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Sources and composition of particulate organic matter in the Sacramento-San Joaquin River Delta, California

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SOURCES AND COMPOSITION OF PARTICULATE ORGANIC MATTER IN THE
SACRAMENTO-SAN JOAQUIN RIVER DELTA, CA

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A Dissertation Presented to
the Faculty of the School of Marine Science
of the College of William and Mary

in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

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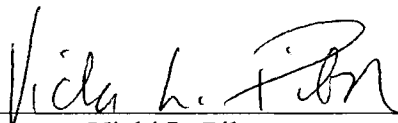
Vicki L. Pilon

January 2006

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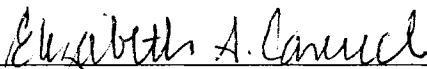
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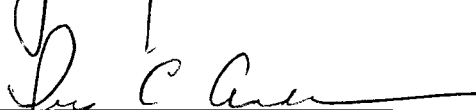
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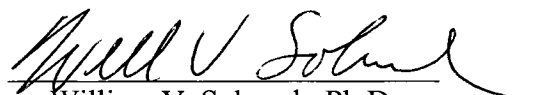
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DEDICATION

This dissertation is dedicated to my husband Frankie Gross and my sister Nancy. To

Frankie, whom I met and married during my tenure at VIMS, for his

continued support and love over the course of my Ph.D., and to Nancy, who was my

greatest champion when I was young, but passed away before this dream could be

realized.

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ACKNOWLEDGMENTS

My greatest praise is reserved for my advisor, Dr. Elizabeth Canuel. Through both good and tough times, she has been instrumental in guiding me and pushing me to develop the best possible dissertation. Her INFINITE patience and encouragement kept me moving forward (sometimes very slowly), and made me believe that an end was in sight!!! To say that she is a gifted scientist, teacher and mentor would not do her justice. She is truly the best. I also want to thank my committee members. To Dr. Iris Anderson, for her roles as scientific guide, Graduate Dean, and reference provider! To Dr. Jim Bauer, thank you for both scientific guidance as well as use of lab equipment and time for my amino acid analyses. To Dr. Robert Orth, I thank you for always providing the biological point of view to my research. Finally, I want to thank Dr. William Sobczak, whose insight and encouragement allowed me to always see hope in the research, and reminded me that the Delta really is a cool place to do research.

I want to thank others outside of VIMS that made the completion of my research possible. The crew (Byron Richards and Scott Conard) of the *R/V Polaris*, for always providing our research team with everything we needed. I would like to thank fellow researchers Dr. James Cloern, Brian Cole, Andrew Arnsberg, Tara Schraga, Jody Edmunds, Dr. Anke Müller-Solger, Francis Parchaso and Ken Forshay for field assistance and providing ancillary data from the cruises. I would also like to thank Dr. Antonio Mannino, Kip Gardner and Dr. David Burdige for providing assistance in developing the carbohydrate protocol I used. Dr. David Burdige also provided lab space, supplies, and assistance for my amino acid analyses. Dr. Reno Nguyen provided protocol assistance and guidance for the total protein analyses.

My labmates have been a pivotal part of my great experience at VIMS, so I would like to thank Beth Waterson, Melissa Ederington-Hagy, Dr. Krisa Arzayus, and Dr. Andrew Zimmerman. Thanks to Cathy Mingee and Courtney Graves, who were my F.I.R.S.T. students, so to speak, and aided in the analyses of the total proteins samples as part of their student projects.

Every member of the VIMS staff should be commended for their dedication to making VIMS a world-class institute, and a home for graduate students. In particular, I would like to thank Sue Presson and Fonda Powell for keeping my paperwork on track. To Cynthia Harris, Cindy Hornsby and Beth Marshall for their assistance on everything from travel reimbursement to getting my paycheck to me. To ITNS for addressing all my software needs and issues. To the entire library staff who always got my articles from obscure journals to me, and the staff at Publications for always making my slides and posters look perfect, I thank you all. To Vicki Clark, thank you for Seafood Seminars, they were always great fun! Finally, to Susan Haynes, for making the Outlook on Ocean Science Program a fun experience, and one that whet my appetite to continue outreach efforts in the future.

VIMS friends can not be forgotten: Christine, Jennifer, Sara, David, and my incoming class in 1998, thanks for making the experience at VIMS a memorable one.

A wonderful experience that I was able to participate in while a student at VIMS was the Knauss Sea Grant Marine Policy Fellowship, working at the EPA in Washington D.C. for a year. I would like to thank all employees of the Wetlands Division, in particular Stan Austin, my branch chief, Donna, Doreen, Connie, Lori, Kathleen, Rebecca, Tracie, and Palmer for their camaraderie and guidance. To fellow Fellows in the Wetlands Division and other EPA offices: Chris, Eric, Jordan and Rachel, Laura, Rachel and Jennifer, thanks for your friendship and support. My coworkers at The Office of Pollution Prevention and Monitoring for The Ocean Conservancy in Virginia Beach also provided invaluable support during the time I was finishing the dissertation. My director, Seba Sheavly and coworkers Charlie (a VIMS Alum!), Sonya, Adina and Bertha made working on coral reef issues a wonderful experience.

Finally, to members of my family: my parents, Jeannette and Edward Pilon, my siblings Sandra and Ed Pilon Jr., and my nieces and nephews (Vanessa, Casey, Nathalie and Kenneth), thanks for all the support and love.

To my husband Frankie Gross, I owe the most: Love, friendship, support and a shoulder to lean on, I could not have done this without you.....I love you.

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ABSTRACT

Determining organic matter sources and their availability to higher organisms is essential to better understanding the link between organic matter (OM) dynamics and secondary production, particularly in highly-disturbed river-delta systems. The San Francisco Bay and its associated Delta, is one of the most modified aquatic systems, and is the focus of an ongoing restoration effort. Particulate organic matter (POM) and surficial sediments were collected in the Sacramento-San Joaquin River Delta, CA to document temporal and spatial variations in biochemical, (total protein, carbohydrate and lipid), lipid biomarker, and total hydrolysable amino acid (THAA) composition. Sources, composition and nutritional quality of OM was assessed at ten sites representing diverse sub-habitats including each of the two major rivers, rehabilitated shallow-water, open water and natural marsh habitats.

Biochemical and biomarker results showed that terrigenous OM and phytoplankton were the primary sources of POM in the Sacramento and San Joaquin Rivers. On average, the Sacramento River exhibited lower quality POM than the San Joaquin River, due to lower contributions from phytoplankton. Winter periods were characterized by increased delivery of highly degraded, low-quality POM, resulting from higher freshwater flows. In contrast, low flow periods were characterized by phytoplankton blooms and higher-quality POM, particularly in the San Joaquin River during summer.

Phytoplankton, submerged macrophytes and terrigenous OM were the dominant sources in SPM and sediments at all shallow-water sites, but to differing degrees. Between-site differences are likely due to variations in the frequency and size of phytoplankton and macrophyte blooms, hydrodynamics and grazing pressures. Shallow-water sites exhibited higher concentrations of biomarkers representing phytoplankton/algal sources than river sites, indicating POM of higher nutritional quality. THAA-based degradation indices (DI) were used to characterize habitats in terms of organic matter degradation state. DI indicated that shallow-water habitats were characterized by less degraded POM than river sites, corroborating lipid biomarker analyses.

This study demonstrates the value of using a multiple biomarker approach in complex systems such as the Delta. This approach, incorporated into a larger study of the system's biology, hydrology and chemistry provides a useful strategy for addressing management issues in complex deltaic-estuarine systems.

SOURCES AND COMPOSITION OF PARTICULATE ORGANIC MATTER IN THE
SACRAMENTO-SAN JOAQUIN RIVER DELTA, CA

CHAPTER 1

INTRODUCTION

Rivers discharge ~0.4×10^{15}gC yr^{-1} (Meybeck 1982; Hedges 1992), providing a potentially important source of organic carbon to the coastal ocean. In many cases, this carbon initially discharges into estuaries, where it may be transformed prior to being delivered into the ocean. These regions provide important ecological services, acting as conduits and modifying chemical species from the terrestrial/anthropogenic realm to the marine realm, providing habitat for plants and animals unique to this system, and home to human populations. Much of the high temporal and spatial variability in chemical, physical and biological processes that characterizes riverine/estuarine systems occurs through variability in climatic, anthropogenic and hydrological conditions (Mannino and Harvey 1999; Lehman 2000; Kimmerer 2004). Because of this incredible complexity, these regions are one of the most challenging environments in which to study the sources, transformations and fate of organic matter (Hedges and Keil 1999). Although much scientific effort has been directed towards understanding estuarine ecology and estuarine food web dynamics, it is still not known what types of organic matter form the base of the food web supporting higher trophic levels in these systems. Determining organic matter sources and their availability to higher organisms is essential to better understanding the link between organic matter dynamics and secondary production in these systems. This is particularly true for highly disturbed estuaries, where a basic understanding of the sources and quality of organic matter is needed to reverse ecosystem degradation.

The Sacramento-San Joaquin River Delta (hereafter, Delta) is located in the northern region of San Francisco Bay, and drains 153,000 km^2, or 40% of California (Conomos et al. 1985). The Delta is tidal, but salinity intrusion is usually limited to its western extension during periods of low river flow. The Delta extends northward to upstream of Sacramento, eastward to the city of Stockton, south to Vernalis, and west to Chipps Island (DWR 1995). The area of the Delta covers 4100 km^2 and 1540 km of waterways (Arthur et al. 1996). Landforms in the Delta are partitioned into tracts separated from rivers by man-made earthen levees. The Delta incorporates a diverse number of habitats, ranging from rivers lined with riparian vegetation to unaltered marsh habitat as well as agricultural lands and sub-tidal shallow-water habitats (Jassby and

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Cloern 2000; Sobczak et al. 2005). Water depths range from less than 1 m in shallow-water habitats to 15 m in channels (Jassby and Cloern 2000). The Sacramento River is the largest source of freshwater to the Delta, supplying 63-83% of the total freshwater over the last 43 years (since completion of most major reservoirs on the Sacramento River). The San Joaquin River accounts for 13-33% of the monthly flow (Arthur et al. 1996). The region has a mild Mediterranean climate with two seasons: a dry summer/autumn season when river flow to the estuary is typically less than 500 m s^{-1}, and a wet winter season when river flow ranges from 1000-10000 m s^{-1} (Nichols and Luoma 1997). The Delta is considered nutrient-rich (Jassby et al. 2002), with nutrients supplied largely through agricultural drainage (Jassby and Cloern 2000).

Since the first wave of gold miners arrived in the 1850s, the Delta has undergone dramatic structural and ecological changes (Nichols et al. 1986, Arthur et al. 1996, Lehman 2000). In its former pristine state 150 years ago, the Delta consisted of large areas of marshlands and meandering river channels (Atwater and Belknap 1980). Today, of the original 2200 km^2 of wetlands surrounding San Francisco Bay and the Delta, all but 85 km^2 has been filled or diked, primarily for agriculture (Nichols et al. 1986). The series of dams and aqueducts constructed in California rivers, one of the largest storage and delivery systems in the world, has greatly reduced water and sediment inputs to the adjacent estuary, particularly during spring (Nichols et al. 1986; Peterson et al. 1989). More than 60% of river flow is now diverted for agricultural use and urban consumption before it reaches the estuary (Nichols et al. 1986). Large expanses of the relatively deep open water that presently occur in flooded Delta islands (former agricultural tracts flooded by levee breaks) were not a part of the original landscape (Brown 2003). San Francisco Bay is also considered one of the most disturbed estuaries due to the large numbers of introduced or non-native species (Cohen and Carlton 1998; Toft et al. 2003). Many invasive species, including zooplankton, benthic invertebrates and fish have migrated into the Delta (Hymanson et al. 1994; Cohen and Carlton 1995) and estimates indicate that one new species is established in the Delta every fourteen weeks (Cohen and Carlton 1998). Concurrent with these changes juvenile and adult fish populations have declined (Bennett and Moyle 1996, Sobczak et al. 2002).

Based on these declines and general habitat degradation of the Delta, a large-scale restoration/rehabilitation project has been established for the Delta (CALFED 2000; Jassby and Cloern 2000). Efforts to rehabilitate the Delta are aimed at increasing primary and secondary production and the food resources available to fish. This plan for rehabilitating the Delta provided the motivation for the study presented in this dissertation. Rehabilitation actions proposed for the Delta include: (1) construction of new canals to facilitate movement of water from the Sacramento River to the pump intakes in the southern Delta, (2) removal of some levees to flood agricultural lands and establish new, permanent shallow-water habitats and (3) increased use of floodplains as temporary seasonal shallow-water habitats (CALFED 2000; Jassby and Cloern 2000).

Until recently, organic carbon had not been characterized in the Sacramento-San Joaquin River Delta, and little was known about the sources, transport and fate of dissolved and particulate organic carbon (DOC and POC, respectively). Previous studies of organic carbon had focused on Northern and Southern San Francisco Bay (Spiker and Schemel 1979; Jassby and Powell 1993; Canuel et al. 1995; Canuel and Cloern 1996; Murrell and Hollibaugh 2000), and indicated that river flow strongly affected organic carbon source and concentration in the northern Delta, while the spring phytoplankton bloom was the dominant control on organic carbon in the south. A recent multi-institute, interdisciplinary study, of which the current study was a part, investigated organic carbon dynamics at multiple sites in different habitats within the Delta, including the Sacramento and San Joaquin Rivers, shallow-water habitats, tidal marsh, and water export sites. Jassby and Cloern (2000) set the tone for future study of Delta organic carbon dynamics using historical water chemistry data records to determine that the primary sources of bulk organic carbon are tributary-borne loading and phytoplankton production. Secondary sources of organic carbon included agricultural drainage, vascular plants and tidal marsh export (Jassby and Cloern 2000). Cloern et al. (2002) utilized stable isotopes (δ^{13}C, δ^{15}N) to determine sources of POC to the Delta, but found that isotopic signatures of primary producers overlapped in the Delta, and were not useful in resolving POC sources. Despite the fact that phytoplankton production is far below most estuaries (Jassby et al. 2002), the importance of phytoplankton carbon was recognized when Müller-Solger et al. (2002) showed that chlorophyll a concentration was a good predictor

of zooplankton production in the Delta. This indicated that phytoplankton carbon was the preferred food source for zooplankton in the Delta, rather than detrital carbon, which is far more abundant. Sobczak et al. (2002, 2005), further explored POC and DOC availability in the Delta using bioassays, and showed that DOC, despite representing a higher fraction of Delta organic carbon, was largely unavailable for biological utilization, while a greater percentage of POC was bioavailable. Phytoplankton carbon, despite making up only 5% of POC, made up >90% of bioavailable POC in some Delta habitats (Sobczak et al. 2005). Results from these studies concluded that POC is an important food resource, and that Delta organisms are likely food-limited, leading to lower secondary production. However, to date, only bulk DOC and POC has been examined in the Delta.

In other systems, several biochemical and molecular techniques have been employed to characterize organic carbon sources and quality. Measures of the characterizable biochemical classes, including protein, carbohydrate and lipid, can provide a conservative estimate of the amount of potentially metabolizable organic carbon available to secondary producers (Fichez et al. 1993; Fabiano and Danovaro 1994). Lipids (sterols and fatty acids) are powerful tracers of organic matter in aquatic systems due to their specific pathways of biosynthesis, adaptation of biosynthetic pathways to environmental parameters and stability in recent sediments (Volkman 1986). Biomarkers such as sterols have been successfully used as proxies for various species of marine and terrestrial plants and animals (Volkman 1986) and sewage (LeBlanc et al. 1992) and have proven to be useful tracers in systems characterized by complex sources (Canuel 2001 and references therein). These compounds possess structural features, such as number of double bonds, double bond positions, functional groups and side-chain alkylation patterns, which are specific to groups of organisms (Volkman 1986). Additionally, hydrolyzable amino acids, derived from proteins, low-molecular weight peptides, and/or bound amino acid monomers, may comprise a significant fraction (40-60%) of particulate nitrogen in coastal and oceanic water columns (Nguyen and Harvey 1998). Amino acids also provide important nutrients to secondary producers (Cowie and Hedges 1992). Amino acids can be characterized as either protein (i.e. aspartic acid) or non-protein amino acids (i.e. β-alanine, a degradation product of aspartic acid). Because

all proteins are comprised of the same complement of L-amino acids, and because of their lability, amino acids are less useful for distinguishing sources (Cowie and Hedges 1992). However, high yields of total amino acids are consistent with fresh plankton sources (Cowie and Hedges 1994) and non-protein amino acids usually reflect bacterial processing (Dauwe and Middelburg 1998). In addition to their quantitative importance and limited usefulness in assessing organic matter sources, amino acids can be used to provide indices of diagenetic maturity (Dauwe and Middelburg 1998; Dauwe et al. 1999). The extent of degradation of different components of natural organic mixtures relative to starting or fresh organic matter largely determines their potential to act as nutritional substrates (Cowie and Hedges 1994).

Despite the recent insights into Delta organic carbon dynamics, key questions still need to be addressed. A detailed characterization of organic carbon, particularly POC, is needed to determine what components are potentially useful to organisms residing in the Delta. Additional information is needed to address the following questions:

1) What are the primary sources of POC in the Delta and how does their abundance vary within sub-habitats?

2) Chlorophyll *a* has provided an indirect measure of food quality (the ability for POC to be metabolized) in the Delta. To fully understand organic carbon quality, what is the biochemical and nutritional composition of POC in the Delta and does food quality vary spatially and temporally among habitats?

3) In areas where benthic food webs are also important, such as shallow-water habitats, what are the sources and quality of organic carbon available for benthic consumers?

4) Based on low productivity and high river-borne loading, can we identify sites of high and low quality organic matter based on the degradation state of organic matter?

Hypotheses

The main goals of this study were to determine the sources and quality of particulate organic carbon across a wide range of habitat types and substrates in a highly disturbed and dynamic deltaic environment using the biochemical (total proteins,

carbohydrates and lipids) and molecular (fatty acids, sterols, amino acids) composition. The following four hypotheses were addressed:

1) Seasonal variability in the sources and quantity of POC loading in the Sacramento and San Joaquin Rivers will be reflected in the temporal and spatial variability of biochemical components and lipid biomarkers (Chapter 2). Higher concentrations will be associated with phytoplankton bloom conditions

2) Shallow-water habitats will differ in sources and quality of organic carbon due to functional variability (Chapter 3). The quality of POC will be higher at sites where phytoplankton are the primary source of POC for secondary producers.

3) Because of the shallow depth of these shallow-water habitats, there will be reduced organic matter processing in the water column, leading to surface sediments enriched in labile components, and of greater nutritional value to benthic organisms (Chapter 4). Because of increased light availability, benthic primary producers may be of greater importance, providing additional sources of labile organic matter to benthic organisms.

4) Organic matter in suspended particles and sediments at shallow-water sites will be less degraded, and thus of higher quality, than organic matter at river sites (Chapter 5). Amino acid concentrations will be higher in shallow-water sites, and mole% composition will be enriched in more labile acids such as aspartic and glutamic acids at these sites.

The above hypotheses have been addressed by this research project. This is the first project of this magnitude to utilize the combination of bulk biochemical measurements, lipid biomarker compounds and amino acids in river/estuarine systems. It is also the first project in the Sacramento-San Joaquin River Delta to study molecular and bulk parameters of POM and sediments in detail for a spectrum of sub-habitat types in this ecologically important system. The results and interpretation of this research are

expected to yield recommendations regarding carbon sources and food quality to resource managers in the Delta that address proposed management strategies, and provide insights regarding proposed strategies for rehabilitation of the Delta and other estuaries undergoing restoration projects of similar scope.

REFERENCES

ARTHUR, J. F., M. D. BALL, and S. Y. BAUGHMEN. 1996. Summary of federal and state water project environmental impacts in the San Francisco Bay-Delta Estuary, California, p. 445-495. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

ATWATER, B.F., and D.F. BELKNAP. 1980. Tidal-wetland deposits of the Sacramento-San Joaquin Delta, CA., p. 89-103. In W.E. Field, A.H. Bouma, I.P. Colburn, R.G. Douglas, and J.C. Ingle [eds.], Quarternary depositional environments of the Pacific Coast: Pacific Coast paleogeography symposium 4. Proceedings of the Society of Ecomonic Paleontologists and Mineralogists, Los Angeles.

BENNETT, W. A., and P. B. MOYLE. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary, p. 519-542. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

BROWN, L. R. 2003. Will Tidal Wetland Restoration Enhance Populations of Native Fishes. San Francisco Estuary and Watershed Science (online serial). 1.

CALFED. 2000. California's water future: a framework for action. CALFED Bay-Delta Program, Sacramento, California, USA.

CANUEL, E. A. 2001. Relations between river flow, primary production and fatty acid composition of particulate organic matter in San Francisco and Chesapeake Bays: a multivariate approach. Org. Geochem. 32: 563-583.

CANUEL, E. A., and J. E. CLOERN. 1996. Regional differences in the origins of organic matter in the San Francisco Bay ecosystems, p. 305-324. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

CANUEL, E. A., J. E. CLOERN, D. B. RINGELBERG, J. B. GUCKERT, and G. H. RAU. 1995. Molecular and isotopic tracers used to examine sources of organic matter and its incorporation into the food webs of San Francisco Bay. Limnol. Oceanogr. 40: 67-81.

CLOERN, J. E., E. A. CANUEL, and D. HARRIS. 2002. Stable carbon and nitrogen isotope composition of aquatic and terrestrial plants of the San Francisco Bay estuarine system. Limnol. Oceanogr. 47: 713-729.

COHEN, A.N., and J.T. CARLTON. 1995. Nonindigenous aquatic species in a United States Estuary: A case study of the biological invasions of the San Francisco Bay and Delta. U.S. Fish and Wildlife Service.

COHEN, A.N., and J.T. CARLTON. 1998. Accelerating invasion rate in a highly invaded estuary. Science. 279: 555-558.

CONOMOS, T.J., R.E. SMITH, and J.W. GARTNER. 1985. Environmental setting of San Francisco Bay. Hydrobiologia. 129: 1-12.

COWIE, G. L., and J. I. HEDGES. 1992. Sources and reactivities of amino acids in a coastal marine environment. Limnol. Oceanogr.: 703-724.

COWIE, G. L., and J. I. HEDGES. 1994. Biochemical indicators of diagenetic alteration in natural organic matter mixtures. Nature 369: 304-307.

DAUWE, B., and J. J. MIDDELBURG. 1998. Amino acids and hexosamines as indicators of organic matter degradation state in North Sea sediments. Limnol. Oceanogr. 43: 782-798.

DAUWE, B., J. J. MIDDELBURG, P. M. J. HERMAN, and C. H. R. HEIP. 1999. Linking diagenetic alteration of amino acids and bulk organic matter reactivity. Limnol. Oceanogr. 44: 1809-1815.

[DWR] CALIFORNIA DEPARTMENT OF WATER RESOURCES. 1995. Sacramento-San Joaquin Delta Atlas. California Department of Water Resources. 121 pp.

FABIANO, M., and R. DANAVARO. 1994. Composition of organic matter in sediments facing a river estuary (Tyrrhenian Sea): relationships with bacteria and microphytobenthic biomass. Hydrobiologia. 277: 71-84.

FICHEZ, R., P. DENNIS, M. F. FONTAINE, and T. D. JICKELLS. 1993. Isotopic and biochemical composition of particulate organic matter in a shallow water estuary (Great Ouse, North Sea, England). Mar. Chem. 43: 263-272.

HEDGES, J. I. 1992. Global biogeochemical cycles: progress and problems. Mar. Chem. 39: 67-93.

HEDGES, J. I., and R. G. KEIL. 1999. Organic geochemical perspectives on estuarine processes: sorption reactions and consequences. Mar. Chem. 65: 55-65.

HYMANSON, Z., D. MAYER and J. STEINBECK. 1994. Long-term trends in benthos abundance and persistence in the upper Sacramento-San Joaquin Estuary, - Summary Report: 1980-1990. IEP Technical Report. 38. 68 pp.

JASSBY, A. D., J. E. CLOERN, and T. M. POWELL. 1993. Organic carbon sources and sinks in San Francisco Bay: variability induced by river flow. Mar. Ecol. Prog. Ser. 95: 39-54.

JASSBY, A. D., and J. E. CLOERN. 2000. Organic carbon sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquat. Conserv.: Mar. Freshwat. Ecosyst. 10: 323-352.

JASSBY, A. D., J. E. CLOERN, and B. E. COLE. 2002. Annual primary production: Patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnol. Oceanogr. 47: 698-712.

KIMMERER, W. 2004. Open Water Processes of the San Francisco Estuary: From Physical Forcing to Biological Responses. San Francisco Estuary and Watershed Science (online serial). 2.

LEBLANC, L. A., J. S. LATIMER, J. T. ELLIS, and J. G. QUINN. 1992. The geochemistry of coprostanol in waters and surface sediments from Narragansett Bay. Estuar. Coast Shelf Sci. 34: 439-458.

LEHMAN. 2000. The influence of climate on phytoplankton community biomass in San Francisco Bay Estuary. Limnol. Oceanogr. 45: 580-590.

MANNINO, A., and H. R. HARVEY. 1999. Lipid composition in particulate and dissolved organic matter in the Delaware Estuary: Sources and diagenetic patterns. Geochim. Cosmochim. Acta 63: 2219-2235.

MEYBECK, M. 1982. Carbon, nitrogen, and phosphorus transport by world rivers. Am. J. Sci. 282: 401-450.

MÜLLER-SOLGER, A. B., A. D. JASSBY, and D. C. MÜLLER-NAVARRA. 2002. Nutritional quality of food resources for zooplankton (*Daphnia*) in a tidal freshwater system (Sacramento-San Joaquin River Delta). Limnol. Oceanogr. 47: 1468-1476.

MURRELL, M. C., and J. T. HOLLIBAUGH. 2000. Distribution and composition of dissolved and particulate organic carbon in northern San Francisco Bay during low flow conditions. Estuar. Coast. Shelf Sci. 51: 75-90.

NGUYEN, R. T., and H. R. HARVEY. 1998. Protein preservation during early diagenesis in marine waters and sediments, p. 88-112. In B. A. Stankiewicz and P. F. van Bergen [eds.], Nitrogen-Containing Macromolecules in the Bio- and Geosphere. American Chemical Society.

NICHOLS, F. H., and S. N. LUOMA. 1997. Long-term investigations provide fundamental insight into natural and human-induced change in the San Francisco Bay (U.S.A.) Estuary, p. 37-53. In B. F. Keegan, P. J. D. Lambshead, B. C. Coull, M. Overcash and C. Nolan [eds.], Change in marine benthos: the case for long-term studies - Proceedings of a Workshop in Long Term Study Influences on Science and Policy. European Commission Environment Research Programme, Ecosystems Research Report 16.

NICHOLS, F. H., J. E. CLOERN, S. N. LUOMA, and D. H. PETERSON. 1986. The modification of an estuary. Science. 231: 567-573.

