Input of nutritionally rich organic matter from the Mississippi River to the Louisiana coastal zone

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Abstract

Isotopes have often been used to discern riverine subsidies to coastal food chains, but there are few direct measurements of nutritional quality of riverine particulates. We tested for nutritionally enriched organic matter in the Mississippi River suspended sediment and evidence for its delivery to Louisiana coastal sediments by measuring enzymatically hydrolysable amino acids (EHAA). Riverine suspended sediments contained EHAA concentrations of up to 5 mg g^{-1}, higher than reported in any coastal sediments. Pigment concentrations indicated that EHAA in some river samples were dominated by phytoplankton, but many samples contained significant non-algal EHAA. Coastal sediments showed EHAA concentrations lower than riverine sediments but still higher than most reported shelf values. Incubation of riverine sediment showed losses of 28-34% of their EHAA over 6d, similar to differences found between riverine and coastal sediments. EHAA concentrations decreased more rapidly than total nitrogen, indicating the relative lability of this pool of material in the studied region. These EHAA–enriched materials provide fuel for various coastal biota whose composition likely depends on factors such as disturbance regimes.

Introduction

Rivers are increasingly thought to provide food for heterotrophic processes both in their own reaches and in their depocenters. Terrigenous organic matter delivered by rivers to the ocean has often been considered to consist of relatively refractory material, but there are increasing indications that it is sufficiently labile to have an impact on biological communities and biogeochemical cycling. Organic carbon and nitrogen concentrations, relative to the mineral diluent, can decrease sharply in marine deltas after delivery by rivers (Keil et al. 1997; Mayer et al. 1998), suggesting remineralization of the lost organic matter.

These organic matter subsidies may be particularly important for bottom-feeding organisms which colonize the sediment delivered by rivers (Sobczak et al. 2005). Darnaude et al. (2004 a,b) demonstrated the appearance of terrigenous carbon in benthic invertebrates and demersal fish which feed upon them, suggesting implications for benthic processes such as bioturbation and fisheries production.

Stable isotopes have proven to be especially useful tracers of allochthonous organic matter inputs. These approaches rely on the markedly different biochemical fractionation or source pools for stable isotopes in the originating watershed. Numerous isotope studies have documented incorporation of terrigenous detritus into aquatic food webs (e.g., Hackney and Haines 1980; Incze et al. 1982; Carpenter et al. 2005). Biochemical markers of allochthonous inputs have also received much attention, being a classical organic geochemical technique for source identification. While markers have the advantage of great sensitivity, they often suffer the disadvantage of uncertain ratio to

either bulk composition (Hedges and Prahl 1993) or functional properties such as nutritional quality.

It would therefore be useful to test if riverine organic matter indeed shows enhanced degradability, or lability. Proteinaceous material in riverine sediments has previously been assessed by measuring total, acid-hydrolyzable amino acids (Ittekot 1988; Duan and Bianchi 2007). In sediments this assay appears to overestimate proteinaceous material available to organisms on short time scales (Mayer et al. 1995), and an assay of more bioavailable food would be desirable. One such assay is the concentration of enzymatically hydrolysable amino acids (EHAA), which detects only a minor fraction of total, acid-hydrolyzable amino acids in marine sediments (Mayer et al. 1995). The EHAA assay has proven useful as an indicator of enhanced food quality of sediments in a variety of studies (e.g., Dauwe et al. 1999; Medernach et al. 2001; Mincks et al. 2005), especially in relation to benthic invertebrate animals.

We focus here on labile organic matter delivered by the Mississippi River to the Louisiana coastal region. This river system dominates the efflux of sediment from central North America. There are indications that it affects benthic heterotrophic communities (Wissel and Fry 2005) though its role in overall benthic respiration is unclear (Green et al. 2006). In this study we ask if riverine suspended sediments are enriched in EHAA relative to those of coastal sediments; if so, then a subsidy of food-rich particulate material for coastal ecosystems would be implied.

Methods and Materials

We sampled both riverine suspended sediment and coastal deposited sediments for this study, in areas including the lower Mississippi River, and coastal, shelf and slope sites offshore of its delta (Fig. 1). Suspended sediments were obtained from water samples collected on the Mississippi River, upstream at St. Francisville, LA (river mile 266 from outflow) and downstream at Venice, LA (river mile 10 from outflow), during the period 2004-05. Suspended particulate matter (SPM) was occasionally concentrated from large volumes of river water samples in plastic-lined garbage bins by adding Instant Ocean (TM) to reach a salinity of 5-10 per mil, and allowing coagulation to occur overnight. After siphoning off most of the clarified supernatants, the residual suspensions were then centrifuged to remove most of the remaining water. Tests showed that insignificant changes in total organic matter content result from this separation approach as compared with direct centrifugation or filtration of bulk river water without seasalt coagulation; it seems likely that similarly effective recovery was made of various components of organic matter described below. Deposited sediments were collected from oceanographic vessels by gravity corer, Kasten corer, box corer, multicorers, and various grabs, on a number of cruises during 2003-2005. Cruises for cores labeled P2 and P4 were conducted July 8-9, 2004 and May 8-10, 2005, respectively. Cores were dissected using core extruders within hours of collection and samples frozen until analysis.

