TRENDS IN SALINITIES AND FLUSHING TIMES OF GEORGIA ESTUARIES

Merryl Alber[1] and Joan E. Sheldon[2]

AUTHORS: [1]Assistant Professor and [2]Research Coordinator, Dept. of Marine Sciences, University of Georgia, Athens, GA 30602.
REFERENCE: Proceedings of the 1999 Georgia Water Resources Conference, held March 30-31, 1999, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

Abstract. From 1973-1992, the Georgia EPD sponsored a monitoring program in which surface salinities were sampled regularly at fixed stations in many of Georgia's estuaries. We used these data to examine changes in the salinities and flushing times of the Savannah, Ogeechee, Altamaha, Satilla, and St. Marys estuaries over the period of record. Water-year average salinities increased slightly over time in four of the five estuaries. When data were smoothed with a three-year moving average (based on fast Fourier analysis of river discharge), the increases in salinity were statistically significant in the Satilla and Savannah River estuaries. We used the measured salinity values to estimate flushing times (average transit time of river water through an estuary) over the period of record. Flushing times averaged 28 d in the Ogeechee, 7 d in the Altamaha, 63 d in the Satilla, and 65 d in the St. Marys, although there was considerable inter-annual variability in these estimates. These results are discussed in light of current proposals to increase surface water withdrawal from the Georgia rivers.

INTRODUCTION

Riverine estuaries are often formed as rivers flow into the coastal ocean. Changes in river discharge can result in fundamental changes in the estuary, as they will affect both the distribution of salt and the amount of time that water spends within the system. These are both characteristics that set the context for all of the biological and chemical processes that occur in the estuary: Much of the vegetation found in estuarine wetlands is adapted to focused salinity ranges, and different stages in the life histories of many estuarine organisms (e.g. striped bass) have specific salinity requirements. Moreover, river water spends more time in estuaries with relatively slow flushing times as compared with those with faster flushing times, therefore providing more time for the processing of material. It is therefore important to understand the impacts of anthropogenic changes in river flow (e.g. dams, water withdrawal, diversions) not only in the context of the river itself but also in terms of the impact that changes in freshwater flow can have on the estuary.

The purpose of this paper is to examine historic patterns of salinity in the five major riverine estuaries of coastal Georgia, the Savannah, Ogeechee, Altamaha, Satilla, and St. Marys. We used data from a monitoring program sponsored by the Georgia Environmental Protection Division (EPD) in which surface salinity was sampled regularly at fixed stations in each estuary. We were interested in determining, first, whether there is evidence for a change in either the amount of river discharge or the salinity of these systems over the period of record; and second, how flushing times have varied over the same period.

METHODS

The Georgia EPD sponsored a monitoring program conducted monthly from September 1973 through December 1982 (Brunswick Junior College, 1975-1983) and then reinstated on a quarterly basis (EPD, 1985-1992). Conductivity at 25°C was measured in surface water samples collected at approximately slack low tide at a station close to the mouth of each of the five Georgia Estuaries (Table 1). Conductivity data were converted to salinity using standard UNESCO equations (Grasshoff *et al.*, 1983).

Flushing times were calculated for each salinity measurement using a modification of the fraction of freshwater method (Dyer, 1973). This method calculates flushing times of an estuary based on the freshwater volume and river discharge. The conversion

Table 1. Sampling Locations from Georgia EPD Coastal Monitoring Programs.

Estuary	Latitude	Longitude
Savannah	32° 01' 16" N	80° 52' 48" W
Ogeechee	31° 52' 15" N	81° 09' 32" W
Altamaha	31° 19' 09" N	81° 19' 30" W
Satilla	30° 57' 52" N	81° 30' 29" W
St. Marys	30° 43' 24" N	81° 30' 58" W

of point measurements of surface salinity to freshwater volume in these estuaries has been described in detail elsewhere (Alber and Sheldon, submitted).

