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Bly Creek Ecosystem Study—Inorganic Sediment Transport Within an Euhaline Salt Marsh Basin, North Inlet, South Carolina

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ABSTRACT

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Inorganic suspended sediment (ISS) concentrations in Bly Creek, a subcomponent of North Inlet estuary in South Carolina, varied seasonally from 6.5 mg l^{-1} in winter to 85.1 mg l^{-1} in summer. A multiple regression model based on envirionmental parameters and ISS flux estimates from 34 tidal cycles equally distributed throughout the time period June 20, 1983 to June 19, 1984 produced an estimated input of 9.76×10^5 kg y^{-1} (S.E. = 5.95×10^5 kg y^{-1}). Input of ISS to the Bly Creek basin by freshwater streams was negligible.
Within the basin, the salt marsh was a statistically significant sink for ISS while the oyster reef was a statistically insignificant sink. Although the annual amount of ISS removed by the salt marsh was significant, it was less than the standard error of the ISS flux into the basin. The amount of ISS removed by the marsh appears sufficient to maintain its elevation in relation to current local sea level rise.

ADDITIONAL INDEX WORDS: *Salt marsh basin, nutrient cycling, inorganic sediment, tidal flux, streamwater, vegetated marsh, oyster reef.*

INTRODUCTION

Salt marshes along the east coast of the United States have been shown to accumulate inorganic material at rates high enough to keep pace with the local rise in sea level (REDFIELD, 1972; HARRISON & BLOOM, 1974; ARMENTANO & WOODWELL, 1975; MUZYKA, 1976; FLESSA *et al.*, 1977; RICHARD, 1978; LORD, 1980). These marshes are part of much larger systems, estuaries, which also include oyster reefs and subtidal benthic habitats. The observed annual inorganic accretion of coastal marshes must be accounted for by the net inorganic sediment transport per tidal cycle through the tidal creeks connecting the salt marsh with adjacent water bodies. However, most of the sediment transport studies conducted in tidal creeks have shown an export of total suspended sediment from the tidal creek (SETTLEMYRE & GARDNER, 1978; WARD, 1981; DAME *et al.*, 1986) with the inorganic suspended sediment (ISS) transport direction being variable. The tendency for these tidal creeks to export particulates has been explained by time-velocity asymmetry and discharge (BOON, 1975), whereas large ISS imports into these systems are thought to be caused by severe storms which influence particulate resuspension and transport (SETTLEMYRE & GARDNER, 1978; WARD, 1981; JORDAN & VALIELA, 1983; STUMPH, 1983; JORDAN & CORRELL, 1986).

One aspect of the "Bly Creek Ecosystem Study" was to evaluate the transport of ISS within and through a salt-marsh dominated basin and thereby gain a better understanding of the processes controlling its movement. This project evaluated simultaneously (1) the major system fluxes (tidal and discharge) and (2) the contribution of the major subsystems (salt marsh, oyster reef, and tidal creek) to material

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transport. This work will describe the system-level fluxes of inorganic suspended sediment. These results will be integrated with those from salt marsh flume studies (WOLAVER *et al.*, 1985; WOLAVER *et al.*, 1987) and the oyster reef.

METHODS

To study ISS exchange between the Bly Creek basin and the adjacent water body, material flux measurements were made at a transect across the only tidal creek within the system. The Bly Creek transect (BCT) was 53 m wide and averaged 1.33 m deep at mean tide height, and was located near the southern end of the Bly Creek basin, North Inlet, South Carolina (Figure 1). The vegetation within the basin is dominated by the various growth forms of *Spartina alterniflora*. The area of the basin is 660,000 m^2 of which 531,808 m^2 are covered by salt marsh, and 128,192 m^2 by tidal creek channels including 1,000 m^2 of oyster reef community.

ISS concentration and water velocity measurements were made at the BCT during 34 complete tidal cycles, every 11.8 days, between June 19, 1983 and June 20, 1984. This sampling schedule provided a representative range of lunar and diel periods over each season. For each of the 34 tidal cycles, water samples were taken at two depths (near bottom and mid-water column) once every hour during the tidal cycle, starting at low tide. These samples were collected from one station in the middle of the BCT. All water samples were placed immediately on ice in the field and were returned to the chemistry laboratory for processing within 2 h of collection. Two hundred milliliters of the original sample were filtered through pre-weighed GF/C filters. These filters were heated in an oven at 60°C and stored for later ISS analysis. For each sample, ISS concentrations were obtained by subtracting the weight of the filter plus sediment after it had been heated in a muffle furnace for 4–5 hours (450°C) from the weight previous to this procedure.