To assess the biodegradability of riverine EHAA, freeze-dried samples of suspended sediment collected at St. Francisville in April and May of 2005, were suspended in artificial seawater at a concentration of 25 g L^{-1}. These suspensions were gently agitated in the dark on a reciprocal shaker. One set was removed at 10 minutes,

centrifuged and frozen. The duplicate set was incubated for 6 d at room temperature, and then also centrifuged and frozen. Pre- and post-incubation sediments were analyzed for EHAA.

EHAA analyses were carried out using the method of Mayer et al. (1995). Briefly, this method entails incubating the sediment in a suspension with a set of fungal, nonspecific proteolytic enzymes (Proteinase–K, Sigma P-8044) at 37° for 3h. Following this incubation, trichloroacetic acid (TCA) was added to precipitate the enzymes and the suspension clarified by centrifugation. The hydrolyzed monomers and oligomers of amino acids remaining in solution represent the EHAA, and for analysis they were then further hydrolyzed to monomeric amino acids, using strong HCl, and quantified fluorimetrically using orthophthaldialdehyde (OPA) on a spectrofluorometer.

Organic carbon and total nitrogen contents of sediments were analyzed on a Perkin-Elmer 2400B Elemental Analyzer, after decarbonation by gas phase acidification (Mayer 1994). Pigment samples were frozen on site and kept frozen. Samples were freeze-dried in the dark and extracted by sonication for 30 s in 100% acetone (Buffan-Dubau and Carman 2000). Extracts were filtered through 0.45μm Teflon filters, diluted to 70% acetone with distilled water, and analyzed by HPLC using a reversed phase C18 column following the method of Van Heukelem et al. (1992) but without the addition of the ion pairing reagent to the samples. Analyses were performed on a Hitachi 7000 HPLC system with UV-Vis and fluorescence detection.

Results

Suspended sediment samples collected from the Misssissippi River showed very high EHAA concentrations of 2.6-5.0 mg g^{-1} at the upstream station at St. Francisville and 1.8 - 4.2 mg g^{-1} at the downstream station at Venice (Table 1). To our knowledge, there are no other published EHAA values for riverine suspended sediment. Chlorophyll values ranged 8 – 101 μg g^{-1} (or 0.6 – 11.5 μg L^{-1}) for these samples, consistent with previous reports (Dagg et al. 2005; Duan and Bianchi 2006).

Surficial sediment samples collected immediately after a mid-summer flood pulse in early July, 2004, adjacent to the Birdfoot Delta and in transects up to 62 km to the west of Southwest Pass (the usual plume direction from the principal river outlet), showed values of 1.6-2.2 mg g^{-1}. Subsurface values were somewhat lower, though without any consistent depth trend. Surficial sediment samples collected from the same area in early May of 2005, almost three weeks after the peak of the late spring flood pulse, showed values of 1.2-1.8 mg g^{-1}. Surficial samples from two deeper water sites to the east of the delta, collected at four times, showed lower values of 0.9-1.6 mg g^{-1}.

The two riverine suspended sediment samples incubated in the dark had initial EHAA concentrations of 2.3 and 2.7 mg g^{-1}, and after the 6 d incubation lost 28 and 34% of their initial EHAA concentrations, respectively. The EHAA concentrations at the beginning of the experiments were each about 10% lower than those in the same samples analyzed shortly after collection; this loss during frozen storage suggests that even larger fractions of the original EHAA were quite labile to decay.

Discussion

Distribution and Nature of EHAA

EHAA concentrations have been studied for over a decade, and a reasonably extensive data base exists with which to compare our data (Table 2). In such a comparison, it is necessary to match analytical protocols. In particular, our analyses on freeze-dried samples must be compared with literature values using similar frozen preparations, because freezing enhances access of peptides to proteolytic enzymes in this assay (Mayer et al. 1995). Most reported EHAA concentrations in ocean margin environments are less than 1 mg g^{-1} (Table 2), with some exceptions reported from coastal regions of Chile, the Gulf of Maine (USA) and Puget Sound (USA). Thus, with values of 1.8 – 5 mg g^{-1} Mississippi River suspended sediment (Table 1) delivered to the coast generally contains higher EHAA concentrations than are found in most reported coastal sediments.

Values at the upstream sampling location (St. Francisville) were higher than those at the lower station (Venice) for three out of four sampling times. Roughly proportional changes were seen in total organic matter – as total organic carbon or nitrogen (Fig. 2). These changes in organic matter concentration were not associated with grain size changes, as specific surface area values of the mineral fraction were very similar between the stations (unpub. data). Such organic matter decreases would be consistent with downstream loss of chlorophyll concentrations over a similar stretch of the river found by Dagg et al. (2005) and Duan and Bianchi (2006), who sampled the river in a more rigorous, Lagrangian manner. The small number of comparisons in our study, however, does not allow a statistically significant test of downstream change.

There was no positive correlation between EHAA and chlorophyll (Fig. 3); indeed, the relationship was instead slightly negative though not significant. Nevertheless, those samples that plot toward the lower right end of this graph, typically summer and autumn samples, had EHAA:chlorophyll ratios of 19 – 68 g-EHAA (g-chlorophyll)$^{-1}$. These ratios are similar to those of phytoplankton, which typically have protein:chlorophyll ratios of 20-100 (Moal et al., 1987; Dortch and Packard, 1989). In addition, we previously found similar ratios in estuarine seston in which phytoplankton appear to dominate the EHAA pool (Laursen et al. 1996). These low EHAA:chlorophyll ratios were found at both the upstream St. Francisville and downstream Venice stations, implying that algal growth in the lowest reaches of the river is not necessary to achieve these low ratios. The springtime samplings, on the other hand, had higher EHAA:Chlorophyll ratios of 160 – 632, implying dominance by organic matter not held in live plant cells. Chlorophyll degradation products usually account for <40% of chlorophyll (Duan and Bianchi, 2006), suggesting that this material was not generally dominated by recently dead phytodetritus. Sediment delivery by the Mississippi is usually dominated by spring-time flows. Thus, while our data support the suggestion of Dagg et al. (2005) and Duan and Bianchi (2006) that this and other large river systems with human influence can be important suppliers of labile phytodetritus to coastal zones, the springtime samples indicate that some other form(s) of labile proteinaceous material is also supplied to this coastal zone.