PETERSON, D.H., D.R. CAYAN, J.F. FESTA, F.H. NICHOLS, R.A. WALTERS, J.V. SLACK, S.E. HAGER, and L.E. SCHEMEL. 1989. Climate variability in an estuary: effects of riverflow on San Francisco Bay. Geophys. Monogr. 55: 419-442.

SPIKER, E. C., and L. E. SCHEMEL. 1979. Distribution and stable-isotope composition of carbon in San Francisco Bay, p. 195-212. In T. J. Conomos [ed.], San Francisco Bay: The Urbanized Estuary. Pacific Division of the American Association for the Advancement of Science.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, and A. B. MÜLLER-SOLGER. 2002. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. Proc. Natl. Acad. Sci. 99: 8101-8105.

SOBCZAK, W.V., J.E. CLOERN, A.D. JASSBY, B.E. COLE, T.S. SCHRAGA, and A. ARNSBERG. 2005. Detritus fuels ecosystem metabolism but not metazoan food webs in San Francisco Estuary's freshwater Delta. Estuaries. 28: 124-137.

TOFT, J. D., C. A. SIMENSTAD, J. R. CORDELL, and L. F. GRIMALDO. 2003. The effects of introduced water hyacinth on habitat structure, invertebrate assemblages and fish diets. Estuaries. 26: 746-758.

VOLKMAN, J. K. 1986. A review of sterol markers for marine and terrigenous organic matter. Org. Geochem. 9: 83-99.

CHAPTER 2

SPATIAL AND TEMPORAL VARIATIONS IN ORGANIC CARBON DYNAMICS
OF THE SACRAMENTO AND SAN JOAQUIN RIVERS, CA

ABSTRACT

Biochemical compounds (total proteins, carbohydrates and lipids) and lipid biomarker compounds (fatty acids and sterols) associated with suspended particulate matter (SPM) were measured during nine cruises during 1998-2000 to determine sources and quality of organic carbon in the Sacramento and San Joaquin Rivers, CA. Biochemical compounds, measures of nutritional quality, varied between the rivers. The protein and lipid fractions of particulate organic carbon were similar in both rivers, but varied temporally; higher concentrations were observed in spring and fall in the Sacramento River, while higher concentrations occurred during summer in the San Joaquin River. Overall, carbohydrate concentrations were higher in the San Joaquin River, with higher values in the spring, summer and fall. Lipids (TLE-C) were the only biochemical class that was positively correlated with chlorophyll a at all sites. Fatty acid and sterol biomarker compounds indicated that both rivers were influenced by contributions from diverse sources of organic matter including vascular plants, phytoplankton, bacteria and zooplankton. Polyunsaturated fatty acids (PUFAs), essential fatty acids for invertebrates and fish were higher in the San Joaquin River, particularly during summer, indicative of higher food quality during this time. In the Sacramento River, PUFAs reached their maximum in spring, a period of high larval fish recruitment in the Delta. Lipid measures used to assess organic matter degradation (branched fatty acids and stanol/stenol ratios) were higher in winter, during high flow periods in both rivers. Food energy calculations also were also higher in the San Joaquin River, likely due the abundance of phytoplankton that contain high-energy lipids. Based on food energy and the relative abundance of PUFAs, the San Joaquin River has SPM of a higher quality than the Sacramento River. Relative to other North American rivers, bulk SPM characteristics (SPM, POC, chl a) are similar to other rivers, while the composition and abundance of lipid classes (total fatty acids and sterols) are comparable to the Delaware River, but lower than the York River, VA.

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INTRODUCTION

River inputs of suspended particles and organic matter provide an important connection between land and the coastal ocean, and are controlled by a complex interplay of physical, geological and biological processes. The riverine export of organic carbon from land to estuarine ecosystems can be substantial (Degens and Ittekot 1985), with estimates on the order of 0.4×10^{15} gC yr^{-1} (Richey et al. 2004). Although this input is low relative to the other carbon pools linked by rivers, soils (1515×10^{15}g C yr^{-1}, Schlesinger 1984) and the ocean ($40\,600 \times 10^{15}$g C yr^{-1}, JGOFS 1992), these contributions may be important to the uptake of atmospheric CO_2 and carbon burial in coastal areas (Degens and Ittekot 1985; Hedges et al. 1988). River carbon is comprised of particulate (POC) and dissolved (DOC) forms (Spitzy and Ittekot 1991), and composed of biologically inert material such as humic acids and polyphenols, as well as metabolizable compounds such as fatty acids and proteins which are easily degraded in riverine environments (Degens 1982). POC transport in the world's rivers is in the range of 0.19-0.23×10^{15} gC yr^{-1}, of which roughly 35% (0.08×10^{15} gC yr^{-1}) is estimated to belong to the metabolizable fraction (Ittekot 1988; Ittekot and Laane 1991). While the influences of POC and DOC carried by large rivers on estuarine and coastal regions are recognized, recent data have indicated that small and mid-sized rivers (rivers not identified as one of the 25 major word rivers) may affect marine ecosystems both on regional (Cauwet et al. 1990), and global scales (Blair et al. 2003; Leithold et al. 2005).

The composition and quality of particulate organic matter (POM) in rivers is influenced by the balance of various processes, including adsorption/desorption, advection/settling, and production/grazing (Hopkinson and Vallino 1995). Most rivers are net heterotrophic (Cole and Caraco 2001) with the organic matter fueling heterotrophy originating primarily from allochthonous inputs from river drainage basins (Hopkinson and Vallino 1995; Gupta 1997). It has been generally assumed that riverine organic carbon is relatively refractory and largely unavailable for metabolic breakdown in the time frame of estuarine mixing and burial (Ittekot and Laane 1991; Hopkinson et al. 1998). This is due to the highly degraded nature of terrigenous organic matter as well as transformations occurring during river transport (Hopkinson et al. 1998). Hence, the

quantity and quality of POC entering the coastal zone is different from that entering rivers from land (Ittekot and Laane 199; Hopkinson et al. 1998). The organic composition of riverine suspended particles may affect the trophic pathways and the biochemical processes of the rivers and the estuaries/coastal waters into which they drain. Rivers are also dynamic systems with variability driven by high-frequency tidal fluctuations, seasonal changes in freshwater flows, long-term alterations in hydrology and climate, and changes in land use within the drainage basin (Findlay et al. 1996). Information on the magnitude of spatial and temporal variation and the underlying mechanisms contributing to these variations is important both for improving our basic understanding of organic carbon dynamics as well as for understanding and managing rivers (Findlay et al. 1996).

Many organic geochemical studies of organic carbon quality have focused on measures of elemental composition (C/N ratios, POC, PN), stable isotopes (Thurman 1985; Depetris and Kempe 1993) and lignin phenols (Hopkinson et al. 1998). Studies involving the analysis of individual compounds are less common (Kempe and Depetris 1992; Hedges et al. 1994), with few addressing both biochemical and molecular level compounds in small and mid-sized rivers. Proteins, carbohydrates and lipids are the basic biochemical components of all organisms, and their total contribution to riverine POM can allow us to determine the amount of organic matter which may be utilized by secondary producers within river systems (Zhang et al 1992). Lipid biomarkers, compounds whose structures can be related to specific biological sources, have been used in studies to determine both organic carbon sources and the quality of organic carbon in different aquatic ecosystems (Laureillard and Saliot 1993; Mudge and Norris 1997; Canuel 2001). Specifically, fatty acid and sterol biomarker compounds have been utilized as measures of the sources and quality of organic matter in riverine and estuarine ecosystems (Saliot et al. 1988; Galois et al. 1996; Canuel 2001 and references therein).

The Sacramento and San Joaquin Rivers are the two major rivers entering the Sacramento-San Joaquin Delta and northern San Francisco Bay and contribute 85% and 15% of freshwater input to northern San Francisco Bay, respectively (Fig. 1). Dramatic declines in phytoplankton production (Lehman and Smith 1991) and zooplankton production (Nichols et al.1986; Orsi and Mecum 1996; Kimmerer and Orsi 1996) over

the last three decades in Northern San Francisco Bay and the adjacent Delta have been attributed to alterations in river flow. Restoring productivity of this region is the focus of large restoration efforts. Due to the large influx of suspended sediments and POM from these rivers and low primary production (Jassby and Powell 1994; Schemel et al. 1996), the northern region of San Francisco Bay has been thought to support a detrital-based food web (Jassby and Powell 1994; Jassby et al. 2002). Consistent with this, Jassby and Cloern (2000) identified the major sources of organic carbon to the system as tributary-borne loading and agricultural runoff into rivers. Recent studies in other systems have indicated that rivers may be dominated by detrital organic carbon that is "old" based on its radiocarbon age (Raymond and Bauer 2001), and hence of potentially lower quality to secondary producers such as zooplankton. Thus, phytoplankton-derived organic carbon, although it may not be important quantitatively, may play a disproportionate role in controlling food quality and secondary production in the Delta (Jassby and Cloern 2000; Jassby et al. 2002; Sobczak et al. 2002; Müller-Solger et al. 2002). In the Delta rivers, phytoplankton blooms are controlled by river flow and seasonal runoff, with the San Joaquin River generally characterized as more productive than the Sacramento River, despite differences in river sizes (Jassby and Cloern 2000). Knowles (2000) indicated that interannual variability in both the timing and the volume of river flows can be large due to natural (large rainfall events) and human effects (reservoir release, water diversion). Therefore, the timing of changes in river flow, and spatial differences in each of these rivers, may play an important role in determining organic carbon quality in each major river and its delivery to northern San Francisco Bay. In this study, we used the dominant rivers draining into northern San Francisco Bay and the adjacent Delta as model systems for examining the role of interannual fluctuations in flow on the source and composition of POC at the biochemical and molecular level in small (San Joaquin) and mid-sized (Sacramento) rivers.

To address spatial and temporal differences in the sources and quality of POC in the Sacramento and San Joaquin Rivers, measurements of bulk parameters (C:N atomic ratios (C:N_a), chlorophyll a, phaeophytin), biochemical classes (proteins, carbohydrates and lipids) and molecular markers (select sterols and fatty acids) were made seasonally over two years, and during high and low flow periods. In particular, we examined: 1)

spatial and temporal variations in organic matter sources to each river, 2) variations in food quality between rivers, and 3) implications of food quality for river rehabilitation strategies.

MATERIALS AND METHODS

STUDY AREA

The Sacramento-San Joaquin River Delta (hereafter referred to as the Delta) is part of the drainage system within California that flows into San Francisco Bay. The Delta extends northward to upstream of Sacramento, eastward to the city of Stockton, south to Vernalis, and west to Chipps Island (DWR 1995). The Delta receives drainage from 153,000 km^2, or 40% of California (Conomos et al. 1985; Lehman and Smith 1991). The area of the Delta covers 4100 km^2, and 1540 km of waterways (Arthur et al. 1996), with the Sacramento and San Joaquin Rivers being the two major rivers draining into the Delta (Fig. 1). The Sacramento River, the largest source of freshwater to the Delta, flows from the north and has supplied 63-83% of the total freshwater over the last 43 years (since completion of most major reservoirs on the Sacramento River). The San Joaquin River flows from the south and accounts for 13-33% of the monthly flow (Arthur et al. 1996). The combined outflow of the rivers ranges from 1000-10000 m^3 s^{-1} during the winter and spring, to 100-500 m^3 s^{-1} in the summer and fall. Semi-diurnal tidal currents flow upstream within the Sacramento River at 1-3 m^3 s^{-1} and affect daily river flows throughout the Delta. Seawater often intrudes upstream during the summer and fall (Lehman and Smith 1991). Water from the Sacramento River is drawn through the Delta Cross Channel, and Three Mile Slough during low flow periods to the water pumps of the state and federal export facilities in the southern Delta (Arthur et al. 1996). This can drastically alter the way water flows through the estuary, often producing reverse flows in the San Joaquin River (Moyle et al. 1992; Arthur et al. 1996).

SAMPLE COLLECTION

Suspended particle samples were collected from two sites on the Sacramento River, and two sites on the San Joaquin River (Fig. 1). These were Hood (HD) and Rio Vista (RV) on the Sacramento River, and Mossdale (MM) and Twitchell Island (TI) on the San Joaquin River. Samples were collected on nine cruises from October 1998 – July 2000 representing periods of high and low flow (Fig. 2). Because water depth varied at each of the study sites (Table 1), samples were collected from 1-m above the bottom to standardize the samplings. Water was collected using a large-volume peristaltic pump

and filtered through a 243 µm Nitex mesh to remove large particles and zooplankton. For lipid samples, water was collected into 40-1 stainless steel cans, while water for bulk biochemical analyses, nutrients and POC/PON were filtered into 15 L plastic jugs that were pre-rinsed with distilled water. Particulate matter for lipid analyses was collected by filtration using 142 mm diameter glass fiber filters (GFF), per-baked at 450 °C for 4 hours, and a single sample was generally collected due to the length of filtering time (approximately 3 hours). For bulk biochemical analyses, samples of total carbohydrate measurements were filtered onto 47 mm GF filters, in triplicate, while samples for total protein analyses were filtered onto 25 mm GFF filters.

Separate aliquots of water were filtered onto GF/F filters for particulate organic carbon (POC) and nitrogen (PN), chlorophyll a (chl a), phaeophytin and suspended particulate matter (SPM). These samples were analyzed at the U.S. Geological Survey in Menlo Park, CA (Sobczak et al. 2005).

LIPID EXTRACTION AND ANALYSIS

Prior to extraction, filters were shredded into small pieces using forceps rinsed with methanol, 2:1 methanol/dichloromethane, and hexane. The shredded filters were placed into a pre-rinsed Teflon liner and spiked with surrogate standards of myristyl arachidonate, methyl nonadecanoate and nonadecanol prior to microwave extraction (CEM MSP100) at 80°C and 200 psi for ten minutes. Samples were extracted twice using a modification of the method of Bligh and Dyer (1959) with 2:1 (v:v) methylene chloride: methanol. Samples were centrifuged and the solvent decanted to a separatory funnel following each extraction. Water and methanol were added to create a mixture 2:2:1.9 (MeCl$_2$: MeOH: H$_2$O; v:v:v) and the samples were shaken. Samples were allowed to separate into two phases and the lower (organic) phase was collected to a round-bottomed flask. The aqueous phase was back-extracted with hexane and the hexane phase was collected into the round-bottomed flask. A portion of the lipid extract (generally 50%) was saponified (base hydrolyzed) using 1N KOH in aqueous CH$_3$OH, to cleave ester linkages. During saponification, samples were heated to 110°C using a dry heating block for 2 hr. Neutral lipids were extracted into hexane (nC$_6$) under basic conditions, and acidic lipids were extracted into nC$_6$ under acidic conditions (pH=2)

(Canuel and Martens 1993). The neutral fraction was subsequently separated into lipid classes using column chromatography (5% deactivated silica), and solvents of increasing polarity from hexane through 20% ethyl acetate in hexane. The alcohol/sterol fraction was eluted with 15% and 20% ethyl acetate in hexane. The acid fraction was methylated using 3% BF_3-CH_3OH and purified by column chromatography. Sterols and fatty acid methyl esters (FAMEs) were analyzed by gas chromatography (Canuel and Zimmerman 1999). Internal standards (methyl heneicosanoate and 5α-cholestane) were added to the fatty acid and alcohol/sterol fractions, respectively and used for quantification. Sterols and FAMEs were analyzed by gas chromatography using a 30 m x 0.32 mm i.d. DB-5 fused silica capillary column with a flame ionization detector. Sample injection temperature was 60 °C with a helium gas (carrier gas) flow rate of 2.3 ml min^{-1}. Following an initial fast ramp to 110 °C (FAMEs) and 225 °C (sterols), temperature was increased at 3 °C min^{-1} to 280 °C (FAMEs) and 310 °C (sterols/alcohols). Individual peaks were identified based on relative retention times of known standards and peak areas were quantified relative to internal standards. Mass spectrometry using a Hewlett Packard 5972 mass selective detector interfaced with a HP 6890 GC was used to confirm compound identifications.

TOTAL LIPIDS

From the remainder of the total lipid extract (TLE), triplicate sub-samples of 10 µl each were added to 5 ml foil cups and weighed on a microbalance. These weights were used to calculate TLE concentrations gravimetrically (De Baar et al. 1983). Lipid–carbon equivalents were calculated by multiplying total lipid concentrations by a conversion factor (0.75 µg C $µg^{-1}$ lipid, Fichez 1991) prior to normalizing data to POC.

TOTAL PROTEINS

Samples (25 mm GF/F) were analyzed for total particle protein (PROT) using a modification of Nguyen and Harvey (1994). Filters were dried for 30 minutes at 60 °C and transferred to 1.8 ml centrifuge tubes. NaOH (500 µl of 0.1 N) was added to each tube, and centrifuged for 1 minute at 16,000 x g. The tubes were then incubated for 15 minutes at 4 °C in a cold room. Samples were then homogenized and the filters broken

up using a sonicating tip for 2 minutes, at 30% power. Samples were then diluted by adding 1 ml distilled water (total volume 1.5 ml), and vortexed for 30 seconds. Samples were centrifuged again for 20 minutes at 16,000 x g, to pellet particulates and filtered.

A portion (100 μl) of the supernatate from the sample was transferred to a 15 ml round-bottom centrifuge tube. A working solution of bicinchoninic acid (BCA) was added (2 ml), and the samples incubated for 60 minutes at 60 °C in a drying oven. Samples and standards were then read on a spectrophotometer at 562 nm against a - reagent blank of BCA working solution. Protein-carbon equivalents were calculated using a conversion factor of 0.49 μg C μg^{-1} (Fichez 1991) prior to normalizing to POC

TOTAL CARBOHYDRATES

Total carbohydrates (TCHO) were quantified using the Pakulski and Benner (1992) method for suspended particles. Carbohydrate-carbon equivalents were calculated using a conversion factor of 0.40 μg C μg^{-1} carbohydrate (Fichez 1991) prior to normalizing to POC.

ANALYTICAL PRECISION AND SAMPLING ERROR

Analytical precision was measured by comparing triplicate samples of total protein, total carbohydrate and total lipid of suspended particle samples. The analytical precision, taken as the median of three aliquots, was 1.42 μg mg^{-1} OC for total proteins, 2.74 μg mg^{-1} OC for total carbohydrates, and 3.74 μg mg^{-1} OC for total lipids (Fig. 3a).

Sampling error was examined, as the median of triplicate samples of suspended particle matter collected at the same site for total proteins and carbohydrates, and the median of replicate samples of total lipid samples collected at the same time. The difference between samples was larger than the differences between aliquots. They were 2.63 μg mg^{-1} OC for total proteins, 3.34 μg mg^{-1} OC for total carbohydrates, and 9.00 μg mg^{-1} OC for total lipids (Fig. 3b).

STATISTICAL ANALYSES

Data were analyzed statistically using MiniTab (Minitab Inc.: release 13.32, 2003). Analytical results were used in a multivariate statistical analysis (Principal Components Analysis). The analysis included the concentrations of individual lipid biomarkers and

biochemical compounds normalized to organic carbon (μg mg^{-1} OC). Some variables were grouped to reflect a common source. All concentrations were log-transformed prior to analysis, which distributes data points more uniformly on the principal component plots and simplifies plot examination (Meglen 1992). Transformed data were subjected to a R-mode varimax factor analysis, which simplifies the loading structure, allowing you to more easily interpret the factor loadings. Varimax rotation maximizes variance of squared loadings within factors (i.e. simplifies the columns of the loading matrix). This method attempts to make the loadings either large or small to ease interpretation (Minitab Inc.: release 13.32, 2003)

Within Minitab, the General Linear Model analysis of variance (ANOVA) was used. Results are considered significant when $p<0.05$. Because our data sometimes violated the assumptions of parametric tests, that all data be normally distributed and display homogeneity of variance, a nonparametric test was also used. For these data, the Fisher's least significant squares (Fisher's LSD) was employed to test the differences of means, after rejecting the null hypothesis using ANOVA. Fisher's LSD method compares the means for each pair of factor levels using the individual error rate you select. Results are reported during analysis as a set of confidence intervals for the difference between pairs of means. If an interval does not contain zero, there is a statistically significant difference between the corresponding means. If the interval does contain zero, the difference between the means is not statistically significant (Minitab Inc.: release 13.32, 2003). All data were log-transformed prior to data analysis to minimize effects from outliers.

For analysis of ANOVA data, data were pooled as follows based on river position: HD and RV (Sacramento River), MM (San Joaquin River), and TI (Mixed source). Although TI is located on the San Joaquin River, it often receives water from the Sacramento River, making it more representative of a mixed or confluence site than a lower San Joaquin River site (Monsen 2001). Seasons were blocked as follows: December-February (Winter), March-May (Spring), June-August (Summer), September – November (Fall). Flows were blocked as follows: flows for Sacramento River with daily cfs < 30000 (low flow), and >30000 (high flow), flows for the San Joaquin River with daily cfs <1500 (low flow) and >1500 (high flow).

The interdependence of variables was tested using the Pearson Product Moment Correlation and coefficient (calculated using Minitab) to measure the degree of linear relationship. The method performs a two-tailed test of the correlation (reported as a p-value) (Helsel and Hirsch 1992).

RESULTS

BULK COMPOSITION

The measurements of bulk organic carbon parameters for river sites are summarized in Sobczak et al. (2005), but not on a monthly or seasonal basis as presented here (Table 1). Overall, chl a, phaeophytin, POC and PN were significantly higher (p<0.01 for each) at MM, while HD, RV and TI had similar values. Chl a concentrations averaged 2.61 ± 1.42 μg L^{-1} in the Sacramento River, and 23.40 ± 32.30 μg L^{-1} at MM, and 1.40 ± 0.80 μg L^{-1} at TI. The highest chl a values occurred at MM in July 1999 (53.30 μg L^{-1}) and July 2000 (98.20 μg L^{-1}). Phaeophytin followed a similar pattern, with concentrations averaging 1.85 ± 0.75 μg L^{-1} at the Sacramento River sites, 6.80 ± 5.29 μg L^{-1} at MM, and 1.80 ± 0.95 μg L^{-1} at TI (Table 1). Maximum phaeophytin concentrations were also found during July 1999 (14.10 μg L^{-1}) and July 2000 (15.70 μg L^{-1}) at MM.

POC and PN averaged 717.51 ± 250.97 μg L^{-1} and 9.75 ± 3.91 μg L^{-1}, respectively, in the Sacramento River, 1624.40 ± 973.21 μg L^{-1} and 29.2 ± 26.31 μg L^{-1} at MM and 717.51 ± 250.97 μg L^{-1} and 9.50 ± 3.94 μg L^{-1} at TI (Table 1). POC and PN were significantly higher at MM than at the Sacramento River sites, while concentrations at TI were similar to the Sacramento River sites throughout the study, at The highest concentrations of POC and PN were coincident with periods when chlorophyll and phaeophytin were high, at MM in July 1999 and July 2000 (Table 1). C:N$_a$ ratios were similar among all sites, averaging 9.00 ± 2.26, although lower ratios of 4.50-6.90 occurred at HD, RV and MM in July 2000, as well as MM in January 1999 (4.8, Table 1). %POC was also similar among sites, at 2.90 ± 1.46%. However, higher % were observed at MM in July 2000 (7.56%) and TI in January 1999 (8.08%).

BIOCHEMICAL COMPOSITION

On the Sacramento River, TLE-C was higher at HD than RV in the winter and spring (Fig. 4e), while in summer and fall, all biochemical compounds were generally higher at HD (Fig. 4a, c, e). At HD, PROT-C and TLE-C (Figs 4a,e) were highest during fall (78.10 ± 2.25 μg mg^{-1}OC and 240.39 ± 10.02 μg mg^{-1}OC, p<0.01), while TCHO-C was highest during summer (235.45 ± 18.59 μg mg^{-1}OC, p<0.01). Downstream at RV, PROT-

C and TCHO-C were highest in the winter (48.94±4.39 µg mg^{-1}OC and 186.56±9.20 µg mg^{-1}OC, Figs. 4a,c), during high flows (p<0.05), while TLE-C concentrations were higher during spring and fall (70.24±10.52 µg mg^{-1}OC and 81.06±37.87 µg mg^{-1}OC, p=0.02).

In the San Joaquin River, TCHO-C and TLE-C varied seasonally, with TCHO-C significantly lower in the fall at MM (119.43±15.12 µg mg^{-1}OC, p=0.02, Fig. 4d), and TLE-C significantly lower at MM in spring and fall (94.84±30.28 µg mg^{-1}OC and 62.44±15.12 µg mg^{-1}OC, Fig. 4f). Variability in the three biochemical classes during winter months resulted from an event during January 1999, when PROT-C, TCHO-C and TLE-C reached significantly higher values (64.26 µg mg^{-1}OC, 281.54 µg mg^{-1}OC, and 217.21 µg mg^{-1}OC, respectively) relative to winter sampling in February 1999 and 2000. At TI, PROT-C was lower in the spring compared to other seasons (11.97±3.13 µg mg^{-1}OC vs. 33.08±10.16 µg mg^{-1}OC, p=0.05, Fig. 4b), while TLE-C was lower in the winter (57.50±26.94 µg mg^{-1}OC vs.125.77±26.21 µg mg^{-1}OC, p=0.01, Fig. 4f) and during high flow periods (p=0.05). TCHO-C did not vary by season at TI, but was elevated during high flow periods (173.80±50.27 µg mg^{-1}OC vs. 107.28±29.73 µg mg^{-1}OC, p=0.01). Despite these temporal variations, concentrations of biochemical compounds were similar in the Sacramento and San Joaquin Rivers on an annual basis.

LIPID MEASURES OF ORGANIC CARBON QUALITY

PUFAs and 20:5ω3 were significantly higher at Sacramento River sites during spring months compared to other months (PUFA: 7.00±2.30 µg mg^{-1}OC vs. 3.15± 1.37 µg mg^{-1}OC, 20:5ω3: 2.34±0.86 µg mg^{-1}OC vs. 0.89±0.41 µg mg^{-1}OC, Figs. 5a,c). In the Sacramento River, PUFAs and 20:5ω3 were similar at HD and RV during all seasons except fall, when PUFAs were higher at HD (5.69±1.13 µg mg^{-1}OC vs. 1.64±0.83 µg mg^{-1}OC for RV). Overall, concentrations of PUFAs and 20:5ω3 were lower during high flow periods (p=0.03) in the Sacramento River (i.e. winter).

PUFA and 20:5ω3 concentrations were significantly higher in the San Joaquin River (MM, Figs. 5b,d) than either the Sacramento River (8.67±6.85 µg mg^{-1}OC and 4.42±3.82 µg mg^{-1}OC respectively), or TI, particularly during winter and summer (Fig.

5). Similar to biochemical classes, concentrations of PUFAs and 20:5w3 were markedly higher at MM in January 1999 (18.35 μg mg^{-1}OC and 7.92 μg mg^{-1}OC), resulting in greater variability during winter months (Fig. 5).