To determine the appropriate number of days of discharge to average for these calculations, we used a date-specific method which assumes that the appropriate time period over which to average discharge is equivalent to the flushing time (Alber and Sheldon, submitted). This allows us to vary the discharge according to measured river flow and gives a better estimate of the actual flushing time for a given date. River discharge is readily available from USGS (Stokes and McFarlane, 1995, 1996; EarthInfo, 1997). We used the most downstream gaging stations in each tributary and corrected for ungaged area in the watershed.

Water year (October through September) river discharges 1968-1997 were analyzed for inter-annual variability using a fast Fourier analysis. This detected cycles of approximately 3 years in each of the 5 rivers. Discharge data cycled in phase (but inversely) with salinity. We therefore applied 3-year moving averages to discharge, salinity, and flushing time estimates to smooth the data before performing linear regressions.

RESULTS

Average annual discharge in each river over the period of the EPD salinity record is plotted in Figure 1, along with 3-year moving averages and trendlines through the 3-year-averaged data. Average annual salinity at the EPD monitoring stations during this period showed strong inter-annual variability (Figure 2). Average annual flushing times that correspond to the salinity data are plotted in Figure 3. Over the entire period, average annual flushing times were 28 ± 9 d (s.d.) in the Ogeechee, 7 ± 2 d in the Altamaha, 63 ± 27 d in the Satilla, and 65 ± 22 d in the St. Marys. Smoothing the data with 3-year moving averages damped some of the variability, although there is evidence that there are longer cycles in the data set (e.g. St. Marys). Slopes and significance values for trendlines fit to 3-year moving averages in all figures are summarized in Table 2.

Taking the estuaries individually, we can make the following observations. In the Savannah, there was a significant decrease in discharge and a concurrent increase in salinity. We could not estimate flushing times for this estuary because of the station location, but we would expect it to have increased, as flushing is largely driven by discharge in these systems (Alber and Sheldon, submitted). In the Ogeechee, there is no evidence for significant changes in discharge, salinity, or flushing time. In the Altamaha, there was a marginally significant decrease in discharge. As expected, this was coupled to a concurrent (although not significant) increase in both salinity and flushing time. In the Satilla, salinity increased significantly and the trends in the other two factors (a decrease in discharge and an increase in flushing time), although not significant, were in keeping with our observations in the other estuaries. Finally, the St. Marys had no significant trends in discharge or salinity but did show a significant increase in flushing time. It is not clear why this is the case, but it may be that reduced variability in flushing times as compared with the other data in the St. Marys enabled a linear trend to be more readily distinguished from inter-annual cycles.

DISCUSSION

There is growing concern among conservationists and local fishermen about the potential impact of upstream water withdrawal on the estuaries of Georgia. There are anecdotal reports that historic changes in salinity have already had an impact on the distribution of plants (e.g. wild rice) and animals (e.g. crabs) in these systems (J. Holland, Georgia Watermen's Assoc., pers. comm.). Although there are very few historic salinity data available, the limited data set used in this work suggests that downstream salinities did in fact show a significant increase in the Savannah and Satilla River estuaries between 1974 and 1992, with increasing

Table 2. Slopes (m), Correlation Coefficients (r^2), and Significance of Slopes (p) for Linear Regressions of 3-Year Moving Averages of Variables Shown in Figures.

Estuary	Variable	m	r^2	p
Savannah	Discharge	-6.460	0.250	0.029
	Salinity	0.205	0.426	0.005
	Flushing Time	-----	-----	-----
Ogeechee	Discharge	0.170	0.001	0.884
	Salinity	-0.065	0.024	0.552
	Flushing Time	0.268	0.062	0.334
Altamaha	Discharge	-6.108	0.202	0.054
	Salinity	0.117	0.064	0.325
	Flushing Time	0.148	0.218	0.059
Satilla	Discharge	-0.592	0.030	0.481
	Salinity	0.305	0.372	0.009
	Flushing Time	1.380	0.161	0.111
St. Marys	Discharge	-0.236	0.039	0.418
	Salinity	0.091	0.042	0.428
	Flushing Time	1.074	0.278	0.030

trends in the Altamaha and St. Marys. These were coupled to significant decreases in the discharge of the larger rivers (Savannah, Altamaha), again with similar trends in the Satilla and the St. Marys. Finally, flushing times increased in four of the estuaries, although only the St. Marys had a significant slope.