EHAA concentrations in surficial sediments of the coastal region around the Birds Foot Delta of the Mississippi River (core series P2 and P4) – with values of 1.3 – 2.2 mg-EHAA g-sediment^{-1} - are also high relative to most other regions (Table 2) although

lower than the river values. The overall drop in EHAA concentrations between river and coast is consistent with the 28-34% losses observed in our incubation experiments, and suggests that only days to weeks are required to eliminate significant fractions of the EHAA brought in with riverine sediment. The MSS-2 core is anomalous in its low EHAA values, but its location in a slump basin in an area of mass-wasting suggests that it represents primarily subsurface sediment (Corbett et al. 2006) which has presumably undergone considerable prior diagenesis. Distal stations in deeper water to the east of the delta –(Stations 1 and 3) had lower values more in keeping with literature reports of other shelf regions (Table 2). These shelf distributions suggest a halo effect around the river outfalls reflecting enriched sediments recently delivered by the river. This halo is opposite to the contribution of marine organic matter to the total organic matter in roughly the same set of samples (Mayer et al. 2007), and implicates the river as a principal source of proteinaceous material.

Enhanced shelf primary production resulting from the high dissolved nutrient loads of the Mississippi River is another possible source of EHAA to the sediments. The Mississippi River, for example, currently delivers far more dissolved nitrate than particulate nitrogen (Dagg et al., 2003), which can be converted to EHAA-rich particulates. However, samples such as P2S4 and P2S5 were collected within days of the highest flood event of 2004 and very close to outlets of the river to open water, so that primary production would have had little opportunity to develop in these highly turbid waters.

This enhanced food quality is clearer when considered as the contribution of EHAA to the total nitrogen (Fig. 2). Most samples of deposited sediments reported from

other regions have EHAA levels that make up only about 2 – 10% of the total nitrogen. Most exceptions to this statement are coarse-grained sediments in shallow areas with low contents of both materials. Thus, Dauwe et al. (1999) and Mayer et al. (2002) found higher concentrations of EHAA but lower ratios of EHAA to total organic matter in relatively deep, fine-grained sediments as compared to shallow water sands. These coarse-grained sediments presumably had especially low contents of humified organic matter to dilute the fresher organic matter that is richer in EHAA. For the majority of finer-grained sediments, however, EHAA concentrations increase with total nitrogen concentrations when the latter exceeds exceed ca. 0.5 mg-N g-sediment^{-1}. This correlation suggests that a baseline level of nitrogenous compounds are made available to the EHAA analytical protocol but are apparently not sufficiently labile to be reduced by ambient biological communities in near-surface sediments on time scales of residence times in the surface layers. These "baseline" EHAA-N:TN ratios of 0.02-0.10 are also consistent with the values we typically find in deep sections of cores in the Lousiana coastal region (Table 1), which represent residual EHAA left after the intense biological attack nearer the sediment-water interface.

The riverine suspended sediments from the upstream St. Francisville station show EHAA-N:TN ratios of 0.16-0.26 (Table 1), much higher than deposited shelf sediments reported in the literature (Fig. 2). Most coastal sediment-water interface samples taken outside the Birdfoot delta show intermediate values (Fig. 2), reflecting selective loss of the EHAA fraction after deposition. Thus EHAA clearly represent a relatively labile component of the overall sedimentary nitrogen delivered by the river.

We did not measure total, acid-hydrolyzable amino acids (TAHAA) in this study, but our EHAA-N:TN ratios are similar to reported TAHAA-N:TN ratios reported for Mississippi River suspended sediment by Duan and Bianchi (2007), as well as other muddy, large rivers (Ittekot and Zhang 1989). If this rough equivalence between EHAA and TAHAA applies to these suspended sediments, it implies that riverine suspended sediments differ quite strongly from shelf sediments in their ratios of EHAA to TAHAA, because shelf sediments usually have low EHAA:TAHAA ratios (Mayer et al. 1995; Dauwe et al. 1999; Medernach et al. 2001; Gremare et al. 2005). Similar contents of EHAA and TAHAA would corroborate the claim of Ittekot (1988) that TAHAA provides a measure of the labile component of riverine particulate organic matter. It is also consistent with Keil and Fogel's (2001) finding that terrigenous amino acids are readily replaced by marine-derived amino acids in coastal sediments. Relatively fresh organic detritus usually has EHAA:TAHAA ratios approaching 1, and so this equivalence is also consistent with Duan and Bianchi's (2007) finding that the amino acid spectra of riverine particulates reflected relatively fresh material.

There are no consistent downcore trends, which is not surprising given the shallow nature of most cores, the major losses of EHAA prior to burial, and the unsteady sedimentation conditions in this region. About 3/4 of the cores show lower EHAA-N:TN ratios at the bottom of the core than at the sediment-water interface, reaching values of < 0.10 (Table 1) and pointing toward a general trend of continued preferential loss of EHAA nitrogen.