% BrFA were highest in both rivers during winter months, particularly during periods of high flow (high: 6.13±1.62%; low: 3.32±0.52%, Figs. 6a,b). Sacramento River sites displayed higher %BrFA than MM or TI during winter months (7.31±1.43% vs. 4.96±0.53%). Stanol/stenol ratios give an indication of the extent to which organic matter has been transformed/degraded, with higher ratios indicting a greater extent of organic matter degradation, and decreased quality. Ratios of 5α(H)-cholestan-3β-ol/cholest-5-en-3βol ($C_{27}\Delta^{\circ}/C_{27}\Delta^{5}$) were similar among sites and between rivers (Figs 6c,d), but varied significantly over time. Higher ratios occurred during winter months (0.38±0.11), particularly February 1999 and February 2000 (Fig.6c-d). Ratios at other time periods averaged 0.16±0.04.

STEROL COMPOSITION

Thirty-one sterol compounds were identified in suspended particles from the Sacramento and San Joaquin Rivers representing a range of organic carbon sources. A subset of these sterols were used for source identification either because of their higher abundances relative to other sterols identified, or source specificity (Table 2). These eight sterols generally comprised 66-89% of total sterols. Data were expressed as a percentage of total sterols to interpret the relative abundance of each compound and change in the contribution of each relative to total sterols on temporal and spatial scales.

Of the sterols reported, dinosterol ($C_{30}\Delta^{22}$) and coprostanol ($C_{27}\Delta^{\circ}$) made up only a small percentage of the sterols, indicating that dinoflagellates and anthropogenic sewage were not significant sources of organic carbon in the Sacramento or San Joaquin Rivers (Table 3). Dinosterol ranged from 0.0-3.9% in the rivers during the study period, and was similar among sites during all seasons. Coprostanol, on the other hand, showed significant spatial differences, with higher percentages (p<0.01) at HD (2.91±0.84%) and RV (2.87±0.64%) on the Sacramento River than at MM on the San Joaquin River (1.58±0.45%) and TI (1.65±0.56%), the mixed site (Table 3).

Stigmasterol ($C_{29}\Delta^{5,22}$) and 24-ethylcholest-5-en-3β-ol ($C_{29}\Delta^{5}$), two sterols associated primarily with higher plant sources (Table 2), were amongst the dominant sterols at each site over time. Stigmasterol averaged 6.85±1.51% at the sampling sites, with no discernible between-site or temporal differences (Table 3). 24-ethylcholest-5-en-3β-ol was similar in % abundance between sites and between rivers, but differed as a function of flow regimes and seasonally. 24-ethylcholest-5-en-3β-ol was significantly higher (23.65±2.01%, p=0.02) during winter samplings (January 1999, February 1999, February 2000) relative to other seasons and months (15.46±2.85%), and during high flow periods relative to low flow (p<0.01, Table 3). 24-ethylcholest-5-en-3β-ol was lowest (13.93±1.46%) during the summer months (July 1999-2000), a period of low flow in the rivers (Table 3).

Campesterol ($C_{28}\Delta^{5}$), indicative of both plant and algal sources (Table 2) was significantly higher at MM on the San Joaquin River (p<0.01), averaging 19.36±15.81% over the sampling period relative to the Sacramento River and mixed sites (7.95±2.52%, Table 3). Campesterol made up the highest percentage of sterols at MM in July 1999 (41%) and July 2000 (51.1%), months that also correspond to elevated chlorophyll *a*, phaeophytin, TOC and TN concentrations (Table 3)

Sterols that are normally associated with diatom and phytoplankton sources, brassicasterol ($C_{28}\Delta^{5,22}$) and 24-methylenecholesterol ($C_{28}\Delta^{5,24(28)}$) made up 9-23% of total sterols (Table 3). Brassicasterol was significantly lower at the upstream sites, HD (7.99±3.43%) and MM (8.21±2.10%), relative to the downstream (RV:11.9±2.18%) and mixed (TI:12.55±5.25) sites (p=0.01). Overall, brassicasterol was significantly higher at the Sacramento River and mixed sites (p=0.05, Table 3). On a seasonal basis, brassicasterol was significantly lower in the winter (high flow) relative to other seasons at all sites, particularly during February 1999 and 2000 (p<0.03). 24-methylenecholesterol, also indicative of phytoplankton sources (Table 2), exhibited only spatial differences. Abundances of 24-methylenecholesterol were higher on the Sacramento (5.33±1.31%) vs. the San Joaquin River (3.53±1.5%, p=0.05, Table 3), with intermediate concentrations at TI (4.20±1.10%).

Cholesterol ($C_{27}\Delta^{5}$) is typically used as a biomarker for zooplankton, but occurs at trace levels in some algae and higher plants (Table 2). In the Sacramento and San

Joaquin Rivers, cholesterol showed significant spatial, but not temporal differences (Table 3). Cholesterol was significantly lower ($p<0.01$) at MM on the San Joaquin River ($15.41\pm4.59\%$) relative to the other sites ($24.17\pm3.50\%$).

FOOD ENERGY

Food energy was calculated using food energy values from Fabiano and Pusceddu (1998), with lipids having the highest energy value at 39.5 J L^{-1}, proteins at 24.0 J L^{-1} and carbohydrates having the lowest energy values (17.5 J L^{-1}). Food energy was similar at HD, RV and TI (4.67 ± 1.11 J mg^{-1}), but significantly higher at MM (13.96 ± 10.44 J mg^{-1}). Food energy at MM exhibited the highest values in summer, averaging 33.19 ±8.82 J mg^{-1}).

PCA ANALYSIS OF LIPIDS AND BIOCHEMICAL COMPOUNDS

Principal component analysis (PCA) was used to examine the complete data set for all organic matter variables. PC1 loadings were most positive for campesterol, $20:5\omega3$ and 22pufa3 (i.e. $22:5\omega3$ and $22:6\omega3$) and $16:3/2$ with slightly lower values for brassicasterol, $20:4\omega6$, $18:4$, $16:4$, $16:1\omega7$, $14:0$ (Fig. 8a). The compounds with the most negative loadings were $18:0$ and $5\alpha(H)$-stanols. PC 1 separates variables based on degradation state, in particular, PUFA and algal biomarkers vs. degraded (plant) organic matter. PC 1 scores support this interpretation (Fig. 8b, Fig.9), with more positive scores at MM, a site on the San Joaquin River subject to phytoplankton blooms, and more negative scores at TI in January and February 1999 and February 2000.

PC 2 loadings were most positive for campesterol and $14:0$ fatty acid, and brassicasterol, $20:5\omega3$, and carbohydrates. $18:2/3$, Br15,17 were the most negatively weighted compounds, along with $16:1\omega9$, $18:1\omega9c$, $18:1\omega9t$, and $16:0$ (Fig. 8a). Scores for PC 1 are most positive for samples collected in January 1999 and May 1999, and most negative for samples collected in October 1999 and February 2000. PC 2 likely represents variations related to flow conditions (Fig. 8b, Fig. 9).

CORRELATIONS OF POC PARAMETERS

Other studies have used chl *a* as a proxy measurement of food quality, with higher concentrations indicating higher food quality. Therefore, Pearson Product Moment correlations were calculated to determine whether there were significant correlations between biochemical classes and chl *a* (Table 4). Overall, we found positive correlations between chl *a* and PROT-C (r=0.71), TCHO-C (r=0.70) and TLE-C (r=0.80). However, when data were analyzed by site, the results indicated that not all of the biochemical data correlated with chl *a*. On the Sacramento River, only TLE-C was correlated with chl *a* at HD (r=0.85), while at RV, none of the classes correlated with chl *a* (Table 4). At MM, there were significant correlations between all biochemical classes and chl. *a* (r=0.74, 0.80 and 0.91). At TI, there was a significant positive correlation with total lipids (r=0.81), but significant negative correlations between TCHO-C and chl.*a*.

DISCUSSION

SPATIAL AND TEMPORAL VARIATION OF ORGANIC CARBON SOURCES

The origin of organic carbon in rivers and estuaries in complex, with potential sources including terrigenous material such as soil runoff and vascular plants (Hedges et al. 1994), in situ production such as phytoplankton and aquatic macrophytes (Degens 1982; Cloern et al. 2002), resuspended sediments (Small et al. 1990), and organisms such as zooplankton and large vertebrates. Previous studies (Jassby et al. 1993; Canuel and Cloern 1996; Jassby and Cloern 2000) have indicated that the dominant sources of POC in the Sacramento-San Joaquin River Delta are tributary-borne loading (in this case consisting of higher plant material), and phytoplankton. This is also consistent with other rivers, where primary sources appear to be soil erosion in the form of plant debris, and in situ primary production (Vannote et al. 1980; Hedges et al. 1986; Zhang et al. 1998). To assess the importance of allochthonous (plant) to autochthonous (algal) sources to the Delta during our study, the terrestrial to aquatic fatty acid ratio (TAR_{FA}) was calculated (Bourbonniere and Meyers 1996; Meyers 1997). The ratio, which is calculated according to: $TAR_{FA} = (C_{24}+C_{26}+C_{28})/ (C_{12}+C_{14}+C_{16})$, was higher at downstream sites (0.25 ± 0.07) than upstream sites (0.10 ± 0.05), indicating plant sources contribute more to POC sources at downstream sites than upstream sites.

Two sterols are often enriched in higher plants: $C_{29}\Delta^5$ and $C_{29}\Delta^{5,22}$ (Volkman 1986). In our study these biomarkers made up a consistent fraction ($24.69\pm5.42\%$) of sterols in the rivers (Table 3). On a temporal scale, only one of these higher plant biomarkers exhibited variability. The significant increase in $C_{29}\Delta^5$ during winter months, and during high flow periods (which only occur during the winter) indicates that higher plant sources are delivered after they have been scoured from terrestrial environments and transported by runoff into the river. Alternatively, this could be due to flushing of riverine plant material, or erosion of soils or marshes. Canuel and Cloern (1996) also found that sterols from terrestrial plants had the highest concentrations during high flow periods. The low abundance of $C_{29}\Delta^5$ during summer months supports the idea that the delivery of higher plant sources is controlled by flow, and not by plant production in the Delta. Our samples were also taken during above normal-wet years (Gerhts 2002), the

type of water-year in which Jassby and Cloern (2000) concluded that tributary-borne loading is dominant.

Campesterol has been used as a higher plant biomarker in many environments (Huang and Meinschein 1979; Volkman 1986), including the Delta in previous studies (Canuel et al. 1995; Canuel and Cloern 1996). However, campesterol has also been found in high relative concentrations in some freshwater diatoms, and at trace concentrations in others (Volkman 1999). For example, *Skeletonema* and chlorophytes synthesize campesterol (Mannino and Harvey 1999). These organisms are present in the Delta, particularly during the summer (Lehman 2000). Elevated abundances of campesterol during summer months at MM on the San Joaquin River (Table 3), which is known to experience phytoplankton blooms during these months (Lehman 2000; Leland et al. 2001), and the associated elevated chl *a* and phaeophytin concentrations during the same months (Table 1), suggests that campesterol may be a better marker for phytoplankton at this site. At other river sites campesterol was found in much lower concentrations, concomitant with lower chl *a* and phaeophytin concentrations.

Phytoplankton productivity in the Delta is an important source for secondary production (Jassby and Cloern 2000; Müller-Solger et al. 2002) in all seasons except winter of above-normal rainfall years, and a dominant source in spring and summer of below-normal rainfall years (Jassby et al. 2002). Sterols that are traditionally used as indicators for diatoms, brassicasterol and 24-methylenecholesterol, also exhibited spatial and temporal variability (Table 3). Both were higher at lower rivers sites (RV and TI), during spring-fall months. This was a little surprising, since neither sterol made up a significant percentage of sterol composition during summer phytoplankton blooms at MM. Phytoplankton community composition may play a role in explaining this observation. The dominant species at MM in the summer was *Cyclotella meneghiniana* Kuetzing and *Thallasiosira lacustris* (Grunow), while at HD and RV, dominant species were *Cyclotella atomus* and *Nitzschia fonticola* in spring, and *Thallasiosira hendeyi* and *Stephanodiscus medius* in the fall (A. Müller-Solger, unpublished data). Therefore, campesterol may be a significant sterol in the phytoplankton species present at MM, (statement about camp in diatoms).while brassicasterol and 24-methylenecholesterol are not. However, brassicasterol and 24-methylenecholesterol were however dominant

downstream, which may be indicative of downstream transport of phytoplankton sources over time, or compositional changes in phytoplankton communities. Tidal action in these lower regions could also contribute to lower contributions from phytoplankton sterols. Tidal exchanges in the Western Delta can be 50-60x the net flows, and can introduce net landward directed fluxes of water and suspended particulate matter by lateral mixing (Burau 2000). Therefore, the net exchange water past a given location, can be from the Bay to the Delta, especially during low-flow periods (Burau et al. 2000). This exchange could also dilute local sources.

Cholesterol, a sterol often associated with zooplankton and other crustaceans (Volkman 1986) made up a significant percentage of sterols at all sites, and varied between sites and rivers (Table 3). Cholesterol may also be present in algae and vascular plants, although generally at lower abundances. The San Joaquin River (MM) had the lowest relative abundance of cholesterol. Cholesterol can also be found at low concentrations in some phytoplankton (Volkman 1986), but its low concentrations at MM with significant phytoplankton inputs indicates it may be a better indicator of zooplankton/crustaceans in the Delta. The mixed site, TI, had the highest abundances of cholesterol, which is likely due to its role as a downstream receiving area for the Sacramento River. During periods of low flow, when the highest cholesterol abundance was observed, the upstream section of the San Joaquin River was likely experiencing reverse flow, where upper San Joaquin River water is largely diverted to pumping stations for export to Southern California (Arthur et al. 1996). Therefore, TI is likely largely influenced by the Sacramento River during this period. Although not characterized as a primary source for POC in the Delta in previous studies (Jassby et al. 1993; Jassby and Cloern 2000), the higher percent of cholesterol in this study suggests that zooplankton or zooplankton products (e.g. fecal pellets) may significantly contribute to river POC.

Sterol data corroborate previous studies indicating that higher plant sources and phytoplankton are the primary sources of organic carbon in the Delta (Jassby and Cloern 2000, Cloern et al. 2002). Sterol abundances indicated differences in organic carbon sources between the Sacramento and San Joaquin Rivers, in particular in the phytoplankton sterols, but no difference in higher plant sterols. This indicates that

phytoplankton sources control source differences between these two rivers, rather than tributary borne loading, corroborating previous findings (Sobczak et al. 2005). Differences between upstream and downstream sources of the dominant sources of organic carbon vary based on season and flow, but in general were consistent during the two years during which we sampled the Sacramento and San Joaquin Rivers.

VARIABILITY IN ORGANIC CARBON QUALITY

Bulk biochemical compounds have been used separately (Relexans et al. 1988) or as a sum (as a measure of biopolymeric carbon), to assess the quality of organic carbon in suspended particles (Fabiano et al 1993). Poor food quality is determined by the presence of deficiencies in the biochemical composition of food relative to the consumer's requirements. In our study, carbohydrates made up the greatest fraction of particulate biochemical compounds (10-29%), followed by lipids (5-24%) and protein (1-8%). Previous studies have shown that carbohydrates can dominate the biochemical composition of POM in rivers (Sigleo 1996). The sum of these compounds, in particular proteins and carbohydrates, are considered a measure of the potentially metabolizable fraction of riverine OM to grazing metazoans (Ittekot and Arain 1986; Ittekot 1988). Using this approach, metabolizable OC ranged from 11-56% in the Delta rivers, which is within the range of % labile particulate fraction reported by Ittekot (1988) in temperate world rivers.

In our study, only carbohydrates varied between river sites during the study period (Fig. 4). Higher carbohydrate concentrations in the San Joaquin River may result from higher plant and phytoplankton inputs. Carbohydrates can comprise up to 75%wt of higher plants and 20-40%wt in phytoplankton (Opsahl and Benner 1999; Cotrim de Cunha 2002). Carbohydrate exhibited between-site differences, with higher concentrations at HD and MM. Concentrations were in the same general range as other rivers (Ittekot and Arain 1986; Zhang et al. 1992; Ochiai et al. 1998). Although carbohydrates are part of the "labile" fraction of organic matter, they are generally considered of lower quality than proteins and lipids for utilization by organisms (Sreepada et al. 1996). Based on higher phytoplankton contributions in the San Joaquin

River, carbohydrates may derive from different sources in each river, with higher plants dominating in the Sacramento River and phytoplankton in the San Joaquin River.

Biochemical compounds have also been found to correlate with chl a (De Lange and Arts 1999). In the Delta, chl a and zooplankton have been shown to correlate well (Müller-Solger et al. 2002). However, because chl a is used as a proxy for food quality, correlations between chl a and direct measurements of food quality (biochemical compounds) were also calculated (Table 4). Overall, TLE-C was the only biochemical class that consistently correlated with chl a. Positive correlations between chl a and each of the three biochemical classes at MM indicates that phytoplankton biomass is the likely source for these constituents. At sites where the correlations were not significant, higher plant or detrital sources likely dominate and reflects generally poor food quality (Grange and Allanson 1995).

Another series of measurements used to assess organic carbon quality were select fatty acids, in particular, polyunsaturated fatty acids (PUFAs). PUFAs such as eicosapentanoic acid (EPA: 20:5ω3) are known essential fatty acids and have been shown to be important to zooplankton reproduction (Müller-Navarro 1995; Müller-Navarro et al. 2003). Absence or low concentrations of PUFAs may affect clutch size and the rate of reproduction in cladocerans (Müller-Navarro 1995, Goulden et al. 1999). 20:5ω3 can be a major PUFA in aquatic insects, and is a source of nutrition for fish (Adams 1999). PUFAs are a good index of live phytoplankton and undegraded plant material because they are sensitive to oxidation (Napolitano 1999). Enrichments of total PUFAs and 20:5ω3 (Fig. 5) at MM indicate that the San Joaquin River had more labile organic matter compared to other sites, with increased concentrations of these fatty acids occurring in winter and summer. Dominant summer phytoplankton species, such as *Thalassiosira* sp., are known to contain >20% 20:5ω3 during peak bloom periods (Hayakawa et al. 1996). Although *Thalassiosira* sp. were present, sometimes as the dominant species, at other river sites, they were far lower in density and biovolume (A. Müller-Solger, unpublished data). The higher values in winter were caused by a large input of labile organic matter that occurs in January as an initial flushing of the system before high flow events (Oltmann et al. 1999). Phytoplankton species during this flush were dominated by - *Melosira sp. and Cyclotella meneghiniana* (A. Müller –Solger, unpublished data). High

values of PUFAs and 20:5ω3 in the Sacramento during the spring (Fig. 6) coincides with a critical period of fish spawning in the Delta (Bennett and Moyle 1996; Grimaldo et al. 2004)

The degree of OM degradation can also be important in understanding food quality in river systems. We used %branched fatty acids, as a measure of bacterial biomass, and stanol/stenol ratios, to assess carbon quality and the extent to which POM has undergone degradation (Sicre et al. 1993; Arzayus and Canuel 2004). Stanols are the degradation products of sterols, and higher stanol/stenol ratios may be indicative of the preferential degradation of stenols (Wakeham 1989). Based on the high relative abundance of cholesterol in the rivers, we utilized the 5α-cholestan-3β-ol/cholest-5-en-3β-ol ratio (Fig. 6). Higher ratios in winter at all sites indicated that there was a significant influx of degraded material during high winter flow events, which suggests that much of the degraded terrestrial material transported into the Delta occurs during high flows events, and is in a degraded form (Fig. 6). This is supported by Cloern et al. (2002), who concluded that, based on stable isotope analyses, seston in the Delta likely includes a large signal from non-living organic matter. It is also consistent with the emerging concept that riverine POM includes large components of "old", more degraded organic matter (Raymond and Bauer 2001) whose structure has been altered by selective degradation occurring over long periods as POM transport is interrupted by multiple cycles of deposition and processing. %BrFA also supports this concept, with increased concentrations during winter flow events (Fig. 6). Increased branched fatty acids were observed in both rivers during high winter flow, suggesting that soil microbes may be imported into rivers by these events (Canuel and Cloern 1996). This pattern has also been observed in the freshwater region of San Francisco Bay and Chesapeake bay estuaries (Canuel et al. 1995; Canuel 2001).

Overall, the collective findings indicate that much of the organic carbon in the Sacramento and San Joaquin Rivers is heavily degraded with 50% or greater not being characterizable. POC in winter generally exhibits lower food quality, except during the "first flush" of soil organic matter, which leads to a short-term increase in metabolizable POC, particularly in the San Joaquin River. Food quantity and quality is controlled by flow differences between seasons, as well as phytoplankton occurring at river sites. Food

quality, based on our measurements, appears to be higher in the San Joaquin River, particularly during summer months.

ENERGY FOR SECONDARY PRODUCERS

Using the bulk biochemical parameters of PROT-C, CARB-C and TLE-C, it is possible to calculate the food energy of suspended POM in the rivers (Fig. 7). Food energy was calculated using food energy values from Fabiano and Pusceddu (1998), with lipids having the highest energy value at 39.5 J L^{-1}, proteins at 24.0 J L^{-1} and carbohydrates having the lowest energy values (17.5 J L^{-1}). Values indicate that overall, the food energy of suspended particles is highest in the San Joaquin River, at MM, at all times of the year. At the other sites, in the Sacramento River and Twitchell Island, food energy is similar spatially and relatively constant on a temporal scale. Our data analysis shows that TLE-C tended to vary both spatially and temporally, and correlated with chl *a* at all sites (Table 4). Therefore, it is reasonable to deduce that lipid concentrations likely contribute significantly to the variability of food energy in Delta rivers, which supports the idea that nutritional components associated with phytoplankton rather than detritus regulate zooplankton growth. Phytoplankton, diatoms in particular, are known to have a higher food value than higher-plant-derived detritus and bacteria (Jassby and Cloern 2000). This corroborates other studies that have also concluded that phytoplankton biomass may be the critical factor in evaluating nutritional quality of organic matter in the Delta, and that phytoplankton biomass was a strong predictor of bioavailable POC and likely the major food source for metazoans (Sobczak et al. 2002; Sobczak et al. 2005). This also indicates that, as previous studies have indicated, higher quality POC does not reach the Delta generally because San Joaquin River water is diverted during summer periods of low flow to state and federal water projects (Jassby 2005), reinforcing that the Delta overall receives largely poor-quality POC for secondary production in the Delta and Northern San Francisco Bay.

IMPLICATIONS OF POC QUALITY ON REHABILITATION

Based on all data, the Sacramento River (HD and RV) and mixed (TI) sites is characterized by POM of lower nutritional quality than the San Joaquin River (MM). When the data was analyzed by PCA, MM was characterized by fatty acids and sterols

indicative of higher-quality POM derived from phytoplankton (Figs. 8,9). An additional concern for the San Joaquin River is that some algal blooms producing high quality POC may be toxic, or produce negative effects such as oxygen depletion. In recent years, the colonial cyanobacteria *Microcystis aeruginosa* has become abundant in Delta rivers (Lehman et al. 2004), causing concern that the benefits of algal blooms in the Delta may be counteracted by additional toxic effects for secondary producers. Although *M. aeruginosa* can contain significant amounts of PUFAs (primarily short-chain 18:2ω6, 18:3ω3, 18:3ω6, and 18:4ω3, with trace amounts of 20:5ω3, Hayakawa et al. 2002), *M. aeruginosa* never made up a significant fraction of phytoplankton species present at any river sites during our study. However, oxygen depletion in the San Joaquin River in the Stockton Ship Channel can be attributed to transport of high phytoplankton biomass into the area from upstream regions, such as MM. Oxygen depletion in the San Joaquin River has deleterious effects on fish production through several factors affecting mortality, growth rate, behavior, food web processes and reproductive success (Breitburg 2002). Low DO can also block upstream migration of Chinook salmon, an endangered species, and can also lead to fish kills (Lehman et al. 2004). Therefore, the benefits of producing high-quality POC in the Delta through increasing phytoplankton production may be counteracted by the negative effects to other regions of the Delta, and further study is needed to determine the consequences of blooms on Delta health.

The Sacramento and San Joaquin Rivers appear to have SPM bulk and lipid biomarker characteristics that are similar to other North American Rivers (Table 5). SPM concentrations for the Sacramento and San Joaquin Rivers were comparable to the Hudson River on the U.S. East Coast, but generally higher than other rivers. Chlorophyll *a* and phaeophytin were low in the Sacramento River compared to other rivers, but values in the San Joaquin river were comparable in range to other rivers. The Delta as a whole has been previously characterized as a highly turbid, nutrient-rich estuary (Jassby et al. 2002), but exhibits primary productivity levels that are approximately a third of other estuaries (Jassby et al. 2002). The Sacramento River follows that pattern, while the San Joaquin River behaves more like other river systems with higher nutrient concentrations and subsequently higher phytoplankton production (Jassby et al. 2005). Lipid biomarker concentrations in the Sacramento and San Joaquin Rivers were comparable to values

from the Delaware River (Table 5), but were lower than concentrations reported from the York River, VA (Countway et al. 2003).

In summary, bulk biochemical and lipid biomarker analyses indicate that while sources of POM can differ on a seasonal basis at individual river sites, on an annual basis sources do not differ between the Sacramento and San Joaquin Rivers. However, the quality of POM, otherwise characterized as the "metabolizable" fraction of POM, does differ between rivers. Based on all data, the Sacramento River (HD and RV) and mixed (TI) sites is characterized by POM of lower nutritional quality than the San Joaquin River (MM). The combined use of biochemical and lipid biomarker analyses can be valuable tools provide insights into the composition and quality of POM in comparable river systems.

LITERATURE CITED

ADAMS, S. M. 1999. Ecological role of lipids in the health and success of fish populations, p. 132-160. In M. T. Arts and B. C. Wainman [eds.], Lipids in Freshwater Ecosystems. Springer-Verlag New York, Inc.

ARTHUR, J. F., M. D. BALL, and S. Y. BAUGHMEN. 1996. Summary of federal and state water project environmental impacts in the San Francisco Bay-Delta Estuary, California, p. 445-495. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

ARZAYUS, K. M., and E. A. CANUEL. 2004. Organic matter degradation in sediments of the York River estuary: Effects of biological vs. physical mixing. Geochim. Cosmochim. Acta 69: 455-463.

BENNETT, W. A., and P. B. MOYLE. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary, p. 519-542. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

BLAIR, N.E., E.L. LEITHOLD, S.T. FORD, K.A. PEELER, J.C. HOLMES, and D.W. PERKEY. 2003. The persistence of memory: the fate of ancient sedimentary organic carbon in a modern sedimentary system. Geochim. Cosmochim. Acta 67: 63-73.

BLIGH, E. G., and W. J. DYER. 1959. A rapid method of total lipid extraction and purification. Can. J. Biochem. Physiol. 37: 911-917.

BOURBONNIERE, R.A., and P.A. MEYERS. 1996. Sedimentary geolipid records of historical changes in the watersheds and productivities of Lakes Ontario and Erie. Limnol. Oceanogr. 4: 352-259.

BREITBURG, D. 2002. Effects of hypoxia, and the balance between hypoxia and enrichment, on coastal fishes and fisheries. Estuaries 25: 767-781.

BURAU, J. R., S. G. MONISMITH, M. T. STACEY, R. N. OLTMANN, J. R. LACY, and D. H. SCHOELLHAMER. 2000. Recent research on the hydrodynamics of the Sacramento-San Joaquin River Delta and North San Francisco Bay. IEP Newsletter 13: 45-55.

