3. Descriptive Statistics and Trends

Data Processing Methods

Data were analyzed by SQL stored procedures and Matlab scripts that we either acquired or developed for this project. These scripted procedures allowed us to automate querying, aggregating, analyzing, plotting, and mapping the data. This approach has several advantages over ad hoc manual analysis: it makes it easier to process large volumes of data without random user errors; the script remains as a transcript of the analysis in case questions arise about how the data were processed; and it will be easy to replicate the analyses with new data in the future. Another advantage to this approach is that the raw data were left intact in the database (with the exception of corrections that arose from quality control), with calculations generally handled in the analytical scripts. For example, some nutrient values that were below the minimum detection limit (MDL) were entered as the MDL value in the data we received, but some were entered as the actual value. Rather than change the data as we entered it in the database, we created a function to raise all low values to the MDL in a working copy of the data. This function was generally included as a first step in any data analysis script to ensure consistency in data processing.

Descriptive Statistics

We evaluated each parameter in terms of the annual minimum, maximum, and a measure of central tendency (median or geometric mean). Although it is possible to calculate additional intervals, such as quartiles, the fact that we sometimes had as few as 5 observations per site per year limited the types of statistics that could reasonably be used to describe the data characteristics. We generally represented central tendency in terms of the annual median. The median is preferable to the mean when the data are not normally distributed, which was the case for all parameters except dissolved oxygen. The median is also easy to interpret in that half of the values were above that value and half below. The only parameters for which we did not use medians as the measure of central tendency were fecal coliforms and enterococci. In these cases we used geometric means, which are commonly used because of the inherently exponential nature of bacteria concentration data. Geometric means were calculated for the calendar year. Note that this is different than the running geometric means that are typically used to evaluate shellfish areas for closure and beaches for swimming advisories.

In several cases we calculated the "spatial median," which is the median of the values reported for a given metric (e.g. annual minimum temperature) for all sites sampled in a given year. This provided us with information on the central tendency of all sites sampled that year, which could then be used to evaluate trends over time coastwide.

We developed routines to query the database, evaluate the data, and then output the results to a table or a map (or both) showing the requested information for the specified sites. The general procedure for these routines is as follows.

Matlab calls a SQL stored procedure to query the database for all values of a requested parameter at requested sites. This procedure returns the parameter values as well as information on the sampling program, site location, station date, MDL, and validation limits associated with each value. Next, the data within a specified time frame such as a calendar year are selected from this list. Parameter values are raised to their MDL, if one is provided. The data for each site are then evaluated to see if sufficient data exist to calculate the requested metric. The criteria for data sufficiency are specified by the user and can include the minimum number of samples that must exist within a critical season (or the entire time period under consideration) and the maximum spacing between those samples to ensure good temporal coverage. For sites with sufficient data, the requested metric (minimum, maximum, median, mean, or geometric mean) is then calculated. Results from this analysis can then be sent to a mapping routine that places colored dots at the site locations, with the color indicating the value of the metric.

Our analyses were generally carried out on the scale of a calendar year. For those parameters that did not exhibit well-defined and consistent seasonal cycles, we developed rules to ensure that observations were spaced out over the entire calendar year before we estimated an annual metric. Ideally, parameters would be sampled at least monthly and we would have liked to require at least ten samples per year (to allow for an occasional missed sample or analytical problem). However, given that CRD has recently reduced some sampling programs to bimonthly in order to meet budget reduction goals, we set the minimum number of samples as 5, which allowed us to use information from bimonthly sampling with one potentially missing or bad sample. Evenness of sampling over the year was assessed by establishing a maximum gap between samples of 92 days (which covers the largest possible quarterly gap e.g. July 1 to September 30). Unless otherwise noted below, the default criteria for calculating annual metrics were: 1) there must be a sample in the first 92 days of the year; 2) there must be a sample in the last 92 days of the year; and 3) there must be no gap between samples of more than 92 days. Any site data not meeting these criteria would be missing an entire quarterly season and would therefore not represent a sufficient sample for an annual estimate.

Although most parameters were handled as described above (the "default rules"), temperature, dissolved oxygen, and nitrite each exhibited consistent seasonality. In these cases we modified the criteria for annual estimates based on a critical period. In the case of temperature, the annual cycle (Figure 3-2) was so well-defined that, out of 656 times when a full year's data were available for a site, the maximum temperature occurred in July-August 88% of the time and the minimum occurred in January-February 78% of the time. We therefore designated these months as the critical periods for estimation of maximum and minimum annual temperatures, respectively, and required at least one sample during these periods before the metric could be calculated. (Annual median values were estimated using the default rules.) This modification allowed the calculation of maxima and minima for years with a partial year of data as long as the critical season was represented. Although the critical season is specified, the actual calculation includes the entire time period under consideration. For example, as long as the criterion for a temperature observation during the July-August period is met, the maximum annual temperature returned by the program will be the maximum for that year, regardless of what month it occurred.

Dissolved oxygen (DO) also has a regular seasonal cycle (Figure 3-10). When a full year's data were available (1005 site x year combinations), minimum DO was in June-October 93% of the time, so these months were used as the critical period, with at least 2 samples required and a maximum gap of 92 days. Maximum DO was observed both before and after this period, so we did not have a special critical season for maximum DO. Median DO calculations also used the default rules. Of all the nutrients evaluated, only nitrite (NO_2) had a fairly consistent seasonal cycle (Figure 3-20). When a full year's data were available (494 site x year combinations), minimum NO_2 was in January-April 86% of the time and maximum NO_2 was in July-November 84% of the time, so these months were the respective critical periods. In both cases, at least 2 samples were required with a maximum gap of 92 days. Calculation of median NO_2 followed the default rules.

Spatial Trends

Spatial trends were generally evaluated using the maps of parameter metrics described above. The sample sites for the four programs included in the analysis were chosen to suit the needs of the individual programs (shellfishing locations, frequently used beaches, etc.) rather than to represent, statistically, the types of habitats that exist on the Georgia coast (as would be the case with stratified random sampling designs). Therefore, observations about the number of sites exhibiting a certain characteristic must be interpreted cautiously. Nevertheless, these sites do cover a wide variety of habitats all along the coast and across the salinity gradient, and many represent sites of particular interest to the public for their commercial and recreational value. Spatial patterns in these sites are therefore still informative and can provide insight into coastal water quality.

Temporal Trends

Irregular sampling frequencies precluded the use of many time-series analysis techniques on these observations. Although most sites were originally sampled roughly monthly, the temporal spacing was uneven, and the change to bimonthly sampling for some sites further complicates the situation. Converting the series to a more regular frequency in order to use time-series analyses would have required a great deal of interpolation. Instead, we evaluated each data series to determine the proportion of variability that could be attributed to seasonality at each site. Where seasonality was unimportant, each site was evaluated for trends over time by common regression analysis. However, most of the parameters showed at least slight seasonal cycles (although the seasonality was not always the same from year to year or consistent across sites). In these cases we opted to filter out the mean annual cycle when possible by fitting trigonometric functions of the form ParameterValue = A*sin(time) + B*cos(time) with the periodicity forced to 1 year. Since the data were deseasonalized site by site, this technique filters out regular annual variation where it exists but has little effect on data without a regular cycle. The residuals from the deseasonalized data were then evaluated for trends using regression techniques.

The presence of sub-annual variation, as described above, makes it necessary to have many samples per year for several years in order to be in a position to detect interannual trends. An additional problem is the fact that there may also be considerable natural variation at the annual timescale. In particular, the weather during the period represented by these data has been extreme relative to historical records, with severe droughts in late 1998-2002 and 2006-2009 and extremely wet weather in early 1998, 2003 and, to a lesser extent, 2005. This can be seen clearly in the streamflow records for the three rivers that are sampled by the River program, which span the Georgia coast (Figure 3-1). The Altamaha is the largest of

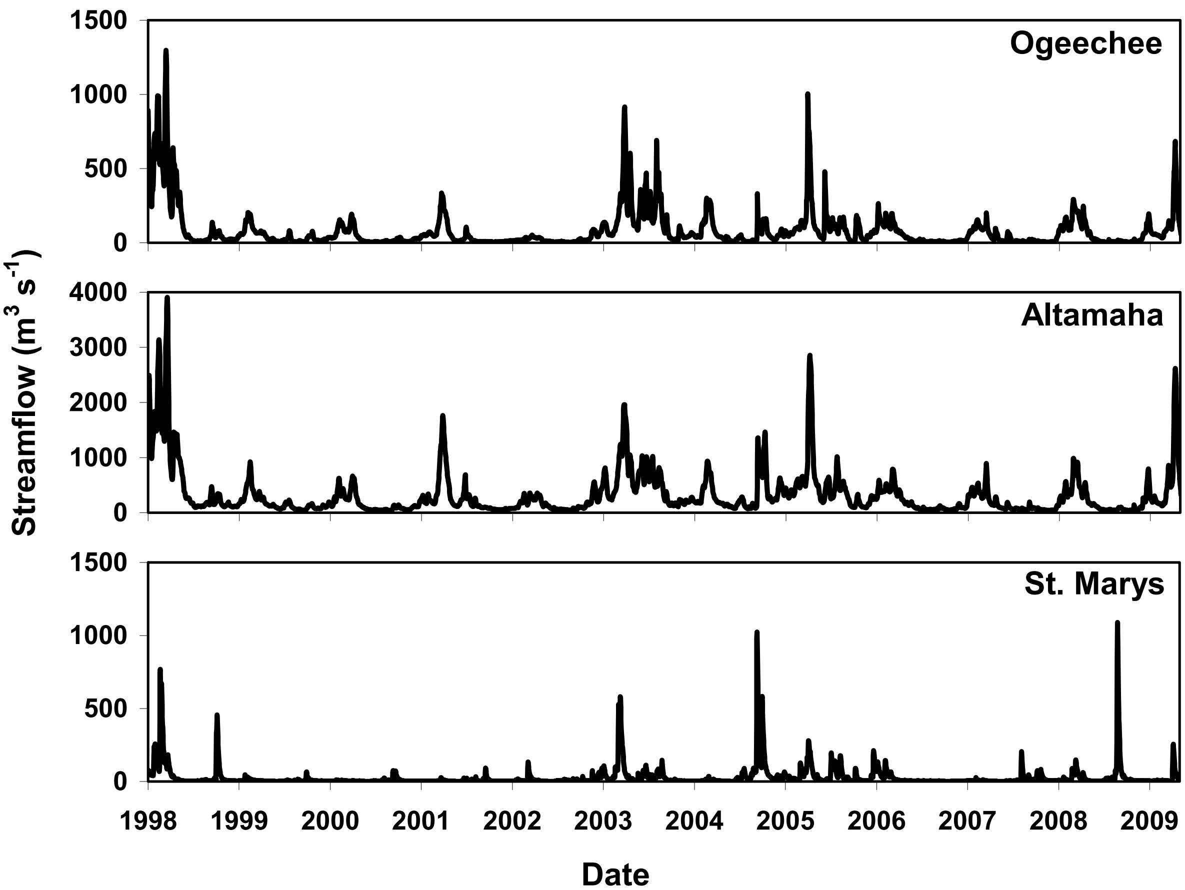

Figure 3-1. Streamflow in three rivers during the period covered by this report.

the three, and the St. Marys the smallest, but the temporal patterns of streamflow are highly correlated, indicating that general patterns of precipitation in their watersheds, and therefore much of the State, are very similar. The fact that there was very little “normal” weather during the study period (just 2004) affects our ability to detect long-term trends in the data. Such extreme weather changes from year to year are likely to produce significant short-term trends in parameter values that will not necessarily persist over longer time scales. Another complicating factor is that the length of most of the datasets included in this analysis (approx. 7 y) is close to the length of known climatological cycles such as the El Niño-Southern Oscillation (ENSO), and data over several cycles would be needed to distinguish long-term trends from normal interannual variation. Therefore, we cautiously interpret the trends found (below) and at present we cannot determine if these represent more than normal variability.