Normalized to carbon, EHAA-C never exceeded 10% of total organic carbon and hence EHAA makes up a minor portion of total organic matter. Thus, variations in

EHAA concentrations do not necessarily represent the changes in the lability of bulk organic matter. For riverine samples in which live plant material dominates the EHAA, there may exist a group of highly nutritious particles that are separate from bulk organic matter. High EHAA concentrations may signal only the existence of a subset of organic particles available to organisms that can access it via selective ingestion or digestion.

Biological Implications

Our results corroborate isotopic evidence for terrigenous OM subsidies to deltaic food chains (Darnaude et al. 2004a,b). The types of organisms best poised to take advantage of this nutritional subsidy probably depend on other oceanographic factors that affect bacterial and macrofaunal success (Alongi and Robertson 1995; Aller and Aller 2004). The very high EHAA concentrations in sediment delivered to coastal regions probably exceeds the consumption ability of resident bacteria on short (hr) time scales (Mayer et al. 2001), providing relative advantage to animals if they are present. Mississippi River sediment arriving at the coast is quickly deposited in shallow waters (Hitchcock et al. 1997), in environments that typically inhibit macrofauna because of the intense sedimentation and disturbance regimes (Alongi and Robertson 1995). Our experimental results show that microbes can utilize much of the delivered EHAA within a few days. This decay time is much shorter than the month-long timescales needed for larger macrofauna to colonize and/or develop biomass capable of directly competing for this food resource (Aller and Aller, 2004). If the riverine organic matter is quickly delivered to greater depths in which benthic macroinvertebrates can persist, then incorporation into macrofaunal food chains seems more likely. Thus, Darnaude et al.

(2004b) found greatest incorporation of terrestrial carbon into demersal flatfish populations at depths of 30-50m off of the Rhone River delta.

Combinations of bacterial and macrofaunal utilization of these subsidies may also occur. Alongi and Robertson (1995) suggested that peneid shrimp in muddy deltas are supported by a short food chain that begins with bacteria feeding on organically enriched sediment, followed by shrimp grazing on the microbe-organic matter assemblage. Indeed, this region has a long history as a rich shrimp fishery ground (Padgett, 1966).

Jumars et al. (1990) suggested that regions of unsteady deposition should result in subsurface horizons rich in food. The rapid inshore deposition of riverine sediment will lead to burial of such horizons rich in EHAA, seen in this study at depths of up to 23 cm (e.g. cores P2S8, P4S5, Table 1). Similar subsurface peaks in chlorophyll concentrations were found by Chen et al. (2005). These subsurface horizons rich in EHAA are rare in normal shelf environments in which EHAA-rich sediment is more slowly mixed by bioturbation while being subjected to heterotrophic attack. The conditions are thus set for subsequent deeper sediment metabolism by bacteria or sub-surface burrowing macrofauna attempting to “mine” deeper food caches (Jumars et al. 1990). Accordingly, Darnaude et al. (2004a) found isotope evidence for significant terrigenous food subsidy to subsurface deposit feeders in the Rhone River delta. Regional bioturbation patterns may thus be influenced by combinations of these riverine subsidies and sedimentation/disturbance regimes.

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Table 1. Station locations and data. "Mississippi" refers to samples taken along the mainstem of the river, followed by the nearest town. Latitudes and longitudes are in degrees, water depths are in m, depths within cores are in cm, total organic carbon (TOC), total nitrogen (TN), and enzymatically hydrolysable amino acids (EHAA) are in mg g-dry weight^{-1}, and the ratio of nitrogen in EHAA to TN is dimensionless.

Sampling Site	Latitude	Longitude	Water Depth (m)	Core Depth (cm)	TOC (mg g^{-1})	TN (mg g^{-1})	EHAA (mg g^{-1})	EHAA-N / TN
SUSPENDED PARTICULATES								
Mississippi, St. Francisville, 7/04	30.77	91.39			29.6	3.4	3.33	0.16
Mississippi, St. Francisville, 10/04	30.77	91.39			18.4	2.3	2.62	0.19
Mississippi, St. Francisville, 3/05	30.77	91.39			25.1	3.2	4.99	0.26
Mississippi, St. Francisville, 4/05	30.77	91.39			18.1	2.1	2.55	0.20
Mississippi, St. Francisville, 5/05	30.77	91.39			21.1	2.7	3.02	0.19
Mississippi, Venice, 7/04	29.27	89.35			21.8	2.4	1.82	0.12
Mississippi, Venice, 7/04	29.27	89.35			21.8	2.4	1.76	0.12
Mississippi, Venice, 3/05	29.27	89.35			23.8	2.6	3.12	0.20
Mississippi, Venice, 4/05	29.27	89.35			14.8	1.7	1.95	0.19
Mississippi, Venice, 5/05	29.27	89.35			26.0	3.3	4.17	0.21
DEPOCENTER SEDIMENTS								
P2, S4	29.38	89.22	2	0-1	20.2	2.3	1.64	0.12
				1-3	18.8	2.2	1.53	0.12
				5-7	11.2	1.1	1.29	0.20
				11-13	16.2	1.6	0.62	0.06
P2, S5	29.42	89.28	2	0-1	24.0	2.5	1.81	0.12
				1-3	20.9	2.1	1.93	0.15
				5-7	23.1	2.4	1.55	0.11
				7-9	16.0	1.7	1.09	0.11
				11-13	15.7	1.5	1.21	0.13
				13-15	15.6	1.6	0.95	0.10
P2, S6	28.92	89.50	39	0-2	18.1	2.1	2.13	0.17
				6-8	15.3	1.8	1.26	0.12
				12-14	15.1	1.7	1.22	0.12
P2, S7	28.83	89.54	81	0-2	18.2	2.2	2.18	0.17
P2, S8	28.91	89.89	45	0-2	15.9	2.1	1.79	0.14
				4-6	15.2	2.0	1.7	0.14
				8-10	15.1	2.0	1.67	0.14
				12-14	14.1	1.8	1.38	0.13
P4S2	28.85	89.42	50	0-1	17.3	1.9	1.54	0.14
				3-5	15.7	1.6	1.01	0.10
				5-8	13.0	1.4	0.97	0.12
				11-14	14.7	1.5	0.96	0.10
P4S3	28.83	89.35	73	0-2	16.7	1.9	1.34	0.12
				2-4	14.8	1.7	1.19	0.11
				6-9	10.9	1.2	0.71	0.10
				12-15	7.4	0.9	0.63	0.12
P4S4	29.32	88.96	20	0-2	6.7	0.9	1.19	0.23