CANUEL, E. A. 2001. Relations between river flow, primary production and fatty acid composition of particulate organic matter in San Francisco and Chesapeake Bays: a multivariate approach. Org. Geochem. 32: 563-583.

CANUEL, E. A., and J. E. CLOERN. 1996. Regional differences in the origins of organic matter in the San Francisco Bay ecosystems, p. 305-324. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

CANUEL, E. A., J. E. CLOERN, D. B. RINGELBERG, J. B. GUCKERT, and G. H. RAU. 1995. Molecular and isotopic tracers used to examine sources of organic matter and its incorporation into the food webs of San Francisco Bay. Limnol. Oceanogr. 40: 67-81.

CANUEL, E. A., and C. S. MARTENS. 1993. Seasonal variations in the sources and alteration of organic matter associated with recently-deposited sediments. Org. Geochem. 20: 563-577.

CANUEL, E. A., and A. R. ZIMMERMAN. 1999. Composition of particulate organic matter in the Southern Chesapeake Bay: Sources and reactivity. Estuaries 22: 980-994.

CAUWET, G., F. GAGEL, MMde SOUZA SIERRA, O. DONARD, and M. EWALD. 1990. Contribution of the Rhone River to organic carbon inputs to the northwestern Mediterranean Sea. Cont. Shelf Res. 10: 1025-1037.

CLOERN, J. E., E. A. CANUEL, and D. HARRIS. 2002. Stable carbon and nitrogen isotope composition of aquatic and terrestrial plants of the San Francisco Bay estuarine system. Limnol. Oceanogr. 47: 713-729.

COLE, J.J., and N.F. CARACO. 2001. Carbon in catchments: connecting terrestrial carbon losses with aquatic metabolism. Mar. Freshwater Res. 52: 101-110. -

COLE, J.J., N.F. CARACO, and B.L. PEIERLS. 1992. Can phytoplankton maintain a positive carbon balance in a turbid, freshwater, tidal estuary. Limnol. Oceanogr.

CONOMOS, T.J., R.E. SMITH, and J.W. GARTNER. 1985. Environmental setting of San Francisco Bay. Hydrobiol. 129: 1-12.

COTRIM DA CUNHA, L., L. SERVE, and J.-L. BLAZI. 2002. Neutral sugars as biomarkers in the particulate organic matter of a French Mediterranean river. Org. Geochem. 33: 953-964.

COUNTWAY, R.E., R.M. DICKHUT, and E.A. CANUEL. 2003. Polycyclic aromatic hydrocarbon (PAH) distributions and associations with organic matter in surface waters of the York River, VA Estuary. Org. Geochem. 34: 209-224.

DE BAAR, H.J.W., J.W. FARRINGTON, and S.G. WAKEHAM. 1983. Vertical flux of fatty acids in the North Atlantic Ocean. J. Mar. Res. 41: 19-41.

DEGENS, T. 1982. Riverine carbon – an overview of transport of carbon and minerals in world rivers. Part 1/SCOPE-UNEP. Hamburg-FRG. Carbon Unit. No. 52. 1-112.

DEGENS, E.T., and V. ITTEKKOT. 1985. Particulate organic carbon – an overview, p. 7-27. In E.T. Degens, S. Kempe, and R. Herrera. [eds.] Transport of Carbon and Minerals in Major World Rivers, Pt. 3. Mitt. Geol. – Palaont. Inst. Univ. Hamburg, SCOPE/UNEP.

DE LANGE, H.J., and M.T. ARTS. 1999. Seston composition and the potential for *Daphnia* growth. Aquat. Ecol. 33: 387-398.

DEPETRIS, P. J., and S. KEMPE. 1993. Carbon dynamics and sources in the Parana River. Limnol. Oceanogr. 38: 382-395.

[DWR] CALIFORNIA DEPARTMENT OF WATER RESOURCES. 1995. Sacramento-San Joaquin Delta Atlas. California Department of Water Resources. 121 pp.

FABIANO, M., P. POVERO, and R. DANOVARO. 1993. Distribution and composition Of particulate organic matter in the Ross Sea (Antarctica). Polar Biol. 13: 525-533.

FABIANO, M., and A. PUSCEDDU. 1998. Total and hydrolyzable particulate organic matter (carbohydrates, proteins and lipids) at a coastal station in Terra Nova Bay (Ross Sea, Antarctica). Polar Biol. 19: 125-132.

FICHEZ, R. 1991. Composition and fate of organic matter in submarine cave sediments; implications for the biogeochemical cycle of organic carbon. Oceanol. Acta 14: 369-377.

FINDLAY, S., M. PACE, and D. FISCHER. 1996. Spatial and temporal variability in the lower food web of the tidal freshwater Hudson River. Estuaries 19: 866-873.

GALOIS, R., P. RICHARD, and B. FRICOURT. 1996. Seasonal variations in suspended particulate matter in the Marennes-Oleron Bay, France, using lipids as biomarkers. Estuar. Coast. Shelf Sci. 43: 335-357.

GERHTS, K. 2002. Water year hydrologic classification indices for the Sacramento and San Joaquin Valleys. IEP Newsletter 15: 16-17.

GNAIGER, E. 1983. Heat dissipation and energetic efficiency in animal anoxibiosis. Economy Contra Power. J. Exp. Zool. 228: 471-490.

GOULDEN, C. E., R. E. MOELLER, J. N. MCNAIR, and A. R. PLACE. 1999. Lipid dietary dependencies in zooplankton, p. 91-108. In M. T. Arts and B. C. Wainman [eds.], Lipids in Freshwater Ecosystems. Springer-Verlag New York, Inc.

GRANGE, N., and B. R. ALLANSON. 1995. The influence of freshwater inflow on the nature, amount and distribution of seston in estuaries of the Eastern Cape, South Africa. Estuar. Coast. Shelf Sci. 40: 403-420.

GRIMALDO, L. F., R. E. MILLER, C. M. PEREGRIN, and Z. P. HYMANSON. 2004. Spatial and temporal distribution of native and alien ichthyoplankton in three habitat types of the Sacramento-San Joaquin Delta. Am. Fish. Society Symp. 39: 81-96.

GUPTA, L. P., V. SUBRAMANIAN, and V. ITTEKOT. 1997. Biochemistry of particulate organic matter transported by the Godavari River, India. Biogeochem. 38: 103-128.

HARVEY, H. R., and A. MANNINO. 2001. The chemical composition and cycling of particulate and macromolecular dissolved organic matter in temperate estuaries as revealed by molecular organic tracers. Org. Geochem. 32: 527-542.

HAYAKAWA, K. and others 2002. Fatty acid composition as an indicator of the physiological condition of the cyanobacterium *Microcystis aeruginosa*. Limnol. 3: 29-35.

HAYAKAWA, K., N. HANDA, and C. S. WONG. 1996. Changes in the composition of fatty acids in sinking matter during a diatom bloom in a controlled experimental ecosystem. J. Exp. Mar. Biol. Ecol. 208: 29-43.

HEDGES, J.I., W.A. CLARK, P.D. QUAY, J.E. RICHEY, and A.H. DEVOL. 1986. Compositions and fluxes of particulate organic material in the Amazon River. Limnol. Oceanogr. 31: 717-738.

HEDGES, J.I., W.A. CLARK, and G.L. COWIE. 1988. Organic matter sources to the water column and surficial sediments of a coastal marine bay. Limnol. Oceanogr. 33: 1116-1136.

HEDGES, J. I., G.L. COWIE, J.E. RICHEY, P.D. QUAY, R. BENNER, M. STROM, and B.R. FORSBERG 1994. Origins and processing of organic matter in the Amazon River as indicated by carbohydrates and amino acids. Limnol. Oceanogr. 39: 743-761.

HELSEL, D. R., and R. M. HIRSCH. 1992. Statistical Methods in Water Resources. Elsevier Science Publishers, Amsterdam.

HOPKINSON, C. S. I. BUFFAM, J. HOBBIE, J. VALLINO, M. PERDUE, B., EVERSMEYER, F., PRAHL, J. COVERT, R. HODSON, M.A. MORAN, E. SMITH, J. BAROSS, B. CRUMP, S. FINDLAY, and K. FOREMAN 1998. Terrestrial inputs of organic matter to coastal ecosystems: An intercomparison of chemical characteristics and bioavailability. Biogeochem. 43: 211-234.

HOPKINSON, J., C.S., and J. J. VALLINO. 1995. The relationships among man's activities in watersheds and estuaries: A model of runoff effects on patterns of estuarine community metabolism. Estuaries. 18: 598-621.

HUANG, W. Y., and W. G. MEINSCHEIN. 1979. Sterols as ecological indicators. Geochim. Cosmochim. Acta 43: 739-745.

ITTEKOT, V., and R.W.P.M. LAANE. 1991. Fate of riverine organic matter, p. 233 -243. In E.T. Degens, S. Kempe, J.E. Richey [eds.] Biogeochemistry of Major World Rivers. SCOPE 42. Wiley & Sons, Chichester.

ITTEKOT, V., and R. ARAIN. 1986. Nature of particulate organic matter in the river Indus, Pakistan. Geochim. Cosmochim. Acta 50: 1643-1653.

ITTEKOT, V. 1988. Global trends in the nature of organic matter in river suspensions. Nature. 332: 436-438.

JASSBY, A. D. 2005. Phytoplankton regulation in a eutrophic tidal river (San Joaquin River, California). San Francisco Estuary and Watershed Science (online serial). 3.

JASSBY, A. D., and J. E. CLOERN. 2000. Organic carbon sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic. Conserv.: Mar. Freshwat. Ecosyst. 10: 323-352.

JASSBY, A. D., J. E. CLOERN, and B. E. COLE. 2002. Annual primary production: Patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnol. Oceanogr. 47: 698-712.

JASSBY, A. D., J. E. CLOERN, and A. B. MÜLLER-SOLGER. 2003. Phytoplankton fuels Delta food web. Cal. Agricult. 57: 104-109.

JASSBY, A. D., J. E. CLOERN, and T. M. POWELL. 1993. Organic carbon sources and sinks in San Francisco Bay: variability induced by river flow. Mar. Ecol. Prog. Ser. 95: 39-54.

JASSBY, A. D., and T. M. POWELL. 1994. Hydrodynamic influences on interannual chlorophyll variability in an estuary: Upper San Francisco Bay-Delta (California, U.S.A.). Estuar. Coast. Shelf Sci. 39: 595-618.

JGOFS (U.S. JOINT GLOBAL OCEAN FLUX STUDY). 1992. Report of the U.S. Workshop on Modeling and Data Assimilation Planning Report Number 14, U.S. JGOFS Planning Office, Woods Hole, MA. 28 pp.

KEMPE, S., and P. J. DEPETRIS. 1992. Factors controlling the concentration of particulate carbohydrates and amino acids in the Parana River. Hydrobiol. 242: 175-183.

KEMPE, S. 1979. Carbon in the freshwater cycle, p. 317-342. In B. Bolin, E.T. Degens, S. Kempe, and P. Ketner [eds.] The Global Carbon Cycle. Wiley, Chichester.

KIMMERER, W.J., and JJ. ORSI. 1996. Causes of long-term declines in zooplankton in the San Francisco Bay Estuary since 1987. p. 403-424. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

KNOWLES, N. 2000. Natural and human influences on freshwater flows and salinity in the San Francisco Bay-Delta estuary and watershed. IEP Newsletter 13: 15-23.

LAUREILLARD, J., and A. SALIOT. 1993. Biomarkers in organic matter produced in estuaries: a case study of the Krka estuary (Adriatic Sea) using the sterol marker series. Mar. Chem. 43: 247-262.

LEHMAN, P.W., G. BOYER, C. HALL, S. WALLER, and K. GERHTS. 2005. Distribution and toxicity of a new colonial *Microsystis aeruginosa* bloom in the San Francisco Bay Estuary, California. 541: 87-99.

LEHMAN, P. W., J. SEVIER, J. GIULIANOTTI, and M. JOHNSON. 2004. Sources of Oxygen demand in the lower San Joaquin River, California. Estuaries 27: 405-418.

LEHMAN. P.W. 2000. The influence of climate on phytoplankton community biomass in San Francisco Bay Estuary. Limnol. Oceanogr. 45: 580-590.

LEHMAN, P. W., and R. W. SMITH. 1991. Environmental factors associated with phytoplankton succession for the Sacramento-San Joaquin Delta and Suisun Bay Estuary, California. Estuar. Coast. Shelf Sci. 32: 105-128.

LEITHOLD, E.L., and N.E. BLAIR. 2001. Watershed control on the carbon loading of marine sedimentary particles. Geochim. Cosmochim. Acta 65: 2231-2240.

LELAND, H.V., L.R. BROWN, D.K. MULLER. 2001. Distribution of algae in the San Joaquin River, California, in relation to nutrient supply, salinity, and other environmental factors. Freshwat. Biol. 46: 1139-1167.

MANNINO, A., and H. R. HARVEY. 1999. Lipid composition in particulate and dissolved organic matter in the Delaware Estuary: Sources and diagenetic patterns. Geochim. Cosmochim. Acta 63: 2219-2235.

McCALLISTER, L. 2002. Organic matter cycling in the York River Estuary, Virginia: An analysis of potential sources and sinks. The College of William and Mary, Williamsburg, VA. 220 p.

MEGLEN, R. R. 1992. Examining large databases: a chemometric approach using principal component analysis. Mar. Chem. 39: 217-237.

MEYBECK, M. 1982. Carbon, nitrogen, and phosphorus transport by world rivers. Am. J. Sci. 282: 401-450.

MEYERS, P.A. 1997. Organic geochemical proxies of paleoceanographic, paleolimnologic, and paleoclimatic processes. Org. Geochem. 27: 213-250.

MONSEN, N.E. 2001. A study of sub-tidal transport in Suisun Bay and the Sacramento-San Joaquin Delta, California. Ph.D. Dissertation, Stanford University, Stanford, California. 335 pp.

MONSEN, N. E., J. E. CLOERN, L. V. LUCAS, and S. G. MONISMITH. 2002. A comment on the use of flushing time, residence time, and age as transport time scales. Limnol. Oceanogr. 47: 1545-1553.

MOYLE, P.B., B. HERBOLD, D.E. STEVENS, and L.W. MILLER. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin estuary, California. Trans. Am. Fish. Soc. 121: 67-77.

MUDGE, S. M., and C. E. NORRIS. 1997. Lipid biomarkers in the Conway Estuary (North Wales, U.K.): a comparison between fatty alcohols and sterols. Mar. Chem. 57: 61-84.

MÜLLER-NAVARRA, D. 1995. Evidence that a highly unsaturated fatty acid limits *Daphnia* growth in nature. Arch. Hydrobiol. 132: 297-307.

MÜLLER-NAVARRA, D. C. M.T. BRETT, S. CHANDRA, A.P. BALLANTYNE, E. ZORITA, and C.R. GOLDMAN 2003. Unsaturated fatty acid content in seston and tropho-dynamic coupling in lakes. Nature 427: 69-72.

MÜLLER-SOLGER, A. B., A. D. JASSBY, and D. C. MÜLLER-NAVARRA. 2002. Nutritional quality of food resources for zooplankton (*Daphnia*) in a tidal freshwater system (Sacramento-San Joaquin River Delta). Limnol. Oceanogr. 47: 1468-1476.

MUNSON, S.A., and A.E. CAREY. 2004. Organic matter source and transport in an agriculturally dominated temperate watershed. Appl. Geochem. 19: 1111-1121.

NAPOLITANO, G. E. 1999. Fatty acids as trophic and chemical markers in freshwater ecosystems, p. 21-44. In M. T. Arts and B. C. Wainman [eds.], Lipids in Freshwater Ecosystems. Springer-Verlag New York, Inc.

NAVARRO, J. M., E. CLASING, G. URRUTIA, G. ASENCIO, R. STEAD, and C. HERRERA. 1993. Biochemical composition and nutritive value of suspended particulate matter over a tidal flat of southern Chile. Estuar. Coast Shelf Sci. 37: 59-73.

NGUYEN, R. T., and H. R. HARVEY. 1994. A rapid micro-scale method for the extraction and analysis of protein in marine samples. Mar. Chem. 45: 1-14.

NICHOLS, F. H., J. E. CLOERN, S. N. LUOMA, and D. H. PETERSON. 1986. The modification of an estuary. Science 231: 567-573.

OCHIAI, M., M. OGINO, K. SASAKI, and T. OKAZAWA. 1988. Behavior of particulate carbohydrates and amino acids in the estuary of the Tama River. Mar. Chem. 25: 265-278.

OLTMANN, R. N., D. H. SCHOELHAMER, and R. L. DINEHART. 1999. Sediment inflow to the Sacramento-San Joaquin Delta and the San Francisco Bay. IEP Newsletter 12: 30-33.

OPSAHL, S., and R. BENNER. 1999. Characterization of carbohydrates during early diagenesis of five vascular plant tissues. Org. Geochem. 30: 83-94.

ORSI, J. J., and W. L. MECUM. 1986. Zooplankton distribution and abundance in the Sacramento-San Joaquin Delta in relation to certain environmental factors. Estuaries 9: 326-339.

ORSI, J. J., and W. L. MECUM. 1996. Food limitation as the probable cause of a long-term decline in the abundance of Neomysis mercedis the opossum shrimp in the Sacramento-San Joaquin Estuary, p. 375-401. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

PAKULSKI, J. D., and R. BENNER. 1992. An improved method for the hydrolysis and MBTH analysis of the dissolved and particulate carbohydrates in seawater. Mar. Chem. 40: 143-160.

QUEMENEUR, M., and Y. MARTY. 1992. Sewage influence in a macrotidal estuary: fatty acid and sterol distributions. Estuar. Coast. Shelf Sci. 34: 347-363.

RAYMOND, P. A., and J. E. BAUER. 2001. Riverine export of aged terrestrial organic matter to the North Atlantic Ocean. Nature 409: 497-499.

RELEXANS, J. C., M. MEYBECK, G. BILLEN, M. BRUGEAILLE, H. ETCHEBER, and M. SOMVILLE. 1988. Algal and microbial processes involved in particulate organic matter dynamics in the Loire Estuary. Estuar. Coast. Shelf Sci. 27: 625-644.

RICHEY, J.E., 2004. Pathways of atmospheric CO_2 through fluvial systems, p. 329-340. In C.B. Field and M.R. Raupach [eds.], The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World, SCOPE, Island Press, Washington, D.C.

SALIOT, A., J. TRONCZYNSKI, P. SCRIBE, and R. LETOLLE. 1988. The application of isotopic and biogeochemical markers to the study of biogeochemistry of organic matter in a macrotidal estuary, the Loire, France. Est. Coast. Shelf Sci. 27: 645-669.

SCHEMEL, L. E., S. W. HAGER, and J. CHILDERS, D. 1996. The supply and carbon content of suspended sediment from the Sacramento River to San Francisco Bay, p. 237-260. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

SICRE, M. A., R. C. TIAN, I. BROYELLE, and A. SALIOT. 1993. Aquatic distribution of 4-desmethyl sterols in the Chang Jiang Estuary, China. Mar. Chem. 42: 11-24.

SIGLEO, A. C. 1996. Biochemical components in suspended particles and colloids: carbohydrates in the Potomac and Patuxent Estuaries. Org. Geochem. 24: 83-93.

SMALL, L. F., C.D. MCINTIRE, K.B. MACDONALD, J.R. LARA-LARA, and B.E. FREY. 1990. Primary production, plant and detrital biomass, and particle transport in the Columbia River Estuary. Prog. Oceanog. 25: 175-210.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, B. E. COLE, T. S. SCHRAGA, and A. ARNSBERG. 2005. Detritus fuels ecosystem metabolism but not metazoan food webs in San Francisco Estuary's freshwater Delta. Estuaries 28: 124-137.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, and A. B. MÜLLER-SOLGER. 2002. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. Proc. Nat. Acad. Sci. 99: 8101-8105.

SPITZY, A. and V. ITTEKOT. 1991. Dissolved and particulate organic matter in rivers. John Wiley and Sons Ltd. New York. pp. 5-17.

SREEPADA, R. A., C. U. RIVONKAR, and A. H. PARULEKAR. 1996. Particulate carbohydrate and proteins in the Bay of Bengal. Estuar. Coast. Shelf Sci. 43: 295-310.

TAYLOR, G.T., J. Way, and M.I. SCRANTON. 2003. Planktonic carbon cycling and transport in surface waters of the highly urbanized Hudson River estuary. Limnol. Oceanogr. 48: 1779-1795.

THURMAN, E.M. 1985. Organic Geochemistry of Natural Waters. Dr. W. Junk Publishers, Boston. 497 pp.

VANNOTE, R.L., G.W. MINSHALL, K.W. CUMMINS, J.R. SEDELL, and C.E. CUSHING. 1980. The River Continuum Concept. Can. J Fish. Aquat. Sci. 37:130-137.

VOLKMAN, J. K., S. M. BARRETT, and S. I. BLACKBURN. 1999. Eustigmatophyte microalgae are potential sources of C_{29} sterols, C_{22}-C_{28} n-alcohols and C_{28}-C_{32} n-alkyl diols in freshwater environments. Org. Geochem. 30: 307-318.

VOLKMAN, J. K. 1986. A review of sterol markers for marine and terrigenous organic matter. Org. Geochem. 9: 83-99.

WAKEHAM, S. G. 1989. Reduction of stenols to stanols in particulate matter at oxic-anoxic boundaries in sea water. Nature 342: 787-790.

ZHANG, J, S.M. LIU, H. XU, Z.G. YU, S.Q. LAI, H. ZHANG, G.Y. GENG, and J.F. CHEN. 1998. Riverine sources and estuarine fates of particulate organic carbon from North China in late summer. Estuar. Coast. Shelf Sci. 46: 439-448.

ZHANG, S., W. B. GAN, and V. ITTEKOT. 1992. Organic matter in large turbid rivers: the Huanghe and its estuary. Mar. Chem. 38: 53-68.

Table 1. Water Column and Suspended Particle Characteristics for the Sacramento and San Joaquin Rivers, CA

Sacramento River

Sample ID	Collection Date	Latitude (^{o}N)	Longitude (^{o}W)	Depth (m)	pH	Temp (^{o}C)	SPM (mg L^{-1})	Chl.a (μg L^{-1})	Phaeo (μg L^{-1})	POC (μg L^{-1})	PN (μg L^{-1})	C:N$_a$	% POC (% of SPM)
HD1	Jan 1999	38 28.056	121 30.270	10.3	7.31	10.3	33.0	3.4	2.1	984	103.6	11.1	2.98
HD2	Feb 1999	38 22.08	121 31.28	11.3	7.13	8.7	48.4	1.4	1.3	1195	130.2	10.7	2.47
HD3	May 1999	38 22.12	121 31.30	8.8	7.20	15.7	28.5	4.2	1.6	840	114.8	8.5	2.95
HD4	Jul 1999	n/a	n/a	7.8	7.26	18.8	29.7	2.1	1.5	662	163.8	4.7	2.23
HD5	Oct 1999	38 22.12	121 31.29	8.7	7.46	18.0	10.7	1.7	1.4	274	47.6	6.7	2.55
HD6	Feb 2000	38 22.10	121 31.29	11.2	7.49	10.4	39.7	1.5	0.7	713	84.4	9.9	1.80
HD7	Apr 2000	38 22.10	121 31.29	9.0	7.54	16.6	30.2	6.5	3.5	649	96.8	7.8	2.15
HD8	Jul 2000	n/a	n/a	7.6	7.26	21	36.1	3.7	2.5	593	69.3	10.0	1.64
RV1	Oct 1998	38 09.08	121 41.35	10.9	7.28	16.6	27.0	1.4	1.7	720	71.4	11.8	2.67
RV2	May 1999	38 09.28	121 41.26	11.2	7.40	14.5	22.4	2.3	1.4	586	72.8	9.4	2.61
RV3	Jul 1999	n/a	n/a	6.1	7.63	19.3	33.2	2.3	2.7	784	166.6	5.5	2.36
RV4	Oct 1999	38 09.28	121 41.26	12.3	7.55	18.8	19.4	1.7	1.7	460	62.7	8.6	2.38
RV5	Feb 2000	38 09.28	121 41.28	12.0	7.30	10.4	48.3	1.6	0.9	910	110.2	9.6	1.89
RV6	Apr 2000	38 09.28	121 41.28	11.0	7.50	17.0	22.6	4.3	2.6	478	64.4	8.7	2.12
RV7	Jul 2000	n/a	n/a	10.9	7.23	20.7	23.4	2.3	2.7	492	50.0	11.5	2.10

n/a = not available

Table 1., ctd. Water Column and Suspended Particle Characteristics for the Sacramento and San Joaquin Rivers, CA

San Joaquin River

Sample ID	Collection Date	Latitude (°N)	Longitude (°W)	Depth (m)	pH	Temp (°C)	SPM (mg L^{-1})	Chl.a (μg L^{-1})	Phaeo (μg L^{-1})	POC (μg L^{-1})	PN (μg L^{-1})	C:N$_a$	% POC (% of SPM)
MM1	Oct 1998	37 47.18	121 18.37	2.7	7.27	15.1	41.9	7.2	3.6	1392	163.8	9.9	3.32
MM2	Jan 1999	n/a	n/a	n/a	7.56	11.9	25.0	8.9	4.7	564	47.6	13.8	2.26
MM3	Feb 1999	37 47.18	121 18.44	5.4	7.13	11.0	40.3	2.5	2.0	983	141.4	8.1	2.44
MM4	May 1999	37 47.17	121 18.43	4.3	7.37	14.4	39.5	5.0	3.2	1010	130.2	9.1	2.56
MM5	Jul 1999	37 47.23	121 18.25	3.2	7.49	21.6	79.9	53.3	14.1	3080	799.4	4.5	3.86
MM6	Oct 1999	37 47.23	121 18.25	2.7	7.66	n/a	61.5	11.9	8.4	1509	251.8	7.0	2.45
MM7	Feb 2000	37 47.23	121 18.25	12.9	7.48	11.8	89.0	2.7	1.1	1238	153.4	9.4	1.39
MM8	Apr 2000	37 47.16	121 18.43	2.3	7.74	19.0	37.3	20.4	8.9	1408	258.5	6.4	3.78
MM9	Jul 2000	n/a	n/a	2.4	8.63	23.1	45.4	98.2	15.7	3436	678.4	5.9	7.56
TI1	Jan 1999	38 05.32	121 38.43	5.2	7.4	8.3	15.0	1.0	1.5	1212	149.8	9.4	8.08
TI2	Feb 1999	38 05.31	121 38.40	6.6	7.21	9.3	33.7	0.8	1.3	1089.6	151.2	8.4	3.23
TI3	May 1999	38 05.31	121 38.42	4.8	7.4	14.9	22.9	2.7	2.1	884.4	88.2	11.7	3.86
TI4	Jul 1999	n/a	n/a	n/a	7.46	18.6	18.3	1.2	1.6	454.8	81.2	6.5	2.48
TI5	Oct 1999	38 05.30	121 38.42	9.1	8.05	19.3	21.0	1.8	2.2	570.29	62.5	10.6	2.72
TI6	Feb 2000	38 05.31	121 38.39	6.0	7.3	11.5	32.8	0.5	0.3	622.16	64.2	11.3	1.90
TI7	Jul 2000	n/a	n/a	14.0	7.32	20.2	25.6	2.1	3.4	666.12	64.7	12.0	2.60

n/a = not available

Table 2. Sterol abbreviations and source assignments used in this study. Compounds are dominant but not exclusive to the sources indicated.