Water velocities were measured at the same station and times as the collection of water samples but with a depth increment of 0.5 m from the tidal creek bottom to the water surface. These measurements were made with current crosses (KJERFVE, 1982), and flow directions were estimated using a surface streamer and compass. Instantaneous water discharge estimates through the BCT were made by decomposing the velocity vectors into an along-channel u-flow component (positive for ebb) and an across channel v-flow component (positive toward northern bank) (KJERFVE *et al.*, 1981; KJERFVE & WOLAVER, 1988). A cubic spline was fitted to each individual vertical u-component velocity profile and 11 equidistant velocity values were interpolated. Each velocity was cross multiplied by the transect width and time-varying depth; the resulting product was summed over the total cross section to yield instantaneous discharge.

Instantaneous mass fluxes (IMF) were calculated by first spline-fitting the ISS values similarly to the procedure used for the velocities. Then 11 interpolated ISS values were cross multiplied with the appropriate velocity, station width, and depth and summed over the cross section. IMF values for each sample period were then integrated over time to obtain the net flux per tidal cycle. This integration was accomplished by fitting the following sine-cosine model to the IMF values:

$$\mathrm{IMF}(t) = \sum_{r=1}^{5} \alpha_r \sin(2\mathrm{IT}\ t/P_r) + \sum_{r=1}^{5} \beta_r \cos(2\mathrm{IT}\ t/P_r) + \epsilon$$

In fitting the model, periodicites of major tidal constituents (K1, M2, M4, M6) were selected with the corresponding periods P_1 = 24.86 h, P_2 = 12.42 h, P_3 = 6.21 h, P_4 = 3.11 h, and P_5 = 4.14 h. In addition, t denotes time in hours from an arbitrary starting time; $\alpha_1 \ldots \alpha_5$, $\beta_1 \ldots \beta_5$ are unknown parameters; and ϵ is a random error term. The model is similar to that used by CHRZANOWSKI *et al.* (1982) and WOLAVER *et al.* (1985).

To estimate the seasonal and annual exchange of material through the BCT, a set of 24 predictor variables (Table 1) was measured for each tidal cycle throughout the sampling year. Annual flux for the time period between June 19, 1983 and June 20, 1984 was estimated. During this time, there were 707 tidal cycles of which 34 were sampled. To obtain monthly and annual flux estimates an initial stepwise regression was performed. This regression was used to select a smaller set (<24) of predictor