Results

Below we describe the annual metrics for each parameter in the database (minimum, median or geometric mean, and maximum value). The discussion of each parameter includes figures showing the patterns observed over the study period for all sites combined, as well as maps showing those sites where there were significant trends over time. At the end of the section is a series of maps that show the spatial distribution of the annual metrics for each parameter. For brevity, maps where all values are low and indistinguishable from each other are not shown. All maps, including those not shown here, as well as tables of these values are included in the supplementary material in electronic format.

Temperature

Annual minimum water temperatures ranged from 6 to 16.1 °C over the period 1998 to 2008 (Figure 3-33), with both the lowest and highest annual minima recorded in 2001. When we used the median of all sites sampled in each year (the spatial median) to assess coastwide trends in minimum temperature, we found that minimum temperatures were markedly lower (by 2 °C or more) in 2003 than in other years and somewhat higher (by 1 °C or more) in 2006. Annual median temperature ranged from a high of 27.5 °C (measured at a site in 2000) to a low of 14.75 °C (measured in 2005) (Figure 3-34). The higher values in 2000 are probably due to the fact that sampling at River and Sound sites began in March of that year and so missed the coldest months. Lower median temperatures were evident coastwide in 2005, but this was partly due to a shift to bimonthly sampling after April at Shellfish sites, which resulted in over-representation of colder months that year. Annual maximum temperatures ranged from 26.75 °C (measured in 2003) to 36.1 °C (measured in 2005) (Figure 3-35), with little variation in the spatial median from year to year.

Temperature showed relatively little spatial variation at any given time: the most prominent changes were temporal. There is a strong and consistent seasonal cycle in water temperature (Figure 3-2) that explained 87-93% of the variability at any given site. These data were therefore deseasonalized before further analysis. Trend analysis revealed statistically significant decreases in temperature over the sampling period (1998-2006) at 10 Shellfish sites just north and south of St. Andrew Sound (Figure 3-3). Six of the sites are in Cumberland Sound, three are in St. Andrew Sound, and one is nearby in St. Simons Sound. The trend is primarily due to the fact that 1998-2000 was a few degrees warmer than later years, rather than a steady decline. No sites (Shellfish, River or Sound) showed any significant trend in temperature from 2001-2006. Beach sites, sampled 2004-2009, were split between a warming trend at Tybee Island and Kings Ferry and a cooling trend at Sea Island (Figure 3-4).

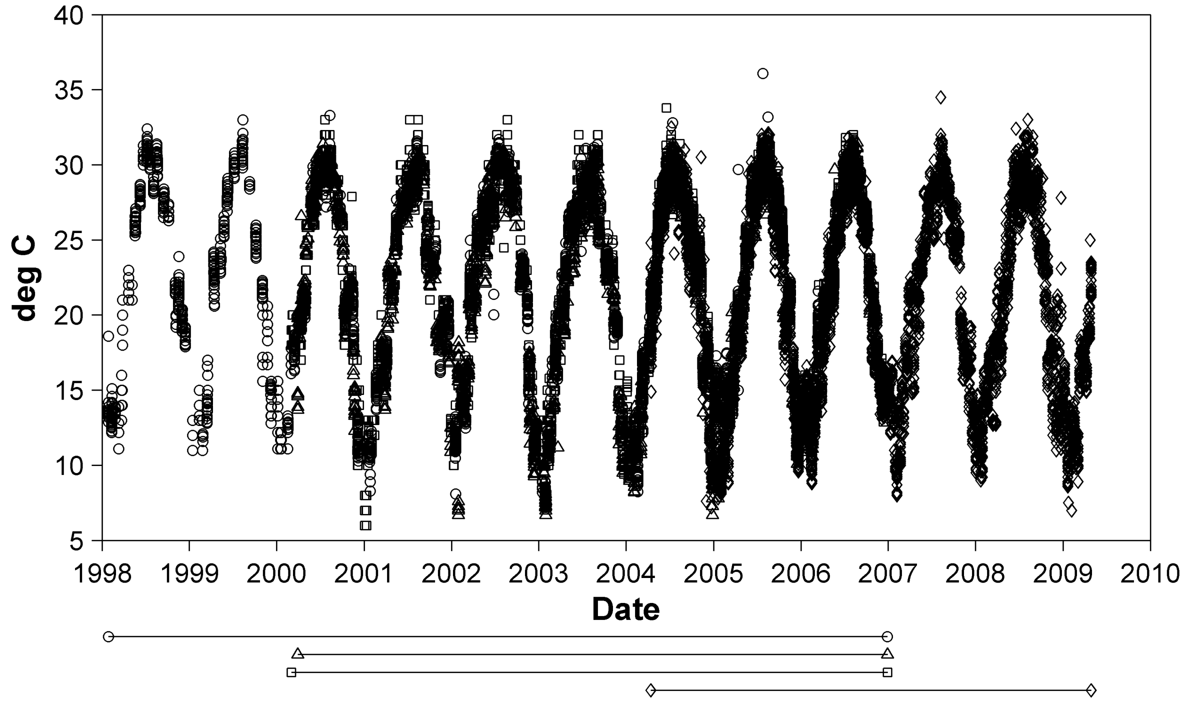

Figure 3-2. Temperature at all CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), Sound (squares), and Beach (diamonds) sites.

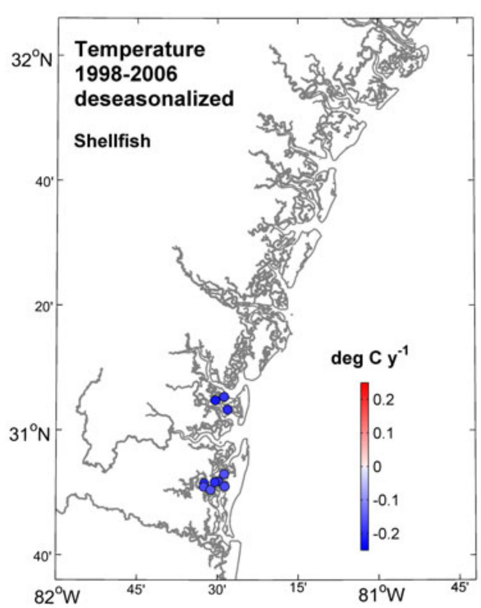

Figure 3-3. Shellfish sites that showed a significant decrease in water temperature over the study period.

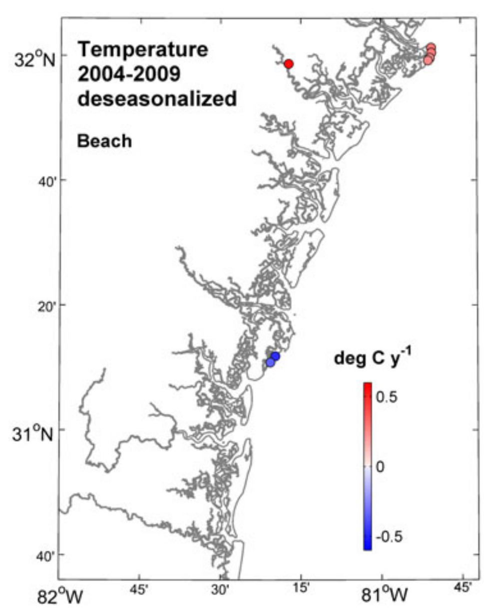

Figure 3-4. Beach sites that showed a significant change in water temperature over the study period.

Salinity

The range of salinities observed across the sampling sites is generally wide because they include habitat types ranging from the freshwater portions of rivers to polyhaline estuaries and beaches. Thus the annual minimum (Figure 3-36), median (Figure 3-37), and maximum (Figure 3-38) salinities for the period 1998-2008 show a great deal of spatial variability in years when all habitat types are sampled. Salinities tended to decrease during years of greater freshwater input (in 1998, 2003, and to a lesser extent in 2005) and increase during years of drought (in late 1998-2002 and 2006-2009), although the effects were manifested in different annual metrics each year. Annual minimum salinity ranged from near 0 at riverine sites in all years when they were sampled to 30 at some coastal sites in 2000-2002 (Figure 3-36). Using the spatial median of these values to assess coastwide trends, minimum salinities were markedly lower in 1998 and 2003 (years of increased inflow) compared to other years. The 1998 minimum is especially notable because only usually-polyhaline Shellfish sites were sampled. Minimum salinities were generally higher during drought years (1999-2002, 2006-2008). Annual median salinity ranged from near 0 (at riverine sites, all years) to 36.1 (measured at a site in 2006) (Figure 3-37). Median salinities were high in 1998 in spite of the low minima, reflecting the extreme precipitation range that year, and remained high through 2002. Lower median salinities in 2003 were followed by a return to higher values in later years. Annual maximum salinity ranged from near 0 at riverine sites in 2001-2006 to 41.8 at a Beach site in 2007 (Figure 3-38). Maximum salinities at individual sites tended to be high from 1998-2001 and low in 2003 and 2005. Twenty-five sites reached annual maximum salinities >36 in 2006 (Figure 3-38). 15 of these were southern sites in the vicinity of St. Simons, St. Andrew, and Cumberland Sounds; 7 were in the Tybee/Wassaw Sound area; and the remaining were in Sapelo (2) and Ossabaw (1) Sounds. Some very extreme values were also recorded in 2007 (5 observations >39.5), but it is difficult to assess the extent of this phenomenon because only Beach site data are currently included in the database.

Salinity has a mild and inconsistent seasonal cycle with some higher values during May-September (Figure 3-5). We deseasonalized the data prior to trend analysis although the cycle only accounted for up

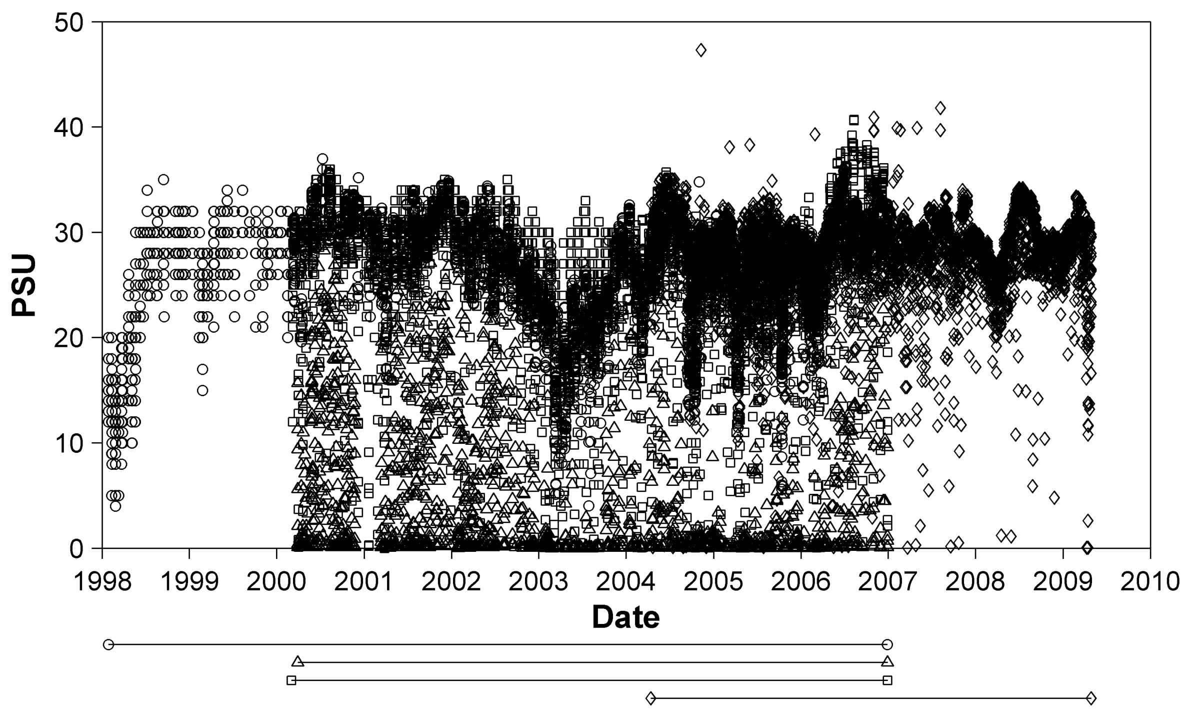

Figure 3-5. Salinity at all CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), Sound (squares), and Beach (diamonds) sites.