	Compounds	Abbreviation	Common Name	Major Sources
1	cholest-5-en-3β-ol	$^a C_{27}\Delta^5$	Cholesterol	Zooplankton[b], phytoplankton[b]
2	5β-cholestan-3β-ol	$C_{27}\Delta^o$	Coprostanol	Sewage[d]
3	24-methylcholest-5,22-dien-3β-ol	$C_{28}\Delta^{5,22}$	Brassicasterol	Phytoplankton, diatoms[b], cyanobacteria[b]
4	24-methylcholesta-5,24(28)-dien-3β-ol	$C_{28}\Delta^{5,24(28)}$	24-Methylene Cholesterol	Phytoplankton, mainly diatoms[c]
5	24-methylcholest-5-en-3β-ol	$C_{28}\Delta^5$	Campesterol	Higher plant[b] and algal[b]
6	24-ethycholest-5-en-3β-ol	$C_{29}\Delta^5$		Higher plant[b]
7	24-ethylcholesta-5,22-dien-3β-ol	$C_{29}\Delta^{5,22}$	Stigmasterol	Higher plant[b]
8	4α,23,24-trimethylcholest-22-en-3β-ol	$C_{30}\Delta^{22}$	Dinosterol	Dinoflagellates[b]

[a]The nomenclature is $C_x D^y$, where x denotes the total number of carbon atoms and y denotes the positions of the bonds

Source references: [b]Volkman et al. 1986, [c]Gladu et al. 1991, [d]Quemeneur and Marty 1992.

Table 3. Carbon-normalized percentages of major sterol compounds for suspended particle samples of river study sites.

Sterol	Stigmasterol	$C_{29}\Delta^5$	Campesterol	Brassicasterol	Methylene Cholesterol	Cholesterol	Coprostanol	Dinosterol
SACRAMENTO								
HD								
Oct 98	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Jan 99	8.02	27.01	6.90	10.70	5.43	18.52	1.10	0.99
Feb 99	6.49	25.10	5.82	7.21	3.46	25.77	2.24	0.00
May 99	7.60	17.57	11.27	6.71	5.01	26.32	6.11	0.86
Jul 99	7.97	15.00	7.56	11.31	6.49	21.81	1.35	1.50
Oct 99	7.20	15.59	7.72	9.88	5.50	23.98	4.56	0.92
Feb 00	7.41	23.34	11.60	6.99	2.74	25.99	2.37	1.68
Apr 00	6.73	18.49	14.58	9.34	6.31	20.55	2.90	0.93
Jul 00	8.52	16.28	6.99	9.77	6.70	21.41	2.83	1.22
RV								
Oct 98	7.73	14.78	5.85	10.18	5.15	24.71	2.90	1.07
Jan 99	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Feb 99	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
May 99	7.59	17.67	8.87	13.86	4.05	25.16	3.79	0.00
Jul 99	7.28	13.83	7.70	12.17	6.76	24.41	3.07	0.00
Oct 99	5.71	12.94	5.90	14.71	6.31	24.60	2.77	0.00
Feb 00	8.65	25.39	6.46	7.23	3.75	19.14	1.67	0.31
Apr 00	6.60	15.54	10.16	14.39	5.50	19.56	3.14	0.61
Jul 00	7.07	12.25	8.29	11.25	6.79	20.41	2.72	0.50

n/a = not available

Table 3. cont. Carbon-normalized percentages of major sterol compounds for suspended particle samples of river study sites.

Sterol	Stigmasterol	$C_{29}\Delta^5$	Campesterol	Brassicasterol	Methylene Cholesterol	Cholesterol	Coprostanol	Dinosterol
SAN JOAQUIN								
MM								
Oct 98	13.02	22.97	8.65	6.62	5.18	9.79	1.91	0.73
Jan 99	6.56	24.36	9.69	4.88	3.82	16.03	2.33	0.46
Feb 99	5.70	23.19	10.23	7.69	1.16	21.72	2.25	0.00
May 99	5.84	18.68	16.79	11.09	0.70	18.55	2.11	0.43
Jul 99	5.63	12.83	41.03	8.01	7.91	13.05	0.25	0.00
Oct 99	8.80	14.52	13.26	11.08	5.63	20.17	1.11	0.45
Feb 00	5.21	21.68	5.72	4.87	3.67	17.42	2.94	3.93
Apr 00	6.05	15.78	17.85	11.06	3.30	13.92	1.12	0.65
Jul 00	3.47	15.36	51.08	8.61	0.37	8.16	0.22	0.47
TI								
Oct 98	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Jan 99	6.28	19.77	6.02	14.60	2.85	26.15	2.06	0.00
Feb 99	6.23	20.62	4.77	5.48	3.56	25.10	2.13	0.45
May 99	4.46	13.59	9.40	18.83	3.84	30.32	1.50	0.00
Jul 99	6.12	12.66	7.40	11.92	3.80	22.90	2.06	0.68
Oct 99	4.39	10.81	5.32	16.92	4.92	35.01	0.77	0.00
Feb 00	7.96	22.19	5.04	5.58	4.15	21.40	2.16	1.96
Apr 00	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Jul 00	6.14	13.19	11.21	14.50	6.25	28.59	1.14	0.00

n/a = not available

Table 4. Correlation Coefficients (R-value) for chl a vs. biochemical classes. The Pearson Product Moment Correlations were calculated using log-transformed biochemical and chl a. data.

	PROT-C	TCHO-C	TLE-C
ALL	0.90*	0.94*	0.96*
HD	NS	NS	0.86*
RV	NS	NS	NS
MM	0.90*	0.95*	0.96*
TI	NS	-0.75*	0.88*

* Significant correlation at p<0.05
NS = not significant

Table 5. Comparison of bulk and lipid biomarker data from North American Rivers

	SPM mg L^{-1}	POC mg L^{-1}	Chl a μg L^{-1}	Phaeophytin μg L^{-1}	C:N ratio	TFA μg mg^{-1} OC	TST μg mg^{-1} OC	Reference
York River		0.4-2.6	5.0-23.5	2.4-19.1	5.5-9.0	11.4-100.2	1.2-8.0	a,b
Hudson River	10.0-200.0	0.3-5.0	1.0-55.0	0.6-2.5				b,c,d,e
Delaware River	1.8-10.7	0.2-1.9	4.1			12.5-30.0	0.1-1.1	f,g
Potomac River		1.9-4.3			7.0-12.0			h
Columbia River	5.7	0.6	7.5		7.3			i
Suquehanna River	3.5	1.0	9.6					i
Satilla River	7.6	0.7	2.0		13.3			i
Parker River	3.3	0.4-2.5	2.8		7.8			b,i
Sacramento River	10.7-48.4	0.3-1.2	1.4-6.5	0.7-3.5	4.7-11.8	6.6-29.1	1.2-4.3	this study
San Joaquin River	15.0-89.0	0.5-3.4	0.5-98.2	0.3-15.7	4.5-13.8	8.3-49.2	1.0-10.2	this study

TFA = total fatty acids, TST - total sterols

a = McCallister (2002), b = Raymond and Bauer (2001), c = Findlay et al. (1996), d = Cole et al. (1992)
e = Taylor et al. (2003), f = Mannino and Harvey (1999), g = Harvey and Mannino (2001)
h = Sigleo (1996), i = Hopkinson et al. (1998)

Fig. 1. Map showing sampling sites on the Sacramento and San Joaquin Rivers, CA.

The symbols identify the locations of the two sampling sites located on the Sacramento

River, Hood (HD) and Rio Vista (RV), a sampling site located on the San Joaquin River,

Mossdale (MM), and Twitchell Island (TI) which is influenced by both the Sacramento

and San Joaquin Rivers.
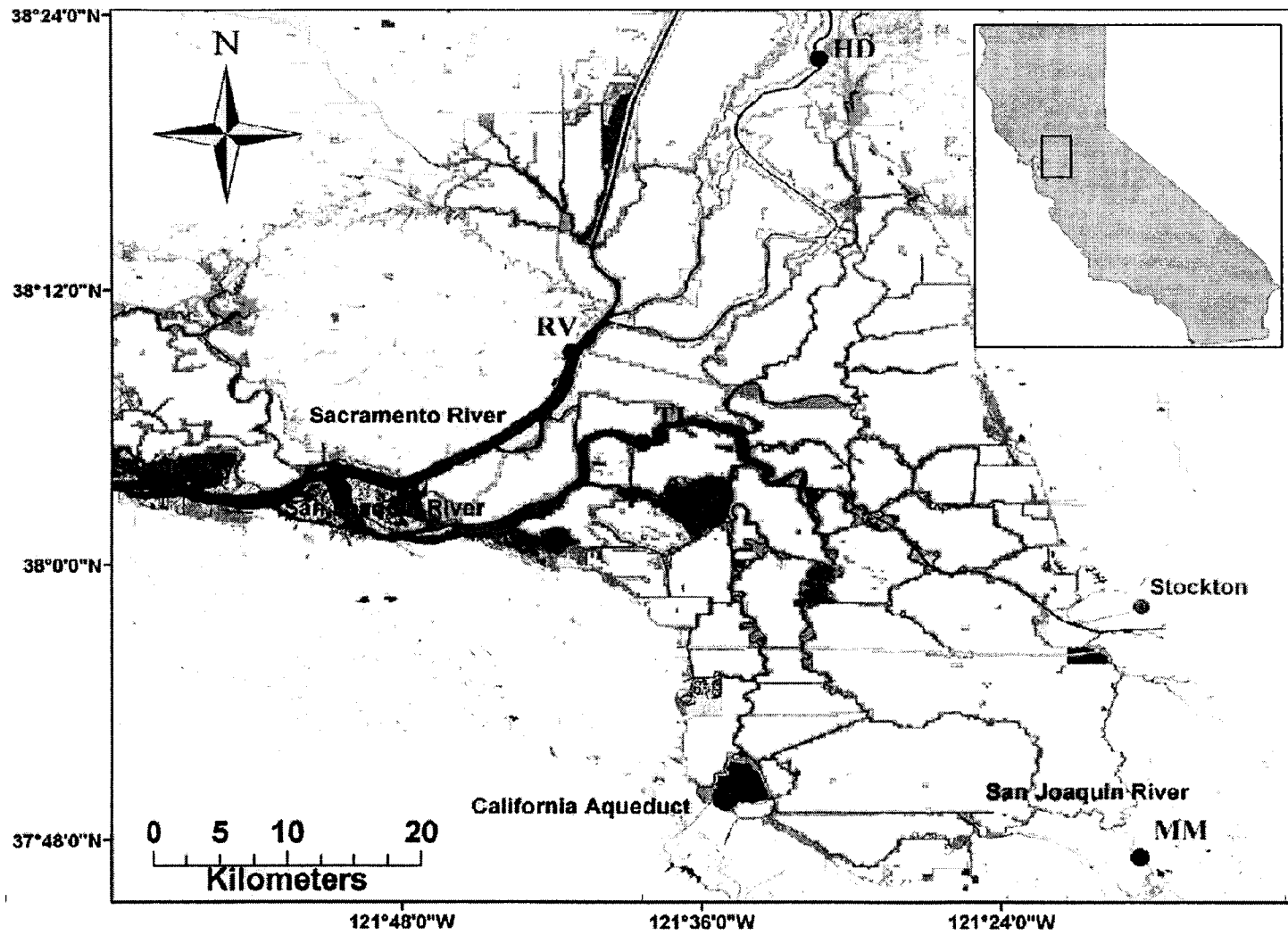
Fig. 2. River discharge (in cfs) for the Sacramento and San Joaquin Rivers for October

1998-July 2000. Arrows indicate sampling dates. Data from permanent sampling

stations at Hood on the Sacramento River and Vernalis on the San Joaquin River were

obtained from the California Data Exchange Center (http://cdec.water.ca.gov).
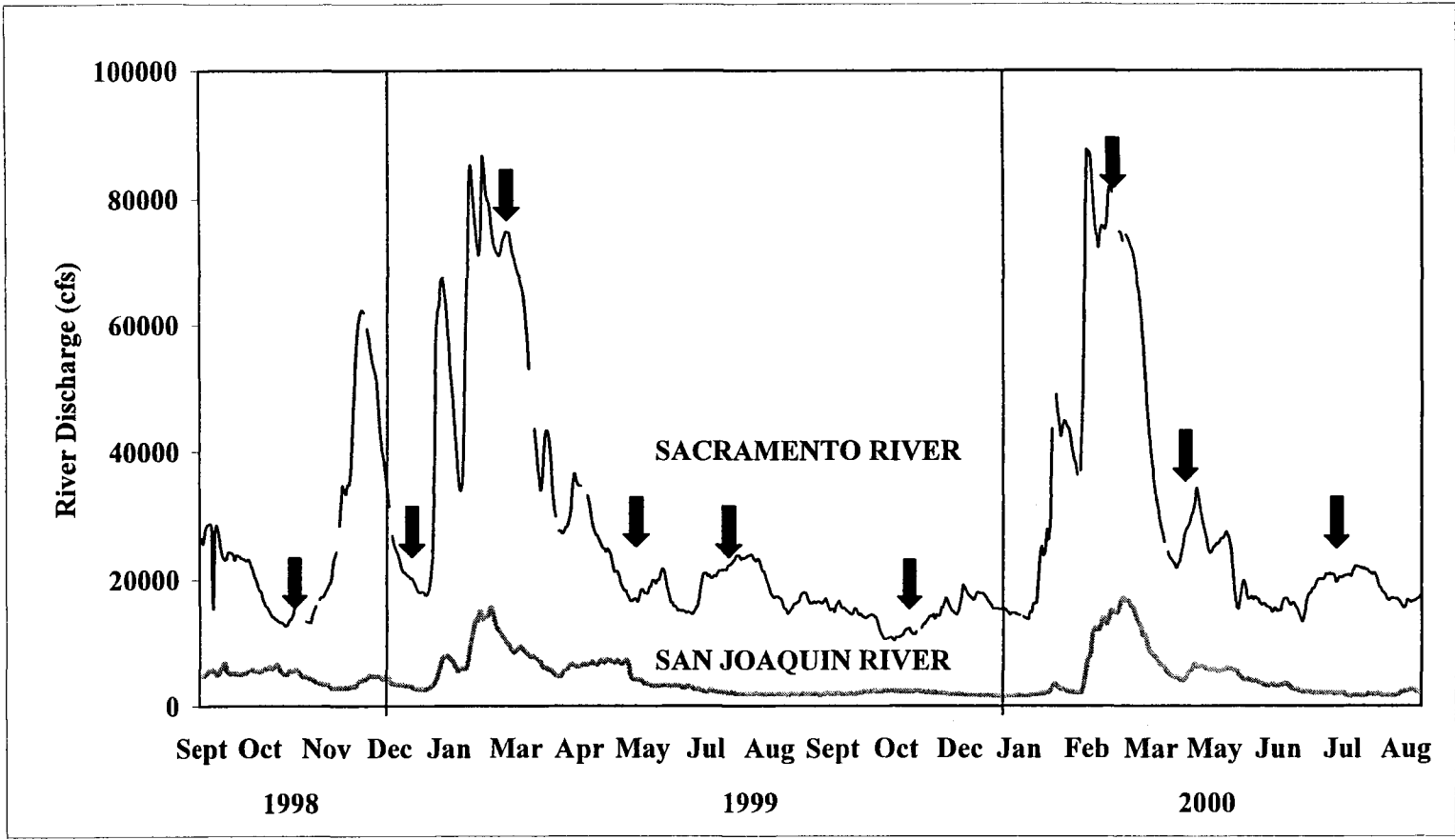
Fig. 3. Boxplots showing differences between (a) analyses of paired or triplicate aliquots of the same suspended particle sample and (b) replicate samples collected from the same site at the same time. Plots show the median (labeled horizontal lines inside boxes) and interquartile range (25th to 75th percentiles as box ends). Whiskers indicate range from 5th to 95th percentile. Separate measures of analytical precision and sampling error were done for total proteins, total carbohydrates and total lipids. Fewer replicate samples were collected for lipids due to the amount of labor required for processing. n = sample number for each comparison.
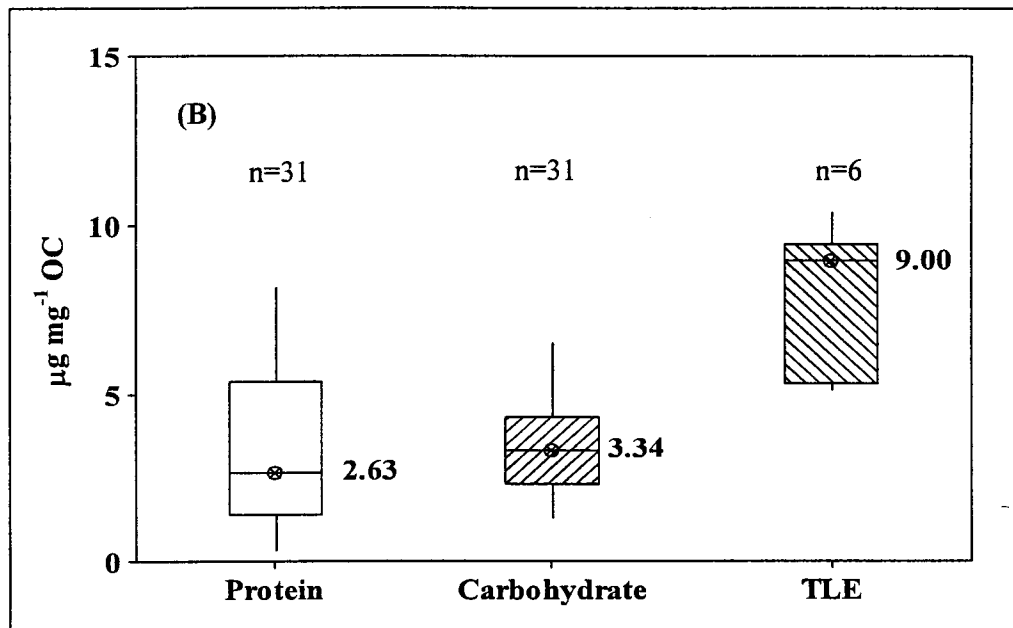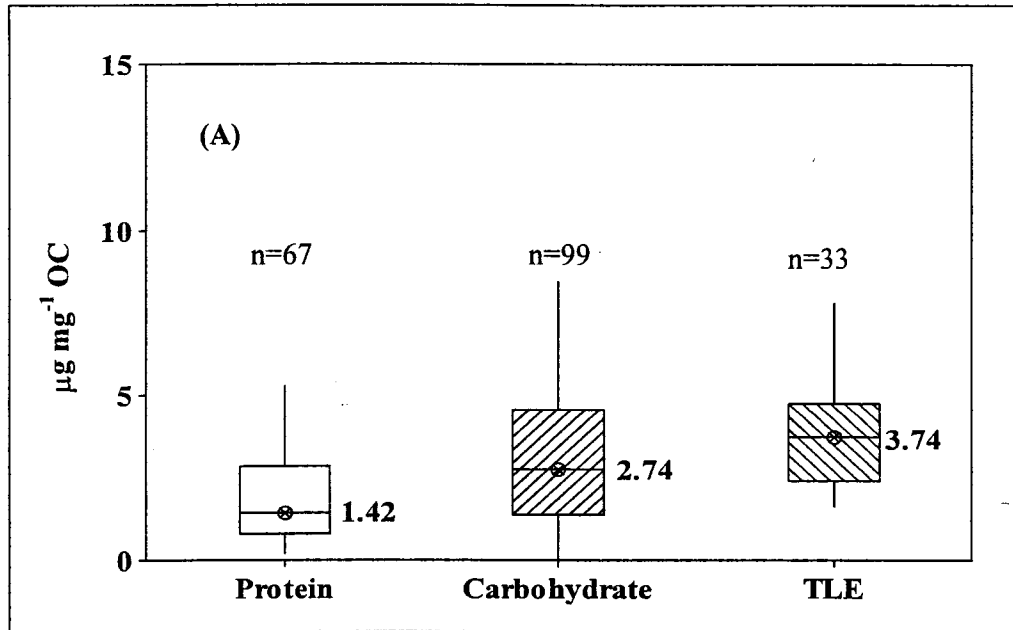
Fig. 4. Carbon-normalized concentrations of total protein, total carbohydrate and total

lipids for the Sacramento (a,c,e) and San Joaquin (b,d,f) by season. In this and

subsequent figures, error bars represent standard deviations from the mean (n=3).

SACRAMENTO   **SAN JOAQUIN**
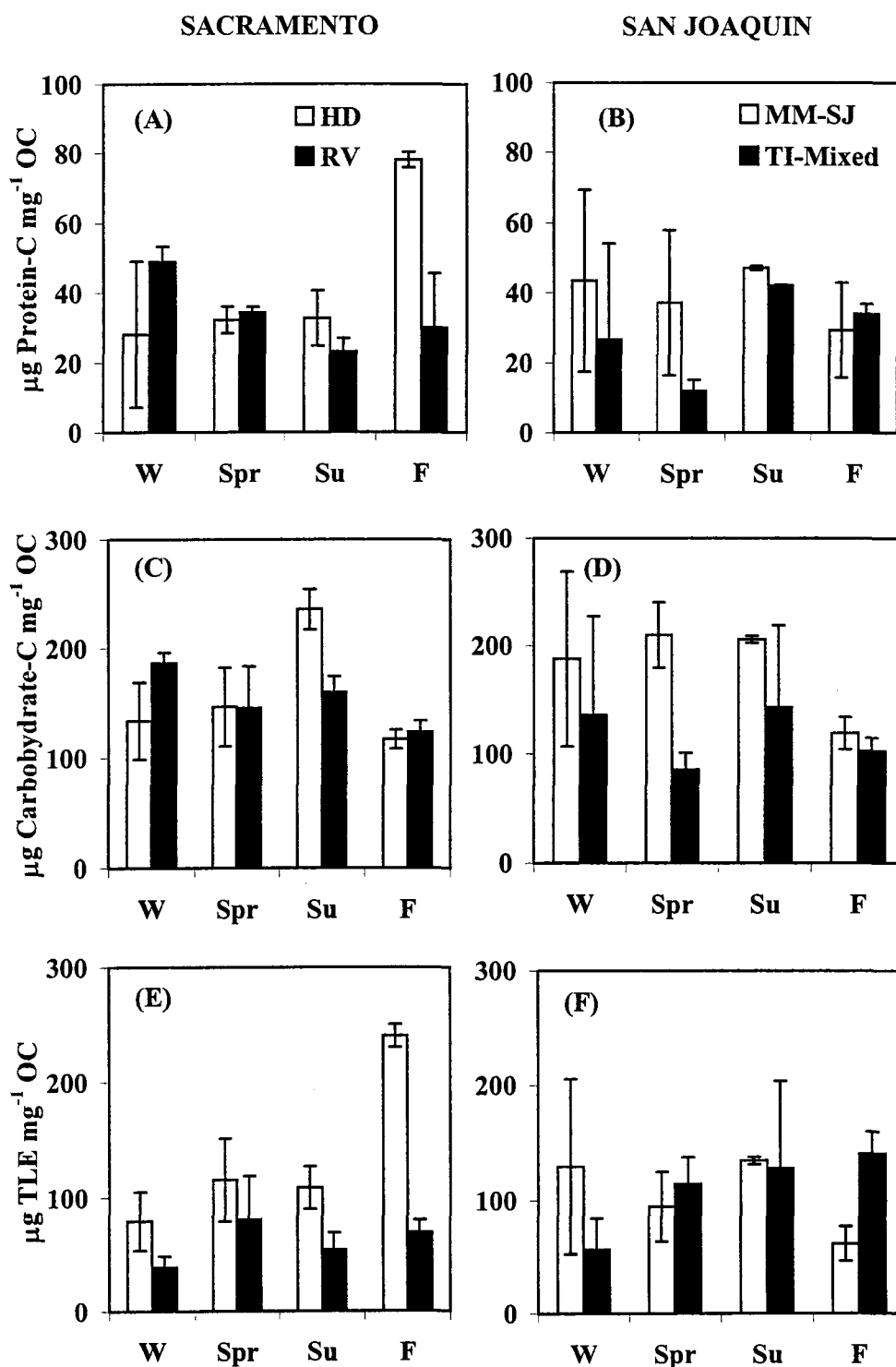
Fig. 5. Measurements of carbon quality of suspended matter including (a,b) total

polyunsaturated fatty acids (PUFAs) and (c,d) 20:5ω3 fatty acid, each expressed as the

concentration of fatty acid per mg organic carbon.

SACRAMENTO

SAN JOAQUIN

(A) HD RV

(B) MM-SJ TI-Mixed

(C)

(D)
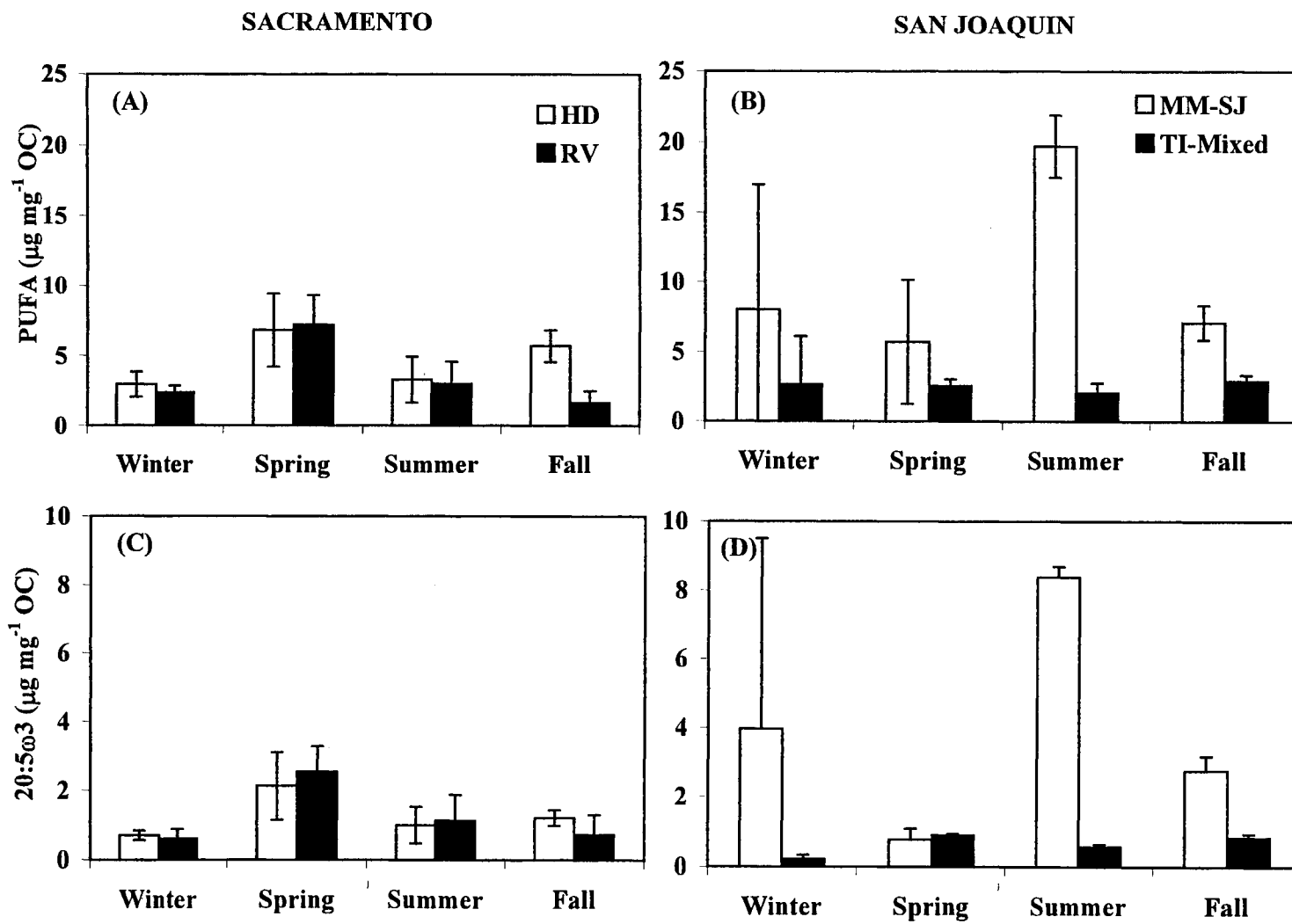
Fig. 6. Measurements of bacterial sources and the reworking of organic matter in river

samples, including (a) branched fatty acids, as a percent of total fatty acids, which can be

used as a measurement of bacterial biomass, and (b) cholestanol/cholesterol ratios.