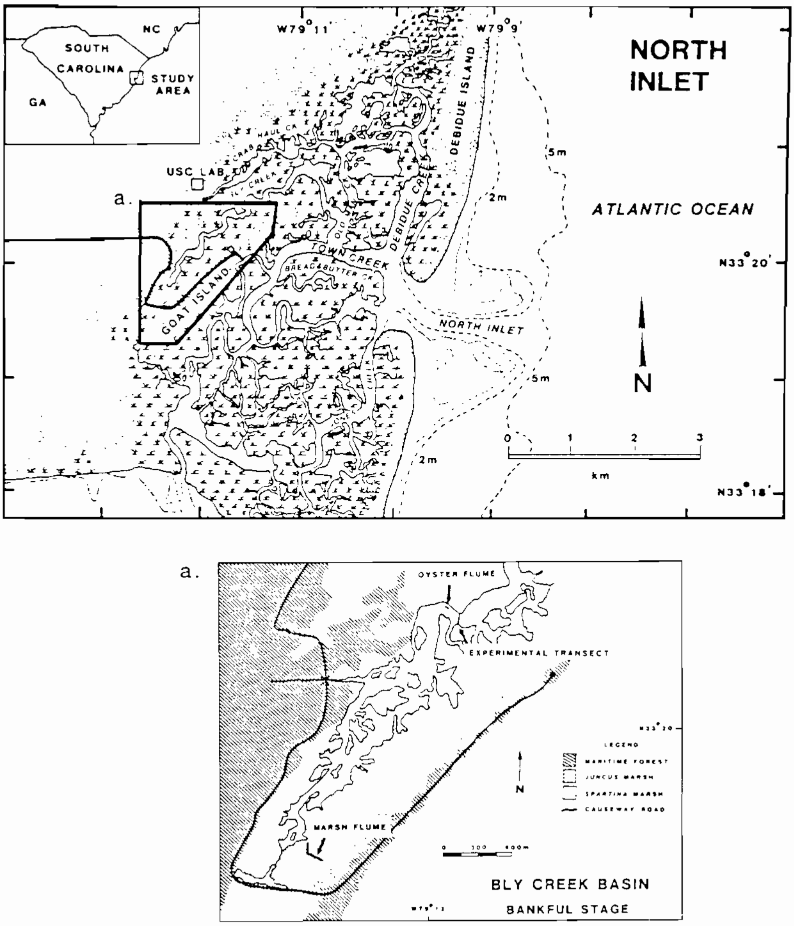

Figure 1. Site Map.

variables to be used in modelling the net flux per cycle for each constituent. This subset of predictor variables was further refined by running all possible regressions and selecting the model that produced the minimum value of Mallows Cp statistic (MALLOWS, 1973). This model was used to form the regression estimate of the net flux on a monthly and annual basis. The standard errors associated with the annual net flux estimates take into account the variability in net flux per cycle estimates as well as the error in estimating the annual net flux from the 34 sampled cycles.

In this study, the purpose of the regression model is to provide the best estimate of the annual flux of a constituent. It is being used to produce a statistical estimator of the annual net flux which has a smaller standard error than the traditional method of averaging the individual tidal cycle estimates and multiplying by the total number of tidal cycles. The variability that the regression explains reduces the standard error of the estimate of annual flux. It is desirable to have high r-square values in this setting but it does not invalidate the approach if you do not have them. It is not the purpose of these regression models to develop a complex understanding of the innerworkings of the estuary. While that is a very important question and might be addressed through

Table 1. *Predictor variables used in stepwise regression analysis.*

Variable Name	Description
TIDE	Maximum tidal height
L1 TIDE	Maximum tidal height on previous cycle
L2 TIDE	Maximum tidal height on second previous cycle
RAIN	Rainfall on current cycle
L1 RAIN	Rainfall on previous cycle
L2 RAIN	Rainfall on second previous cycle
R13	Sum of rainfall (> 1.27 cm/event) during tidal exposure over preceding 8 cycles
R14	Sum of rainfall (> 0.25 cm/event) over preceding 8 cycles
BIO	Biomass of live *Spartina* at creekside
DERBIO	Derivative of BIO with respect to time
FRESHWTR	Freshwater flow during current cycle
L1 FRESH	Freshwater flow during previous cycle
L2 FRESH	Freshwater flow during second previous cycle
AWTMP	Water temperature—18.47[a]
WTMP2	Square of water temperature
LIGHT	Proportion of tidal cycle in daylight
LIGHT2	Square of Light
ALTWT	AWTMP x (Light—0.5)[b]
AWIND	Average wind speed—8.76[c]
AWNDWT	AWIND x AWTMP
AXWIND	Maximum wind speed
AIRTMP	Air temperature less water temperature
L100WT	Water temperature for the 100th previous cycle
L100WT2	Square of L100WT

[a]18.47 = average of water temperatures for sampled cycles
[b](LIGHT-0.5) = average of a variable LIGHT for sampled cycles
[c]8.76 = average of average wind speeds for the sample cycles

regression techniques, one would need many more than 34 tidal cycle samples to distinguish the effects of the 24 predictor variables.

Flume and tunnel studies were also conducted on the vegetated marsh and the oyster reef community, respectively, to evaluate ISS transport. A flume was constructed across a 140 m transect of *Spartina alterniflora* marsh near the upper end of the Bly Creek basin to study sediment exchange between the salt marsh and the adjacent tidal creek during tidal inundation. The flume consisted of two parallel walls, 2 m apart, which channeled tidal water from the edge of the tidal creek across the tall, medium, and short *Spartina* zones. The flume walls were removed after each sampling period to prevent long-term effects from shading, sediment scouring and accumulation. For each of the 34 tidal cycles, water samples and tidal height measurements were taken at a station near the mouth of the flume adjacent to the tidal creek. The tidal height measurements were combined with a knowledge of marsh topography to estimate the discharge of water onto and off of the marsh surface. Instantaneous discharge estimates were cross multipled with ISS concentrations to obtain instantaneous mass fluxes (IMF). As at the transect, IMFs were integrated over a complete tidal cycle to obtain the net material transport. Details of the flume design along with a complete description of the modelling procedure which produced the water discharge and material flux calculations within the marsh flume are provided in WOLAVER *et al.* (1985). A V-notched weir, similar to that implemented by GARDNER (1975), was used to study sediment export from the vegetated marsh during low tide exposure. The inorganic sediment flux results from the flume and weir studies are presented by WOLAVER *et al.* 1988.

