SALINITY RESPONSE OF THE SATILLA RIVER ESTUARY TO SEASONAL CHANGES IN FRESHWATER DISCHARGE

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Abstract. Georgia's vast brackish water landscape is maintained, to a large extent, by the hydrostatic pressure of freshwater discharges which keep the sea out of these areas. The salinity regime throughout this landscape responds to fluctuations in discharge. We describe the salinity regime in the Satilla River Estuary based on two intensive field campaigns in 1999 (20 Jan - 20 Mar and 9 Sept - 19 Oct). River discharge varied from almost 150 m^3s^{-1} in February (twice the average) due to a single rain event in late January, to below 10 m^3s^{-1} in May and June, after which it remained relatively low. The single discharge event resulted in large decreases in salinity throughout the estuary that lasted for about one week. (Salinity in Crows Harbor Reach was between 12-14 practical salinity units (PSU) on 20 Jan but fell to less than 2 PSU by 5 Feb) After early February, salinity slowly increased and had returned to near January levels by mid-April. Thus, during the ramp-up of river discharge in late January, the estuary flushed out much of its salt within about 20 days, and it took more than 2 months (70 days) to return to the salinity levels observed in January. The events analyzed here are described within the context of a series of salinity surveys over the course of 1999 and 2000, which should enable managers to gain insight into the interactions between river discharge, salinity structure, and flushing times in this system.

INTRODUCTION

The estuary of the Satilla River (Fig. 1) receives drainage from a coastal plain watershed with an area of 9,140 km^2. The Satilla River has an average annual discharge rate of less than 100 m^3s^{-1}. Tidal range varies from 2 to 3 meters at neap and spring tide, respectively. The dissipation of tidal energy is the primary agent that mixes river water with seawater in the estuary (Harleman, 1966).

Recent events have provided a unique opportunity to study the response of the salinity regime in this system to a single peak in discharge in February followed by a steady decrease over the following 4 months (Fig. 2a). Provisional discharge data for Atkinson, Georgia (obtained from USGS) show that Satilla River discharge varied from almost 150 m^3s^{-1} in February 1999 (twice the average) to below 10 m^3s^{-1} in May and June 1999 (Fig. 2a). Note that the discharge rates presented here are slightly higher than those recorded at the gauging station, as they have been corrected for the ungauged area of the estuary. We used this isolated event to evaluate the salinity regime of the estuary in terms of its response to the large increase in river discharge in February, as well as its recovery to pre-event levels over the next 4 months.

We also analyzed a more extensive series of observations of salinity in this system, which included the drought of the summer of 2000, to look at how the salinity structure varies over time. Finally, these data were used to estimate flushing times in the Satilla River Estuary, and to evaluate the dependence of flushing times on both river discharge and salinity structure.

METHODS

We conducted a series of field observations in the

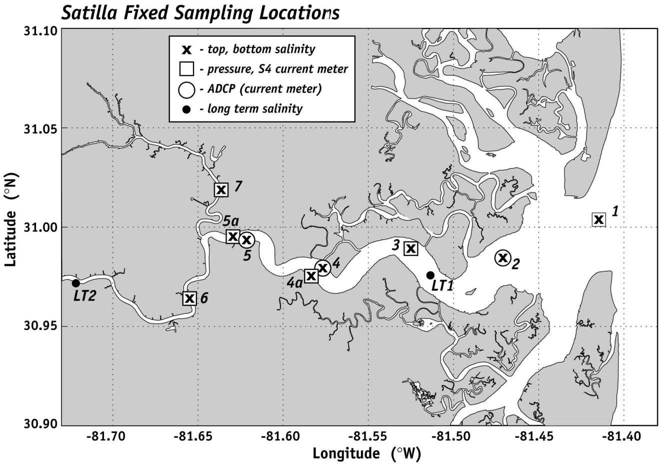

Fig. 1. Satilla River sampling locations during 1999.