SACRAMENTO
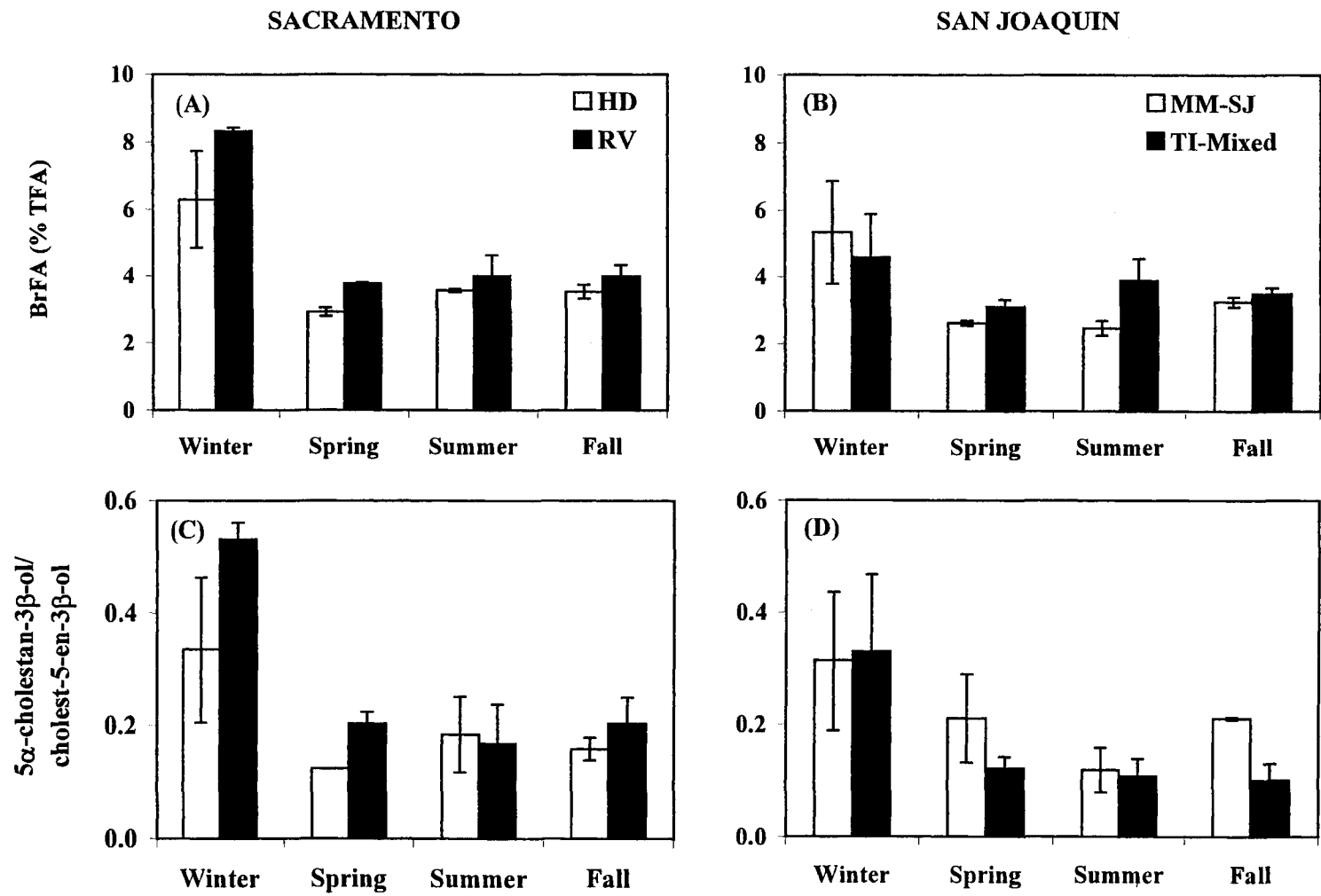
SAN JOAQUIN

Fig. 7. Food energy for suspended particle samples collected in the Sacramento and San Joaquin Rivers, calculated using the biochemical data. Energy equivalents for each biochemical class were obtained using the following coefficients: 24.0 mg L^{-1} for proteins, 17.5 mg L^{-1} for carbohydrates and 39.5 mg L^{-1} for lipids (Navarro et al. 1993, Gnaiger 1983).

SAN JOAQUIN

(B)

SACRAMENTO

(A)
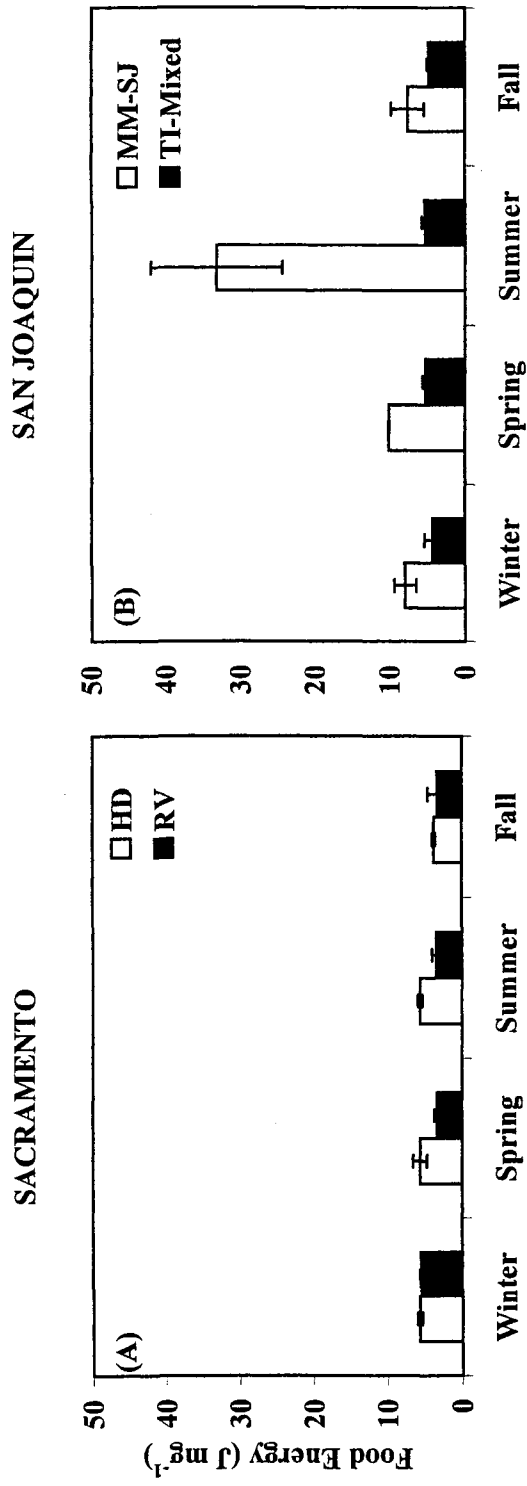
Fig. 8. (a-b) Loadings and (c) score plots for PC 1 and 2 of log-transformed fatty acid,

sterol and biochemical data for the Sacramento and San Joaquin Rivers. PC 1 accounted

for 27.0% of the variability in the dataset while PC 2 accounted for 24.6%. See Table 2

for sterol compound # and source, and text for fatty acid sources and fatty acid

identifications.

Loadings

PC 1 (A), PC 2 (B) loadings for: Br15, 17; 18:1w9; CHOL; BRAS; CAMP; 22:6w3; 20:5w3; 18:2/3; 18:4; 16:1w7; 16pufa; TLE; PROT; n13,15,17; 18:0; 16:0; 14:0; 12:0; TCHO; C29D5; STIG; LCFA; STAN. Groupings: Bacteria, Zooplankton, Algal, Vascular Plant, Degraded OM.

(C) PC 2 vs PC 1 plot showing TI, MM, RV, HD. PC 1 axis: Low quality POM / more degraded (left) — High quality POM / less degraded (right).
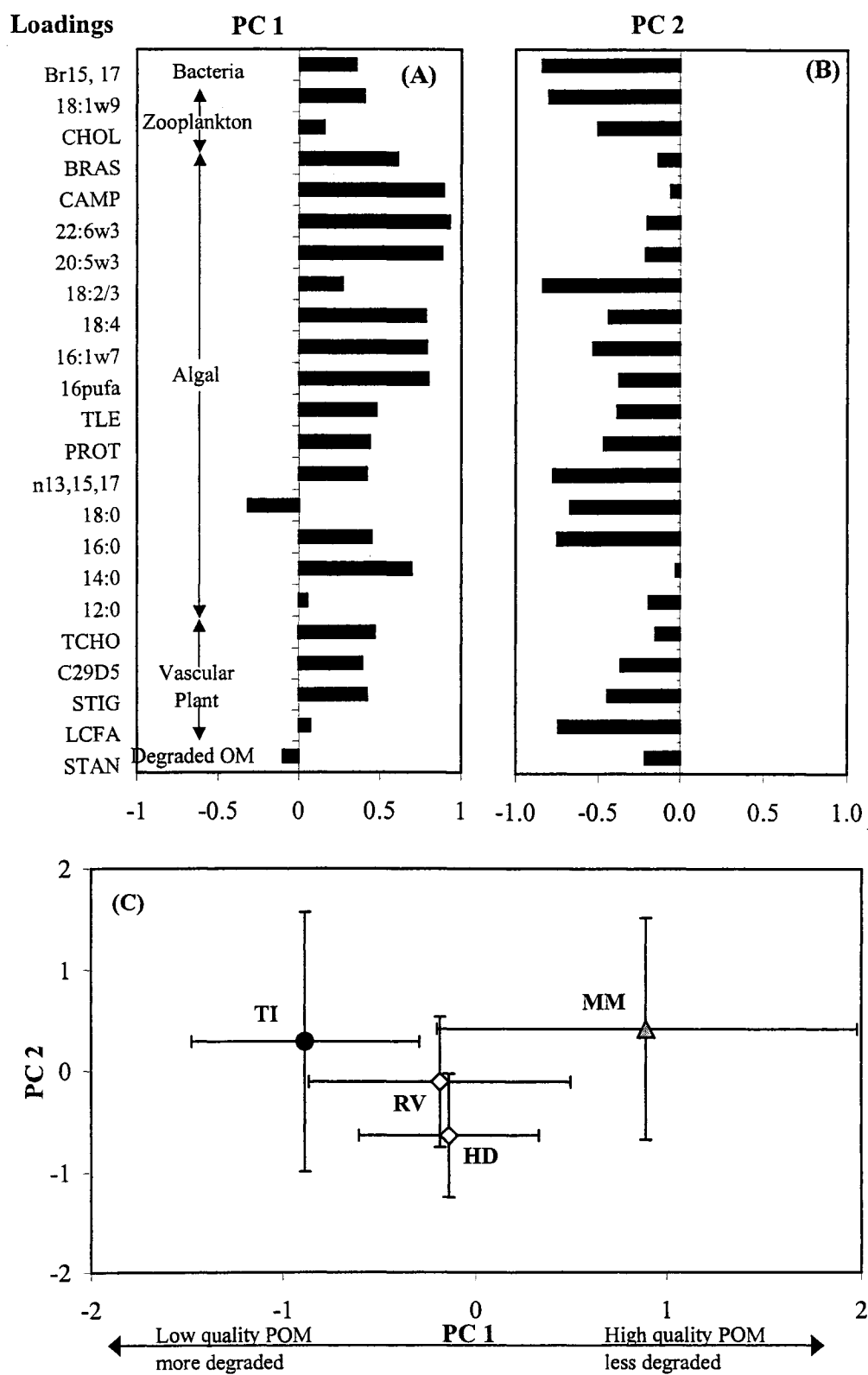
Fig. 9. Score plots for PC 1 and 2 for Sacramento and San Joaquin River sites during fall,

winter, spring and summer.
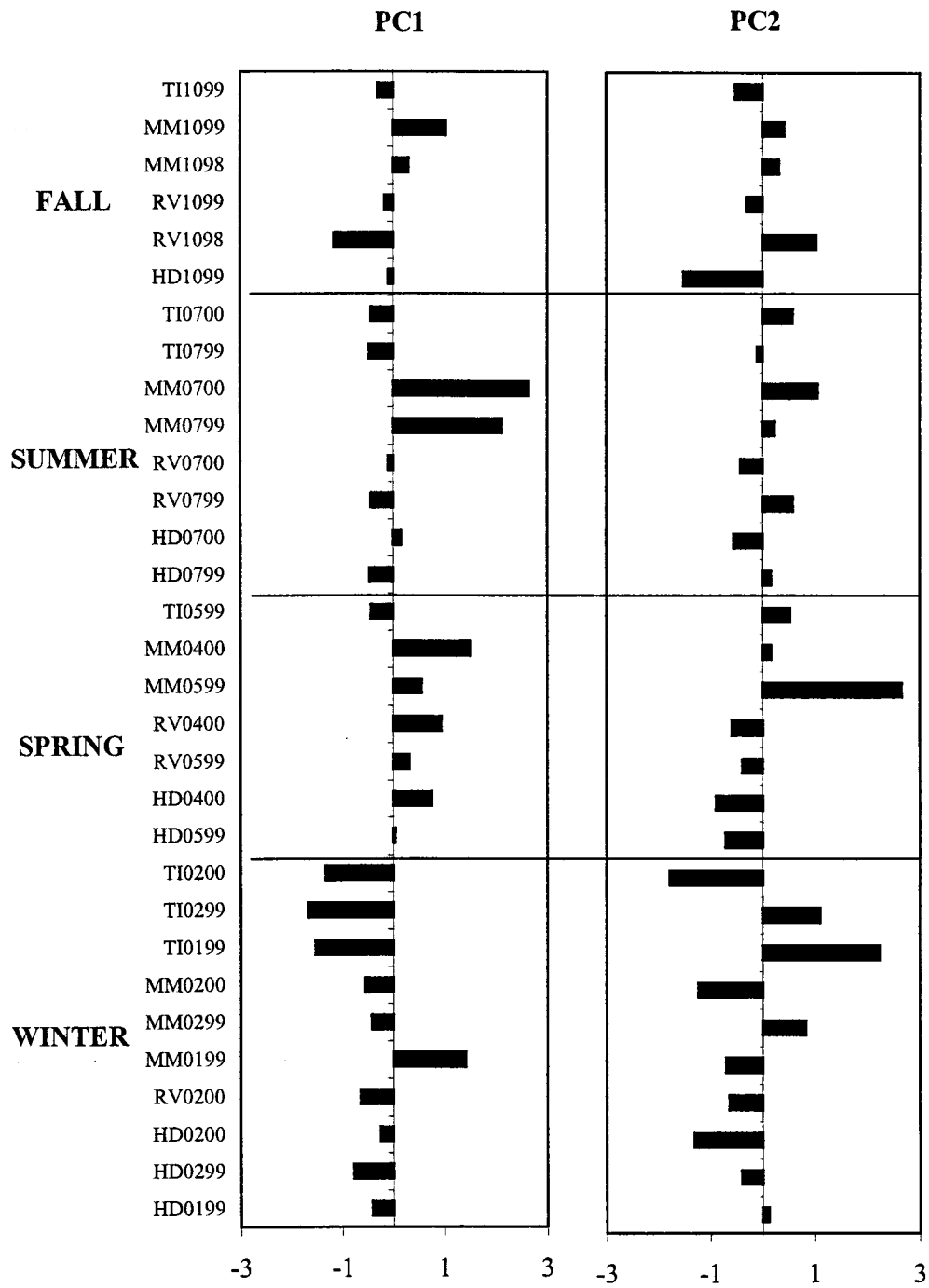
CHAPTER 3

PARTICULATE ORGANIC MATTER COMPOSITION IN THREE SHALLOW-
WATER HABITATS OF THE SACRAMENTO-SAN JOAQUIN RIVER DELTA, CA

ABSTRACT

Sources and quality of particulate organic matter (POM) at three shallow tidal lake sites were examined over a two-year sampling period (October 1998-July 2000). Lipid biomarker compounds (fatty acids and sterols), combined with measures of biochemical classes (protein, carbohydrates and total lipids) and bulk parameters (particulate organic carbon, particulate nitrogen, chlorophyll a and pheaophytin) were analyzed. Suspended particulate matter was collected at three shallow-water tidal breached levee sites in the Sacramento-San Joaquin River Delta, CA. Little Holland Tract (LH) in the Northern Delta, a 1000-acre tidal lake, was breached two years prior to the start of the study. Mildred Island (MI) and Franks Tract (FT) in the southern Delta (1100 acres and 3200 acres in size), were breached twenty-five and fifty years prior to the beginning of the study, respectively. Based on these measurements, sources of organic carbon at the three sites differed; plant (terrigenous and aquatic) sources dominated at FT, while phytoplankton and terrigenous sources were the major sources at MI. Similarly, a mixture of algal (likely pelagic and benthic) and terrigenous sources dominated at LH. Relative to FT and MI, concentrations of total lipid and fatty acid and sterol concentrations were lower at LH, suggesting that food quality was lower. In contrast, protein and carbohydrate content, measures of organic carbon quality, did not differ between sites. Lipid biomarker composition varied over time, with peaks in total fatty acids and C_{27} sterols in May 1999 at MI, suggesting enrichments in contributions from zooplankton and phytoplankton. Similarly, C_{28} sterols and total alcohols (mainly phytol) were elevated at FT and MI in April 2000, a time period characterized by peak larval fish populations. Variations in the sources and composition of POM in each of the shallow-water habitats, suggests that MI and FT are characterized by higher quality food for filter-feeders, particularly during ecological important periods of larval fish development in the spring.

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INTRODUCTION

The composition of particulate organic matter (POM) is an important factor in controlling processes critical to ecosystem function, such as primary and secondary production, and nutrient dynamics (Berg and Newell 1986; Poulet et al. 1986). POM composition is affected by short-term and long-term variability in physical and biological factors, which can lead to high variability over time in food resources for consumers (Canuel et al. 1995). Changes in food availability may be the main factor affecting spatial distribution, growth rates and reproduction of suspension feeders (Pusceddu et al. 1996).

Lipids are an important class of biochemicals associated with POM in aquatic habitats (Canuel et al. 1995; Galois et al. 1996; Canuel and Zimmerman 1999). Lipids make up only a small fraction of organic carbon, but play an important role in the carbon cycle through their metabolism and refractory nature, energy storage and nutritional potential, and control of biological functions such as cell membrane structure and function (Duursma and Dawson 1981). Lipids have a range in structural features and functional groups, and include several compound classes such as fatty acids, sterols, alcohols and hydrocarbons. While generally less abundant than proteins, carbohydrates, humic and molecularly uncharacteristic fractions, lipids provide molecular signatures that can be utilized to determine sources and transformation pathways of SPM in aquatic environments (Huang and Meischein 1976; Volkman 1986; Wakeham and Canuel; 1986; Saliot et al. 1991).

The ability to use lipids as proxies for organic matte rsources derives from biosynthetic pathways unique to specific groups of organisms including bacteria, phytoplankton, zooplankton and higher plants (Ackman et al. 1964; Mayzaud et al. 1989). Sterols, generally specific to eukaryotic organisms, have been utilized to identify sources of POM (Huang and Meinschein 1979; Volkman 1986; Canuel and Zimmerman 1999) and sediments (Mudge and Norris 1997; Zimmerman and Canuel 2001) in aquatic environments. This class of compounds possesses structural features, such as double bonds and side-chain alkylation, which can be taxonomically diagnostic (Volkman 1986; Volkman et al. 1998; Volkman 2003). Fatty acids can be utilized to determine both

sources and nutritional quality of POM for pelagic and benthic filter-feeders (Harvey et al. 1987; Canuel et al. 1995; Müller-Navarra et al. 2003). Suspension feeders, as with all animals, require an adequate amount of dietary lipids (fatty acids and sterols), proteins (amino acids), carbohydrates and energy. Combined with measurements of biochemical compounds (total proteins, total carbohydrates and total lipids) that make up potentially utilizable fractions of POC, lipid biomarker compounds provide a powerful tool for examining how POM supports ecosystem function.

In the San Francisco Bay region of California, several lipid biomarker studies have been carried out. Prior studies have focused on northern and southern San Francisco Bay, and the effects of river flow and the spring bloom (Canuel et al. 1995; Canuel and Cloern 1996; Canuel 2001). Less is known about sites in the Sacramento-San Joaquin River Delta (Delta, hereafter), a vital interface between California's drainage basin and the San Francisco Bay (Jassby et al. 1993; Sobczak 2005). Past efforts to determine sources and quality of organic carbon in the Delta have focused on stable isotopes (Cloern et al. 2002), bulk particulate organic carbon (POC), chlorophyll (Jassby and Cloern 2000; Müller-Solger et al. 2002), and bioassays to measure bioavailability of POC and DOC (Sobczak et al. 2002, 2005). Within the Delta, there are several shallow tidal lakes (shallow-water habitat, or SWH). These lakes were formed when the levees surrounding former agricultural tracts were breached during floods (Simenstad et al. 2000). In recent years, the Delta system has been the focus of a major restoration effort (CALFED 2000). Increasing the amount of SWH has been a focus of restoration efforts to increase native fish production and improve overall Delta ecosystem health (Simenstad et al. 2000; Grimaldo et al. 2004). However, little is known about what facets of SWH are important for increasing system production or how SWH systems evolve over time. Studies of organic matter composition in existing SWH provide an opportunity to examine food quality and POC production in systems established over a range of time scales in order to predict the outcome of proposed restoration efforts. Studies of POM composition, including lipid biomarker compounds and biochemical composition provide an opportunity to examine the sources and composition of organic matter in these systems and the ability to predict the potential usefulness of this organic matter to upper trophic levels.

This study focused on identifying spatial and temporal patterns in lipid biomarker (fatty acids, sterols and alcohols) and biochemical (protein, carbohydrate and lipid) composition of POM in three shallow-water habitats in the Delta. The sites spanned a spectrum of "ages" (2-50 years) since flooding, water depths (0.6-8.0 m), size and hydrologic regimes. We hypothesized that POM composition would differ at each site due to differences in water depth, grazers, and hydrodynamic regime such as river inflow. An additional goal was to compare/contrast measures of food quality to examine the potential implications of differences in POM composition for secondary producers.. We hypothesized that sites where phytoplankton was the primary source would exhibit higher food quality than sites with greater vascular plant or riverine POM sources.

METHODS

Study Sites

Several shallow tidal lakes exist in the Delta, encompassing a spectrum in sizes and ages (Simenstad et al. 2000). In 1850, the Delta consisted of low-lying islands among the channels of the Sacramento and San Joaquin Rivers (Wolff 2003). Much of this marsh habitat was converted to agricultural tracts in the late 1800s. These sites reverted back to shallow-water habitat both due to intentional and accidental breaching of earthen levees over the last 100 years (Simenstad et al. 2000). In systems where the levees have been breached, tidal exchange is generally less than 1 m, and salinity ranges from 0.09-0.27 psu.

For our study we selected three of these shallow lakes for investigation (Fig. 1, Table 1). Little Holland Tract (LH) is a 1000-acre lake located in the northern region of the Delta that was flooded in 1996. LH has one opening in the levee at the southern end of the lake, and a strong current exists through this breach. The lake is shallow, generally ~1 m in depth (Table 1), and receives water from Yolo Bypass, a floodplain, during winter and spring months (Sobczak et al. 2005). At the time of sampling, *Scirpus* sp. existed along the edges of the lake, and there was little to no sediment accretion on the bottom. *Corbicula fluminea*, the invasive freshwater clam prevalent in the other regions of the Delta (Foe and Knight 1985, Hymanson et al. 1994), was found in LH. Samples for these studies were collected just inside the breach.

Mildred Island (MI) is a shallow lake in the southern Delta that is 1100 acres in size; was flooded in 1983 (Fig.1). MI is surrounded by a levee that has two openings, one in the northeastern corner of the lake, and one in the southern part of the lake that connect the lake to the outside channels. Mean depth in MI is ~5-m (Table 1), except for a deep hole (~20-m) near the northeast entrance. Sharply curved levees create calm bays with little current. Bottom friction dampens the currents relative to currents in adjacent channels (Monsen et al. 2002). Flow through the levees is driven by tidal energy and hydrologic conditions on the Sacramento and San Joaquin Rivers. Tidal excursions and dispersion are greater in the north, where the levee opening is wider and deeper than in the south (Lucas et al. 2002; Monsen et al. 2002). Sharp north-south gradients in

temperature, specific conductivity, chl *a* and DO (with maximums of each in the south), suggest longer retention times of water, dissolved substances and particles in the south than the north (Lucas et al. 2002; Monsen et al. 2002; Stacey 2003). Samples were collected from a single site in a cove in the western section of the lake, away from the two main breaches.

Franks Tract (FT) is a 3200 acre lake in the southern Delta that was flooded in 1938. Multiple levee openings allow for exchange of FT water with the adjacent river channels. *C. fluminea* are abundant at this site (Lucas et al. 2002), and the site is characterized by extensive growth of *Egeria densa*, an invasive rooted macrophyte from spring-fall which can cover >50% of its area (Grimaldo et al. 2004). Samples were collected from a site in the northern corner of the lake.

