Analysis of Changes in Seagrass Coverage, 1996-1999 and 1999-2001, for Anna Maria Sound, Sarasota, Roberts, Little Sarasota, and Blackburn Bays

Final Report

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Acknowledgments

This project would not have been possible without the seagrass mapping performed by the Southwest Florida Water Management District, the cooperation of their contractor Avineon, Inc., the excellent weather archives maintained by Dr. Don Hayward, and the unfailing cheerfulness and skill of Ms. Allison Rekow, the cooperation of the entire Chemical Ecology Staff, and the support of the Southwest Florida Water Management District and the Sarasota Bay National Estuary Program.

Executive Summary

Seagrass mapping performed by the Southwest Florida Water Management was subjected to a change analysis between 1996 and 1999 and from 1999 to 2001 with respect to water quality and possible exposure effects. Only polygons larger than apparent changes in adjacent shorelines (due to accuracy increases) were retained for analysis. Photography in different seasons made distinctions between seasonal and interannual changes problematic. The study area was within the boundaries of the Sarasota Bay National Estuary Program, or from Anna Maria Sound to the Venice Inlet.

Change polygons were categorized both by general and specific change category and further segregated by bay segment. Monthly water quality data for the periods were used to create a time series of mean values and departures from segment means for each polygon. Bathymetry and attenuation coefficients were combined to calculate available light at the bottom of the water column. Water quality data were examined by general and specific change category using all data and again using only 'growing season' values (April-October). Detailed light and temperature were modeled for each polygon using an empirically derived model of tidally varying depths, attenuation coefficients, insolation records, and a heat flux approach. Despite modeling assumptions, relative comparisons of light and temperature distributions were permissible between change categories within a given segment, although actual exposures could not be assessed.

Stable patchy polygons were generally deeper in northern Sarasota Bay. Grasses were shallower overall in Palma Sola Bay and the southern portion of the study area with less difference in depth between stable categories. The depths of stable polygons were also significantly and inversely correlated with attenuation coefficient and total nitrogen concentrations across the study area. General loss categories (gain, unchanged, or loss) indicated that light limitation may have played a role in seagrass losses in eastern Palma Sola Bay and Sarasota Bay proper between 1996 and 1999. Very few segments had change distribution consistent with light limitation in the 1999-2001 analysis, but light records were limited for this time period. Several segments experienced losses in the shallowest polygons, consistent with losses due to exposure and dessication and/or thermal extremes. Water quality gradients within a given segment were not strong and so provided little explanation for seagrass changes within a segment. Also within a given segment, the light levels experienced by specific change categories were often contradictory. A specific loss category could have experienced a higher light level than a specific gain category, indicating more than one factor was responsible for seagrass losses. Salinity effects alone did not appear responsible for seagrass losses or gains.

Detailed light analyses focused on 1996-1999 when data were more complete. When a relatively low compensation point was evaluated, all segments recorded significant differences in time below compensation by general change category and many were consistent with light limitation. The durations of modeled high and low temperatures were similar to depth distributions and did not appear to be a controlling factor in either general or specific seagrass change.

Introduction:

The Southwest Florida Water Management District (SWFWMD) has performed aerial mapping of seagrasses in the major waterbodies within their jurisdiction for a number of years and has produced coverages for 1988, 1990, 1992, 1994, 1996, 1999 and 2001. In many of the subregions, since the precipitous declines noted between 1950 and 1982, grasses have made small but consistent gains in coverage through 1996, with recovery attributed to improving water clarity due to reduced nitrogen loading (Johansson and Greening, 1999). In comparing 1996 with 1999 data, however, seagrass acreage exhibited declines in many regions (Tomasko, 2002). More recently, change analyses for the 1999-2001 time period exhibited modest recoveries in some regions and continued losses in others (Tomasko, 2003).

Climatic conditions between 1996 and 1999 mappings were unusual in that an El Nino/ Southern Oscillation event resulted in high rates of rainfall and riverine flows for southwest Florida. The seagrass recovery observed between 1988 and 1996 had taken place under relatively drier conditions. Except in the mouths of rivers and enclosed bays with riverine discharges, salinity was not considered the sole source of seagrass loss. Freshwater discharges in southwest Florida are typically highly colored and the resulting reduced water clarity of the an El Nino period, potentially coupled with increased epiphytism from higher nutrient loading was postulated to have resulted in light levels that were insufficient to maintain seagrasses at depth. Since 1998, rainfall and flows were reduced in 1999 and in 2000 were at the lowest levels since 1960. Flows in 2001 were somewhat larger but were still well below 1998 levels. The reduced flows in the period between the 1999 and 2001 mapping events were expected to allow increased light levels to reach seagrasses and support increased seagrass biomass.

The Project reported here was designed to examine areas of seagrass change within Sarasota Bay in relation to the monitored water clarity and clarity components, depth distribution, nitrogen concentration as a surrogate for epiphytism, and potential exposure during extreme weather events, and to identify likely causes for change. It should be emphasized that the project employed a selected subset of all change polygons and there was to be no assessment of total acreages of seagrass or change in seagrass.

Methods:

Study Area

The study area consisted of Anna Maria Sound, Sarasota Bay, Roberts Bay, Little Sarasota Bay, and Blackburn Bay (**Figure 1**). Areas directly surrounding the passes were not included due to the likelihood of bathymetric change on the flood tidal deltas in these regions. Change in coverage was evaluated by bay segment utilizing the Sarasota Bay National Estuary Program segmentation scheme (Estevez and Palmer, 1990). A total of 12 segments from Anna Maria Sound through Blackburn Bay were evaluated.

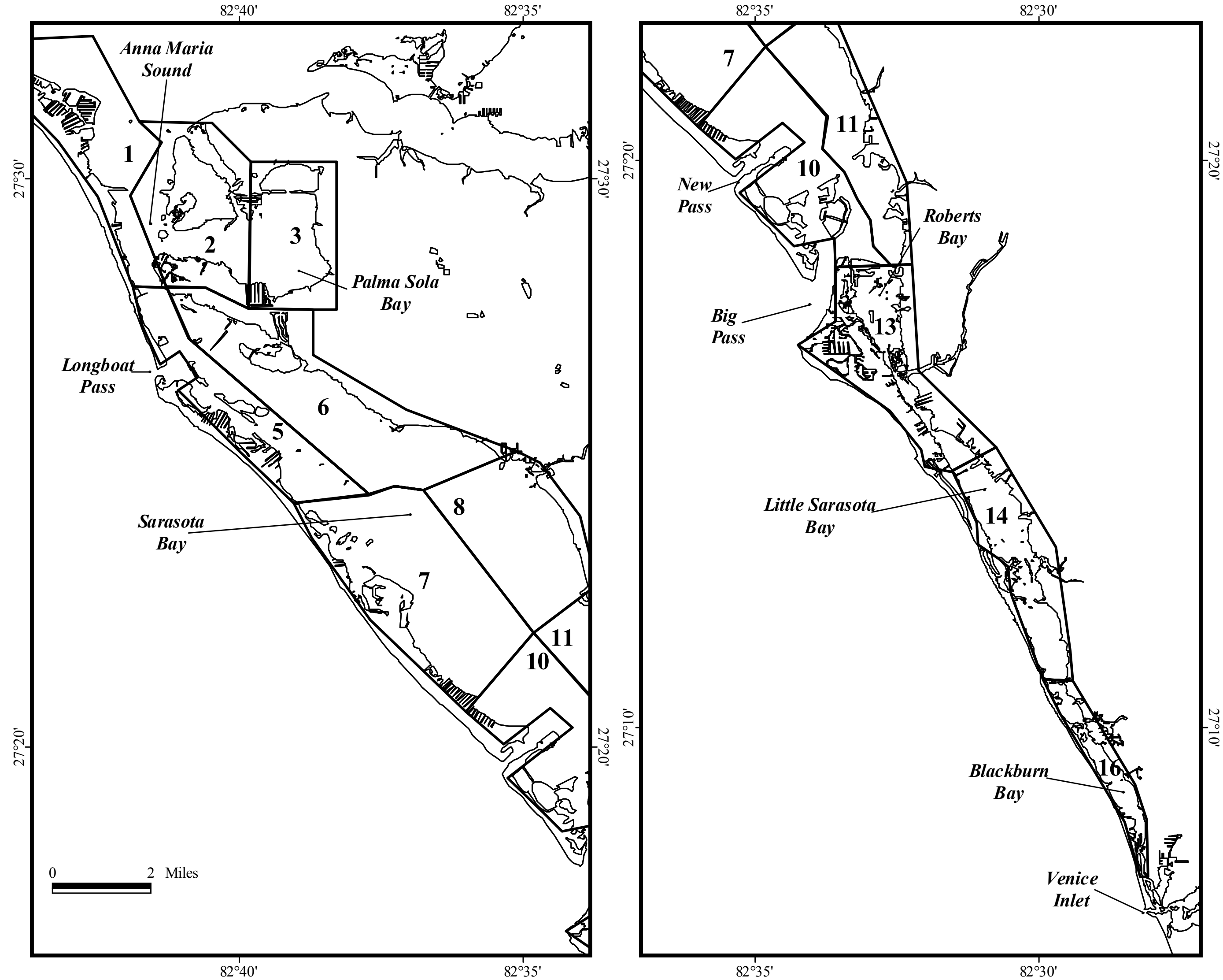

Figure 1. Study area for seagrass change analyses.

Seagrass Mapping

Seagrass mapping was available as Geographic Information System (GIS) coverages from SWFWMD. Categories of seagrass were designated as either 'Continuous' or 'Patchy', with a minimum mapping unit of 0.5 acres. The time periods used for the project included the coverages designated as 1996, 1999, and 2001. (Mapping designations adopted by SWFWMD were maintained for this project, regardless of the calendar date of the photography.)

GIS shapefiles were obtained from www.swfwmd.state.fl.us for 1996 and 1999. The 2001 dataset was in final preparation at this project's commencement and therefore retrieved directly from SWFWMD's contractor, Avineon, Inc. with SWFWMD's permission. The 2001 files are now available at the above mentioned website. The photography effort conducted for the 1996 maps covered a wide range of dates between April and October 1997 due to unfavorable field conditions. The 1999 images were flown in December 1999. The 2001 photography was flown in January 2002, but an unexpected turbidity plume around New Pass and Big Pass prevented interpretation of those areas and the region was reflown in January of 2003. The shapefiles for the 2003 effort were obtained from the Sarasota Bay National Estuary Program, although comparatively little was used in the change analysis since passes were subsequently excluded. Seasonal patterns of biomass which have maxima during summer and early fall were expected to complicate the comparison of the 1996 to 1999 data, while the comparison of 1999 to 2001 should be relatively free of these seasonal artifacts.

Change Analysis

Change analyses were conducted through the union of two shapefiles into a third shapefile which then contained polygons with attributes from both of the original files. Through this step, new shapes were created where attributes describe both initial and final conditions. For example, if a polygon coded as seagrass in one time period migrated to slightly deeper water but was in the same general location in a second time period, the new shapefile would create three polygons: a central portion where seagrass was unchanged, regions where seagrass had been lost, and regions of gain.

Change categories were created using the original Florida Land Use Codes and Classification System codes used to categorize the seagrass coverages. Categories are defined below (SWFWMD, 2001):

"9113 - *Patchy seagrass. This category appears as singular, isolated patches of seagrass or extensive areas of patch strands mixed with open bottom. Typically these areas appear as round clumps, or as elongated strands mixed with sand. The photosignature for 9113 usually has a rough texture when viewed through a stereoscope, and is bluish-gray to almost black depending on water depth and turbidity. 9113 can be found on the deeper and shallower edges of continuous seagrass beds or can be large and expansive and cover the entire bed."*
"9116 - *Continuous seagrass. These areas exhibit a continuous and uniform signature. Small, (less than one-quarter acre) sandy bottom features may be interspersed within the bed, but these areas are not dominant. Areas that appear as continuous beds of seagrass communities, regardless of species composition, will be mapped. The photosignature for 9116 is more smooth than that of 9113 but still has some texture. It also can be bluish-gray to almost black, but has only a few areas of open bottom showing through to interrupt the*

continuous signature. 9116 usually can be found in the center of large, healthy seagrass beds and sometimes runs parallel to the shoreline for hundreds of meters."

In practice, these designations are often presented as 'Continuous' containing no more than 25% of unvegetated bottom within the polygon, while 'Patchy' has more than 25% of unvegetated bottom within the polygon (Kurz, et al., 1999). The possible changes involving seagrass produced eight new categories for analysis under three generalized headings as listed in **Table 1**.

Table 1. Categories of seagrass change.

Gain (G)			
	Other-9116	Bare to Continuous	3
	Other-9113	Bare to Patchy	2
	9113-9116	Patchy to Continuous	1
Unchanged (U)			
	No Change	No Change(Continuous)	9116
	No Change	No Change(Patchy)	9113
Loss (L)			
	9116-9113	Continuous to Patchy	-1
	9113-Other	Patchy to Bare	-2
	9116-Other	Continuous to Bare	-3

Since 1988, slight modifications have improved the SWFWMD seagrass mapping techniques, which, while providing increasingly accurate estimates of actual coverage, complicate direct comparisons of successive mapping efforts for change detection. The first mapping effort in 1988 was conducted using areas of seagrass delineated from photos at a 1:24000 scale. The 1990 effort was similarly performed and, when compared to 1988 in a GIS environment, resulted in numerous "slivers" of change. The "slivers" were considered artifacts of re-mapping all the seagrass polygons in their entirety, as many of the changes were on the order of a pen width. The artifacts could also have been contributed as a result of the accuracy of the geo-registration of the individual photos. In the mapping performed for subsequent years, changes to a polygon were mapped rather than the entire polygon, thus reducing spurious changes.

The 1999 photography, however, increased the accuracy of ground control points such that while mapping accuracy remained at 1:24,000, positional accuracy was increased to 1:12,000. In addition, previous shorelines were updated. Shoreline changes observed between 1996 and 1999 could have reflected true changes, i.e., along unarmored passes, beaches or vegetated shorelines. Shoreline changes observed along hardened seawalls or protected shorelines, however, were attributed to the increase in positional accuracy. Seagrass change polygons were expected to have similar artifacts. A primary task of the seagrass change analysis was to segregate true changes in seagrass coverage from those resulting from positional accuracy increases, prior to investigating water quality or other factors associated with change polygons. Since the 2001 mapping employed the same shoreline as used for the 1999 effort, positional accuracies were similar, and so artifacts were not expected to be as prevalent in the 1999-2001 change analysis.

An analysis of shoreline change between 1996 and 1999 was conducted in order to create a threshold size above which true seagrass change was probable and not an artifact of the higher resolution product or differences in geolocation. Excluding areas where shoreline change was possible (passes or inlets), the 95th percentile of all coastline change polygons was identified as 0.67 acres. Seagrass change polygons below this threshold were automatically eliminated from consideration.

Many seagrass features, however, were linear in nature, i.e. along channels and the fringes of narrow bays to the south of the study area. A small shift in registration of a seagrass polygon could produce a large (but narrow) change polygon, the short axis of which could be comparable to the distance that the shoreline had apparently moved. Seagrass 'change' in these instances was considered spurious. The shoreline shifts are clearly illustrated in the canal systems of Anna Maria (**Figure 2, left**) with the shift in the shoreline carried over into the seagrass changes.

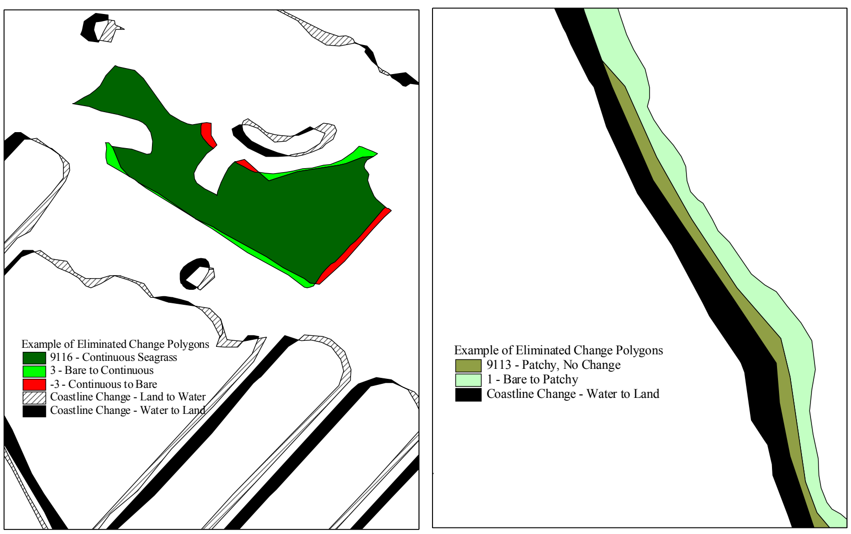

Figure 2. Examples of shoreline change and seagrass change that were eliminated from consideration.

Figure 2, right, illustrates an area near Midnight Pass. Here, an eastward shift in shoreline converted grassbeds to land with a comparable expansion of seagrass. The axis of the seagrass change polygon was comparable to that of the shoreline and so was considered not true change. Similar examples were present in all segments.

Accordingly, any polygons that changed from land to grass or grass to land were eliminated. Finally, a visual inspection of the remaining polygons was performed. Seagrass change polygons were selected if the change in seagrass coverage along the axis of the shift in adjacent shorelines was substantially greater than the shoreline change. Comparable numbers of seagrass polygons of no change were also selected to include in the analyses, using both patchy and continuous categories.

Bathymetry

Bathymetric data were retrieved from the National Ocean Service/National Oceanic and Atmospheric Administration Geophysical Data System for Hydrographic Survey Data, Ver. 4.0. Some 63,000 survey points from the 1950's were used from thirteen surveys. Data were reported to the nearest 0.1 meter. These points were projected from their native geographic datum to that used by SWFWMD and a 30x30 meter bathymetric grid interpolated. The seagrass change polygons created above were overlaid on top of the grid and a depth distribution and mean depth calculated for each change polygon.

Water Quality

Monthly water quality data had been collected for Sarasota and Manatee Counties since January, 1995 and November, 1995 respectively. Sarasota County data were retrieved through June, 2002 from database archives at Mote Marine Laboratory (MML). Manatee County data were retrieved from the EPA's STORET (legacy and modern) databases. Parameters of interest included light attenuation coefficients, total nitrogen, turbidity, color, chlorophyll and salinity. Attenuation coefficients were not available in the northern portion of the study area during 2001. Data reported to be less than the detection limit were evaluated at one half of the detection limit. Attenuation coefficients were computed from raw light readings as necessary.

Water quality data were segregated into two time periods to span the dates of the aerial photography flights. The '96-99' data comprised observations between April 1, 1997, and December 31, 1999; the '99-01' time period encompassed from December 1, 1999 through January 31, 2001. In both data sets, station observations were pooled by month, and each month was separately contoured and gridded at 30 m by 30 m resolution. From the resulting gridded data, spatial means of both individual change polygons and of entire segments (**Figure 3**) were computed by month. Polygon means were further reduced to compute the monthly departure between the segment mean water quality parameter and the polygon mean . water quality parameter, in order to capture spatial distributions that might exist within a given segment. The mean water column depth within individual polygons was also combined with the monthly mean attenuation coefficient for the polygon to compute the approximate

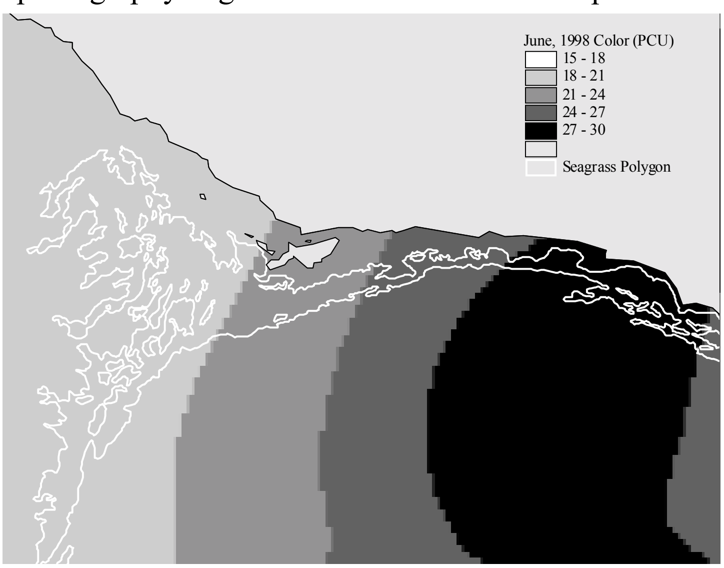

Figure 3. Water quality gradient used to compute mean segment and polygon water quality value for the given month.

fraction of photosynthetically active radiation (PAR, 400-700 nm) available at the bottom. The resulting data provided a monthly time series of water quality data within a segment, within individual polygons, and the differences between the two.

The above water quality data were further segregated to isolate the growing season of April through October. The season was identified with reference to seagrass metrics previously measured in Tampa Bay and Charlotte Harbor (Dixon and Leverone, 1995; Dixon and Kirkpatrick, 1999) under the premise that environmental conditions which can limit photosynthesis are of greater importance during warmer than during cooler temperatures (Tomasko and Hall, 1999).

Thermal Extremes

As a surrogate for the exposure and dessication of seagrass beds, thermal extremes of seagrass beds within the Sarasota Bay system were evaluated through the use of a heat flux model which incorporated tides and was specific to the depth distribution within individual polygons. Hourly predicted tides for Sarasota were obtained from Tides and Currents for Windows^{TM}, Nautical Software, Version 2.5I and referenced to mean lower low water (MLLW). Tides measured at the MML facility on New Pass (relative to mean low water, MLW) were collapsed to hourly values, and used to compute a tidal offset, measured water level less predicted. Large positive or negative offsets were confirmed as reasonable based on other weather data (wind speed direction, temperatures, records of tropical storms) or discarded if instrumental malfunction was suspected (progressive or step trends in offset data). Offsets ranged between -0.4 and 1.0 m.

Data from 1994-1995 were used to develop an empirical regression model of tidal offset. Possible independent terms included barometric pressure, wind speed and wind speed squared, wind direction normalized to a variety of compass headings, cumulative wind speed squared over a variety of periods from three to eighteen hours, and interactive terms. Stepwise regression was used to eliminate terms. The final model incorporated terms for barometric pressure and a multiplicative term consisting of the six hour cumulative wind speed squared and the sin of the wind direction plus 15 $^{\circ}$. Standard error of the estimate was 0.08m. Use of the model with weather data from subsequent years achieved comparable accuracies predicting tidal offsets within 0.07-0.09 m (RMS error). Missing wind speed data were replaced with the mean of the remaining data, 3.31 m/sec. Missing wind directions or barometric readings were replaced with the last observation. The regression model of tidal offset was then used with the predicted tides to generate an unbroken tidal record over the project period.

Hourly water column depths over seagrass polygons were then estimated from the predicted tides, the modeled tidal offsets, and the polygon elevations determined from gridded bathymetric data. The implicit assumption was that water levels fluctuated uniformly across the study area, both in amplitude and in timing. This is known not to be the case, but was used as an approximation for the following reasons. Timing of tidal amplitude along the coast is relatively coherent, and differs by less than 0.5 hours between Venice and Anna

Maria; amplitude differences are on the order of 10% (NOAA, 1994). Regions behind barrier islands are likely to lag both in amplitude and in timing, but times of maxima and minima are unlikely to lag more than one-quarter of a typical 12 hour semi-diurnal period, (i.e., 3 hours). Differences in tidal amplitude are more difficult to assess in the absence of a hydrodynamic model, but the subdivision and analysis of the seagrass polygon data by segments allow the relative comparison of depths among polygon categories of a given segment.

The heat flux model consisted of the summation of insolation, net longwave radiation (infrared) from the water surface, sensible heat flux due to conduction of heat from the water to the atmosphere, and latent heat flux due to evaporation. Insolation values were obtained from MML's weather station and were adjusted for the fraction of reflection at the air-water interface, determined as a function of solar elevation (Kirk, 1994). Data were reported in W/m^2; missing data were replaced with the hourly means from the same calendar days in other years. Net longwave radiation, was computed as blackbody radiation at the temperature of the water, less water vapor absorption. In practice, black body radiation was scaled to achieve annual values near 45-50 W/m^2 as reported for these latitudes (Stewart, 2002). Missing water temperature data, if unavailable from either the MML station or from Venice, were replaced with the daily and hourly means from other years. Sensible heat loss was computed as a function of air and water temperature, while latent heat loss from evaporation was a function of wind speed and relative humidity. Missing relative humidity data were replaced with the mean of other observations.

The net heat lost or gained was applied in hourly steps to a water column determined from elevation and predicted tide plus weather offset. Tidal increases in water column were assumed to import water at a temperature given by the MML weather station at New Pass and to mix instantaneously with the existing water column. Tidal decreases in water column were considered heat lost. Water columns were not allowed to decrease to less than 0.05 m and so actual dessication of seagrass tissues was not addressed. Temperatures within a given polygon were computed as a linear mixture of the temperature records of differing water column depths, combined in proportion to the depth distribution within a given polygon. This technique was superior to using mean polygon depths as the thermal fluctuations were non-linear with water column depth and shallow polygons exhibited much larger thermal variations than deeper polygons under similar ambient conditions.

The modeling technique, while continuously autocorrecting through the import of thermally accurate water with each rising tide, nevertheless adequately represented the thermal variations, both diurnal and seasonal, of a large ($3.2X10^6$ m^2) polygon of varying depths bounding New Pass. The RMS error over a three year period of continuous simulation was less than 0.5 °C. Polygons located farther from New Pass would be expected to exhibit larger seasonal and diurnal fluctuations as the waters of a rising tide would be from shallower, more thermally variable parcels of water. Although the absolute accuracy of the modeled temperatures cannot be assessed with the available data, comparisons among seagrass change categories within a given segment would be expected to provide relative information useful for assessing possible differences in exposure. Modeled temperature records of the individual polygons were further reduced to compute minima, maxima, and durations above or below given critical temperatures: 10°, 15°, 32° and 35°C, drawn from Zieman and Zieman (1989).

Detailed Light Record

A more detailed record of PAR was also prepared for individual polygons to accommodate the nonlinear attenuation of light with depth. The depth distributions of individual polygons were combined with linear interpolations between the polygons' monthly mean attenuation coefficients, hourly tidal heights, and record of insolation. Measurements of underwater spectral irradiance between 0 and 2 m were used to compute a conversion factor between W/m^2 (the insolation record) and PAR (L.K. Dixon, unpublished data). Factors so determined varied by less than a few percent between 0.3 and 2.0 m and so attenuation coefficients determined for PAR could be approximately applied to insolation.

The time series of computed insolation at the bottom of water columns of various depths were linearly combined in the proportion of the depth distribution of the individual polygons. Data were further reduced to compute the fraction of immediately subsurface insolation available at depth, the number of days per month above selected compensation values, mean insolation during daylight hours, maximum insolation per month, number of days per month above reported saturation values, and the longest number of continuous days per month below selected compensation points (where rates of photosynthesis are balanced by respiration rates). Compensation points evaluated were 25, 50, 90, and 200 $\mu E\ m^{-2}\ sec^{-1}$. These values were selected from studies utilizing entire seagrass shoots or *in situ* plants of either *Thalassia testudinum* or *Halodule wrightii* (Dawes and Tomasko, 1988; Fourquean and Zieman, 1991; Dunton and Tomasko, 1991). Compensation points were also increased to adjust for an assumed epiphytic attenuation of 43% as measured on seagrasses of both species during the growing season at a number of locations in Sarasota Bay (Dixon and Kirkpatrick, 1999).

Results and Discussion:

Change polygons

A total of 860 polygons were selected for the 96-99 analysis; 789 were chosen for 99-01. Distribution by segment and category appear in Appendix A, together with mean elevations and approximate total areas. It should be repeated that the selected polygons are essentially all polygons for which a change axis appeared substantially larger that that of an adjacent shoreline change. Polygons were individually reviewed and represent a conservative subset of seagrass change. Unbalanced distribution of either area or numbers of polygons by change category is a result of overall polygon characteristics within a segment, rather than of the selection process. The polygons were selected to investigate probable causes of seagrass loss and gain and cannot be used to make statements about overall areal changes in seagrass within the Sarasota Bay system. Areas are provided in Appendix A solely to provide estimates of the general robustness of the change analysis. Polygons used are illustrated in **Figures 4 through 7**.

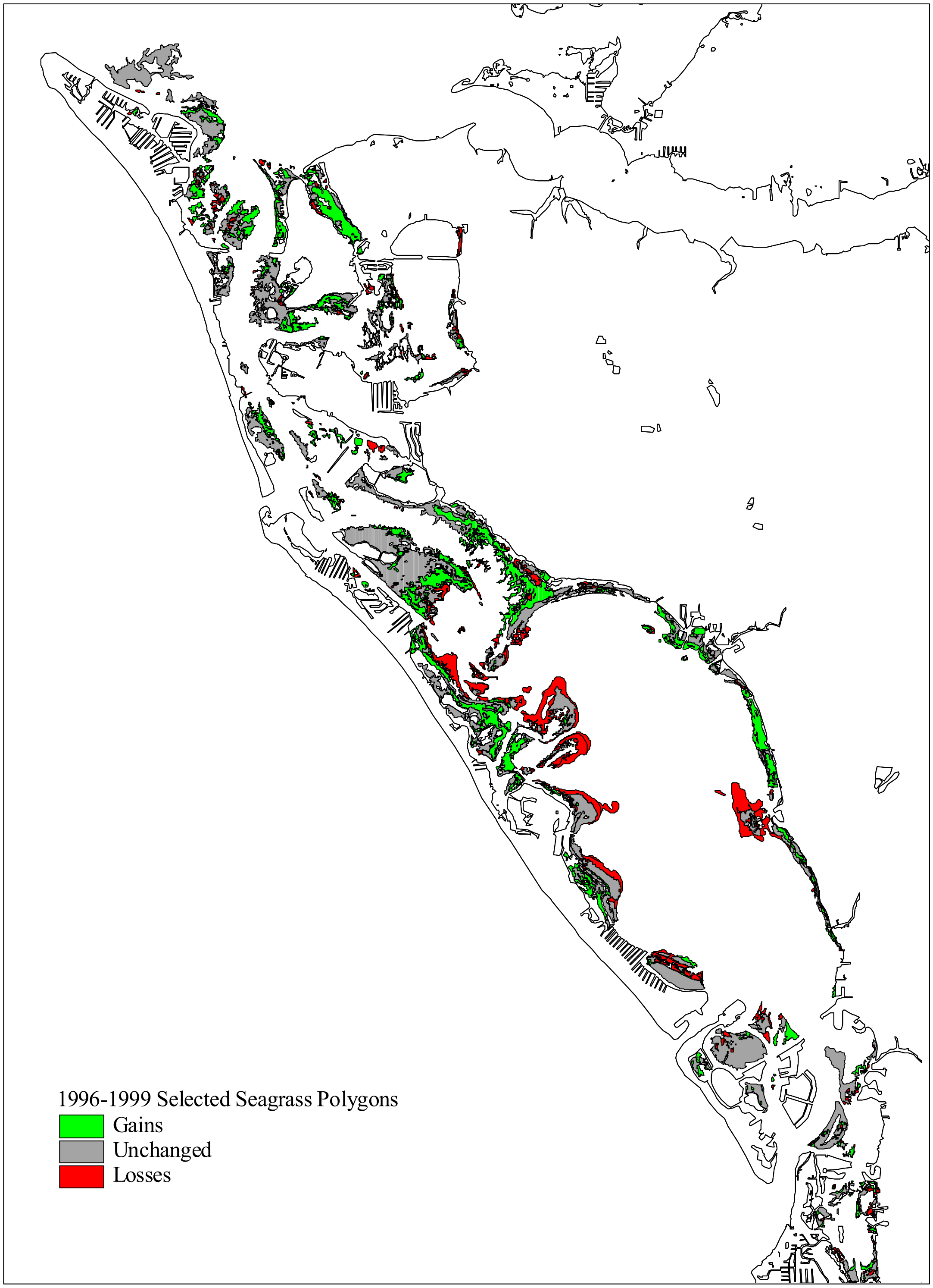

Figure 4. Selected polygons of seagrass change used for analyses, 1996-1999. Northern study area.

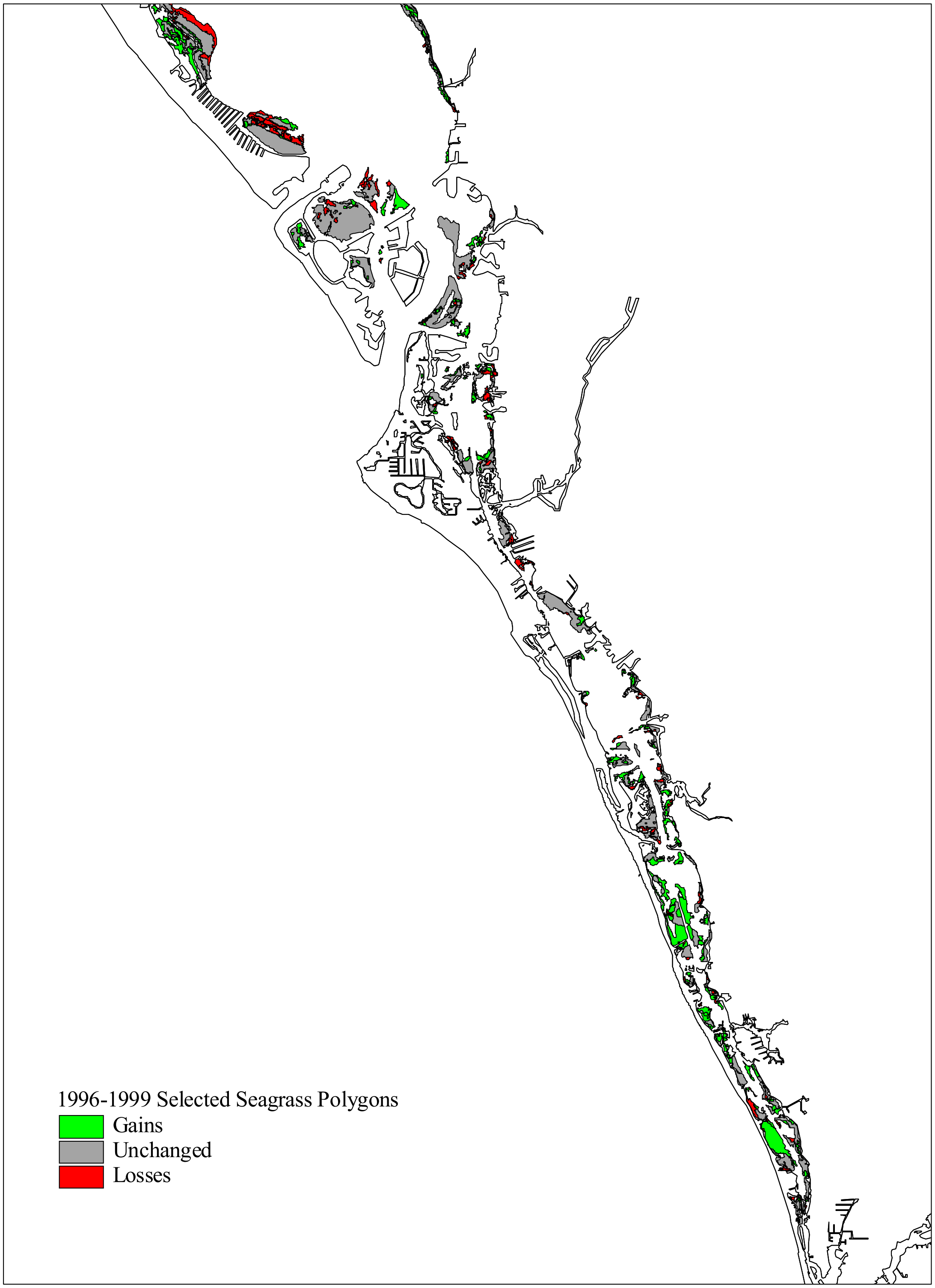

Figure 5. Selected polygons of seagrass change used for analyses, 1996-1999. Southern study area.

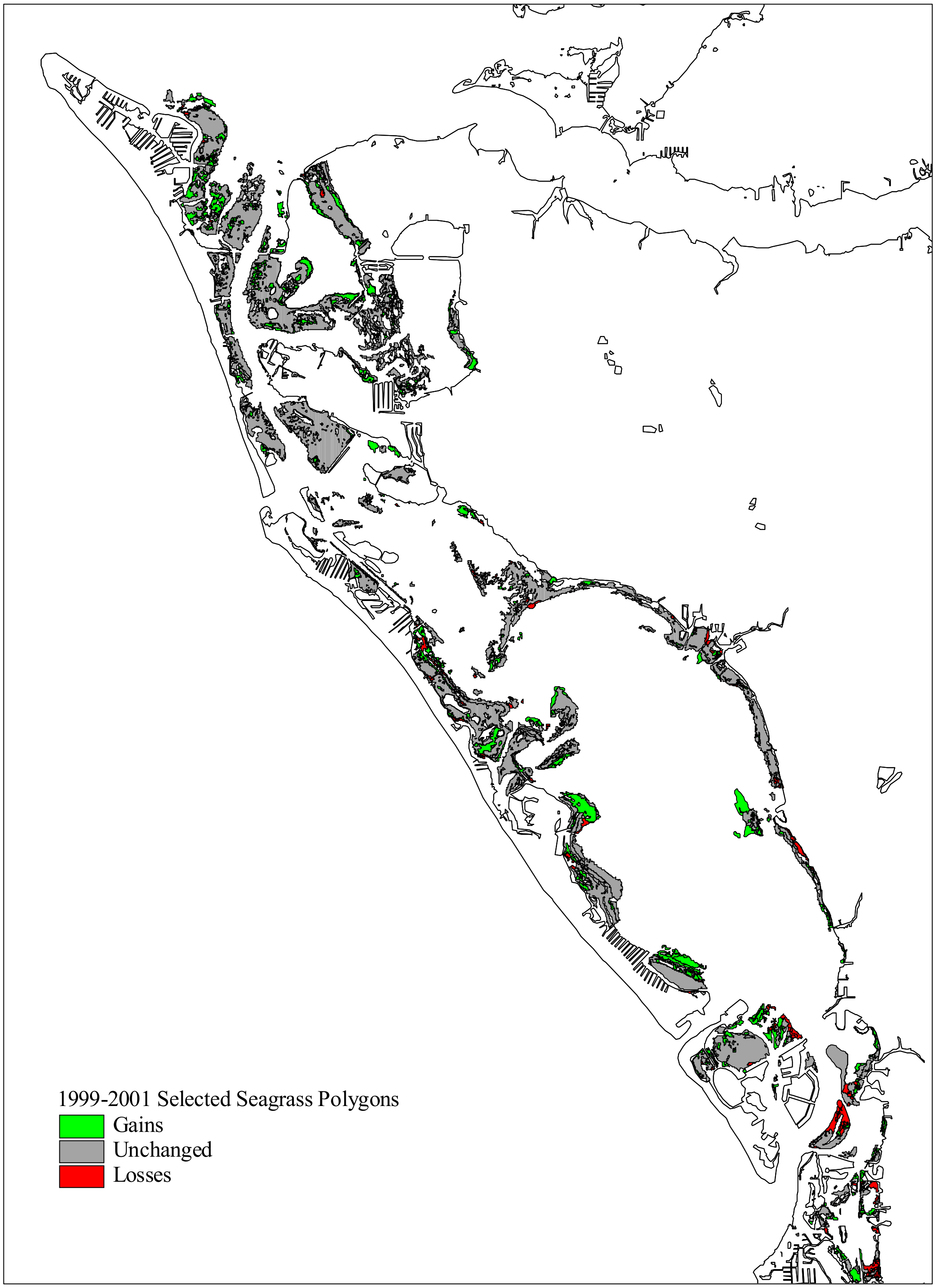

Figure 6. Selected polygons of seagrass change used for analyses, 1999-2001. Northern study area.

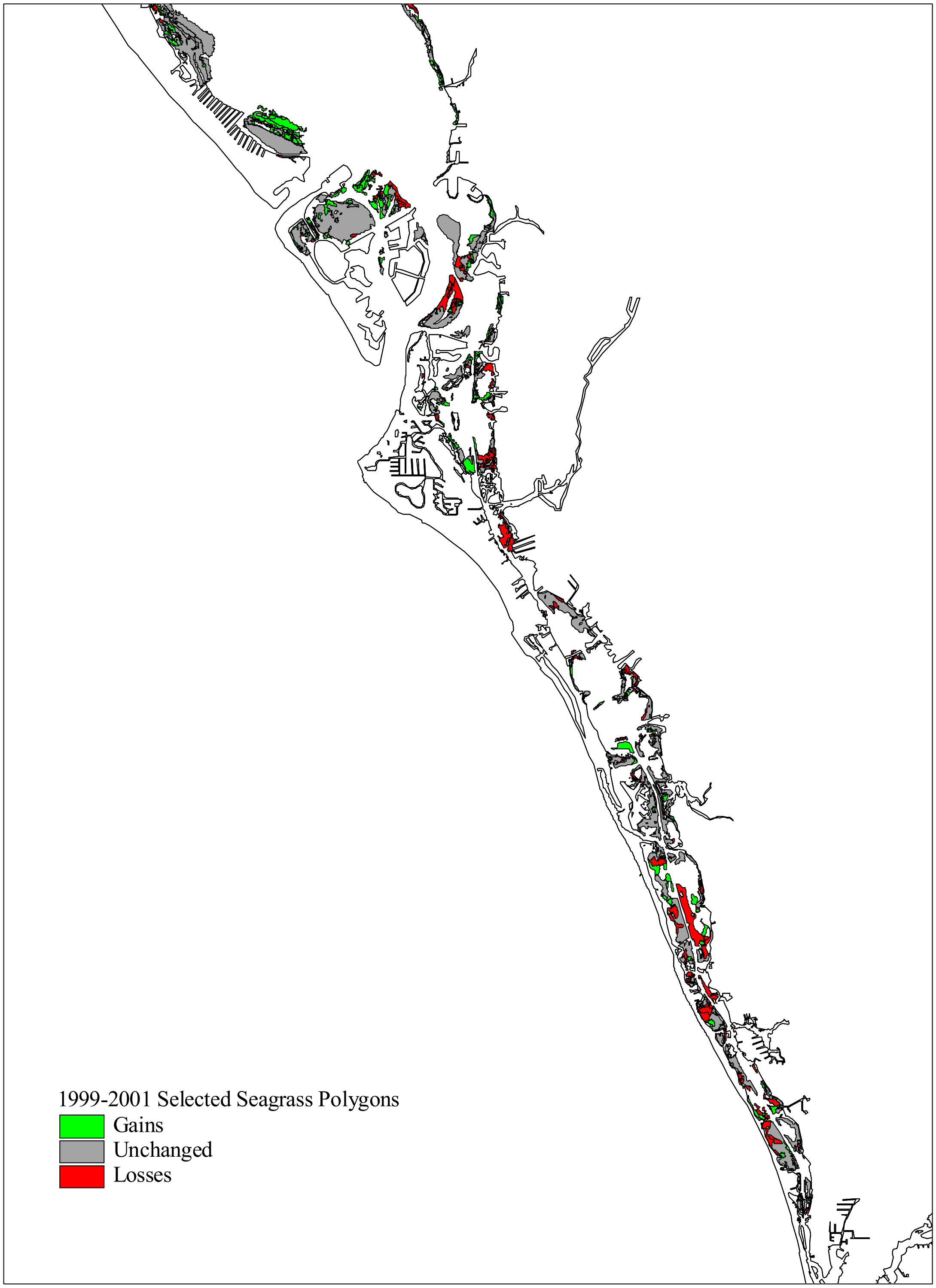

Figure 7. Selected polygons of seagrass change used for analyses, 1999-2001. Southern study area.

Flight Times

While two of the three periods of seagrass photography were flown in the winter when water clarity and cloud conditions were expected to be optimal, the 1996 photography was flown between April and October, 1997, due to logistical and weather complications. Approximate dates and regions of flights for the 1996 mapping are illustrated in **Figure 8** and much was flown when seasonal biomass typically peaks (Dixon and Leverone, 1995; **Figure 9**). A change analysis of stable seagrass beds between a summer and a winter period (August 1997 to December 1999) may easily have produced spurious changes, and the effect may vary by species of seagrass. Seasonally, the deep edges of *Thalassia* beds thin during winter but do not disappear entirely (Dixon and Leverone, 1995). *Halodule* beds, however, are reported to have ephemeral seasonal appearances (COT-BSG, 2003), and can be completely absent during the winter, only to reappear the following spring at a shoot density beyond that expected for vegetative expansion. The degree of contrast between seagrass blades and unvegetated bottom, the resolution of the photography, and water depth and clarity are other issues that will also affect whether seasonal bed thinning is visible between successive periods of photography.

The two seagrass categories that are mapped, however, do not translate well to average biomass or shoot density values (typically measured on meter or sub-meter scales) except on very large spatial scales. The categories are operationally defined by percent of bare space visible in the photography and are more appropriately considered as a measure of the open area between sections of comparatively dense seagrass shoots. Within a given polygon of either patchy or continuous designation, the grassed areas can experience a wide range in shoot density or biomass without any change in classification (**Figure 10**).

While the issue is complex, a seasonal decrease in biomass could prevent recognition of seagrass in the 1:24,000 scale photos during winter biomass and shoot density reductions. The most probable type of change so affected would be a change from patchy to bare. Change from continuous to patchy coverage would require the individual seagrass patches within a polygon to reduce and/or fragment so that more than 25% of unvegetated bottom becomes visible. If a seasonal change in biomass was detected during photo interpretation, then changes based on photography flown between April and August would be the most susceptible to artifact. Of the 1996 photography, the least likely seasonal artifacts were in the regions flown in October and January, or northern Sarasota Bay, portions of Palma Sola Bay, New Pass, and Roberts Bay.

There were indeed large polygons of loss in Sarasota Bay between 1996 and 1999, in an area which was flown in August for the 1996 mapping. Reference to the original photos for some of the largest polygons of loss indicated that much of the change appeared to be large regions of very small patches in 1996 which were no longer visible in December 1999 (i.e., a conversion of patchy to bare). These losses were consistent with the postulated seasonal biomass changes. With the existing photography, however, it is not possible to further allocate losses between seasonal and interannual changes. The protocol of winter flights, adopted by SWFWMD for all subsequent and future flights, will remove this uncertainty from future seagrass change evaluations.

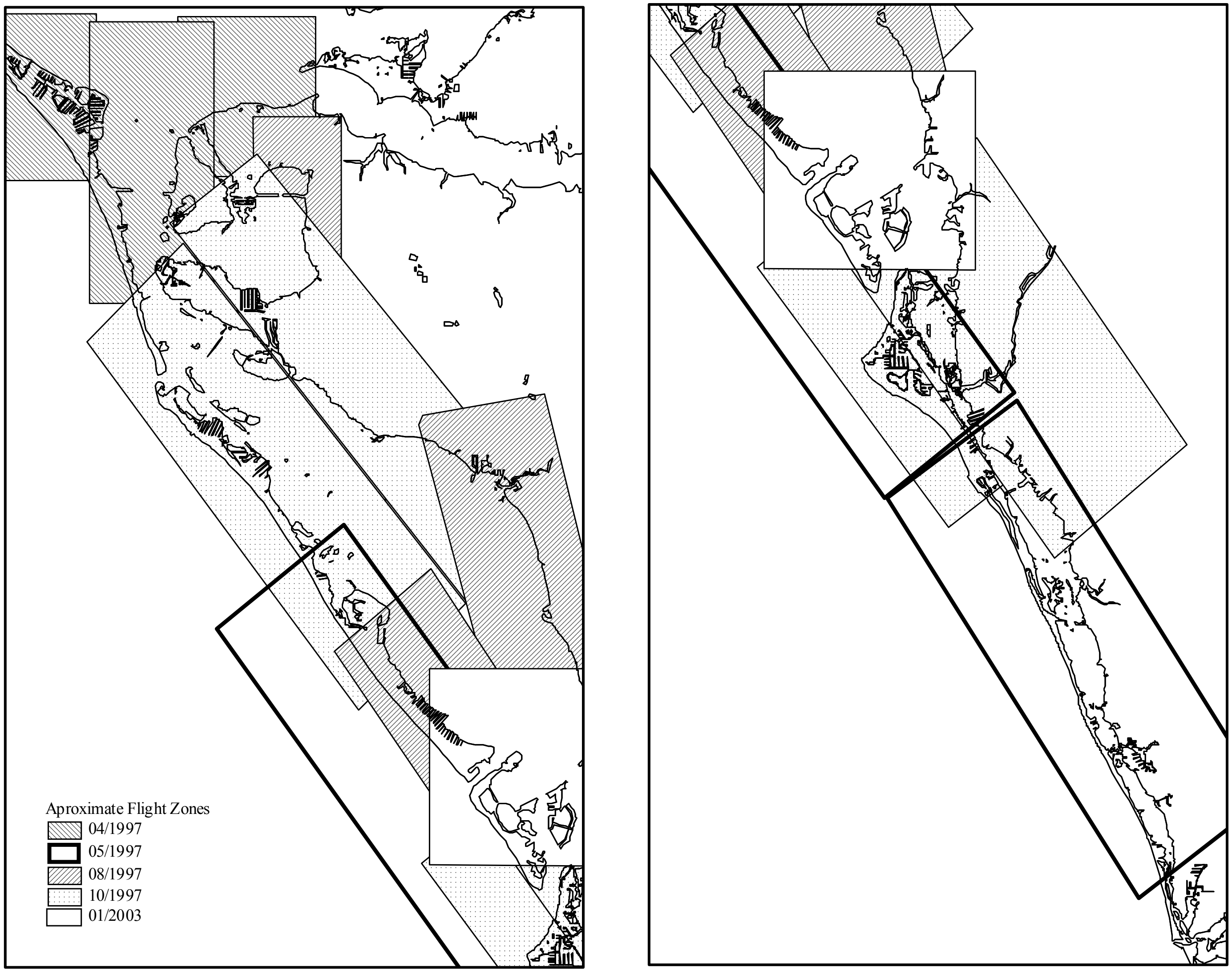

Figure 8. Approximate areas covered and dates of the 1996 aerial photography.

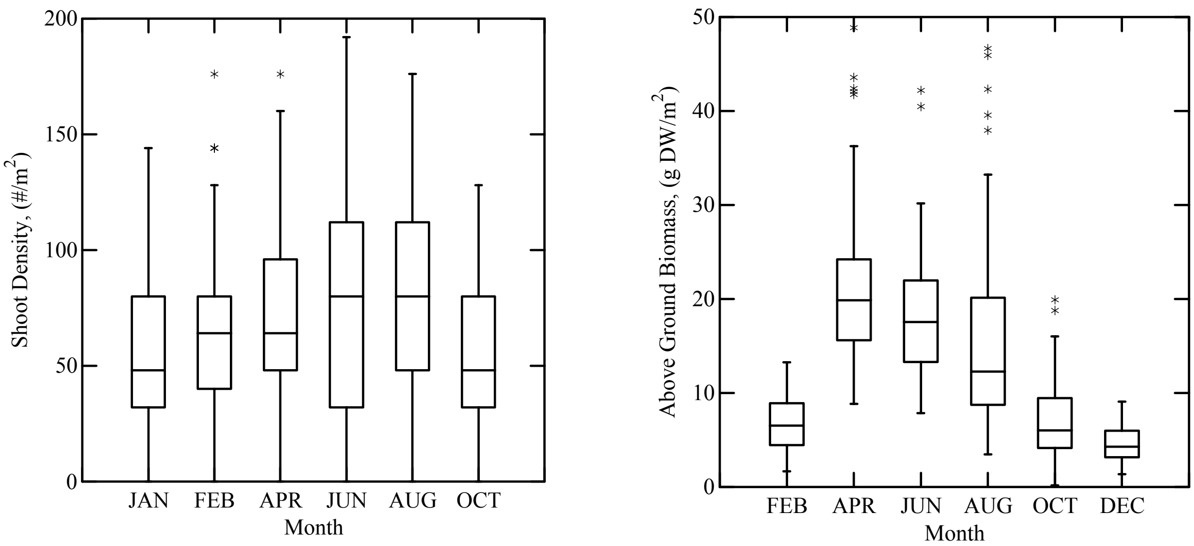

Figure 9. Seasonal fluctuation in *Thalassia testudinum* shoot density and biomass, as measured in Tampa Bay.

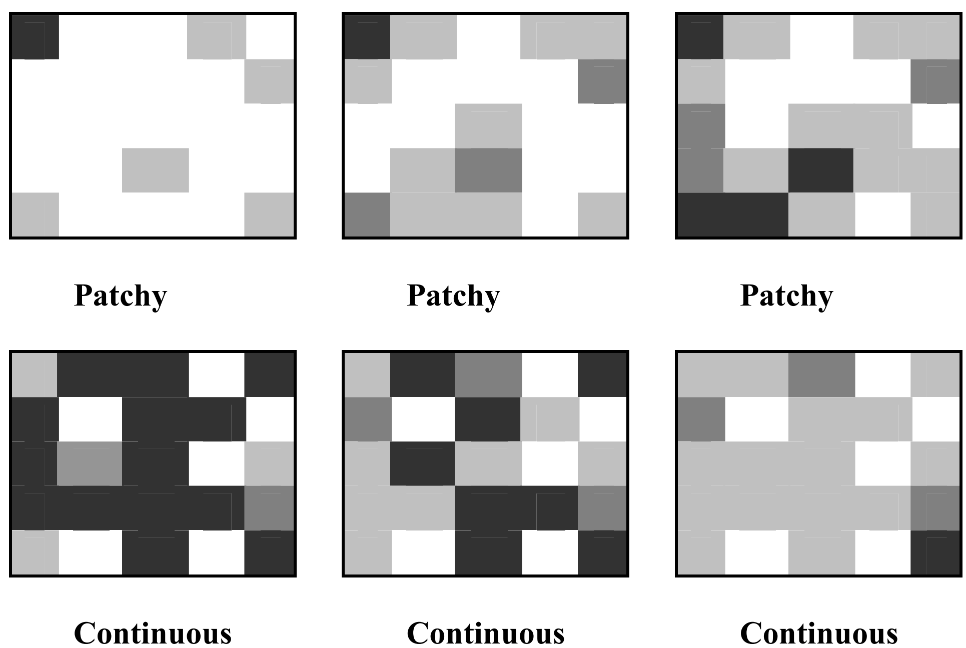

Figure 10. Examples of the variety of coverages under the patchy and continuous seagrass designations. Darker tones indicate higher biomass values and/or shoot density. White space is equivalent to bare bottom.

Polygon depths

The elevations of seagrass polygons where no change had occurred (Category 9113 and 9116) displayed significant differences (Kruskal-Wallis, $p<0.05$) by category for all segments (**Figure 11**), particularly for the central segments of Sarasota through Roberts Bays. Patchy polygons were generally deeper than the continuous beds in the central regions (with the exception of the shallow beds of Palma Sola Bay), and the pattern was present in the individual time periods as well. This was consistent with the observed seagrass growth patterns in the regions, in which deep edges of beds sometimes exhibit very heterogeneous edges. Fewer differences in depths between the stable continuous and stable patchy polygons were apparent for the shallower segments to the south and in Palma Sola Bay (Segments 2 and 3).