If salinity is in fact increasing in some of the estuaries, this could result directly from decreases in surface water discharge. However, several other factors could also affect salt distribution in an estuary, including: 1) changes in geomorphology as the result of natural events (e.g. storms) or human perturbation (e.g. channel dredging); 2) changes in local runoff characteristics due to changes in land use; or 3) changes

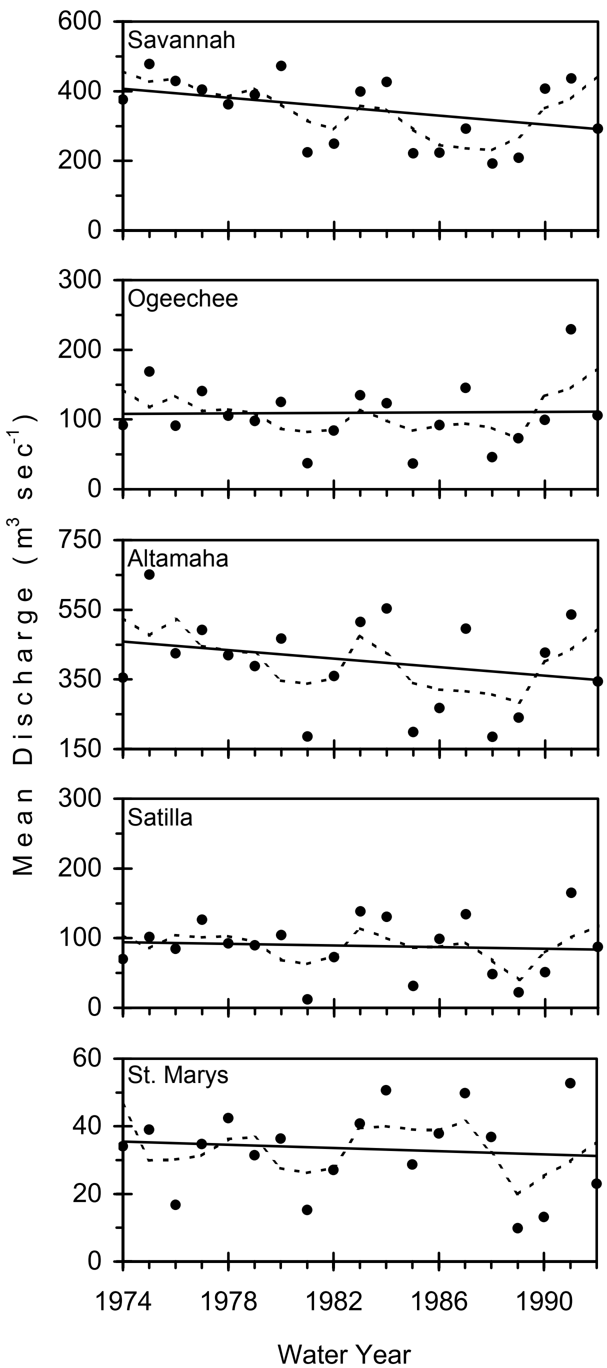

Figure 1. USGS river discharge over 19 years. Dots are water-year averages, dashed lines are 3-year moving averages, and solid lines are linear regressions of 3-year moving averages.