Sample Collection

Samples were collected during six cruises between October 1998 and July 2000 representing spring, summer and fall months (Table 1). In MI and FT, water samples were collected from 1-m above the bottom to standardize the samplings. Because LH was generally 1-m in depth, samples were collected at approximately 0.5-m above bottom. Water was collected using a large-volume peristaltic pump and pre-filtered through a 243 micron Nitex mesh to remove large particles and zooplankton. For lipid samples, water was collected into 40-l stainless steel cans, while water for bulk biochemical analyses, nutrients and particulate organic carbon and particulate nitrogen were filtered into 15 L plastic jugs that were pre-rinsed with distilled water. Lipid samples were collected using 142 mm glass fiber filters (GFF), and a single sample was generally collected due to the length of filtering time (approximately 3 hours). For bulk biochemical analyses, carbohydrate samples were filtered in triplicate on 47 mm GFF filters, while total proteins were filtered onto 25 mm GFF filters.

Separate water samples were filtered onto GF/F filters for particulate organic carbon (POC) and nitrogen (PN), chlorophyll a (chl *a*), phaeophytin and suspended particulate matter (SPM). The samples were analyzed at the U.S. Geological Survey in Menlo Park, CA (Sobczak et al. 2005).

Chemical analyses

Lipid biomarkers were analyzed as described in Chapter 2 of this dissertation, and Arzayus and Canuel (2004). Total proteins were analyzed using the bicinchoninic acid method of Nguyen and Harvey (1994), and described in Chapter 2. Total carbohydrates were analyzed using the method of Pakulski and Benner (1992). Biochemical data were reported in carbon units using correction factors from Fichez (1991). Biopolymeric carbon (BPC) was calculated as the sum of carbon-corrected proteins, carbohydrates and lipids (as TLE).

Statistical analyses

Data were analyzed statistically using MiniTab (Minitab Inc.: release 13.32, 2003). Results from lipid biomarker analyses of all shallow-water habitat samples were combined and analyzed using principal component analysis (PCA). The analysis was based on the carbon-normalized concentrations ($\mu g\ mg^{-1}$ POC) of individual sterol, alcohol, and fatty acid biomarker compounds. Some variables were grouped to reflect a common source. All concentrations were log-transformed prior to analysis and subjected to an R-mode varimax factor analysis. Varimax rotation maximizes variance of squared loadings within factors (i.e. simplifies the columns of the loading matrix). This method attempts to make the loadings either large or small to ease interpretation (Minitab Inc.: release 13.32, 2003)

Within Minitab, the General Linear Model analysis of variance (ANOVA) was used to test for between-site differences in POM composition. Results were significant when $p<0.05$. When our data violated the assumptions of parametric tests, that all data be normally distributed and display homogeneity of variance, a nonparametric test was used. For these data, the Fisher's least significant squares (Fisher's LSD) method was employed to test the differences of means, after rejecting the null hypothesis using ANOVA. All data were log-transformed prior to data analysis to minimize effects from outliers. Data were also analyzed by Pearson Product Moment Correlation, which measures the degree of linear relationship between two variables. The method performs a two-tailed test of the correlation (reported as a p-value) (Helsel and Hirsch 1992). ̃

RESULTS

Bulk Parameters of SPM

SPM concentrations were higher at LH than the other sites, averaging 108.93±34.45 mg L^{-1}, vs. 14.12±2.39 mg L^{-1} for MI and 12.75±4.91 mg L^{-1} for FT, respectively. This was reflected in the secchi depth, which was significantly lower at LH (Table 1). POC and PN were significantly higher at LH, averaging 1.71±0.71 mg L^{-1} and 0.23±0.09 mg L^{-1}, respectively. POC averaged 0.70±0.10 mg L^{-1} and 0.51±0.21 mg L^{-1}, while PN averaged 0.10±0.01 mg L^{-1} and 0.07±0.04 mg L^{-1} at MI and FT, respectively. The proportion of POC relative to SPM was lower at LH (1.63±0.63%) compared to MI and FT (5.45±1.14% and 3.81±0.53%, respectively).

Values for chl *a* averaged 4.18±3.13 μg L^{-1} and 5.32 ±1.64 μg L^{-1} at MI and LH, while phaeophytin averaged 3.45±1.12 μg L^{-1} and 3.67±0.84 μg L^{-1} at the same site. Chl *a* and phaeophytin were lower at FT compared to the other sites (1.97±0.39 μg L^{-1} and 1.95±0.33 μg L^{-1}, respectively). s.

PCA Analysis of Lipid Biomarkers

Loadings on PC1 (Fig. 2a) were most positive for the polyunsaturated fatty acids 16:2/3, 16:4, 20:5ω3 and 22:6ω3, with slightly lower values for 14:0, 16:1ω7 and 18:1ω9. Stigmasterol (24-ethylcholesta-5,22-dien-3β-ol), generally associated with terrestrial/vascular plant sources, was the only compound with a negative loading on PC1. LH consistently had negative scores on PC1 while MI and FT tended to be positive or near the origin. The most positive scores on PC1 occurred at MI and FT during October 1998 and May 1999 (Fig. 2b).

Stigmasterol and 29Δ[5] had the most positive loadings on PC 2. In contrast brassicasterol and phytol had the most negative loadings while loadings for 18:4, 18:2/3 and 16:0 were also quite negative. All of the LH observations were negative on PC2. Scores on PC2 were most negative for FT (April and July 2000) and MI (Apr 00) relative to the remaining sites. MI in July 2000 was also quite negative (Fig. 2b). The variations in lipid biomarker composition at the three sites indicated that a more detailed analysis of

fatty acid and sterol biomarkers, as well as biochemical compounds, was needed to discern spatial and temporal patterns of POC sources and quality.

Lipid Biomarker Compounds

Concentrations of total sterols, fatty acids and alcohols, normalized to POC, were significantly lower at LH than MI and FT (Fig. 3, Table 2). Total sterols (ΣST) were highest at MI (3.77 ± 0.88 μg mg^{-1} POC), followed by FT (2.89 ± 0.95 μg mg^{-1} POC) and LH (2.08 ± 0.29 μg mg^{-1} POC). Total fatty acids (ΣFA) were lower at LH (11.27 ± 4.90 μg mg^{-1} POC) compared to MI and FT (31.43 ± 13.98 μg mg^{-1} POC and 28.44 ± 10.45 μg mg^{-1} POC, respectively) (Fig. 3b). Although ΣFAs were generally similar at MI and FT, concentrations peaked at different times. ΣFAs reached a maximum of 58.97 μg mg^{-1} POC at MI in May 1999, while values were highest at FT in April and July 2000. Total alcohols, of which phytol comprised 50-90%, reached maximums in April 2000 of 5.03 μg mg^{-1} POC and 5.82 μg mg^{-1} POC at MI and FT, respectively.

Sterols were grouped by carbon atom number (Fig. 4), to approximate sources of POC. On average, C_{27} sterols, dominated by cholest-5,22-dien-3β-ol and cholest-5-en-3β-ol, were lower at LH (766.70 ± 115.80 μg mg^{-1} POC, p=0.03). Peaks in C_{27} sterols were observed in May 1999 (1505.24 μg mg^{-1} POC) and July 2000 (1960.73 μg mg^{-1} POC) in MI, and in July 2000 at FT (1539.62 μg mg^{-1} POC). On average, C_{28} sterols including 24-methylcholesta-5,22-dien-3β-ol, 24-methylcholesta-5,24(28)-dien-3β-ol and 24-methylcholest-5-en-3β-ol were higher in MI. vs. FT (Fig.4b). These compounds were least abundant in LH (642.30 ± 117.90 μg mg^{-1} POC, p=0.05) relative to MI (1275.40 ± 378.10 μg mg^{-1} POC) and FT (1163.20 ± 619.20 μg mg^{-1} POC). Maxima in C_{28} sterols were found in April 2000 at both MI (1954.39 μg mg^{-1} POC) and FT (2267.46 μg mg^{-1} POC). C_{29} sterols (Fig. 4c), dominated by 24-ethylcholesta-5,22-dien-3β-ol and 24-ethylcholest-5-en-3β-ol were similar at LH (572.40 ± 80.7 μg mg^{-1} POC) and MI (593.00 ± 104.4 μg mg^{-1} POC), but significantly higher at FT (1012.00 ± 311.60 μg mg^{-1} POC, p=0.01).

Fatty acid groups also exhibited between-site variability (Fig.5, Table 2), with all groups significantly lower at LH compared to FT and MI (p<0.05). Saturated fatty acids,

comprised of short-chained (SCFA) and long-chained fatty acids (LCFA; C_{22}-C_{32}), comprised 34-44% of ΣFAs at the three sites. SCFA concentrations were 3-10x higher than LCFAs. SCFA were significantly lower at LH (p<0.01), averaging 3.05 ± 1.10 µg mg^{-1} POC, compared to 9.25 ± 3.52 µg mg^{-1} POC and 10.05 ± 3.55 µg mg^{-1} POC at MI and FT, respectively. Within this group, 14:0 and 16:0 were dominant (Table 2). LCFAs were similar among sites, averaging 1.05 ± 0.06 µg mg^{-1} POC. The ratio of SCFA:LCFA, a measure of FA source (aquatic vs. terrigenous), was different among sites, with LH (4.65 ± 1.61), lower than FT and MI $(8.99\pm5.34$ and 11.18 ± 4.52, p<0.05). Maximum concentrations of SCFAs and LCFAs occurred in May 1999 at MI, and April 2000 and July 2000 at FT (Table 2).

Monounsaturated fatty acids (MONO) comprised 32-42% of ΣFAs, and averaged 4.34 ± 2.24 µg mg^{-1} POC at LH, 9.89 ± 3.81 µg mg^{-1} POC in FT and 10.87 ± 4.20 µg mg^{-1} POC at MI (Fig.5). Across all sites 16:1ω7 and 18:1ω9 were the dominant MONO FAs (Table 2). At LH, MONO FAs were highest in October 1999 and July 2000. Like SAT FAs, the highest concentrations of MONO FAs were observed in May 1999 at MI, and in April 2000 and July 2000 at FT (Table 2).

Polyunsaturated fatty acids (PUFAs) averaged 2.14 ± 0.94 µg mg^{-1} POC in LH vs. 8.05 ± 5.71 µg mg^{-1} POC in MI and 6.43 ± 3.46 µg mg^{-1} POC in FT (Fig. 5). PUFAs comprised 16-33% of total fatty acids. Dominant PUFAs included 16:3, 16:4, 18:2, 18:4 and 20:5ω3 (Table 2). Higher concentrations of individual PUFAs were observed in October 1999, April 2000 and July 2000 in LH (Table 2). As with other FA groups, individual PUFAs reached maximum concentrations at MI in May 1999 (Table 2). The fatty acid 18:4 reached a maximum of 4485.30 µg mg^{-1} POC in April 2000, while 20:5ω3, the other dominant PUFA at this site, reached maximums of 2961.91 µg mg^{-1} POC and 3028.50 µg mg^{-1} POC in April 2000 and July 2000, respectively.

Branched fatty acids (BrFA), which included iso- and anteiso- 15:0 and 17:0 averaged 0.47 ± 0.10 µg mg^{-1} POC at LH, 0.94 ± 0.19 µg mg^{-1} POC at MI and 0.81 ± 0.23 µg mg^{-1} POC at FT (Fig.5). BrFAs made up only a small percentage, 2-6% of total fatty acids at all sites.

Biochemical Compounds

Concentrations of protein and carbohydrate were similar across sites. Carbohydrate was the dominant biochemical class, comprising 7-30% of POC at the three sites. Maximum carbohydrate concentrations of 271.27 ± 16.82 μg mg^{-1} POC were observed at MI in April 2000. Protein comprised 2-8% of POC at the three sites, and was highest (78.90 ± 20.56 μg mg^{-1} POC) at FT in April 2000. In general, carbohydrate and protein concentrations were lowest at most sites in May 1999 (Table 3).

TLE-C comprised 5-21% of POC over the study period, and was the only biochemical class to exhibit significant spatial and temporal variations. Lower values of TLE-C (78.52 ± 24.14 μg mg^{-1} POC, p=0.05) were found at LH relative to MI (109.32 ± 33.98 μg mg^{-1} POC) and FT (139.55 ± 51.93 μg mg^{-1} POC). Maximum TLE-C values were observed in October 1998 at FT, although high concentrations were also observed in April and July 2000 at FT and MI as well (Table 3).

Biopolymeric carbon (BPC-C), the sum of total protein, carbohydrate and lipid (in this case, TLE), accounted for 17.6-46.6% of POC at the three shallow-water sites (Table 3). %BPC-C was similar between the sites, although higher percentages (>40%) were observed at MI in April 2000 and at FT in April and July 2000.

Correlations of Lipid and Biochemical Compounds

Correlation analysis was used to determine relationships between compound groups important to understanding sources and quality of POC at the three sites (Table 4a-c). In LH, POC did not correlate with any lipid or biochemical parameters. In contrast, POC was negatively correlated with fatty acid groups (PUFA, BrFA, LCFA) in MI and PUFA and sterol groups in FT. BPC and POC were negatively correlated in FT. Chl *a* was positively correlated with C_{29} sterols and LCFAs in LH, and phytol, C_{28} sterols, PUFAs and BrFAs in FT. Phytol was positively correlated with most lipid biomarkers in LH (Table 4a). In MI, phytol was positively correlated to C_{28} sterols, BPC-C and negatively correlated to BrFA. In contrast, phytol was positively correlated all sterols, PUFAs and BPC in FT. C_{27} sterols were positively correlated with C_{29} sterols and BPC in both LH and FT. C_{28} sterols correlated with BPC at FT and MI, but

correlated positively with PUFAs only in FT. C_{29} sterols were positively correlated with all fatty acid groups and BPC in LH.

DISCUSSION

Sources and Composition of POM

Several potential sources of POM exist in Delta shallow water habitats, including emergent vegetation such as *Scirpus acutus* (Common tule), submerged aquatic vegetation (SAV) such as *Egeria densa* and *Myriophyllum spicatum*, phytoplankton, resuspended benthic microalgae, zooplankton and riverborne detritus. However $C:N_a$ ratios at the three sites, used in many studies to assess OC sources (Emerson and Hedges 1988; Hedges and Oades 1997), were similar (Table 1). $C:N_a$ ratios at the three sites indicate that POM had similar sources, with ratios of 6-10, consistent with mixed algal-detrital-terrestrial inputs. This highlights the limited use of $C:N_a$ ratios in assessing general differences in sources of POM among these sites, as has also been found in previous studies (Cloern et al. 2002). Similarly, bulk $\delta^{13}C$ and $\delta^{15}N$ was not useful in resolving sources of OM in sub-habitats of the Delta (Cloern et al. 2002).

Despite similarities in bulk measures, PCA analysis and our detailed analysis of fatty acids and sterols indicated differences in POM sources and composition within the three shallow-water habitats (Fig. 2). Sterol composition in FT and MI indicates that phytoplankton and crustaceans contributed significantly to POC. C_{27} sterols, highest in MI and FT, were dominated by cholesterol (>80%), the most abundant sterol in crustaceans, including zooplankton (Killops and Killops 1993), although high concentrations can be found in some phytoplankton species (Volkman 1986). Higher C_{27} sterol concentrations in MI compared to FT is consistent with higher zooplankton abundance observed at MI throughout the year (Grimaldo et al. 2004). C_{28} sterols, dominated by 24-methylcholesta-5,22-dien-3β-ol, 24-methylcholesta-5,24(28)-dien-3β-ol, were also higher in MI and FT. These compounds typically dominate the sterol composition of diatoms, although they can occur in other phytoplankton (Volkman 1986). Phytoplankton composition studies at MI and FT indicate that diatoms are dominant at MI and FT (45% and 51%, Lopez et al. in press). Sterol source assignments are corroborated by the abundance of fatty acids such as 14:0, 16:1ω7 and 20:5ω3 (Table 3), which are indicative of phytoplankton (Arzayus and Canuel 2004) and 18:1ω9, which is a dominant fatty acid in zooplankton (Prahl et al. 1984; Wakeham and Canuel 1986, Harvey et al. 1987). C_{27} sterols and 18:1ω9 could also be indicative of zooplankton fecal

pellets (Wakeham et al. 1995). Several studies have indicated that algal-derived organic matter is important to the Delta's pelagic food webs (Jassby and Cloern 2000; Müller-Solger et al. 2002; Sobczak et al. 2005). The fatty acid 18:4 was also sometimes abundant at FT, and to a lesser extent at MI. This fatty acid can be dominant in cryptophytes (Sargent et al. 1987). Cryptophytes represented 3-22% of the phytoplankton composition in FT and MI (Sobczak et al. 2005; Lopez et al. in press). Although C_{27} and C_{28} sterols were present in LH, indicating some influence from zooplankton and phytoplankton sources, concentrations were generally lower than at FT and MI (Fig 4. $p < 0.05$).

C_{29} sterols, often attributed to vascular plant sources (Volkman 1986), were higher at MI than at FT or LH. However, C_{29} sterols were not well-correlated to LCFA in MI. LCFAs are generally ascribed to vascular plant sources (Meyers 1997), indicating C_{29} sterols likely represent other sources in MI (Table 4). Although C_{29} sterols did not correlate with PUFAs or C_{28} sterols, other phytoplankton/diatom biomarkers, C_{29} sterols did increase in October 1998 and 1999, when fall blooms are known to occur in MI, possibly indicating a phytoplankton source for these sterols. Volkman and colleagues have noted the occurrence of C_{29} sterols in freshwater algae and cyanobacteria (Volkman 1986; Volkman et al. 1999; Volkman 2003). Similarly, C_{29} sterols did not correlate with LCFAs in FT, and may instead derive from a phytoplankton source, based on correlations with phytol and C_{27} sterols (Table 4). A lack of correlation could indicate mixed sources. An alternative source for these compounds may be macrophytes. *Egeria densa*, an invasive aquatic macrophyte, is present in FT from spring-fall with significant coverage during spring and summer months (Lucas et al. 2002). Lipid analysis of three submerged aquatic macrophyte species (*E. densa, Myriophyllum spicatum,* and *Eichhornia crassipes*) indicated that sterols in all macrophytes were dominated by C_{29} sterols, particularly stigmasterol. In LH, C_{29} sterols and LCFAs were positively correlated, indicating vascular plant sources; these may be delivered through river input or during flooding of Yolo Bypass.

In all likelihood, the dominant sources of POC in FT and MI are likely to change little over time, as these sites are thought to have reached steady state in terms of water depth and leaching of substances from soils. Hydrologic patterns in the two lakes are

well-established based on the location of breaches, and predictable wind patterns (Lucas et al. 2002, Monsen et al. 2002, Stacey 2003). Internannual differences occur in emergent vegetation and SAV coverage, although patterns in submerged aquatic vegetation (SAV) are well established (vegetated only around the circumference of MI, while covering much of FT during spring and summer) (Lucas et al. 2002). Differences may occur in specific sources, such as the dominant species of zooplankton or phytoplankton at each site, as shifts in species abundances have been known to occur in the Delta (Orsi and Mecum 1996). Differences in magnitude may also occur due to changes in physical environment (tidal forcings), climatic regime (freshwater flow, El Nino conditions) or interannual variations in primary and secondary production.

In contrast, LH, the "younger" of these shallow tidal lakes (in terms of time since breaching), may experience changes in sources over time. At the time of this study, LH was 2-4 years old from the time of breach, which is still within the timeframe for geomorphic (elevation, water depth) and hydrologic parameters to change before stabilizing (Williams et al. 2002). Vegetation patterns have not likely been established (Williams and Orr 2002) and communities of phytoplankton and zooplankton have probably not developed into stable communities. In the San Francisco Bay area, most restored breached-levee salt marshes had >50% vegetation cover established within 4-20 years of breach time (Williams and Orr 2002). In LH, high chl a concentrations relative to the other sites is also characteristics of young restoration sites (Piehler et al. 1998; Yallop and O'Connell 2000), and indicative of the potential importance of benthic microalgae to POC sources. Although we could not determine if benthic microalgae or pelagic phytoplankton were the source of high chl a at LH, based on the site's shallow depth (<1m), it is likely that benthic microalgae are contributing some of the chl a at the site. Although currents can be high at our sampling site near the breach, currents lessen further into the site (personal observ.), which would provide suitable shallow habitat, with plenty of light for benthic microalgae to grow (MacIntyre et al. 1996). In newly flooded sites, benthic assemblages are thought to be an important food source for marsh infauna (Piehler et al. 1998). However, it is important to note that the we sampled only one site within each lake, which all have very different geomorphic characteristics,

depths, and sources, so differences between LH, MI and FT may have less to do with "age" and are likely based on numerous biological, hydrological and chemical factors.

Nutritional Value and Quality of SPM

When we refer to the "nutritional value" of POM, we use the term to describe the amount of organic carbon that can be characterized based on biochemical composition. Higher fractions of characterizable C indicate less reworking and suggest a greater fraction of POC is available for secondary production, such as zooplankton and benthic macroinvertebrates (Fabiano et al. 1993; Fabiano and Danovaro 1994; Danovaro et al. 1997). Higher proportions of characterizable POM is generally considered to indicate higher POM quality. POM is also considered to be higher quality when concentrations of PUFAs and "essential" fatty acids (for zooplankton growth) are higher in concentration (Muller-Navarro 1995). This contrasts with the term "bioavailable", which implies organic matter its available to microorganisms, which we do not address in our study, but was addressed in companion studies (Sobczak et al. 2002, 2005). Previous studies have indicated that POC makes up a small proportion of SPM in the Delta, generally <5% (Müller-Solger 2002; Sobczak 2005), indicating SPM is dominated by an inorganic fraction. Among habitats, %POC differed (Table 1); lower values at LH that it is characterized by more inorganic SPM than MI and FT, thus indicating additional differences in nutritional quality. In previous studies, the small POC fraction has been characterized as primarily detrital in origin (Cloern et al. 2002; Muller-Solger 2002; Sobczak et al. 2005).

Lower PUFA concentrations, both collectively (Fig. 5) and individual fatty acids (Table 2), as well as lower TLE-C values, indicate that POM in LH is of lower quality than in FT or MI. Fatty acids such as $20:5\omega3$ and $22:6\omega3$ that have been shown to be important determinants of nutritional quality (Muller-Navarro et al. 1995), were lower in LH. In addition, total lipid content has been shown to be higher in its energy value to consumers (Müller-Navarro et al. 2003). However, despite variability in TLE-C, % BPC-C did not differ among sites (Table 3), indicating the larger contribution of proteins and carbohydrates and their potential role in controlling the composition of POC, and by consumers. The relatively low %BPC-C also indicates that, despite different sources of

OC at each site, POC is generally of poor quality, with 55-85% not characterizable. This finding is consistent with the dominance of detrital POC to shallow-water sites in the system.

Temporal variability was also observed in POM quality, as indicated by PUFA concentrations. In LH, PUFAs (Fig. 5) and many individual PUFAs (Table 2) were higher in 2000 than in 1999 (p<0.05). It may reflect the general maturation of the site after conversion, or changes in phytoplankton composition, but without a long-term dataset from the site, we can not make any conclusions about the mechanisms driving temporal variability. The May 1999 sample collected from MI was unique in its POM composition (Fig. 2). MI exhibited higher PUFAs (total and individual, Table 2) and other FA groups in May 1999, a time when zooplankton are dominant (Orsi 2002). This indicates that zooplankton may be responding to the availability of high-quality POC at MI during this period of time. In addition, zooplankton products (e.g. fecal pellets) may contribute to increased quality of POM. In FT, all FA groups, and in particular PUFAs, higher during April and July 2000 (Fig. 5). These were also periods when protein-C and carbohydrate-C were higher than other sampling periods (Table 3). Together with relatively high %BPC-C, these results indicate higher food quality during these periods. Higher food quality during these periods may be due to increased phytoplankton and zooplankton abundances during April 2000 (Fig. 4), and macrophytes and zooplankton during the summer months, when C_{27} remain high but C_{28} sterols decrease. Macrophytes, in particular *Egeria densa*, which contain up 40% PUFAs (Chapter 4), dominated in FT during summer months.

These findings contrast with expectations based on bulk POM parameters at the three sites. LH exhibited the highest concentrations of chl *a*, POC and PN of our SWH sites. Previous studies in the Delta have used high chl *a* and POC as indicators of higher food quality (Müller-Solger 2002; Sobczak et al. 2005). In contrast, our study indicates that the lowest quality POC (low PUFAs, SCFAs) was found at the site with highest chlorophyll values. A possible explanation for this may be that resuspension has a pronounced effect in shallower systems like LH, or the presence of phytoplankton species that have lower fatty acid concentrations. Also, SPM concentrations were high and % POC was low, consistent with dilution by inorganic particles.

Implications for Delta Fauna

One of the major goals within the Delta is to increase native fish populations by increasing habitat. Thus, it is important to examine our biochemical data in the context of spawning and recruitment periods for ichthyoplankton at within the Delta. In MI, concentrations of fatty acids associated with nutritional quality (PUFAs) peaked in May, a time when native fish ichthyoplankton are most abundant (Grimaldo et al. 2004). MI is known to exhibit high ichthyoplankton abundances relative to other shallow-water restored sites (Grimaldo 2004). In FT, higher quality POC occurred in spring and summer months. These periods coincide with peak in ichthyoplankton for native (spring) and introduced (late summer) species (Grimaldo et al. 2004). Intermediate concentrations of fatty acids such as PUFAs and biochemical compounds in October 1998 in MI and FT indicate that POM quality is still moderate when introduced species are past their peak recruitment period, but still abundant.

In contrast, POC quality was lower at LH, which receives drainage from Yolo Bypass, a seasonal floodplain, in the spring and early summer. Yolo Bypass has been identified as favorable habitat for spring spawning by native Delta species, such as the Sacramento splittail and salmon (Sommer et al 2001; Moyle et al. 2004). Because fish that spawn in the spring at YB travel downstream to brackish waters near Chipps Island and Suisun Marsh, low food quality would likely have minimal impact on fish population in that region.

Fatty acid concentrations may also have implications for populations of *C. fluminea,* an invasive freshwater clam that can be found throughout the Delta. *C. fluminea* were observed in LH during the study period (unpublished data) indicating that food quality and quantity must be sufficient to support benthic filter feeders to some extent, despite lower concentrations of lipid compounds in POM at the site. It is possible that *C. fluminea* can survive on POM that is of lower quality (i.e. lower PUFA composition). Benthic filter feeders, like their pelagic counterparts, are known to be able to utilize low-quality POC through increased filtering of POM (Navarro et al. 1996). This organism may also be utilizing other fractions of the POM for energy, such as carbohydrate and protein, which are similar among sites relative to POC. Our findings

also indicate that differences in *C. fluminea* populations between MI and FT (Lucas et al. 2002) may be, at least in part, due to variables other than the measures of food quality examined in our study. Both sites have similar food quality in terms of fatty acids, carbohydrates and protein composition. Higher observed *C. fluminea* abundances in FT (Lucas et al. 2002) may be due to a specific fraction or set of lipids not yet identified that are different between the sites. Although most measured food quality parameters (FAs, C_{27} sterols, biochemical compounds) were similar or higher in MI vs. FT, there were exceptions, such as 18:4, an indicator for cryptophytes, which was higher in FT. Therefore, differences may be due to specific POM components, hydrodynamics, or another factor not yet identified, such as metals or pesticides at each site. These factors should be explored in future study.