Sampling Site	Latitude	Longitude	Water Depth (m)	Core Depth (cm)	TOC (mg g^{-1})	TN (mg g^{-1})	EHAA (mg g^{-1})	EHAA TN
P4S5	29.40	89.27	6	0-2	15.8	2.3	1.68	0.12
				5-8	11.5	1.2	0.93	0.13
				11-14	11.2	1.4	1.31	0.16
				20-23	20.4	2.1	1.56	0.12
P4S6	28.88	89.6	69	0-1	19.1	2.3	1.61	0.12
				1-4	18.2	2.1	1.48	0.12
				4-7	16.3	1.9	1.45	0.13
				13-16	15.9	1.9	1.01	0.09
				19-22	15.5	1.8	1.06	0.10
P4S7	28.97	89.83	40	0-1	17.6	2.2	1.49	0.11
				4-7	14.9	1.9	1.17	0.10
				13-16	12.1	1.5	0.47	0.05
P4S8	28.93	90.07	72	0-1	12.0	1.5	1.80	0.21
				3-6	7.6	0.9	0.87	0.16
				12-14	7.2	0.8	0.27	0.06
MSS-2	28.83	89.48	45	0-5	13.0	1.3	0.57	0.07
				5-10	12.8	1.3	0.52	0.07
				10-15	12.7	1.3	0.50	0.06
				15-20	12.6	1.3	0.54	0.07
				20-25	12.9	1.4	0.47	0.06
				25-30	13.0	1.4	0.50	0.06
				30-35	13.6	1.4	0.54	0.06
				35-40	12.7	1.3	0.56	0.07
				40-45	11.2	1.2	0.47	0.07
				45-50	12.8	1.4	0.57	0.07
				50-55	13.3	1.5	0.58	0.06
				55-60	13.5	1.5	0.55	0.06
				60-65	13.4	1.4	0.55	0.06
				65-70	12.9	1.4	0.52	0.06
				70-75	13.0	1.4	0.49	0.06
				75-80	12.2	1.3	0.53	0.07
				80-85	13.3	1.5	0.61	0.07
				85-90	13.0	1.4	0.57	0.07
				90-95	12.4	1.4	0.59	0.07
				95-100	13.0	1.4	0.54	0.06
				100-110	12.1	1.3	0.49	0.06
				110-120	10.5	1.1	0.51	0.07
				120-130	11.2	1.2	0.58	0.08
				130-140	13.4	1.5	0.58	0.06
				140-150	13.5	1.5	0.50	0.06
				150-160	12.1	1.4	0.59	0.07
STATION 3								
MC-1, 5/5/04	29.30	88.68	62	0-0.5	15.5	2.0	1.44	0.12
				0.5-1	14.7	1.8	1.34	0.12
				1-1.5	14.5	1.8	1.27	0.12
				1.5-2	14.2	1.8	1.24	0.12
				2-3	14.4	1.8	1.33	0.12
				3-4	14.2	1.8	1.26	0.12
				4-5	14.3	1.8	1.18	0.11
				5-6	14.1	1.8	1.38	0.13
				6-7	14.1	1.7	1.23	0.12
				7-8	13.7	1.7	1.19	0.12
				8-9	13.7	1.7	1.06	0.10
				9-10	13.0	1.6	1.05	0.11
				10-12	12.6	1.6	0.86	0.09
				14-16	12.3	1.5	0.77	0.09
				18-20	11.4	1.4	0.62	0.08