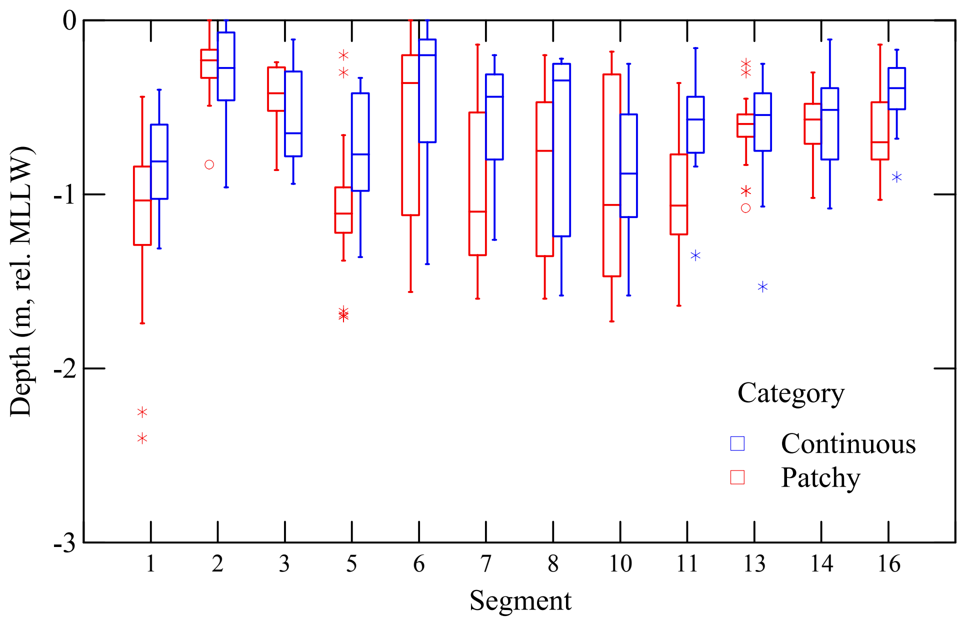

Figure 11. Elevations of seagrass polygons of no change, by segment, for '9113-Patchy' and '9116-Continuous'.

Examining depth distribution by general change category and segment indicated that polygons exhibiting any type of loss between 1996 and 1999 (**Figure 12**) were generally deeper in the northern Sarasota Bay segments. Segments 5, 6, 7, and 13 had significantly different depths by general change category (non-parametric Kruskal-Wallis, $p<0.05$), although median depths of loss polygons in Segment 13 were shallower than the other categories. Patterns were less obvious elsewhere and in the 99-01 polygons (**Figure 13**) and polygon elevations ranged widely within all categories. Further investigation of Segments 5, 6, and 7 during 1996-1999 indicated that detailed categories of loss (**Table 1**) were not uniformly consistent with respect to depths and inferred reduction in available light with increasing depth (**Figure 14**). Even within a given segment, some categories of loss occurred at shallower depths than did some types of gains.

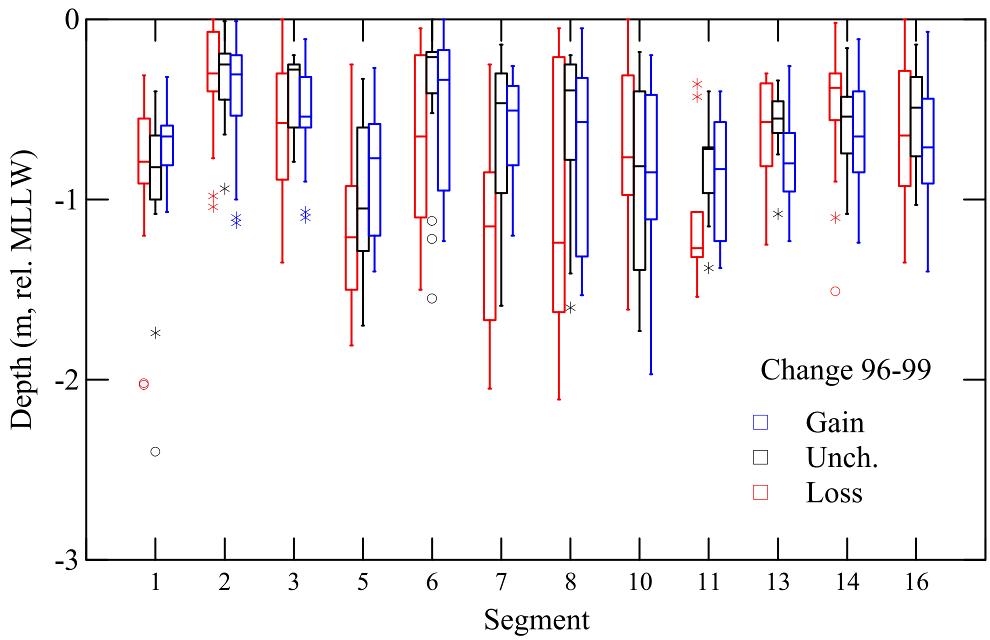

Figure 12. Elevations of general categories of seagrass change, by segment, for 1996-1999.

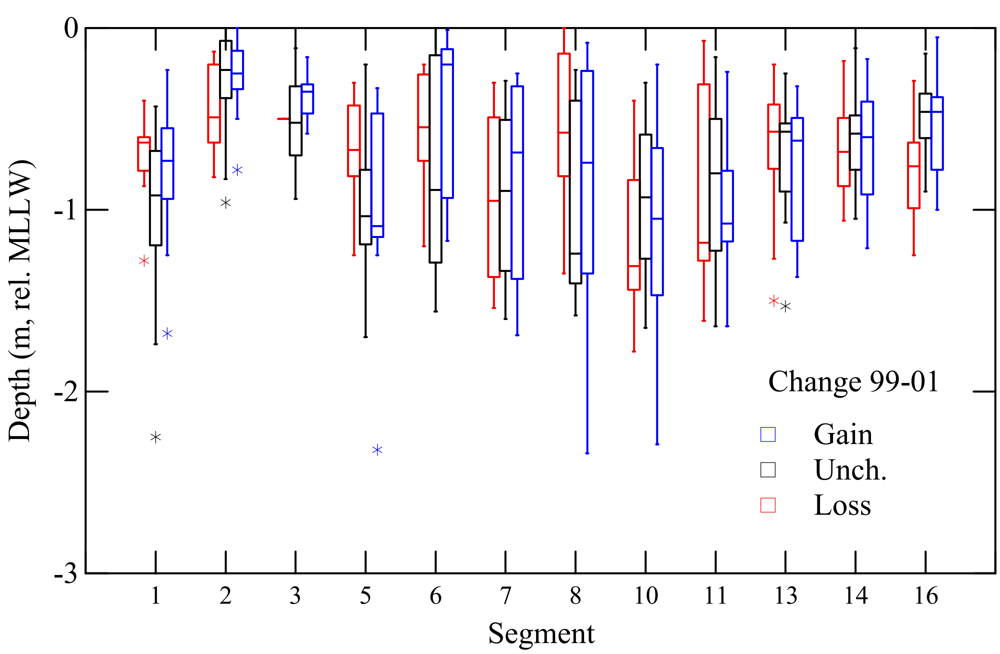

Figure 13. Elevations of general categories of seagrass change, by segment, for the 1999-2001.

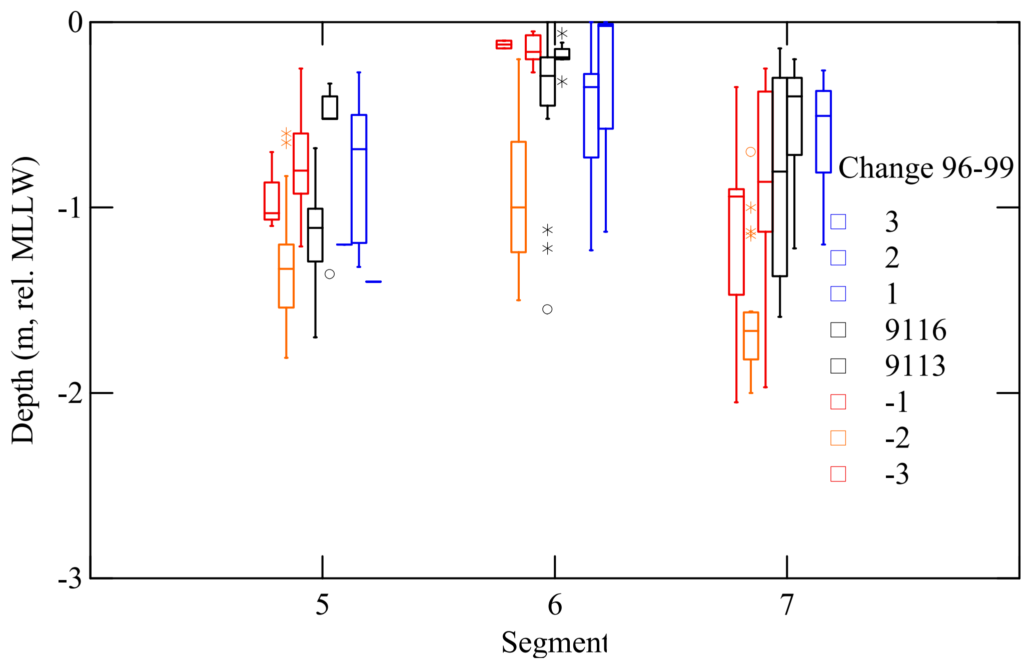

Figure 14. Elevations of specific change categories of seagrass for Segments 5, 6, and 7, for 1996-1999.

Distributions of depths among polygon categories are more pertinent for seagrasss change analysis than are measures of central tendency, however. The tails of the distribution, the very deep and the very shallow, are where environmental constraints on seagrasses occur, either through reduced light at depth, or increased exposure, light, and/or thermal extremes (of both high and low temperature). Non-parametric Kolmogorov-Smirnov tests were used to compare the cumulative distributions between pairs of change categories. General change categories (loss, unchanged, and gain) were first evaluated by time period and segment, followed by the evaluation of specific change categories (-3, -2, -1, 9113, 9116, 1, 2, and 3) if general change categories proved significant. **Table 2** summarizes the results as to whether significant differences in depth distributions were present. Table 2 also provides qualitative information as to whether exposure effects were likely to differentiate between categories. **Figure 15** illustrates for Segment 7 (96-99) that loss polygons were significantly different and generally deeper than other categories. (Data are illustrated against a standard normal distribution but are unstandardized to retain the magnitude of differences between change categories.) Light limitation probably plays a large role for many of the seagrass loss polygons in this segment. Unchanged polygons are among the shallowest in this segment and so impacts from exposure or recovery from exposure are unlikely in Segment 7. In **Figure 16**, on the other hand, the distribution of Segment 2 polygons at depth is comparable between change categories and there are no significant differences in depth distribution. The loss polygons, however, appear to have a few extremely shallow examples (between -0.2 and 0.0m) and exposure effects could be important in this segment and time period.

Table 2. Distribution of polygon depths by general change category and evaluation of potential for low light or exposure effects based on relative depth distribution

Time Period	Segment	Sig. Diff. in Polygon Depth, (K-S, *p*<=0.05)	Possible Exposure Effects	Comments
96-99	1			Only a few deep 'L' polygons
96-99	2		Y	A number of 'L' were very shallow
96-99	3			'L' generally deeper
96-99	5	Y		'L' generally deeper
96-99	6	Y		'L' generally deeper
96-99	7	Y		'L' generally deeper
96-99	8			
96-99	10			
96-99	11			
96-99	13	Y	Y	Some 'L' were very shallow
96-99	14		Y	Some 'L' were very shallow
96-99	16			Some 'L' were very deep
99-01	1	Y		'L' and 'G' were generally shallower than 'U'
99-01	2			
99-01	3	Y		Only one polygon of 'L'
99-01	5	Y		'L' generally shallower
99-01	6			'U' and 'G' categories in very shallow water
99-01	7			
99-01	8		Y	'L' generally shallower
99-01	10			
99-01	11		Y	'L' polygons either very deep or very shallow
99-01	13			
99-01	14			'L' polygons generally deeper
99-01	16	Y		'L' deeper overall than other categories

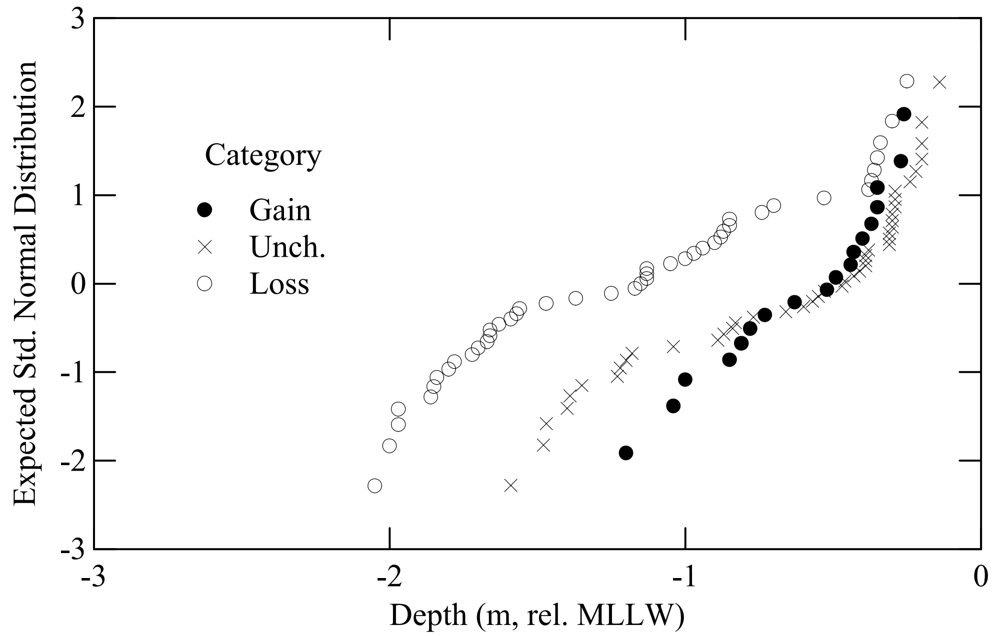

Figure 15. Distribution of polygon depths by general change category for Segment 7, 1996-1999.

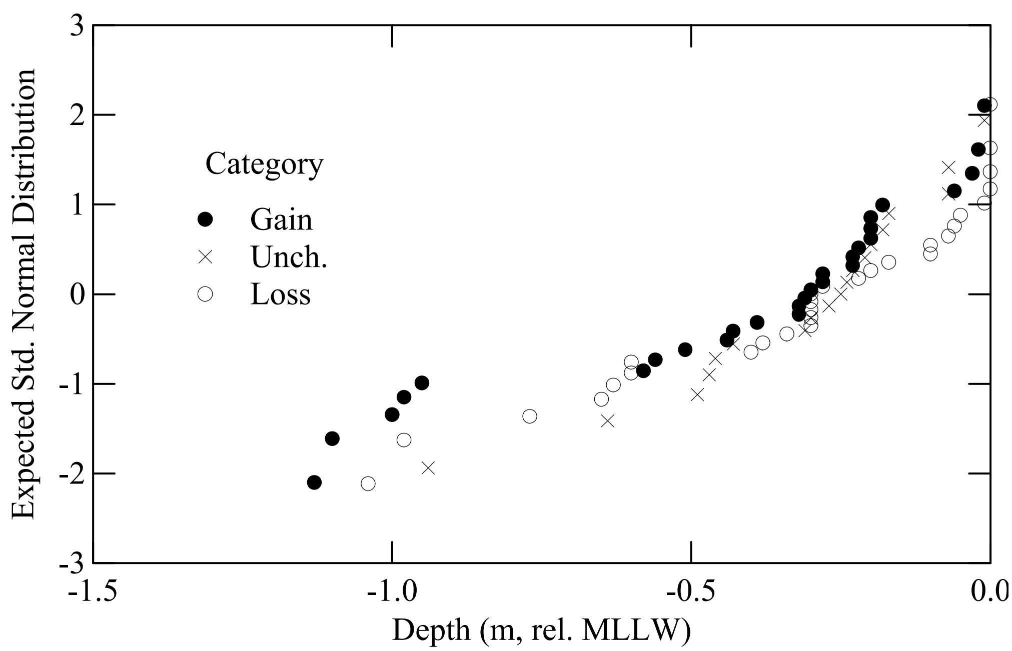

Figure 16. Distribution of polygon depths by general change category for Segment 2, 1996-1999.

Segment Water Quality

The entire Sarasota Bay study area exhibited wide ranges of the water quality parameters investigated. Light attenuation coefficients, turbidity, color, chlorophyll, total nitrogen, and salinity were all significantly different both between periods (96-99 and 99-01; Kruskal-Wallis, $p<=0.05$) and between segments. The distributions of the mean monthly water quality parameters by period and by segment appear in Appendix B with segment means mapped by time period in Appendix C. The combination of multiple gradients across the study area makes possible a wide variety of controlling influences on seagrasses in the region. While water quality gradients across the entire study area were pronounced, the gradients within any one segment were much less noticeable, due in part to the morphological segment boundaries employed.

The largest three polygons of each of the three general change categories (Loss, Unchanged, Gain) within each segment were also selected. The time series of the polygon-specific water quality values appear in Appendix D and illustrate that water quality was highly variable over the study period. Most importantly, Appendix D visually indicates that there was no single 'controlling' water quality parameter among those investigated that was consistently associated with the general seagrass change categories.

As turbidity, chlorophyll, and color are components of light attenuation, analytical efforts centered on total nitrogen (as a possible surrogate for ephiphytic growth), salinity, and remaining light at depth. When analyzed by time period and by segment, there were few significant differences between general change categories for total nitrogen distributions. In 96-99 data, loss polygons in Segment 7 were significantly higher in nitrogen than either unchanged or gain polygons. Differences were on the order of <0.1 mg/L of total N. In Segment 8, however, loss and unchanged polygons both experienced significantly lower total nitrogen concentrations. During the 99-01 period, significant differences in nitrogen between change categories were limited to Segments 1 and 8, with loss polygons lower in total nitrogen in Segment 1 than in other categories and nitrogen higher in the loss polygons of Segment 8 than for other changes. In general, the gradient across specific categories of change did not correspond with polygon nitrogen concentrations in any consistent way.

While a relationship has been previously observed between nitrogen loading to the region and seagrass productivity (Tomasko and Hall, 1996), water column total nitrogen was relatively uniform across the various seagrass change categories within a given segment. More detailed investigation by specific change category (-3, -2, etc.) was often contradictory, with some gain and loss categories exhibiting similar total nitrogen concentrations, or some loss categories exhibiting relatively high nitrogen and other loss categories appearing much lower. It was anticipated that total nitrogen might serve as a useful surrogate for epiphytic attenuation on seagrass blades, an effect which further reduces available light. There proved to be low gradient of nitrogen concentration within individual segments, however, reducing the usefulness of nitrogen to evaluate seagrass change within a segment.

Nitrogen concentrations between segments varied widely (**Figure 17**), however, and a large body of literature leads us to expect ecological effects from differing concentrations. The water quality values of the polygons of no change (9113, 9116) were averaged by time period, by segment and by category. A simple but significant regression was developed in which the depth of the polygons of no change were significantly predicted by attenuation coefficient and total nitrogen alone (n=48, r^2=0.378, p<0.0001). Additionally, an important component of attenuation is chlorophyll, itself a function of nitrogen. It is evident that nitrogen plays an important role in regulating the maximum depths at which seagrasses can exist in the Sarasota Bay system, but under current nitrogen loadings, it does not appear to be the most important variable *within a segment* for predicting seagrass change.

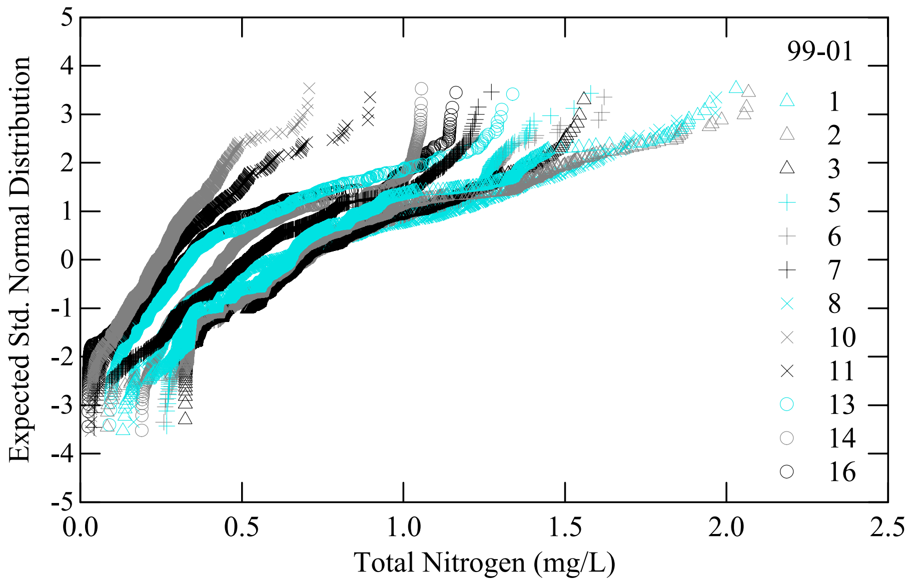

Figure 17. Distribution of total nitrogen by segment for 1999-2001.

Salinity values were similarly evaluated. High salinities were not expected to be problematical for seagrasses in the Sarasota Bay system based on reported tolerances, but excursions of freshwater are linked to leaf loss (Zieman and Zieman, 1989). In 96-99, Segment 8 loss categories experienced significantly different salinities than either unchanged or gain categories (**Figure 18**) with differences most apparent in the low salinity distributions. The lowest salinities were between 7-13 PSU for all categories. The lowest salinities of the loss category polygons were approximately 2-5 PSU lower than non-loss categories. For Segment 10 on the other hand, the salinities of loss polygons were significantly higher. In 99-01 data, salinity of loss polygons was depressed overall in Segment 8. No other segment experienced significant differences by loss category, although distributions often differed by ~1 PSU in the low salinity 'tails'. Other than Segment 8 in 96-99, observed differences, based on spatially interpolated data developed from monthly samplings, did not appear substantive enough to account for losses.

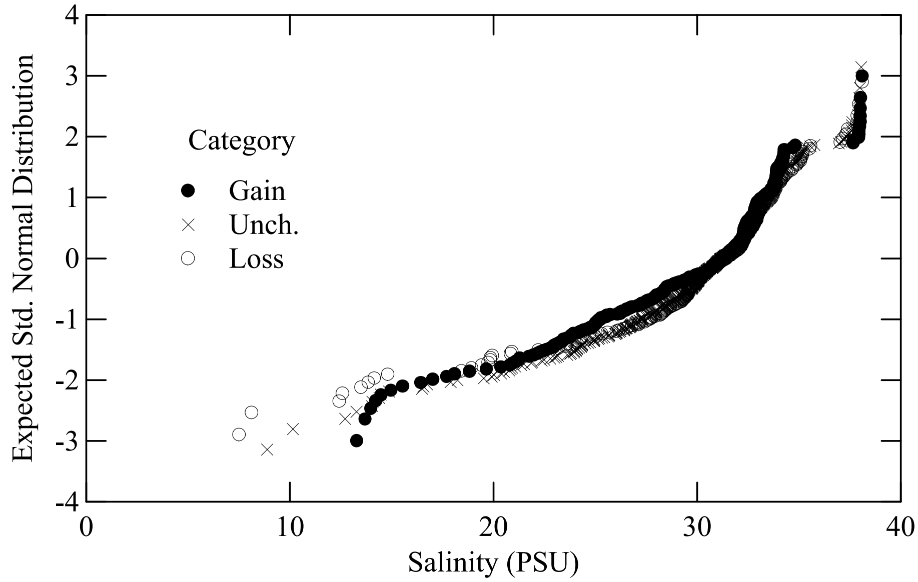

Figure 18. Distribution of salinity by general change category for Segment 8, 1996-1999.

The salinity distribution of polygons of no change (9113 and 9116) in both 96-99 and 99-01 appear in **Figure 19**. Segments 8, 13, 14, and 16 routinely experience salinity depressions below 15 PSU with Segment 13 as low as 7-8 PSU. The remaining segments have minima between 18 and 28 PSU. The low values experienced by polygons of no change would appear to indicate that the few salinity differences observed by loss category, while statistically significant, were not environmentally relevant.

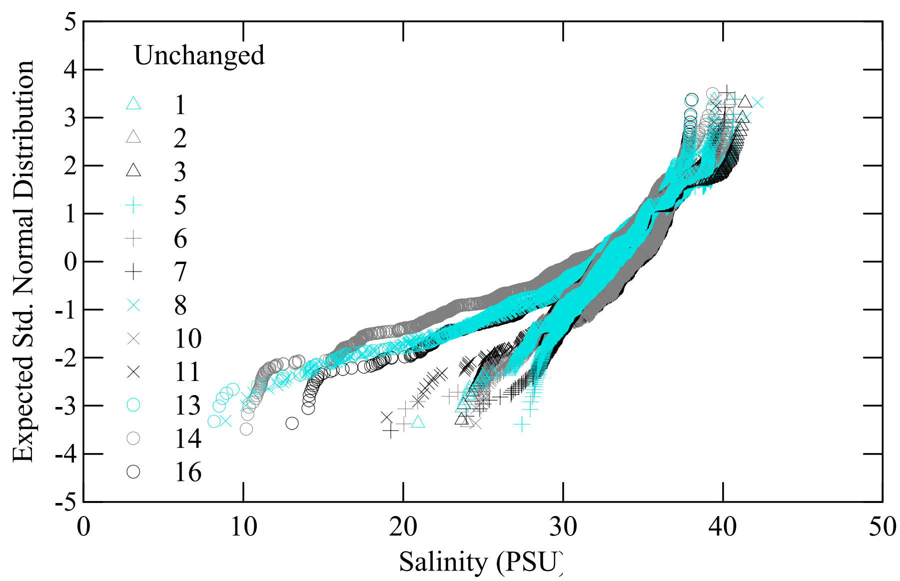

Figure 19. Distribution of salinity by segment for unchanged polygons (9113 and 9116) during both 1996-1999 and 1999-2001.

Available light

Light levels at the seagrass bed are a function of both water column depths and attenuation coefficients (which are in turn a function of chlorophyll, turbidity, and water color). To integrate depth and water column characteristics, the fraction of immediately subsurface light still available to the seagrasses was calculated from the mean monthly attenuation value of each polygon together with mean water column depths (bed elevation plus the additional water column between MLLW and mean tide level). This approach did not account for attenuation by epiphytes. With the exception of Segment 13 during 1999-2001, all segments displayed significant differences (Kruskal-Wallis, p<=0.05) in available light fraction between general change categories. Most (20 of the 24 segment-period combinations) were highly significant (p<=0.001). Counterintuitively, however, in nine of the 24 combinations, median values of available light for the loss polygons were greater than the median light received by polygons of no change. When investigated by exact change category, the pattern was as inconsistent as it appeared for total nitrogen.

Distributions of light fraction, however, were more useful. Significant differences (Kolmogorov-Smirnov, p<=0.05) appeared between general change categories for all but one of the segment-time period combinations (**Table 3**). Many of the segment comparisons, particularly in 96-99, displayed the lowest light distributions for the general loss category. The results in Segment 7 (**Figure 20**) were somewhat expected based on the depth distribution of polygons by change category within the segment. Even in segments where depth distributions were comparable across change categories (Segment 10, 99-01, **Figure 21**), light distributions were significantly lower for the general loss category. Results from Segments 1-8 in the 99-01 time period should be viewed with caution as 2001 data on light attenuation were not available for these segments and as attenuation coefficients in 2001 from other segments were elevated over 2000 data. Qualitative and quantitative distributions of light fraction by change category were almost identical for the data truncated to the growing season (April-October).

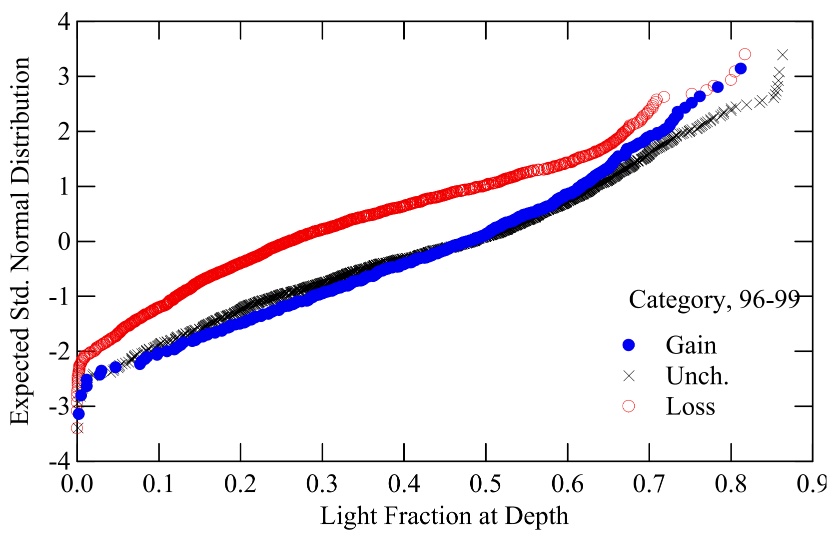

Figure 20. Distribution of light fraction at depth by general change category for Segment 7, 1996-1999.

Table 3. Distribution of fraction of light at the bottom of the water column by general change category and evaluation of potential for low light based on depth distributions by change category

Time Period	Segment	Sig. Diff. in Light Frac., (K-S, $p<=0.05$)	Possible Low Light Effects	Comments
96-99	1	Y		'L','U' comparable light, lower than 'G'
96-99	2	Y		'L' higher at high light
96-99	3	Y	Y	'L' lowest light overall
96-99	5	Y	Y	'L' lowest light overall
96-99	6	Y	Y	'L' lowest light overall
96-99	7	Y	Y	'L' lowest light overall
96-99	8	Y	Y	'L' lowest light overall, medium at high light
96-99	10	Y		'L' highest light overall
96-99	11	Y	Y	'L' lowest light overall
96-99	13	Y		'G' lowest light overall, 'L' lower at low light
96-99	14	Y		'L' highest light overall
96-99	16	Y		'L', 'G' comparable light and lower than 'U'
99-01*	1	Y		'L' highest light overall
99-01*	2	Y	Y	'L' lowest light overall
99-01*	3	Y		'U' lowest light overall, few 'L'
99-01*	5	Y		'L' highest light overall
99-01*	6	Y		'L' higher at low light, lower at high light
99-01*	7	Y		all very comparable
99-01*	8	Y		'L' higher light overall
99-01	10	Y		'L lower light overall, esp. at high light
99-01	11	Y		'L' lower at low end, higher at high light
99-01	13			all very comparable
99-01	14	Y		all very comparable
99-01	16	Y	Y	'L' lowest light overall

* - Data from 2001 unavailable

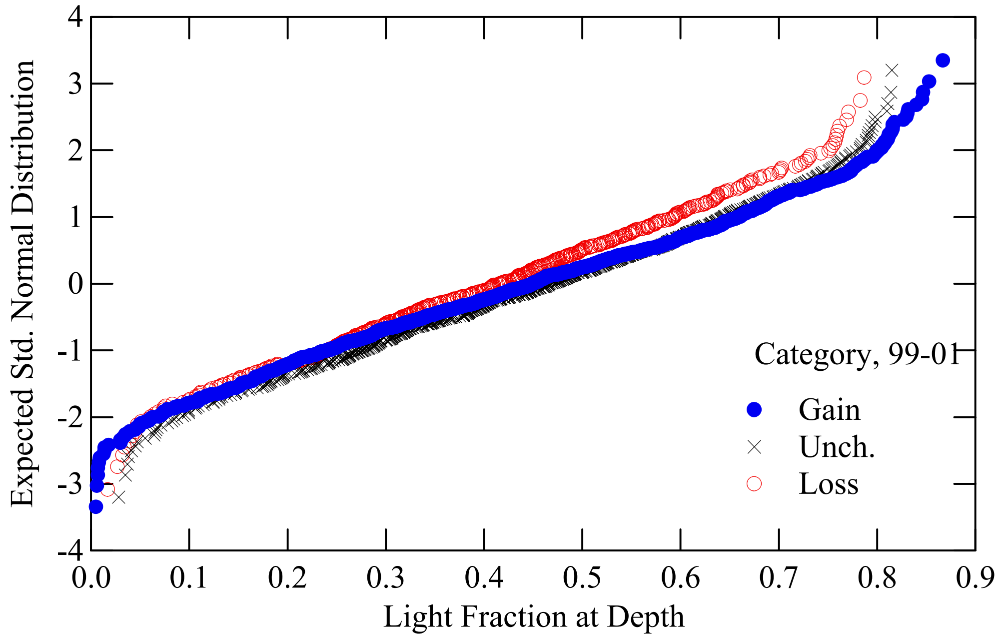

Figure 21. Distribution of light fraction at depth by general change category for Segment 10, 1999-2001.

Even for segments with complete data sets and large separations in both light and depth distributions by general change category, segregation of the light distributions by specific change category again produced conflicting results. **Figure 22** illustrates Segment 8, 96-99, for the specific change categories. Depth distributions appear in **Figure 23**, and it was apparent that a single shallow polygon produced the very high light levels of the -3 loss category. With little variation in attenuation coefficients within segments, the fraction of light available was largely a function of the depth of the water column within a given segment. The seagrass in the shallow polygon was more likely lost as a result of exposure rather than low light levels. This illustrates the complexity of assigning probable cause to changes in seagrass coverage.

The distribution of light fraction by specific change category was examined in the more complete data record of 1996-1999 (e.g., **Figure 22**). In all segments with the exception of Segments 10 and 14, the change category of -2 (patchy to unvegetated) experienced lower light levels in both the center and in the low light 'tail' of the distribution. Means of light fraction by specific categories and by segment for 96-99 also illustrated this (**Figure 24**). The other loss categories, in aggregate, generally experienced as much or higher light levels than did unchanged or gain polygons. In fact, the loss category of -3 (continuous to unvegetated) often experienced the highest mean light levels. Segment and category means of polygon elevation (**Figure 25**) also illustrated that the -3 and -1 loss categories were generally shallower than other polygons and indicated that there was more than one factor responsible for changes in seagrass coverage in the Sarasota Bay system.

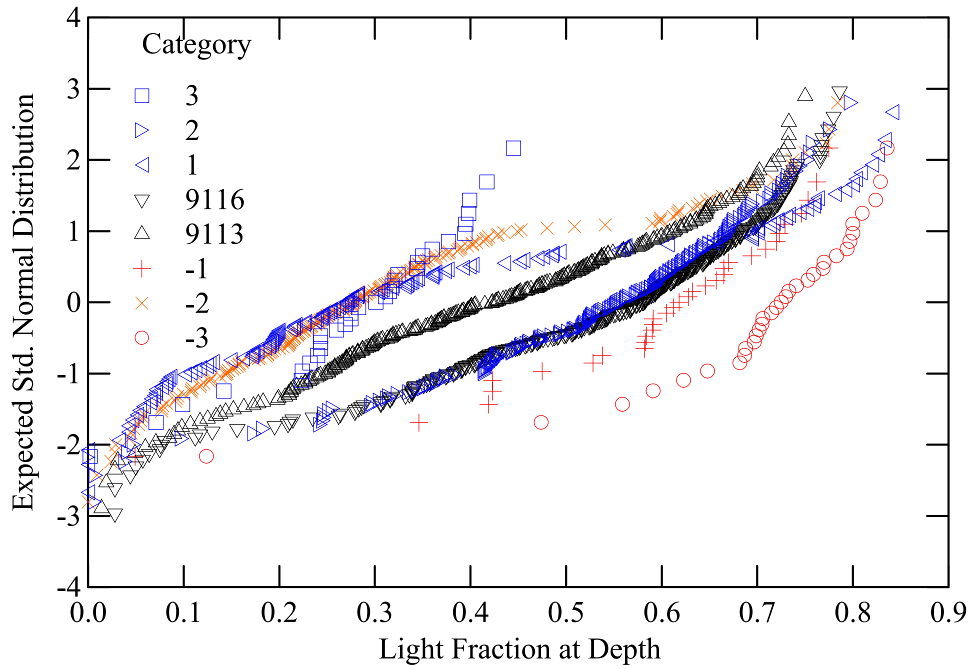

Figure 22. Distribution of light fraction at depth by specific change category for Segment 8, 1996-1999.

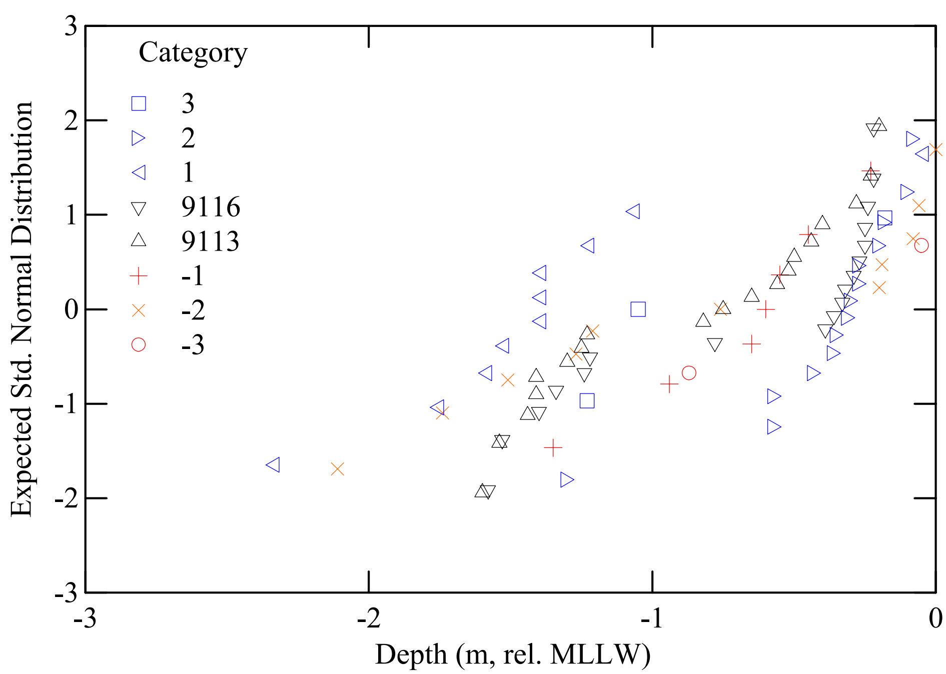

Figure 23. Distribution of polygon depths by specific change category for Segment 8, 1996-1999.

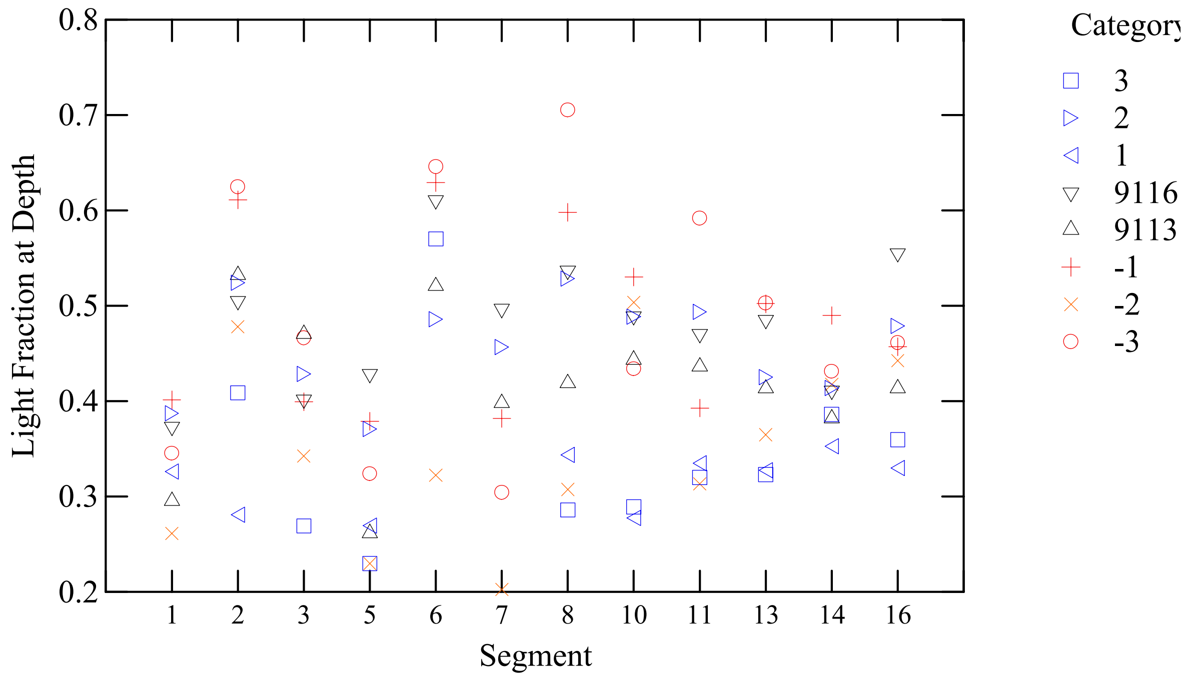

Figure 24. Mean light fraction at depth for 1996-1999, by segment and specific change category.

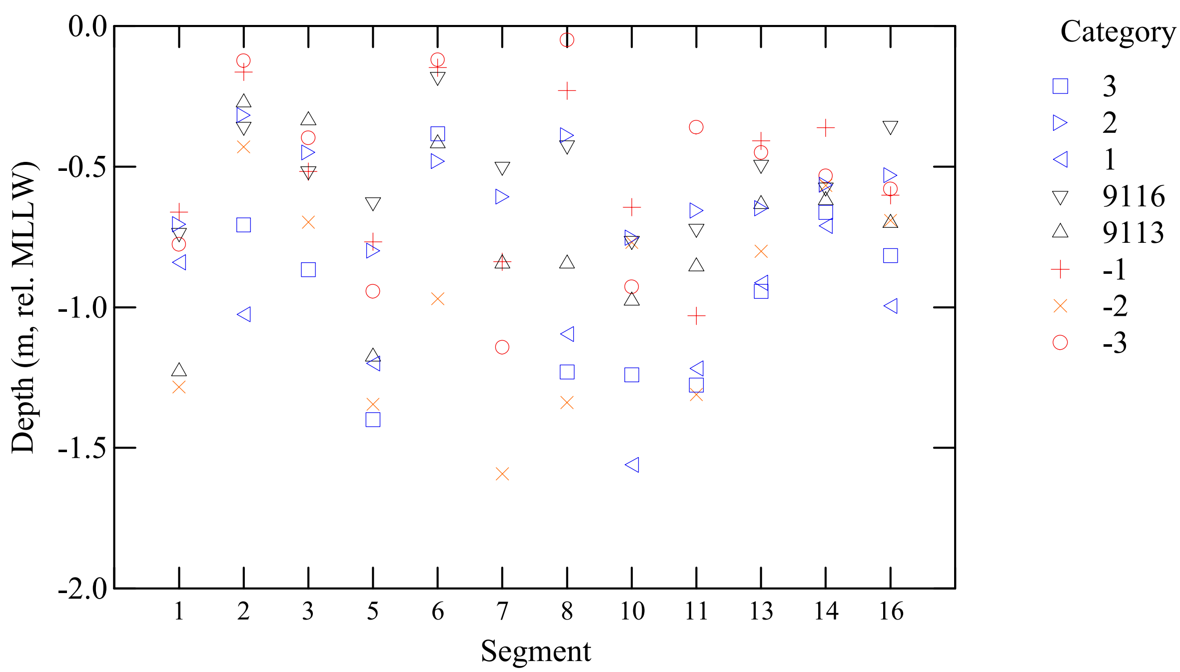

Figure 25. Mean polygon elevation for 1996-1999 by segment and specific change category.

Further analyses of light levels with respect to seagrass change examined the duration of low light events as interpolated from available data. Selected seagrass compensation points were evaluated against a modeled record of hourly light records for individual polygons. Modeled water column elevations, the insolation record, and linear interpolation of attenuation coefficients between monthly estimates were used to generate the record of available light. A number of assumptions were implicitly included and discussed in the methods section, and while comparisons between segments may be subject to errors due to known approximations, inferences within segments but between change categories should be robust.

Analyses concentrated on the 96-99 period due to the completeness of the water quality record. Parameters examined included monthly values of total duration below selected compensation points, as well as the longest period of time where light levels were continuously below the compensation point. Larger values of the two parameters were indicative of lower ambient light levels. Using 25 $\mu E\ m^{-2} sec^{-1}$ as a compensation point and within a given segment, the polygons of general loss categories had either similar or longer durations below the compensation point than did unchanged or gain polygons. Differences between change categories were more prevalent in the center of the distribution and at the low light, longer duration tails rather than in the short duration region. All segments exhibited significant differences by general change category, with differences consistent with light limitation in Segments 3, 5, 6, 7, 11, and 16 (**Figure 26**). Segments 5 and 7 in particular exhibited a number of months where ambient light in a loss polygon did not exceed the estimated compensation point for the entire month.

If higher compensation points were used, changes in the distribution of the above parameters for a given segment or change category altered in predictable ways (**Figure 27**); duration below the compensation point and the continuous time below the compensation point both increased. Separation between general change categories was greatest for lower compensation points, however. The use of higher compensation points also increased the number of months where polygons of all change categories did not exceed the compensation point, and so their use for a species commonly accepted to be depth and light-limited appears less reasonable. Without further knowledge as to the species distribution within the Sarasota Bay system and the length of time that a given species can survive when photosynthesis does not exceed respiration, however, the change analysis cannot differentiate between appropriate compensation points except in a qualitative sense.

Returning to the 25 $\mu E\ m^{-2} sec^{-1}$ compensation point, and examining the continuous number of days in a month when light levels did not exceed the compensation point, an interesting pattern appears between segments. In Segments 1, 3, 5, 6, 7, and 8, the longest continuous durations appeared between July and December, and were predominantly in August through October of 1999. Many were longer than 10 days. The remaining segments experienced much lower continuous durations with the larger ones during the winter months, October through February. Increased periods of light below the compensation point during the warmer growing season would be expected to have a more deleterious impact than low light periods during cooler periods.

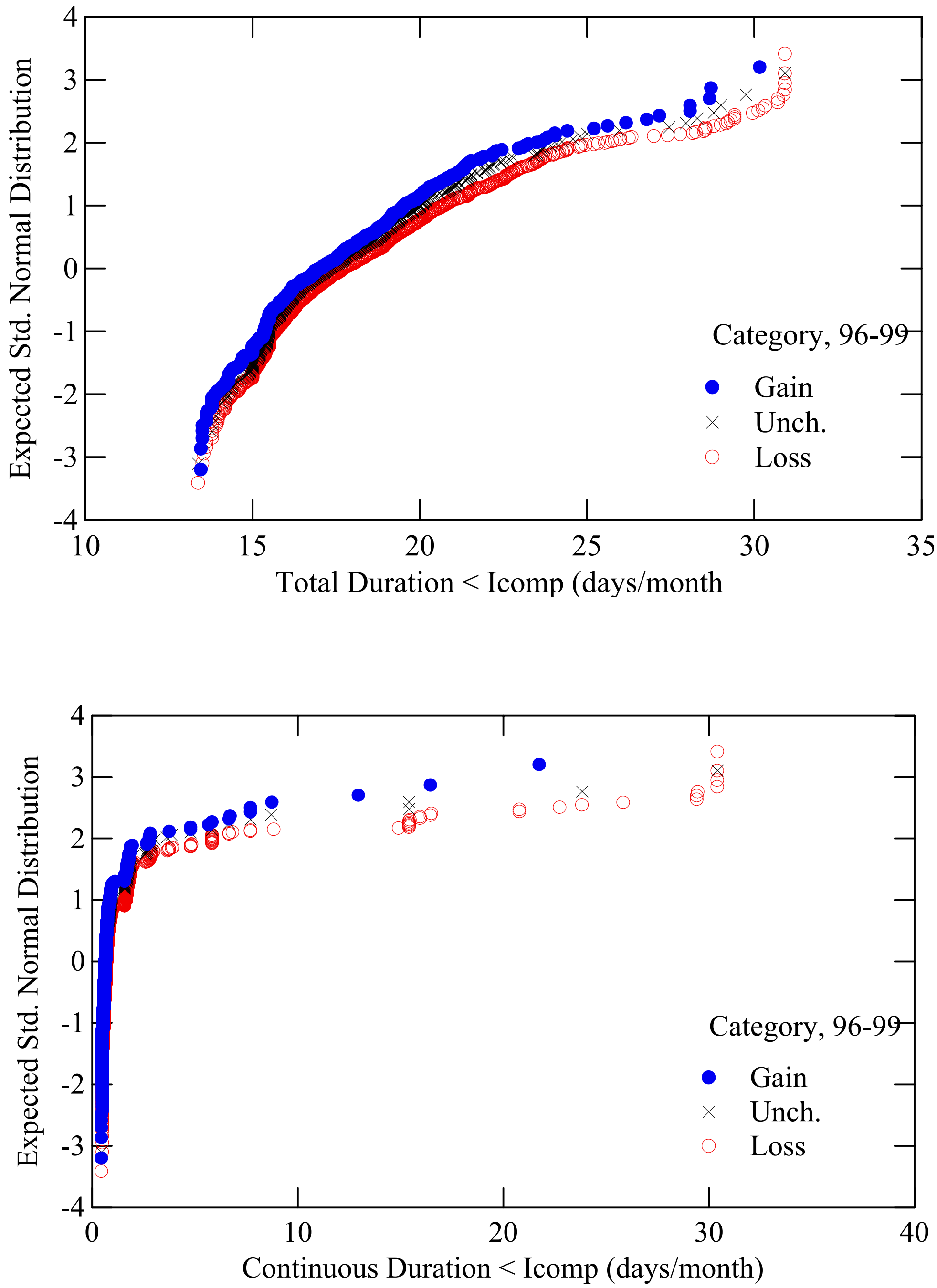

Figure 26. Light duration parameters for Segment 5 using compensation irradiance of 25 µE m^2 sec^{-1}

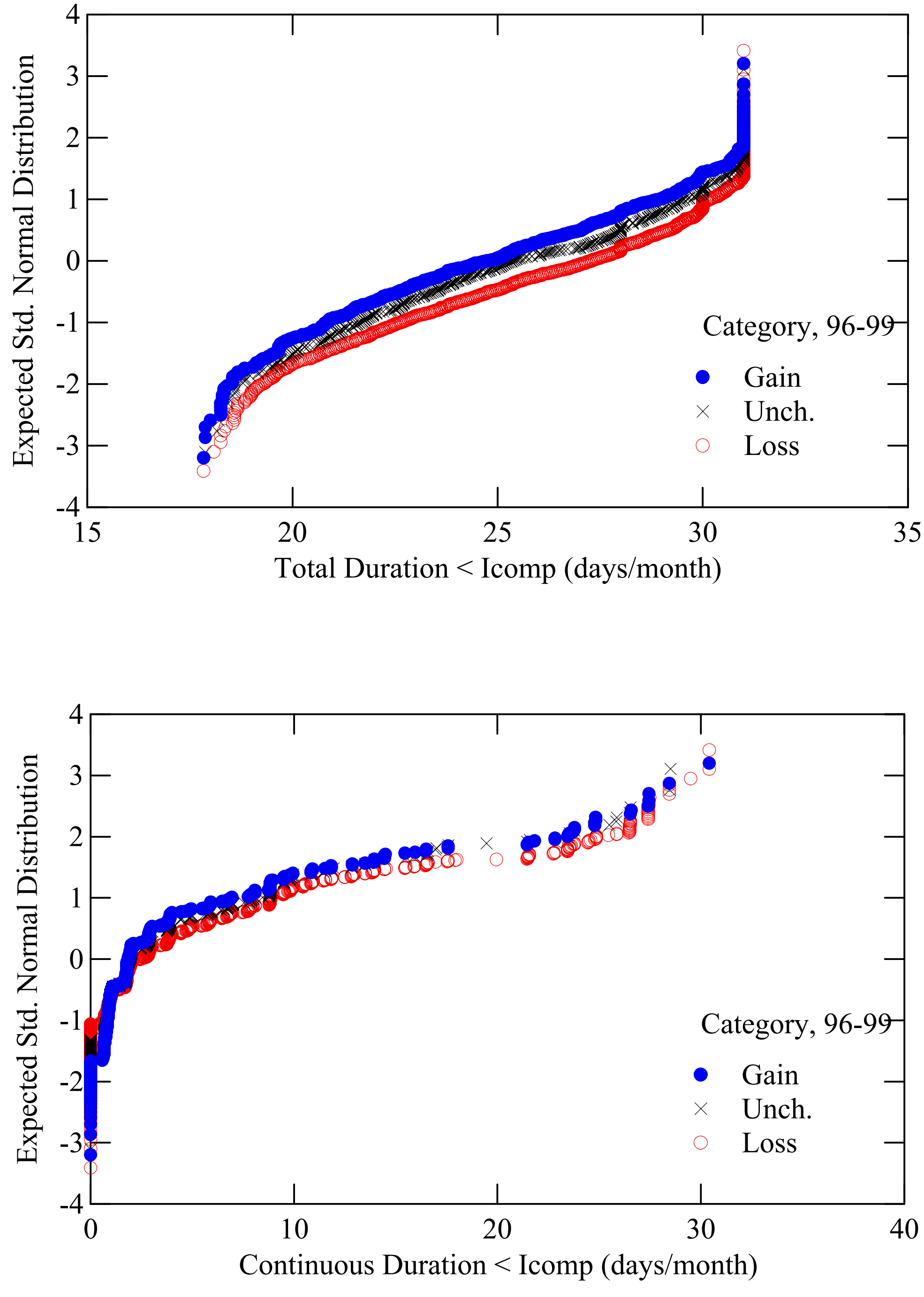

Figure 27. Light duration parameters for Segment 5 using compensation irradiance of 200 µE m^2 sec^{-1}

The analysis of the modeled light record by specific change categories displayed similar patterns to the other parameters. While some segments exhibited expected patterns of extended low light duration with losses, others did not, indicating that some losses of seagrass can be attributed to causes other than low light levels. Due to the low within segment variation in attenuation coefficients and the dependence of light fractions and durations on water column depth, detailed light simulations have very similar distributions to that observed for polygon depths.

Temperature

The modeled temperature of a single polygon (**Figure 28**) illustrates that the winters of 1995-6, 1996-7, and 2000-2001 contained some extreme cold days, but that the winter of 1997-8 experienced an extended cold season. The summer of 1995 and 2000 were both warm for extended periods of time. Consistent with the cold winter (and presumed cold fronts) of 1995-6, there were a number modeled low tide events during this season (**Figure 29**).

As expected, the minima of modeled temperatures were lower in the shallower polygons, and as such, the temperature distributions were expected to appear similar to depth distributions. Durations below selected set points (10˚C and 15˚C) were both evaluated. While some segments (Segments 8, 11, and 13) experienced longer durations, durations for all categories were seldom predicted to be longer than ~10 hours, differences between change categories were slight (<1 hour) and none were statistically significant. In some segments, loss categories of -1 and -3 experienced generally longer durations of temperatures below set points than did loss category -2. This result is again a product of the elevation and assumed water column depth above a polygon. In most instances, however, distribution of temperatures for gain or unchanged categories were very similar to that modeled for loss polygons.