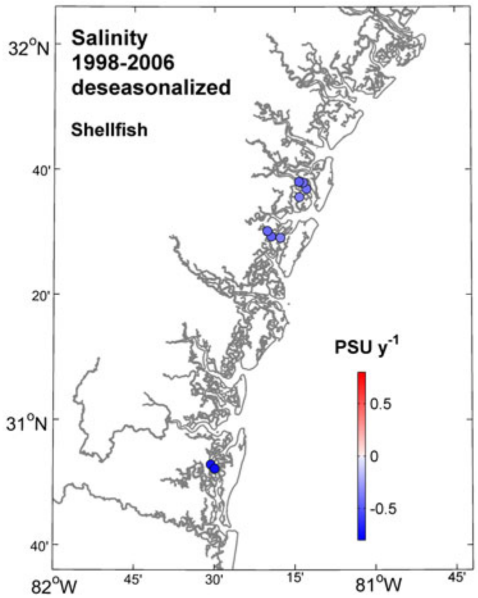

Figure 3-6. Shellfish sites that showed a significant decrease in salinity over the study period.

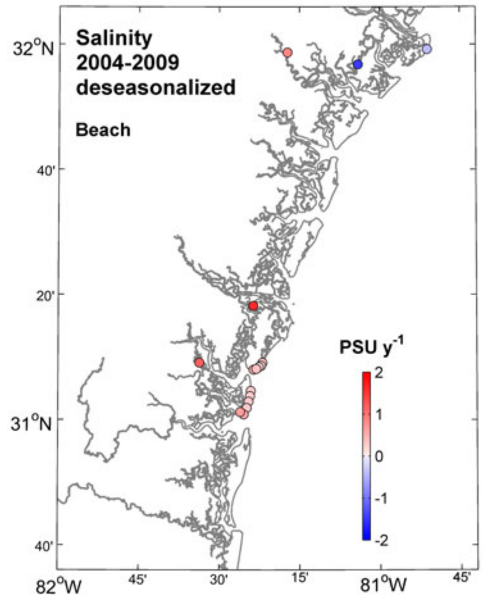

Figure 3-7. Beach sites that showed a significant change in salinity over the study period.

to 17% of the variability in any site's observations. Nine Shellfish sites showed statistically significant decreases in salinity over the sampling period (1998-2006) (Figure 3-6). The sites spanned the coast, with seven in creeks north and south of Sapelo Sound and two in the St. Andrew/Cumberland Sound area. The trend may be due to the large effect of freshwater input in 2003 rather than a steady decline, because trends at other sites seem to depend on whether they were sampled in 2003. A few River and Sound sites (mostly Ogeechee/Ossabaw Sound) also showed significant declines over 2001-2006 (not shown), but most Beach sites, sampled 2004-2009, showed increasing trends in salinity (Figure 3-7).

Specific Conductance

Specific conductance is used to calculate salinity, so the patterns are the same and are not shown again here. The relationship between the two is discussed in Section 4.

pH

Sites sampled for pH in 2002 and 2003 did not have sufficient data to calculate annual metrics, so our analysis covers the period 2004-2008. The ranges of annual metrics observed depend in large part on which sites were sampled, as pH varies depending on salinity and estuary type with low values in the blackwater river sites and highest values at beach sites. Annual minimum pH ranged from 3.79 (measured in 2004 at a St. Marys River site) to 7.8 (measured in 2008 at a Beach site) (Figure 3-39). Annual median pH ranged from 5 (measured in 2005 in the St. Marys River) to 8.1 (measured in 2007-2008 at Beach sites) (Figure 3-40). When compared across years, Ogeechee and St. Marys River sites generally had lower median pH in 2005 than in other years. Annual maximum pH ranged from 6.5 (measured in 2005 in the St. Marys River) to 8.7 (measured in 2006 and 2008) (Figure 3-41).

Although it is not obvious in the time plot of pH data for all sites (Figure 3-8), there is a seasonal cycle at some sites that accounts for up to 38% of the variability, so data were deseasonalized before trend analysis. There are, however, barely enough data to evaluate trends. Some low-salinity River and Sound sites, but no Shellfish sites, showed significant increases in pH from 2004-2006, and several St. Simons and Jekyll Island Beach sites showed significant increases from 2004-2009 (all shown in Figure 3-9).

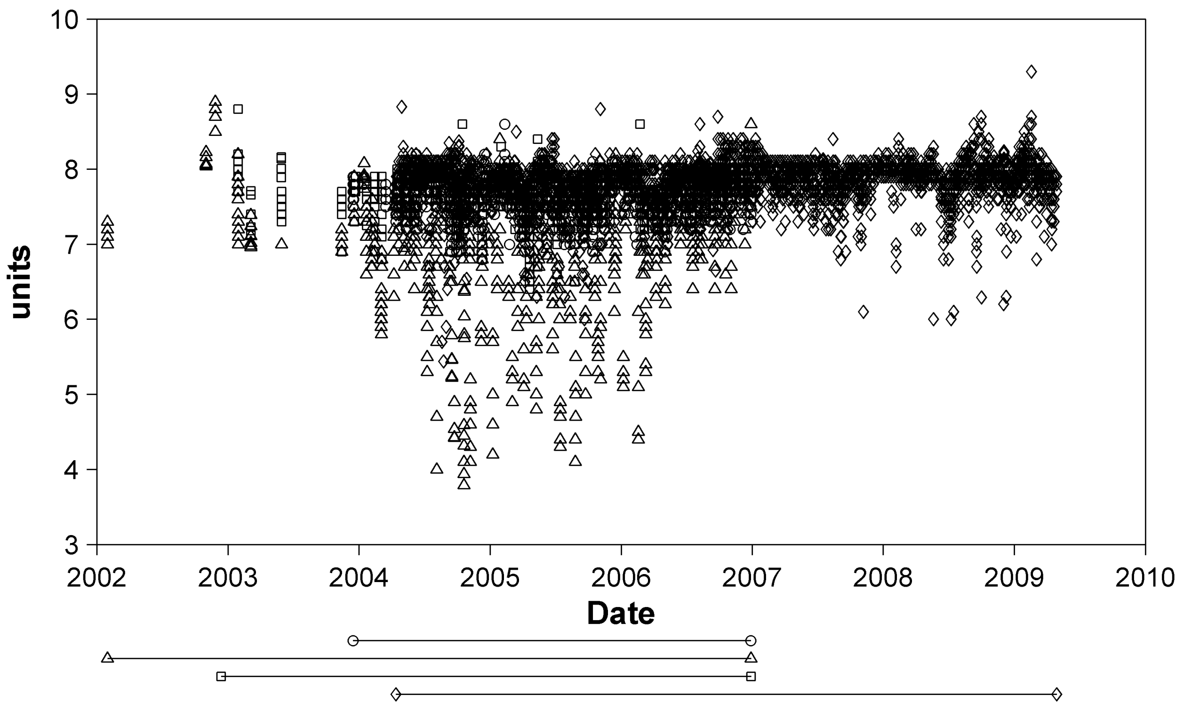

Figure 3-8. pH at all CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), Sound (squares), and Beach (diamonds) sites.

Dissolved Oxygen

Dissolved oxygen (DO) measurements over the period 2000-2008 were analyzed for annual metrics. DO tended to be consistently lower in blackwater systems than in others, although low values were sometimes found in other habitat types as well. Annual minimum DO ranged from 1.67 mg L^{-1} (measured in 2001) to 6.3 mg L^{-1} (measured in 2005) (Figure 3-42). The spatial median of these values was typically near 4 mg L^{-1}, but was markedly lower in both 2001 (by 0.75 mg L^{-1}) and 2003 (by 1.25 mg L^{-1}). Annual median DO ranged from 3.6 mg L^{-1} (at a site in 2003) to 7.8 mg L^{-1} (at a site in 2006) (Figure 3-43). Spatial median values in 2003 were markedly lower (by at least 1 mg L^{-1}) than in other years, while values in 2006 were higher by at least 0.5 mg L^{-1}. Annual maximum DO ranged from 5.3 mg L^{-1} (measured in 2000 when sampling began in March after the usual high DO period) to 11.43 mg L^{-1} (measured in 2006) (Figure 3-44), with little variation in the spatial median from year to year.

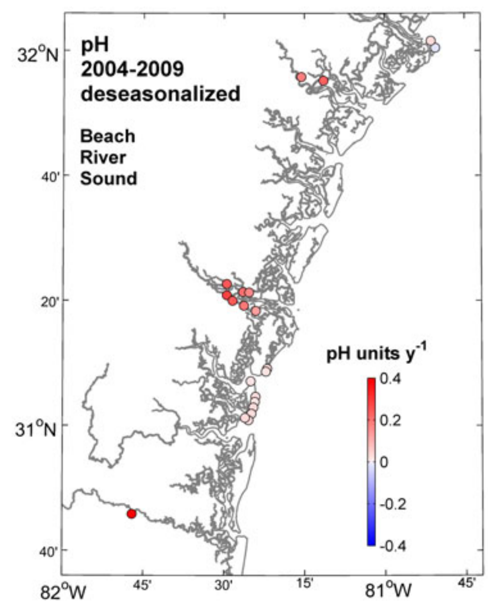

Figure 3-9. Sites that showed a significant increase in pH over the study period. River and Sound sites were sampled 2004-2006.

There is a strong and consistent seasonal cycle in DO concentrations (Figure 3-10) that is partly due to the solubility of oxygen in water, which changes in response to changes in temperature and salinity. When DO is expressed as a percentage of the saturation value to remove this source of variation from the data, a seasonal cycle is still evident (Figure 3-11), indicating that other processes such as photosynthesis and respiration also affect the observed oxygen levels. In cases where DO becomes supersaturated (>100%), this may be due to excess oxygen production by algae or to wave action.

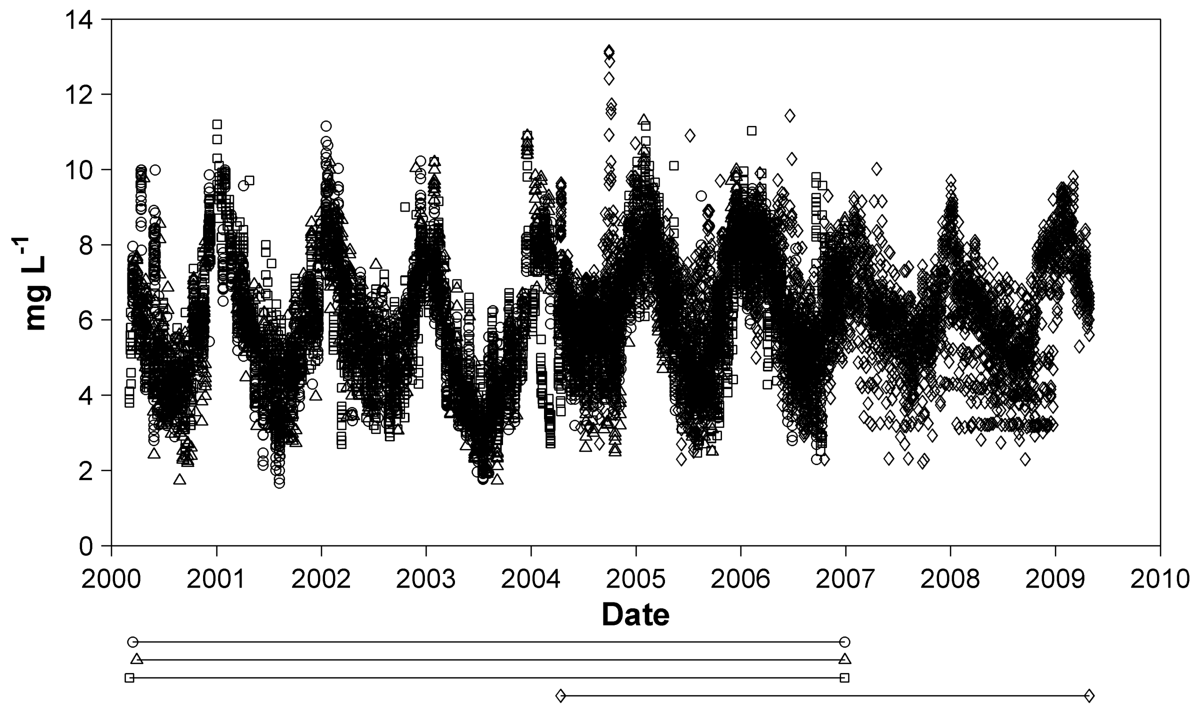

Figure 3-10. Dissolved oxygen concentrations at all CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), Sound (squares), and Beach (diamonds) sites.

