.007	0.238	0.626
	Residual	1933	53.162	0.028		
1996	edgetype	1	0.011	0.011	0.387	0.534
	Residual	1937	56.543	0.029		
1997	edgetype	1	0.326	0.326	13.780	0.0002
	Residual	1915	45.309	0.024		
1998	edgetype	1	0.612	0.612	24.919	<0.0001
	Residual	1883	46.240	0.025		
1999	edgetype	1	0.294	0.294	12.736	0.0004
	Residual	1896	43.770	0.023		
2000	edgetype	1	0.721	0.721	28.951	<0.0001
	Residual	1869	46.565	0.025		

G20: Zone 6—Pocomoke Sound. ANOVA results of PLL at the current year's edge vs. PLL at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	1.734	1.734	95.267	<0.0001
	Residual	4116	74.924	0.018		
1987	edgetype	1	1.015	1.015	53.371	<0.0001
	Residual	1948	37.063	0.019		
1989	edgetype	1	0.607	0.607	29.902	<0.0001
	Residual	1979	40.186	0.020		
1990	edgetype	1	0.093	0.093	4.445	0.035
	Residual	1983	41.439	0.021		
1991	edgetype	1	0.006	0.006	0.223	0.637
	Residual	2073	52.538	0.025		
1992	edgetype	1	0.014	0.014	0.658	0.417
	Residual	2073	44.015	0.021		
1993	edgetype		MAXIMUM YEAR			
	Residual					
1994	edgetype	1	0.200	0.200	7.784	0.005
	Residual	1978	50.717	0.026		
1995	edgetype	1	0.006	0.006	0.245	0.621
	Residual	1933	44.699	0.023		
1996	edgetype	1	0.011	0.011	0.455	0.500
	Residual	1937	45.922	0.024		
1997	edgetype	1	0.251	0.251	13.430	0.000
	Residual	1915	35.793	0.019		
1998	edgetype	1	0.521	0.521	24.411	<0.0001
	Residual	1883	40.226	0.021		

G21: Zone 7—Lower Eastern Shore. Spearman correlations of depth of the deepest edge each year vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
DEPTH & SAV	14	-.591209	-2.53932	.025971
DEPTH & SAV CHANGE	14	.261538	.93867	.366411

G22: Zone 7— Lower Eastern Shore. Spearman correlations of water quality (at maximum abundance cells) vs. SAV Area and Change in SAV. Significance at α=0.05 is highlighted.

Pair of Variables	Valid N	Spearman R	t(N-2)	p-level
SAV & PLW	14	.200000	.70711	.493004
SAV & PLL	12	.027972	.08849	.931234
SAV & KD	14	-.200000	-.70711	.493004
SAV & TSS	12	.678322	2.91936	.015317
SAV & CHL	14	-.235165	-.83814	.418334
SAV & DIN	14	.024229	.08396	.934475
SAV & DIP	14	-.410123	-1.55774	.145264
SAV & WTEMP	14	.032967	.11426	.910919
SAV & SAL	14	-.068132	-.23657	.816984
SAV & SALMIN	14	-.151815	-.53207	.604388
SAV & SALMAX	14	-.156044	-.54726	.594235
SAV CHANGE & PLW	14	.230769	.82158	.427336
SAV CHANGE & PLL	12	.132867	.42392	.680598
SAV CHANGE & KD	14	-.230769	-.82158	.427336
SAV CHANGE & TSS	12	.118881	.37862	.712884
SAV CHANGE & CHL	14	.138462	.48431	.636885
SAV CHANGE & DIN	14	.376653	1.40849	.184364
SAV CHANGE & DIP	14	-.145156	-.50822	.620514
SAV CHANGE & WTEMP	14	-.318681	-1.16467	.266785
SAV CHANGE & SAL	14	.367033	1.36683	.196739
SAV CHANGE & SALMIN	14	.316832	1.15715	.269725
SAV CHANGE & SALMAX	14	.345055	1.27352	.226949