Sampling Site	Latitude	Longitude	Water Depth (m)	Core Depth (cm)	TOC (mg g^{-1})	TN (mg g^{-1})	EHAA (mg g^{-1})	EHAA TN
MC-5 , 7/8/04	29.31	88.68	62	0-0.5	15.5	2.0	1.61	0.14
				0.5-1	14.7	1.8	1.35	0.12
				1-1.5	14.6	1.8	1.38	0.13
				1.5-2	14.7	1.8	1.33	0.12
				2-3	14.6	1.8	1.30	0.12
				3-4	14.4	1.7	1.26	0.12
				4-5	14.2	1.7	1.16	0.11
				5-6	14.4	1.8	1.29	0.12
				6-7	14.6	1.8	1.12	0.11
				7-8	14.7	1.8	1.16	0.11
				8-9	14.4	1.8	1.04	0.10
				9-10	13.8	1.8	0.99	0.09
				10-12	13.4	1.7	0.89	0.09
				14-16	12.4	1.5	0.77	0.08
				18-20	12.1	1.4	0.60	0.07
MC 7, 10/29/04	29.30	88.68	62	0-0.5	19.9	2.5	1.38	0.09
				0.5-1	20.3	2.6	1.39	0.09
				1-1.5	20.1	2.5	1.38	0.09
				1.5-2	20.5	2.5	1.28	0.08
				2-3	19.9	2.5	1.35	0.09
				3-4	17.0	2.1	1.41	0.11
				4-5	12.5	1.6	1.03	0.11
				5-6	12.4	1.5	0.91	0.10
				6-7	12.2	1.5	0.81	0.09
				7-8	12.5	1.5	0.80	0.09
				8-9	12.6	1.5	0.79	0.09
				9-10	12.6	1.5	0.73	0.08
				10-12	12.1	1.5	0.70	0.08
				14-16	12.0	1.4	0.64	0.08
				18-20	11.7	1.4	0.66	0.08
MC 9, 5/9/05	29.30	88.68	62	0-0.5	14.1	1.9	0.94	0.08
				0.5-1	13.6	1.8	0.91	0.09
				1-1.5	14.2	1.8	0.82	0.07
				1.5-2	15.2	1.9	0.94	0.08
				2-3	14.1	1.8	0.81	0.07
				3-4	10.7	1.4	0.74	0.09
				4-5	6.0	0.8	0.43	0.09
				5-6	8.7	1.2	0.55	0.08
				6-7	7.5	1.0	0.50	0.08
				7-8	10.5	1.4	0.61	0.07
				8-9	11.3	1.5	0.68	0.08
				9-10	10.7	1.4	0.56	0.07
				10-12	12.2	1.5	0.63	0.07
				12-14	12.0	1.5	0.61	0.07
				14-16	11.9	1.5	0.57	0.06
				16-18	11.7	1.5	0.55	0.06
				18-20	11.5	1.4	0.52	0.06
STATION 1								
MC-2 5/04	29.00	88.84	200	0-0.5	17.1	2.1	1.18	0.10
				0.5-1	16.3	2.0	1.08	0.09
				1-1.5	16.2	1.9	1.09	0.10
				1.5-2	15.6	1.8	1.18	0.11
				2-3	15.3	1.8	1.11	0.10
				3-4	15.4	1.8	1.07	0.10
				4-5	15.3	1.9	1.17	0.11
				5-6	15.2	1.8	1.09	0.10
				6-7	15.1	1.8	1.07	0.10
				7-8	14.8	1.8	1.18	0.11

Sampling Site	Latitude	Longitude	Water Depth (m)	Core Depth (cm)	TOC (mg g^{-1})	TN (mg g^{-1})	EHAA (mg g^{-1})	EHAA TN
				8-9	14.7	1.8	1.09	0.10
				9-10	14.7	1.7	1.01	0.10
				10-12	14.8	1.8	1.05	0.10
				14-16	15.3	1.8	0.96	0.09
				18-20	14.4	1.7	0.80	0.08
MC-4, 7/8/04	29.00	88.84	200	0-0.5	15.8	2.0	0.87	0.07
				0.5-1	15.5	1.9	1.01	0.09
				1-1.5	15.4	1.8	1.45	0.13
				1.5-2	15.5	1.9	1.12	0.10
				2-3	15.4	1.9	1.11	0.10
				3-4	15.2	1.9	1.14	0.10
				4-5	15.0	1.9	1.17	0.10
				5-6	14.8	1.9	1.05	0.09
				6-7	14.8	1.9	1.04	0.09
				7-8	14.8	1.9	1.02	0.09
				8-9	14.7	1.9	0.93	0.08
				9-10	14.5	1.9	1.04	0.09
				10-12	14.4	1.7	0.96	0.09
				12-14	14.5	1.7	0.77	0.08
				14-16	14.4	1.7	0.85	0.08
				16-18	14.4	1.7	0.82	0.08
MC-6, 10/29/04	29.00	88.84	200	0-0.5	17.5	2.2	0.85	0.06
				0.5-1	16.5	2.1	0.86	0.07
				1-1.5	14.6	1.8	0.75	0.07
				1.5-2	12.5	1.5	0.80	0.09
				2-3	12.5	1.6	0.79	0.08
				3-4	9.8	1.2	0.72	0.10
				4-5	9.2	1.2	0.69	0.10
				5-6	11.5	1.3	0.76	0.10
				6-7	9.8	1.2	0.67	0.09
				7-8	9.8	1.2	0.63	0.09
				8-9	10.0	1.2	0.89	0.12
				9-10	7.1	0.8	0.49	0.10
				10-12	7.0	0.8	0.50	0.11
				12-14	14.5	1.8	0.98	0.09
				16-18	15.6	1.9	0.95	0.08
MC 8, 5/9/05	29.00	88.84	200	0-0.5	17.9	2.2	0.96	0.07
				0.5-1	17.1	2.2	0.95	0.07
				1-1.5	16.4	2.1	1.10	0.09
				1.5-2	15.2	1.9	0.93	0.08
				2-3	15.9	2.1	1.11	0.09
				3-4	16.1	2.1	1.04	0.08
				4-5	16.0	2.1	1.10	0.09
				5-6	15.7	2.1	1.01	0.08
				6-7	15.6	2.1	0.98	0.08
				7-8	15.4	2.0	0.93	0.08
				8-9	15.3	2.1	0.92	0.07
				9-10	15.0	2.0	0.90	0.07
				10-12	14.8	2.0	0.87	0.07
				12-14	15.0	2.1	0.81	0.07
				14-16	14.7	2.0	0.81	0.07

Table 2. Sedimentary EHAA values reported from other sampling areas.