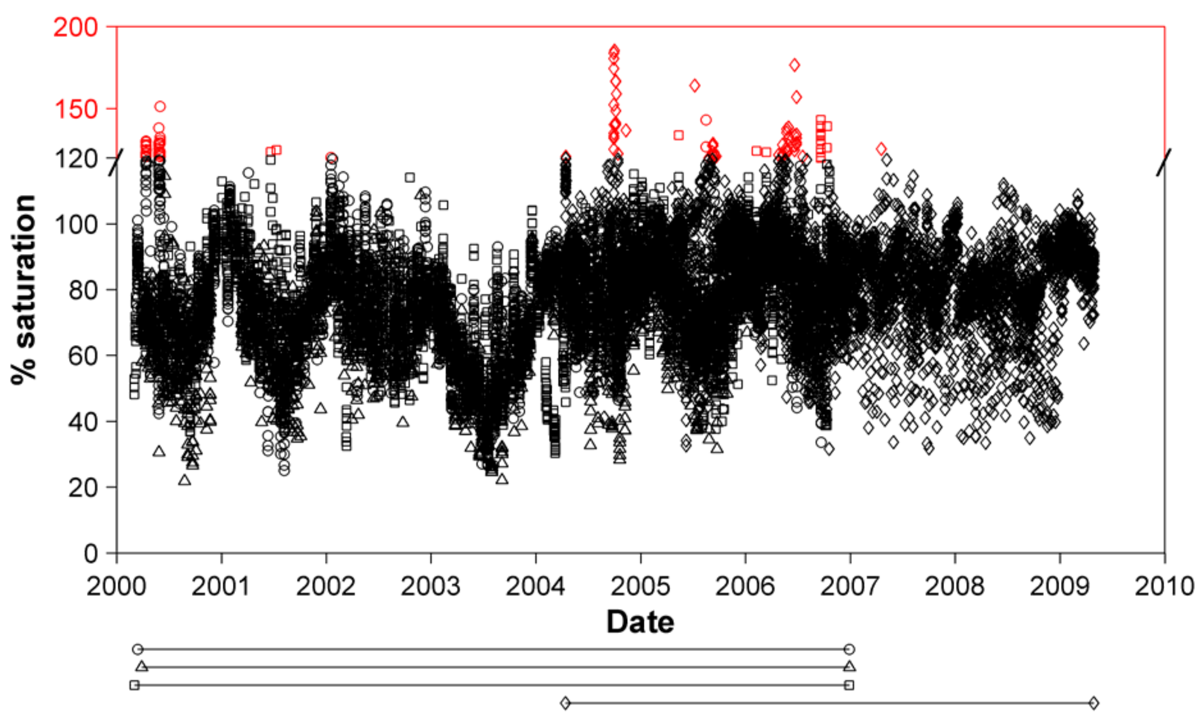

Figure 3-11. Dissolved oxygen percent saturation at all CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), Sound (squares), and Beach (diamonds) sites. Note the split scale with higher values in red.

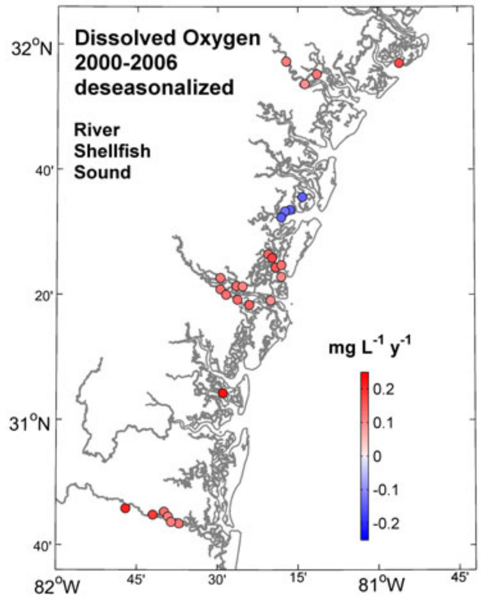

Figure 3-12. Shellfish, River, and Sound sites that showed a significant change in dissolved oxygen over the study period.

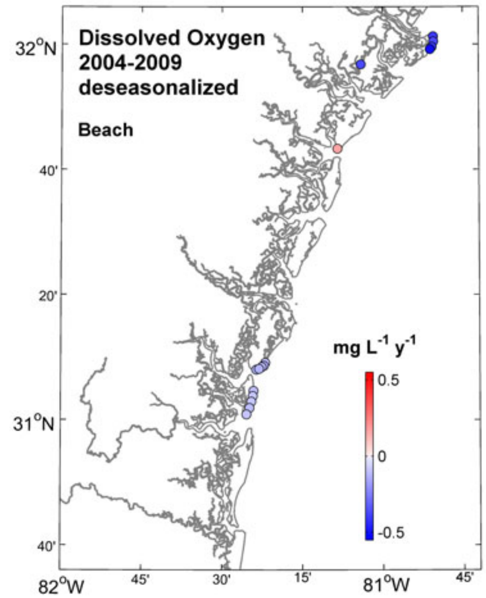

Figure 3-13. Beach sites that showed a significant change in dissolved oxygen over the study period.

The DO data were deseasonalized before trend analysis. The cycle explained 32-77% of the variability at any given site. 28 Shellfish, River, and Sound sites coastwide showed significant trends in DO from 2000-2006. With the exception of several sites in Sapelo Sound, most of these showed increases over time (Figure 3-12). In contrast, most Beach sites, which were sampled over a different period (2004-2009), showed decreasing trends (Figure 3-13). These increases and decreases likely reflect the extreme variability in fairly short time series rather than steady long-term trends.

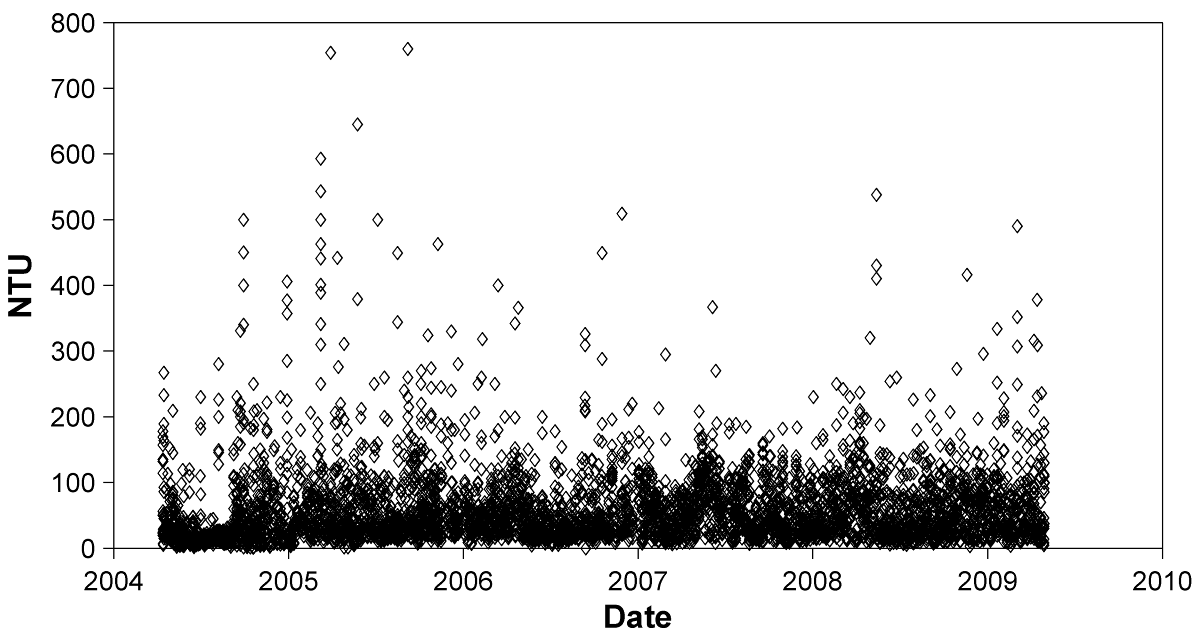

Figure 3-14. Turbidity at all Beach sites over the study period.

Turbidity

Turbidity data are included only for Beach sites, so annual metrics could be calculated for 2005-2008. Annual minimum turbidity at each site was very low compared to peak values, ranging from 0 to 27 NTU (not shown). Annual median turbidity ranged from 17 to 106 NTU (Figure 3-45), with high values found consistently at some Jekyll Island sites and little change in range or spatial pattern from year to year. Annual maximum turbidity ranged from 64 to 760 NTU, with both the lowest and highest values recorded in 2005 (Figure 3-46).

Turbidity is highly variable temporally but there is no obvious seasonal cycle (Figure 3-14), and the data were not deseasonalized. A few sites, mostly at Tybee Island, showed slight but significant increases in turbidity over this relatively short study period (Figure 3-15).

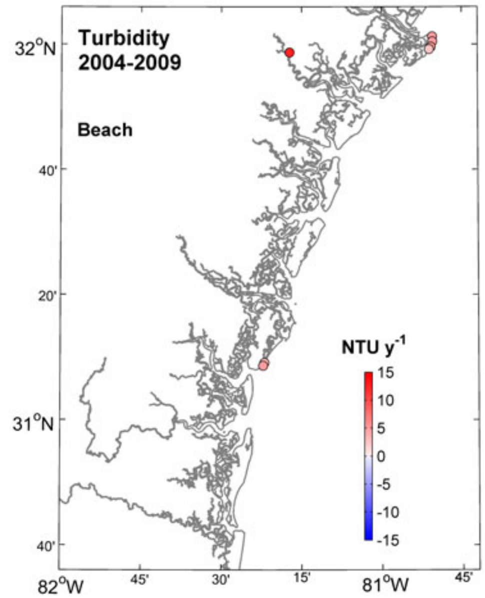

Figure 3-15. Beach sites that showed a significant increase in turbidity over the study period.

Silicate

Nutrient analyses began in 2001, but this was a partial year so annual metrics could be calculated for the period 2002-2006. Rivers are the primary source of silicates to Georgia coastal waters, and the spatial patterns in silicate concentrations reflect that fact. Annual minimum silicate ranged from the MDL (0.019 mg SiO_2 L^{-1}) to 8.1 mg L^{-1} (Figure 3-47), with higher values in the River sites and little change in the spatial pattern from year to year. The same was true for annual median silicate, which ranged from 1 to 10.8 mg L^{-1} (Figure 3-48). Annual maximum silicate was also fairly steady from year to year, ranging from 2.4 to 21.7 mg L^{-1} (measured in 2004 in the St. Marys River) (Figure 3-49). In other years, maximum values were below 13.7 mg L^{-1}. Silicate concentrations were not measured at Beach sites.