G23: Zone 7—Lower Eastern Shore. ANOVA results of DEPTH at the current year's edge vs. DEPTH at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	7.382	7.382	61.005	<0.0001
	Residual	2296	277.816	0.121		
1987	edgetype	1	5.833	5.833	50.303	<0.0001
	Residual	1152	133.576	0.116		
1989	edgetype	1	2.646	2.646	24.338	<0.0001
	Residual	1173	127.521	0.109		
1990	edgetype	1	2.554	2.554	24.578	<0.0001
	Residual	1199	124.573	0.104		
1991	edgetype	1	0.527	0.527	5.317	0.021
	Residual	1208	119.621	0.099		
1992	edgetype	1	0.055	0.055	0.559	0.455
	Residual	1177	116.207	0.099		
1993	edgetype			MAXIMUM YEAR		
	Residual					
1994	edgetype	1	0.030	0.030	0.285	0.593
	Residual	1142	119.989	0.105		
1995	edgetype	1	0.22	0.220	2.081	0.149
	Residual	1135	120.023	0.106		
1996	edgetype	1	0.337	0.337	3.162	0.076
	Residual	1151	122.487	0.106		
1997	edgetype	1	0.479	0.479	4.614	0.0319
	Residual	1153	119.669	0.104		
1998	edgetype	1	0.972	0.972	8.935	0.003
	Residual	1171	127.449	0.109		
1999	edgetype	1	0.008	0.008	0.073	0.787
	Residual	1142	130.012	0.114		
2000	edgetype	1	1.974	1.974	18.395	<0.0001
	Residual	1149	123.295	0.107		

G24: Zone 7—Lower Eastern Shore. ANOVA results of PLW at the current year's edge vs. PLW at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	1.589	1.589	89.360	<0.0001
	Residual	2220	39.481	0.018		
1987	edgetype	1	1.347	1.347	60.014	<0.0001
	Residual	1105	24.802	0.022		
1989	edgetype	1	0.493	0.493	30.841	<0.0001
	Residual	1125	17.972	0.016		
1990	edgetype	1	0.430	0.430	27.630	<0.0001
	Residual	1147	17.857	0.016		
1991	edgetype	1	0.0580	0.058	4.423	0.036
	Residual	1153	15.135	0.013		
1992	edgetype	1	0.004	0.004	0.233	0.630
	Residual	1124	17.359	0.015		
1993	edgetype		MAXIMUM YEAR			
	Residual					
1994	edgetype	1	0.0001	0.0001	0.004	0.950
	Residual	1164	16.508	0.015		
1995	edgetype	1	0.029	0.029	1.904	0.468
	Residual	1085	16.183	0.015		
1996	edgetype	1	0.037	0.037	2.101	0.148
	Residual	1088	18.911	0.017		
1997	edgetype	1	0.077	0.077	4.399	0.0362
	Residual	1096	19.199	0.018		
1998	edgetype	1	0.147	0.147	8.903	0.003
	Residual	1121	18.561	0.017		
1999	edgetype	1	0.005	0.005	0.267	0.6055
	Residual	1104	19.040	0.017		
2000	edgetype	1	0.271	0.271	15.929	<0.0001
	Residual	1104	18.811	0.017		

G25: Zone 7—Lower Eastern Shore. ANOVA results of PLL at the current year's edge vs. PLL at the maximum abundance year's edge by year. Significance at α=0.05 is highlighted.

		DF	Sum of Squares	Mean Square	F-Value	P-Value
1986	edgetype	1	1.054	1.054	83.196	<0.0001
	Residual	2220	28.138	0.013		
1987	edgetype	1	0.958	0.958	57.796	<0.0001
	Residual	1105	18.311	0.017		
1989	edgetype	1	0.422	0.422	30.804	<0.0001
	Residual	1125	15.420	0.014		
1990	edgetype	1	0.365	0.365	27.587	<0.0001
	Residual	1147	15.160	0.013		
1991	edgetype	1	0.051	0.051	4.429	0.036
	Residual	1153	13.165	0.011		
1992	edgetype	1	0.003	0.003	0.229	0.633
	Residual	1124	15.005	0.013		
1993	edgetype		MAXIMUM YEAR			
	Residual					
1994	edgetype	1	0.00003	0.00003	0.002	0.963
	Residual	1085	14.392	0.013		
1995	edgetype	1	0.022	0.022	1.723	0.190
	Residual	1072	13.879	0.013		
1996	edgetype	1	0.028	0.028	1.947	0.163
	Residual	1088	15.534	0.014		
1997	edgetype	1	0.060	0.060	4.047	0.044
	Residual	1096	16.019	0.015		
1998	edgetype	1	0.126	0.126	8.581	0.004
	Residual	1121	16.487	0.015		