Location	EHAA range (mg g^{-1})	Reference
Puget Sound, WA, USA	1.1 – 3.7	Mayer et al. (1995)
San Francisco Bay, CA, USA	0 – 0.75	Lesen (2006)
So. California Basins, USA	0.2 – 0.6	Demopoulos et al. (2003)
Gulf of Maine, USA	1.5 – 4.3	Mayer et al. (1995), Wildish et al. (2004), Mayer, unpub. data
Lagoon, SC, USA	0.2 – 0.3	Hymel and Plante (2000)
Cape Hatteras, NC, USA	0.05 – 1.0	Mayer et al. (2002)
Central Chile	1.45 – 5.85	Gremare et al. (2005)
Discovery Bay, Jamaica	0.1 – 0.3	Mills and Sebens (2004)
West Antarctic Peninsula shelf	0.3 – 0.7	Mincks et al. (2005)
Bay of Biscay	0.53 – 1.21	Gremare et al. (2005)
Bay of Banyuls-sur-Mer, FR	0.1 – 0.3	Charles et al., (2005)
North Sea	0.17 – 0.45	Dauwe et al. (1999)
Gulf of Lions	0.09 – 0.75	Gremare et al. (2005)
Amazon shelf	0.2 - 0.8	Mayer et al. (1995)
Ariake Sound, Kyushu, JP	0.4 – 0.5	Kimura et al. (2002)

Figures

1. Map of coastal sampling stations. EHAA concentrations (mg g^{-1}) in surface horizon given as numbers next to stations, with seasonal range described for the two easternmost stations that were sampled repeatedly. Station data are in Table 1.
2. EHAA vs. TN concentrations in Mississippi River suspended sediments (large solid circles), surficial sediments from the Lousiana coastal region (large open circles) and other areas around the world (small solid symbols). Lines on the plot indicate the proportion of TN contained in EHAA, and are calculated assuming that EHAA-N = EHAA/6 (Mayer et al., 1995). References for data from other regions are: Gulf of Maine (Mayer, unpub. data), Antarctica (Mincks et al., 2005), Cape Hatteras (Mayer et al., 2002), San Francisco Bay (Lesen, 2006), North Sea (Dauwe et al., 1999), and So. California Basins (Demopoulos et al., 2003).

3. EHAA vs. chlorophyll concentrations in riverine suspended sediment at the St. Francisville and Venice stations. Lines and numbers refer to ratios of EHAA to chlorophyll (g-EHAA g-chlorophyll^{-1}).

Fig. 1

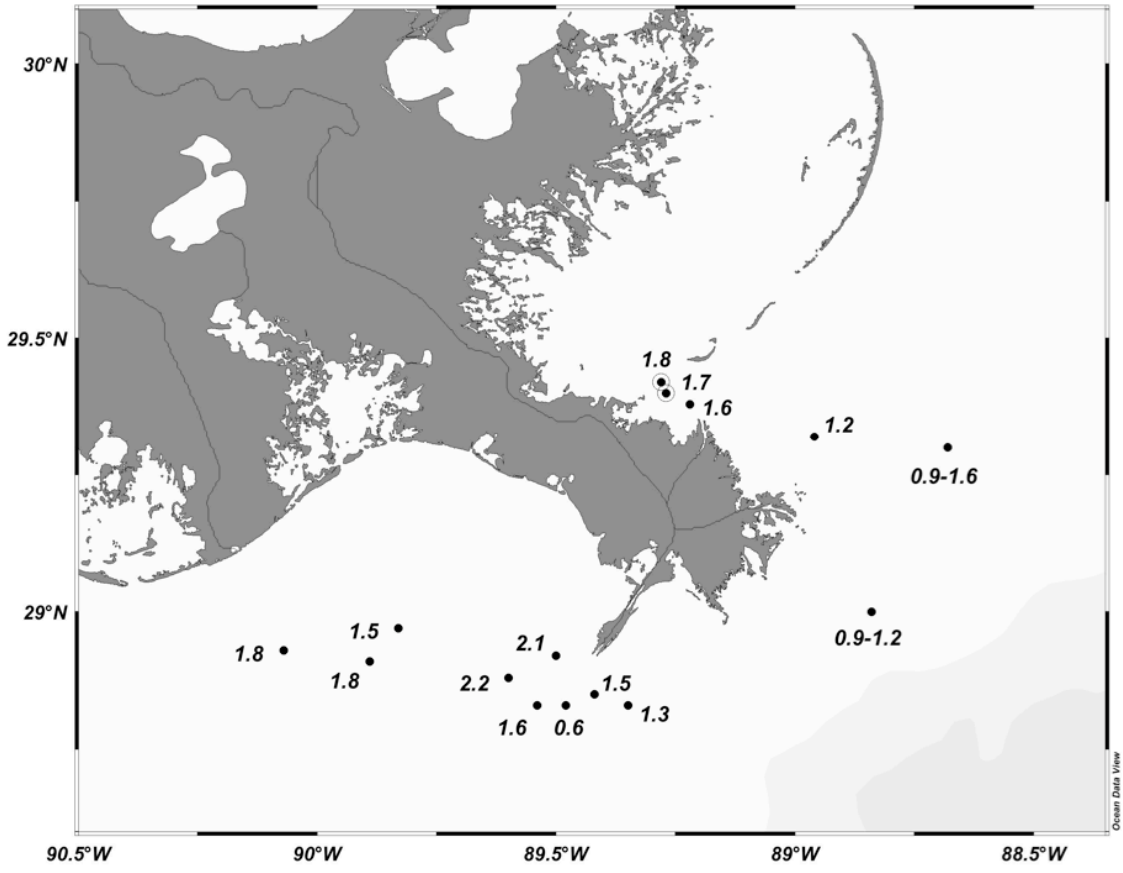
30°N
29.5°N
29°N
90.5°W
90°W
89.5°W
89°W
88.5°W
1.8
1.7
1.6
1.2
0.9-1.6
0.9-1.2
1.5
1.8
1.8
2.1
2.2
1.5
1.6
0.6
1.3
Ocean Data View