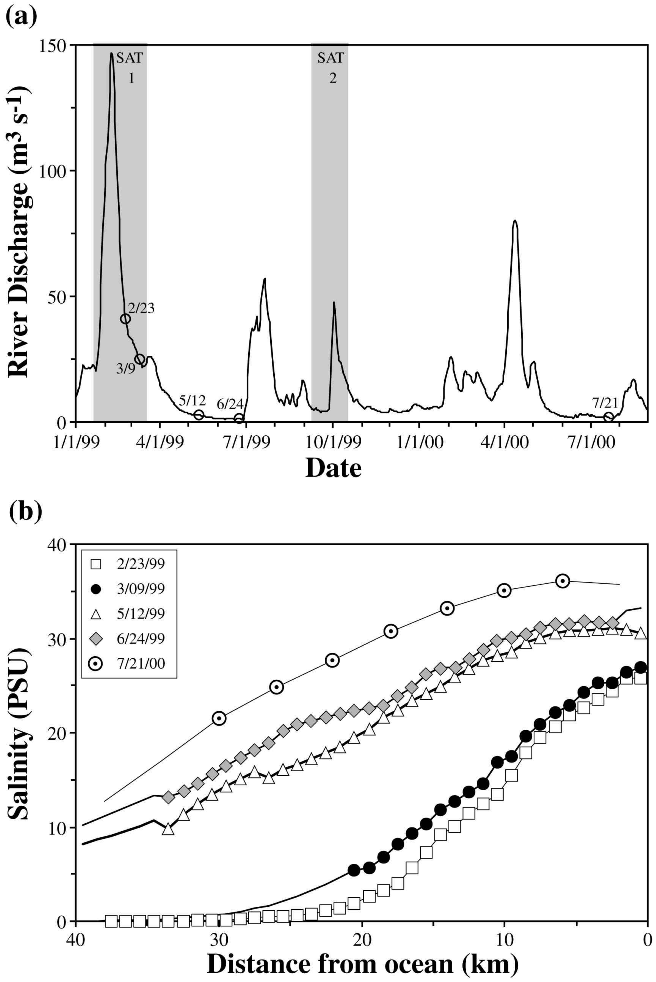

Fig. 2. (a) Satilla River discharge into the estuary, 1/1/99-8/31/00. Dates of salinity transects (below) are circled; dates of SAT1 and SAT2 instrument deployments are shaded. (b) Salinity distributions in the Satilla River estuary at mid-tide. All transects represent surface salinities except 7/21/00, which is average water column salinity.

estuary of the Satilla River during 1999 and 2000. From 20 Jan to 20 Mar (SAT1) and from 9 Sept to 19 Oct (SAT2), we conducted intensive field campaigns during which we placed instruments that continuously recorded salinity, temperature and bottom pressure at six monitoring stations in the estuary (Fig. 1).

These data were complemented by surveys conducted along the central axis of the estuary throughout 1999 as well as in July 2000. In 1999, surface salinity was measured continuously during mid-tide using a flow-through CTD (Sea-Bird Electronics SBE-21) mounted on our research vessel. An examination of vertical salinity profiles in the Satilla revealed that the salinity usually changes less than 1-2 PSU from top to bottom (not shown). Therefore, the surface salinities presented here can be used as estimates of average water column salinities. In July 2000, salinity profiles were taken every 4 km at both high and low water, and these data were used to calculate average water column salinity. In this case, the average of the high/low pairs was used to represent mid-tide conditions.

The freshwater volume of the estuary was estimated for each set of salinity observations, as follows. Where the salinity range sampled did not cover the estuary from the mouth to 0 PSU, logistic functions were fit to the data and then extrapolated to fill this range. Salinity was converted to fraction of freshwater using either 35 or the highest observed salinity (> 35) as the seawater end-member. Freshwater volume was then obtained by multiplying the fraction of freshwater by estuarine volume. The freshwater volumes calculated in this manner were combined with the discharge record to determine date-specific flushing times for each observation according to the methods of Alber and Sheldon (1999).

INTENSIVE MONITORING STATIONS

The evolution of salinity over the year (Fig. 3) is shown by data obtained at all of the monitoring stations. The first set of lines comes from the monitoring stations during SAT1 while the second set comes from SAT2. We used the data at LT1 (Fig. 1). to tie together the SAT1 and SAT2 periods.

The estuarine mixing zone was found to lie downstream of Crows Harbor Reach (station 5) for the period from late January until late March, but this zone had moved far upstream of Crows Harbor Reach during late summer. We therefore added monitoring station LT2 at Woodbine (Fig. 1) for SAT2.