A portable 10-m long plexiglass tunnel which was composed of eight sections was used to determine the import or export of sediments from the oyster reef community. The tunnel was deployed at low tide and removed at the next low tide. Water velocities and material concentrations were measured at each end of the tunnel. Because there was continuity of water flow through the tunnel, water flux was estimated from the velocity measurements. The difference in material concentrations between input and output ends of the tunnel was multiplied by water discharge to yield instantaneous mass transport (IMF). The IMF values were integrated over the flood and ebb tides separately in order to arrive at net material transport values. Details of the flume design and discharge and the material transport calculations are available in DAME *et al.* (1985) and DAME *et al.* (submitted).

RESULTS AND DISCUSSION

Tidal Water Flux

The most important aspect of any study of material flux through a tidal creek is the water budget due to its strong influence on material transport. The regression estimate for water discharge out of the Bly Creek basin during a tidal cycle was not statistically significantly different from zero.

The estimated yearly net discharge of water was 1.15×10^7 m^3, with an estimated standard error of 8.01×10^6 m^3. WILLIAMS (*unpubl. data*) observed annual inputs of water into the Bly Creek basin due to streamflow, groundwater flow and rainfall an order of magnitude lower (1.7×10^6 m^3). In addition, EISER and KJERFVE (1986) showed water storage due to sheetflow to be 2,500 m^3 per tidal cycle (1.8×10^6 m^3 y^{-1}) or again an order of magnitude lower than the export predicted by the model. Thus the net export of water from the Bly Creek basin is small, less than 2.4% of the water in the basin at basinfull stage, and unpredictable at the cross section at our level of precision.

Tidal Creek ISS Flux

Mean tidal ISS concentrations varied between 6.5 and 85.1 mg l^{-1}, with the highest concentrations observed during the summer months (Figure 2a). These data show a seasonal cycle and may be the result of bioturbation and resuspension (WARD, 1981). The highest ISS concentration was found on 8/25/84 just after a major storm passed through North Inlet (3.4 cm rain during the previous low tide), suggesting surface runoff from the salt marsh as a major contributing factor.

The net ISS flux data (Figure 2b) suggest that there was a general import into the basin during late summer and fall while during the winter and spring no particular trend was observed. In addition, the largest ISS fluxes, regardless of direction, were found during the summer and fall when the highest ISS concentrations were observed within the tidal water. The regression estimates of monthly fluxes reflect these trends as well (Table 2). The model for ISS flux on a tidal cycle in Bly Creek is

$$ISS_{BC} = 3.69 \times 10^4 - 1.68 \times 10^2(TIDE) - 7.25 \times 10^3 (L1RAIN) - 8.67 \times 10^2 (R13) - 4.84 \times 10^2 (AWIND) + 3.06 \times 10^2 (AIRWTR)$$
$$(r^2 = 0.51)$$

The regression estimate for Bly Creek ISS flux was not significantly different from zero, although an ISS import of 9.75×10^5 kg was estimated, with a standard error of 5.95×10^5 kg.

Salt Marsh ISS Flux

Within the Bly Creek basin, the salt marsh was shown to be a statistically significant ISS sink during tidal inundation (WOLAVER *et al.*,

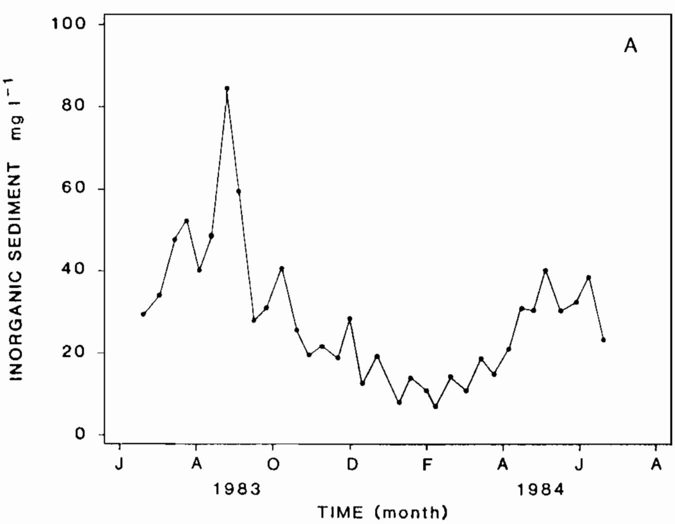

Figure 2. Mean tidal ISS concentrations as a function of time of year (export +, import −).