Fig. 2

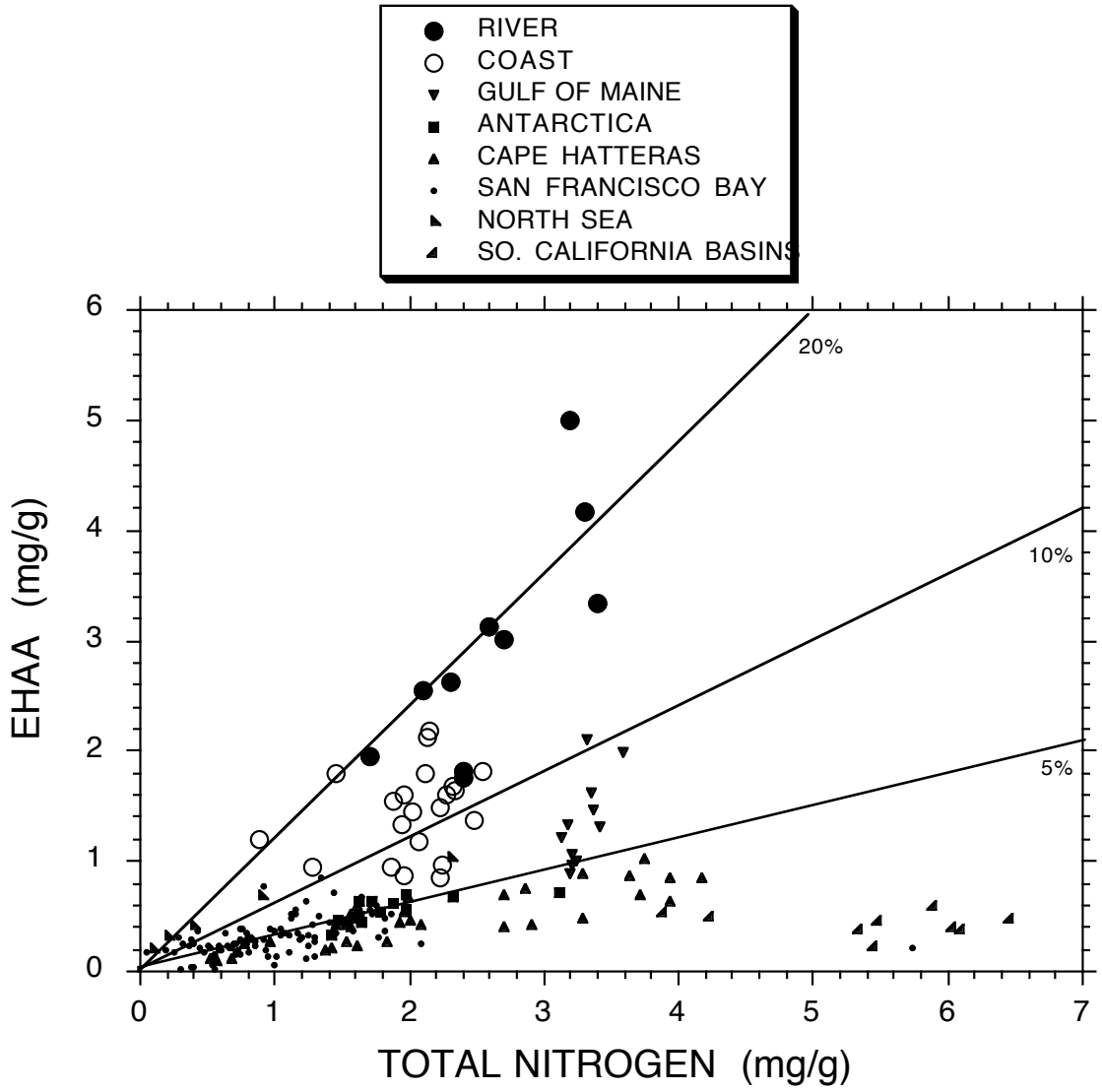
RIVER
COAST
GULF OF MAINE
ANTARCTICA
CAPE HATTERAS
SAN FRANCISCO BAY
NORTH SEA
SO. CALIFORNIA BASINS
20%
10%
5%
EHAA (mg/g)
TOTAL NITROGEN (mg/g)
0
1
2
3
4
5
6
7

Fig. 3