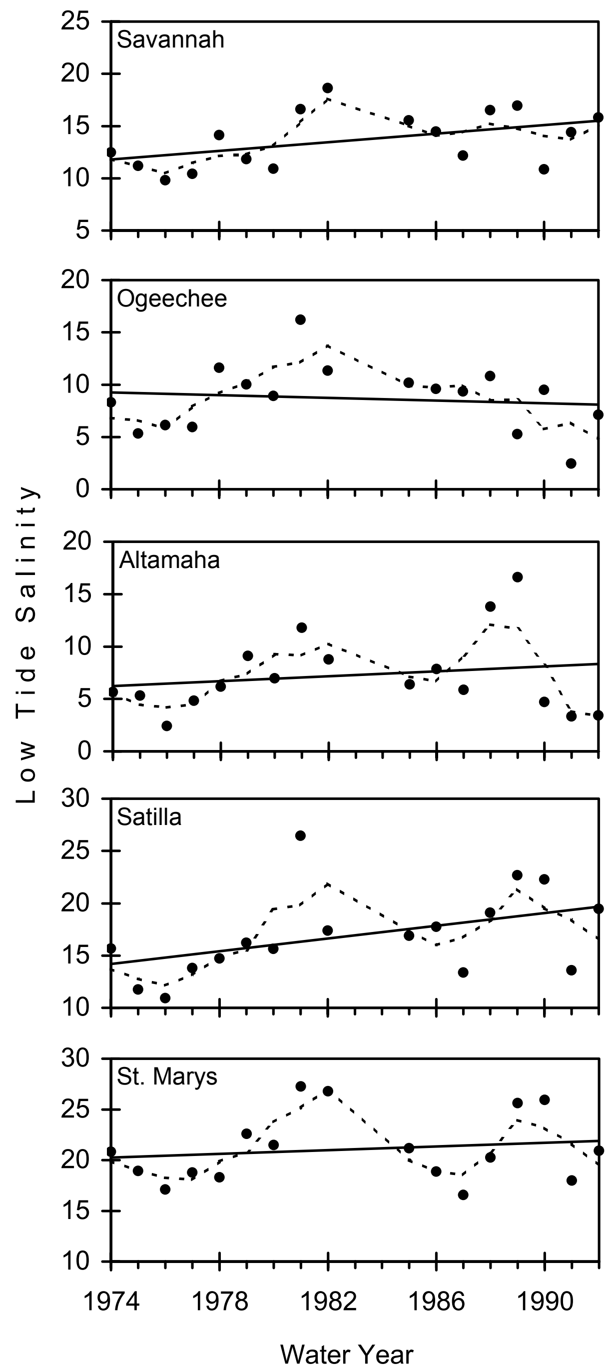

Figure 2. Salinity at EPD stations over 19 years. Dots are water-year averages, dashed lines are 3-year moving averages, and solid lines are linear regressions of 3-year moving averages.

in direct groundwater input, either from the shallow surficial aquifer or as the result of diminished diffuse upward leakage from the deeper Floridan aquifer. To our knowledge, this latter possibility has not been explored. Finally, observed increases in salinity could be the result of large-scale changes such as sea level rise or short-term increases embedded in a larger climatological cycle of rainfall and drought. The data we have in hand cannot be used to distinguish among these possibilities.

We should caution that the salinities examined here were limited to only one station per estuary, and the data set is not long enough to filter out long-term cycles. However, the trends are suggestive and consistent with anecdotal reports that salinity has increased in the estuaries of Georgia. Currently, there is inadequate monitoring of salinity in these systems: Georgia EPD has changed their program to sample each estuary every 5 years on a rotating basis, with quarterly samples taken during the sampling year. We recommend that a long-term salinity monitoring program be put into place, with vertical salinity profiles measured at least monthly at fixed locations at a consistent stage of the tide. It would be useful to measure several stations within each estuary so that local changes can be separated from larger-scale trends. It is important to collect this type of salinity information, because only long-term data sets will enable us to understand long-term trends in salinities and flushing times in estuaries.