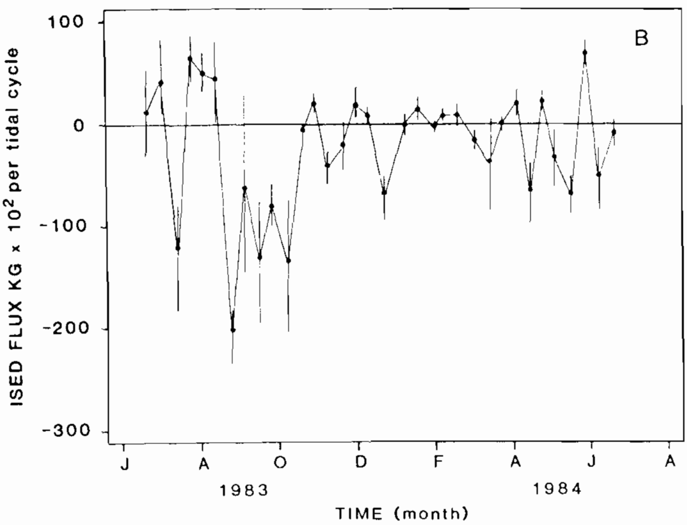

Figure 2b. Net ISS flux as a function of time of year (export +, import −).

Table 2. *Monthly and annual net ISS flux estimates through the Bly Creek transect (kg (month)$^{-1}$*; + export, -import).

Date (1983–1984)	# Tidal Cycles	H_2O (m^3[month]$^{-1}$)	ISS
6/19– 7/18	58	2.8 x 10^5	− 1.21 x 10^5
7/19– 8/18	60	3.1 x 10^5	− 1.98 x 10^5
8/19– 9/18	60	− 1.5 x 10^5	− 1.37 x 10^5
9/19–10/18	58	7.1 x 10^5	− 2.27 x 10^5
10/19–11/18	59	1.2 x 10^6	− 1.98 x 10^5
11/19–12/18	58	1.3 x 10^6	4.08 x 10^4
12/19– 1/18	60	2.2 x 10^6	− 6.28 x 10^4
1/19– 2/18	60	2.4 x 10^6	1.61 x 10^5
2/19– 3/18	56	1.2 x 10^6	5.46 x 10^4
3/19– 4/18	60	1.1 x 10^6	− 1.20 x 10^5
4/19– 5/18	58	9.2 x 10^5	− 1.07 x 10^5
5/19– 6/18	60	− 8.1 x 10^5	− 6.12 x 10^4
Annual Budget (6/19–6/18)	707	1.15 x 10^7	− 9.76 x 10^5
Std. error		8.01 x 10^6	5.95 x 10^5

Table 3. *Summary of annual fluxes (kg yr^{-1}*, + export, − import).

	H_2O (m^3yr^{-1})	ISS
Tidal creek	1.2 x 10^7	− 9.76 x 10^5
Streamwater	− 7.7 x 10^5	0.0
Groundwater	− 1.2 x 10^5	0.0
Rainwater	− 7.9 x 10^5	0.0
Net Basin Budget	9.8 x 10^6	− 9.76 x 10^5
Salt Marsh		
a) transport during tidal inundation		− 3.7 x 10^5
b) export via runoff during tidal exposure		1.4 x 10^5
Oyster Reef		− 3.0 x 10^4

1988). Most of the removal of ISS from the tidal water occurred during the summer and fall when concentrations within the flooding water inundating the salt marsh were high, especially following rain events. The salt marsh model for flux on a tidal cycle:

$$ISS_{MF} = 7.78 \times 10^{-1} - 3.40 \times 10^{-3}\,(L2TIDE) - 9.50 \times 10^{-2}\,(R13) - 1.92 \times 10^{-4}\,(BIO) \quad (r2 = 0.48)$$

estimated an annual net import of 2.5×10^5 kg of ISS into the salt marsh, with a standard error of 4.9×10^4 kg (Table 3). Calculations by WOLAVER *et al.* (1988) have shown this import of ISS to be sufficient to keep up with the local rise in sea level.