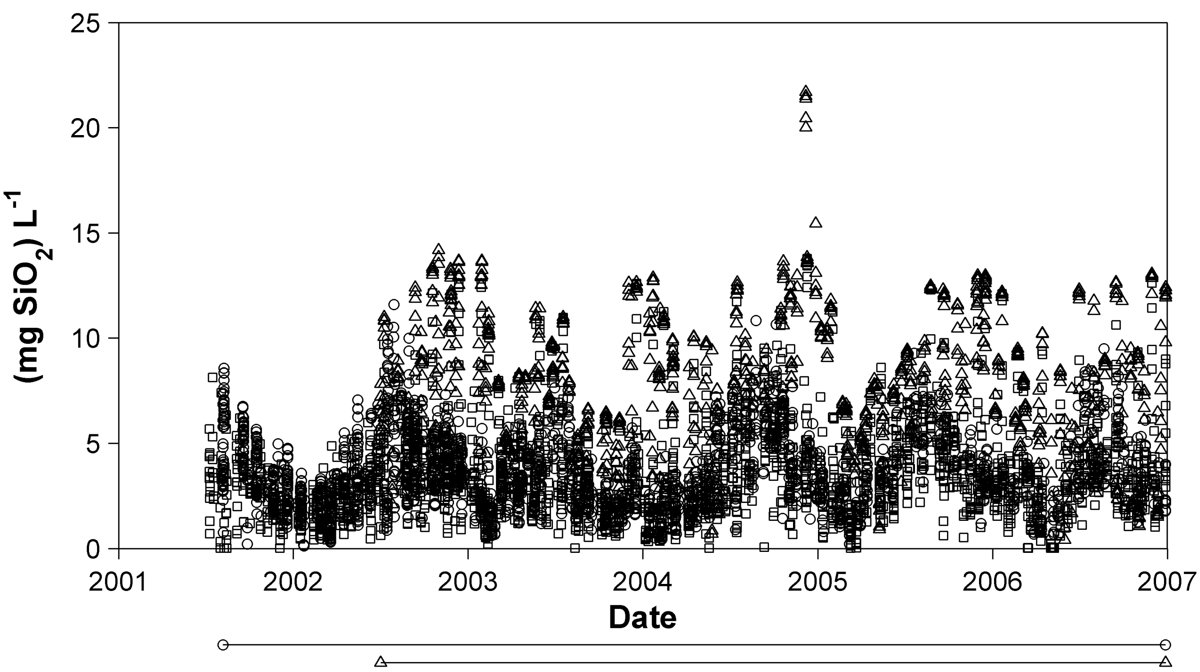

Figure 3-16. Silicate concentrations at CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), and Sound (squares) sites.

Silicate concentrations show an inconsistent seasonal cycle (Figure 3-16), but since the annual cycle accounted for up to 74% of the variability at some sites, the data were deseasonalized prior to trend analyses. Trends in silicate concentrations were found at a few sites, but the directions of the trends were inconsistent (Figure 3-17). Two clusters of Shellfish and Sound sites, in Wassaw and Doboy/Sapelo Sounds, had increasing trends, whereas a few River sites had decreasing trends over the study period.

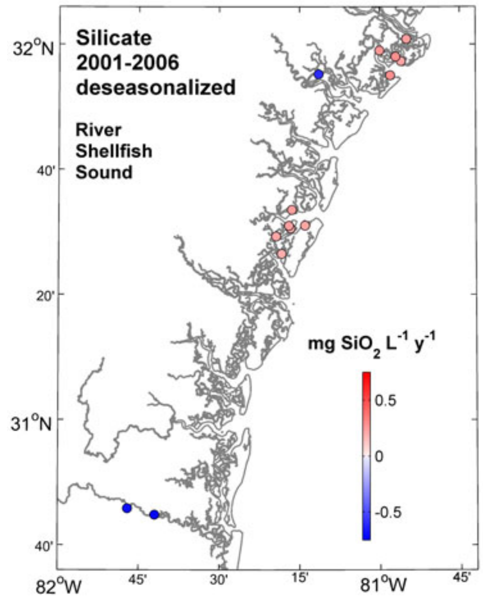

Figure 3-17. Sites that showed a significant change in silicates over the study period.

Ammonia

"Ammonia" (NH_3) in this report refers to the sum of ammonia (NH_3) and ammonium (NH_4^+), with the actual balance between the two in any given sample controlled by pH, temperature, and salinity. Annual metrics that could be calculated cover the period 2002-2006. Concentrations of ammonia were low at most sites most of the time. Annual minimum ammonia ranged from near the MDL (0.003 mg N L^{-1}) in all years to 0.05 mg N L^{-1} (measured in 2004) (not shown), with little change from year to year. Annual median ammonia ranged from 0.008 mg N L^{-1} (measured at a site in 2004) to 0.09 mg N L^{-1} (measured in 2002) (not shown). Annual maximum ammonia ranged from low values at most sites in most years (with the lowest being 0.034 mg N L^{-1} in 2006) to a single site with the highest value in 2004 (5.9 mg N L^{-1}) (Figure 3-50) There were, however, many sites with values over 1 mg N L^{-1} in 2006. Ammonia concentrations were not measured at Beach sites.

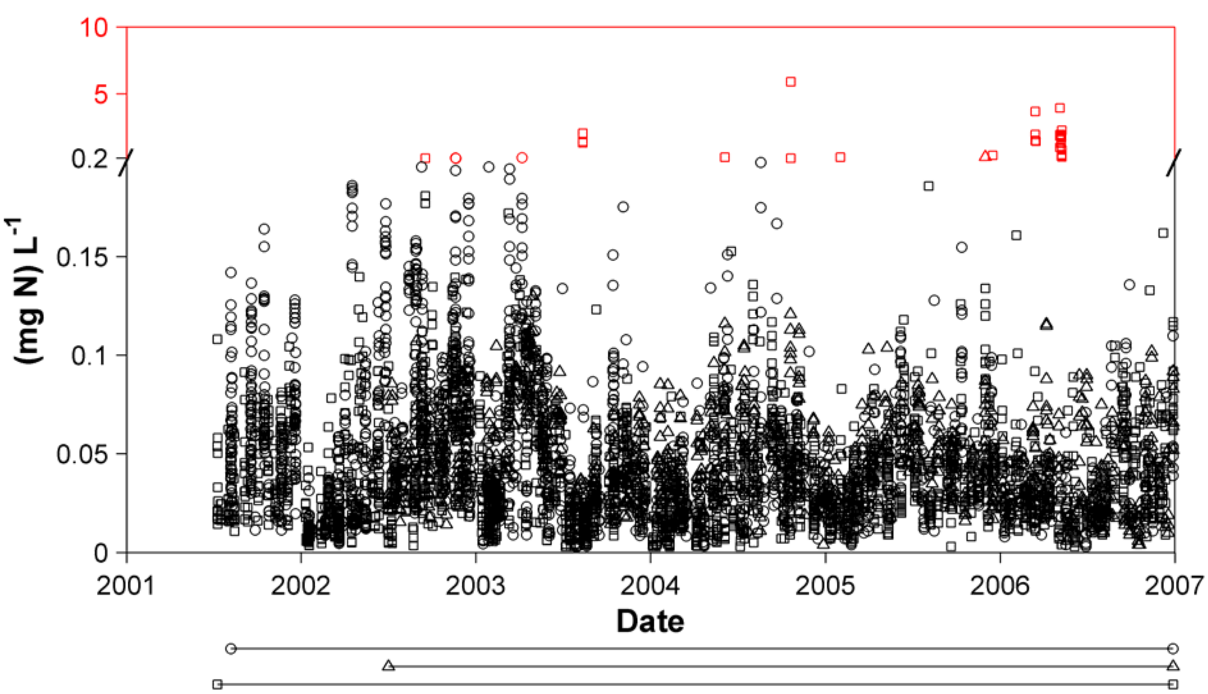

Figure 3-18. Ammonia + ammonium concentrations at CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), and Sound (squares) sites. Note the split scale with higher values in red.

Ammonia concentrations show an inconsistent seasonal cycle, with generally lower values in winter, and spring and fall peaks sometimes evident (Figure 3-18). The data were deseasonalized prior to trend analysis, which explained up to 50% of the variability at some sites. In spite of several sites with high maximum values in 2006, the only significant trends were decreasing values over the study period at 15 sites spread throughout the coast, and the rates of decrease were very low (Figure 3-19).

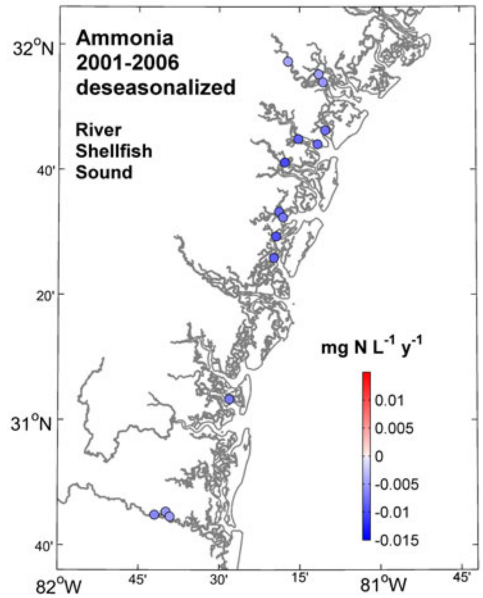

Figure 3-19. Sites that showed a significant decrease in ammonia over the study period.

Nitrite

Nitrite (NO_2) annual minima and medians cover the period 2002-2006, whereas annual maxima could be calculated for the partial year 2001 through 2006 because of the critical season criteria (this was the only annual nutrient metric for which this was the case). Annual minimum nitrite at each site was always near the MDL (0.004 mg N L^{-1}) (not shown). Annual median nitrite was also often near the MDL although it ranged up to approximately 0.01 mg N L^{-1} at some sites in all years (not shown). Annual maximum nitrite was more variable both spatially and temporally, ranging from the MDL in most years to 0.69 mg N L^{-1} (measured at a site in 2001) (Figure 3-51). High concentrations were found at several sites in 2001, 2003 and 2005, with the higher values generally in Shellfish and Sound sites rather than River sites. Nitrite concentrations were not measured at Beach sites.

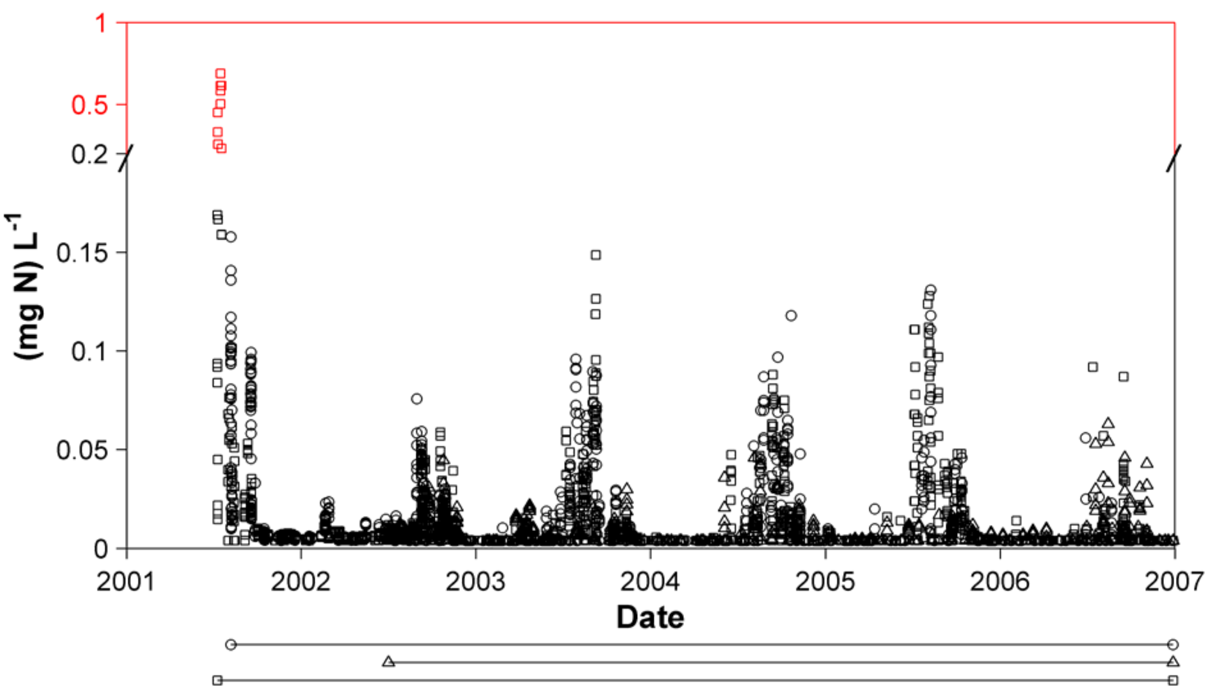

Figure 3-20. Nitrite concentrations at CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), and Sound (squares) sites. Note the split scale with higher values in red.