The rapid increase in river discharge was reflected at all locations by large decreases in salinity near 4 Feb that lasted until 9 Feb (Fig. 3). The rather dramatic effect of the increasing river discharge is clearly shown by the salinity distribution at low water along the axis of the estuary. Low water salinity was between 12-14 PSU at Station 5 (Fig. 1) on 20 Jan but fell to less than 2 PSU by 5 Feb (Fig. 4). The mixing zone, defined by a median salinity of 15 PSU, had shifted about 10 km downstream.

Salinity increased more or less uniformly after early February in keeping with the gradual decrease in discharge. This was reflected in the slow increase to near January salinity levels by mid-April (Fig. 3). Thus, during the increase of river discharge in late January, the estuary flushed out much of its salt within about 20

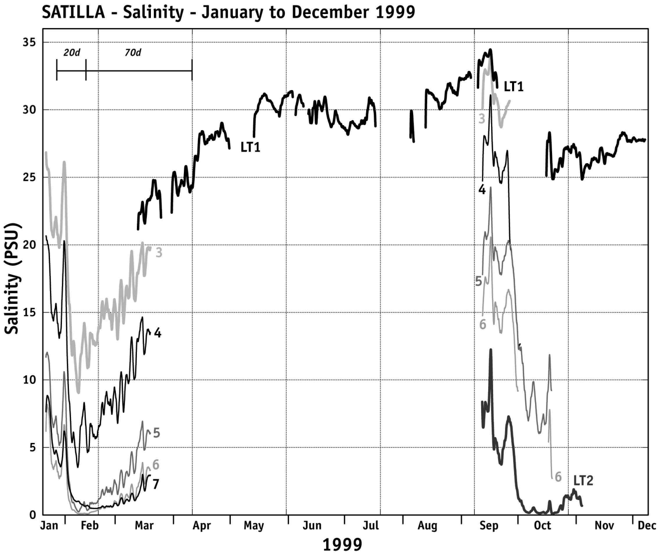

Fig. 3. Salinity measured throughout the Satilla River estuary during 1999. Tidal fluctuations have been removed by applying a low-pass digital filter to the original data. The number adjacent to the lines denote sampling locations in Figure 1. Response times of the estuary discussed in the text are shown in the upper left of the figure.

days. However, it took more than 2 months (70 days) for the estuary to return to levels observed in January.

A second discharge event occurred in early September due to heavy rain related to Hurricane Floyd (Fig. 3). This rain did not lower the salinity in the estuary to the levels observed in February, and we did not record data long enough to determine the recovery time from this event.

SURVEYS

There was a large variation in the salinity regime of the Satilla River Estuary over the course of our observations (Fig. 2b). Salinities throughout the estuary after the high discharge event (February 1999) were the lowest observed, but they had increased by May, as described above. However, salinities increased even further as the drought continued, and those observed in July 2000 were near record levels.

The freshwater volume of the estuary also varied in response to changes in discharge (Table 1). On 2/23/99, approximately 3 weeks after the large discharge event, the freshwater volume was still fairly high (230 x 10^6 m^3). By June 1999 it had fallen to less than half the level observed in February, and by July 2000, as the drought continued, it was 60% below the average volume of 194 x 10^6 m^3 estimated for this system (Alber and Sheldon 1999).

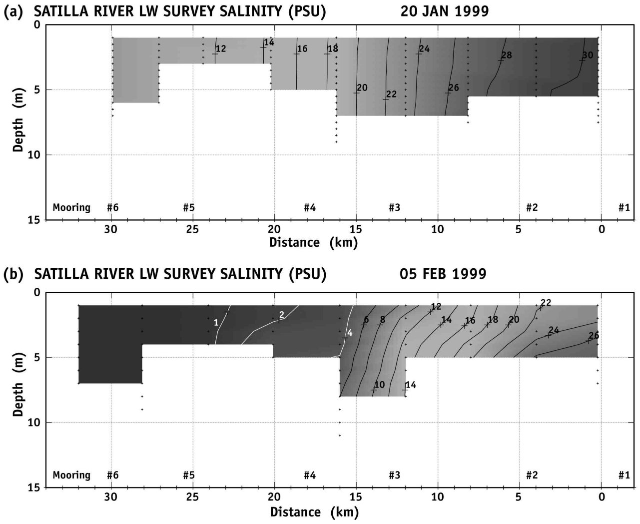

Fig. 4. Distribution of salinity as a function of depth along the axis of the Satilla River estuary. (a) 20 January 1999; (b) 5 February 1999.