Oyster Reef ISS Flux

The oyster reef susbsystem exhibited a net uptake of particulate materials on flooding tides and a net removal on ebbing tides. This difference in sediment flux on flooding and ebbing tides has been attributed to the higher water velocities over the oyster reef on ebb tides

(DAME *et al.*, 1984; DAME *et al.*, 1985). Thus separate regression models were developed for flooding tides and ebbing tides. The flood tide model for uptake/release on a flood tide (+ denotes uptake) is

$$ISS_{OF} = -6.89 + 0.03\,(TIDE) + 2.60\,(R14) - 4.70 \times 10^{-5}\,(L2FRESH) + 6.98 \times 10^{-2}\,(AWTMP) \quad (r^2 = 0.78)$$

and generated an annual estimate of 89.1 kg m^{-2} uptake, with a standard error of 17.1 kg m^{-2}. This uptake was statistically significant at the 5% level. The ebb tide model for uptake/release is

$$ISS_{OE} = 3.11 - 1.82 \times 10^{-2}\,(L1TIDE) + 1.10\,(L2RAIN) - 1.07\,(LIGHT) + 6.55 \times 10^{-2}\,(AXWIND) \quad (r^2 = 0.23)$$

and produced a yearly estimate of 56.4 kg m^{-2} release, with a standard error of 15.1 kg m^{-2}. This release was statistically significant at the 5% level. Although a net uptake of ISS by the oyster reef was predicted, direct observations showed the reef was not being buried by sediments. Additional sediments are probably removed as a result of rain events during low tide exposure and wave action at very low submergence of the oyster reef. Thus, the net ISS uptake was probably overestimated. In any case, the extrapolated uptake of ISS by all oyster reefs in the Bly Creek basin (3.0×10^4 kg) is still an order of magnitude lower than the ISS uptakes estimated for the salt marsh and total basin system.

System ISS Mass Balance

To evaluate the ISS mass balance for the Bly Creek basin, it is necessary to know all the external system inputs and outputs, including tidal exchange (discussed above) and streamwater. The only upland stream entering the basin is an intermittently flowing blackwater stream which has a maximum discharge of approximately 30,000 m^3 per day during severe storms. It drains a low lying maritime forest that grows on a relict dune-ridge topography composed of 99% sand. The low discharge rates plus a lack of source material (silt and clay) result in ISS concentrations too low to measure (WILLIAMS, *unpubl*). Correspondingly, the ISS input to the basin via streamwater was negligible. A summation of system fluxes (tidally mediated exchange and streamwater) suggests that the basin may be a sink for ISS. However, this assertion cannot be made with certainty since the tidally mediated flux was not statistically significant.

CONCLUSIONS

The studies on the salt marsh suggest that this subsystem removes considerably more ISS from the tidal water than it exports to the tidal creek. The total ISS removed by this subsystem is well within the 95% confidence interval around the estimated import through the tidal creek. If the point estimate of ISS flux through the tidal creek is accurate then some of this flux may be unaccounted for. In a study on particulate flux in tidal marshes and subtidal shallows of the Rhode River estuary (JORDAN & CORRELL, 1986), it was suggested that 87% of the removal of particulates occurred within the tidal creek subsystem (mud flats and creek bottoms) even though 60% of the study area was covered by marsh. Within the Bay Creek basin, a similar phenomenon may occur with ISS being deposited on the creek bottoms.

Most of the suspended sediment transport studies in tidal creeks have not been able to show the necessary annual input of ISS to account for the accretion of the marsh surface in accordance with the local rise in sea level. Very often this discrepancy has been attributed to ISS transport during storms. For example, practically all the ISS import into the Little Fools Creek (SETTLEMYRE & GARDNER, 1978) occurred during one sampling when wind turbulence greatly increased suspended particulates into the flooding water. STUMPH (1983) also showed the importance of major storms in ISS transport onto a vegetated marsh in Delaware. The Bly Creek data set also suggests that storms were important in determining ISS transport in this system. A significant percentage of the sediment input to the vegetated marsh on an annual basis may have occurred during a limited number of tidal cycles after major storms. Likewise, approximately 45% of the material exported from the marsh occurred via rainstorms during low tide exposure. In addition, one of the largest inputs into the Bly Creek basin occurred just after a major storm passed through North Inlet (3.4 cm of rain during the previous low tide). These results suggest that storms significantly increased the transport of ISS within and through the basin.