High temperatures were also evaluated. Duration above high temperature set points (32˚C, 35˚C) were surprising in that the longest average durations were experienced by unchanging or gain polygons. In some segments, loss polygons experienced among the highest temperatures, while in other segments, gain or unchanged polygons experienced as high or higher temperatures. Modeled thermal maxima and/or minima did not appear to be a controlling factor of seagrass change.

The model of thermal extremes for seagrasses does not incorporate actual exposure and dessication of grasses since it was not possible to verify the water column depths and actual tidal regimes above polygons under this project. Grasses are observed to be exposed at times in Sarasota Bay and so the probability for losses in shallow polygons due to exposure (**see Figure 25**) remains high but cannot be quantified at this time.

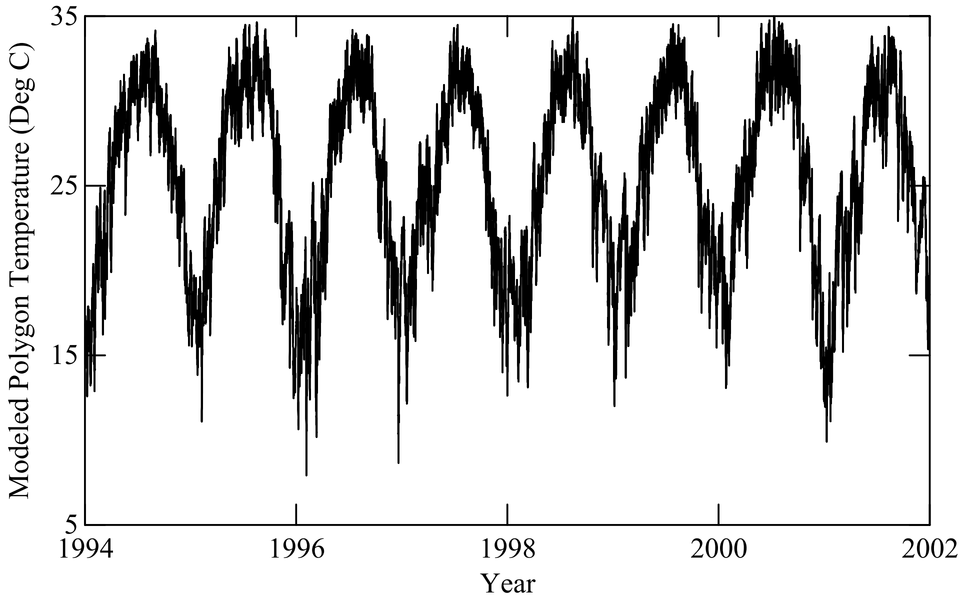

Figure 28. Time series of modeled temperatures for a single polygon.

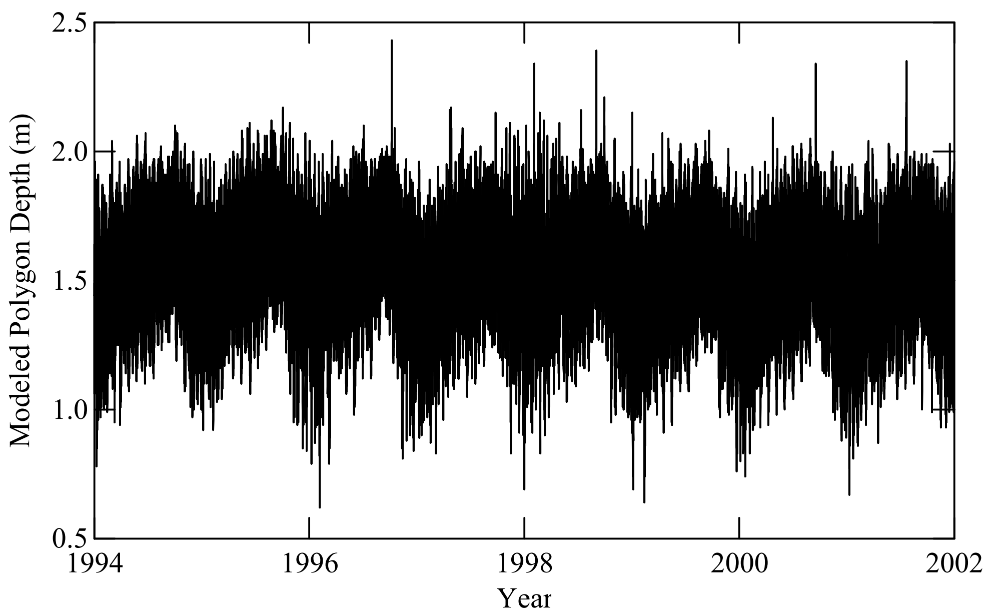

Figure 29. Time series of modeled water column depths for a single polygon.

Summary

A subset of seagrass change polygons was selected for the Sarasota Bay area and analyzed for the 1996-1999 and 1999-2001 periods. Polygons with changes similar to nearby shoreline changes were not included so as not to include spurious change due to improvements in locational accuracy between different periods of photo-interpretation. As not all polygons were included, no attempt was made to weight the remaining polygons for differences in areas. Analyses focused on the 1996-1999 time period due to the completeness of the water quality record available.

Seasonal differences in biomass could account for some of the losses observed between 1996 and 1999, as the 1996 photography was flown between April and October, in comparison to December-January flights for the remaining periods. The large areas of loss in central Sarasota Bay were predominantly due to the disappearance of numerous small patches at depth, and were consistent with seasonal patterns of *Halodule* growth observed nearby. Not all of the loss may have been seasonal however, as some gains were noted between 1999 and 2001 in the same regions.

Looking at unchanged seagrass polygons, patchy seagrass predominated at depth in central Sarasota and Roberts Bays. General loss categories were also predominantly deeper in Sarasota Bay (Segments 5, 6, 7, and 8). The distribution of polygon depths was more useful than mean or median values for interpreting losses and gains, however. Depth distributions were significantly different by general change category in Segments 5, 6, 7, and 13, but losses were deeper in Segment 5, 6, and 7, and shallower in Segment 13. Segments 2, 6, 8, 13, and 14 had been identified as potentially subject to exposure losses due the number of shallow polygons in those segments. Using specific change categories (patchy to bare, etc.), loss categories did not exhibit a consistent depth gradient in any segment. A number of segments exhibited losses of patchy to bare (-2) at depth, while losses of continuous to patchy (-1) and continuous to bare (-3) occurred at very shallow depths. Some categories of gain received less light than did some loss categories. It was clear that reduced light at depth was not the only cause of seagrass loss.

Monthly water quality values (total nitrogen, salinity, attenuation coefficients and other attenuators) were spatially interpolated and means computed for all segments and polygons. Gradients within a segment were generally not high, and so there was little variation in water quality either among all polygons or between any change categories for polygons *within a given segment.* The few significant differences observed between change categories in salinity or nitrogen within a segment did not appear to be environmentally relevant when viewed in respect to distributions experienced by polygons of no change. Variations in water column nitrogen, while not associated with change categories within a segment, was significantly corrected (together with attention is efficient) with the depth of stable seagrass beds for the entire Sarasota Bay system. As a result, total nitrogen should continue to be considered in any seagrass restoration plan.

The light fraction available at depth was computed for all polygons from monthly attenuation coefficients and estimated water column depths. As gradients in attenuation were low across a given segment, distributions of light fraction were generally very similar to that expected based on polygon depth. Significant differences existed in all polygons and light fractions were lower in the general loss category for Segments 3, 5, 6, 7, 8, 11, and 13. Specific categories of change were as varied for light fraction as they were for depths.

Using a number of assumptions, detailed estimates of time series of light at depth and polygon temperature were prepared and compared to literature values where deleterious effects are thought to occur. Both estimates depended largely on the water column depths of individual polygons and the assumption that the difference between MLLW and mean tide level (MTL) was uniform across the bay with respect to the tidal reference station. It is expected that any differences between MTL and MLLW were smaller within segment than between segments and so comparisons between change categories within a segment were correspondingly more robust than comparisons between segments. Differences in distribution of duration of light below selected compensation points and between change categories again reduced to patterns similar to that expected from the depth distributions. The gradient of light available did not uniformly correspond with a progression of specific loss and gain categories. There were few differences in the distribution of thermal extremes by change category, either general or specific. Actual exposure and dessication, which could not be evaluated due to uncertainties in MTL across segments, remain a likely cause of losses in the shallowest polygons.

Low light was associated with seagrass losses, particularly in 1996-1999 and in north and central Sarasota Bay. An incomplete record of water quality hampered comparisons in 1999-2001, but low light was again associated with general losses in some segments. Selected categories of loss were associated with very shallow polygons in some segments and may be attributed to exposure. Depressed salinities were present in Segments 8, 13, 14, and 16 but values were comparable to areas with no change. Salinity effects alone did not appear responsible for seagrass losses or gains. Nitrogen did not vary among the change categories within a given segment but was significantly and inversely related to the depths of stable polygons of seagrass.

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Appendix A

Distribution of polygon change categories by time period and by segment.

Period	Segment	Change Category	Number of Polygons	Mean Elevation (m, MLLW)	Area (m^2)
96-99	1	-3	3	-0.8	12,600
96-99	1	-2	6	-1.3	24,300
96-99	1	-1	17	-0.7	135,000
96-99	1	9113	6	-1.2	936,900
96-99	1	9116	9	-0.7	1,032,300
96-99	1	1	1	-0.8	6,300
96-99	1	2	19	-0.7	711,000
96-99	2	-3	3	-0.1	4,500
96-99	2	-2	17	-0.4	75,600
96-99	2	-1	9	-0.2	84,600
96-99	2	9113	10	-0.3	232,200
96-99	2	9116	9	-0.4	1,197,900
96-99	2	1	2	-1.0	2,700
96-99	2	2	23	-0.3	1,145,700
96-99	2	3	3	-0.7	66,600
96-99	3	-3	5	-0.4	30,600
96-99	3	-2	19	-0.7	163,800
96-99	3	-1	4	-0.5	24,300
96-99	3	9113	7	-0.3	183,600
96-99	3	9116	5	-0.5	216,900
96-99	3	2	14	-0.4	174,600
96-99	3	3	3	-0.9	2,700
96-99	5	-3	3	-0.9	6,300
96-99	5	-2	33	-1.3	403,200
96-99	5	-1	11	-0.8	45,000
96-99	5	9113	11	-1.2	431,100
96-99	5	9116	5	-0.6	2,003,400
96-99	5	1	1	-1.2	1,800
96-99	5	2	20	-0.8	653,400
96-99	5	3	1	-1.4	900
96-99	6	-3	2	-0.1	8,100
96-99	6	-2	27	-1.0	342,000
96-99	6	-1	10	-0.1	183,600
96-99	6	9113	19	-0.4	692,100
96-99	6	9116	7	-0.2	790,200
96-99	6	2	19	-0.5	1,901,700
96-99	6	3	3	-0.4	34,200
96-99	7	-3	5	-1.1	54,900
96-99	7	-2	20	-1.6	1,427,400
96-99	7	-1	20	-0.8	120,600
96-99	7	9113	20	-0.8	1,285,200
96-99	7	9116	24	-0.5	981,000
96-99	7	2	18	-0.6	1,168,200
96-99	8	-3	1	-0.1	1,800
96-99	8	-2	6	-1.3	547,200
96-99	8	-1	1	-0.2	2,700
96-99	8	9113	8	-0.8	205,200
96-99	8	9116	10	-0.4	290,700
96-99	8	1	4	-1.1	10,800
96-99	8	2	6	-0.4	576,900
96-99	8	3	1	-1.2	2,700

Period	Segment	Change Category	Number of Polygons	Mean Elevation (m, MLLW)	Area (m2)
96-99	10	-3	5	-0.9	74,700
96-99	10	-2	10	-0.8	163,800
96-99	10	-1	21	-0.6	126,900
96-99	10	9113	9	-1.0	318,600
96-99	10	9116	9	-0.8	1,566,900
96-99	10	1	2	-1.6	43,200
96-99	10	2	22	-0.8	245,700
96-99	10	3	1	-1.2	6,300
96-99	11	-3	1	-0.4	6,300
96-99	11	-2	4	-1.3	45,000
96-99	11	-1	4	-1.0	20,700
96-99	11	9113	6	-0.9	603,000
96-99	11	9116	1	-0.7	4,500
96-99	11	1	4	-1.2	34,200
96-99	11	2	10	-0.7	122,400
96-99	11	3	3	-1.3	13,500
96-99	12	2	1	0.0	18,900
96-99	13	-3	3	-0.5	10,800
96-99	13	-2	10	-0.8	90,900
96-99	13	-1	6	-0.4	63,000
96-99	13	9113	9	-0.6	476,100
96-99	13	9116	7	-0.5	215,100
96-99	13	1	7	-0.9	52,200
96-99	13	2	9	-0.6	98,100
96-99	13	3	3	-0.9	17,100
96-99	14	-3	3	-0.5	7,200
96-99	14	-2	12	-0.6	73,800
96-99	14	-1	6	-0.4	34,200
96-99	14	9113	16	-0.6	330,300
96-99	14	9116	15	-0.6	482,400
96-99	14	1	15	-0.7	115,200
96-99	14	2	22	-0.6	475,200
96-99	14	3	10	-0.7	157,500
96-99	16	-3	5	-0.6	12,600
96-99	16	-2	11	-0.7	66,600
96-99	16	-1	8	-0.6	36,900
96-99	16	9113	12	-0.7	299,700
96-99	16	9116	10	-0.4	237,600
96-99	16	1	6	-1.0	47,700
96-99	16	2	21	-0.5	389,700
96-99	16	3	11	-0.8	63,000
99-01	1	-3	1	-0.7	1,800
99-01	1	-2	5	-0.8	23,400
99-01	1	-1	1	-0.4	7,200
99-01	1	9113	12	-1.1	155,700
99-01	1	9116	19	-0.9	2,877,300
99-01	1	1	2	-1.1	9,900
99-01	1	2	52	-0.7	594,900
99-01	2	-2	3	-0.6	14,400
99-01	2	-1	2	-0.2	18,000
99-01	2	9113	9	-0.3	80,100
99-01	2	9116	15	-0.3	3,307,500
99-01	2	1	2	-0.2	45,900
99-01	2	2	36	-0.2	596,700
99-01	2	3	2	-0.3	25,200

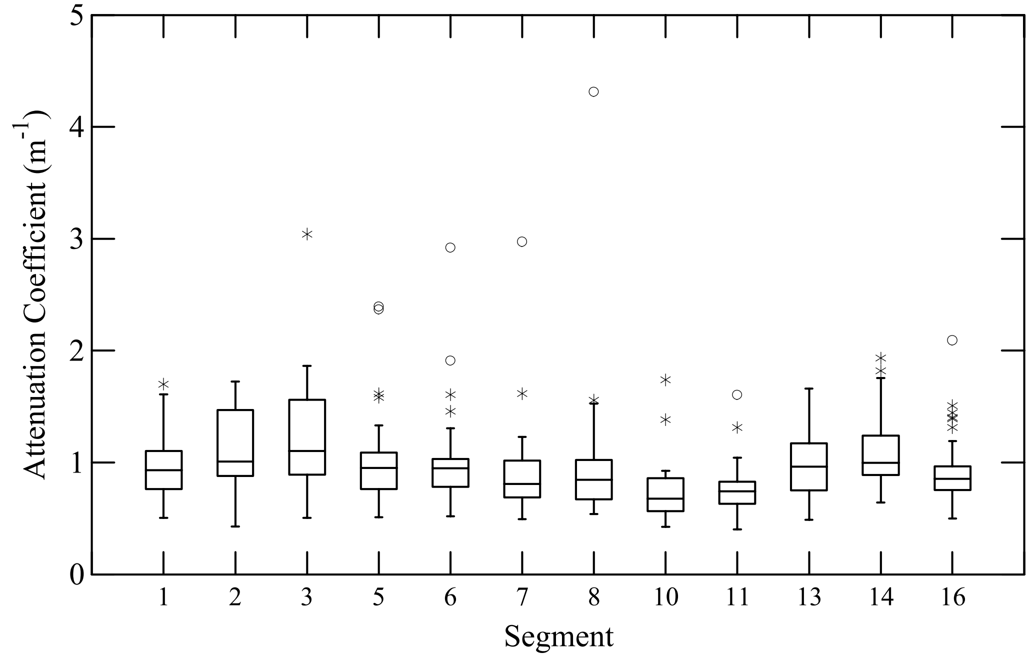
Period	Segment	Change Category	Number of Polygons	Mean Elevation (m, MLLW)	Area (m2)
99-01	3	-1	1	-0.5	3,600
99-01	3	9113	10	-0.5	193,500
99-01	3	9116	15	-0.6	667,800
99-01	3	1	1	-0.5	12,600
99-01	3	2	11	-0.4	74,700
99-01	3	3	2	-0.3	42,300
99-01	5	-3	2	-0.5	10,800
99-01	5	-1	10	-0.7	78,300
99-01	5	9113	26	-1.0	351,000
99-01	5	9116	8	-0.8	971,100
99-01	5	1	1	-1.2	5,400
99-01	5	2	15	-0.8	248,400
99-01	5	3	2	-1.2	9,000
99-01	6	-2	4	-0.6	17,100
99-01	6	-1	4	-0.5	37,800
99-01	6	9113	10	-0.8	169,200
99-01	6	9116	10	-0.7	3,035,700
99-01	6	1	1	-0.2	7,200
99-01	6	2	17	-0.5	207,000
99-01	6	3	2	-0.4	22,500
99-01	7	-3	1	-0.5	14,400
99-01	7	-2	9	-1.1	78,300
99-01	7	-1	3	-0.7	20,700
99-01	7	9113	21	-1.0	1,196,100
99-01	7	9116	11	-0.7	2,320,200
99-01	7	1	8	-1.3	115,200
99-01	7	2	17	-0.6	541,800
99-01	7	3	1	-0.8	26,100
99-01	8	-3	1	-0.9	5,400
99-01	8	-2	5	-0.2	48,600
99-01	8	-1	6	-0.8	35,100
99-01	8	9113	11	-0.9	137,700
99-01	8	9116	8	-1.0	953,100
99-01	8	1	6	-1.6	185,400
99-01	8	2	8	-0.4	38,700
99-01	8	3	2	-0.6	32,400
99-01	10	-3	4	-0.8	62,100
99-01	10	-2	10	-1.2	252,900
99-01	10	-1	5	-1.2	41,400
99-01	10	9113	12	-0.9	135,000
99-01	10	9116	16	-0.9	1,692,000
99-01	10	1	13	-1.2	167,400
99-01	10	2	27	-0.9	414,000
99-01	10	3	7	-1.3	86,400
99-01	11	-2	5	-0.9	93,600
99-01	11	-1	4	-1.0	18,900
99-01	11	9113	12	-1.1	642,600
99-01	11	9116	11	-0.6	185,400
99-01	11	1	4	-1.1	36,900
99-01	11	2	9	-0.9	154,800
99-01	11	3	3	-1.0	22,500

Period	Segment	Change Category	Number of Polygons	Mean Elevation (m, MLLW)	Area (m2)
99-01	13	-3	7	-0.7	89,100
99-01	13	-2	8	-0.7	155,700
99-01	13	-1	4	-0.5	75,600
99-01	13	9113	13	-0.6	406,800
99-01	13	9116	11	-0.7	246,600
99-01	13	1	2	-0.9	13,500
99-01	13	2	11	-0.8	174,600
99-01	13	3	3	-0.5	11,700
99-01	14	-3	8	-0.7	132,300
99-01	14	-2	11	-0.7	92,700
99-01	14	-1	8	-0.6	302,400
99-01	14	9113	21	-0.6	548,100
99-01	14	9116	19	-0.6	889,200
99-01	14	1	6	-0.9	98,100
99-01	14	2	12	-0.5	125,100
99-01	14	3	5	-0.7	54,900
99-01	16	-3	10	-0.8	194,400
99-01	16	-2	12	-0.8	128,700
99-01	16	-1	8	-0.6	61,200
99-01	16	9113	9	-0.5	178,200
99-01	16	9116	14	-0.4	561,600
99-01	16	2	13	-0.5	101,700
99-01	16	3	1	-0.8	19,800

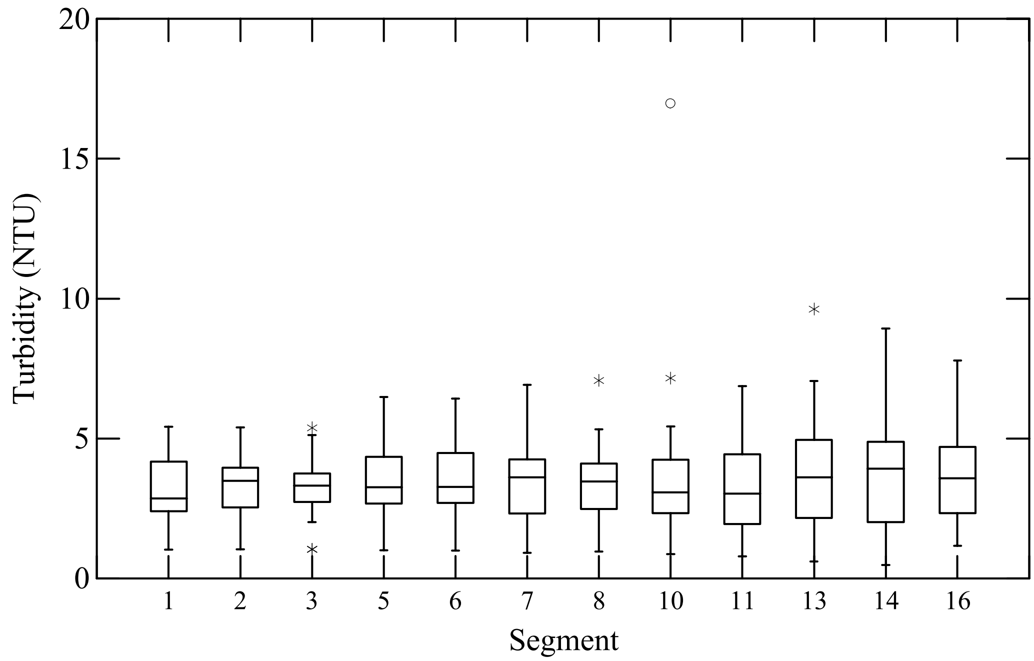
Appendix B

Distribution of water quality parameters by time period and by segment.

96-99 Period

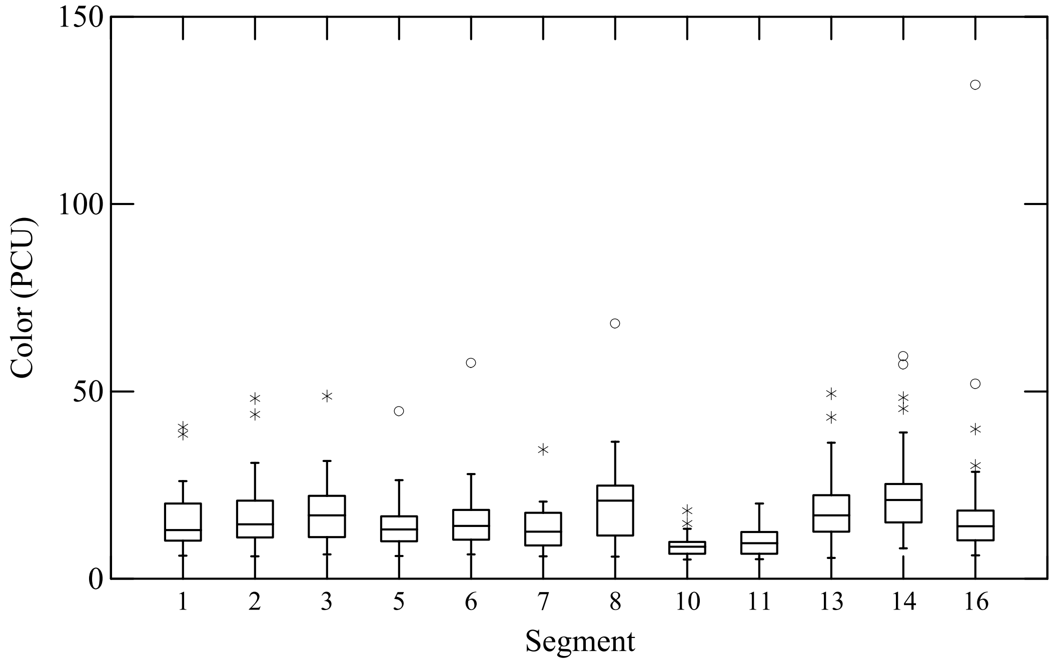


Attenuation Coefficient (m-1)
0
1
2
3
4
5
1
2
3
5
6
7
8
10
11
13
14
16
Segment

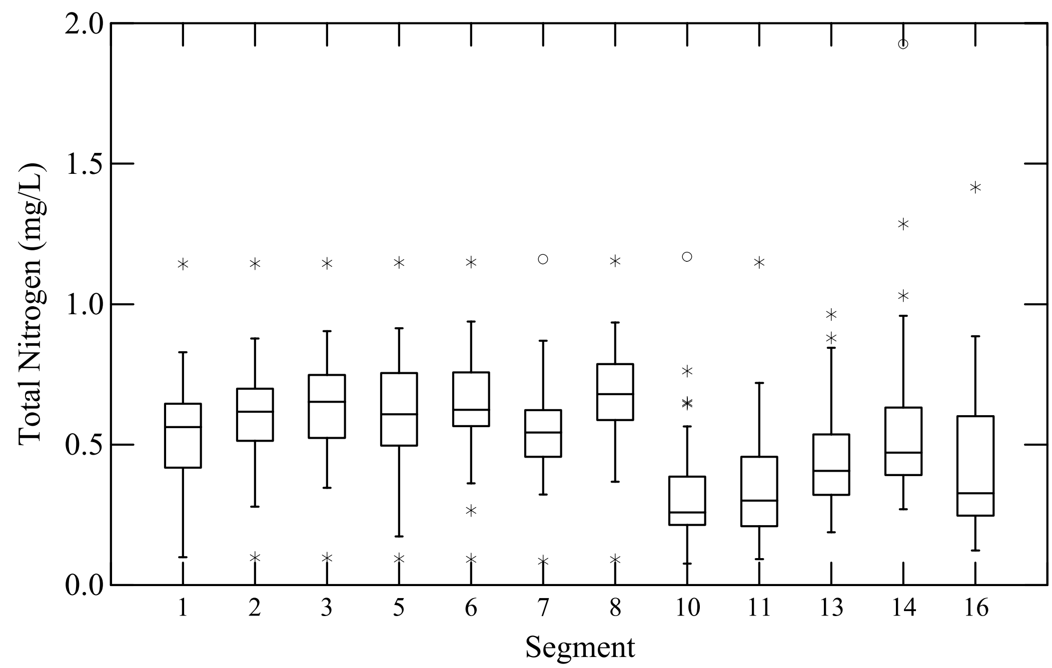


Turbidity (NTU)
0
5
10
15
20
1
2
3
5
6
7
8
10
11
13
14
16
Segment

96-99 Period

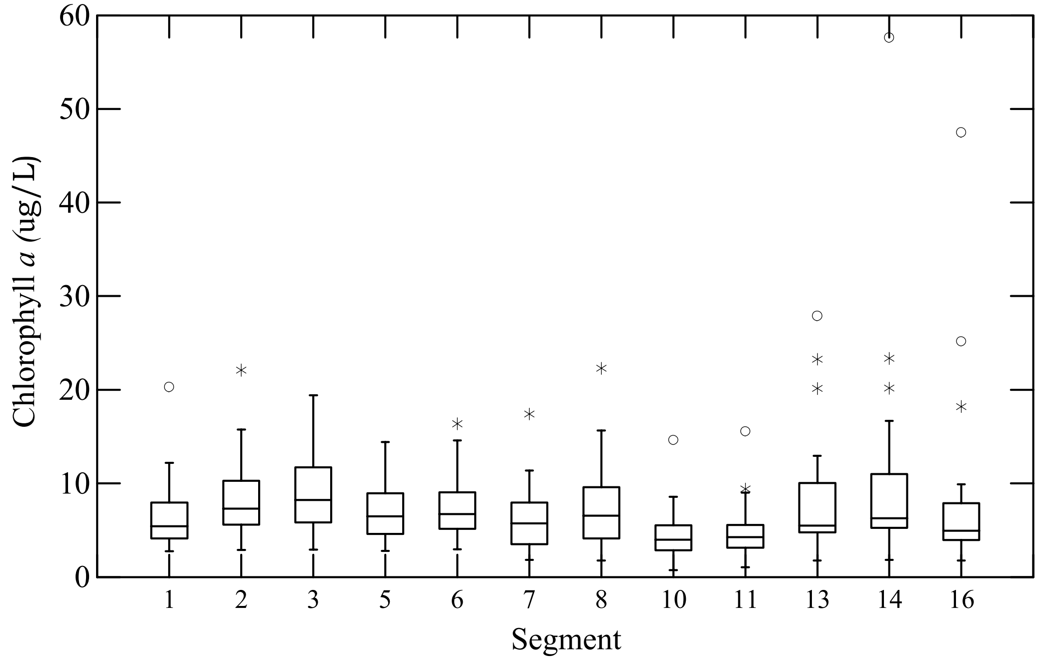


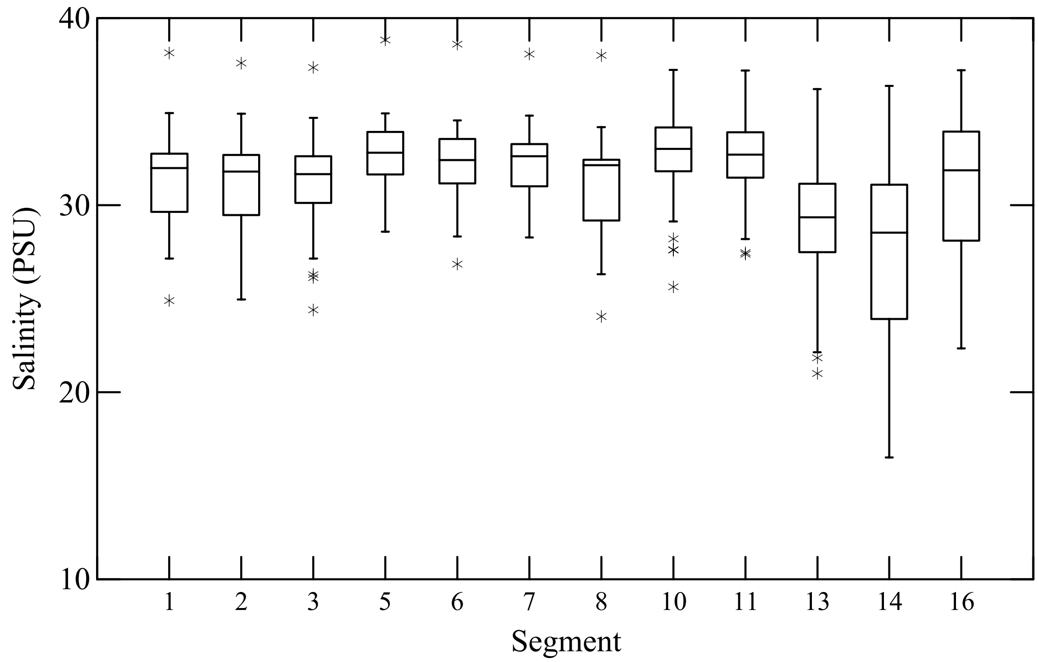
150
100
50
0
Color (PCU)
1
2
3
5
6
7
8
10
11
13
14
16
Segment



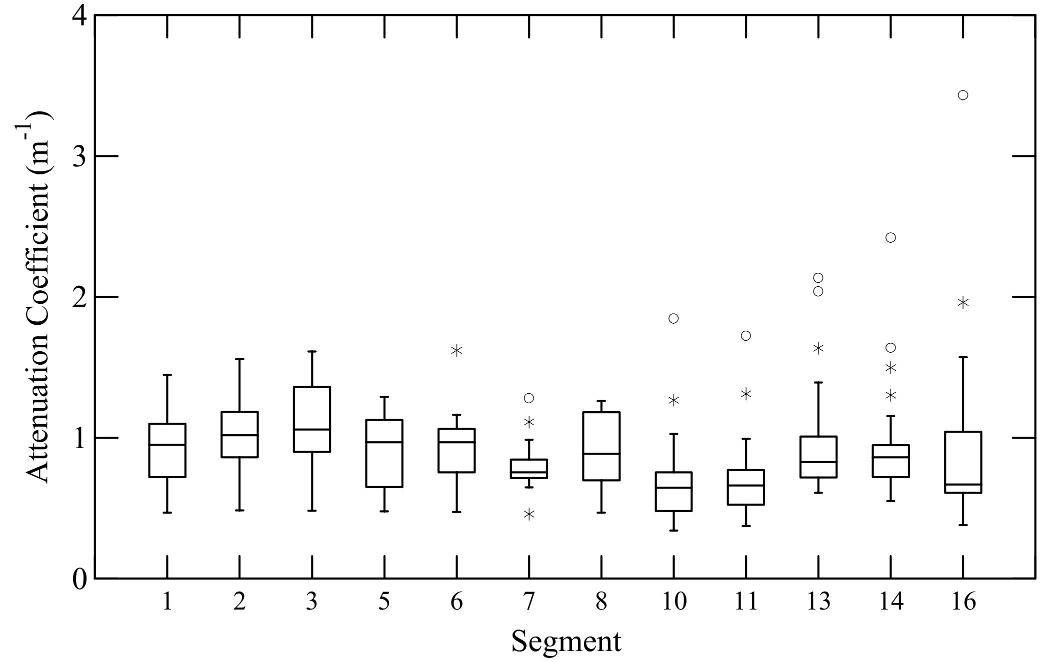
2.0
1.5
1.0
0.5
0.0
Total Nitrogen (mg/L)
1
2
3
5
6
7
8
10
11
13
14
16
Segment

96-99 Period

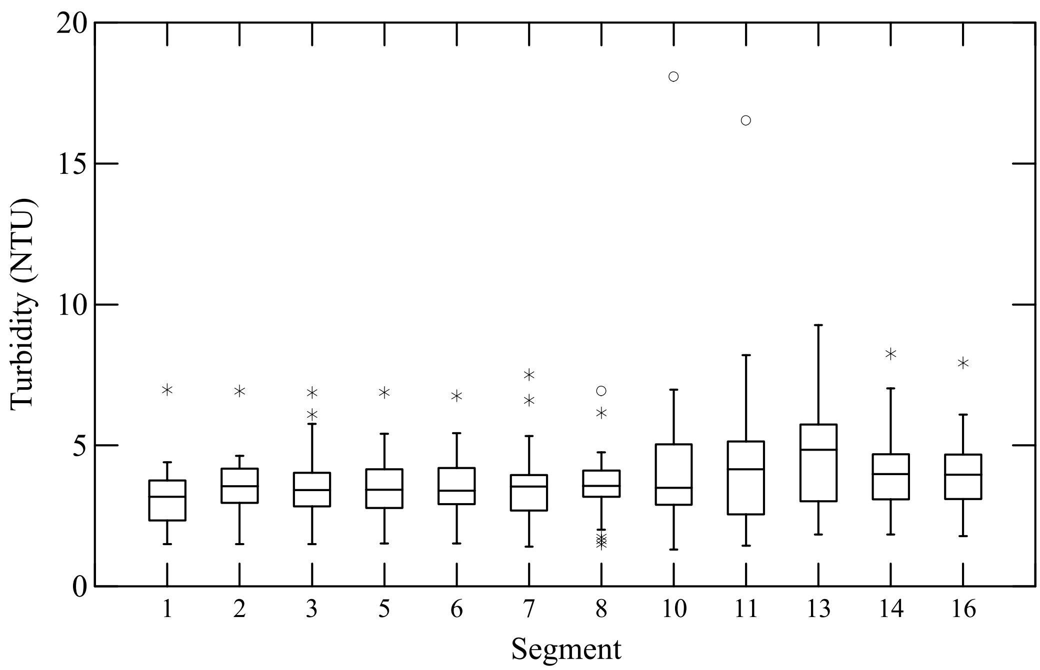

Chlorophyll a (ug/L)
0
10
20
30
40
50
60
1
2
3
5
6
7
8
10
11
13
14
16
Segment


Salinity (PSU)
10
20
30
40
1
2
3
5
6
7
8
10
11
13
14
16
Segment

99-01 Period

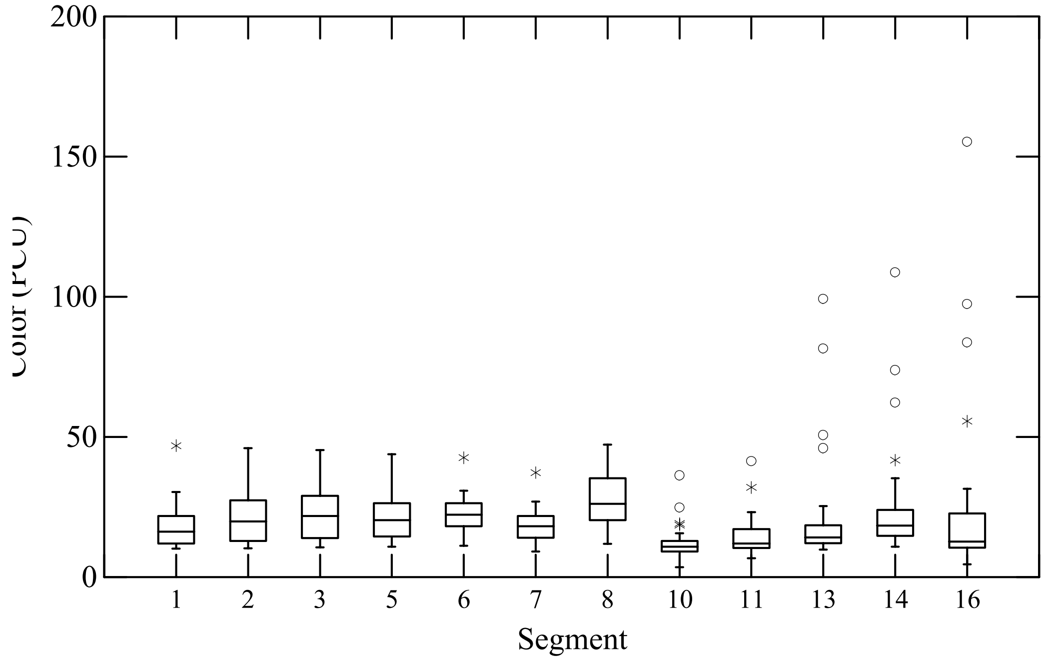


Attenuation Coefficient (m-1)
0
1
2
3
4
1
2
3
5
6
7
8
10
11
13
14
16
Segment

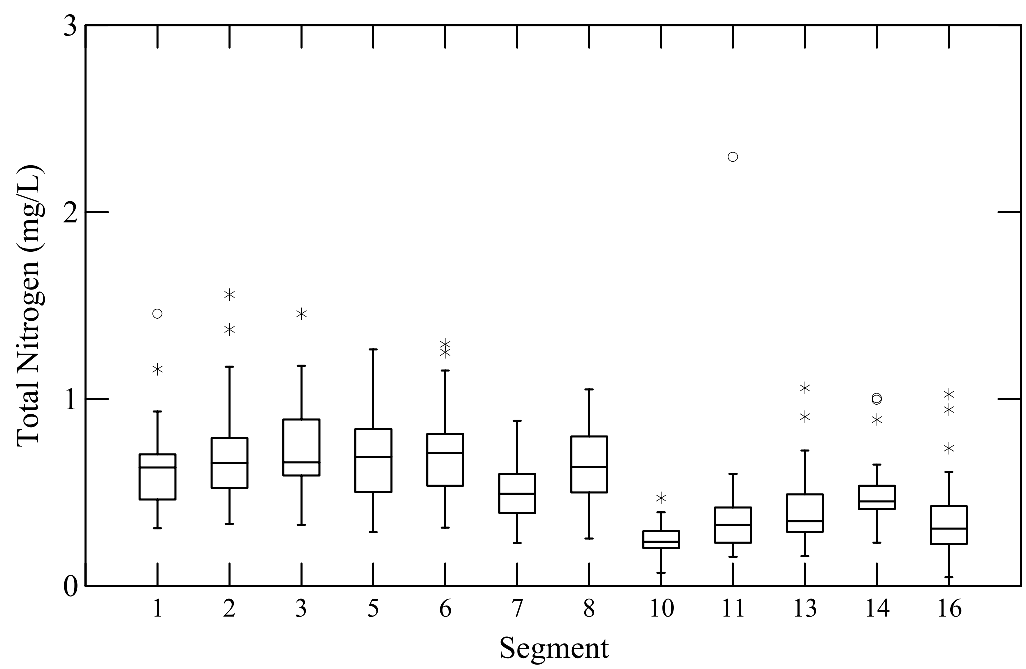


Turbidity (NTU)
0
5
10
15
20
1
2
3
5
6
7
8
10
11
13
14
16
Segment

99-01 Period

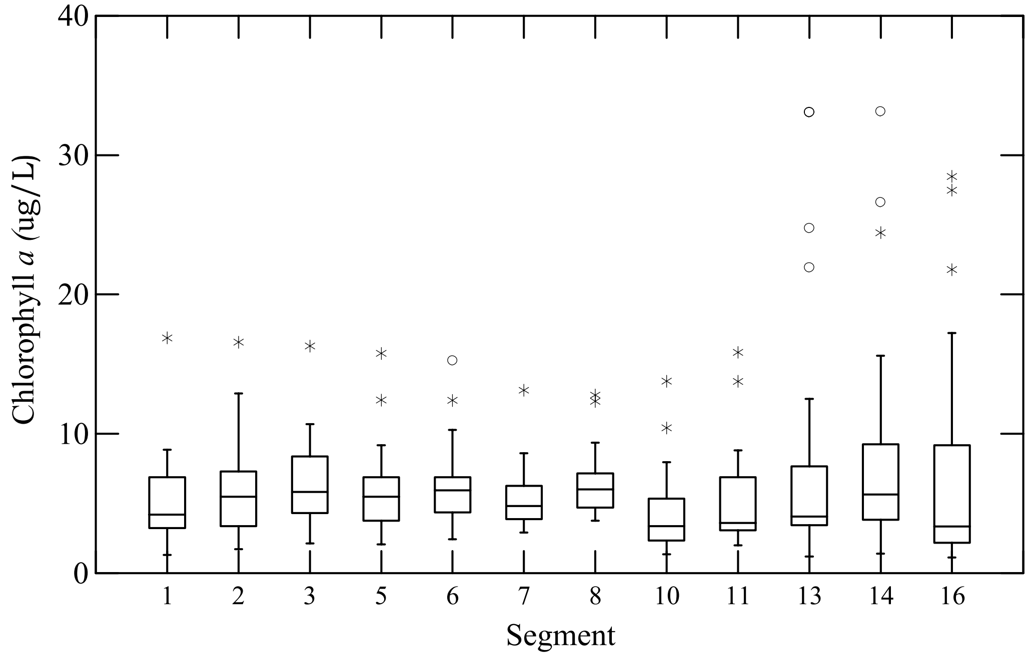


200
150
100
50
0
Color (PCU)
1
2
3
5
6
7
8
10
11
13
14
16
Segment

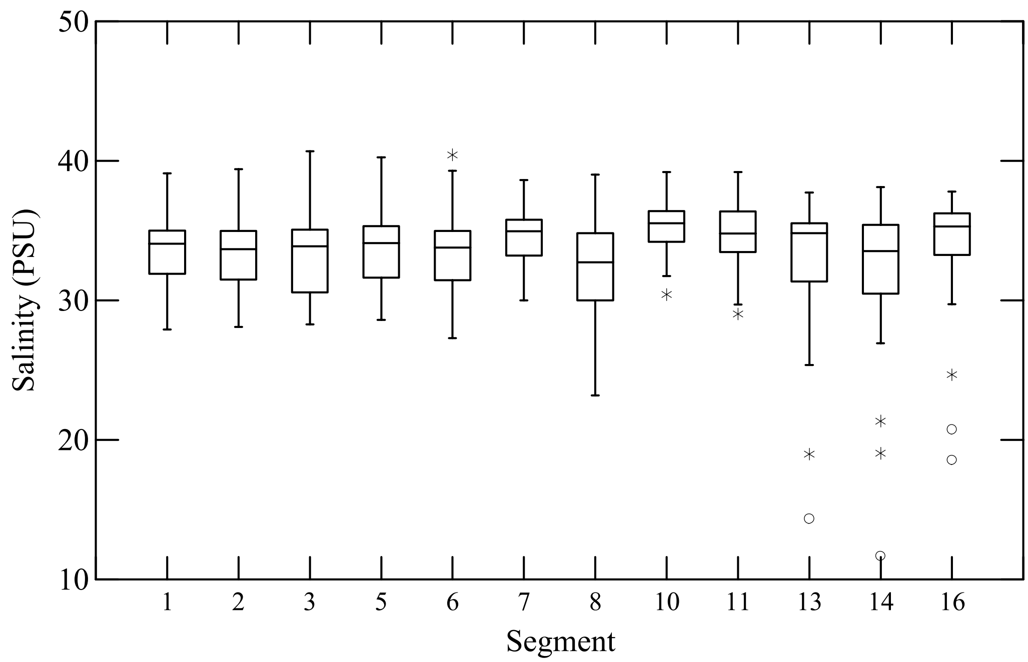


3
2
1
0
Total Nitrogen (mg/L)
1
2
3
5
6
7
8
10
11
13
14
16
Segment

99-01 Period



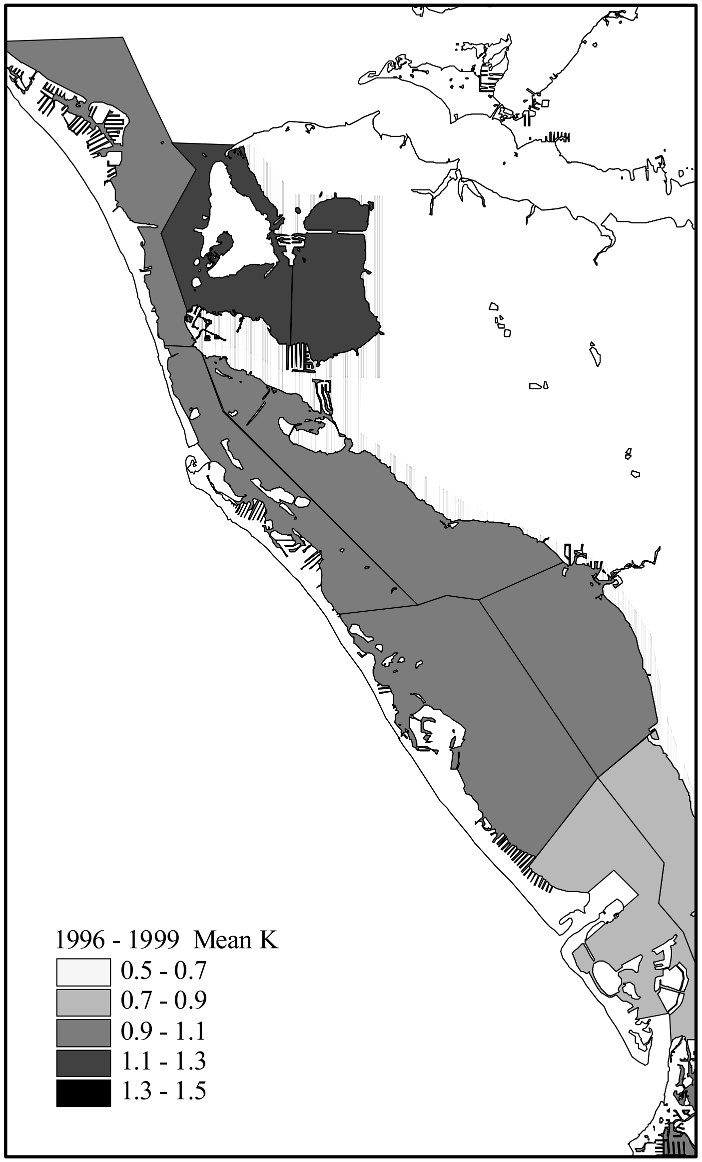
40
30
20
10
0
Chlorophyll a (ug/L)
1
2
3
5
6
7
8
10
11
13
14
16
Segment

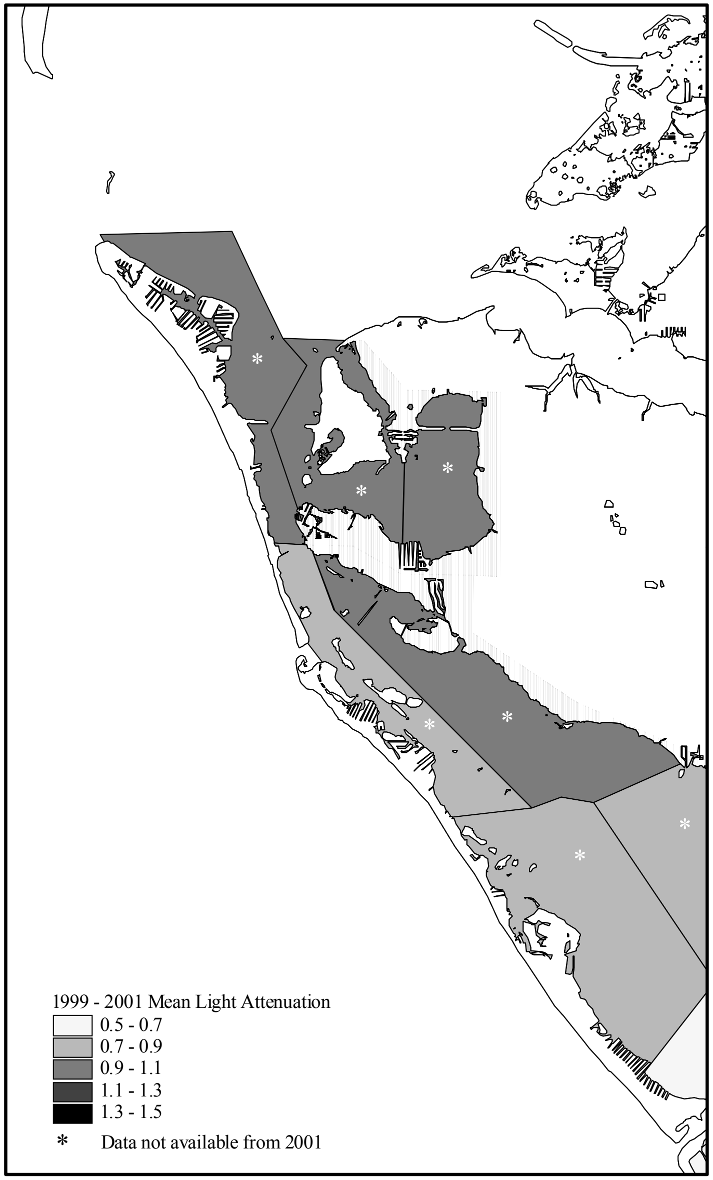


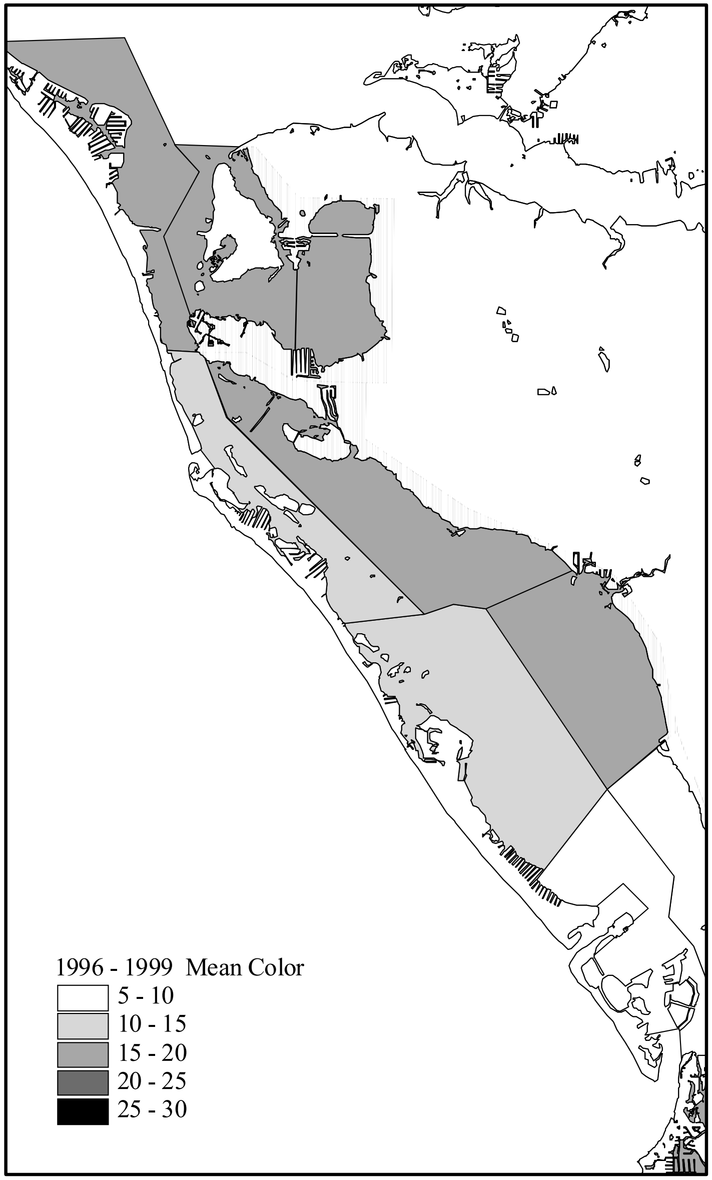
50
40
30
20
10
Salinity (PSU)
1
2
3
5
6
7
8
10
11
13
14
16
Segment