Nitrite concentrations show a consistent seasonal cycle with late summer-fall peaks at many sites (Figure 3-20). The cycle accounted for up to 50% of the variability at some sites, so the data were deseasonalized prior to trend analysis. Only 5 sites showed significant decreasing trends over the study period, and the rates of decrease were very low (Figure 3-21).

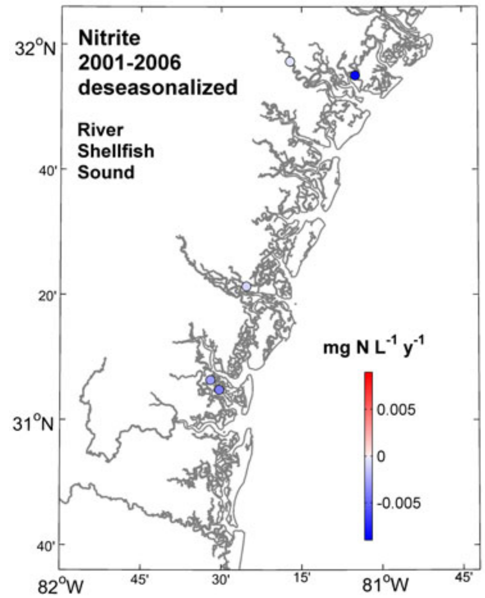

Figure 3-21. Sites that showed a significant decrease in nitrite over the study period.

Nitrate

Annual metrics that could be calculated for nitrate (NO_3) cover the period 2002-2006. Rivers represent an important source of nitrate to the coast, with large amounts brought in by the Altamaha River (the largest river represented in this database). One would therefore expect higher nitrate concentrations in this area. Annual minimum concentrations ranged from the MDL (0.004 mg N L^{-1}) in all years to 0.12 mg N L^{-1} (measured in Altamaha River and Sound in the high flow years of 2003 and 2005) (Figure 3-52). Annual median nitrate ranged from near the MDL in most years to 0.3 mg N L^{-1} (measured in 2006) (Figure 3-53), with highest values always in the Altamaha River. Annual maximum nitrate ranged from the MDL (measured at a few sites in 2006) to 1.24 mg N L^{-1} (at one site in 2004 where lower values were found nearby) (Figure 3-54). Other than that one site, higher values were generally found at River sites with the highest in the Altamaha River. Nitrate concentrations were not measured at Beach sites.

Nitrate concentrations show an inconsistent seasonal cycle (Figure 3-22), but at some sites the cycle accounted for up to 55% of the variability so the data were deseasonalized prior to trend analysis. 55 sites

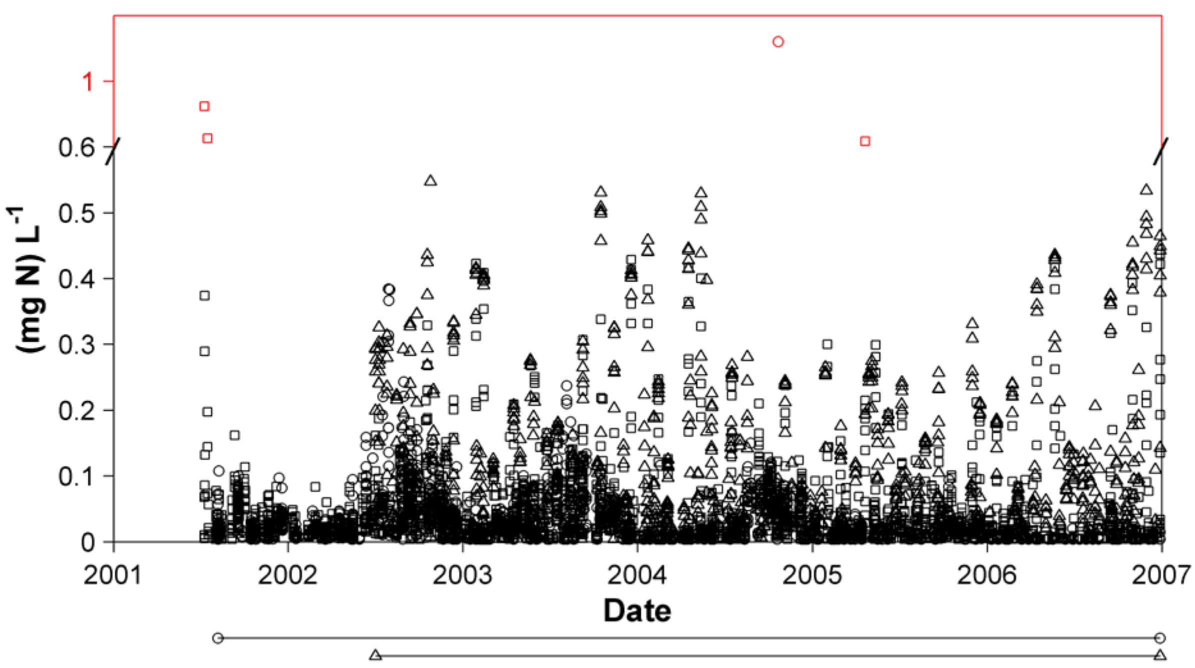

Figure 3-22. Nitrate concentrations at CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), and Sound (squares) sites. Note the split scale with higher values in red.

showed significant decreasing trends in nitrate concentrations over the period 2001-2006 (Figure 3-23). The rates of decrease are not large compared to the concentrations, however, and the Altamaha River sites with the consistently highest concentrations showed no significant change.

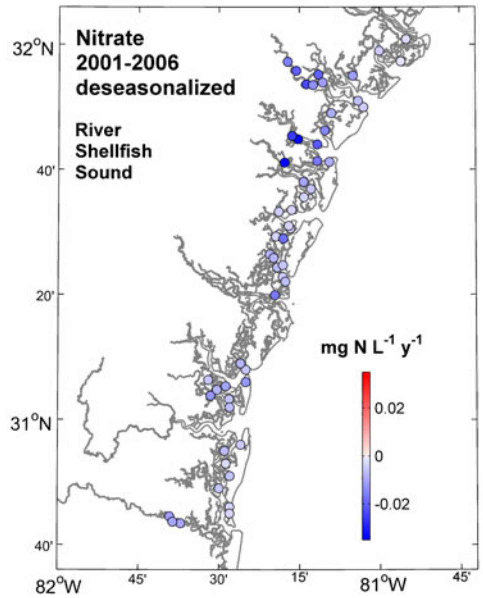

Figure 3-23. Sites that showed a significant decrease in nitrate over the study period.

Dissolved Inorganic Nitrogen

Dissolved inorganic nitrogen (DIN) is the sum of ammonia, nitrite, and nitrate; annual metrics of DIN were calculated for the period 2002-2006. Nitrate, with the highest annual peak concentrations, tends to be the largest contributor to the DIN pool most of the time, although ammonia concentrations dominate occasionally. This means that some of the patterns observed for annual metrics of DIN are similar to observations for nitrate alone. Annual minimum DIN ranged from the combined MDL (0.011 mg N L^{-1}) in most years to highs of 0.17-0.18 mg N L^{-1} (measured in the Altamaha River in 2005 and 2003, respectively) (Figure 3-55). Annual median DIN ranged from 0.019 mg N L^{-1} (measured in 2004 and 2006) to 0.357 mg N L^{-1} (measured at a site in 2006) (Figure 3-56), with highest values in the Altamaha River each year. Annual maximum DIN ranged from 0.044 mg N L^{-1} (measured in 2006) to 5.97 mg N L^{-1} (measured in 2004 at the station where nitrate peaked that year) (Figure 3-57). Although the Altamaha River had consistently moderate values of DIN due to nitrate, spikes in ammonia concentrations resulted in occasionally much higher values at some Sound and Shellfish sites, particularly in 2006. DIN concentrations were not measured at Beach sites.

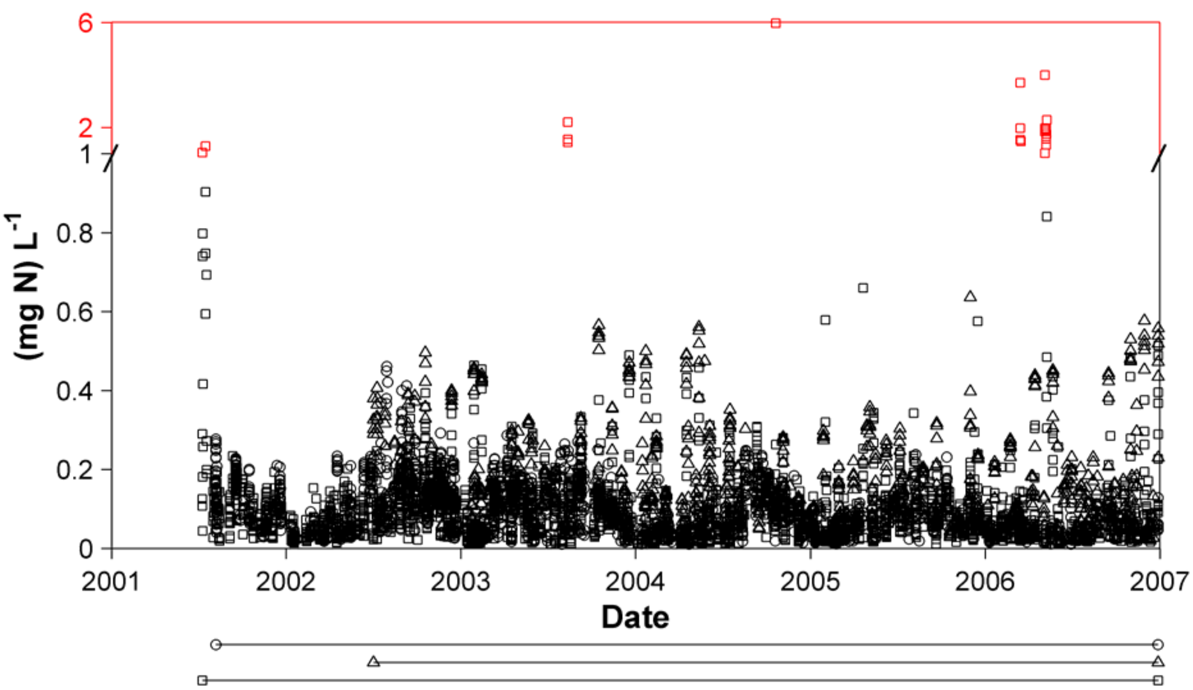

Figure 3-24. Dissolved inorganic nitrogen concentrations at CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), and Sound (squares) sites. Note the split scale with higher values in red.

DIN concentrations show an inconsistent seasonal cycle, similar to that seen for nitrate alone (Figure 3-24). The cycle accounted for up to 45% of the variability at some sites, so the data were deseasonalized prior to trend analysis. 40 sites showed significant decreasing trends in DIN concentrations over the study period (Figure 3-25). 21 of these sites had significant decreasing trends in nitrate but not ammonia; 3 had trends in ammonia but not nitrate; 12 had trends in both; and 4 are sites that did not have trends in component values, indicating that DIN trends can be complex. Once again, the Altamaha River, a consistent source of DIN to the coast, showed no significant temporal change over the study period.