The flushing time of an estuary, the average amount of time fresh water spends in the system, is equal to the freshwater volume divided by the discharge. A summary of flushing time and flushing-associated discharge (discharge averaged over the period of the flushing time) estimates for all observation dates is given in Table 1. As can be seen, flushing times ranged from 31 to 119 d. These flushing time estimates are all within the range of the 9-year, monthly Georgia EPD data set examined by Alber and Sheldon (1999).

It is interesting to note that the lowest flushing-associated discharge, in July 2000, did not correspond to the longest flushing time. This is a result of the two competing effects that changes in river discharge can have on estuarine flushing: although a decrease in river flow can generally be expected to result in an increase in flushing time (slower flushing), it will also serve to decrease freshwater volume. Since the flushing time is dependent on both factors (it is the quotient of freshwater volume and discharge), a reduction in freshwater volume acts to moderate the effect of decreased discharge on flushing time. As the drought continued through summer 2000, river flows were consistently low long enough that the freshwater volume dropped to the point where it had an ameliorating effect on flushing time. This type of information helps us to better understand the response of an estuary to prolonged decreases in flow.

Table 1. Estimated flushing times and related calculations for dates shown in Figure 2.

Date	Freshwater Volume (10^6 m^3)	Flushing Time (days)	Average Prior Discharge (m^{3}s^{-1})
02/23/99	230	31	86
03/09/99	216	35	71
05/12/99	125	82	18
06/24/99	107	119	10
07/21/00	78	96	9

DISCUSSION

The results reported here show how changeable the salinity structure of an estuary can be. Over the course of our observations, freshwater discharge varied 8-fold, with consequent impacts on the salinity regime of the Satilla River Estuary. The salinities observed during the surveys shifted significantly, with the approximate location of 15 PSU varying from approximately 10 km from the mouth during high discharge to further than 35 km during low flow (Fig. 2b). Thus, the estuary and its habitats experienced large changes in the salinity regime over a period of a few months.

The observed changes in the salinity structure of the estuary had consequent impacts on both freshwater volume and flushing times (Table 1). However, it should be noted that the freshwater volumes and flushing times reported here are approximations only and represent rough estimates that can be calculated when few data are available. These calculations provide managers with information regarding the response of the estuary to changes in discharge and are easy to apply under a variety of circumstances. However, the detailed observations gathered from the monitoring stations will enable us to develop a more sophisticated, predictive model of salinity in this system, and this work is ongoing.

The intensive monitoring results demonstrate that the salinity regime of the estuary responds almost immediately to changes in discharge. Discharge tends to increase sharply at the beginning of a rain event. However, it falls off more gradually as the result of freshwater storage in the watershed. This can be seen in Fig. 2a, where discharge increased sharply within 2 weeks but took more than 2 months to come back down. The discharge increase caused salinity in the estuary to fall quickly at the beginning of February, a few days before discharge had peaked, and increase more slowly over the next few months. These results suggest that salinity in estuaries like the Satilla will tend to decrease rapidly and increase more slowly in response to storm events.

The southeastern United States is in the midst of a drought that began in 1997. It is not surprising that the abnormally low discharge of the Satilla River has lowered the hydrostatic pressure so that seawater can be transported farther inland. The salinity values observed in the summer of 1999 were extremely high, and reached almost 35 PSU approximately 10 km from the ocean. This is within 1 PSU of oceanic values found near the Gulf Stream. The large intrusion of salt into the estuary pushed the mixing zone far inland, such that values reached higher than 10 PSU at Woodbine (Fig. 3). Although we do not have complete monitoring data from July 2000, the survey data suggest that saltwater intruded even further upstream at that time (Fig. 2b). We do not know if salt intrusion has reached record levels, but to our knowledge, the high salinities observed in this study this far inland have not been recorded within the last two decades. However, Brooks and McConnell (1983) reported zero salinity on the Satilla River as far inland as 95 km (52 miles) in 1981.

We suspect that when the southeastern United States recovers from the present drought, the freshwater pressure needed to keep seawater intrusion in abeyance should increase to more normal levels. This should provide more favorable brackish conditions in the estuary compared to those prevalent in the late 1990s.

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