Appendix C

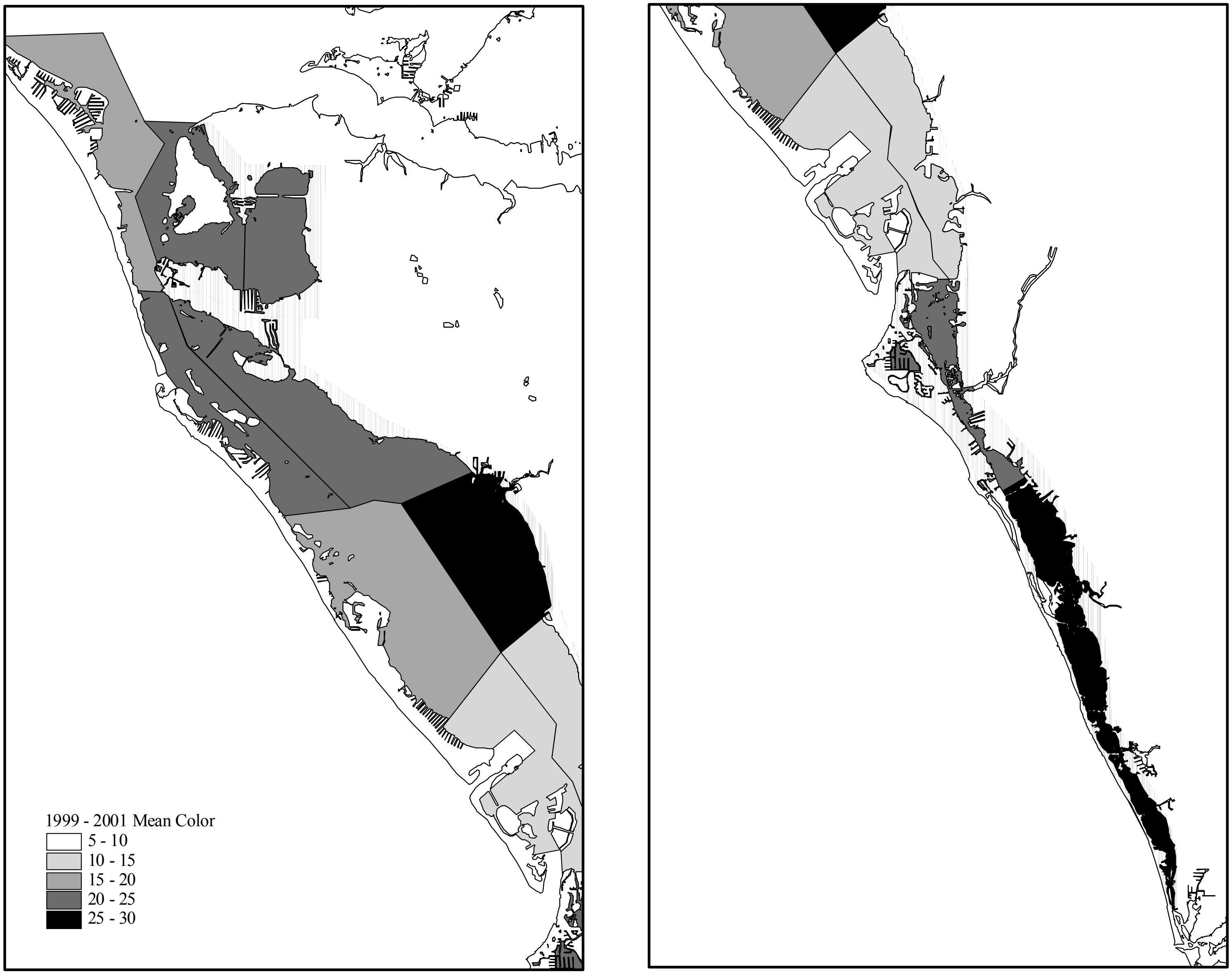
Period water quality means, mapped by segment

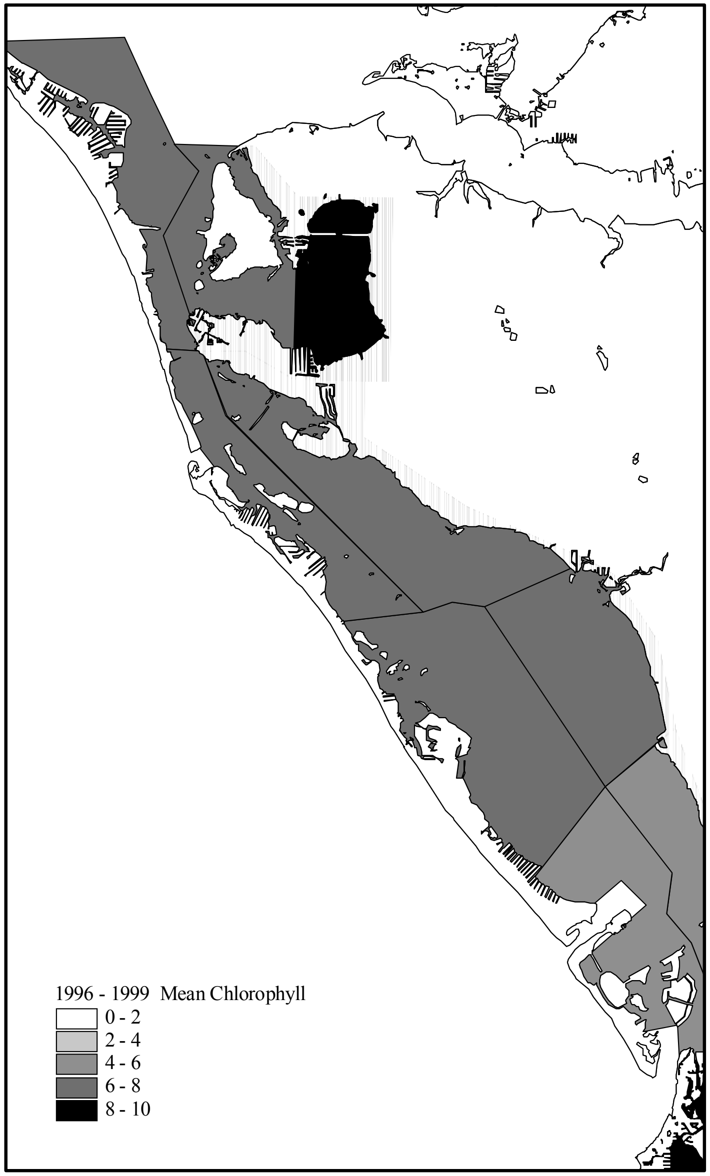

1996 - 1999 Mean K
0.5 - 0.7
0.7 - 0.9
0.9 - 1.1
1.1 - 1.3
1.3 - 1.5

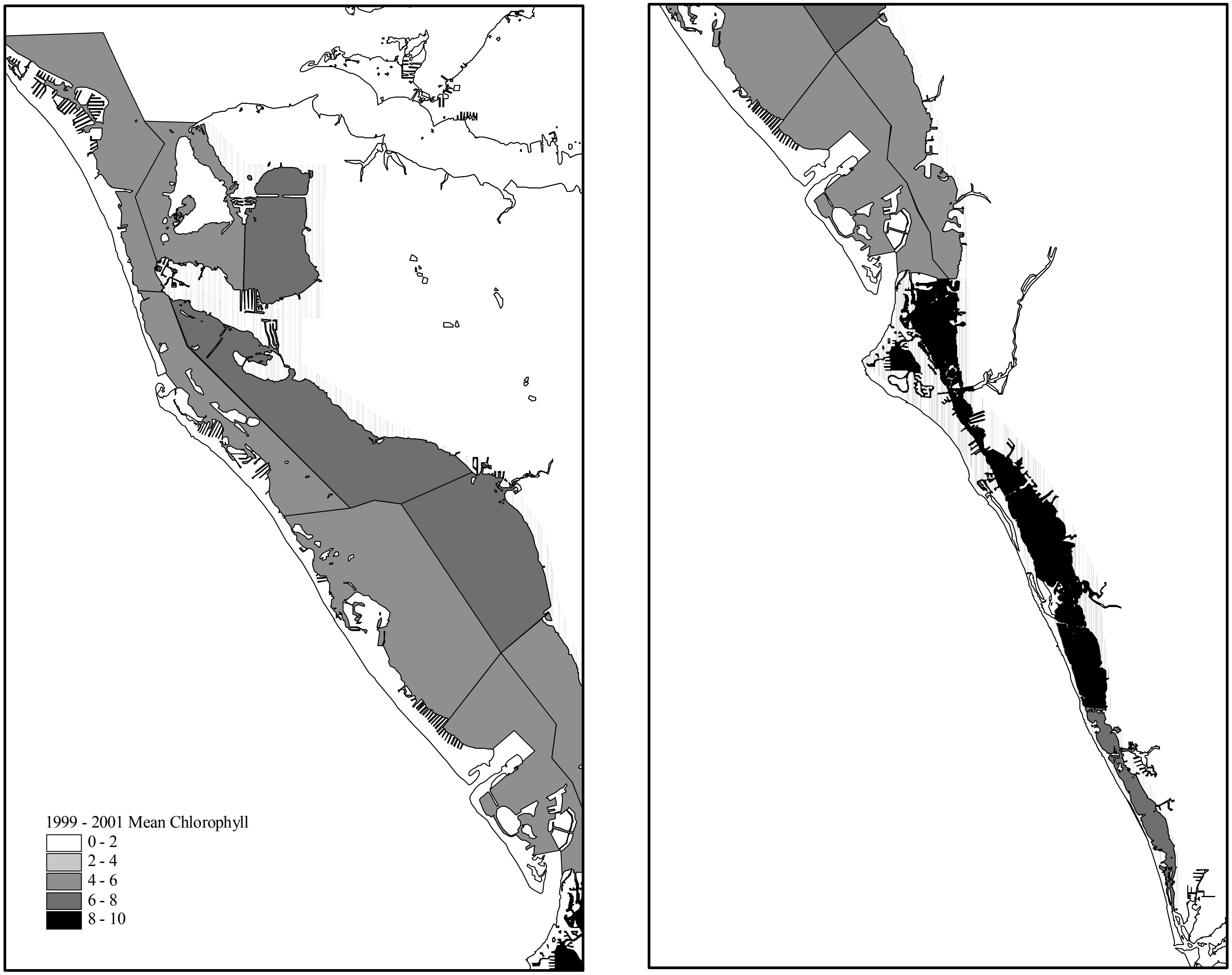

1999 - 2001 Mean Light Attenuation
0.5 - 0.7
0.7 - 0.9
0.9 - 1.1
1.1 - 1.3
1.3 - 1.5
* Data not available from 2001



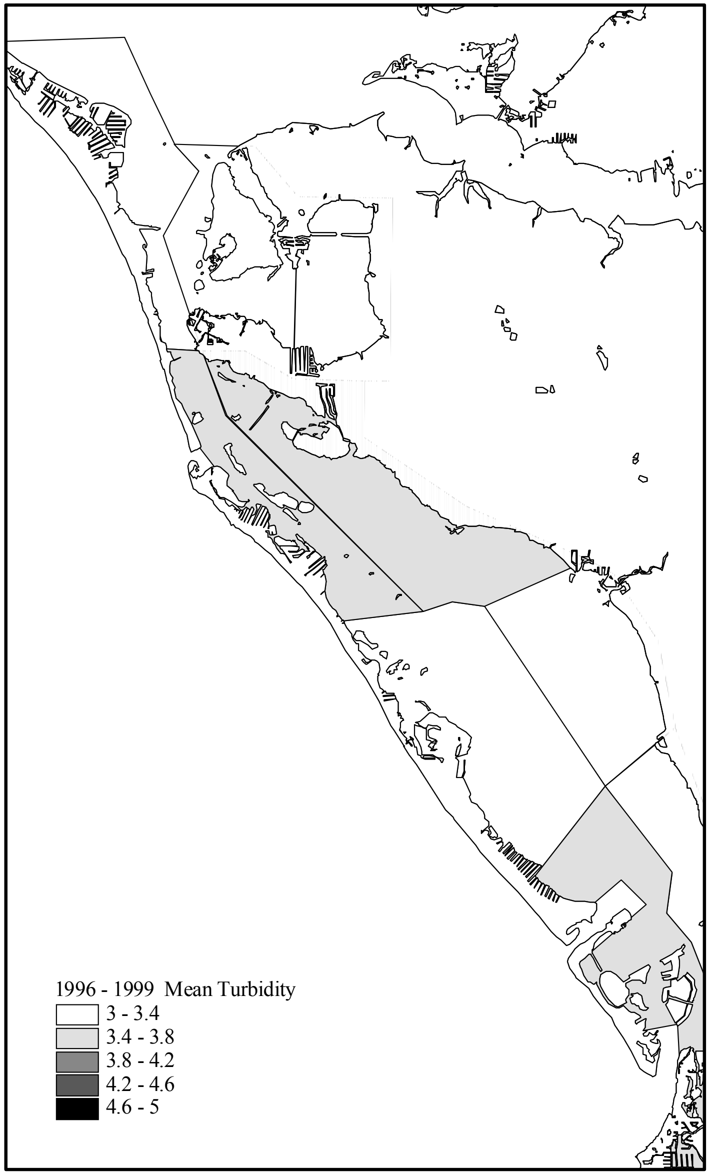
1996 - 1999 Mean Color
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30

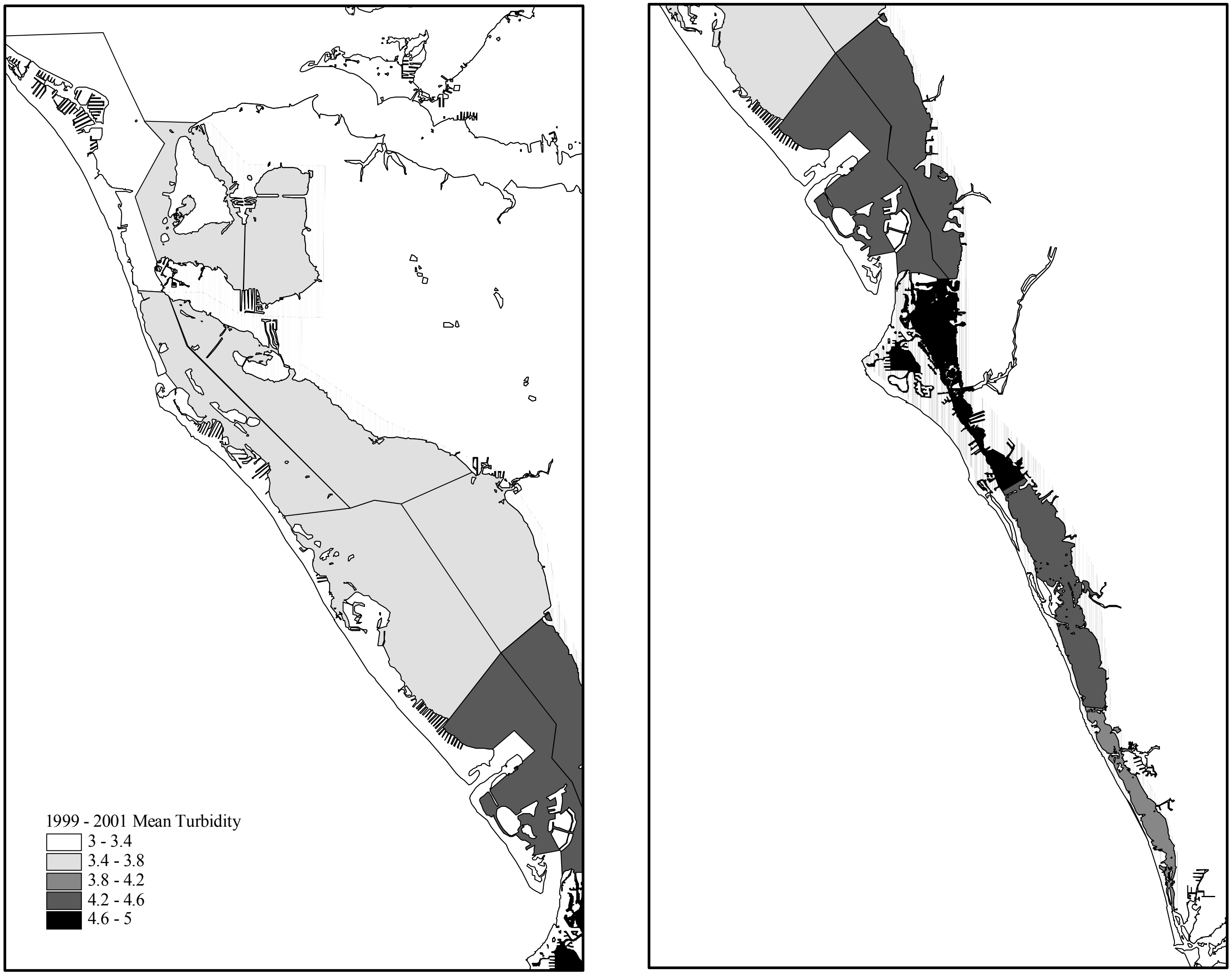

1999 - 2001 Mean Color
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30

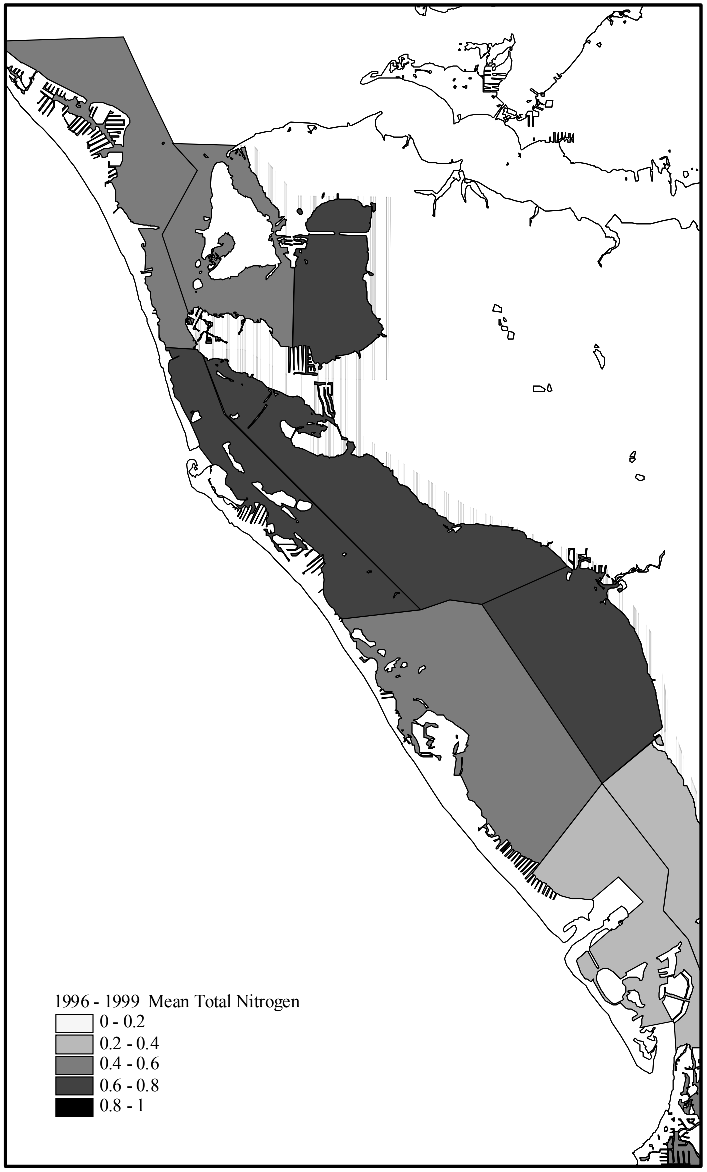

1996 - 1999 Mean Chlorophyll
0 - 2
2 - 4
4 - 6
6 - 8
8 - 10

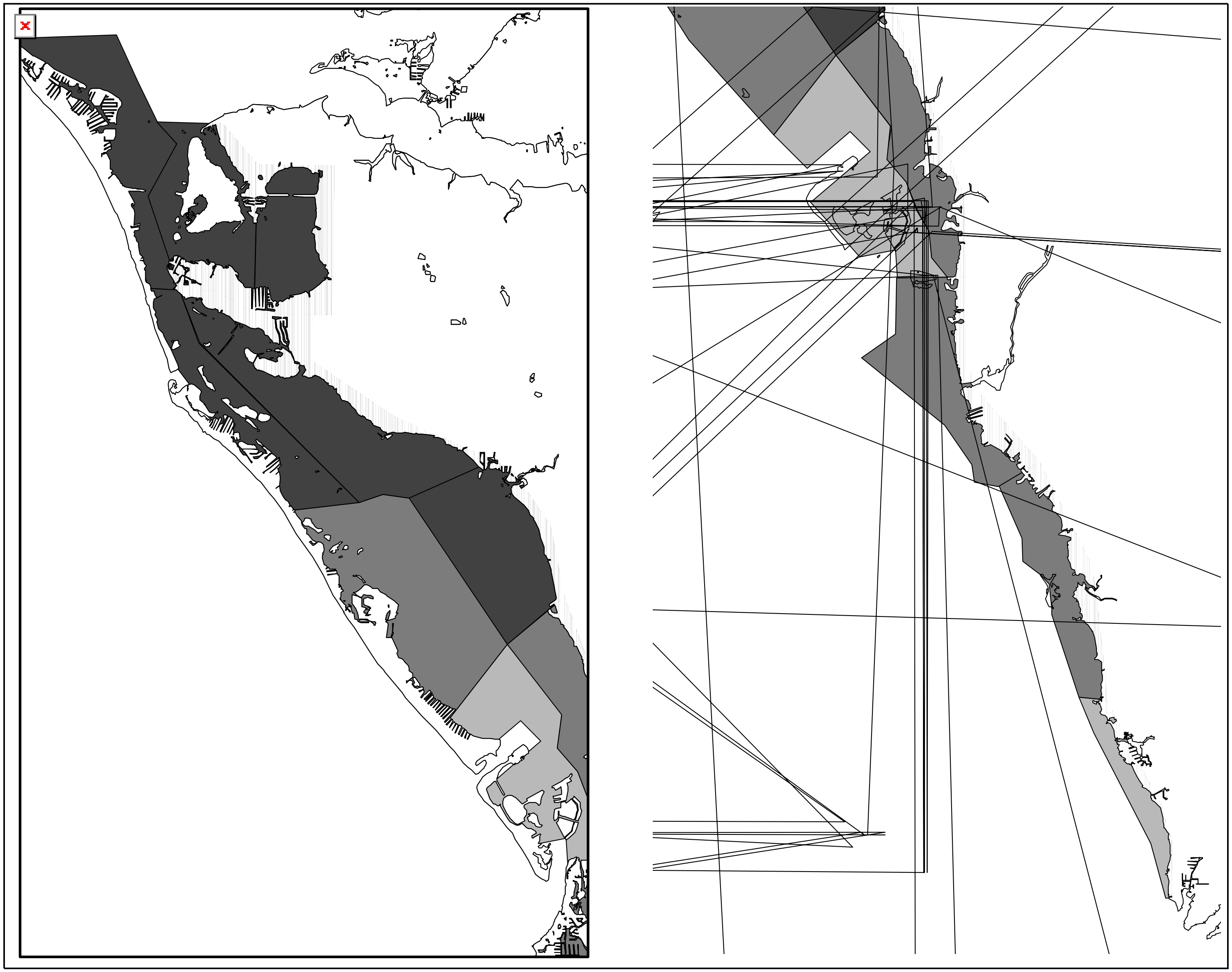


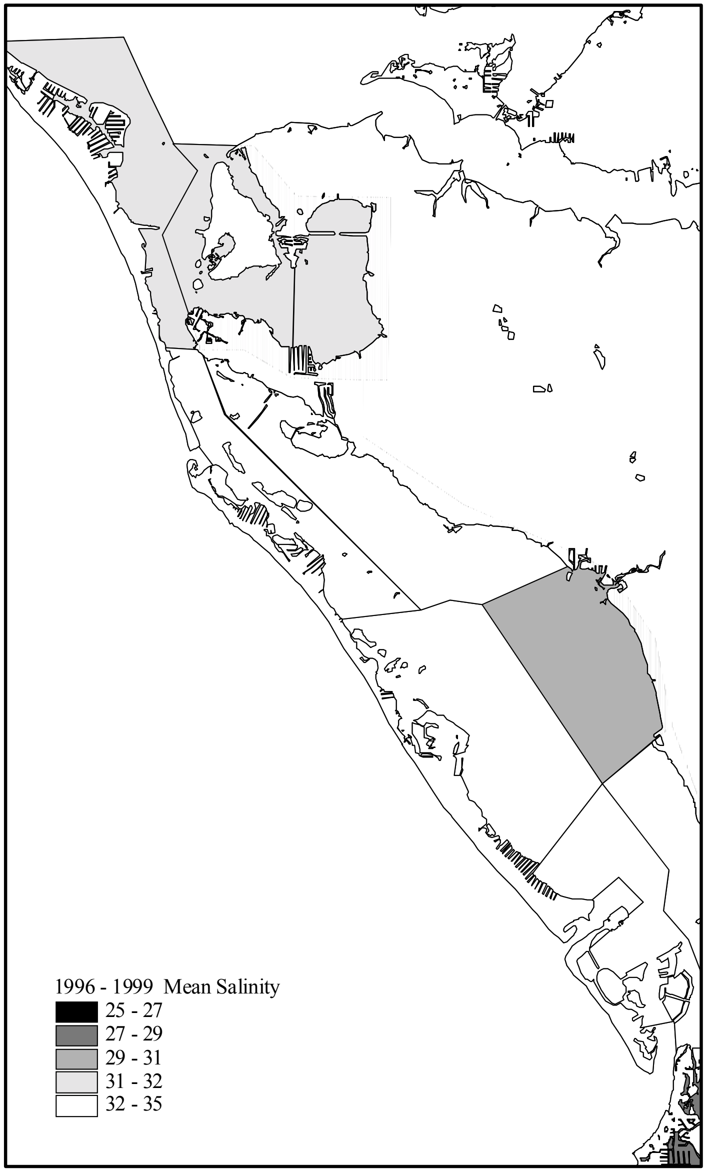
1999 - 2001 Mean Chlorophyll
0 - 2
2 - 4
4 - 6
6 - 8
8 - 10

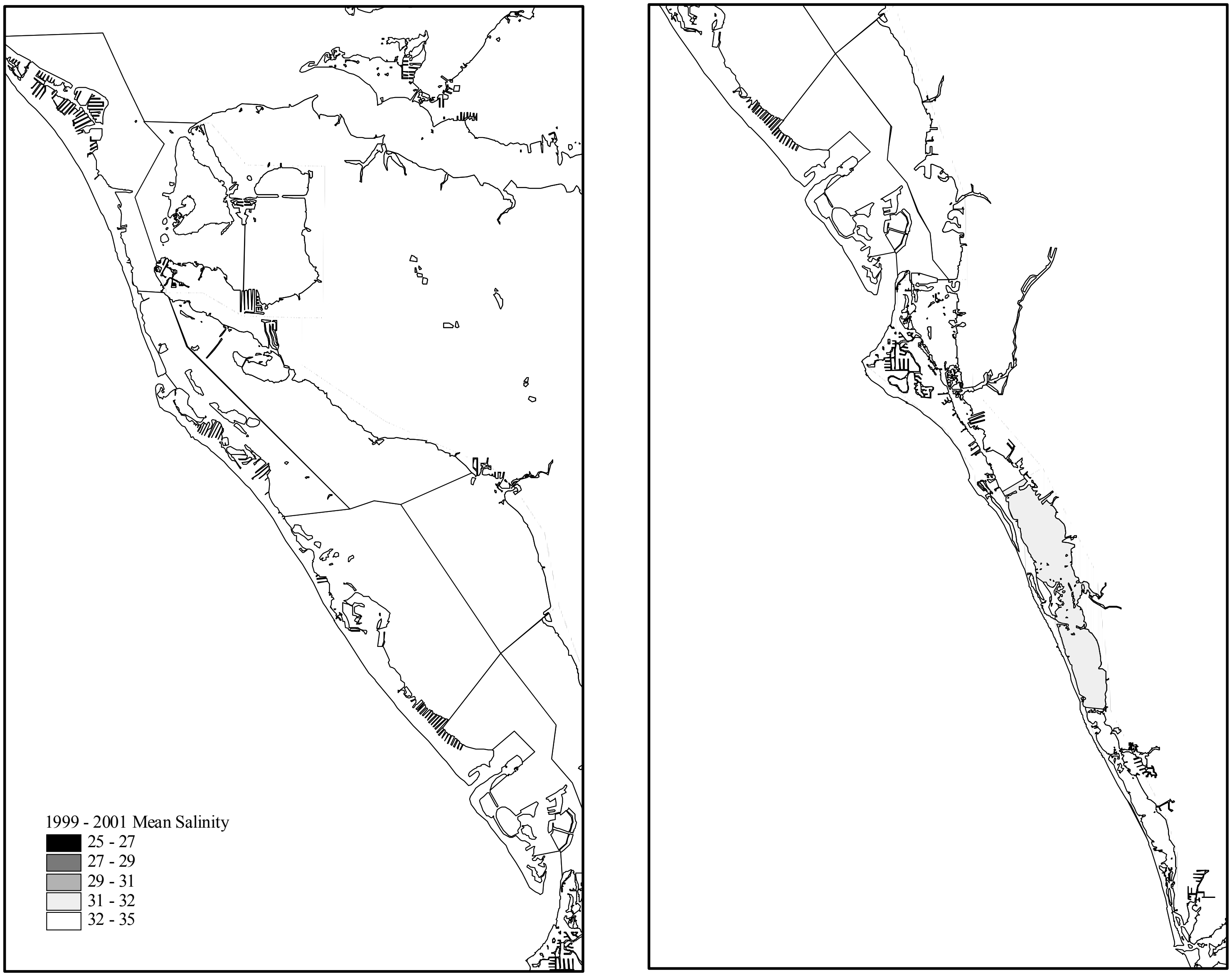

1996 - 1999 Mean Turbidity
3 - 3.4
3.4 - 3.8
3.8 - 4.2
4.2 - 4.6
4.6 - 5


1999 - 2001 Mean Turbidity
3 - 3.4
3.4 - 3.8
3.8 - 4.2
4.2 - 4.6
4.6 - 5


1996 - 1999 Mean Total Nitrogen
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1



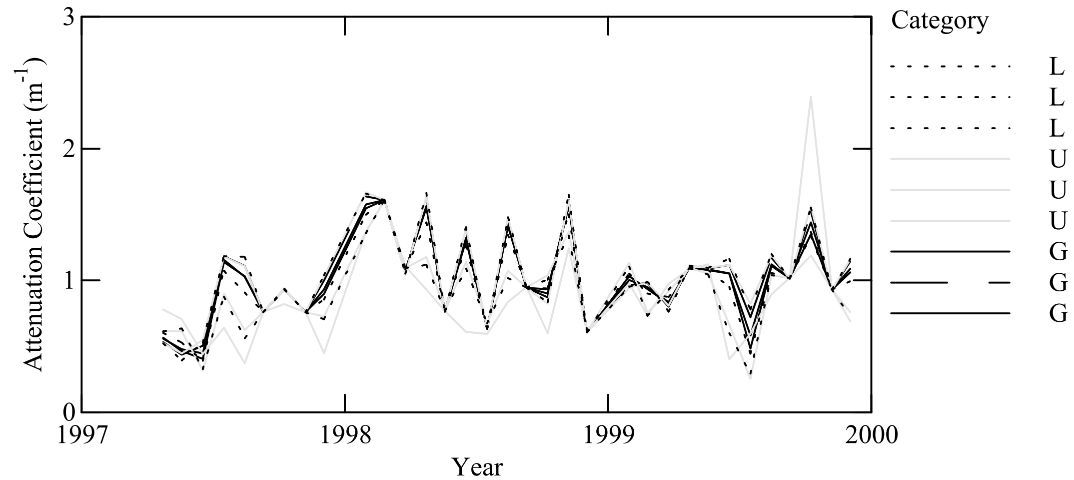

1996 - 1999 Mean Salinity
25 - 27
27 - 29
29 - 31
31 - 32
32 - 35


1999 - 2001 Mean Salinity
25 - 27
27 - 29
29 - 31
31 - 32
32 - 35

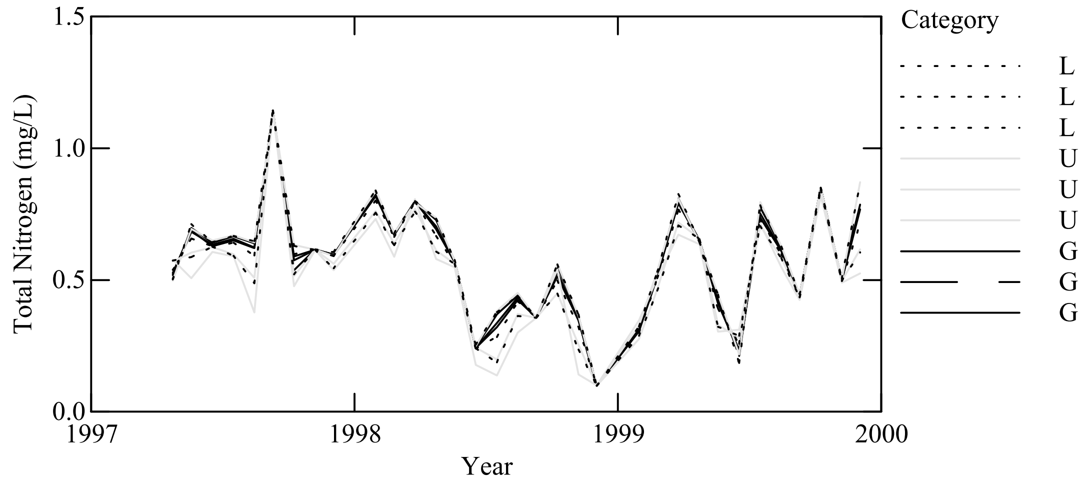
Appendix D

Time series of water quality parameter for the larger change polygons, by time period and by segment.

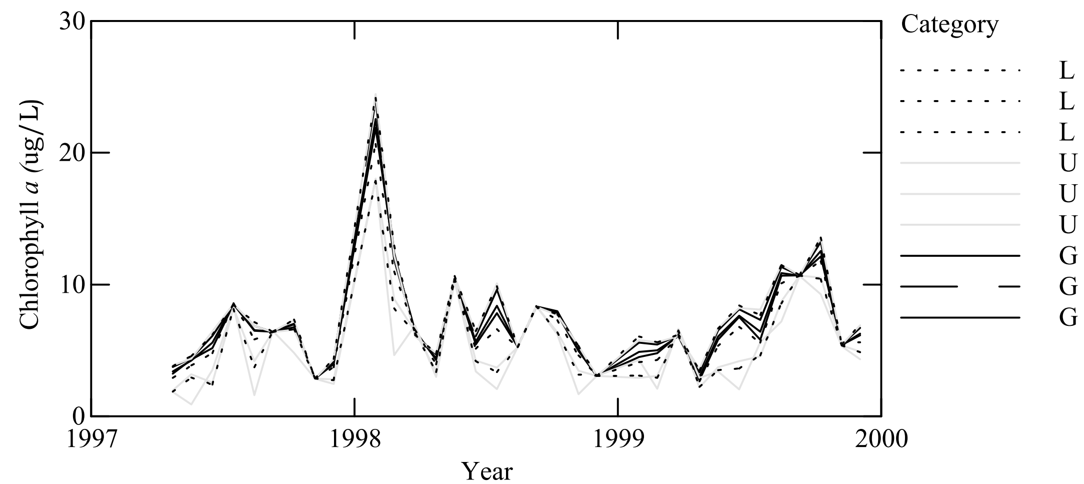
Segment 1



3
2
1
0
Attenuation Coefficient (m-1)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

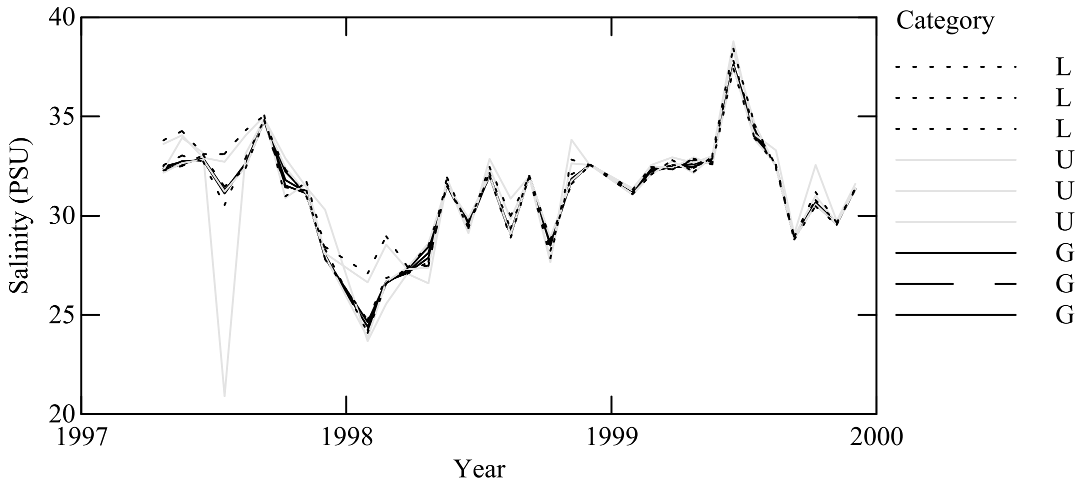


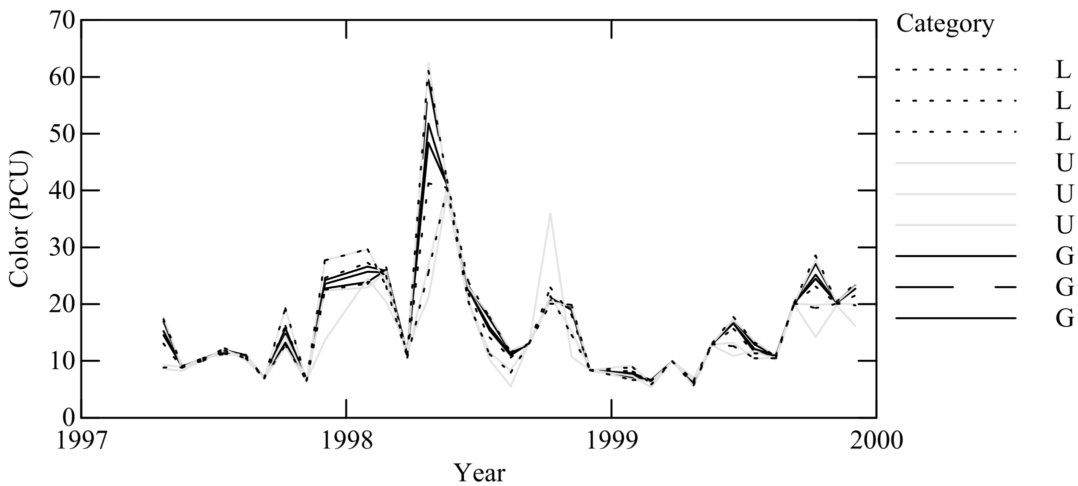
1.5
1.0
0.5
0.0
Total Nitrogen (mg/L)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

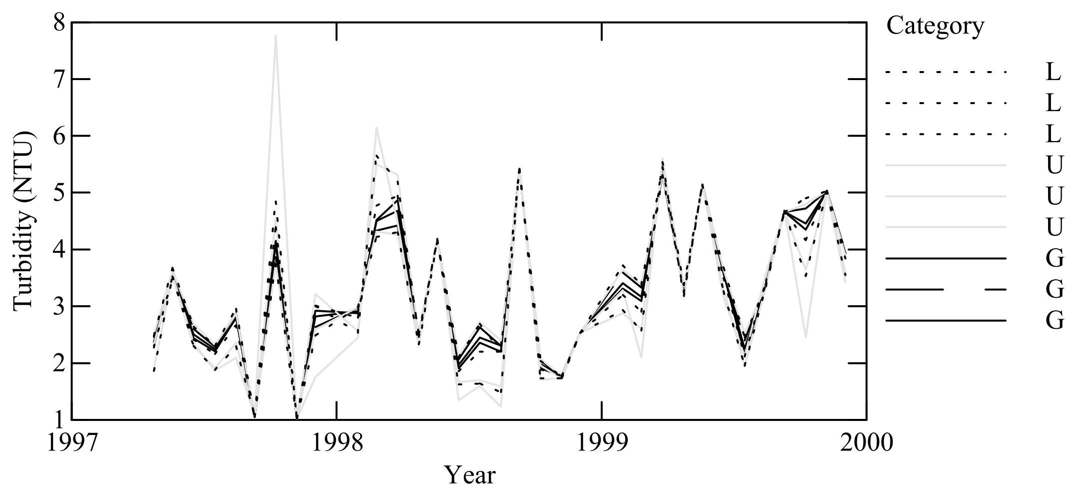


30
20
10
0
Chlorophyll a (ug/L)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

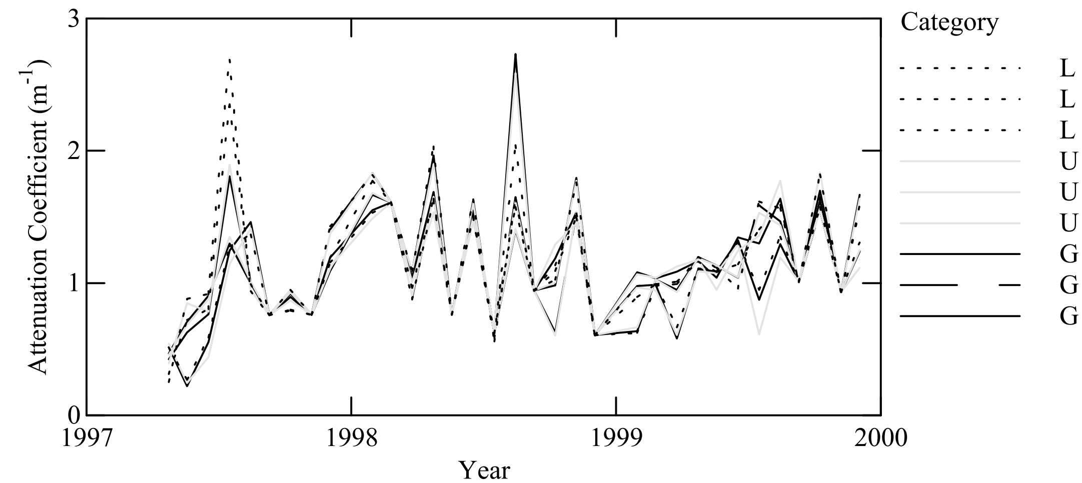
Segment 1

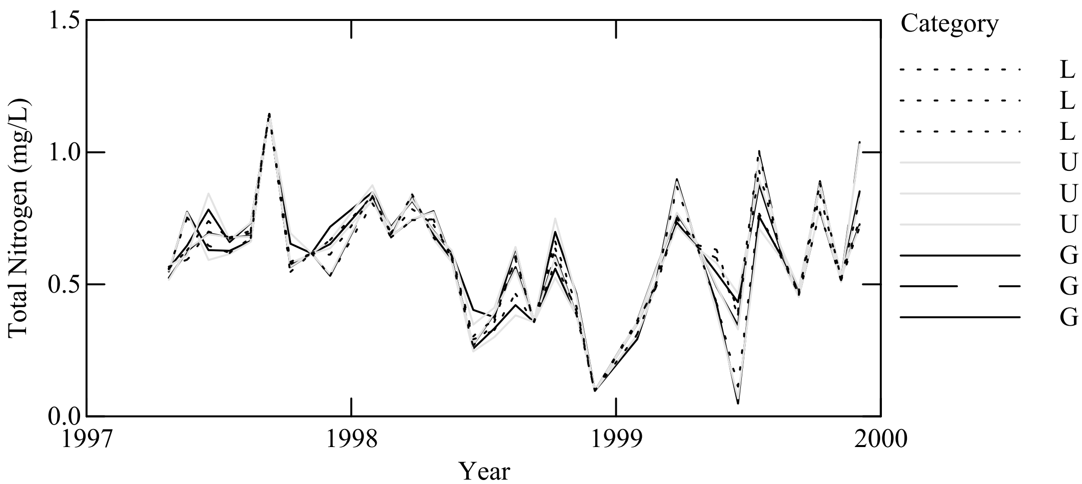

40
35
30
25
20
Salinity (PSU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

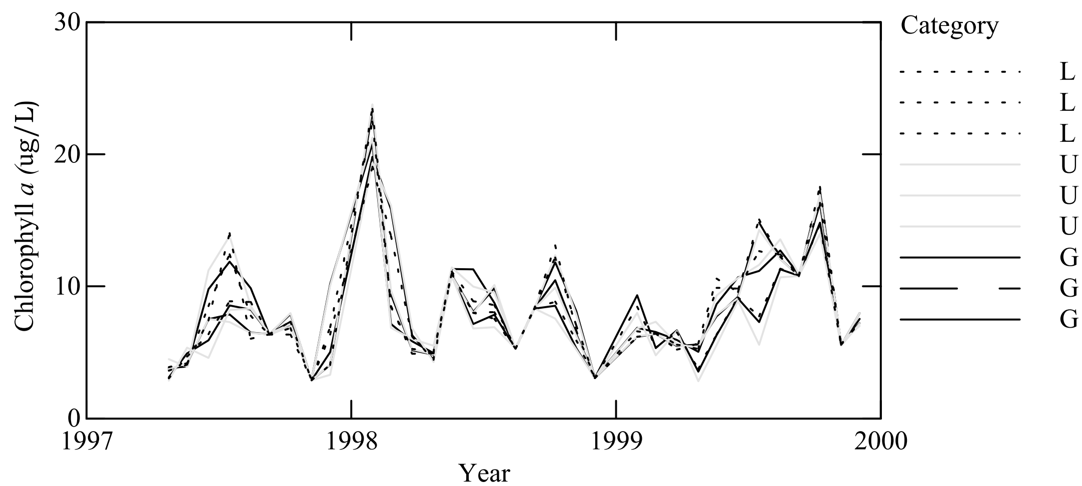

70
60
50
40
30
20
10
0
Color (PCU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G


8
7
6
5
4
3
2
1
Turbidity (NTU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

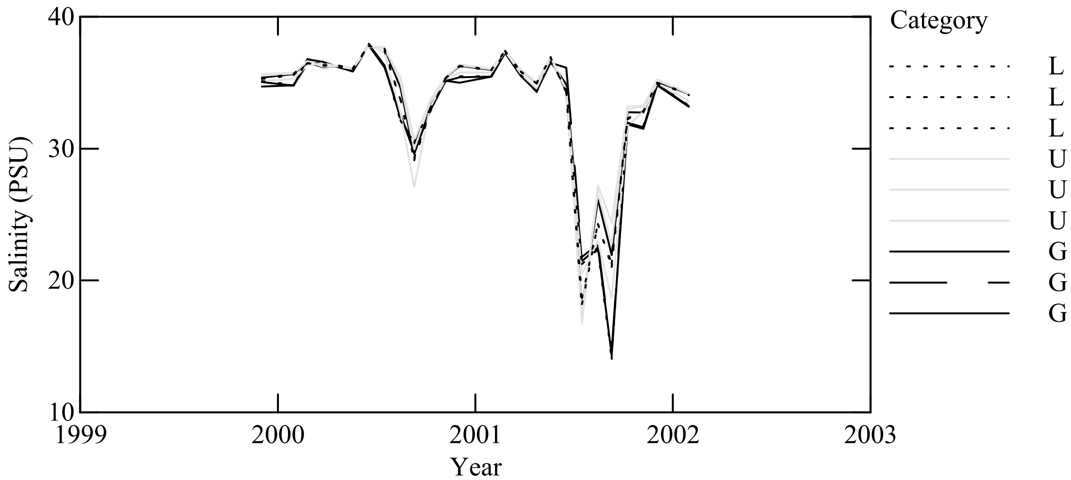
Segment 2


Attenuation Coefficient (m^{-1})
0
1
2
3
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

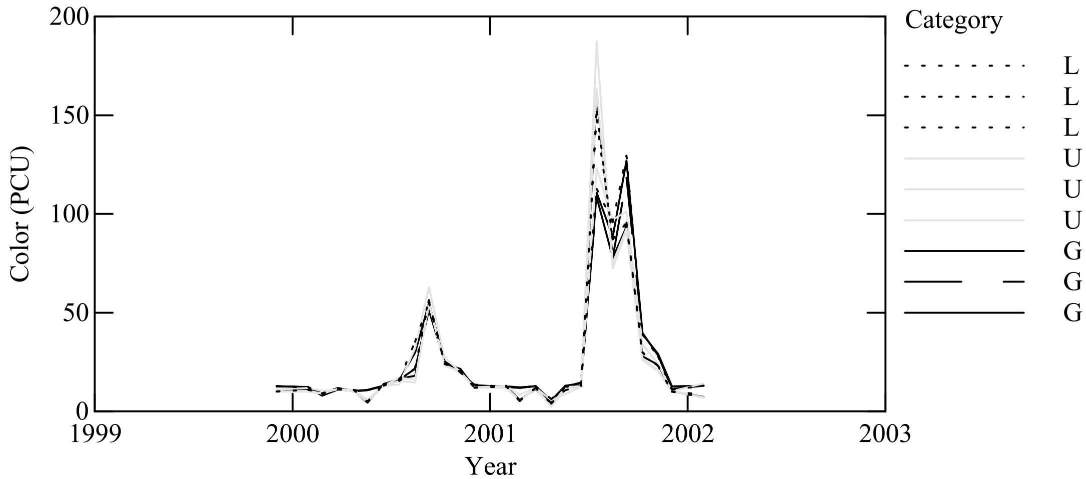

Total Nitrogen (mg/L)
0.0
0.5
1.0
1.5
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G


Chlorophyll *a* (ug/L)
0
10
20
30
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

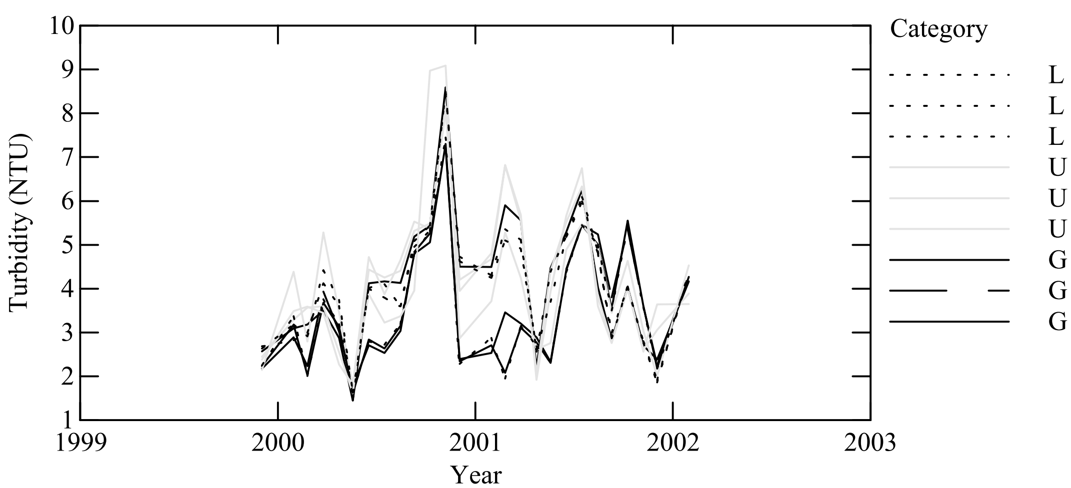
Segment 16



Salinity (PSU)
40
30
20
10
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

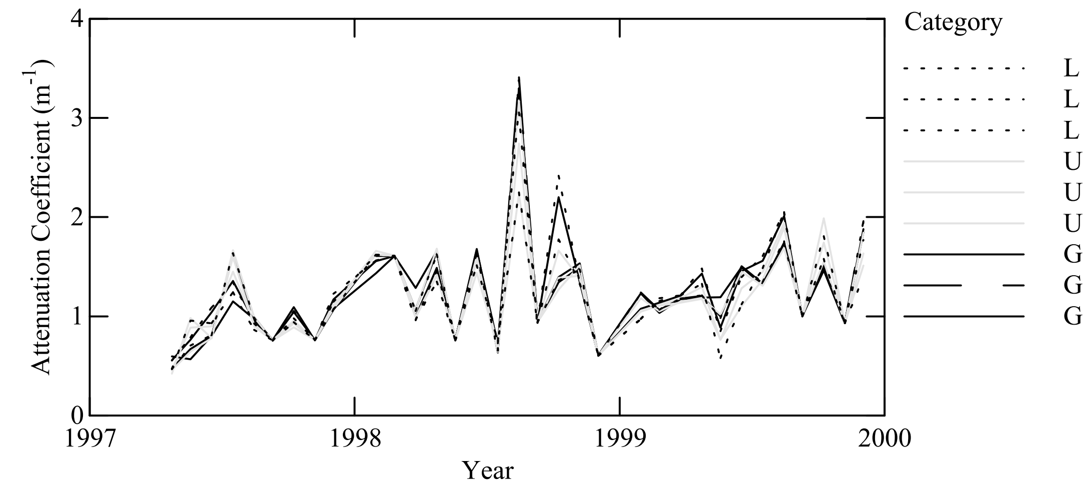


Color (PCU)
200
150
100
50
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

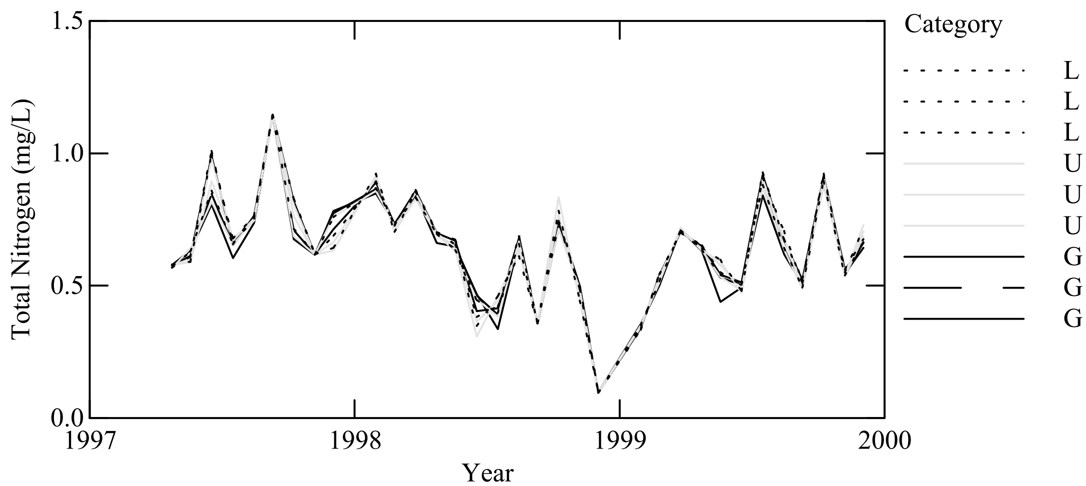


Turbidity (NTU)
10
9
8
7
6
5
4
3
2
1
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

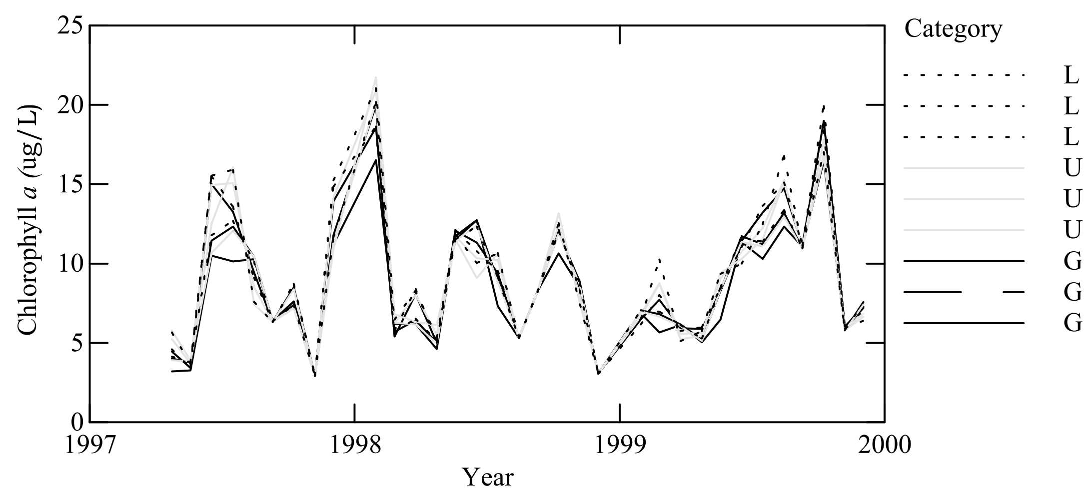
Segment 3



Attenuation Coefficient (m-1)
0
1
2
3
4
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