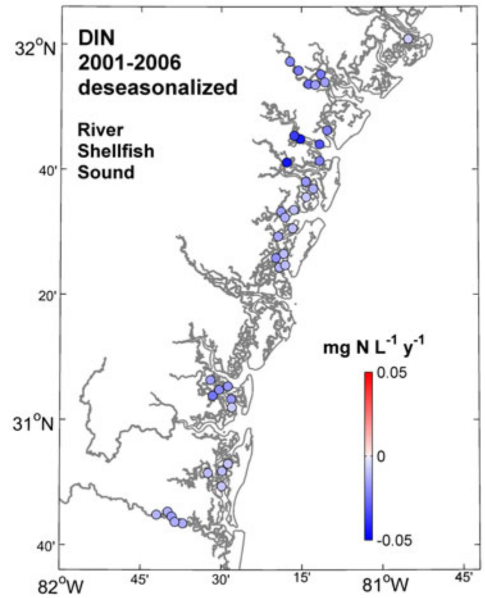

Figure 3-25. Sites that showed a significant decrease in DIN over the study period.

Orthophosphate

Annual metrics that could be calculated for orthophosphate (PO_4) cover the period 2002-2006. Annual minimum orthophosphate ranged from near the MDL (0.002 mg P L^{-1}) in most years to 0.052 mg P L^{-1} (measured at a site in 2006) (not shown). Annual median orthophosphate ranged from approximately 0.01 to 0.06-0.08 mg P L^{-1} in all years, with lower values at River sites and higher values in St. Simons, St. Andrew, St. Catherines, and Sapelo Sounds (Figure 3-58). Annual maximum orthophosphate ranged from 0.02-0.03 mg P L^{-1} in all years to 0.44 mg P L^{-1} (measured at a site in 2005) (Figure 3-59), with sporadically high values at different sites each year. Orthophosphate concentrations were not measured at Beach sites.

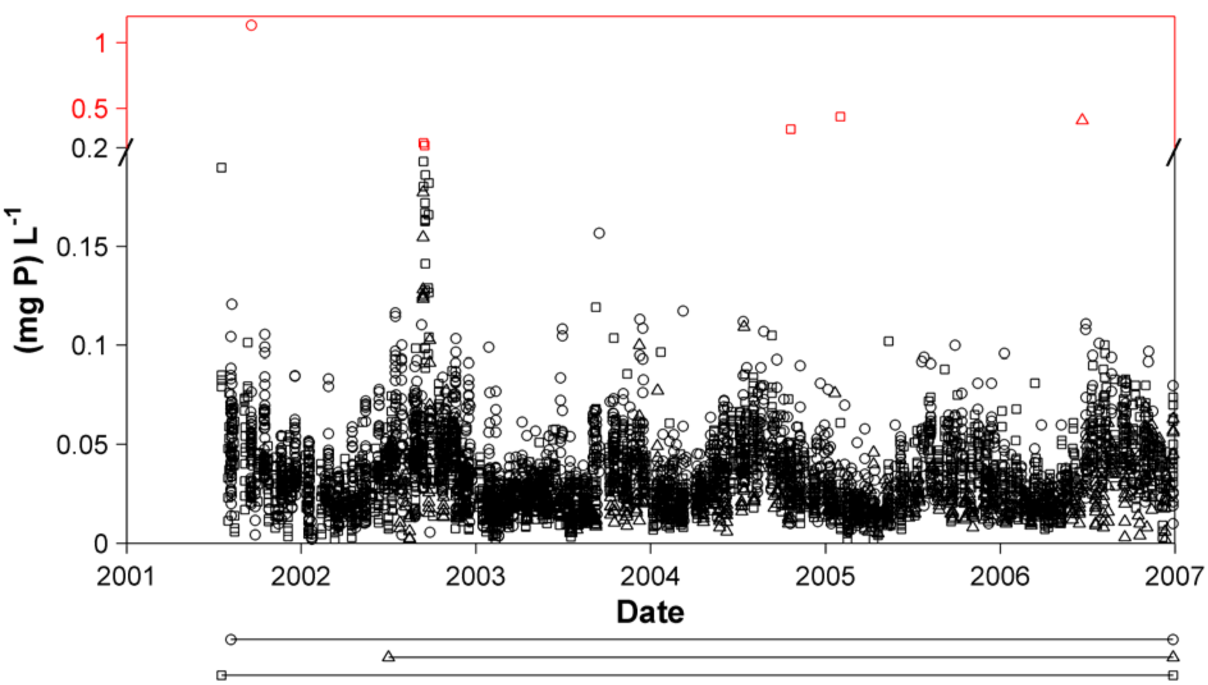

Figure 3-26. Orthophosphate concentrations at CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), and Sound (squares) sites. Note the split scale with higher values in red.

Orthophosphate concentrations show an inconsistent seasonal cycle (Figure 3-26). At some sites the cycle accounted for up to 83% of the variability, so the data were deseasonalized prior to trend analysis. 11 sites showed small but significant increases in orthophosphate concentrations over the study period (Figure 3-27), mostly in Wassaw, Altamaha, and Doboy Sounds.

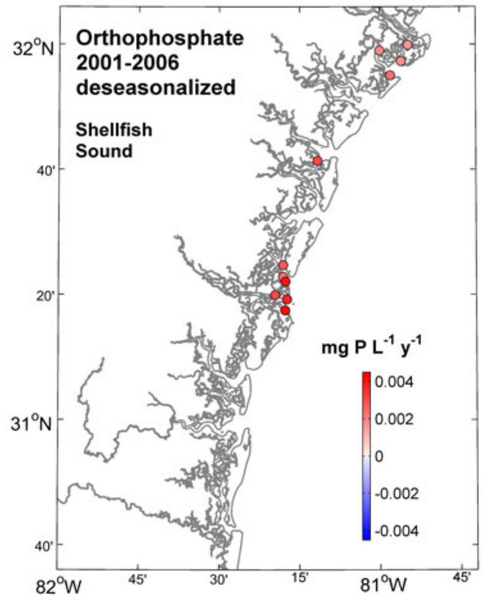

Figure 3-27. Sites that showed a significant increase in orthophosphate over the study period.

Total Dissolved Phosphorus

Annual metrics that could be calculated for total dissolved phosphorus (TDP) cover the period 2002-2006. Annual minimum total dissolved phosphorus ranged from the MDL (0.018 mg P L^{-1}) in all years to 0.06 mg P L^{-1} (measured at a site in 2002) (not shown). Annual median TDP ranged from near the MDL in all years to 0.09 mg P L^{-1} (measured in 2002) (Figure 3-60), with higher values consistently found in St. Simons, St. Andrew, and St. Catherines Sounds. Annual maximum TDP ranged from 0.03-0.04 mg P L^{-1} in all years to 2.6 mg P L^{-1} (measured in 2004) (Figure 3-61), with sporadically high values at different sites each year. TDP concentrations were not measured at Beach sites.

TDP concentrations show an inconsistent seasonal cycle (Figure 3-28) accounting for up to 51% of the variability at some sites, so the data were deseasonalized prior to trend analysis. 6 sites showed significant trends in TDP concentrations over the study period (not shown); however, the trend magnitudes (approximately 0.007 mg P L^{-1} y^{-1}) were trivially small compared to the MDL and the directions of the trends were inconsistent, indicating that the results were probably an effect of sporadic high values.

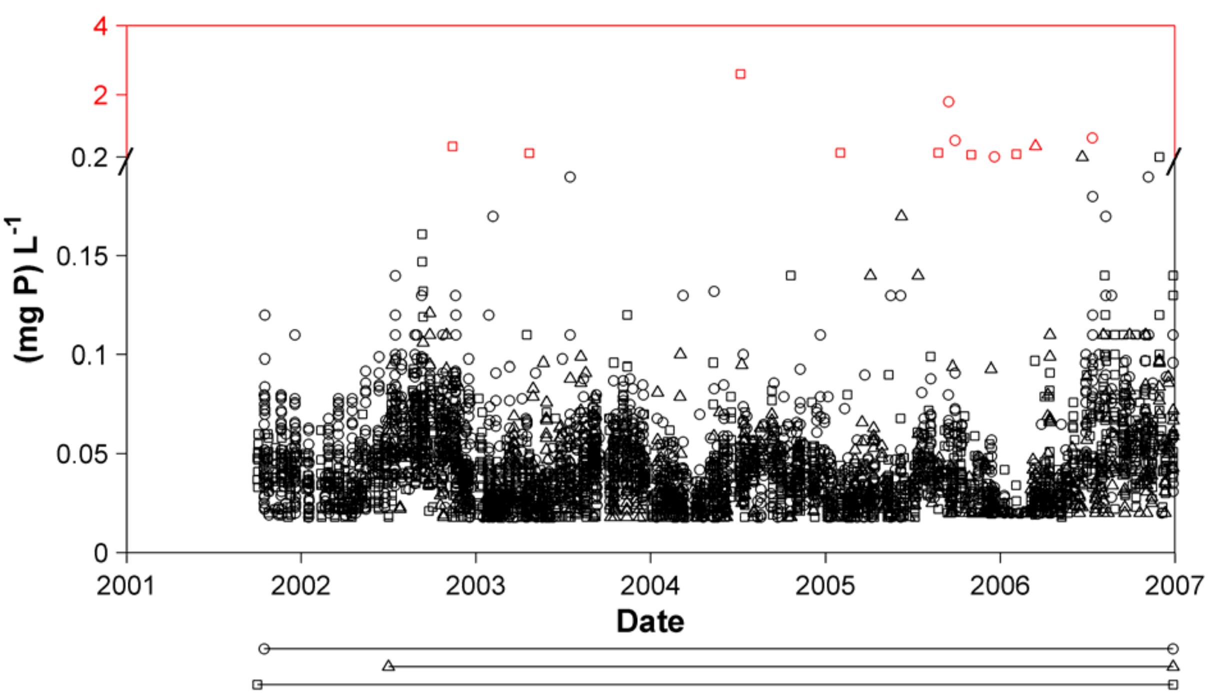

Figure 3-28. Total dissolved phosphorus concentrations at CRD sampling sites over the study period. Bars at bottom show sampling periods for Shellfish (circles), River (triangles), and Sound (squares) sites. Note the split scale with higher values in red.

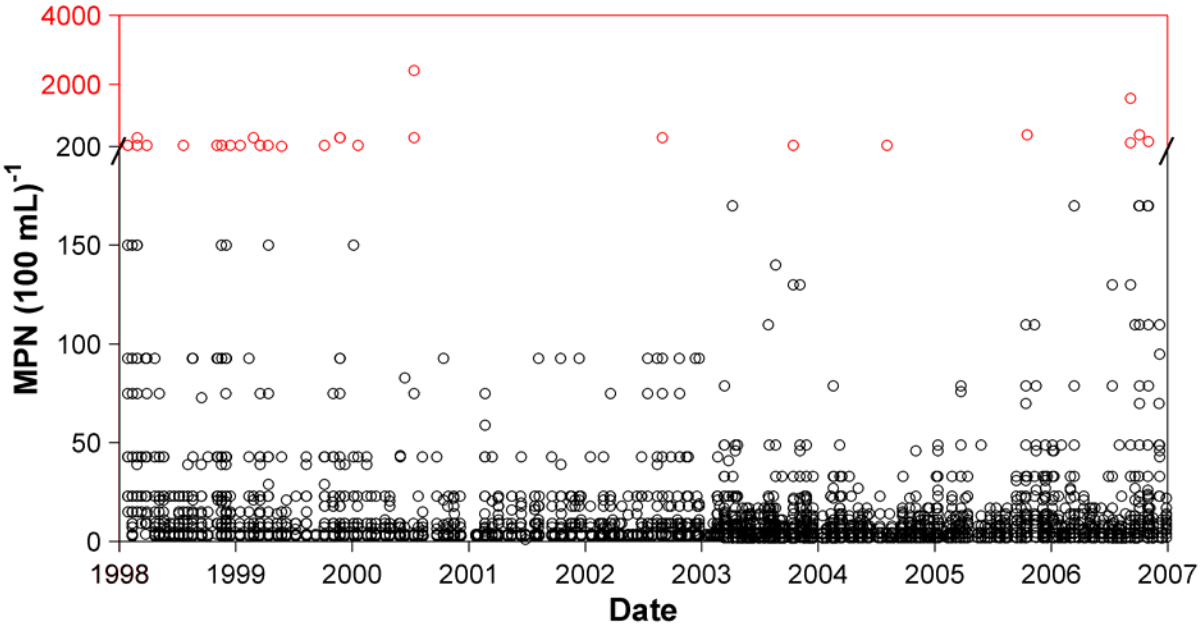

Figure 3-29. Fecal coliform bacteria counts at Shellfish sites over the study period. Note the split scale with higher values in red.