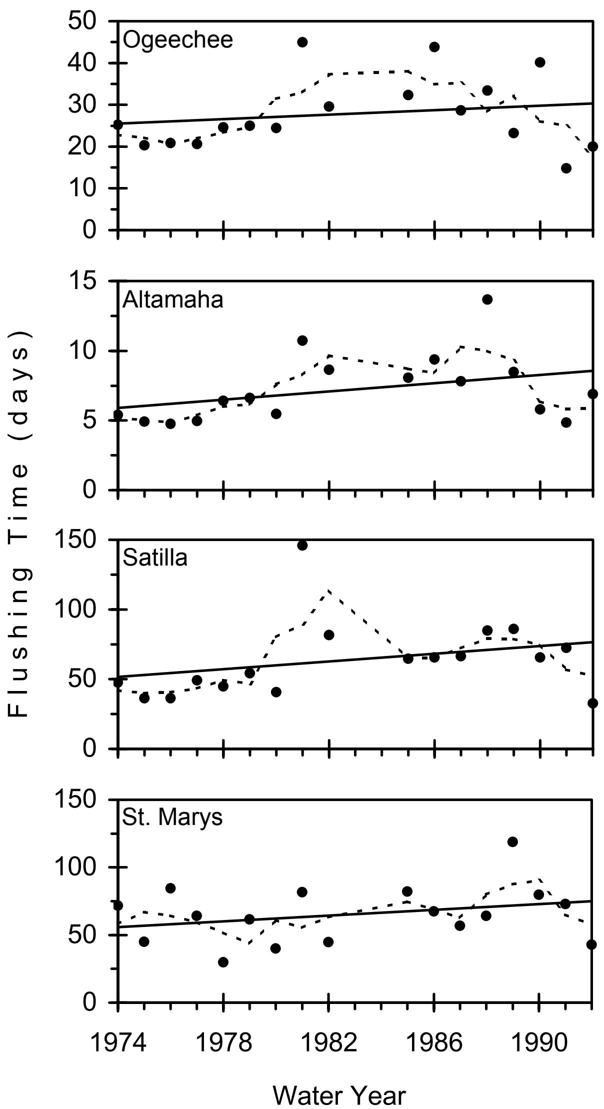

Figure 3. Flushing times in Georgia estuaries over 19 years. Dots are water-year averages, dashed lines are 3-year moving averages, and solid lines are linear regressions of 3-year moving averages.

ACKNOWLEDGMENTS

We thank the Georgia Environmental Protection Division and Eugene Keferl of Coastal Georgia Community College for providing data reports, and Changsheng Chen for help with Fourier analysis. Financial support was provided by NSF Land-Margin Ecosystems Research Program Grant No. DEB-9412089 and by the Georgia Coastal Management Program and the Office of Ocean and Coastal Resource Management through the Coastal Zone Management Act of 1972, NOAA Award NA87OZ0115.

LITERATURE CITED

Alber, M. and J.E. Sheldon. Use of a date-specific method to examine variability in the flushing times of Georgia Estuaries. *Estuarine, Coastal and Shelf Science*, submitted.

Brunswick Junior College, 1975-1983. Water quality investigations of estuaries of Georgia. Reports submitted to Environmental Protection Division, Georgia Department of Natural Resources.

Dyer, K.R., 1973. *Estuaries: A Physical Introduction*. John Wiley and Sons, New York, 140 p.

EarthInfo, Inc., 1997. EarthInfo CD^2 USGS Daily Values. Boulder, CO.

Environmental Protection Division, Georgia Department of Natural Resources, 1985-1992. Coastal Monitoring Project Annual Reports.

Grasshoff, K., M. Ehrhardt and K. Kremling, eds., 1983. *Methods of Seawater Analysis: Second, revised and extended edition*. Verlag Chemie, Weinheim, 419 p.

Stokes, W.R., III and R.D. McFarlane, 1995. Water resources data, Georgia, water year 1995. U.S. Geological Survey Water-Data Report GA-95-1.

Stokes, W.R., III and R.D. McFarlane, 1996. Water resources data, Georgia, water year 1996. U.S. Geological Survey Water-Data Report GA-96-1.