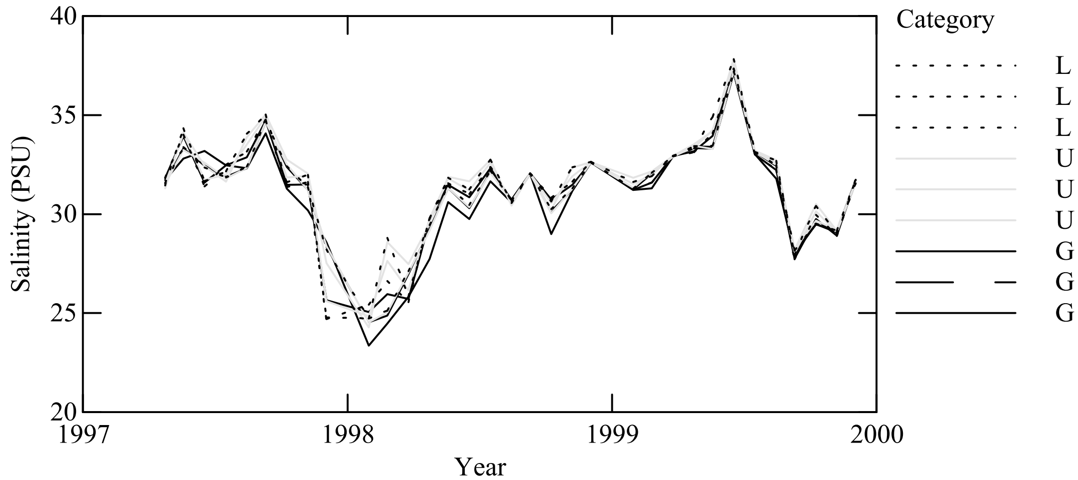


Total Nitrogen (mg/L)
0.0
0.5
1.0
1.5
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

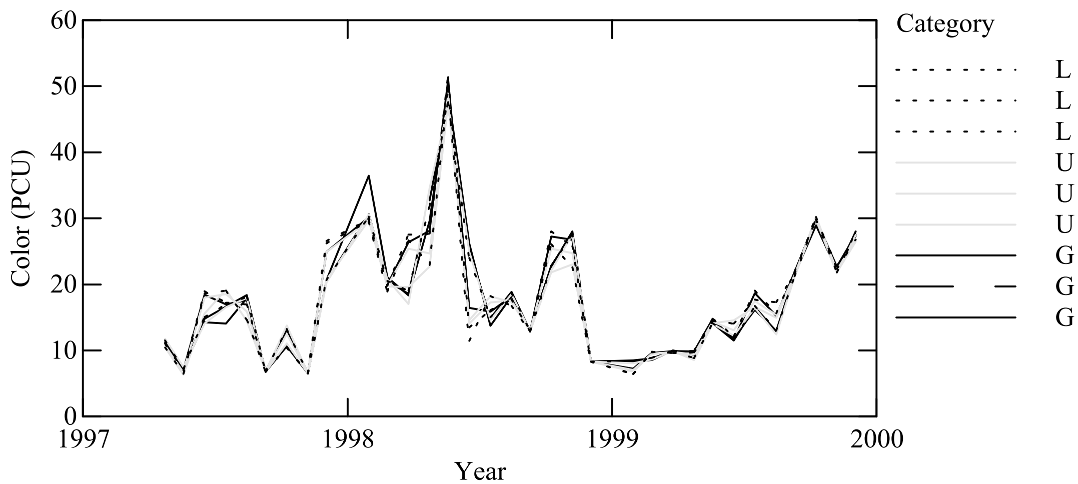


Chlorophyll a (ug/L)
0
5
10
15
20
25
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

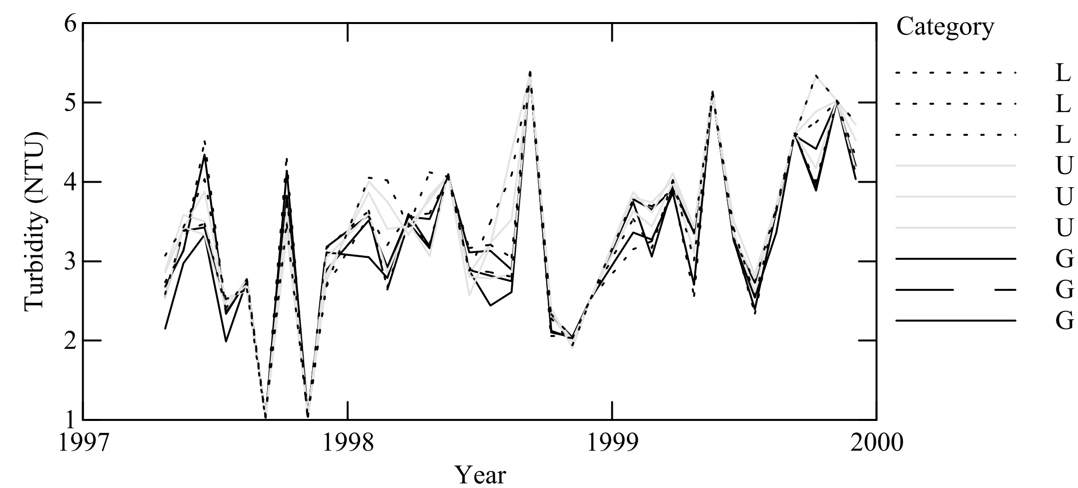
Segment 3



Salinity (PSU)
40
35
30
25
20
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

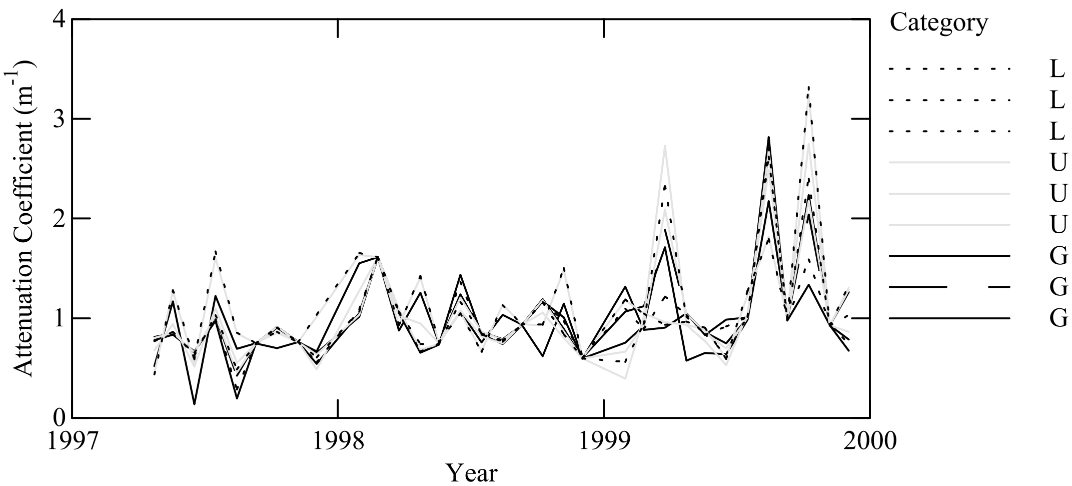


Color (PCU)
60
50
40
30
20
10
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

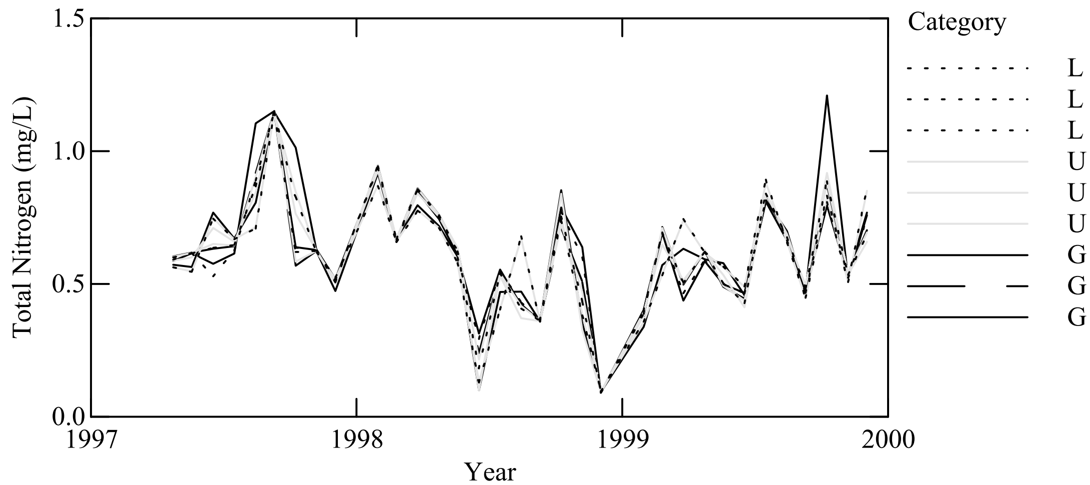


Turbidity (NTU)
6
5
4
3
2
1
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

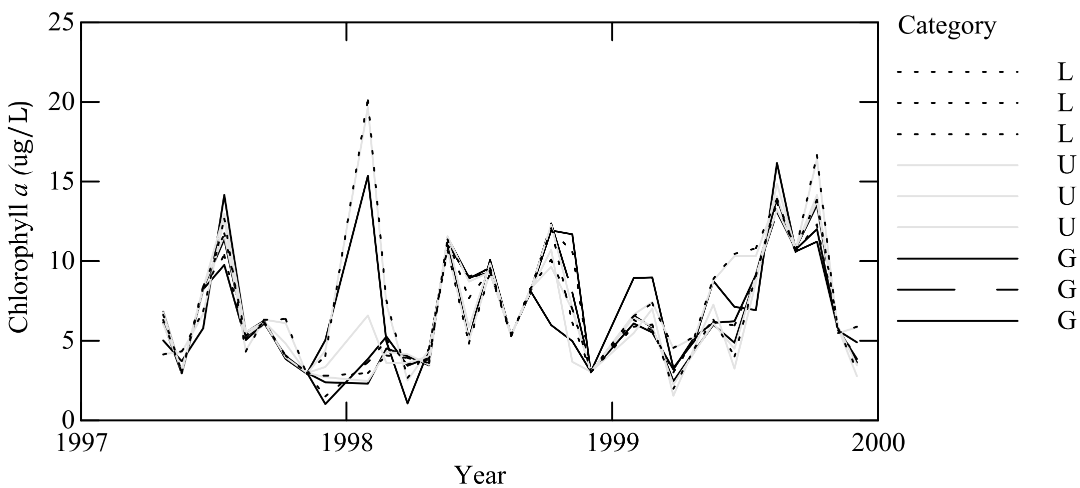
Segment 5



4
3
2
1
0
Attenuation Coefficient (m^{-1})
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

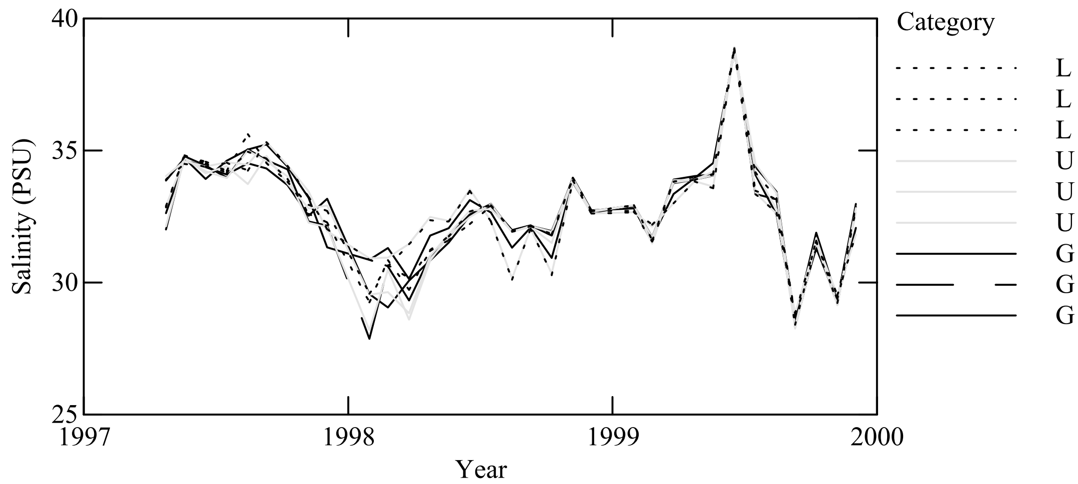


1.5
1.0
0.5
0.0
Total Nitrogen (mg/L)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

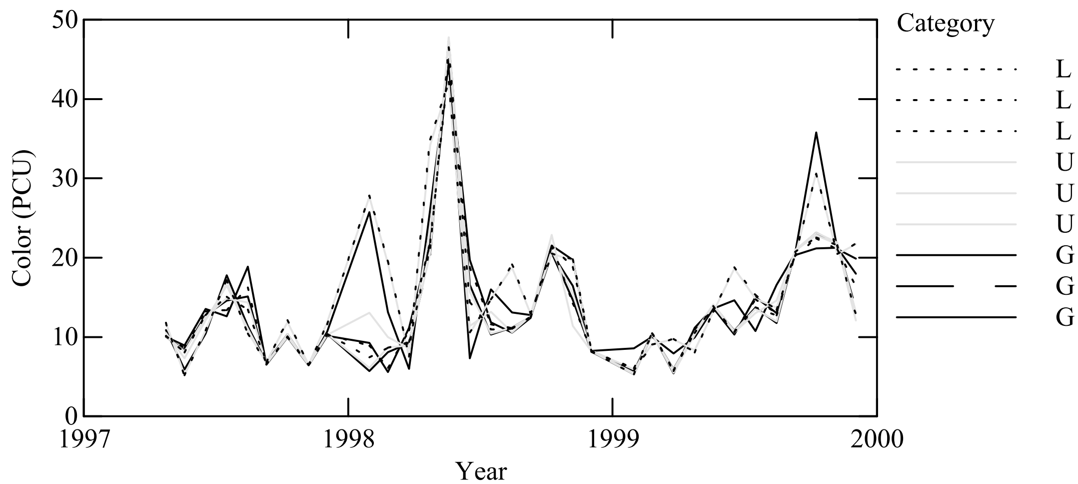


25
20
15
10
5
0
Chlorophyll *a* (ug/L)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

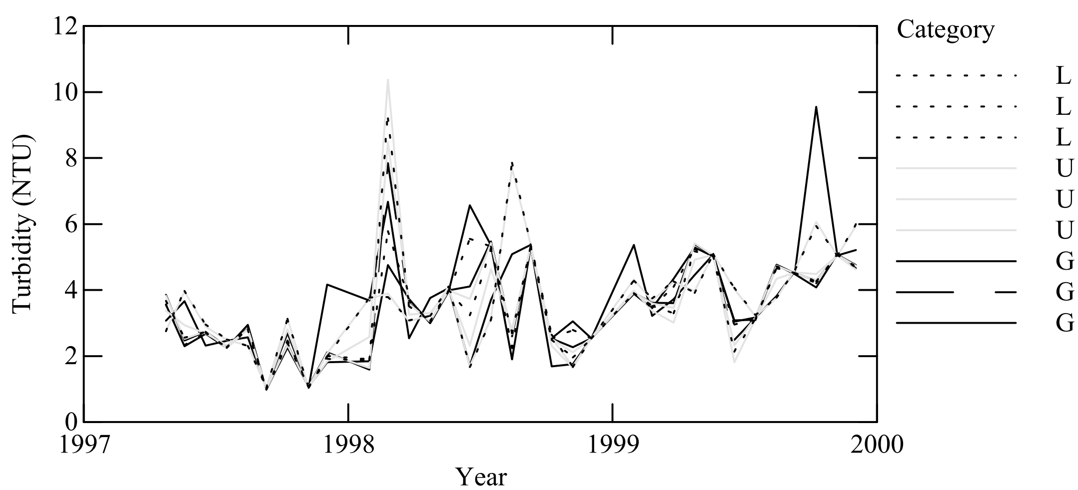
Segment 5



Salinity (PSU)
40
35
30
25
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

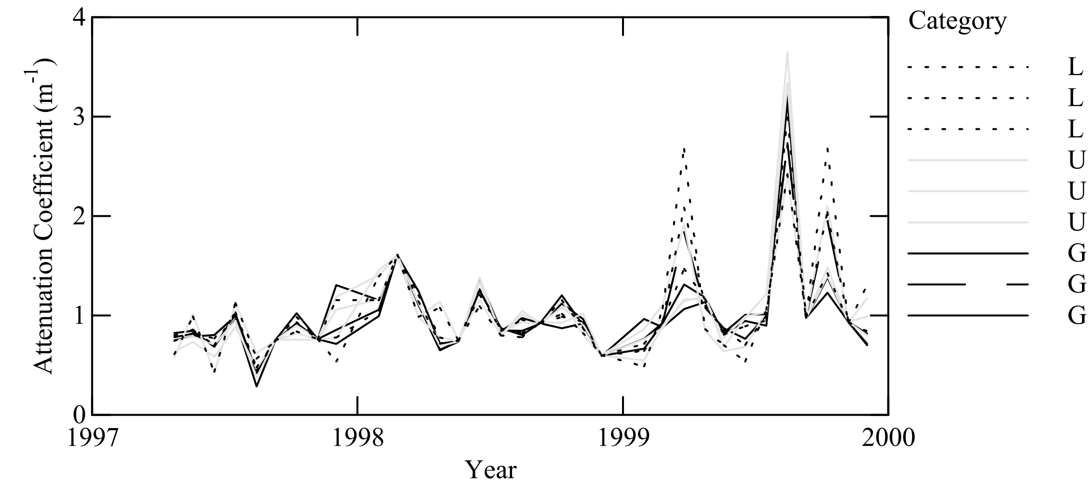


Color (PCU)
50
40
30
20
10
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

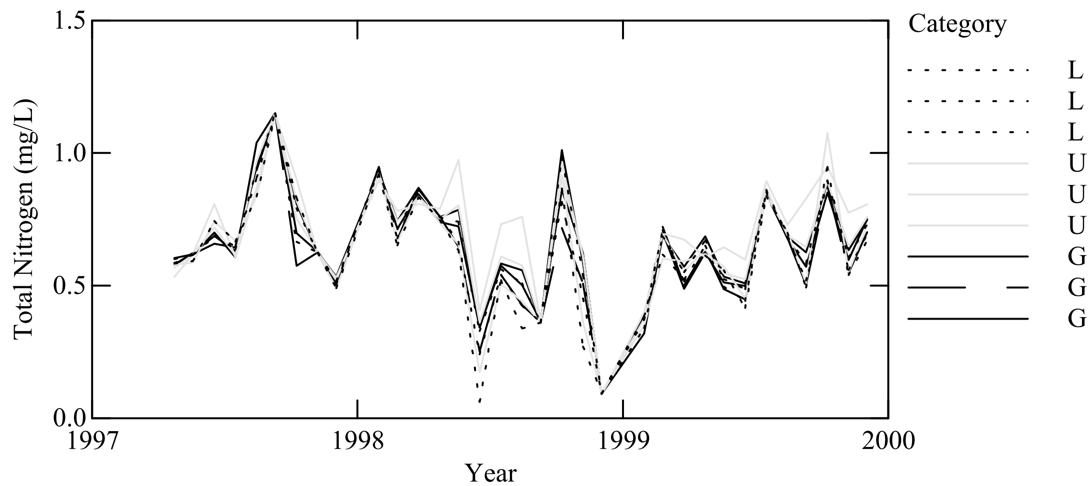


Turbidity (NTU)
12
10
8
6
4
2
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

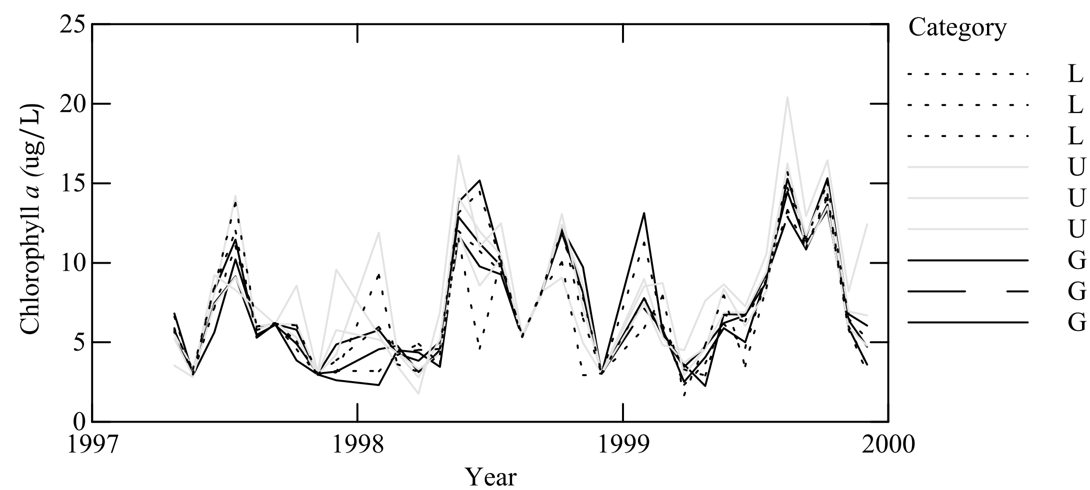
Segment 6



4
3
2
1
0
1997
1998
1999
2000
Year
Attenuation Coefficient (m-1)
Category
L
L
L
U
U
U
G
G
G

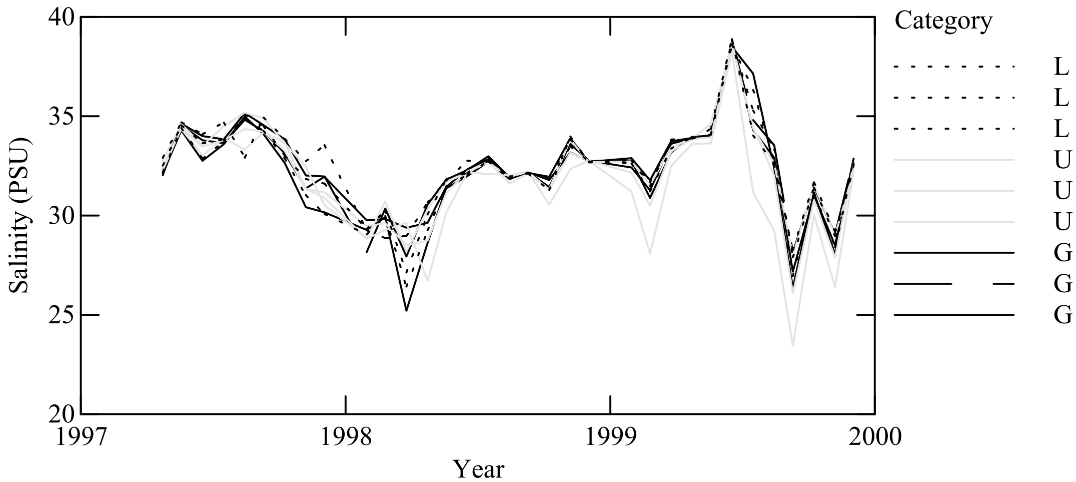


1.5
1.0
0.5
0.0
1997
1998
1999
2000
Year
Total Nitrogen (mg/L)
Category
L
L
L
U
U
U
G
G
G

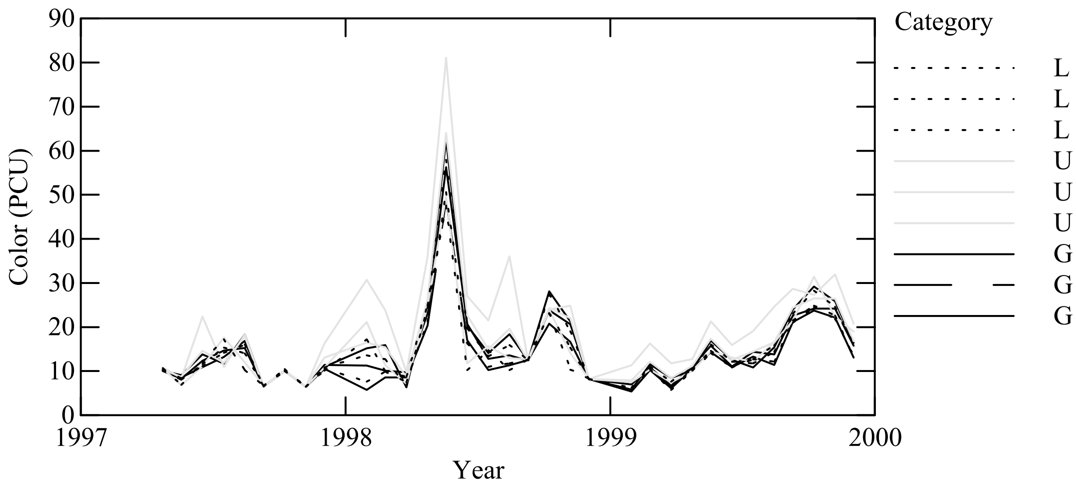


25
20
15
10
5
0
1997
1998
1999
2000
Year
Chlorophyll a (ug/L)
Category
L
L
L
U
U
U
G
G
G

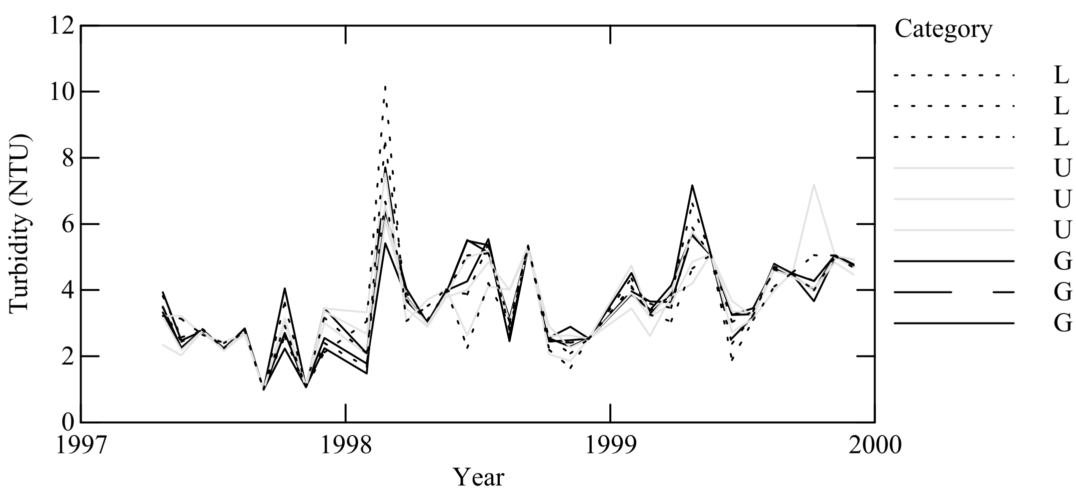
Segment 6



40
35
30
25
20
Salinity (PSU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

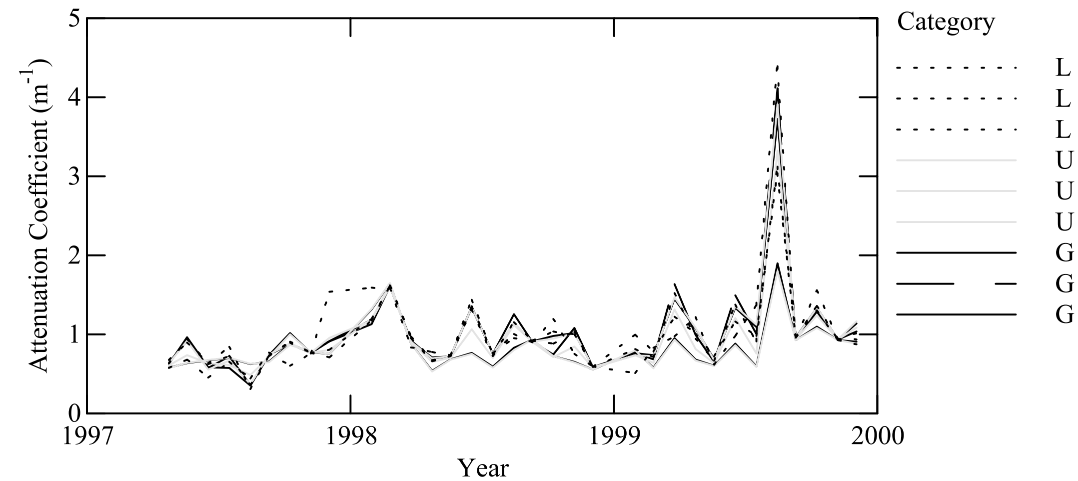


90
80
70
60
50
40
30
20
10
0
Color (PCU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

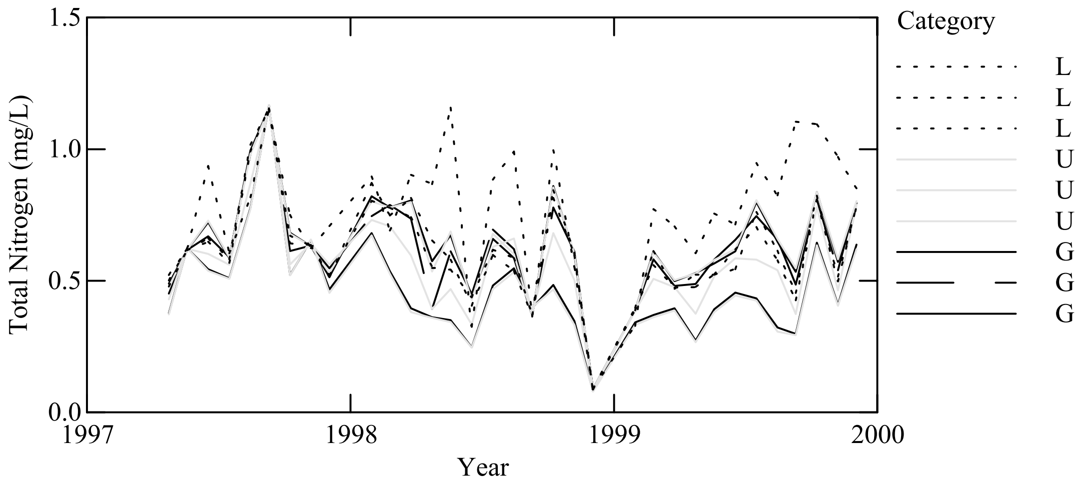


12
10
8
6
4
2
0
Turbidity (NTU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

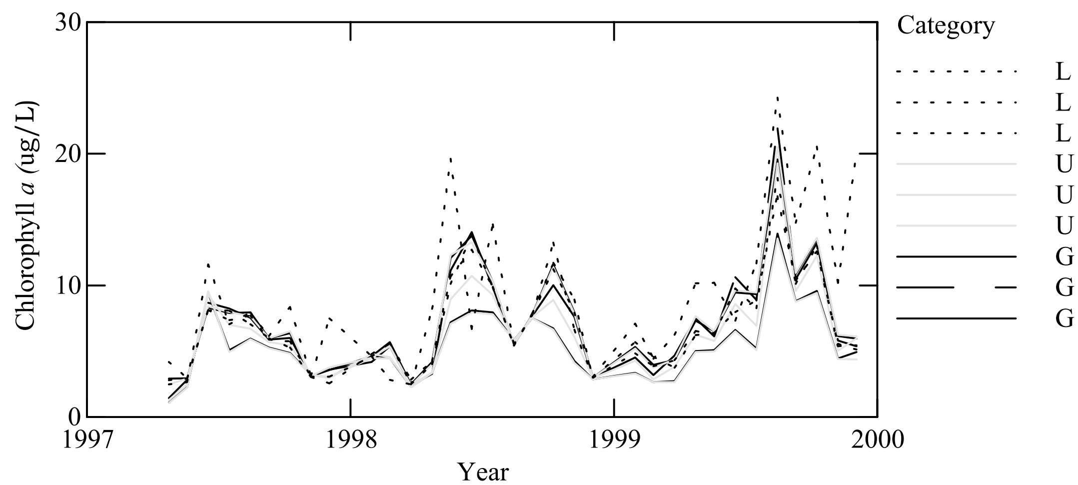
Segment 7



Attenuation Coefficient (m^{-1})
Year
Category
L
L
L
U
U
U
G
G
G

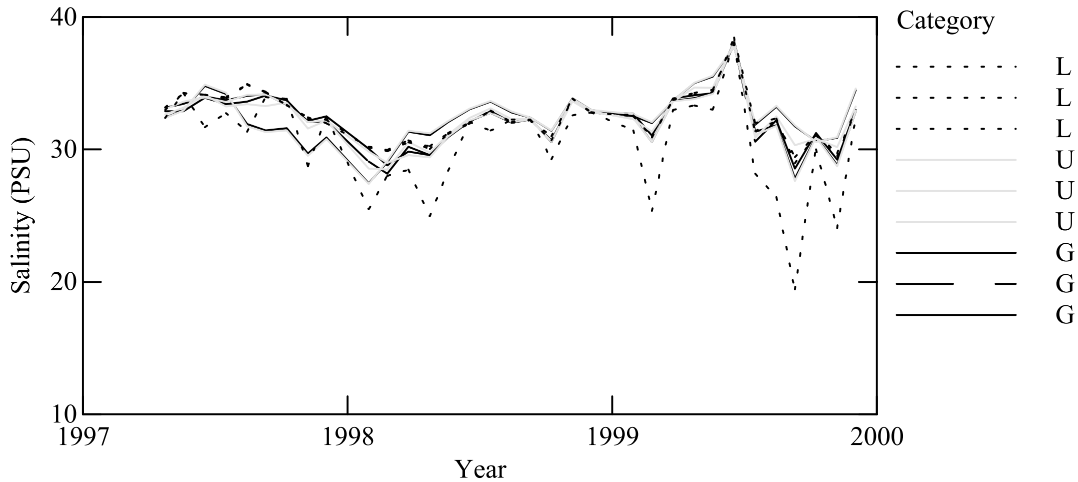


Total Nitrogen (mg/L)
Year
Category
L
L
L
U
U
U
G
G
G

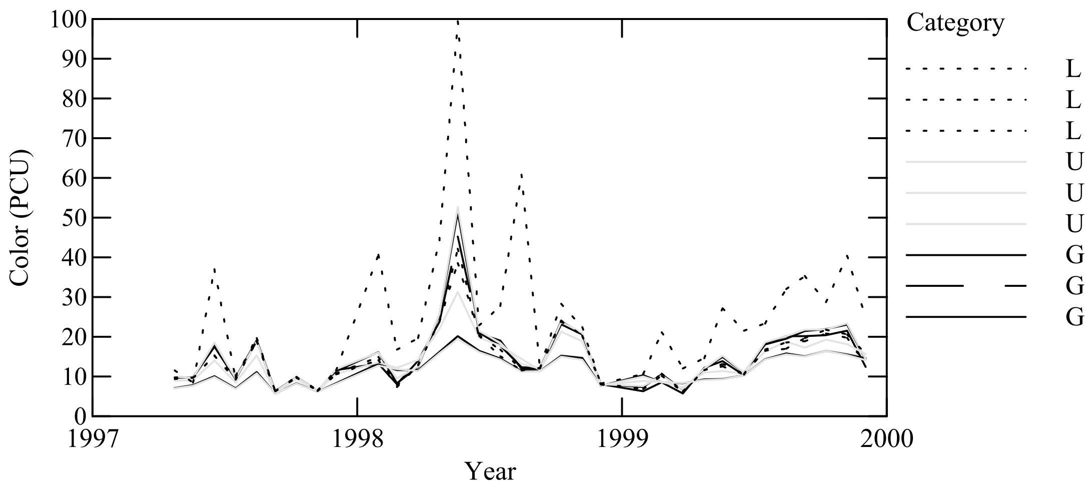


Chlorophyll *a* (ug/L)
Year
Category
L
L
L
U
U
U
G
G
G

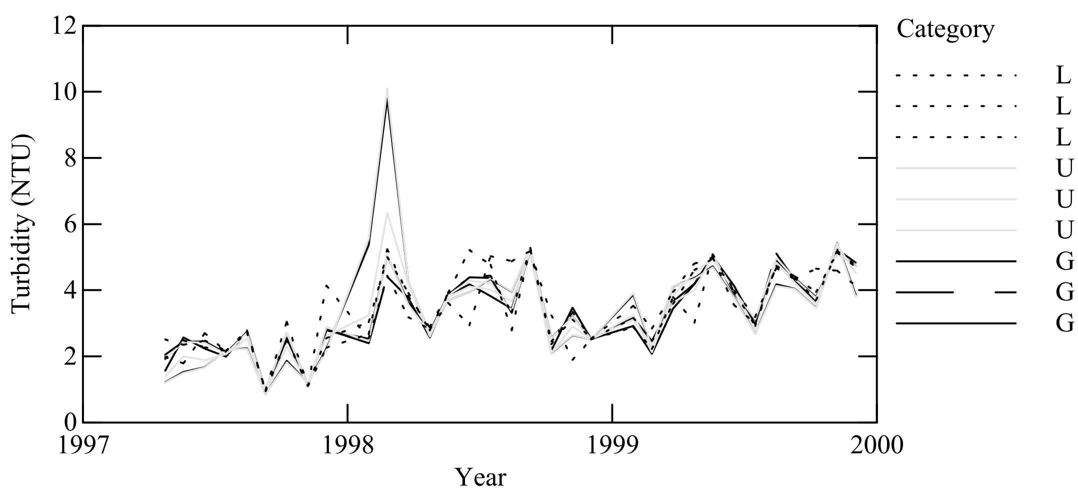
Segment 7



Salinity (PSU)
40
30
20
10
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

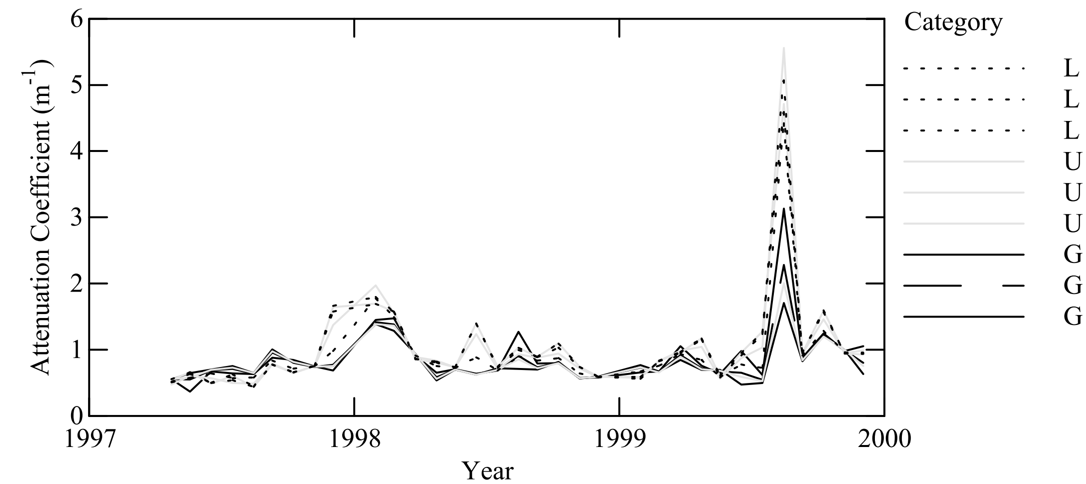


Color (PCU)
100
90
80
70
60
50
40
30
20
10
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

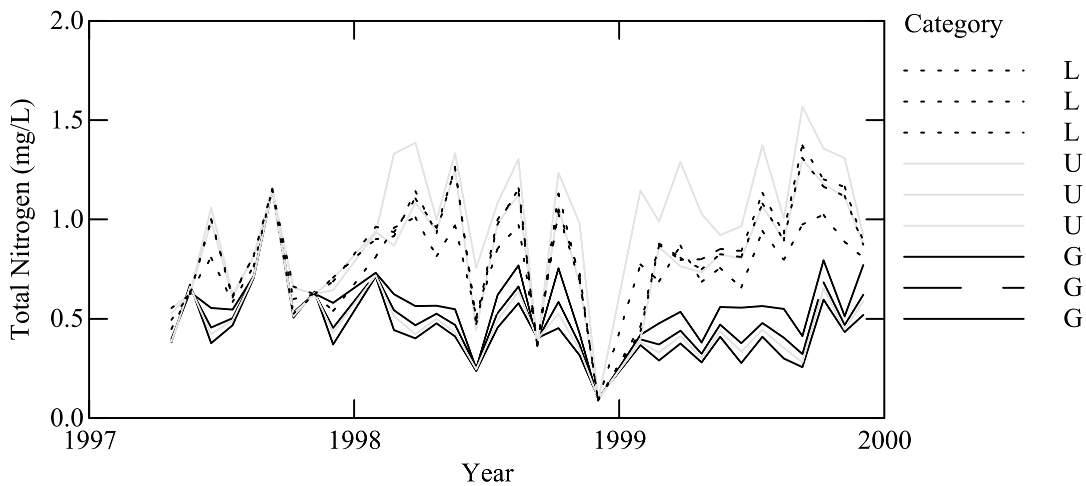


Turbidity (NTU)
12
10
8
6
4
2
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

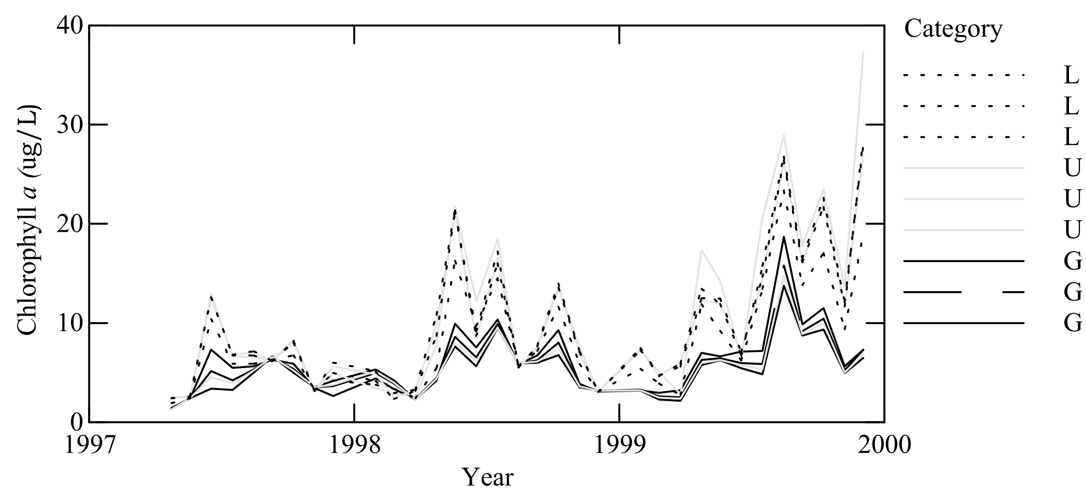
Segment 8



Attenuation Coefficient (m^-1)
0
1
2
3
4
5
6
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

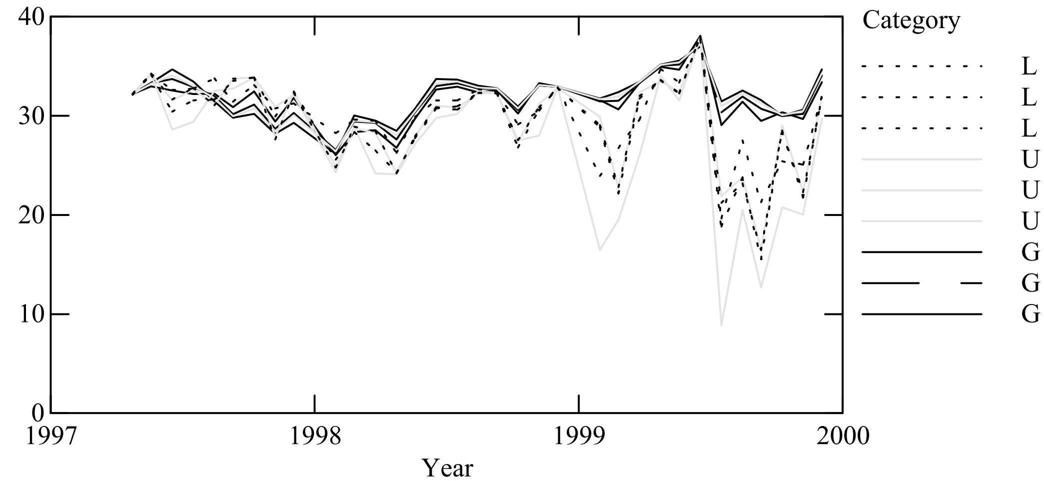


Total Nitrogen (mg/L)
0.0
0.5
1.0
1.5
2.0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

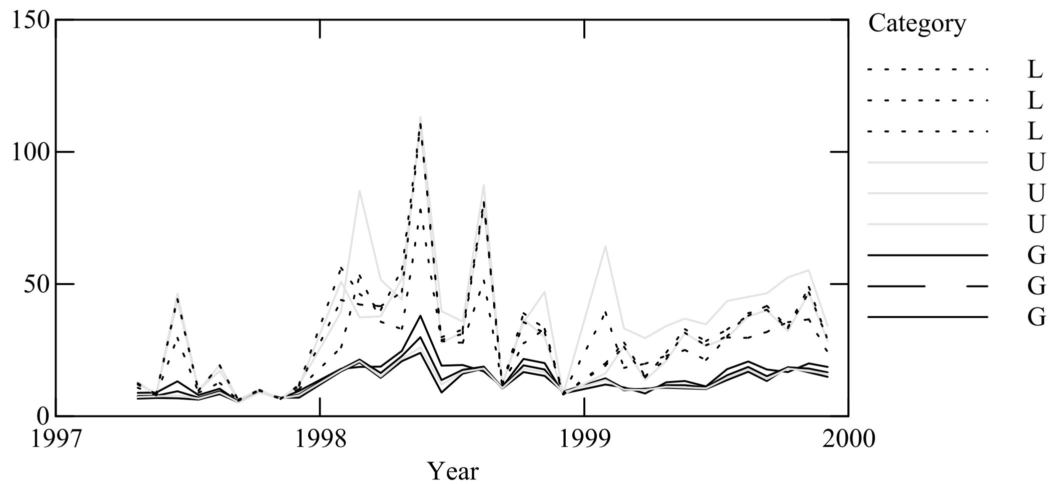


Chlorophyll a (ug/L)
0
10
20
30
40
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

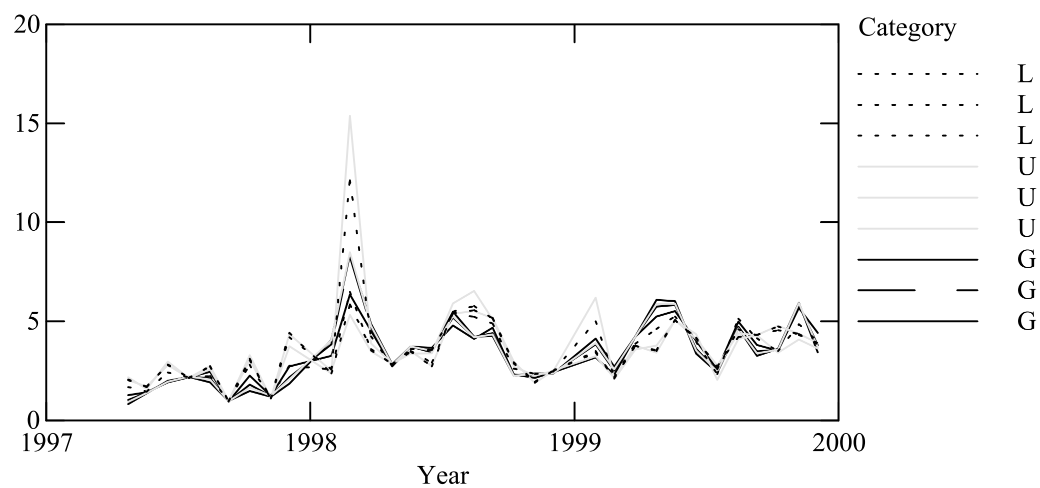
Segment 8



40
30
20
10
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

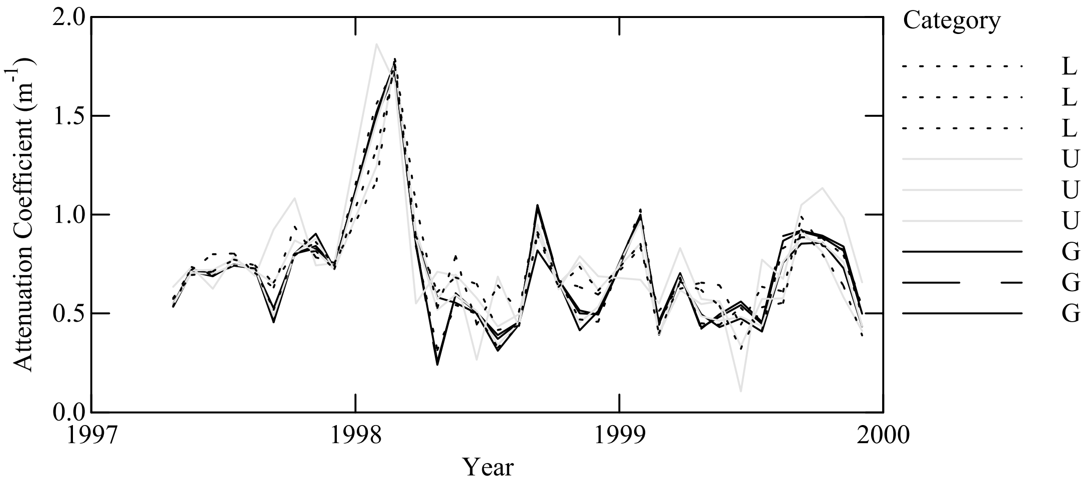


150
100
50
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

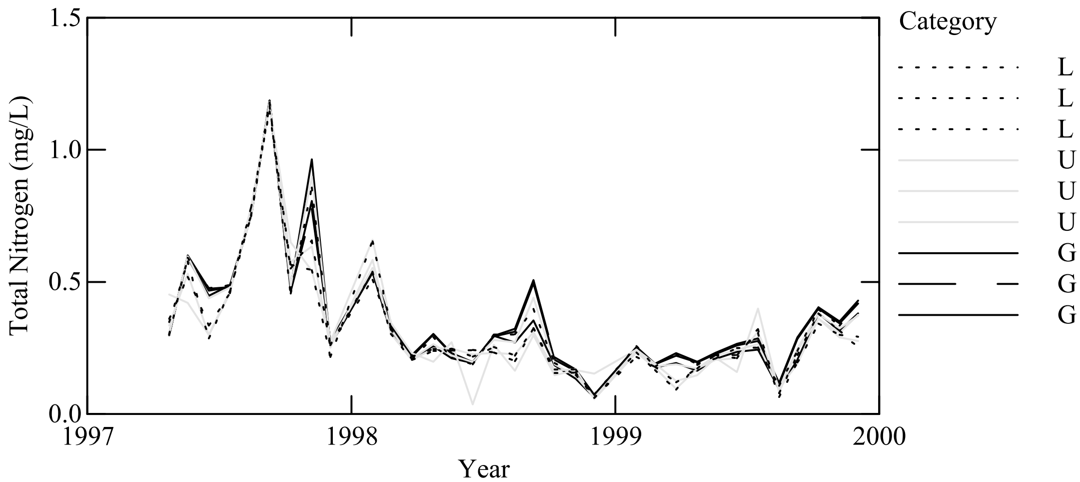


20
15
10
5
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

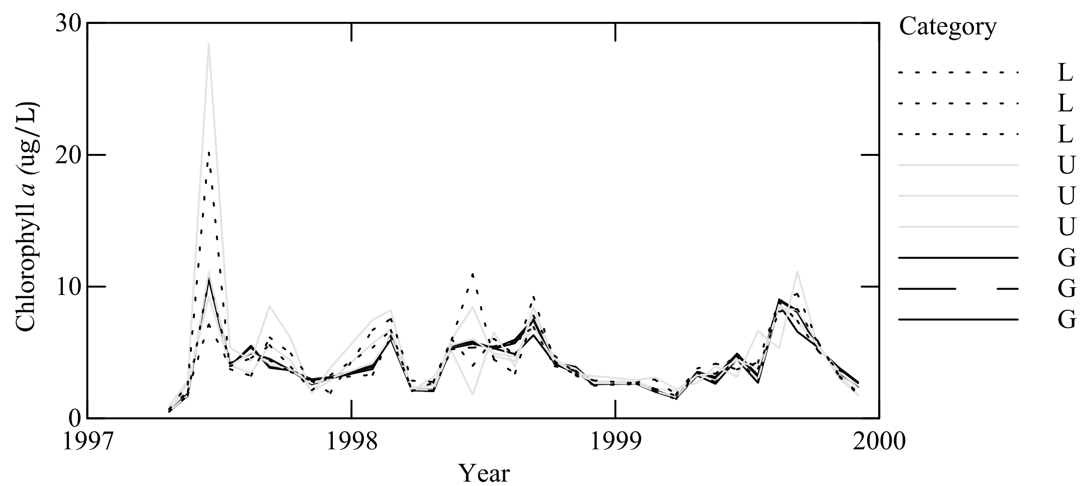
Segment 10



2.0
1.5
1.0
0.5
0.0
Attenuation Coefficient (m^{-1})
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

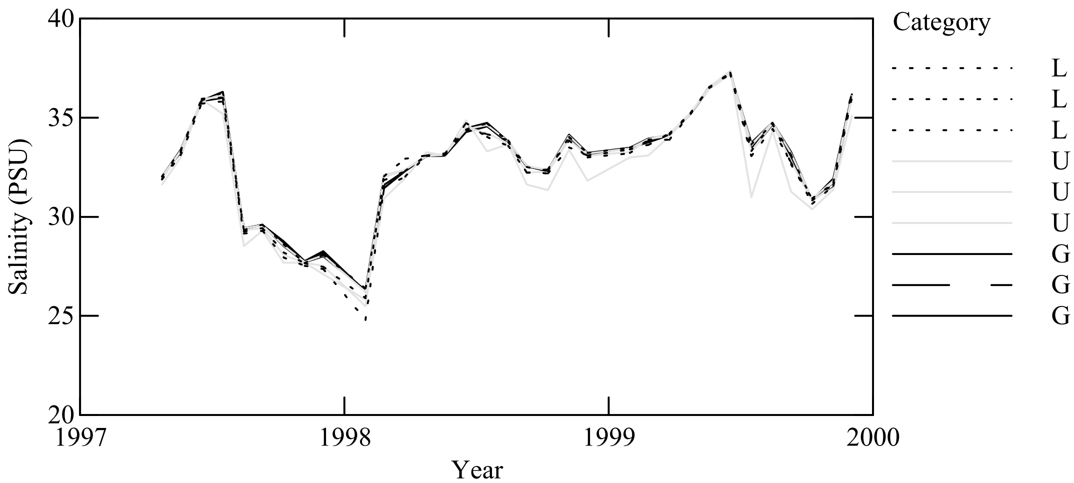


1.5
1.0
0.5
0.0
Total Nitrogen (mg/L)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