Fecal Coliforms

Abundances of fecal coliform bacteria are only measured at Shellfish sites. Annual metrics could be calculated for the period 1998-2006. Annual minimum fecal coliform counts were <3 MPN 100 mL^{-1} at most sites in most years, with a high value of 11 MPN 100 mL^{-1} (measured at a site in 2006) (not shown). Annual geometric mean fecal coliform counts ranged from 2-3 MPN 100 mL^{-1} in most years to 38 MPN 100 mL^{-1} (measured in 1998) (not shown), with most sites having a geometric mean <6 MPN 100 mL^{-1} in most years. Annual maximum fecal coliform counts had a low of <5 MPN 100 mL^{-1} in most years but were sporadically high at different sites each year, with a maximum of 2400 MPN 100 mL^{-1} (measured at a site in 2000) (Figure 3-62). Two sites in the Duplin River that had consistently high maximum values were dropped from the Shellfish program in 2004.

There is no obvious seasonal cycle in fecal coliform counts (Figure 3-29), so the data were not deseasonalized. There is, however, an obvious change in the precision of the counts in March 2003 when the method was changed from a 3-tube to a 5-tube MPN procedure. 20 sites in Sapelo, St. Andrew, and Cumberland Sounds showed significant decreasing trends over the study period (Figure 3-30), but these were all quite small and may simply have been related to the lower values that are made possible by the 5-tube method.

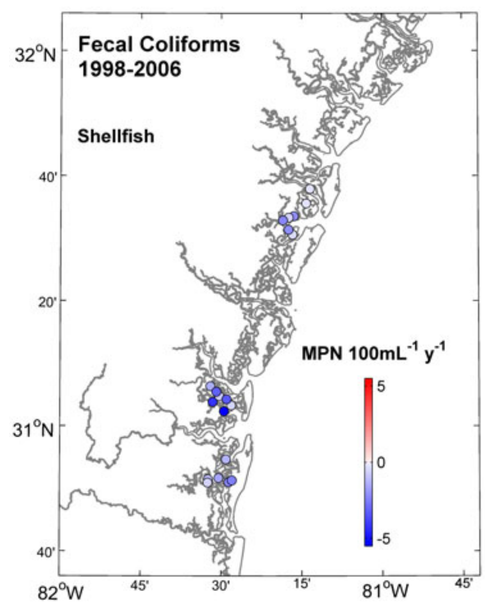

Figure 3-30. Sites that showed a significant decrease in fecal coliform counts over the study period.

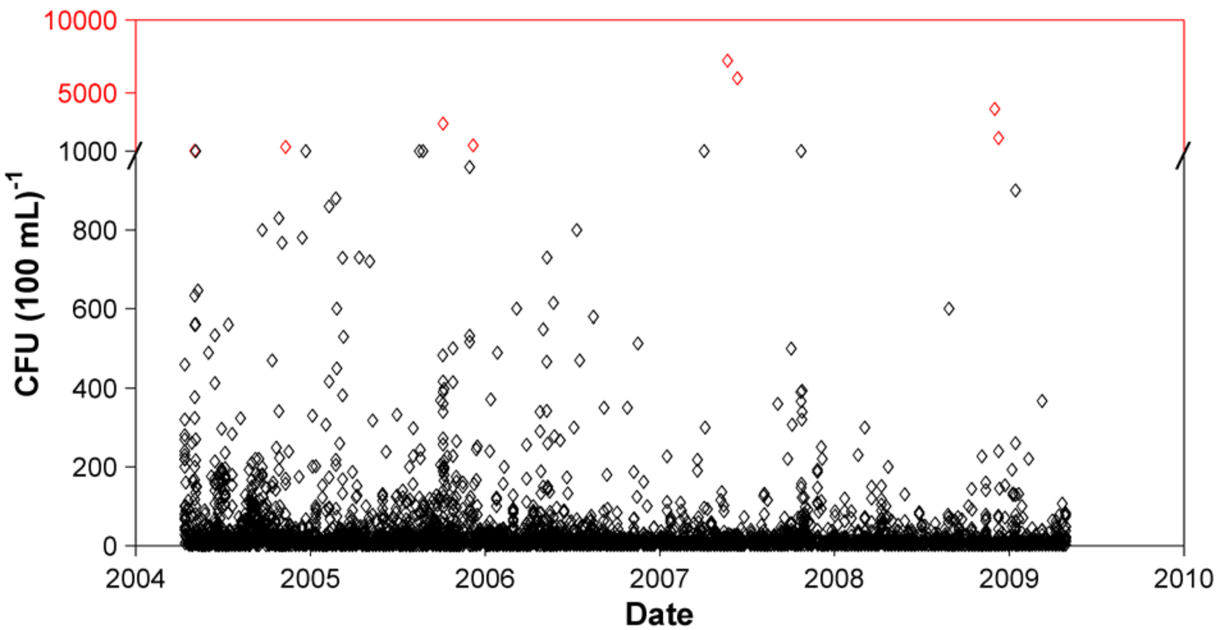

Figure 3-31. *Enterococcus* abundances at Beach sites over the study period. Note the split scale with higher values in red.

Enterococci

Enterococcus abundances are only measured at Beach sites. Annual metrics could be calculated for the period 2005-2008. Annual minimum counts at each site were 1-2 CFU 100 mL^{-1} in all years (not shown). Annual geometric mean counts ranged from 3-5 CFU 100 mL^{-1} in all years to 49 CFU 100 mL^{-1} (measured at a site in 2005) (not shown), with the highest values typically at some St. Simons and Jekyll Island beaches. Annual maximum counts ranged from 18 to 7200 CFU 100 mL^{-1} (Figure 3-63), with both the lowest and highest values measured in 2007. St. Andrews Picnic Area on Jekyll Island and Goulds Inlet on St. Simons Island were typically within the 3 highest values each year.

There is a slight, inconsistent seasonal cycle in *Enterococcus* abundances that explains up to 19% of the variability at some sites (Figure 3-31), so the data were deseasonalized prior to trend analysis. There is also an obvious break in the data in mid-2006, with lower values afterwards, that coincides with both a switch in processing labs and the onset of a drought (Figure 3-1). 14 sites showed slightly decreasing trends over the sampling period (Figure 3-32), but this could be either a real decrease in abundances or an apparent decrease related to the change in processing labs. One site (Kings Ferry on the Ogeechee River) showed a significant increase in *Enterococci* over the sampling period that is likely due to a single high value in late 2008.

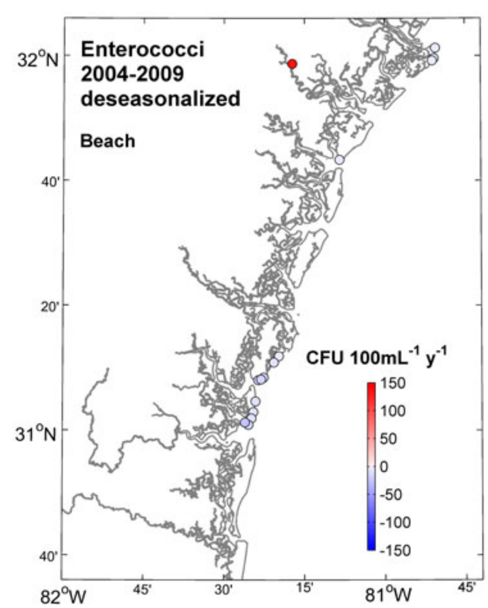

Figure 3-32. Sites that showed a significant change in *Enterococcus* abundances over the study period.

Summary of Trend Analyses

Spatial Patterns

Some parameters maintained consistent spatial patterns that were related to habitat characteristics. Salinities observed across the sampling sites ranged from near 0 in the freshwater portions of rivers to near oceanic salinity (>30) in the lower estuaries and beaches. pH also varied widely, with low values in the blackwater river sites (often <6.5) and highest values at beach sites (near 8). Dissolved oxygen also tended to be consistently lower in blackwater systems, although low values were sometimes found in other habitat types as well. Silicate and nitrate concentrations tended to be higher in river sites, whereas orthophosphate and total dissolved phosphorus were higher in some sounds. Enterococci and turbidity concentrations (measured only at beach sites) were consistently higher at some St. Simons and Jekyll Island beaches. Temperature showed little spatial variation at any given time, while ammonia, nitrite, and fecal coliforms were low at most sites most of the time.

Seasonal Variability

A number of parameters exhibited significant variability over annual cycles. Temperature showed strong annual seasonality, as would be expected (high in summer and low in winter). Salinity had a mild and inconsistent seasonal cycle with lower values in October – April due to increased runoff. Dissolved oxygen had a pronounced seasonal cycle, with lowest concentrations in summer. All nutrients exhibited seasonal trends, but the patterns were inconsistent from year to year.

Temporal Trends

It is difficult to draw generalizations from these analyses as the significant trends were often small changes that occurred at only selected sites. Indeed, after seasonality was accounted for, most sites did not show significant changes over time for most parameters, and sites that did show changes for a given parameter were not necessarily the same as those that were significant for other factors. To further complicate the analysis, the study period varied among parameters. However, the significant trends for a given parameter were usually in the same direction for multiple sites, suggesting that those sites were responding to similar drivers.

There was evidence for some shorter-term trends that appear to be linked to patterns of freshwater input. These can be roughly divided into two time periods during which sites exhibited similar directions and rates of change in parameter values: an early period (generally 2000-2006) and a later period (generally 2004-2009). During the early period, salinity and temperature decreased significantly at several sites; many sites showed decreases in nitrate with a few also showing decreases in other forms of DIN (ammonia and nitrite); and many sites showed significant increases in dissolved oxygen. Silicate showed a mixed picture, with some sites showing significant increases while others showed decreases. There were also changes in orthophosphate and fecal coliform concentrations over this period, but these were extremely small and the fecal coliform changes could be due to a change in methods. These changes occurred over a period in which the weather shifted from a severe drought (which extended from 1998-2002) to several wet years (particularly 2003 and 2005), and some of the observed trends (e.g. increasing rainfall, decreasing salinity, and decreasing temperature) are consistent with these events.

Observations in 2004-2009 were limited to beach stations and so fewer sites and fewer parameters were included in the analysis (e.g. no nutrients were measured). Over this latter period there were significant increases in salinity, turbidity, and pH, and decreases in dissolved oxygen and *Enterococcus* concentrations. (Again, these changes were not necessarily at the same sites.) Temperature showed increases at some sites and decreases at a few others over this period. The observed changes in *Enterococcus* abundances may be due to changes in processing laboratories. Other changes may again be related to the weather during this period, which followed the opposite pattern of the early period as it began with wetter years and ended in a drought (2006-2009).

It should be clear from the above discussion that the trends observed to-date are not necessarily indicative of long-term patterns. It will take additional years of data before we can separate interannual variability from any underlying, longer-term trends.