The large tidally mediated ISS input into the basin (8/25/83) just after a major storm is of particular interest. This input of sediment is associated with a low slack high tide and high tidal water sediment concentrations (bottom samples >190 mg l^{-1}). The high ISS levels within the tidal creek probably were associated with a storm which occurred during the previous low tide. During the storm, rain impaction probably caused erosion of ISS from the exposed marsh surface, feeder creek channels, and creek banks. SETTLEMYRE & GARDNER (1973) showed that rain impaction on exposed feeder creek channels as well as the vegetated marsh can be effective in resuspending and transporting particulates. A large percentage of the eroded material might then have been transported into the tidal creeks of North Inlet near the time of low tide. On the subsequent flood tide, ISS were resuspended and transported landward (including bed load) and deposited on the salt marsh or within the tidal creek. Thus, rain and wind events which occur near the time of low tide might result in an import of ISS landward within North Inlet, against the tendency of an ebb-dominant water flux to export materials.

A previous study of the total North Inlet system suggested there was an annual export of total sediments from the system to the Atlantic Ocean, with a seasonal import during fall and winter (DAME *et al.*, 1986). However, for the North Inlet marshes to accrete at a rate near that of local rise in sea level, there must be an import of sediments to North Inlet from either the Atlantic Ocean or the adjacent Winyah Bay. It was argued previously that inorganic sediments may be transported landward immediately after storms which occur during low tide exposure. The Bly Creek study suggests that once ISS entered the Bly Creek basin they were removed by the salt marsh and possibly other subsystems within the tidal creek. In addition, the oyster reef probably does not play a major role in ISS flux within the system. The Bly Creek ecosystem study showed that the estimated ISS import to the basin through the tidal creek may be real because of significant ISS uptake by the salt marsh.

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□ RESUMEN □

Las concentraciones de sedimentos inorgánicos suspendidos (ISS) en Bly Creek, un brazo del estuario de North Inlet, en Carolina del Sur, varian estacionalmente desde 6.5 mg/l en invierno hasta 85.1 mg/l en verano. Un modelo de regresión múltiple basado en los parámetros ambientales y en las estimaciones del flujo de ISS obtenidas a partir de 34 ciclos de marea distribuidos por igual durante el periodo comprendido entre el 19 de junio 1983 al 20 de junio de 1984, ha producido una entrada estimada de 9.76×10^5 Kg/año (S.E. = 5.95×10^5 Kg/año). Las entradas de ISS en la bahia de Bly Creek debidas a las corrientes de agua dulce fueron despreciables.

Dentro del estuario, las praderas de marisma fueron un sumidero de ISS estadisticamente significante, mientras que el arrecife ostrifero fue un sumidero estadisticamente insignificante. Aunque la cantidad de ISS fijada por las marismas fue importante, fue menos que la desviación tipica del flujo de ISS entrante en la bahia. La cantidad de ISS fijada por las praderas de marisma parece suficiente para mantener su elevación por encima del ascenso local del nivel medio del mar.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ ZUSAMMENFASSUNG □

Die Konzentration anorganischer Schwebfracht (AS) im Bly Creek, ein Teil des North inlet Astuars in South Carolina, schwankt saisonal zwischen 6,5 mg/1 im Winter und 85,1 mg/1 im Sommer. Anhand eines Modells, welches mittels multipler Regression auf der Basis von Umweltfaktoren und AS-Strömungsabschätzungen von 34 Gezeitenzyklen beruht, wurde für die Periode zwischen dem 19. Juni 1983 und dem 20. Juni 1984 ein geschätzter Betrag eingespeister Gesamtmenge von $9{,}76 \times 10^5$ kg/a errechnet. Die Einspeisung von AS in den Bly Creek durch Süßwasserzuflüsse war vernachlässigbar. In dem Becken war das Salzmarschgebiet eine statistisch signifikante Sedimentationsfalle für AS; demgegenüber zeigtew das Austernriff keine signifikante Aufnahme von As Obohl die Menge der jährlich von der Salzmarsch abeführten Menge von AS signifikant war, war sie niedriger als der Standardfehler des AS-Eintrags in das Becken. Die Menge von AS, die von der Salzmarsch entnommen wird, erscheint ausreichend um die Höhenlage im Verhältnis zum gegenwärtigen lokalen Meeresspiegelanstieg zu halten.—*Ulrich Radtke, Geographisches Institut, Universität Düsseldorf, F.R.G.*