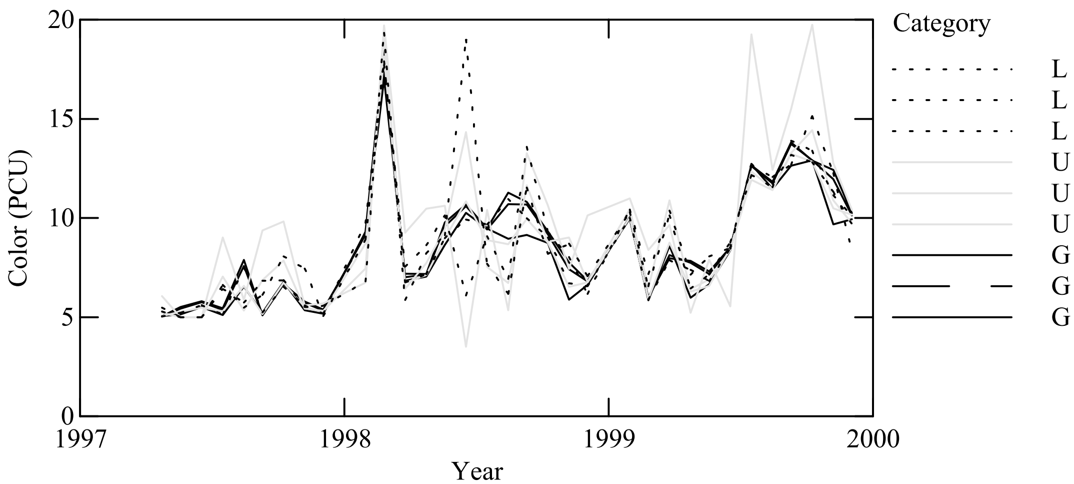


30
20
10
0
Chlorophyll *a* (ug/L)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

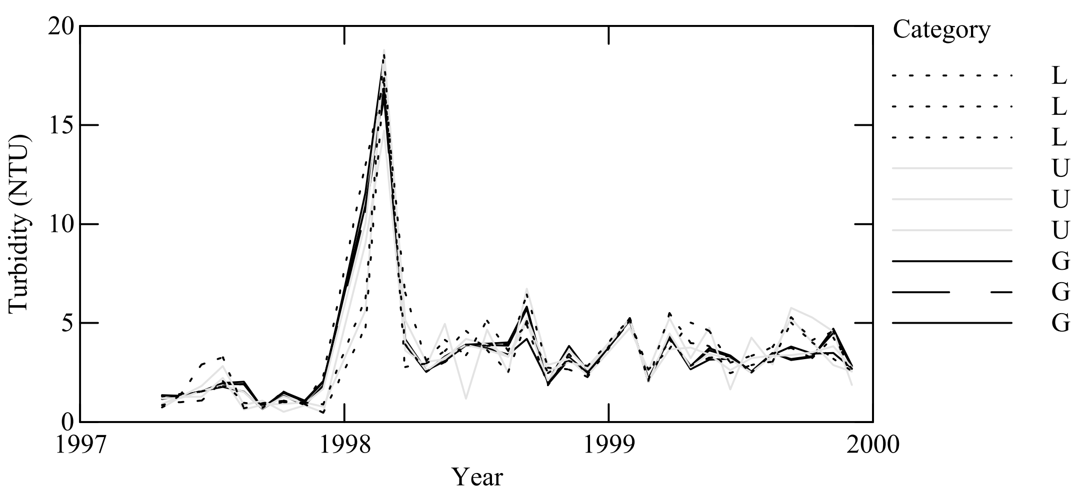
Segment 10



40
35
30
25
20
Salinity (PSU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

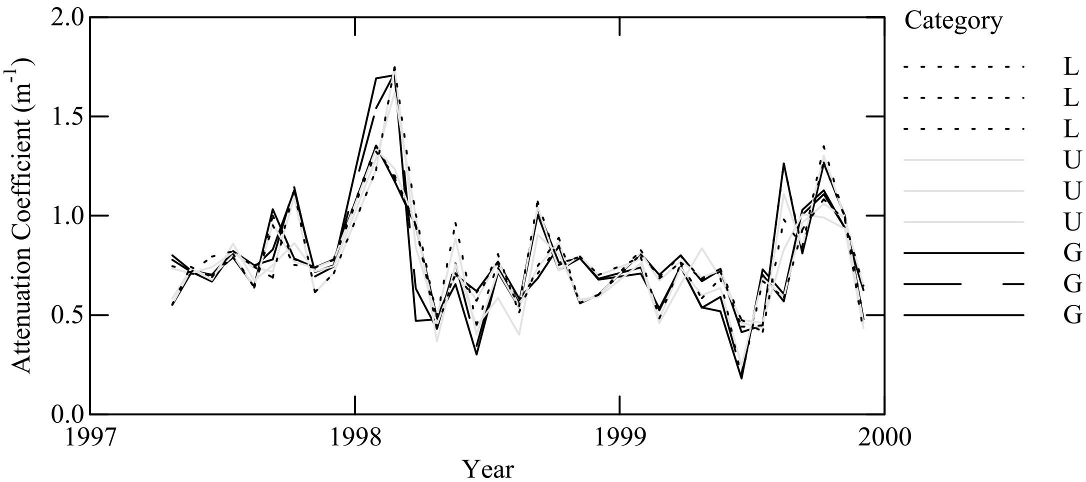


20
15
10
5
0
Color (PCU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

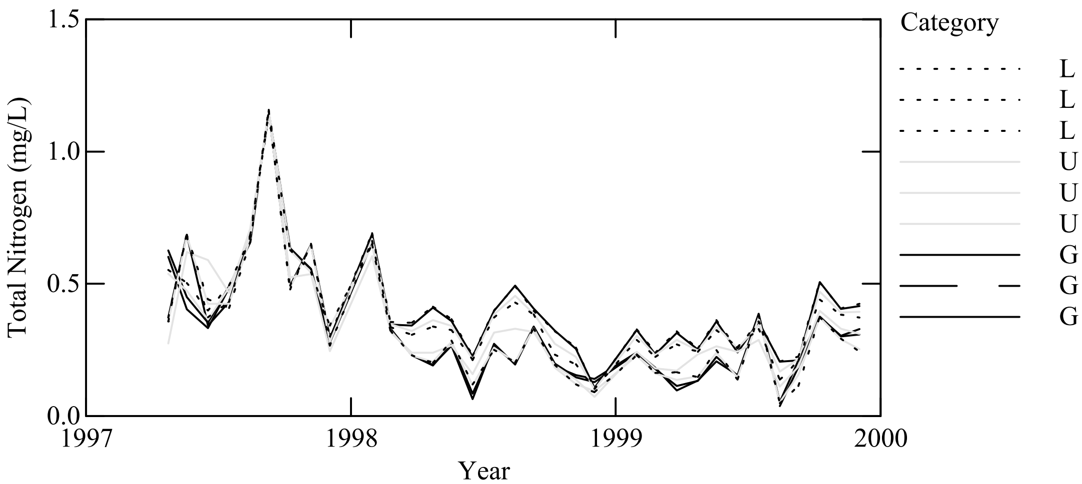


20
15
10
5
0
Turbidity (NTU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

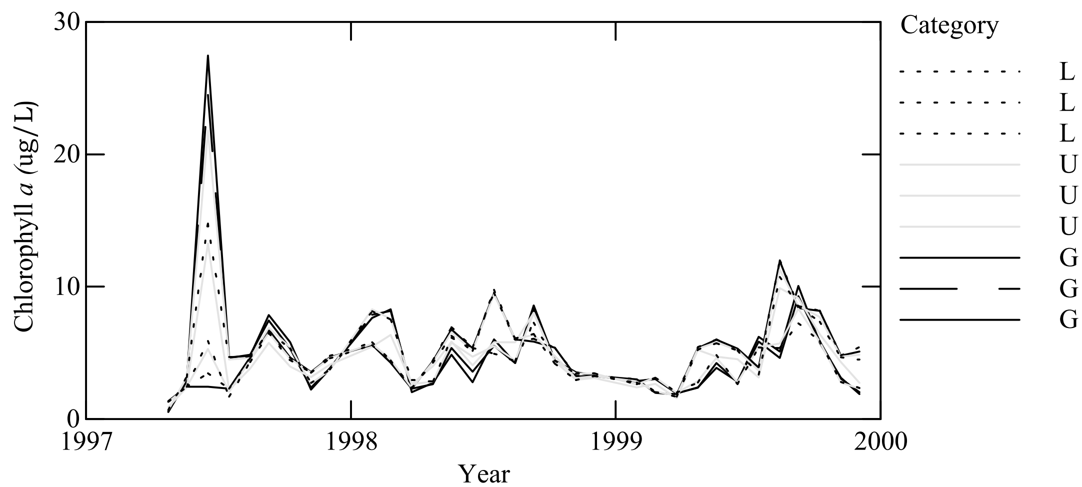
Segment 11



2.0
1.5
1.0
0.5
0.0
Attenuation Coefficient (m-1)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

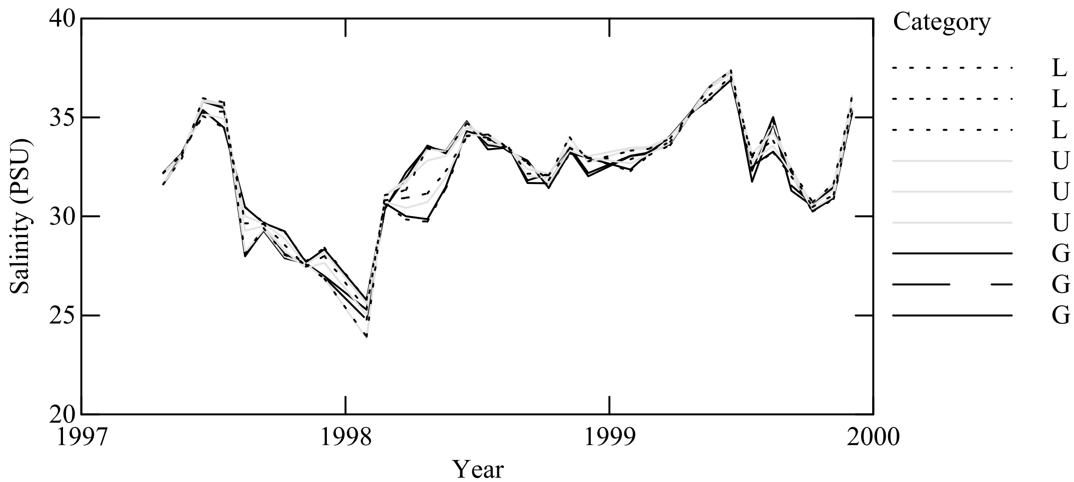


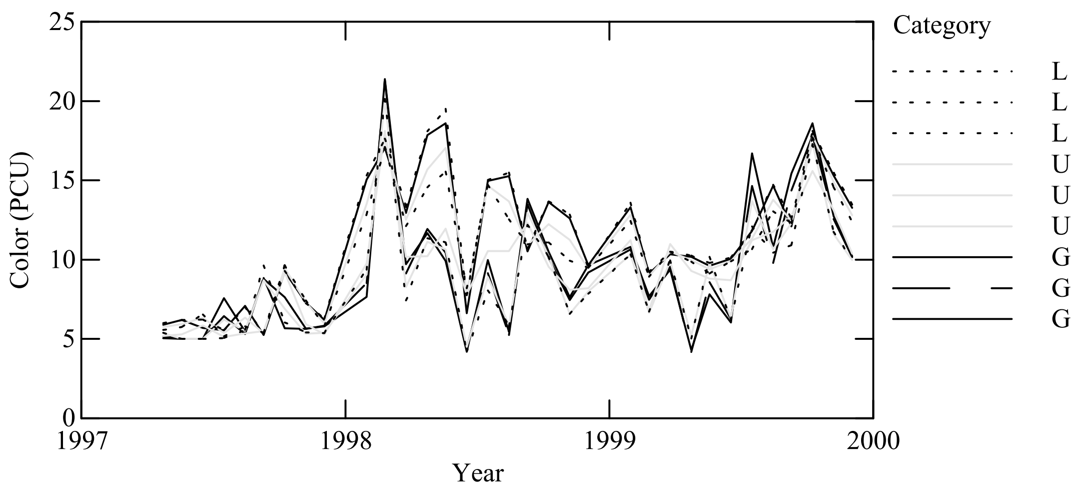
1.5
1.0
0.5
0.0
Total Nitrogen (mg/L)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

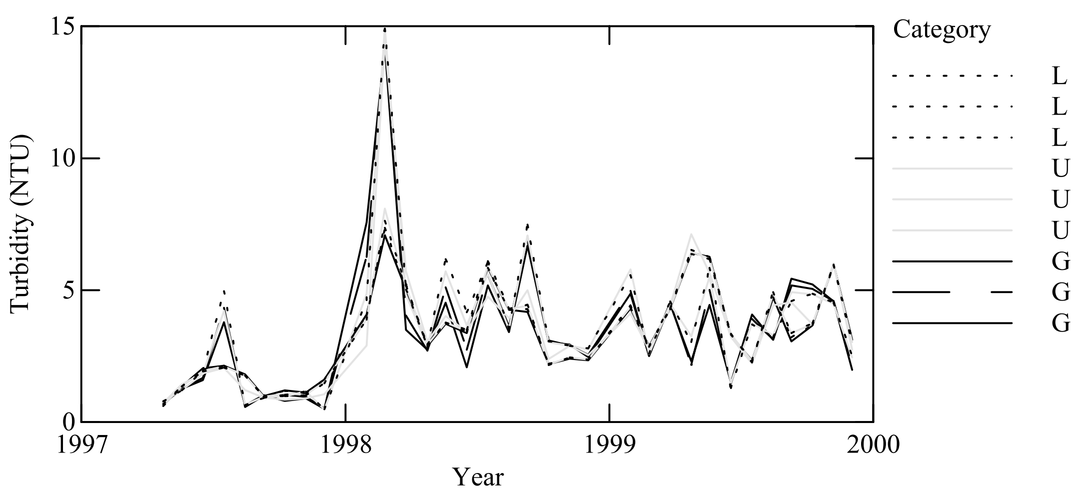


30
20
10
0
Chlorophyll a (ug/L)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

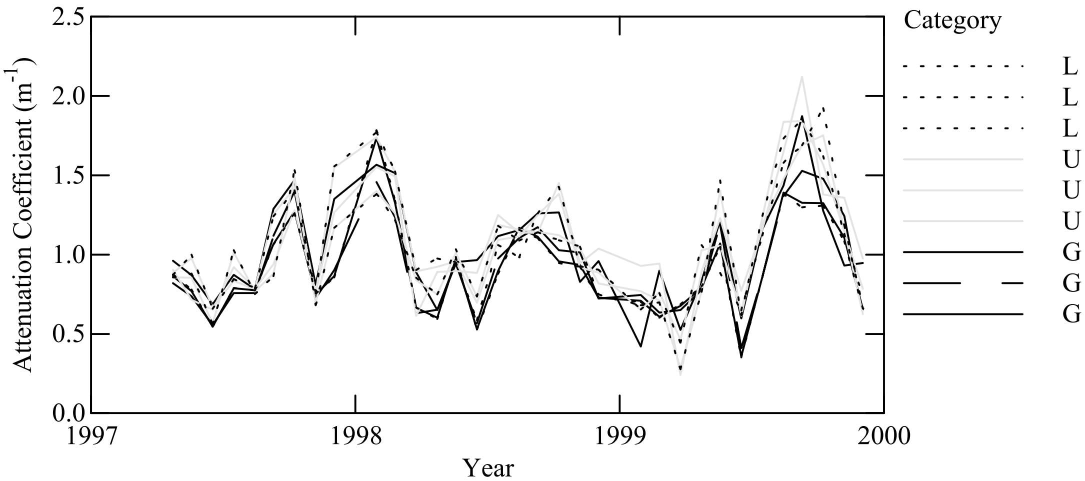
Segment 11


Salinity (PSU)
40
35
30
25
20
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

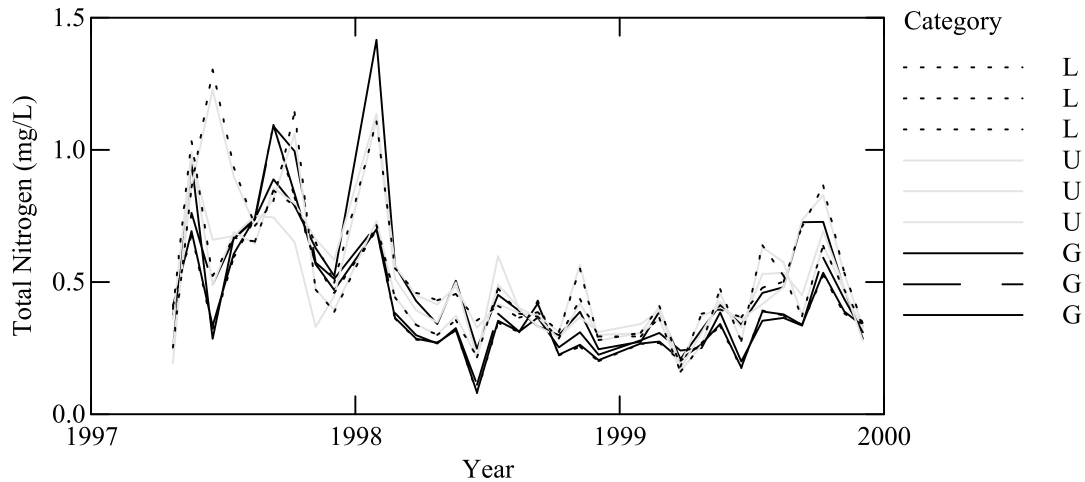

Color (PCU)
25
20
15
10
5
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G


Turbidity (NTU)
15
10
5
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

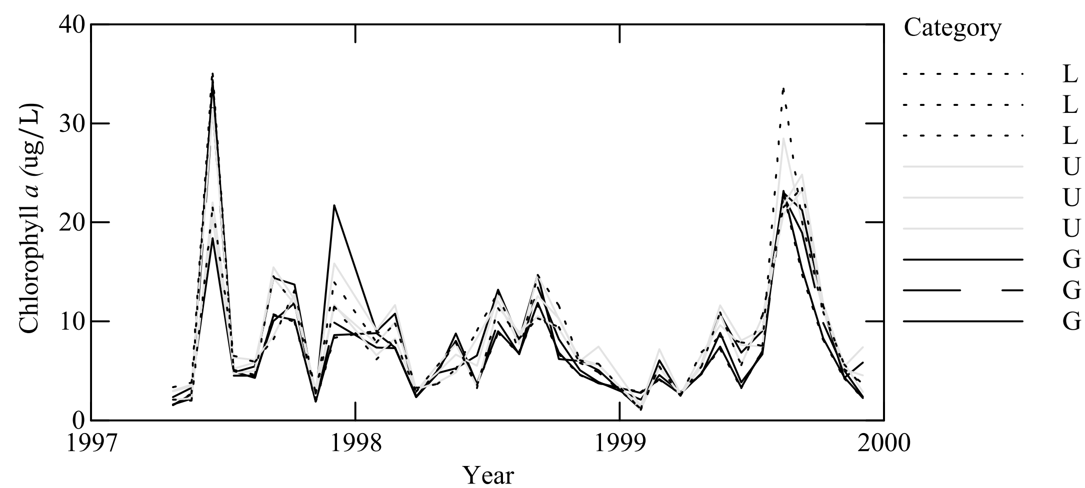
Segment 13



Attenuation Coefficient (m-1)
2.5
2.0
1.5
1.0
0.5
0.0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

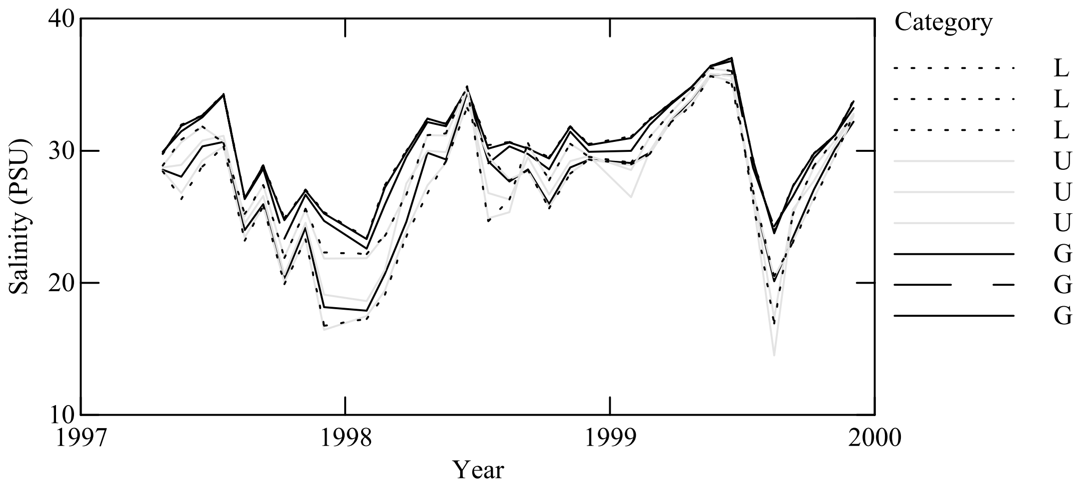


Total Nitrogen (mg/L)
1.5
1.0
0.5
0.0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

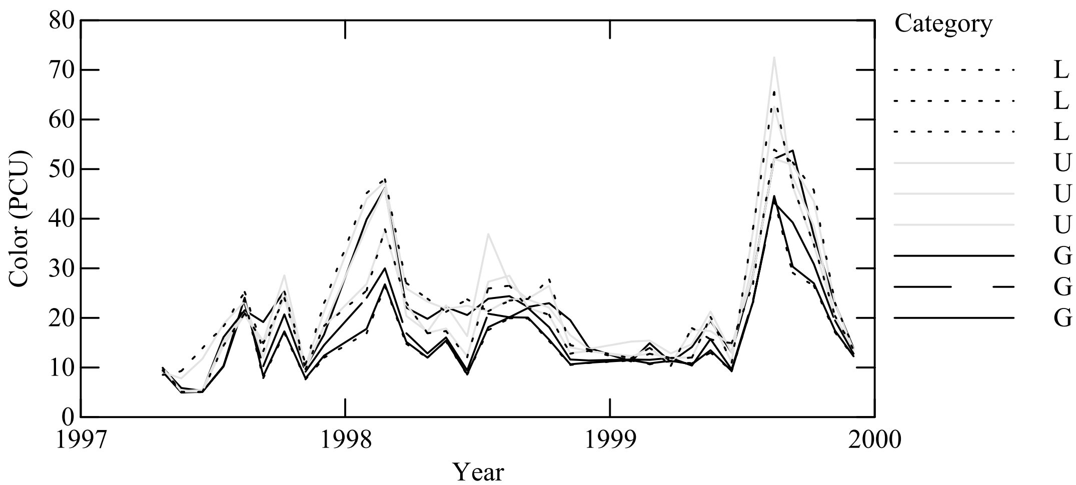


Chlorophyll a (ug/L)
40
30
20
10
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

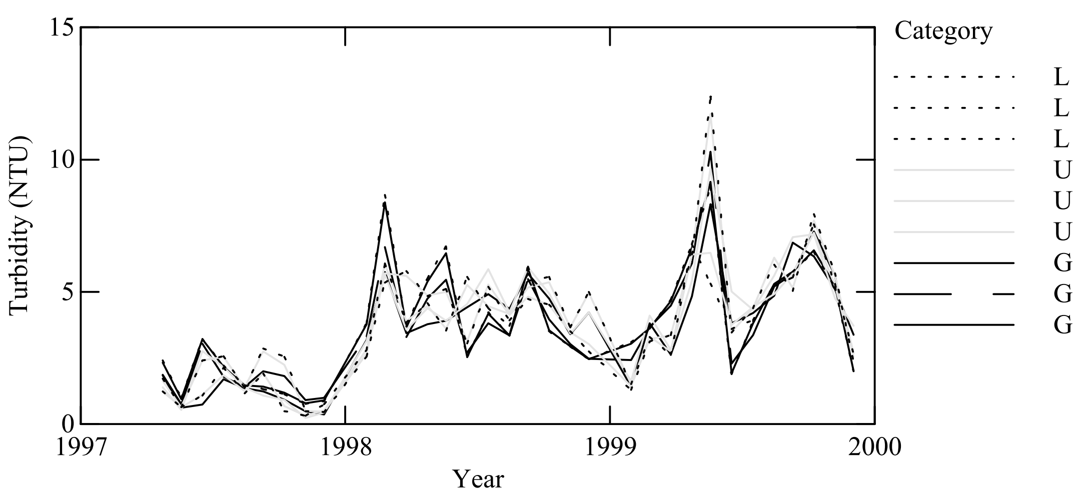
Segment 13



40
30
20
10
Salinity (PSU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

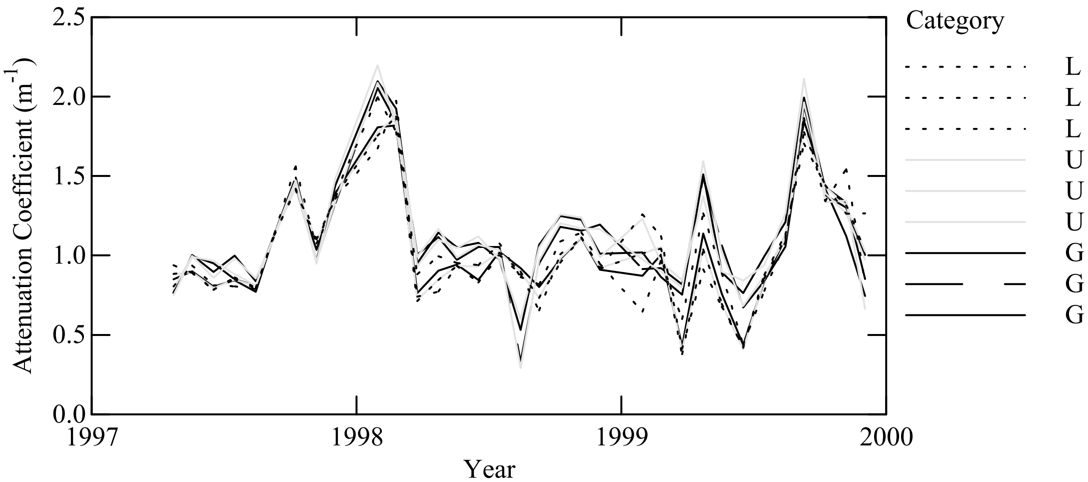


80
70
60
50
40
30
20
10
0
Color (PCU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

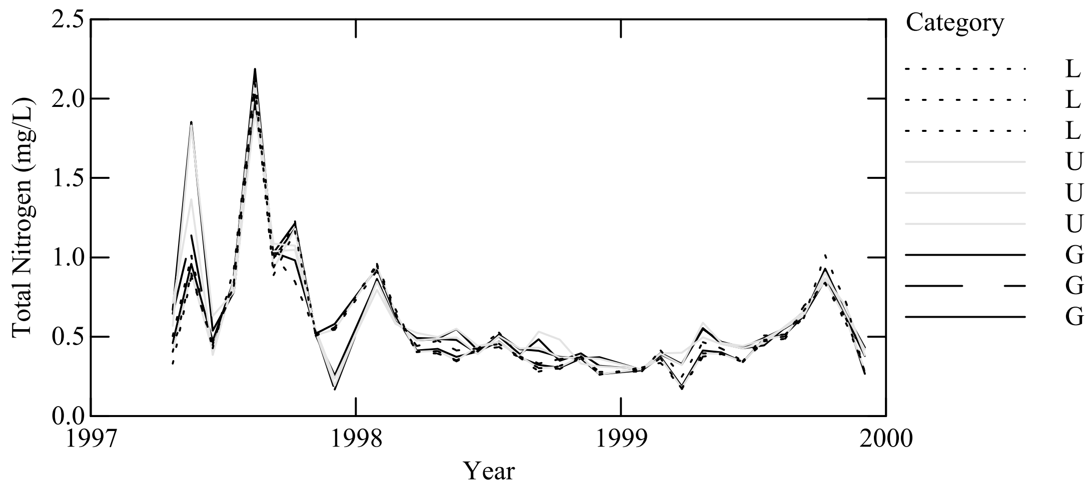


15
10
5
0
Turbidity (NTU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

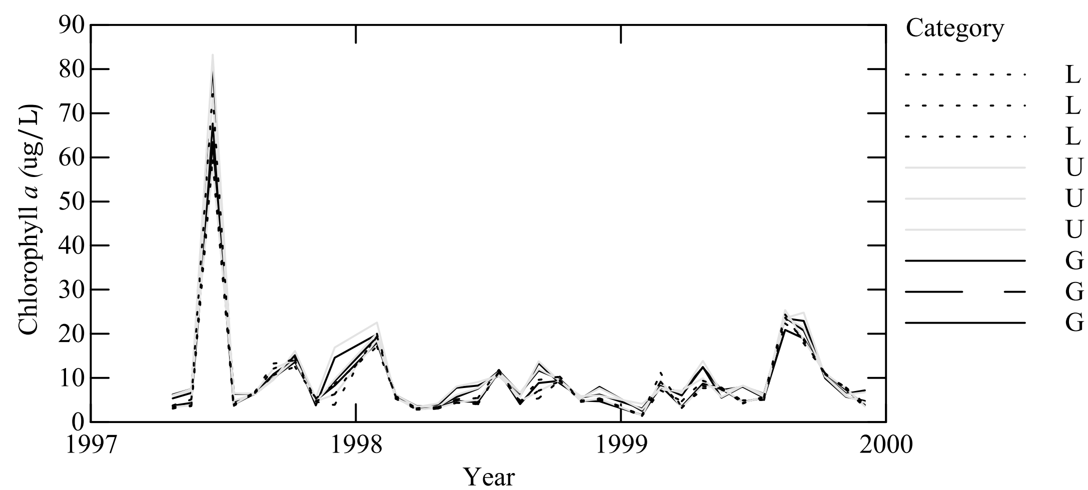
Segment 14



Attenuation Coefficient (m-1)
0.0
0.5
1.0
1.5
2.0
2.5
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

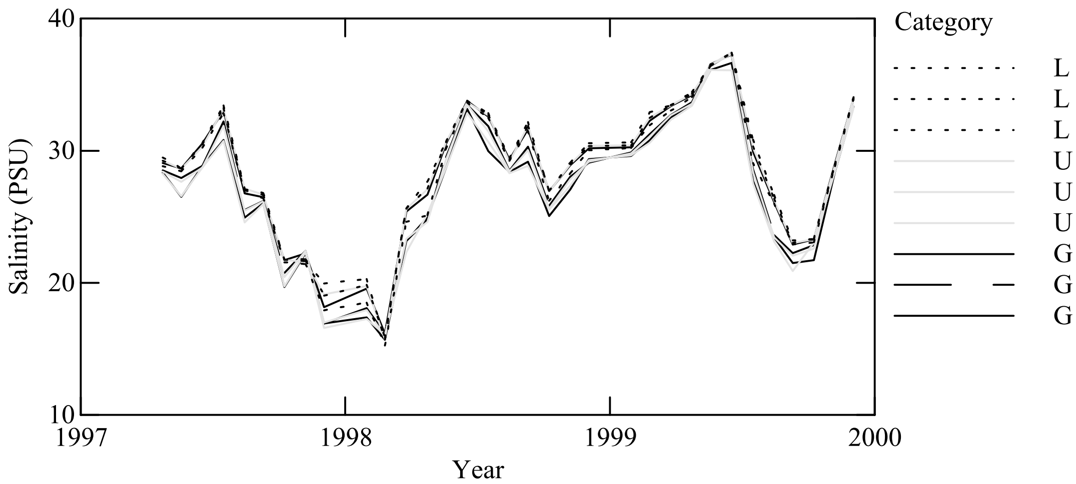


Total Nitrogen (mg/L)
0.0
0.5
1.0
1.5
2.0
2.5
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

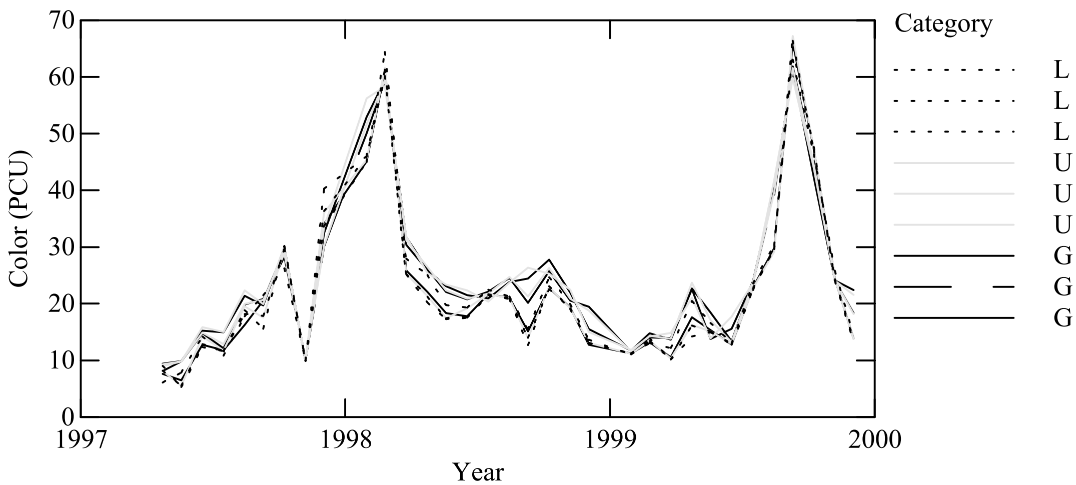


Chlorophyll a (ug/L)
0
10
20
30
40
50
60
70
80
90
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

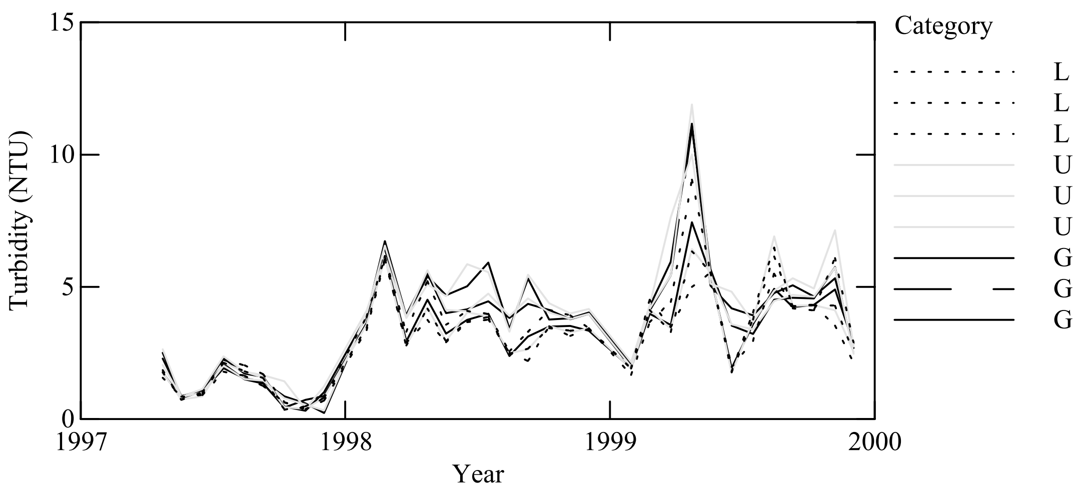
Segment 14



40
30
20
10
Salinity (PSU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

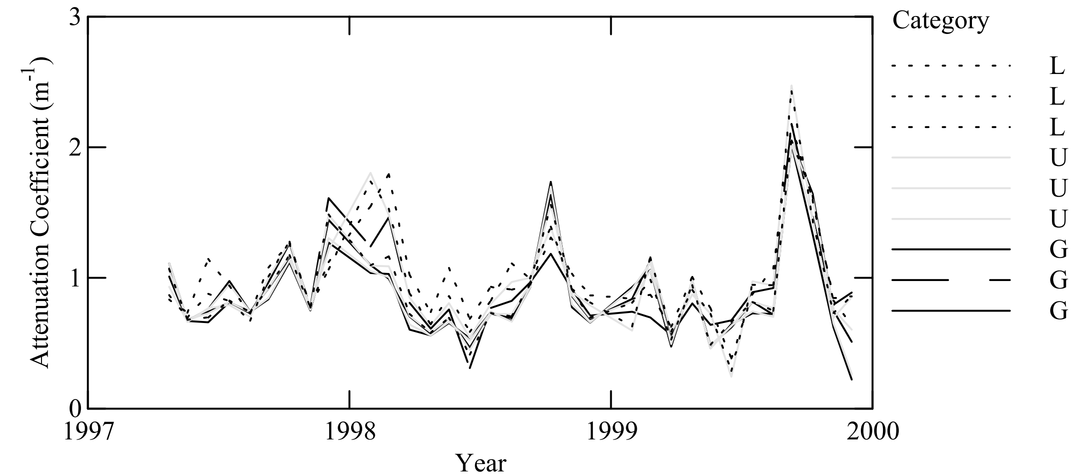


70
60
50
40
30
20
10
0
Color (PCU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

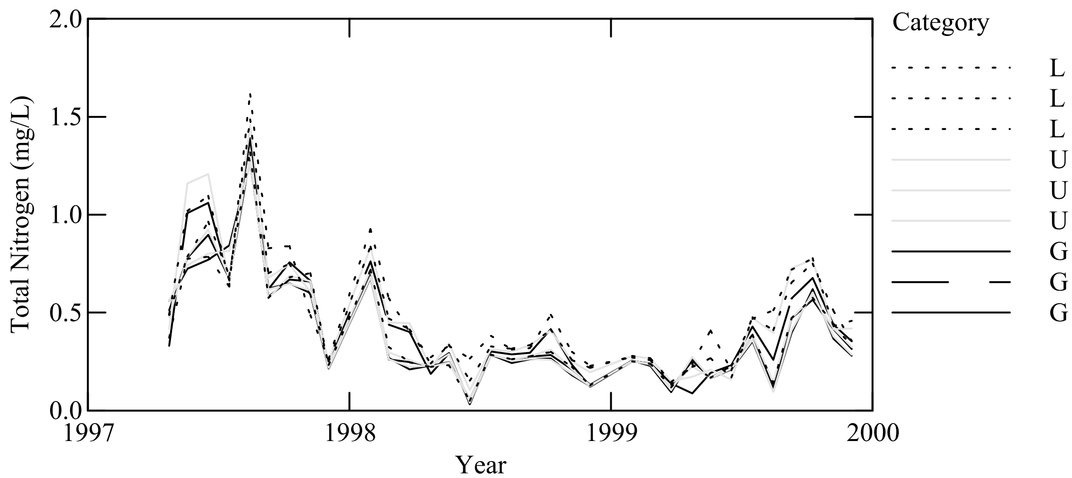


15
10
5
0
Turbidity (NTU)
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

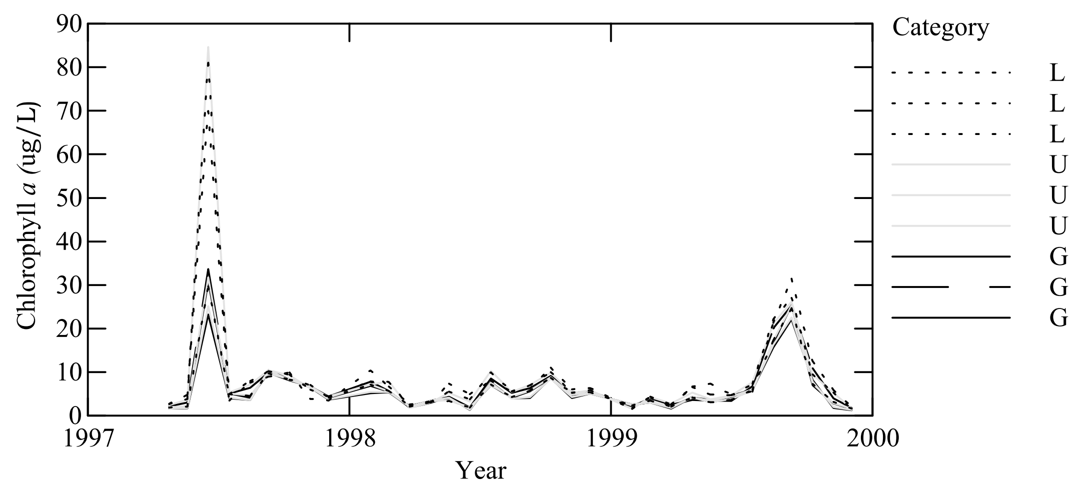
Segment 16



Attenuation Coefficient (m-1)
0
1
2
3
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

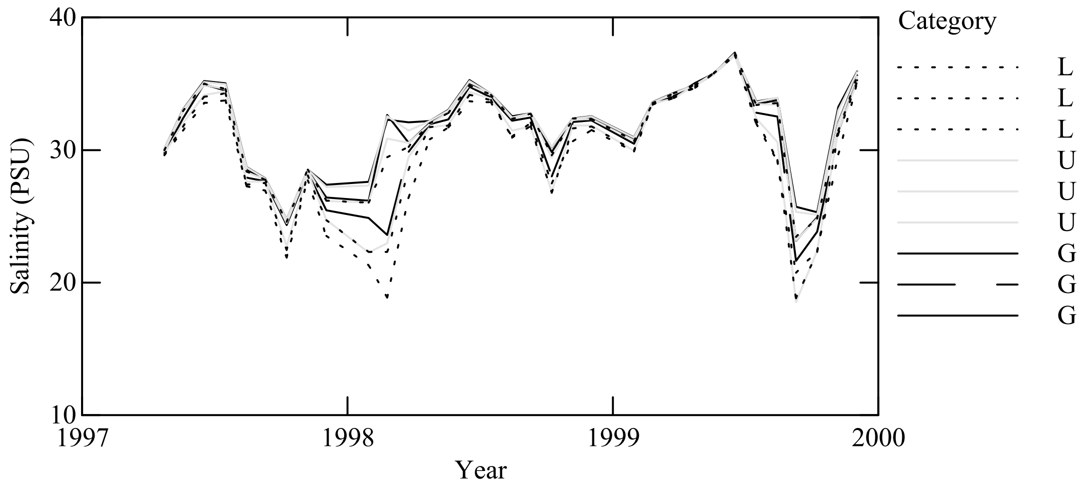


Total Nitrogen (mg/L)
0.0
0.5
1.0
1.5
2.0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

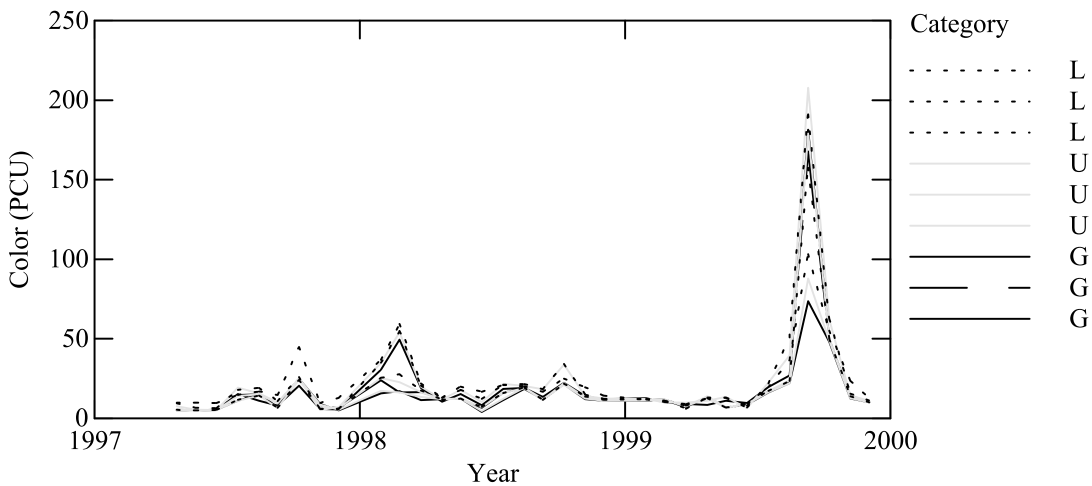


Chlorophyll a (ug/L)
0
10
20
30
40
50
60
70
80
90
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

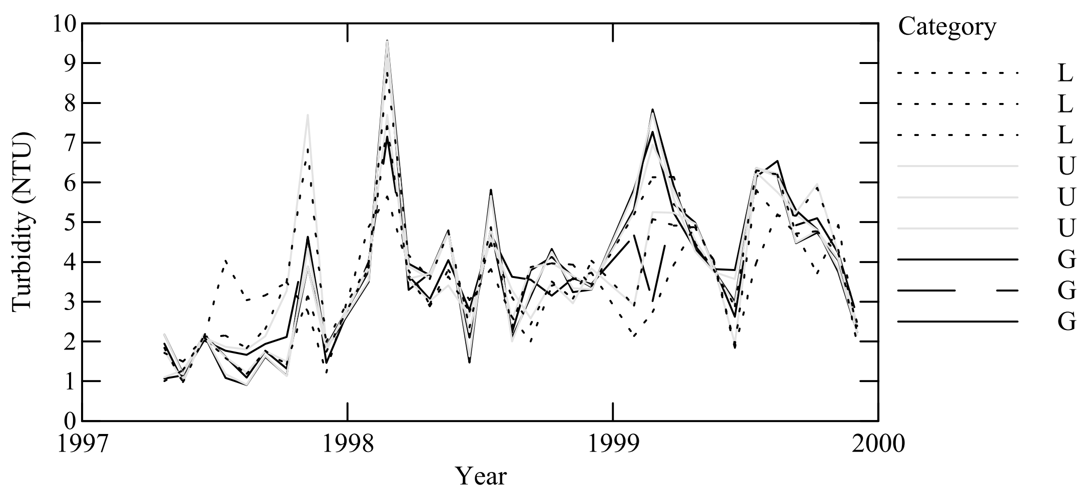
Segment 16



Salinity (PSU)
40
30
20
10
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

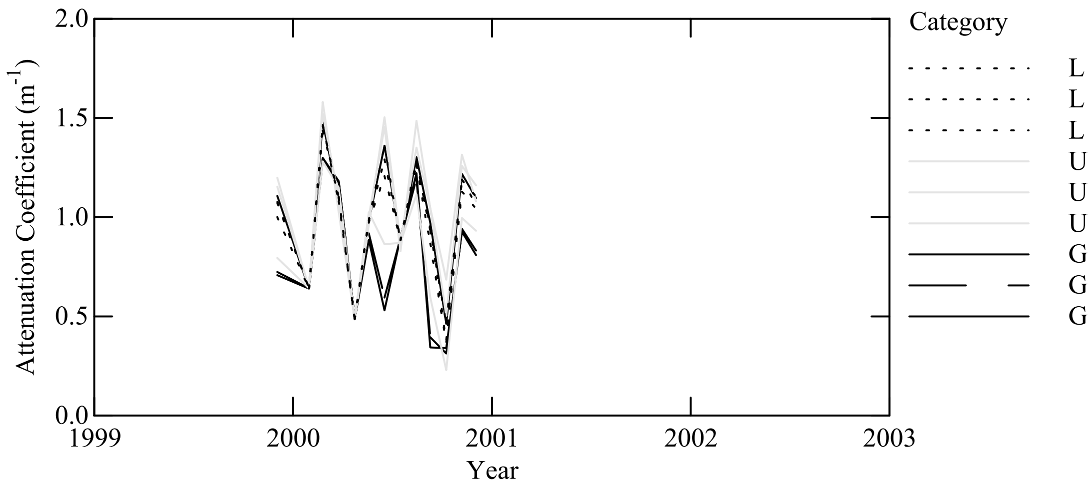


Color (PCU)
250
200
150
100
50
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

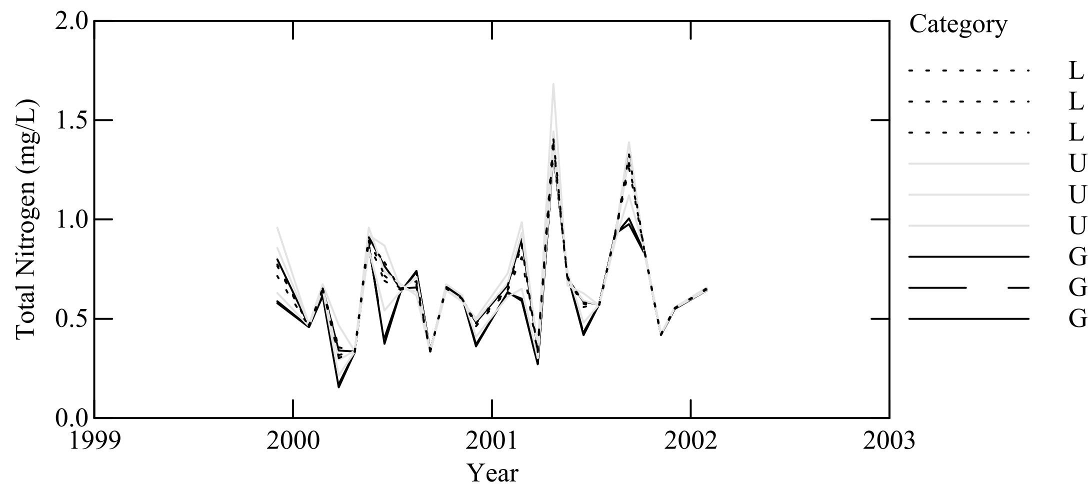


Turbidity (NTU)
10
9
8
7
6
5
4
3
2
1
0
1997
1998
1999
2000
Year
Category
L
L
L
U
U
U
G
G
G

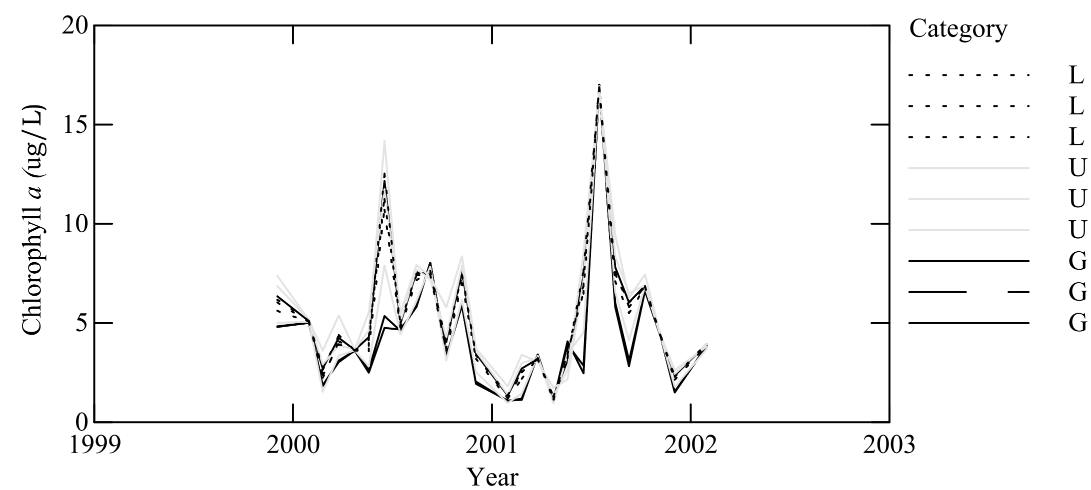
Segment 1



Attenuation Coefficient (m^{-1})
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

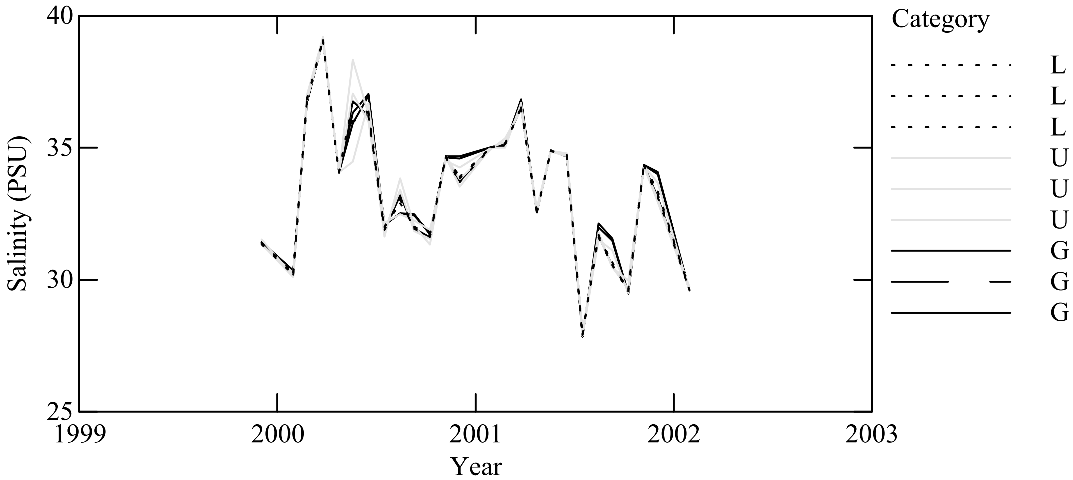


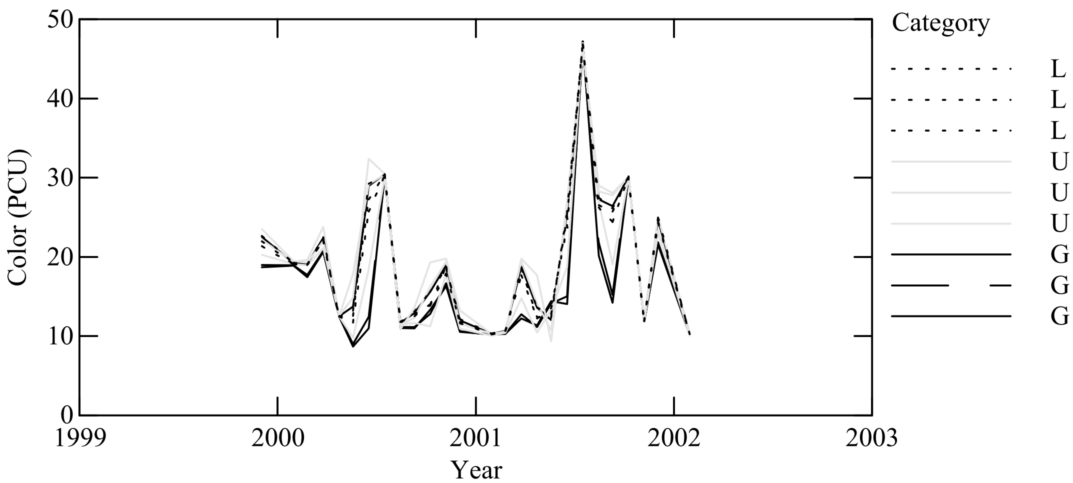
Total Nitrogen (mg/L)
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

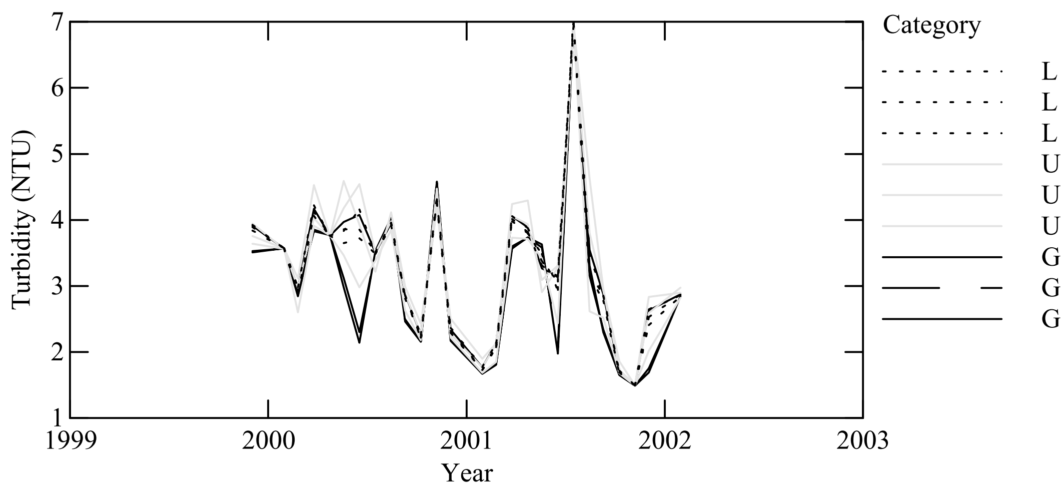


Chlorophyll *a* (ug/L)
20
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

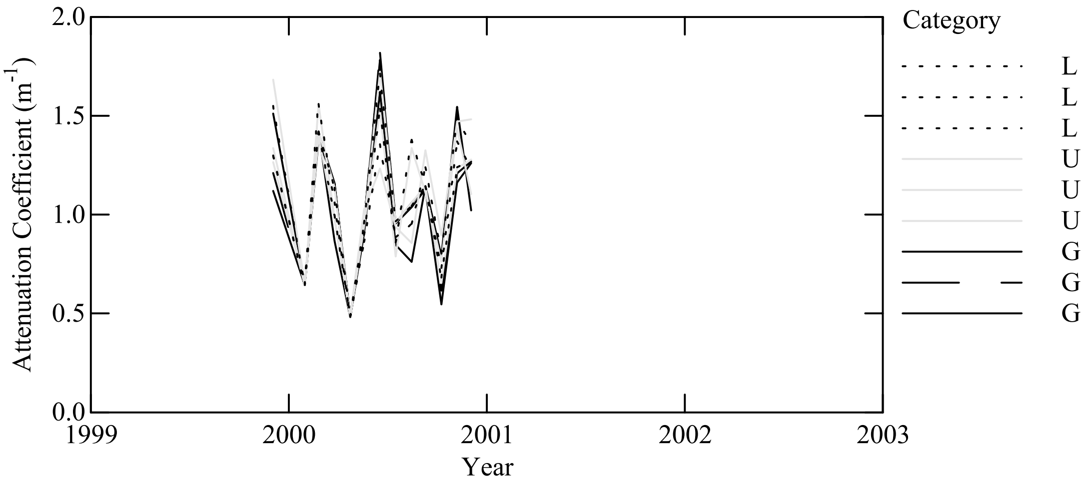
Segment 1

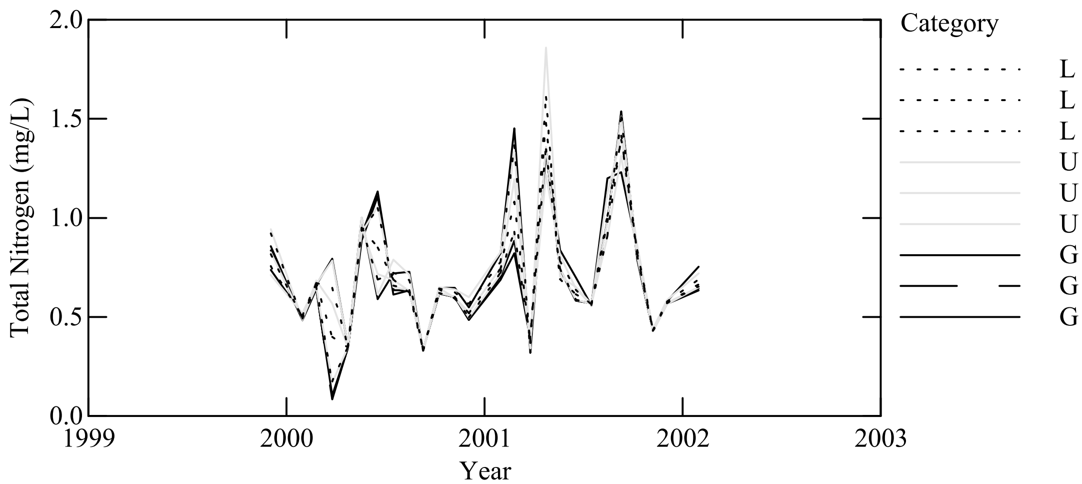

40
35
30
25
Salinity (PSU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

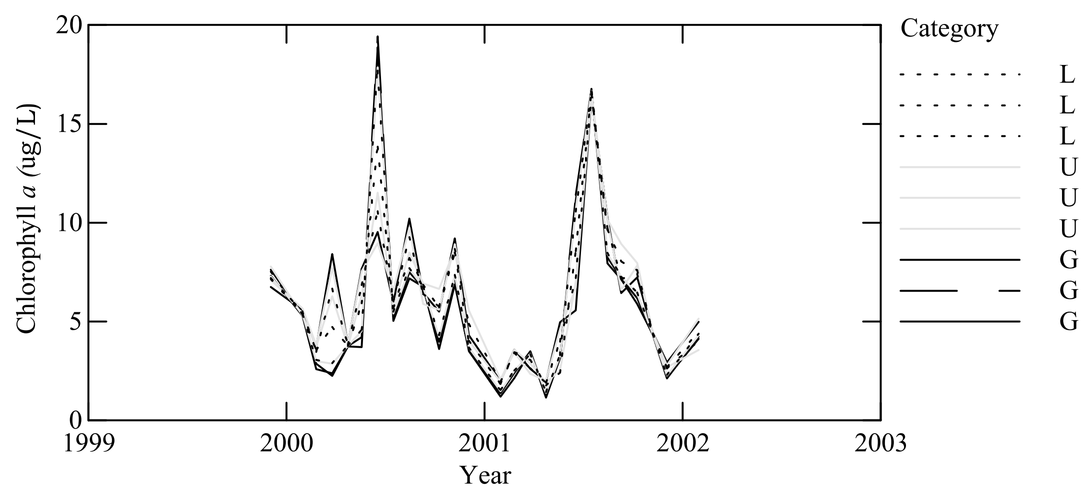

50
40
30
20
10
0
Color (PCU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G


7
6
5
4
3
2
1
Turbidity (NTU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

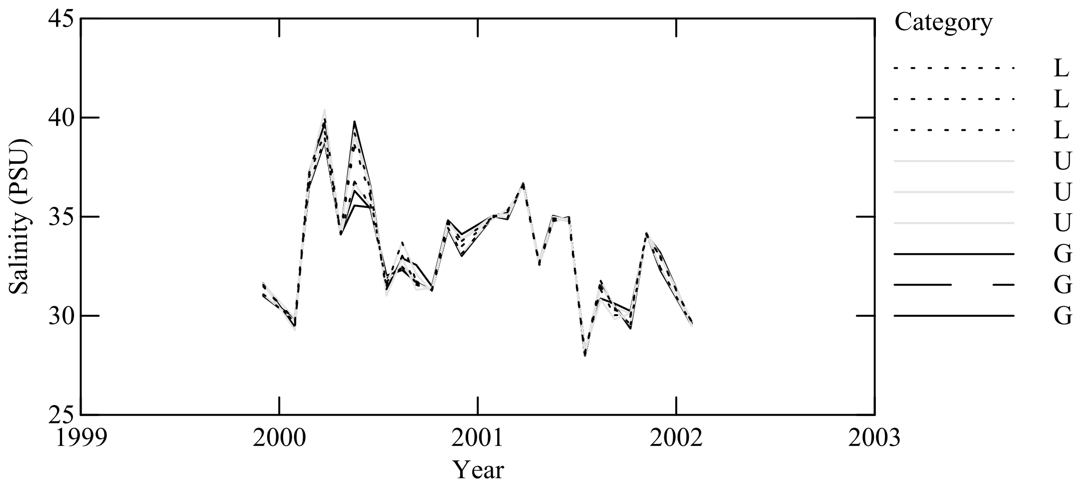
Segment 2

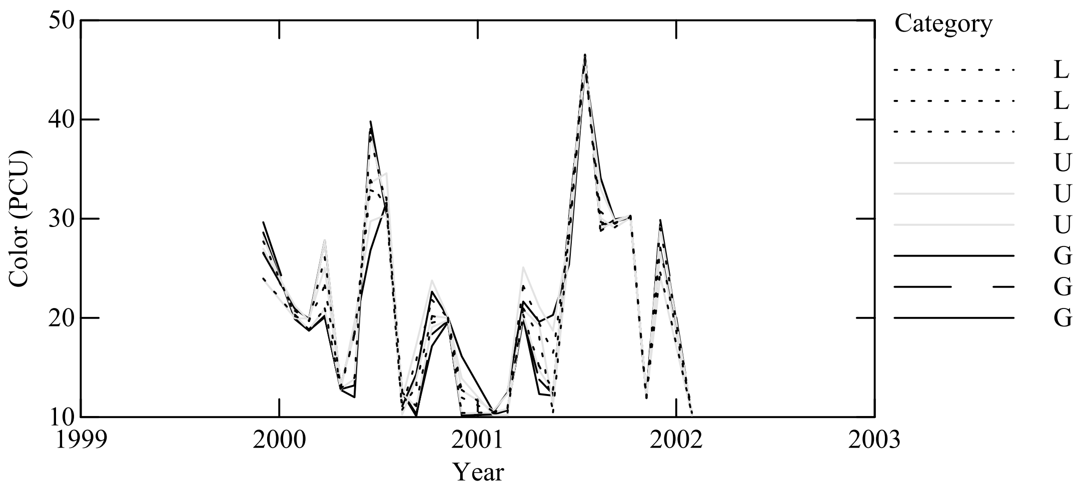

Attenuation Coefficient (m^{-1})
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

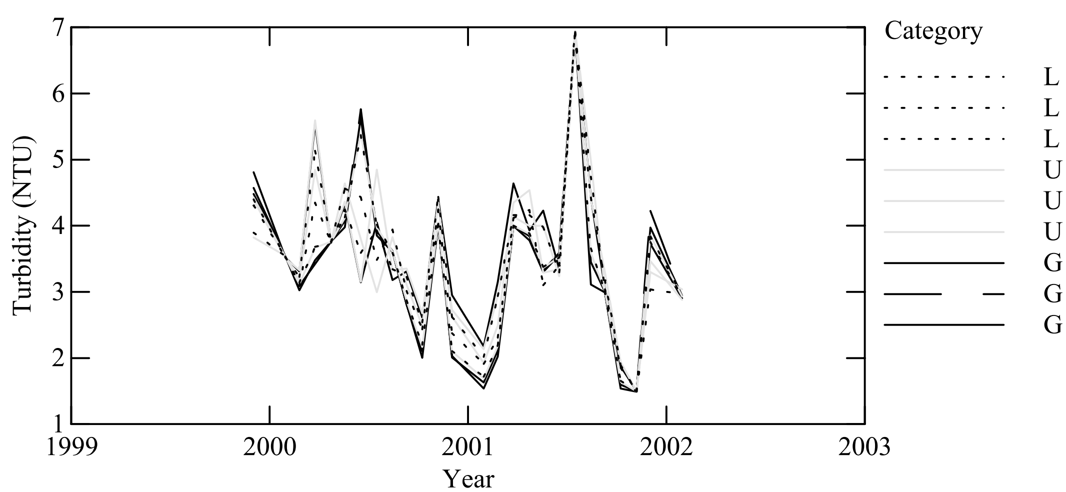

Total Nitrogen (mg/L)
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G


Chlorophyll *a* (ug/L)
20
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

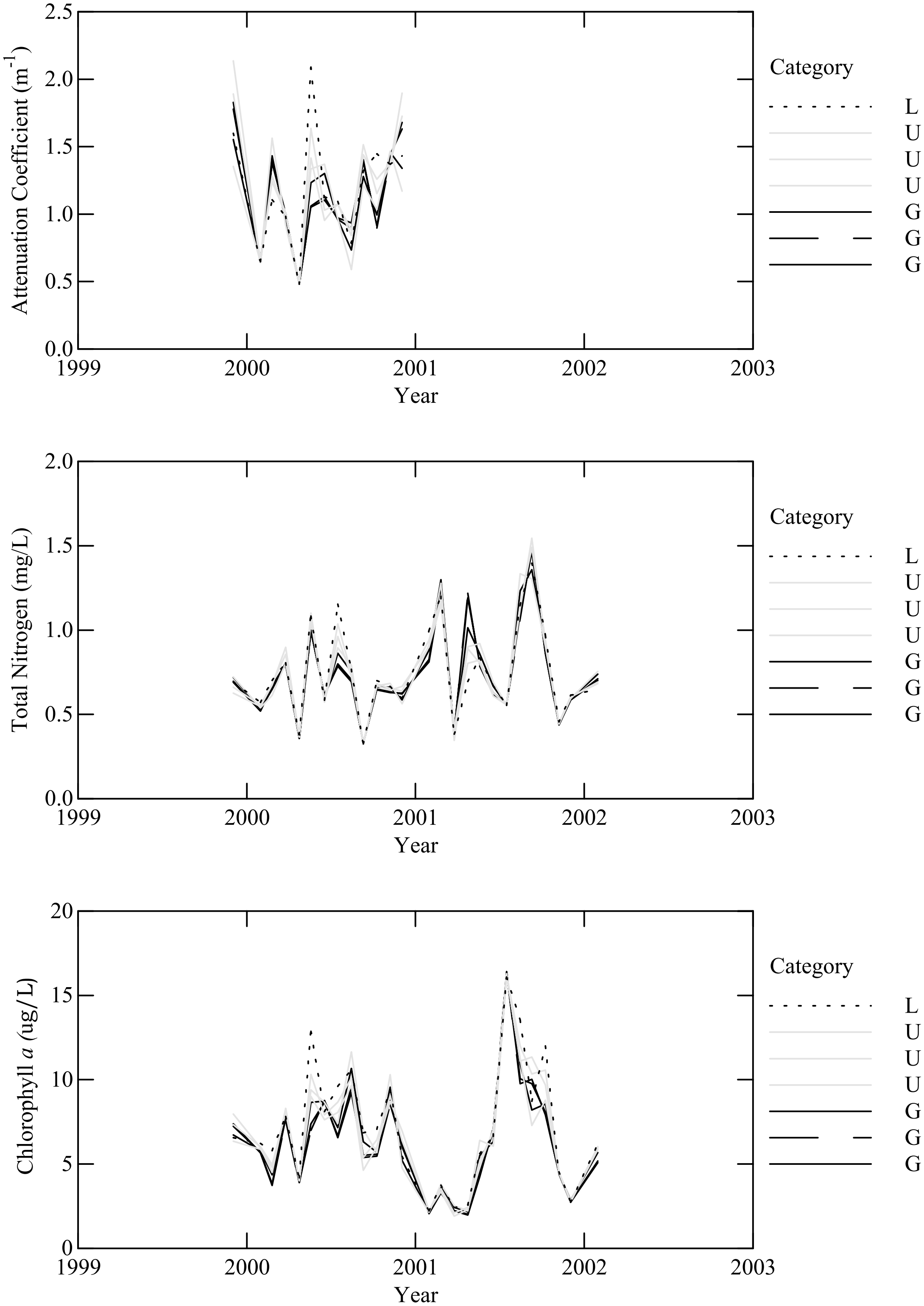
Segment 2


Salinity (PSU)
45
40
35
30
25
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G


Color (PCU)
50
40
30
20
10
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

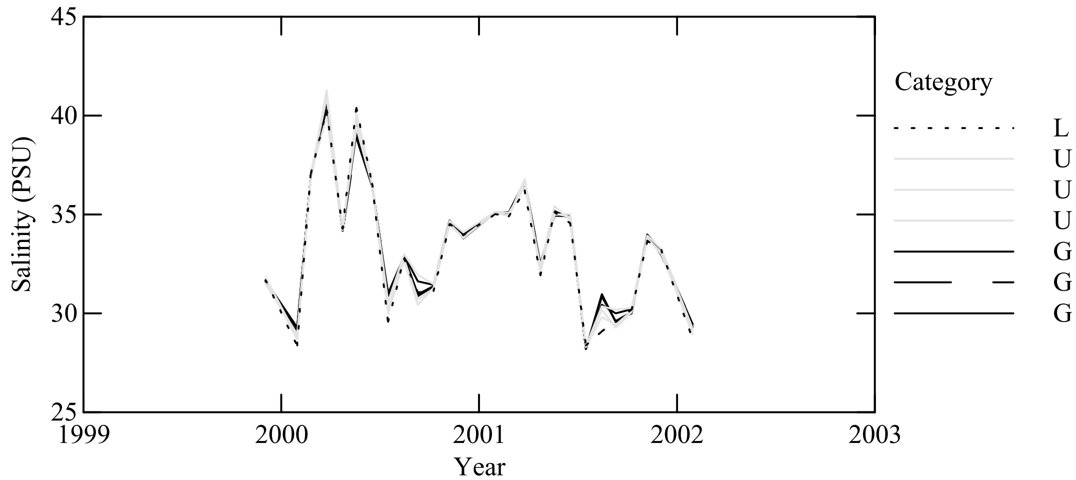

Turbidity (NTU)
7
6
5
4
3
2
1
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

Segment 3

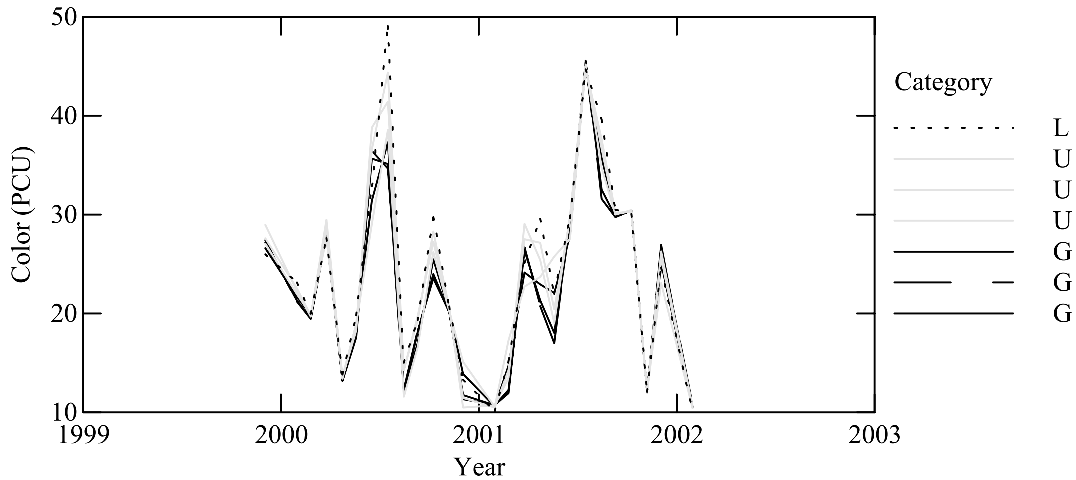


Attenuation Coefficient (m-1)
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
U
U
U
G
G
G
Total Nitrogen (mg/L)
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
U
U
U
G
G
G
Chlorophyll a (ug/L)
20
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
U
U
U
G
G
G

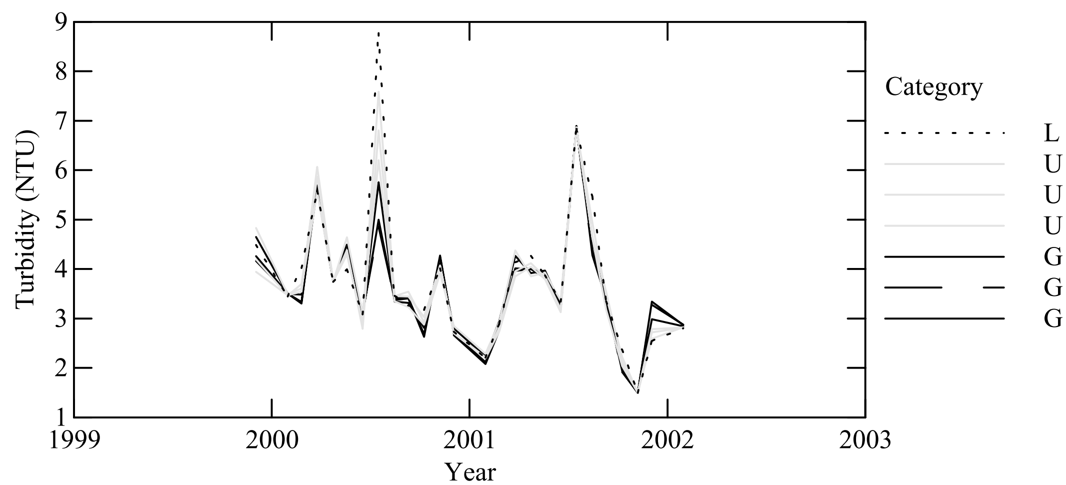
Segment 3



45
40
35
30
25
Salinity (PSU)
1999
2000
2001
2002
2003
Year
Category
L
U
U
U
G
G
G

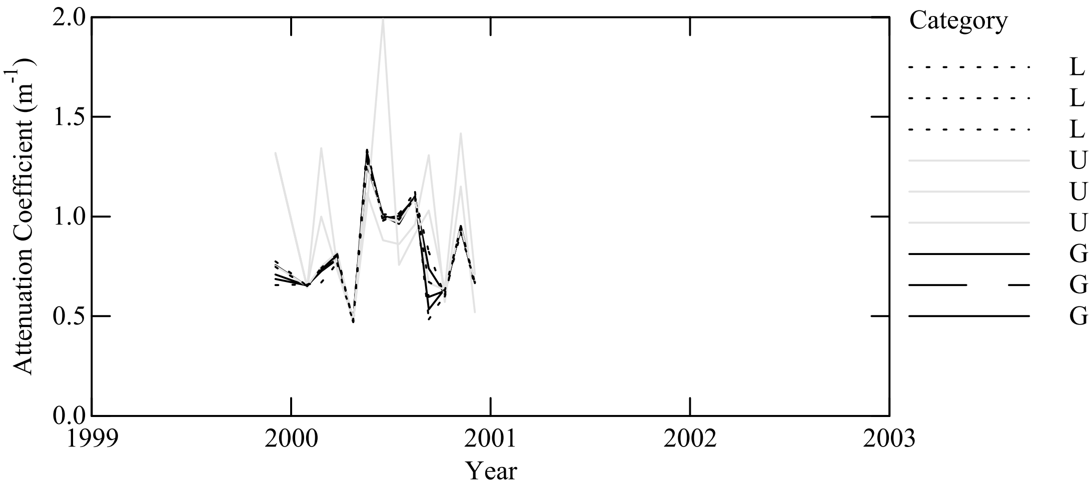


50
40
30
20
10
Color (PCU)
1999
2000
2001
2002
2003
Year
Category
L
U
U
U
G
G
G

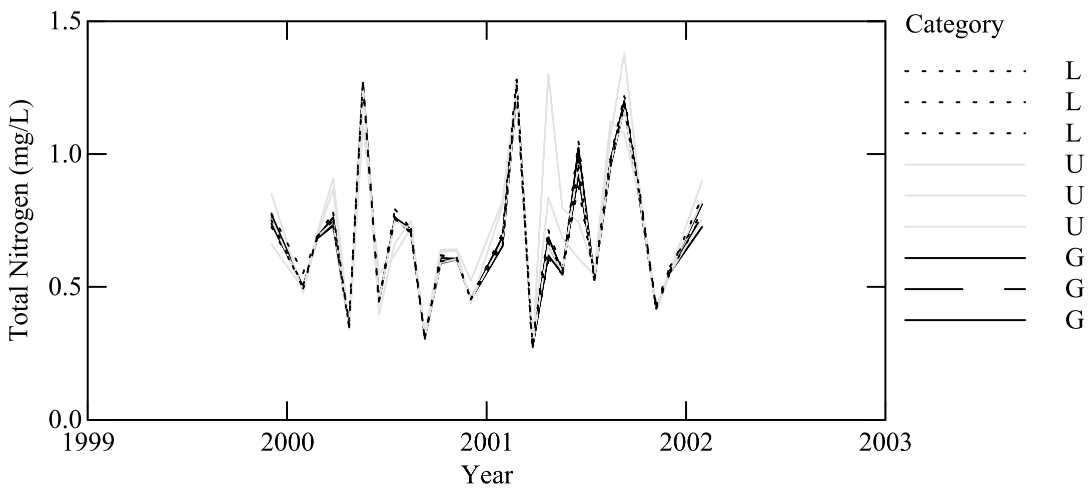


9
8
7
6
5
4
3
2
1
Turbidity (NTU)
1999
2000
2001
2002
2003
Year
Category
L
U
U
U
G
G
G

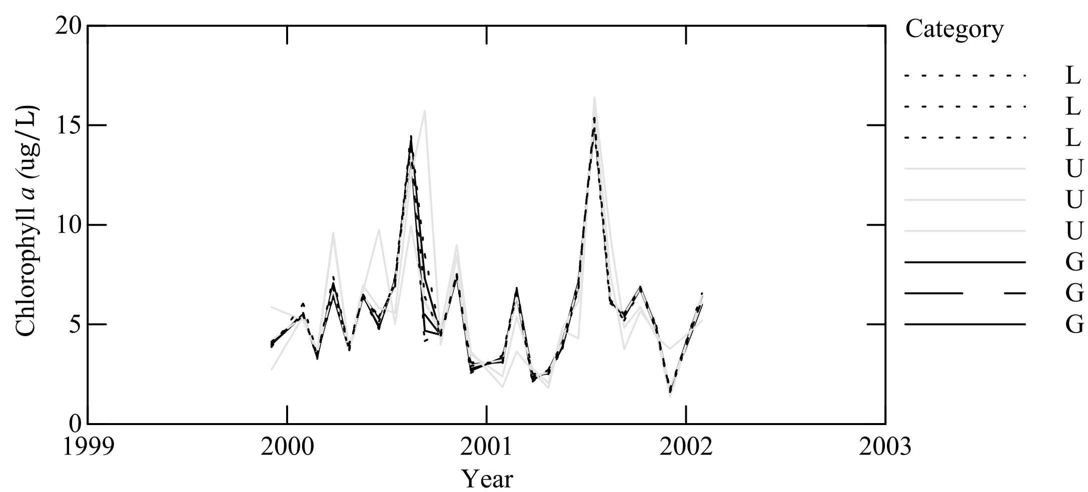
Segment 5



Attenuation Coefficient (m-1)
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

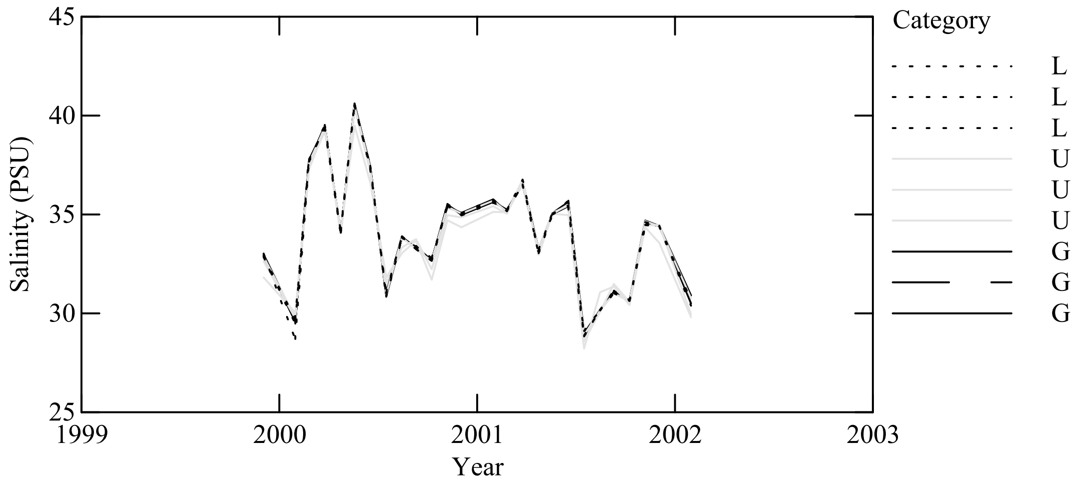


Total Nitrogen (mg/L)
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

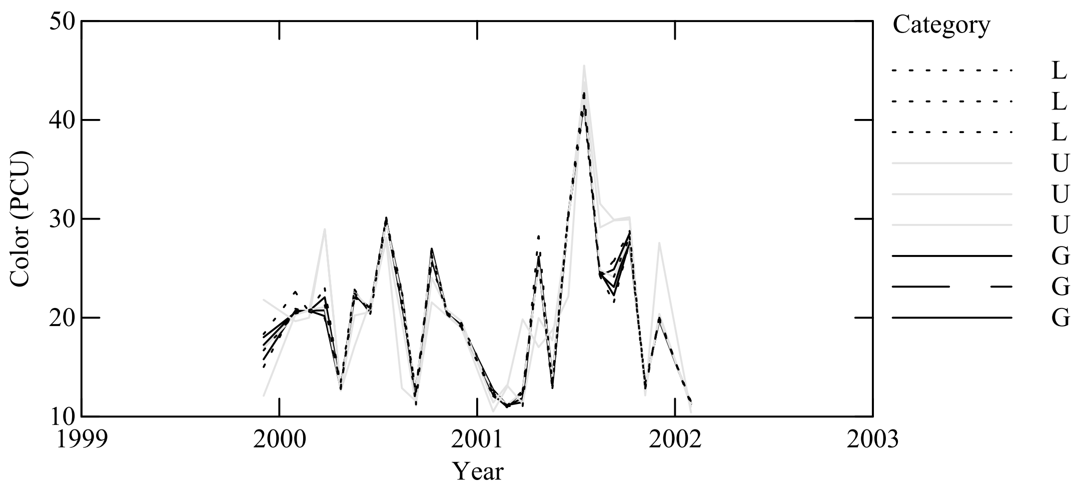


Chlorophyll a (ug/L)
20
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

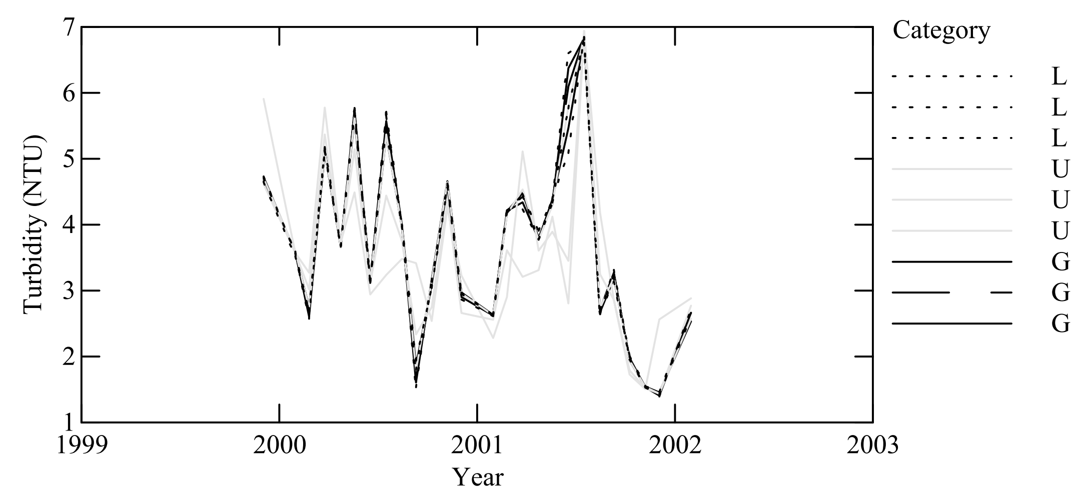
Segment 5



Salinity (PSU)
45
40
35
30
25
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

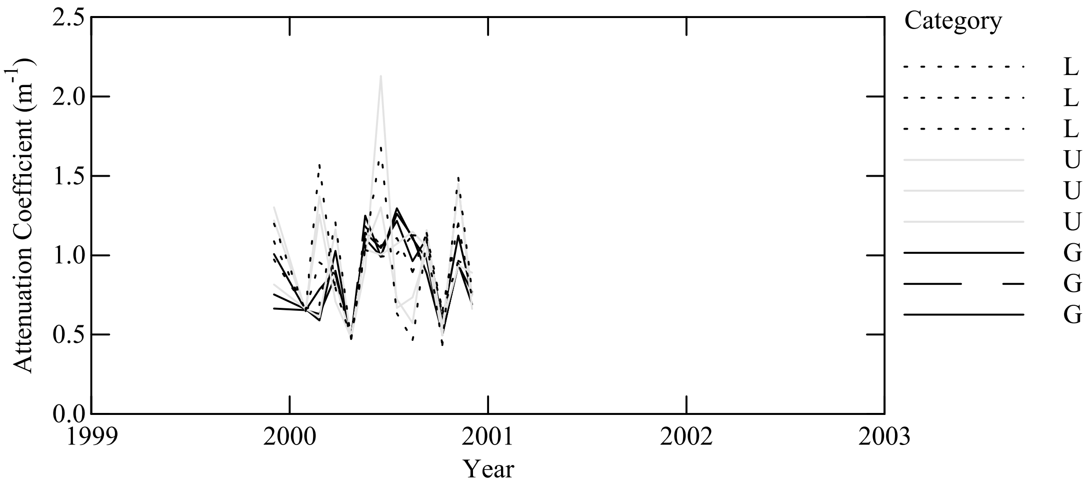


Color (PCU)
50
40
30
20
10
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

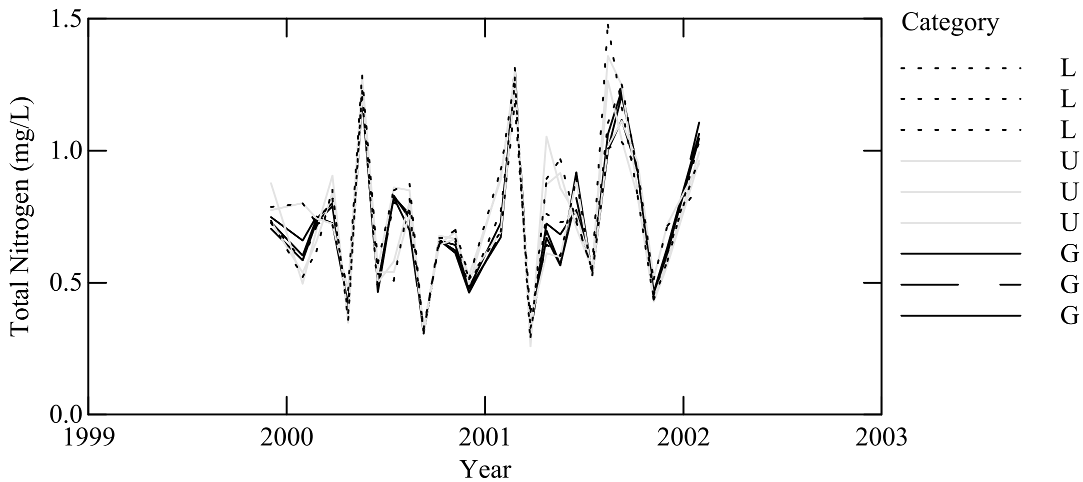


Turbidity (NTU)
7
6
5
4
3
2
1
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

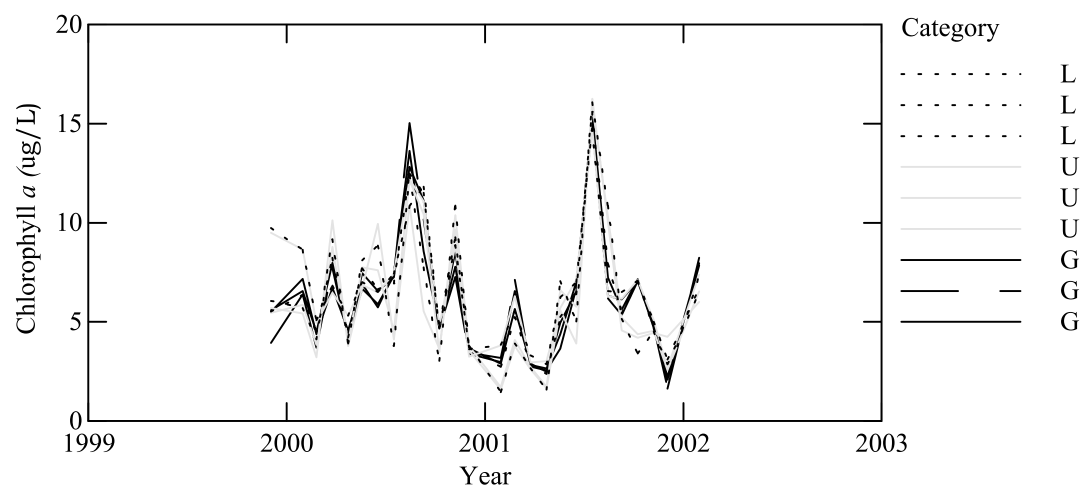
Segment 6



Attenuation Coefficient (m-1)
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

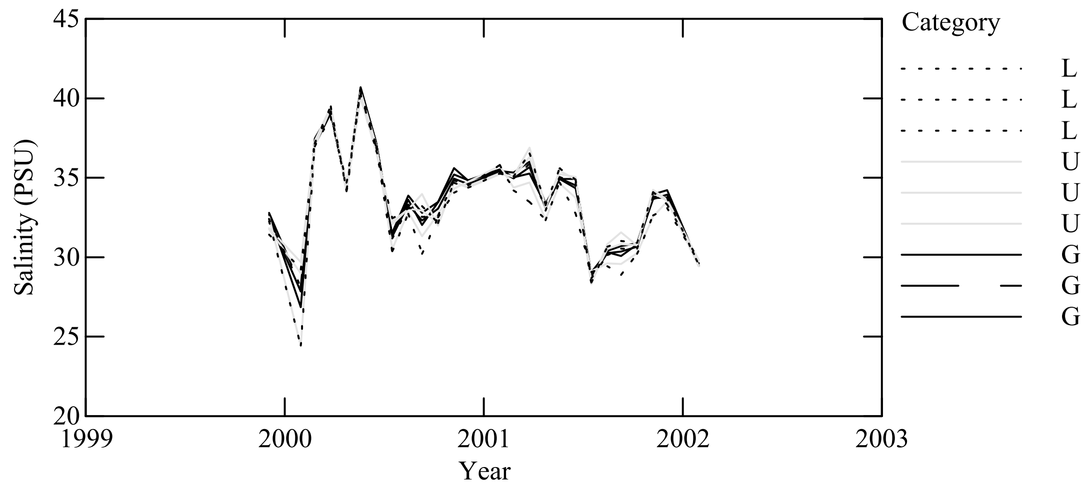


Total Nitrogen (mg/L)
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

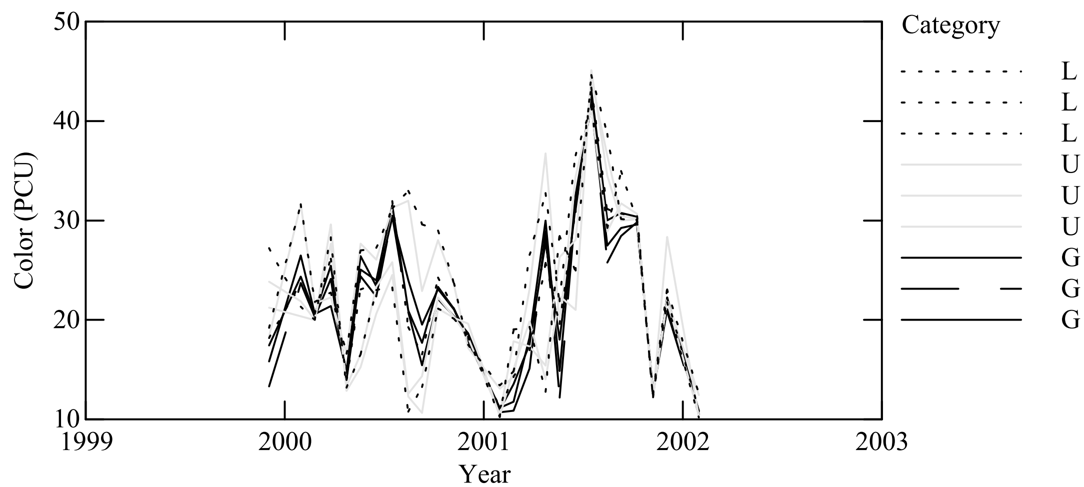


Chlorophyll a (ug/L)
20
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

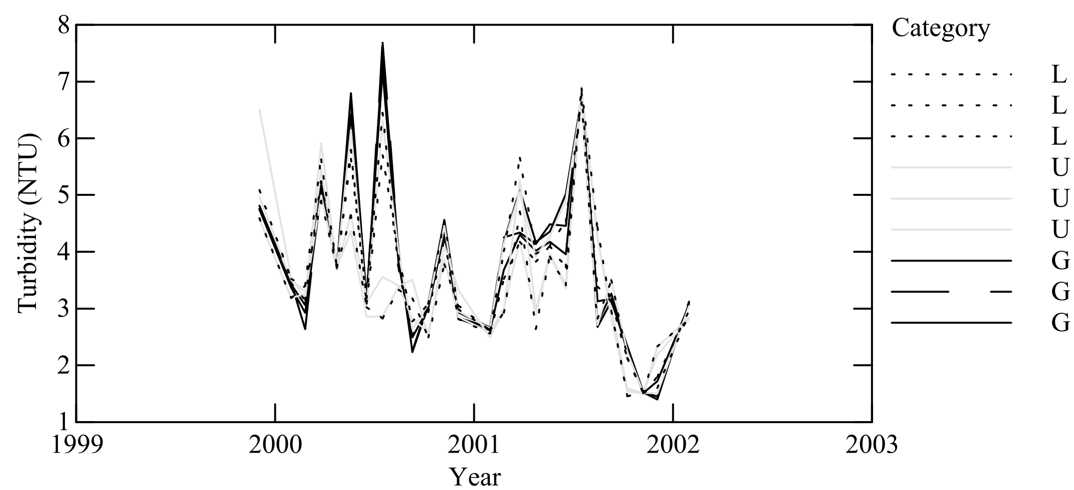
Segment 6



45
40
35
30
25
20
Salinity (PSU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

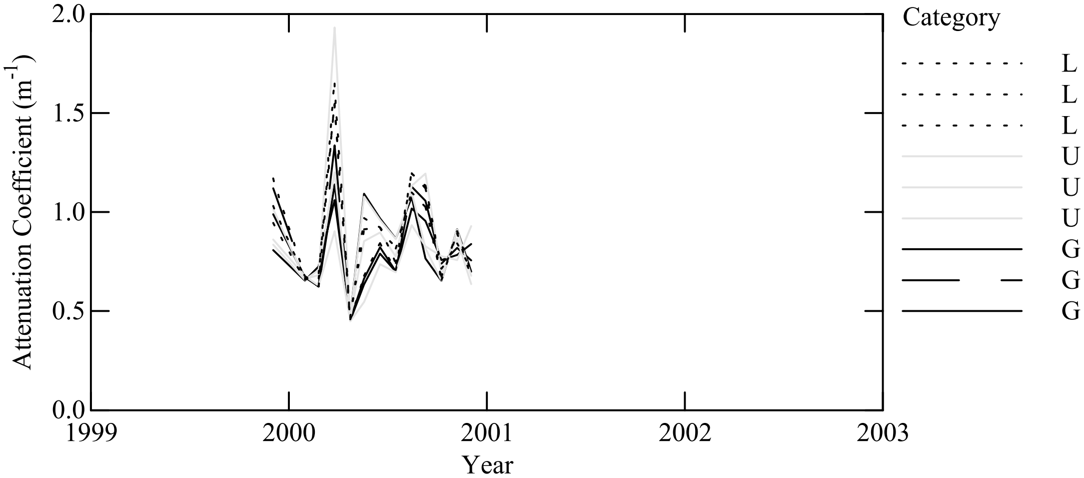


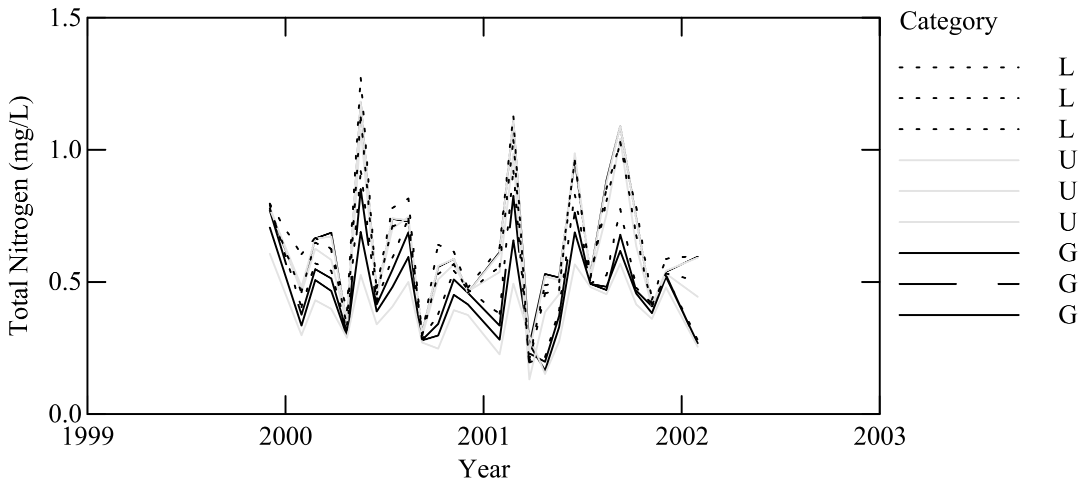
50
40
30
20
10
Color (PCU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

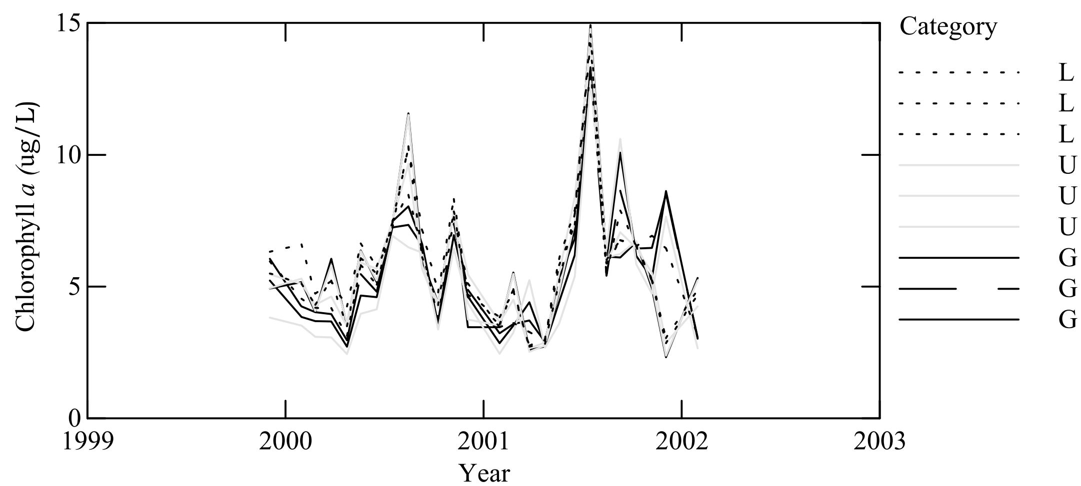


8
7
6
5
4
3
2
1
Turbidity (NTU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

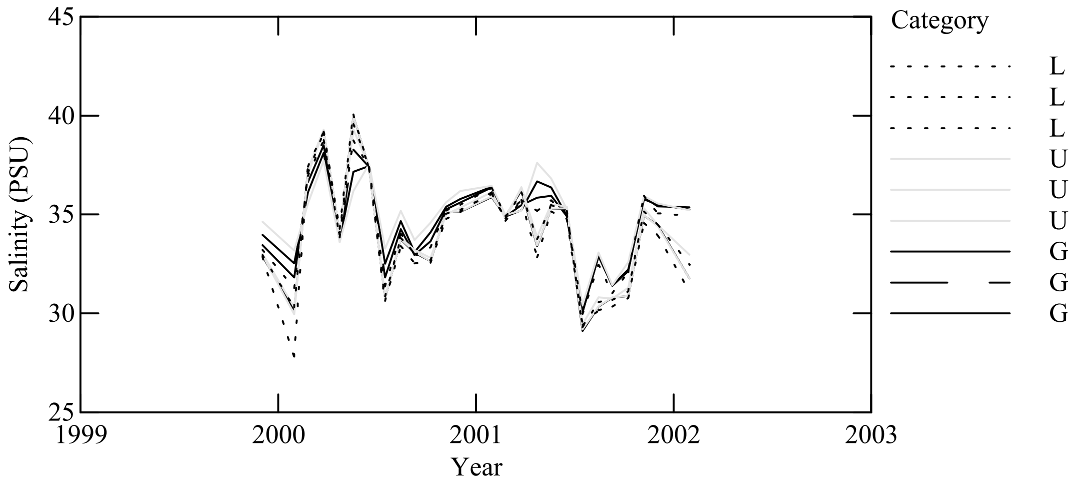
Segment 7

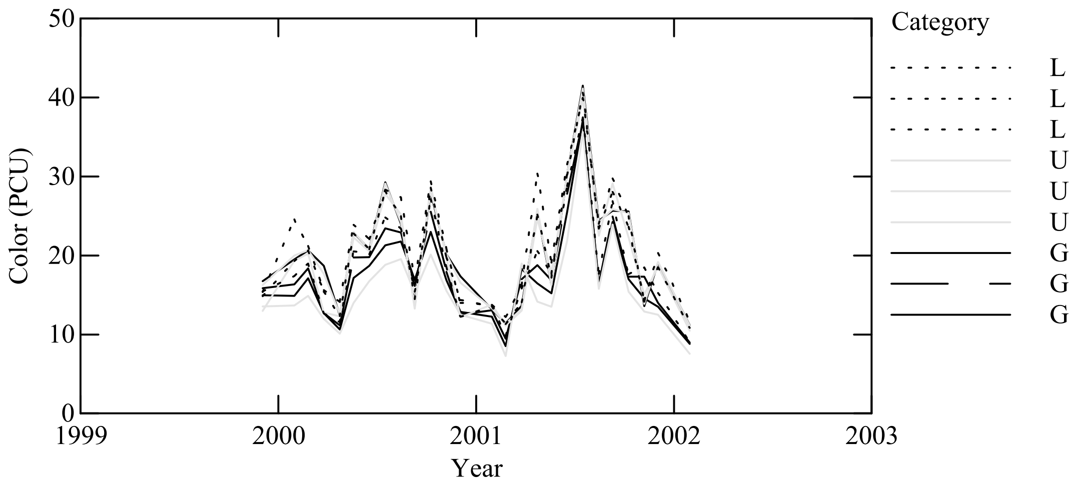

Attenuation Coefficient (m^{-1})
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

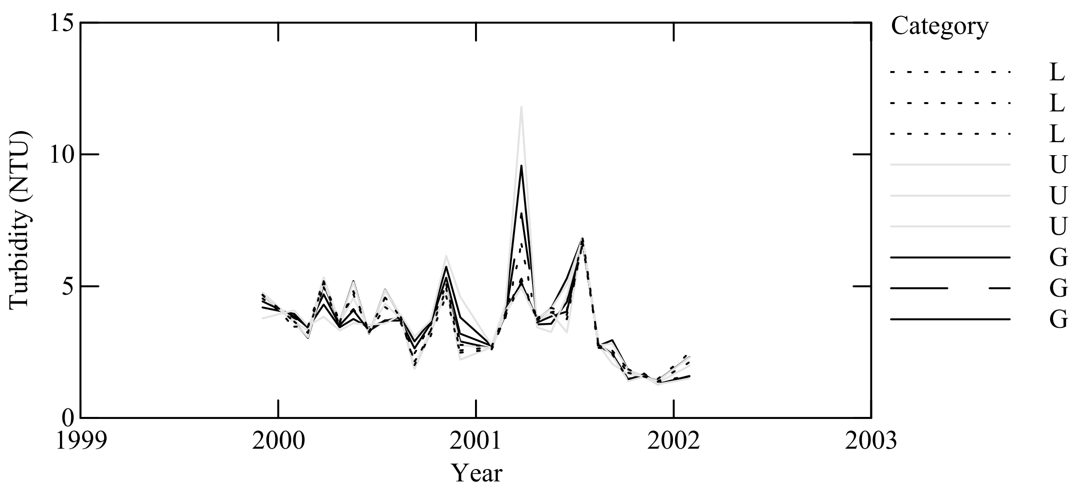

Total Nitrogen (mg/L)
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G


Chlorophyll *a* (ug/L)
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

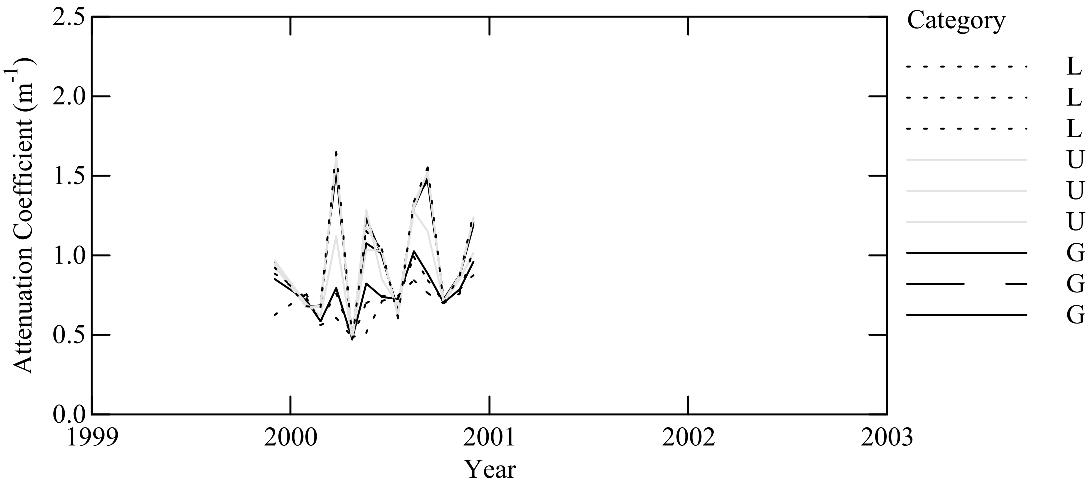
Segment 7


45
40
35
30
25
Salinity (PSU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

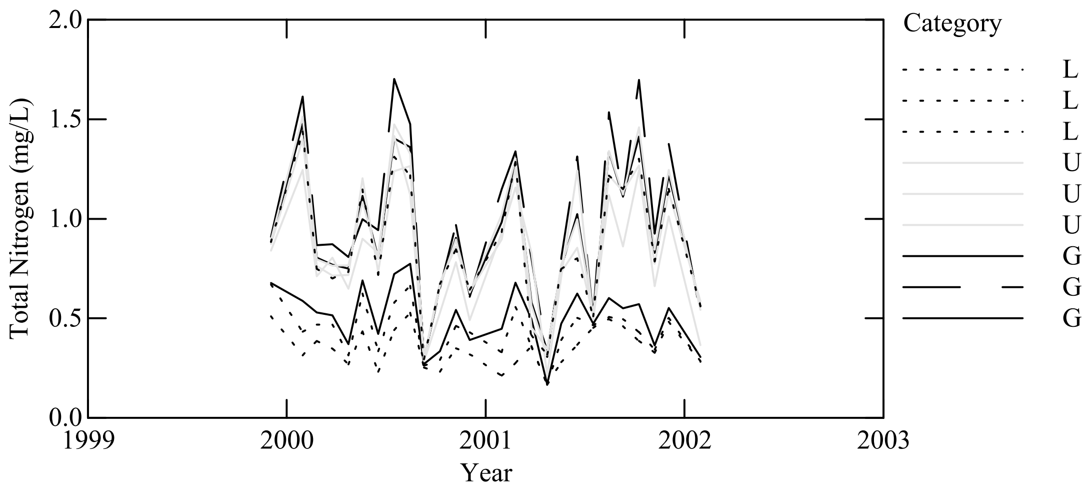

50
40
30
20
10
0
Color (PCU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G


15
10
5
0
Turbidity (NTU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

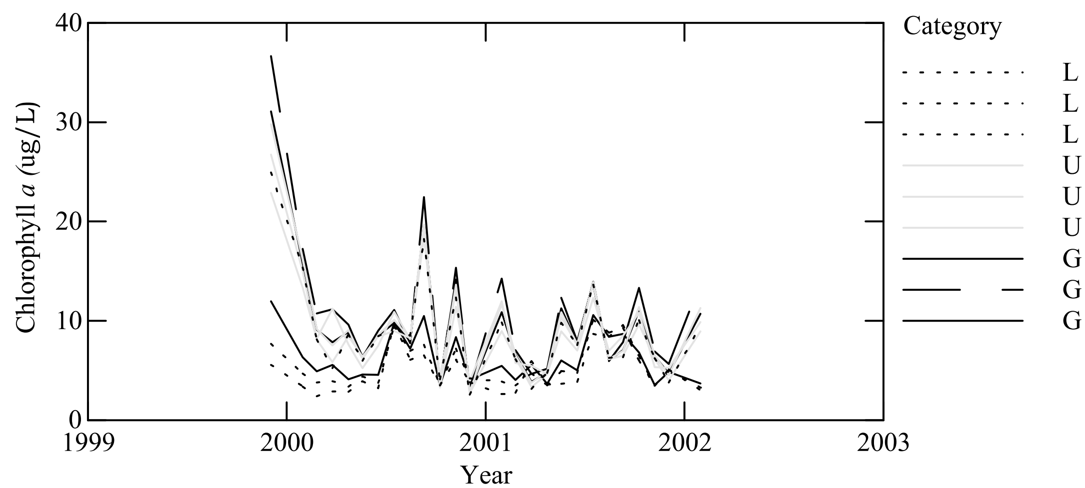
Segment 8



Attenuation Coefficient (m-1)
2.5
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

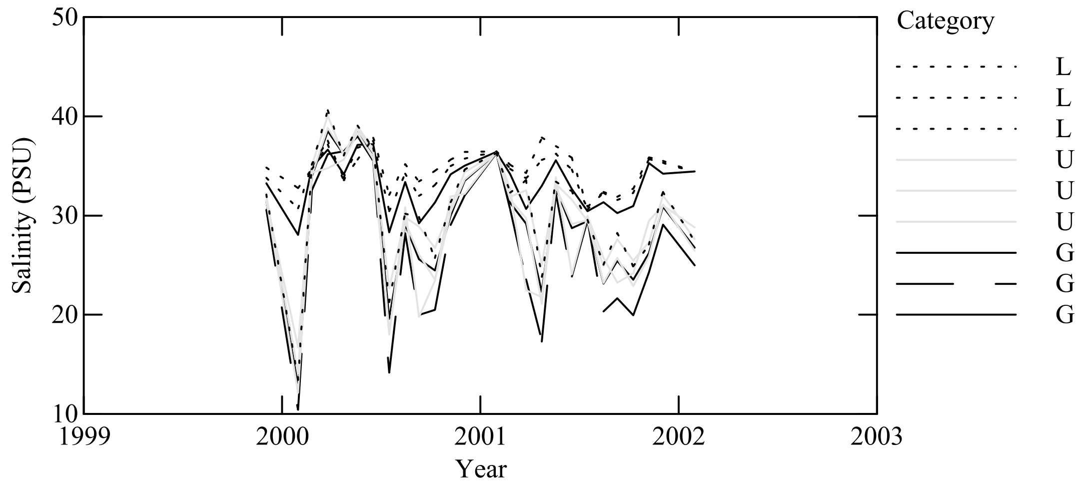


Total Nitrogen (mg/L)
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

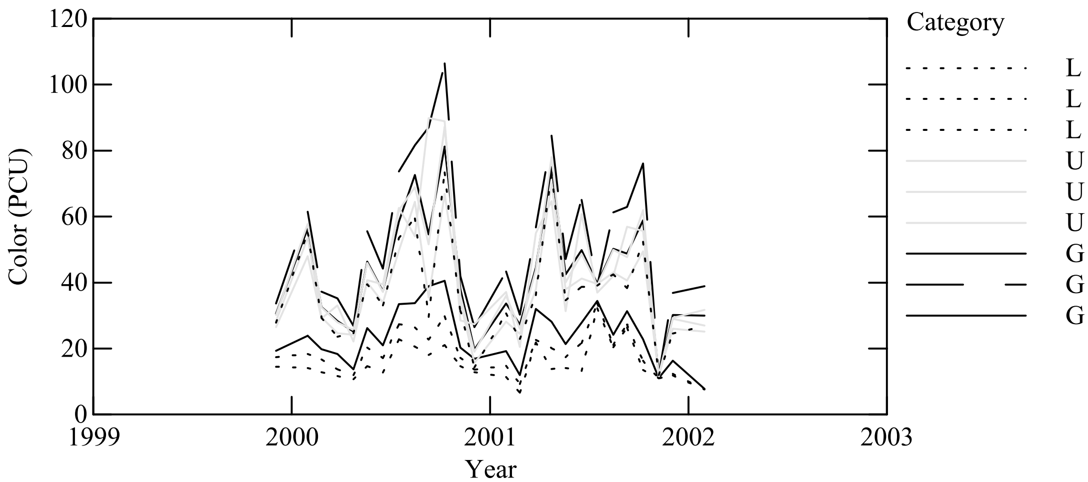


Chlorophyll a (ug/L)
40
30
20
10
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

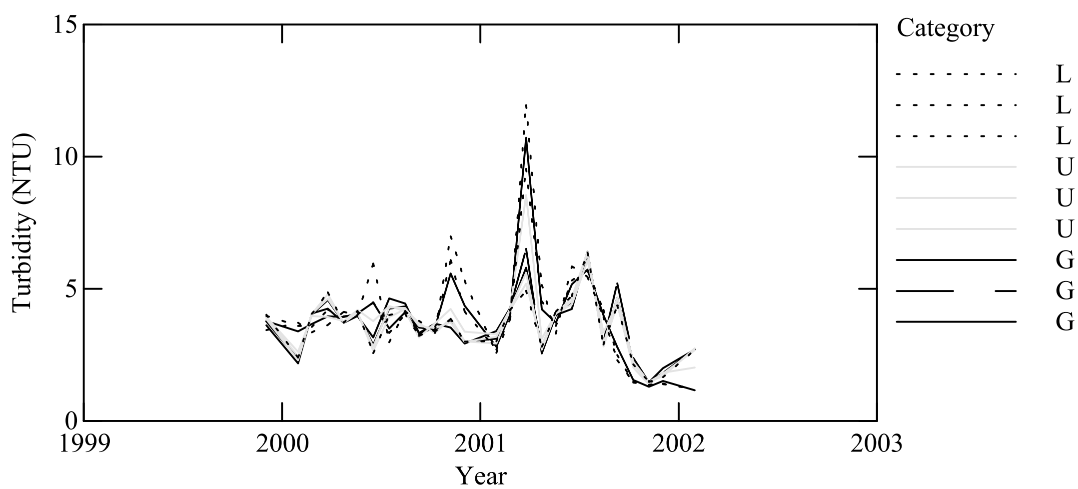
Segment 8



Salinity (PSU)
50
40
30
20
10
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

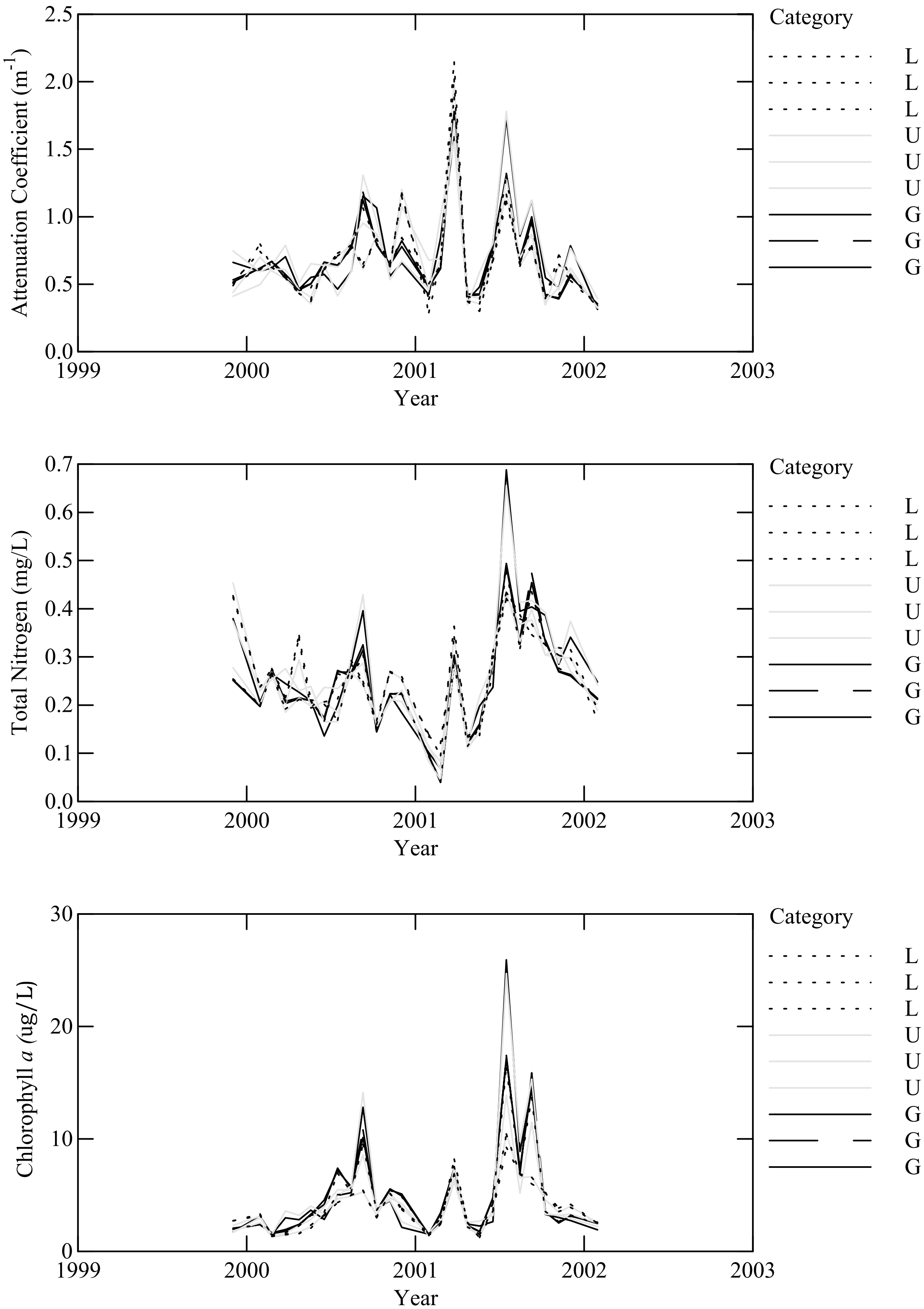


Color (PCU)
120
100
80
60
40
20
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

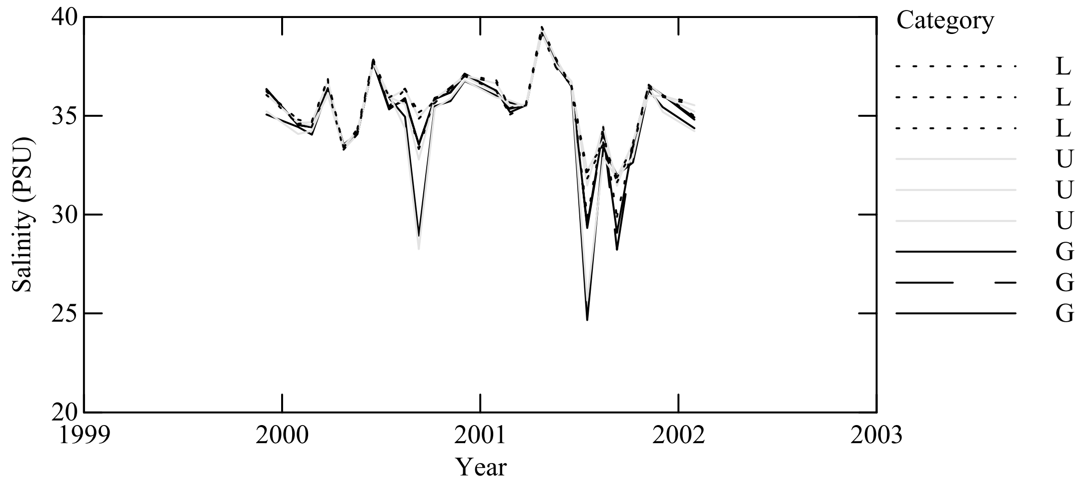


Turbidity (NTU)
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

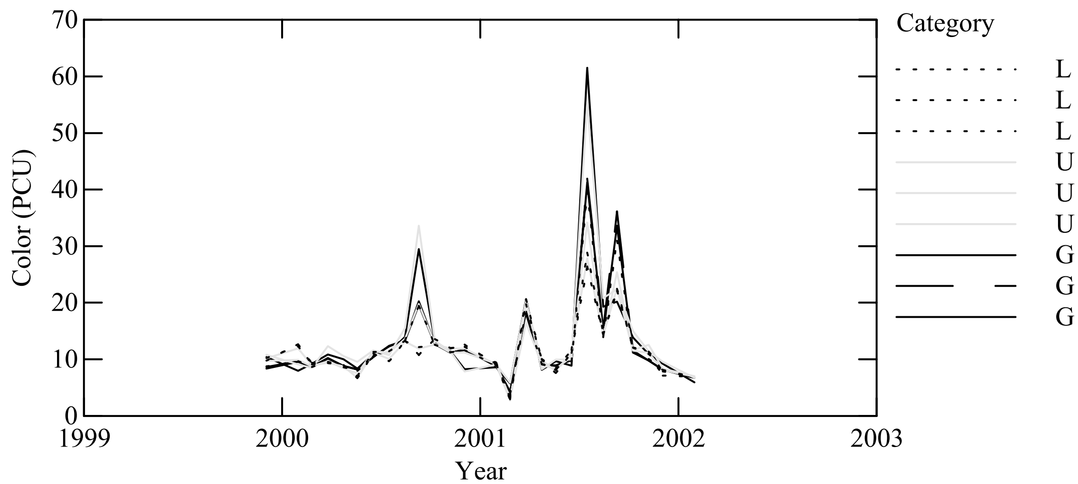
Segment 10


Attenuation Coefficient (m-1)
0.0
0.5
1.0
1.5
2.0
2.5
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G
Total Nitrogen (mg/L)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G
Chlorophyll a (ug/L)
0
10
20
30
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

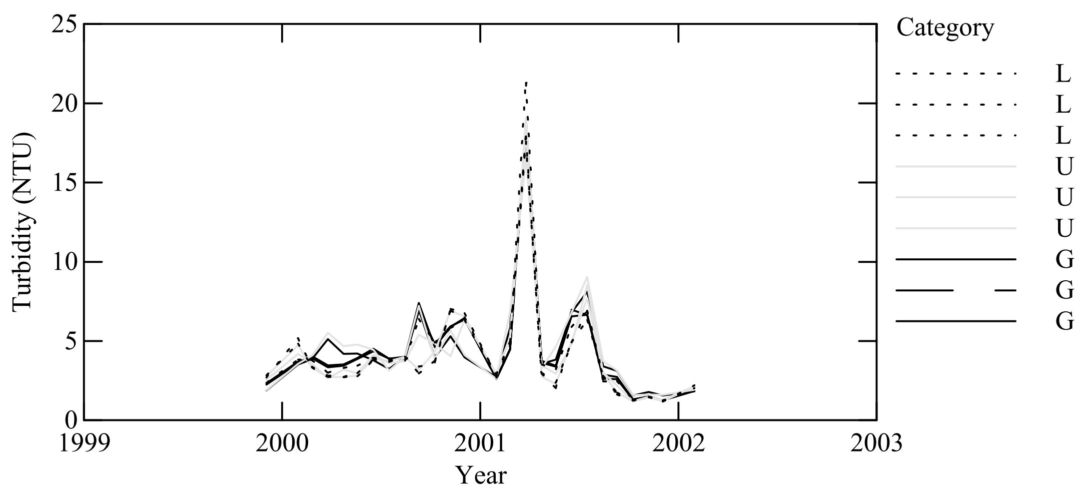
Segment 10



Salinity (PSU)
40
35
30
25
20
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

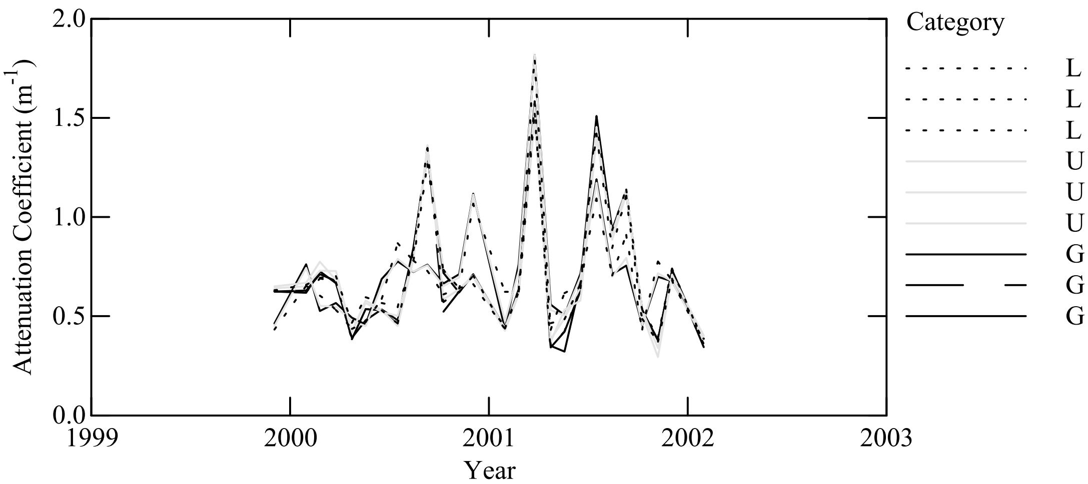


Color (PCU)
70
60
50
40
30
20
10
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

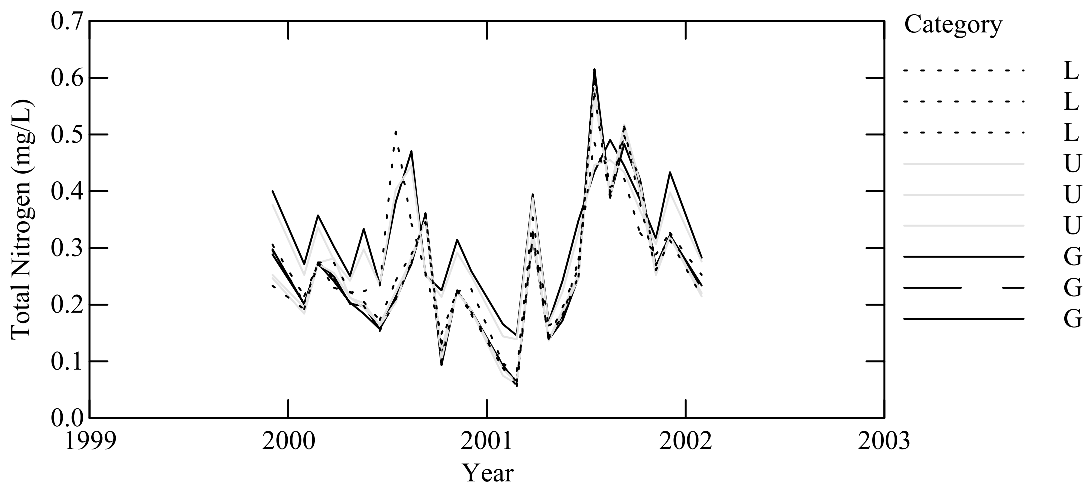


Turbidity (NTU)
25
20
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

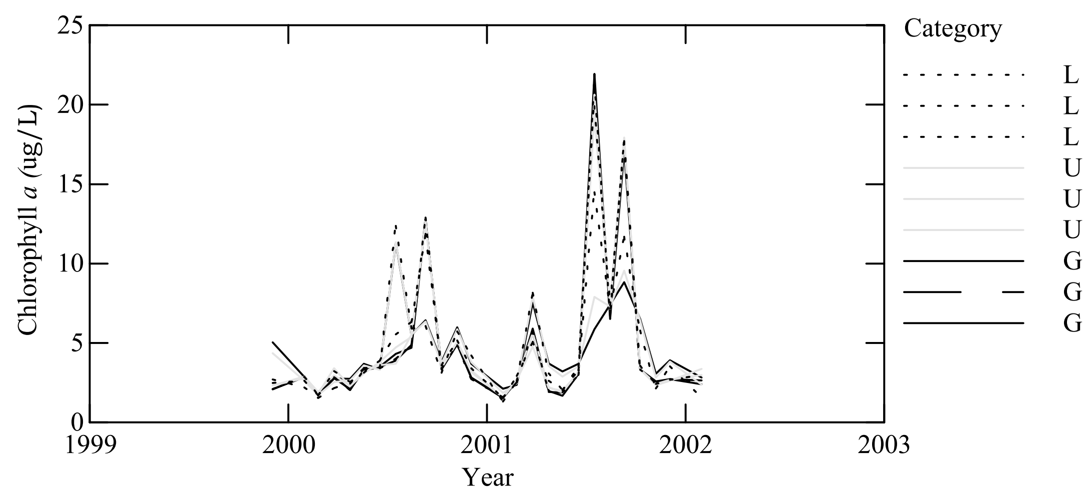
Segment 11



Attenuation Coefficient (m^{-1})
2.0
1.5
1.0
0.5
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

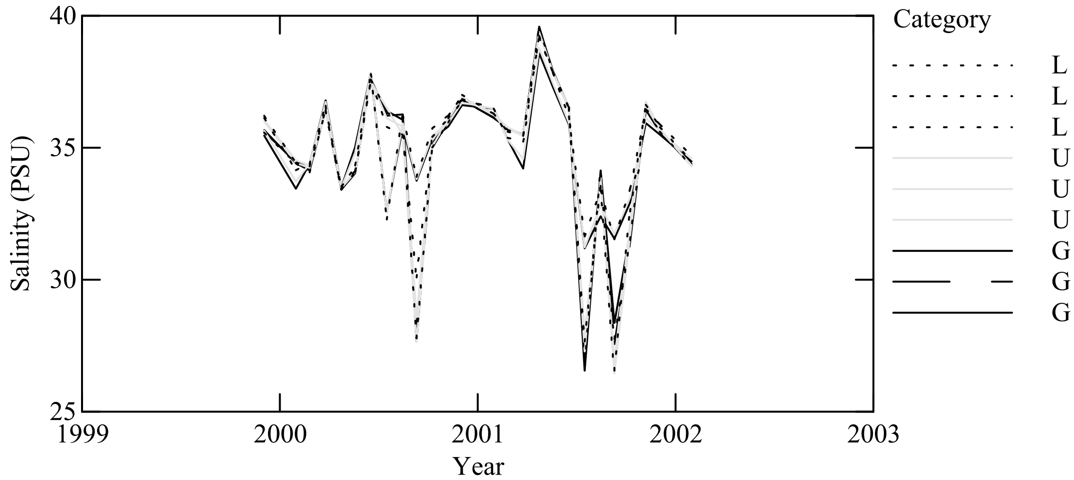


Total Nitrogen (mg/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

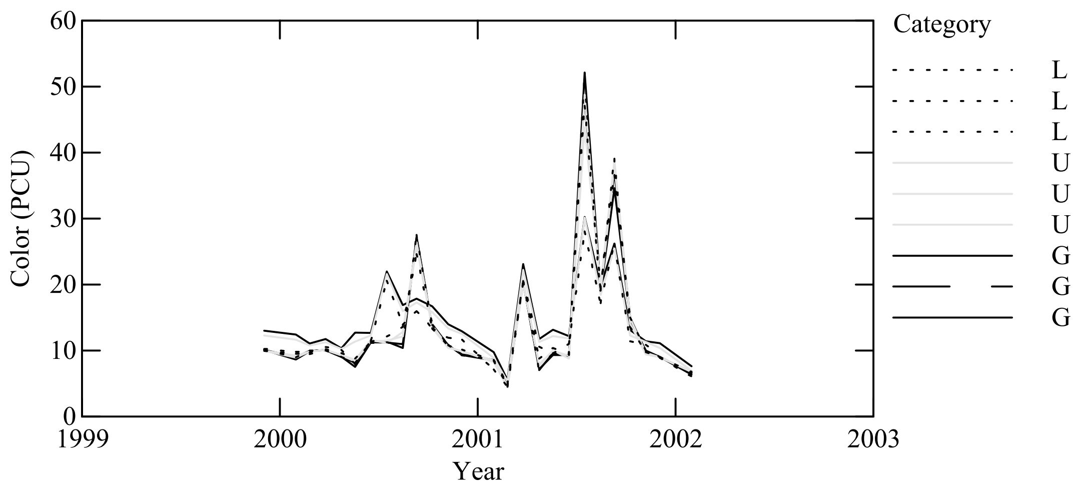


Chlorophyll *a* (ug/L)
25
20
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

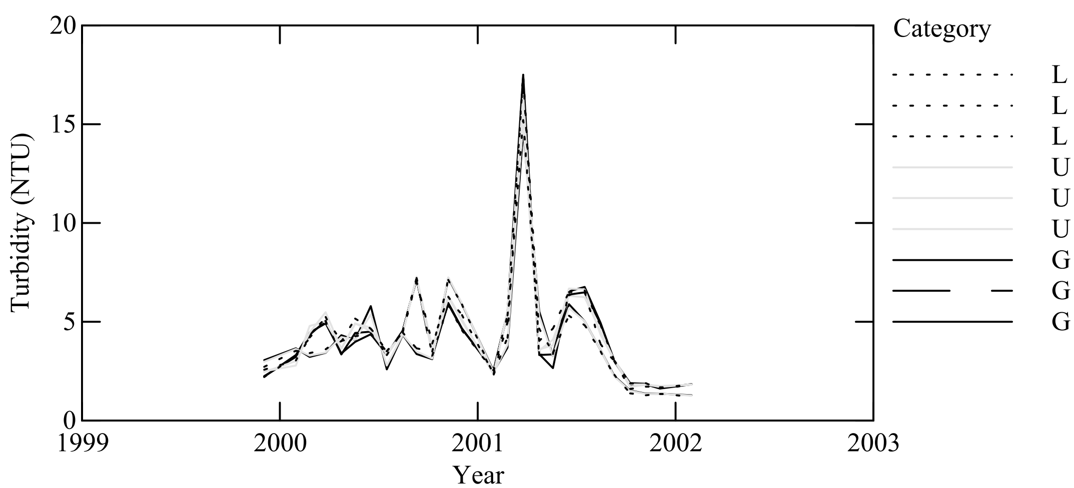
Segment 11



Salinity (PSU)
40
35
30
25
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

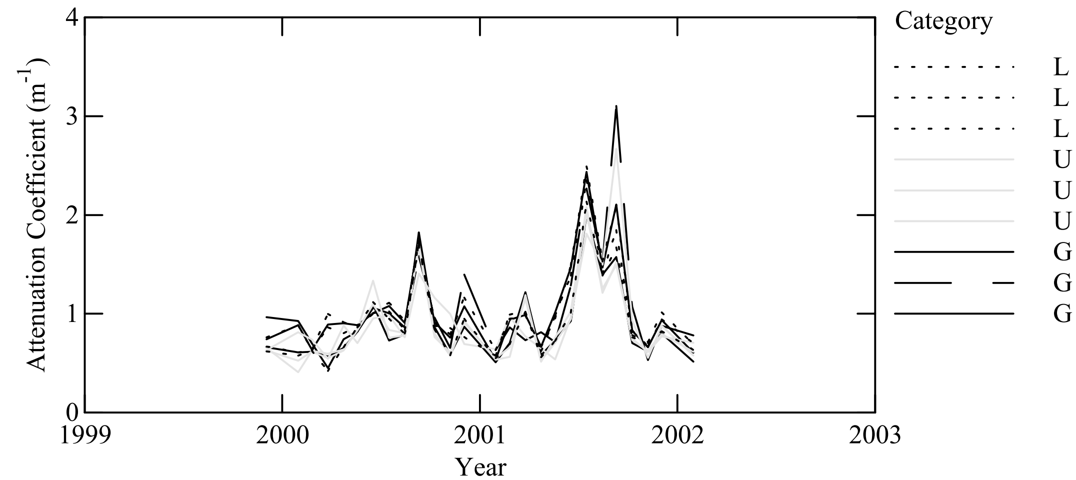


Color (PCU)
60
50
40
30
20
10
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

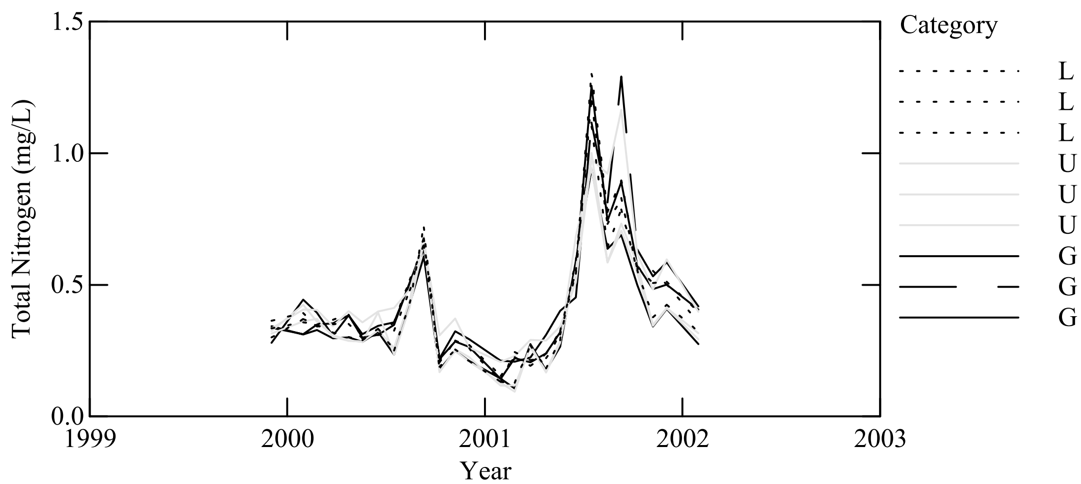


Turbidity (NTU)
20
15
10
5
0
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

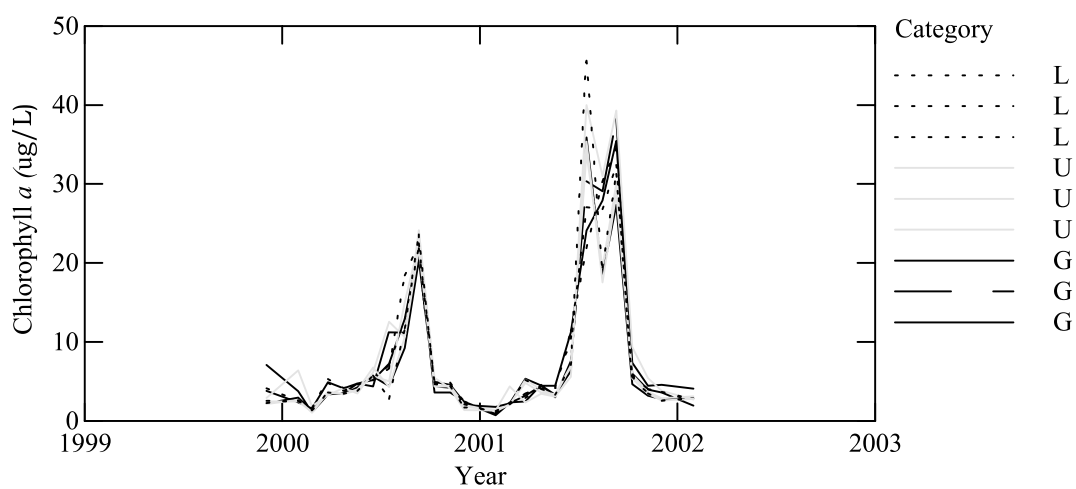
Segment 13



Attenuation Coefficient (m^{-1})
0
1
2
3
4
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

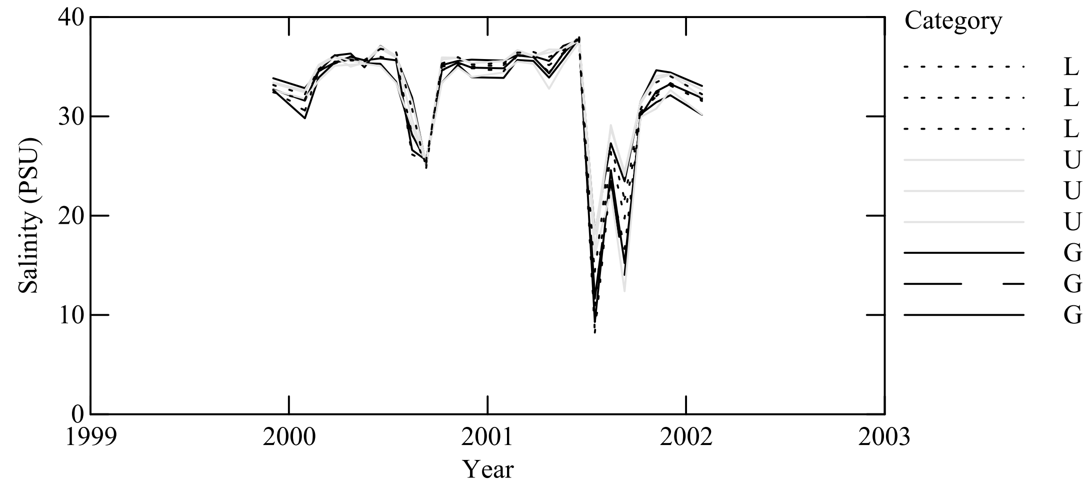


Total Nitrogen (mg/L)
0.0
0.5
1.0
1.5
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

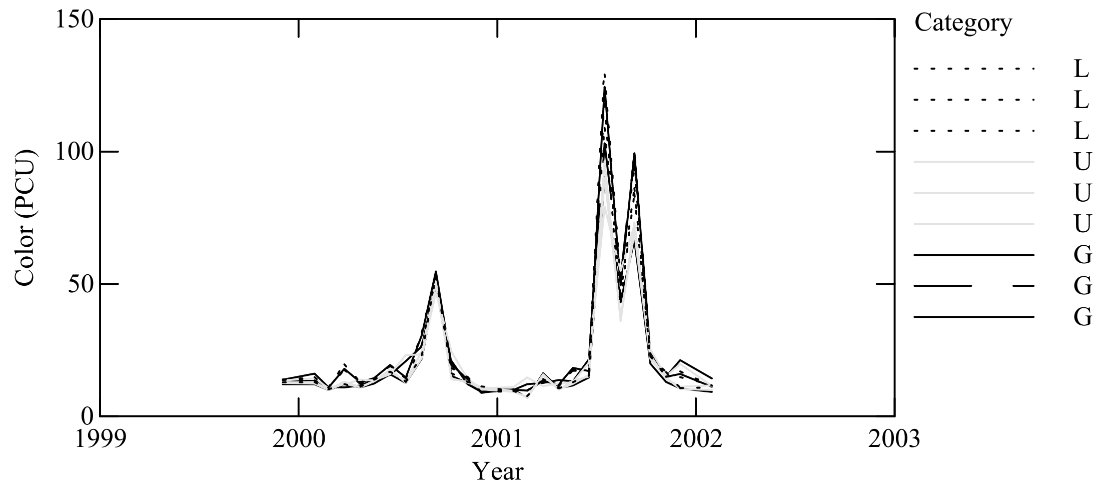


Chlorophyll *a* (ug/L)
0
10
20
30
40
50
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

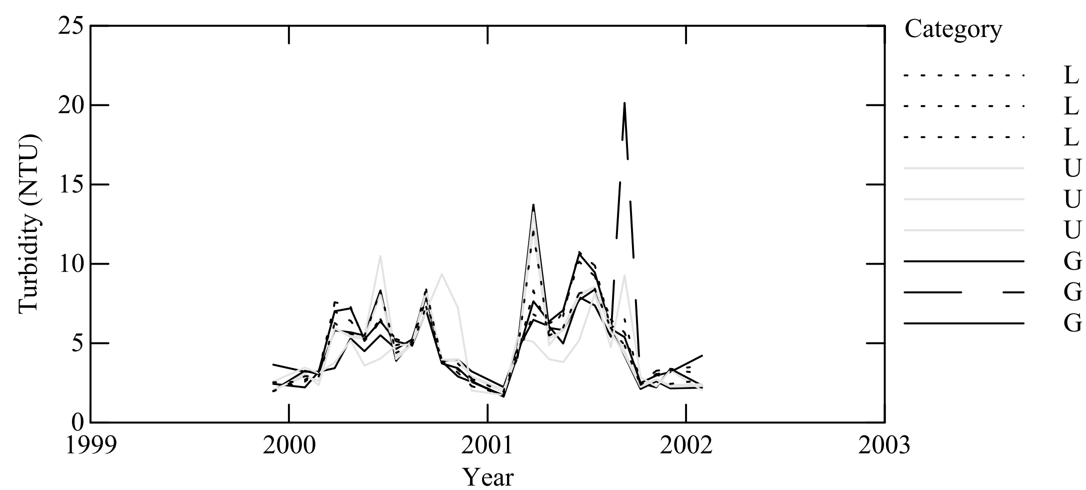
Segment 13



40
30
20
10
0
Salinity (PSU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

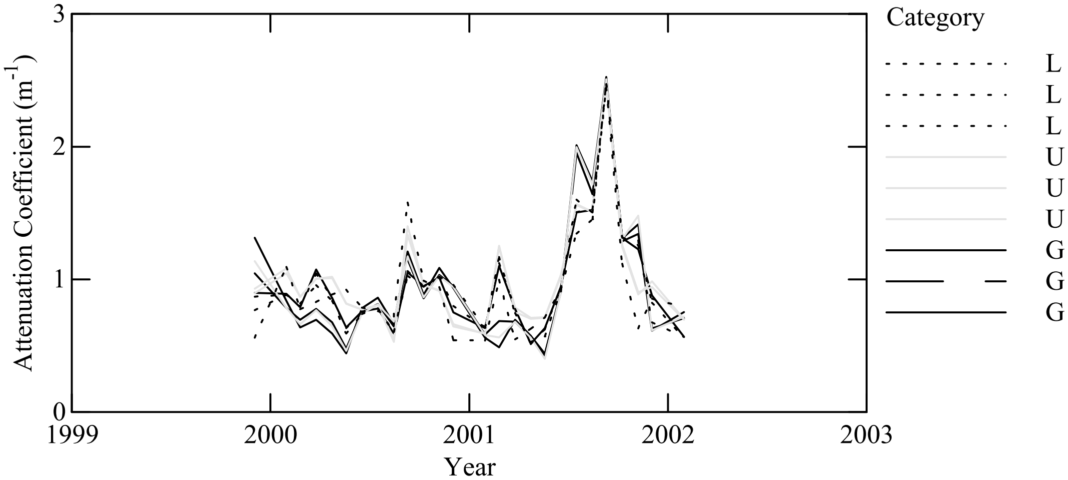


150
100
50
0
Color (PCU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

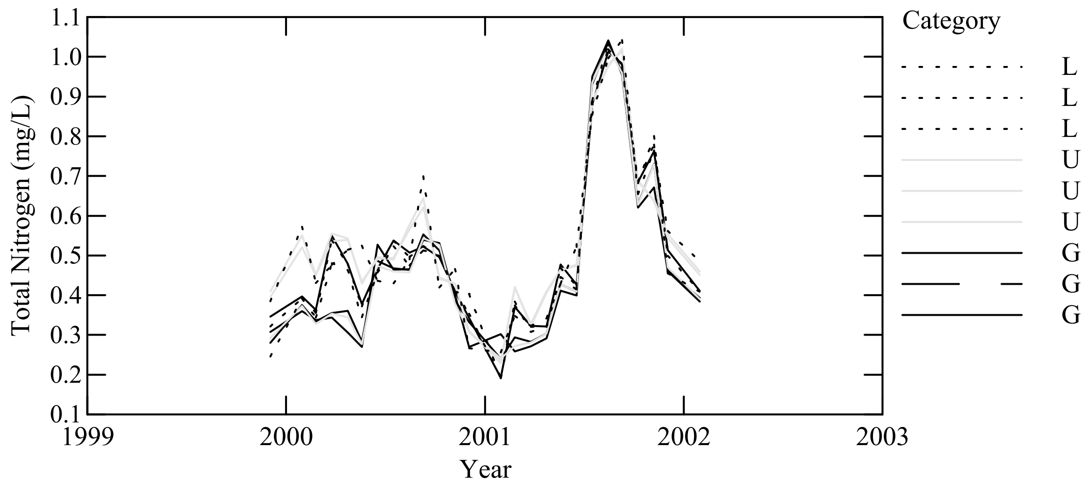


25
20
15
10
5
0
Turbidity (NTU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

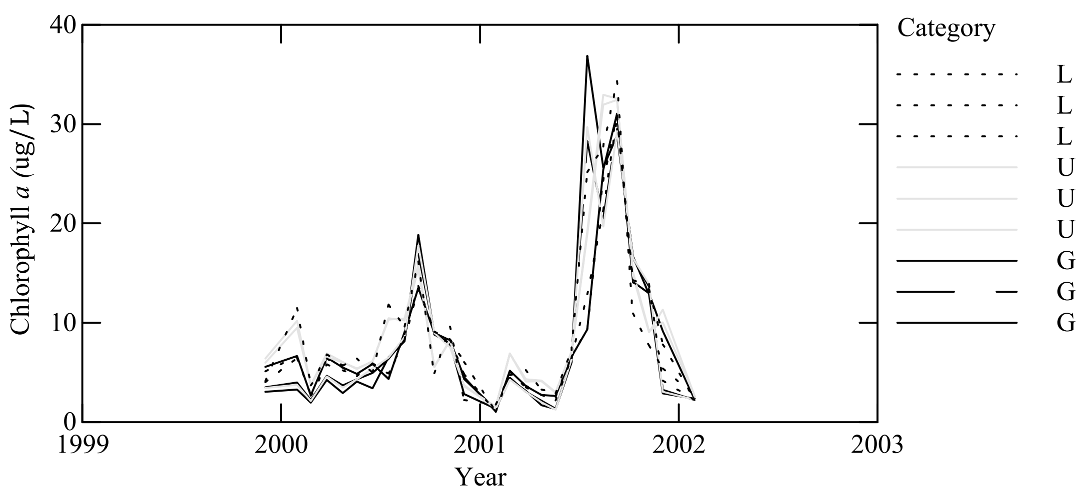
Segment 14



Attenuation Coefficient (m^{-1})
0
1
2
3
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

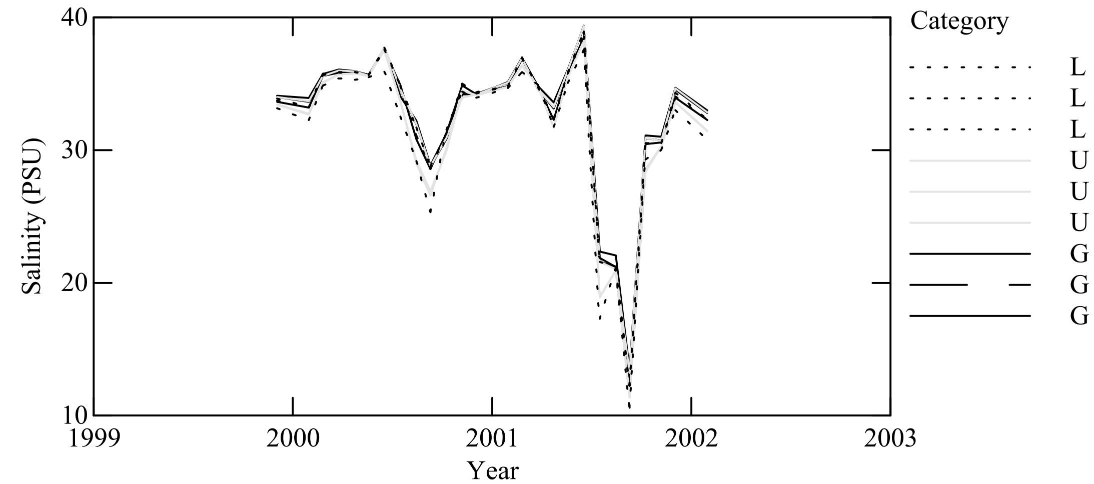


Total Nitrogen (mg/L)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

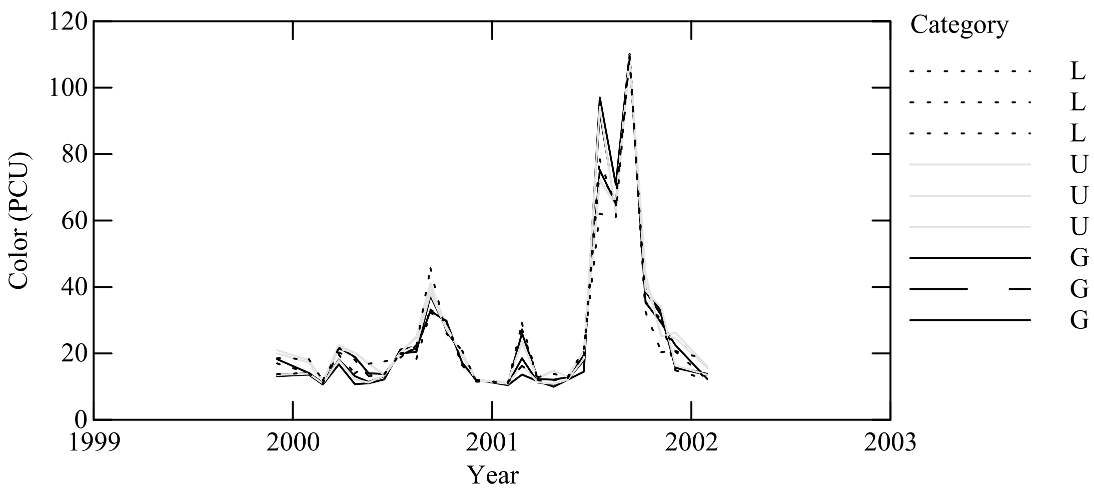


Chlorophyll *a* (ug/L)
0
10
20
30
40
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

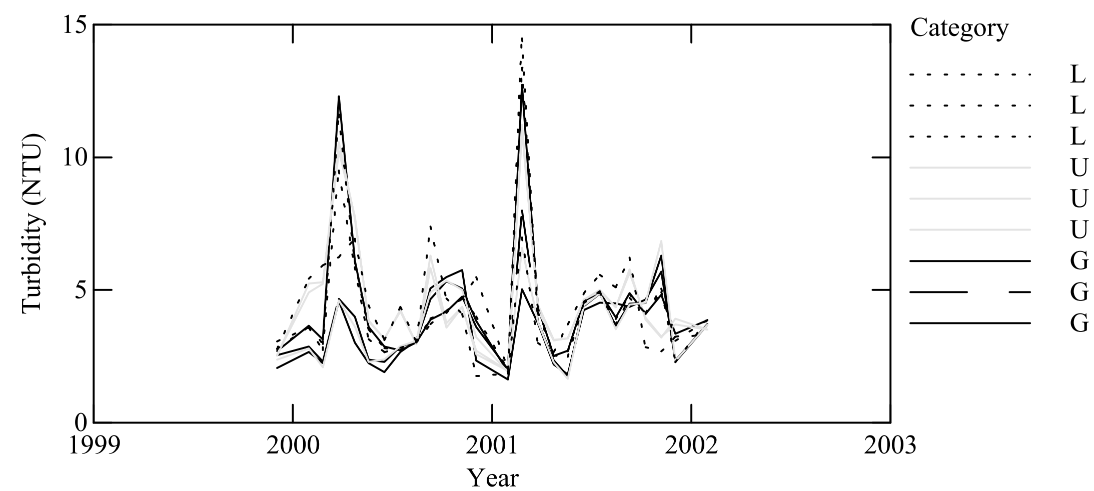
Segment 14



40
30
20
10
Salinity (PSU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

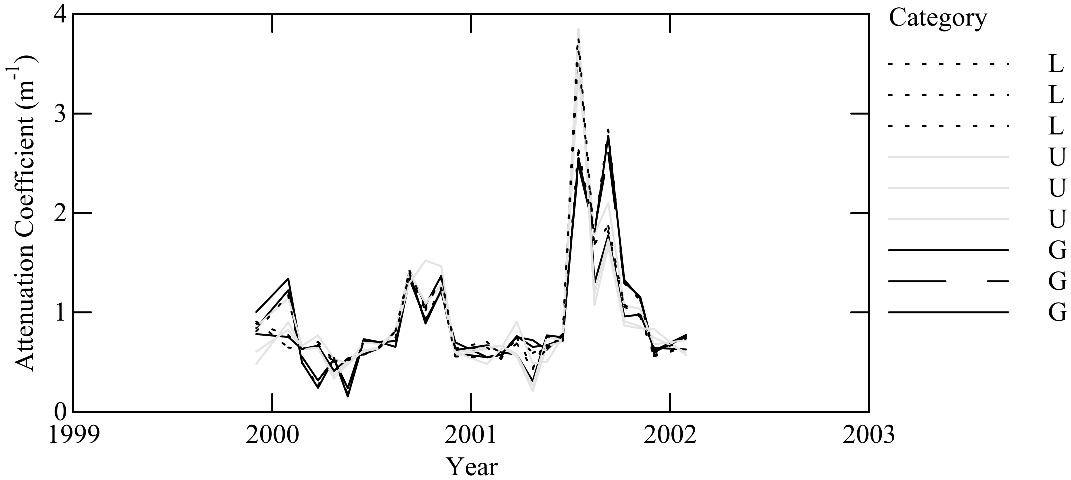


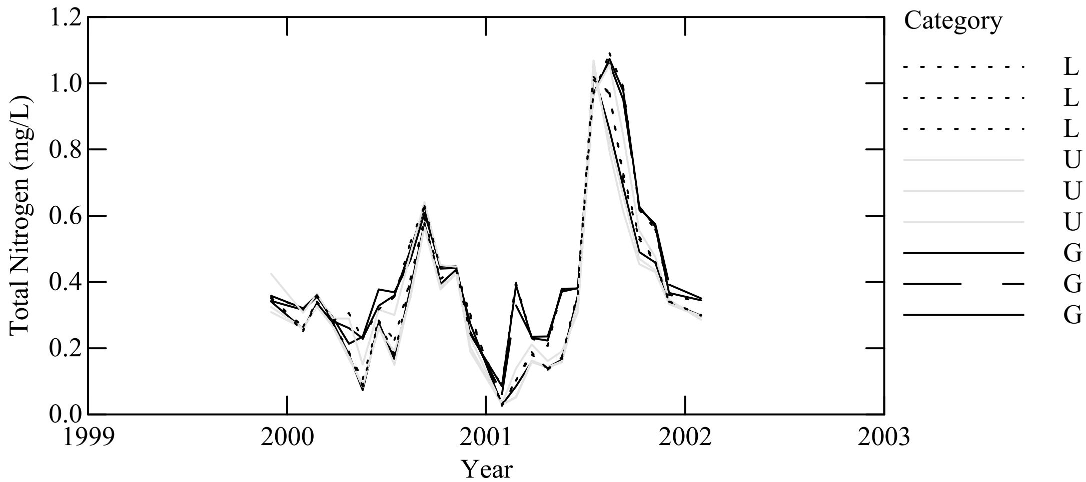
120
100
80
60
40
20
0
Color (PCU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

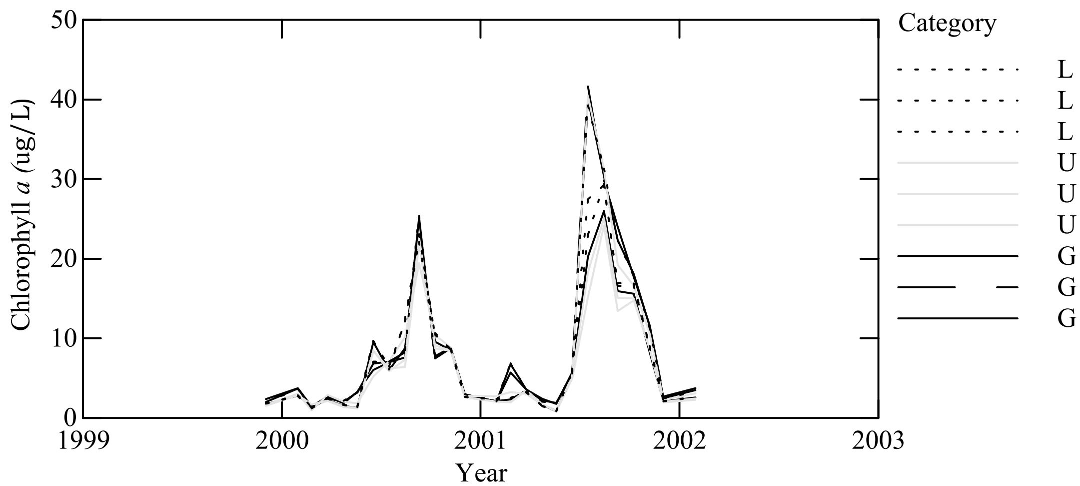


15
10
5
0
Turbidity (NTU)
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G

Segment 16


Attenuation Coefficient (m-1)
0
1
2
3
4
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G


Total Nitrogen (mg/L)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G


Chlorophyll a (ug/L)
0
10
20
30
40
50
1999
2000
2001
2002
2003
Year
Category
L
L
L
U
U
U
G
G
G