CONCLUSIONS

Shallow-water habitats within the Sacramento-San Joaquin Delta differ in the sources and food quality of POM. LH, in the northern Delta and a relatively new restored site, had lower food quality (as determined by PUFAs and C_{28} sterols) than MI or FT, which are more established sites. Lipid biomarkers (FAs and sterols indicate that sources of POM are dominated by phytoplankton and zooplankton in MI, while plant and phytoplankton sources dominate in FT. LH has a mixture of sources including vascular plants, phytoplankton and zooplankton; benthic microalgae may be important as well. The nutritional quality of POC in LH is significantly lower than at other sites, as indicated by lower fatty acid concentrations, in particular PUFAs, and lower TLE-C concentrations. Higher POC quality coincides with periods of larval recruitment for native fish species (spring) and to a lesser extent with periods of introduced species (late summer). Higher zooplankton abundances during these periods indicates that higher quality SPM may be available for native ichthyoplankton at shallow water sites, particularly at MI. Despite lower food concentrations, *C. fluminea* was observed in LH, indicating that the nutritional quality of SPM, despite being lower than other sites, may still be sufficient for the growth of benthic filter feeders.

It is important is note that while differences in biochemical and lipid biomarker composition between the three shallow-water habitats studied, it is not possible with the current dataset to elucidate mechanisms controlling POM sources and quality at these sites. Our sampling occurred at one point within each shallow-lake, which may not adequately characterize POM for the whole lake. Our study characterized POM composition in three distinct shallow-water habitats over two years. The sites we chose, while ranging in age from 2-50 years, were too far apart in age (25-50 years) to develop a functional trajectory for LH. Long-term studies are needed to follow shallow-water habitats from inception in order to track changes during the first 5-10 years, in order to fully understand the shallow-water systems that are being rehabilitated in the Delta, and what is controlling the organic carbon dynamics in these systems.

REFERENCES

ACKMAN, R.G., P.P. JANGAARD, R.J. HOYLE, H. BROKERHOFF. 1964. Origin of marine fatty acids I. Analyses of the fatty acids produced by the diatom *Skeletonema costatum*. J. Fish. Res. Board Can. 21: 747-756.

ARZAYUS, K. M., and E. A. CANUEL. 2004. Organic matter degradation in sediments of the York River estuary: Effects of biological vs. physical mixing. Geochim. Cosmochim. Acta 69: 455-463.

BERG, J.A., and R.I.E. NEWELL. 1986. Temporal and spatial variations in the composition of seston available to suspension feeder *Crassostrea virginica*. Est. Coast. Shelf Sci. 23: 375-386.

CALFED. 2000. California's water future: a framework for action. CALFED Bay-Delta Program.

CANUEL, E. A., 2001. Relations between river flow, primary production and fatty acid composition of particulate organic matter in San Francisco and Chesapeake Bays: a multivariate approach. Org. Geochem. 32: 563-583.

CANUEL, E. A., and J. E. CLOERN. 1996. Regional differences in the origins of organic matter in the San Francisco Bay ecosystems, p. 305-324. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

CANUEL, E. A., J. E. CLOERN, D. B. RINGELBERG, J. B. GUCKERT, and G. H. RAU. 1995. Molecular and isotopic tracers used to examine sources of organic matter and its incorporation into the food webs of San Francisco Bay. Limnol. Oceanogr. 40: 67-81.

CANUEL, E. A., and A. R. ZIMMERMAN. 1999. Composition of particulate organic matter in the Southern Chesapeake Bay: Sources and reactivity. Estuaries 22: 980-994

CLOERN, J. E., E. A. CANUEL, and D. HARRIS. 2002. Stable carbon and nitrogen isotope composition of aquatic and terrestrial plants of the San Francisco Bay estuarine system. Limnol. Oceanogr. 47: 713-729.

DANOVARO, R., and M. FABIANO. 1997. Seasonal changes in quality and quantity of food available for benthic suspension-feeders in the Golfo Marconi (North-western Mediterranean). Est. Coast. Shelf Sci. 44: 723-736.

DUURSMA, E.K., R. DAWSON. 1981. Marine Organic Chemistry: Evolution, Composition, Interaction and Chemistry of Organic Matter in Seawater. Elsevier, Amsterdam.

EMERSON, S. and J.I. HEDGES. 1988. Processes controlling the organic carbon content of open ocean sediment. Paleoceanogr. 3: 621-634.

FABIANO, M., and R. DANAVARO. 1994. Composition of organic matter in sediments facing a river estuary (Tyrrhenian Sea): relationships with bacteria and microphytobenthic biomass. Hydrobiol. 277: 71-84.

FABIANO, M., R. DANOVARO, and S. FRASCHETTI. 1995. A three-year time series of elemental and biochemical composition of organic matter in subtidal sandy sediments of the Ligurian Sea (northwestern Mediterranean). Cont. Shelf Res. 15: 1453-1469.

FICHEZ, R. 1991. Composition and fate of organic matter in submarine cave sediments; implications for the biogeochemical cycle of organic carbon. Oceanol. Acta 14: 369-377.

FOE, C., and A. KNIGHT. 1985. The effect of phytoplankton and suspended sediment on the growth of Corbicula fluminea (Bivalvia). Hydrobiol. 127: 105-115.

GALOIS, R., P. RICHARD, and B. FRICOURT. 1996. Seasonal variations in suspended particulate matter in the Marennes-Oleron Bay, France, using lipids as biomarkers. Estuar. Coast. Shelf Sci. 43: 335-357.

GRIMALDO, L. F., R. E. MILLER, C. M. PEREGRIN, and Z. P. HYMANSON. 2004. Spatial and temporal distribution of native and alien ichthyoplankton in three habitat types of the Sacramento-San Joaquin Delta. Am. Fish. Society Symp. 39: 81-96.

HARVEY, H. R., and J. R. JOHNSTON. 1995. Lipid composition and flux of sinking and size-fractionated particles in Chesapeake Bay. Org. Geochem. 23: 751-764.

HARVEY, H.R., G. EGLINTON, S.C.M. O'HARA and E.D.S. CORNER. 1987. Biotransfromation and assimilation of dietary lipids by Calanus feeding on a dinoflagellate. Geochim. Cosmochim. Acta.

HEDGES, J. I., and J. M. OADES. 1997. Comparative organic geochemistries of soils and marine sediments. Org. Geochem. 27: 319-361.

HELSEL, D. R., and R. M. HIRSCH. 1992. Statistical Methods in Water Resources. Elsevier Science.

HUANG, W. Y., and W. G. MEINSCHEIN. 1976. Sterols as source indicators of organic materials in sediments. Geochim. Cosmochim. Acta 40: 323-330.

HUANG, W. Y., and W. G. MEINSCHEIN. 1979. Sterols as ecological indicators. Geochim. Cosmochim. Acta 43: 739-745.

HYMANSON, Z., D. MAYER and J. STEINBECK. 1994. Long-term trends in benthos abundance and persistence in the upper Sacramento-San Joaquin Estuary, Summary Report: 1980-1990. IEP Technical Report. 38. 68 pp.

JASSBY, A. D., J. E. CLOERN, and T. M. POWELL. 1993. Organic carbon sources and sinks in San Francisco Bay: variability induced by river flow. Mar. Ecol. Prog. Ser. 95: 39-54.

JASSBY, A. D., and J. E. CLOERN. 2000. Organic carbon sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic. Conserv: Mar. Freshw. Ecosyst. 10: 323-352.

KILLOPS, S. D., and V. J. KILLOPS. 1993. An Introduction to Organic Geochemistry, 265 pp. John Wiley & Sons, Inc.

LOPEZ, C.B., J.E. CLOERN, T.S. SCHRAGA, A.J. LITTLE, L.V. LUCAS, J.K. THOMPSON, and J.R. BURAU. 2006. Ecological values of shallow-water habitats: Implications for restoration of disturbed systems. Ecosystems. In press.

LUCAS, L. V., J. E. CLOERN, J. K. THOMPSON, and N. E. MONSEN. 2002. Functional variability of habitats within the Sacramento-San Joaquin Delta: Restoration implications. Ecol. Appl. 12: 1528-1547.

MACINTYRE, H. L., R. J. GEIDER, and D. C. MILLER. 1996. Microphytobenthos: The ecological role of the "secret garden" of unvegetated, shallow-water marine habitats. I. Distribution, abundance and primary production. Estuaries 19: 186-201.

MANNINO, A., and H. R. HARVEY. 1999. Lipid composition in particulate and dissolved organic matter in the Delaware Estuary: Sources and diagenetic patterns. Geochim. Cosmochim. Acta 63: 2219-2235.

MAYZAUD, P., J. P. CHANUT, and R. G. ACKMAN. 1989. Seasonal changes of the biochemical composition of marine particulate matter with special reference to f atty acids and sterols. Mar. Ecol. Prog. Ser. 56: 189-204.

MONSEN, N. E., J. E. CLOERN, L. V. LUCAS, and S. G. MONISMITH. 2002. A comment on the use of flushing time, residence time, and age as transport time scales. Limnol. Oceanogr. 47: 1545-1553.

MOYLE, P. B., R. D. BAXTER, T. SOMMER, T. C. FOIN, and S. A. MATERN. 2004. Biology and population dynamics of Sacramento Splittail (*Pogonichthys macrolepidotus*) in the San Francisco Estuary: A review. San Francisco Estuary and Watershed Science (online serial). 2.

MUDGE, S. M., and C. E. NORRIS. 1997. Lipid biomarkers in the Conway Estuary (North Wales, U.K.): a comparison between fatty alcohols and sterols. Mar. Chem. 57: 61-84.

MÜLLER-NAVARRA, D. C., M.T. BRETT, S. PARK, S. CHANDRA, A.P. BALLANTYNE, E. ZORITA, and C.R. GOLDMAN. 2003. Unsaturated fatty acid content in seston and troph-dynamic coupling in lakes. Nature 427: 69-72.

MÜLLER-SOLGER, A. B., A. D. JASSBY, and D. C. MÜLLER-NAVARRA. 2002. Nutritional quality of food resources for zooplankton (*Daphnia*) in a tidal freshwater system (Sacramento-San Joaquin River Delta). Limnol. Oceanogr. 47: 1468-1476.

NAVARRO, E., J. I. P. IGLESIAS, A. PEREZ CAMACHO, and U. LABARTA. 1996. The effect of diets of phytoplankton and suspended bottom material on feeding and absorption of raft mussels (*Mytilus galloprovincialis* Lmk). J. Exp. Mar. Biol. Ecol. 198: 175-189.

NGUYEN, R. T., and H. R. HARVEY. 1994. A rapid micro-scale method for the extraction and analysis of protein in marine samples. Mar. Chem. 45: 1-14. -

ORSI, J. J. 2002. Zooplankton production in shallow water and channel habitats: an example from Mildred Island. IEP Newsletter 15: 27-32.

PAKULSKI, J. D., and R. BENNER. 1992. An improved method for the hydrolysis and MBTH analysis of the dissolved and particulate carbohydrates in seawater. Mar. Chem. 40: 143-160.

PIEHLER, M.F., C.A. CURRIN, R. CASSANOVA and H.W. PAERL. 1998. Development and N$_2$-fixing activity of the benthic microbial community in transplanted *Spartina alterniflora* marshes in North Carolina. Restor. Ecol. 6: 290-296.

POULET, S.A., D. COSSA, J.-C. MARTY. 1986. Combined analysis of size spectra and biochemical composition of particles in the St. Lawrence Estuary. Mar. Ecol. Prog. Ser. 30: 205-214.

PRAHL, F.G., G. EGLINTON, E.D.S. CORNER, S.C.M. O'HARA and T.E.V. FORSBERG. 1984. Changes in plant lipids during passage though the gut of *Calanus*. Assoc. U.K. 64: 317-334.

PUSCEDDU, A., E. SERRA, O. SANNA and M. FABIANO. 1996. Seasonal fluctuations in the nutritive value of the particulate organic matter in a lagoon. Chem. Ecol. 13: 21-37.

SALIOT, A., J. LAUREILLARD, P. SCRIBE., M.A. SICRE and M. BRANICA. 1991. Evolutionary trends in the lipid biomarker approach to investigating the biogeochemistry of organic matter in the marine environment. Mar. Chem. 36.

SARGENT, J.R., R.J. PARKES, I. MUELLER-HARVEY and R.J. HENDERSON. 1987. Lipid biomarkers in marine ecology, p. 119-138. In M.A. Sleigh [ed.], Microbes in The Sea. Ellis Horwood Limited, Chichester, England.

SIMENSTAD, C., J. TOFT, H. HIGGINS, J. CORDELL, M. ORR, P. WILLIAMS, L. GRIMALDO, Z. HYMANSON, and D. REED. 2000. Sacramento/San Joaquin Delta Breached Levee Wetland Study (BREACH), 45 pp. University of Washington.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, B. E. COLE, T. S. SCHRAGA, and A. ARNSBERG. 2005. Detritus fuels ecosystem metabolism but not metazoan food webs in San Francisco Estuary's freshwater Delta. Estuaries 28: 124-137.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, and A. B. MÜLLER-SOLGER. 2002. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. Proc. Nat. Acad. Sci. 99: 8101-8105.

SOMMER, T., B. HARRELL, M. NOBRIGA, R. BROWN, P. MOYLE, W. KIMMERER, and L. SCHEMEL. 2001. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26: 6-16.

STACEY, M. T. 2003. Hydrodynamics of shallow water habitats in the Sacramento-San Joaquin Delta, 13 pp. UC Water Resources Center.

VOLKMAN, J. K. 1986. A review of sterol markers for marine and terrigenous organic matter. Org. Geochem. 9: 83-99.

VOLKMAN, J.K. 2003. Sterols in microorganisms. Appl. Microbiol. Biotechnol. 60: 495-506.

VOLKMAN, J.K., S.M. BARRETT, S.L. BLACKBURN, M.P. MANSOUR, E.L. SIKES, and F. GELIN. 1998. Microalgal biomarkers: A review of recent research Developments. Org. Geochem. 29: 1163-1179.

VOLKMAN, J. K., S. M. BARRETT, and S. I. BLACKBURN. 1999. Eustigmatophyte microalgae are potential sources of C_{29} sterols, C_{22}-C_{28} n-alcohols and C_{28}-C_{32} n-alkyl diols in freshwater environments. Org. Geochem. 30: 307-318.

WAKEHAM, S. G. 1995. Lipid biomarkers for heterotrophic alteration of suspended particulate organic matter in oxygenated and anoxic water columns of the ocean. Deep-Sea Res. I 42: 1749-1771.

WAKEHAM, S.G. and E.A. CANUEL. 2001. Lipid composition of the pelagic crab *Pleuroncodes planipes*, its feces, and sinking particulate organic matter in the Equatorial Pacific Ocean. Org. Geochem. 9: 331-343.

WILLIAMS, P.B. and M.K. ORR. 2002. Physical evolution of restored breached levee salt marshes in the San Francisco Bay Estuary. Restor. Ecol. 10: 527-542.

WILLIAMS, P.B., M.K. ORR and N.J. GARRITY. 2002. A geomorphic design tool for tidal marsh channel evolution in wetland restoration projects. Restor. Ecol. 10: 577-590.

WOLFF, J. 2003. Delta Primer: A field guise to the California Delta. William Stout Publishers. San Francisco, CA. 195 pp.

YALLOP, M.L., and M. O'CONNELL. 2000. Wetlands creation: early stages in colonization of phytoplankton and submerged macrophytes in hypereutrophic freshwater lagoons. Aquatic Conserv: Mar. Freshw. Ecosyst. 10: 305-309.

ZIMMERMAN, A.R. and E.A. CANUEL. 2001. Bulk organic matter and lipid biomarker composition of Chesapeake Bay surficial sediment as indicators on environmental processes. Estuar. Coast. Shalf Sci. 53: 319-341.

Table 1. Study site water column characteristics

Site	Date	Water Depth (m)	Secchi Depth (m)	Temperature (° C)	SPM (mg L^{-1})	Chlorophyll a (μg L^{-1})	Phaeophytin (μg L^{-1})	POC (mg L^{-1})	PN (mg L^{-1})	C:N$_a$	% POC
LH	Oct 98	0.80	0.15	16.70	98.24	3.60	3.40	1.94	0.25	7.76	1.98
LH	May 99	1.20	0.12	17.20	112.81	4.54	2.56	2.88	0.37	7.82	2.55
LH	Jul 99	0.90	0.18	19.50	168.52	5.93	3.99	1.13	0.18	6.18	0.67
LH	Oct 99	0.60	0.20	19.10	61.61	4.97	2.89	0.82	0.11	7.59	1.33
LH	Apr 00	1.00	0.18	17.00	106.51	8.29	4.43	1.80	0.26	6.91	1.69
LH	Jul 00	1.00	0.10	20.00	106.02	4.56	4.68	1.65	0.19	8.52	1.56
		0.92 (0.20)^a	0.16 (0.04)	18.25 (1.44)	108.95 (34.45)	5.32 (1.64)	3.66 (0.85)	1.70 (0.72)	0.23 (0.09)	7.46 (0.81)	1.63 (0.63)
MI	Oct 98	3.00	0.90	17.20	11.73	10.40	4.60	0.90	0.13	7.06	7.67
MI	May 99	4.10	0.82	17.70	11.22	2.64	1.97	0.53	0.07	7.25	4.71
MI	Jul 99	4.10	0.50	22.50	15.78	2.21	2.24	0.76	0.12	6.44	4.80
MI	Oct 99	3.30	0.65	21.20	15.14	2.88	4.07	0.78	0.12	6.39	5.14
MI	Apr 00	4.80	0.70	17.50	13.29	5.13	3.75	0.62	0.10	6.52	4.61
MI	Jul 00	3.50	0.99	21.20	11.86	2.43	3.22	0.61	0.08	7.37	5.08
		3.60 (0.66)	0.76 (0.18)	19.55 (2.34)	13.17 (1.91)	4.28 (3.18)	3.31 (1.04)	0.70 (0.14)	0.10 (0.02)	6.84 (0.44)	5.53 (1.16)
FT	Oct 98	1.80	1.00	17.30	10.42	1.71	1.40	0.44	0.05	9.61	4.26
FT	May 99	8.00	0.58	15.70	19.02	2.06	1.90	0.75	0.09	7.96	3.92
FT	Jul 99	3.00	0.57	19.70	17.73	1.71	2.02	0.78	0.15	5.17	4.37
FT	Oct 99	7.80	0.97	19.40	10.31	1.79	2.06	0.39	0.05	7.41	3.80
FT	Apr 00	3.50	1.47	17.00	7.86	2.75	2.34	0.28	0.04	6.49	3.69
FT	Jul 00	2.40	1.20	21.70	12.74	1.82	2.05	0.41	0.04	9.33	3.24
		4.42 (2.76)	0.97 (0.35)	18.47 (2.19)	13.01 (4.45)	1.97 (0.40)	1.96 (0.31)	0.51 (0.21)	0.07 (0.04)	7.66 (1.69)	3.88 (0.41)

^{a}Data are expressed as mean ($\pm$standard deviation) for each site

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Table 2. Concentrations of major fatty acids normalized to POC for shallow-water sites ($\mu g\ mg^{-1}$ OC).

	LH						MI						FT					
	Oct-98	May-99	Jul-99	Oct-99	Apr-00	Jul-00	Oct-98	May-99	Jul-99	Oct-99	Apr-00	Jul-00	Oct-98	May-99	Jul-99	Oct-99	Apr-00	Jul-00
SAT																		
12:0	28.73	15.56	15.82	35.17	22.27	22.46	12.43	130.68	53.81	53.71	76.58	80.36	102.53	103.68	51.41	97.52	98.19	0.00
13:0	0.00	7.50	7.97	13.50	10.43	16.24	0.00	93.88	24.42	0.00	21.05	22.32	0.00	0.00	0.00	0.00	0.00	0.00
14:0	465.82	388.60	569.65	1273.79	663.35	1018.33	667.01	3718.34	1962.34	2148.23	1745.58	1863.59	2047.61	1674.96	1334.01	1712.20	2254.98	2117.53
15:0	80.26	103.99	92.33	161.65	148.22	143.24	80.91	512.39	305.69	244.80	295.10	304.29	361.47	415.35	219.66	425.31	493.32	347.00
16:0	1322.70	1308.16	1247.56	3076.20	1880.51	1778.62	1502.65	9521.32	4470.64	4541.17	5410.98	4408.27	7907.02	4804.51	2965.73	5099.86	10049.17	9138.63
17:0	54.03	64.91	60.31	92.45	85.63	92.86	210.28	241.22	193.91	136.05	169.27	178.90	178.26	161.43	95.91	189.56	239.71	172.02
18:0	323.97	324.61	233.69	379.86	335.32	382.23	773.42	1286.10	750.64	633.45	1006.57	999.13	1961.23	738.76	463.95	903.47	1152.33	1242.76
LCFA	624.15	814.73	765.99	796.09	979.60	803.52	664.49	4253.94	1098.25	1712.15	1581.54	1587.49	810.91	1084.12	951.44	1401.45	941.97	1361.03
MONO																		
14:1	17.89	10.58	26.45	51.35	17.93	21.85	80.45	110.03	82.13	54.45	33.46	83.32	55.40	0.00	52.92	0.00	0.00	57.04
16:1w7	1259.27	1138.10	1391.44	3445.87	2020.20	2418.63	5994.05	8720.25	4821.98	4833.30	4254.08	4031.58	5426.06	4212.84	2779.61	4921.14	5665.06	8762.62
16:1w9	85.83	93.05	92.07	166.13	176.19	122.60	409.33	518.43	254.23	537.06	297.17	282.24	198.06	324.47	188.68	306.39	320.30	253.81
17:1	25.54	0.00	0.00	0.00	0.00	35.88	24.80	0.00	0.00	0.00	0.00	0.00	241.20	0.00	0.00	0.00	0.00	29.10
18:1w9	1167.45	1133.84	1175.44	2867.13	1815.70	1995.89	4156.01	9272.63	3395.39	3848.94	3811.77	2788.11	3811.75	2938.29	2005.65	3056.39	7388.43	5885.52
20:1	36.93	28.89	22.00	48.45	44.27	0.00	305.77	0.00	1163.15	67.62	89.30	54.23	64.29	0.00	0.00	0.00	50.04	57.29
22:1	0.00	17.33	11.15	15.77	19.49	9.92	150.54	98.48	36.02	663.66	101.32	54.56	121.22	0.00	0.00	0.00	0.00	76.63
24:1	0.00	10.49	6.62	10.19	16.71	0.00	91.18	155.99	0.00	0.00	42.23	35.80	0.00	0.00	0.00	0.00	0.00	60.10
PUFA																		
16:2	135.04	105.26	185.25	387.08	236.86	65.60	0.00	1222.96	340.07	0.00	0.00	0.00	274.42	282.41	206.41	0.00	0.00	0.00
16:3	227.32	202.04	250.56	407.06	582.64	435.54	1125.17	1273.98	689.31	398.27	1086.77	541.42	671.52	1131.98	278.47	610.34	1192.44	494.70
16:4	97.61	130.68	166.27	401.89	317.54	79.15	304.36	3446.00	394.94	404.55	717.04	285.07	638.96	827.17	267.53	323.35	1004.78	498.08
18:2	168.04	153.95	179.00	398.21	270.91	257.08	2286.61	2563.68	826.43	1126.34	2056.20	405.60	542.34	397.10	291.24	416.34	1284.51	1210.46
18:4	305.23	175.84	144.34	467.05	370.05	151.17	642.89	1283.45	651.34	465.51	929.67	746.91	2131.63	866.17	352.38	750.61	4485.30	1902.65
20:4w6	56.18	39.58	61.38	80.80	87.28	91.25	244.84	403.12	236.01	218.49	112.36	155.76	128.48	109.76	97.12	159.18	173.85	316.41
20:5w3	436.26	255.76	301.67	620.63	846.40	815.79	2539.36	7587.71	1366.31	1828.80	1942.49	1131.77	1926.56	2074.74	613.69	1061.79	2961.91	3028.50
22:6w3	72.49	31.30	38.50	80.23	123.45	75.21	637.98	1438.82	236.32	625.84	454.04	159.81	409.26	323.79	58.69	167.56	692.20	425.51
BrFA	368.03	419.29	398.26	615.02	541.46	470.70	850.09	1111.85	1074.73	1033.02	591.49	782.94	613.56	1040.29	539.50	1023.24	978.72	646.93
Total	7358.76	6974.03	7449.14	15906.75	11612.38	18340.07	32034.04	58965.26	24463.77	25575.42	26855.91	20983.49	30821.75	23511.81	13843.43	22625.69	41544.03	38313.12

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Table 3. Concentrations of biochemical classes normalized to POC, percent of POC that can be characterized by biochemical compounds (BPC-C) and food energy at the three shallow-water sites.

Site	Month	Protein-C ($\mu g\ mg^{-1}$ POC)	Carb-C ($\mu g\ mg^{-1}$ POC)	TLE-C ($\mu g\ mg^{-1}$ POC)	BPC-C[a] (% of POC)
LH	Oct 98	11.9 (0.29)	80.7 (4.67)	83.1 (8.26)	17.6
LH	May 99	28.6 (3.41)	102.0 (8.60)	52.8 (2.72)	18.3
LH	Jul 99	23.4 (0.30)	143.3 (7.73)	63.3 (2.65)	23.0
LH	Oct 99	33.5 (2.79)	124.0 (9.05)	92.5 (2.98)	25.0
LH	Apr 00	22.0 (1.81)	139.3 (2.29)	61.9 (3.52)	22.3
LH	Jul 00	35.7 (3.12)	149.3 (7.72)	117.0 (5.77)	30.3
Site Mean		25.8 (8.69)[b]	123.1 (26.8)	78.5 (24.1)	22.8 (4.64)
MI	Oct 98	27.2 (1.67)	114.0 (8.45)	145.0 (3.44)	28.6
MI	May 99	25.6 (9.28)	84.2 (7.20)	88.6 (3.04)	19.8
MI	Jul 99	41.3 (6.71)	108.0 (5.28)	70.0 (2.00)	22.0
MI	Oct 99	58.4 (4.21)	118.0 (7.76)	95.0 (2.02)	27.1
MI	Apr 00	37.5 (6.05)	271.0 (16.8)	157.0 (5.60)	46.6
MI	Jul 00	37.8 (4.65)	141.0 (7.99)	101.0 (4.63)	27.9
Site Mean		38.0 (11.8)	139.4 (67.1)	109.3 (34.0)	28.7 (9.44)
FT	Oct 98	30.6 (0.77)	153.0 (7.53)	210.0 (37.2)	39.4
FT	May 99	18.1 (5.39)	76.9 (3.56)	87.2 (4.15)	18.2
FT	Jul 99	30.0 (2.53)	160.0 (7.55)	80.3 (4.14)	27.1
FT	Oct 99	39.8 (2.98)	140.0 (6.57)	121.0 (4.17)	30.1
FT	Apr 00	78.9 (20.6)	192.0 (7.33)	163.0 (5.22)	43.4
FT	Jul 00	38.3 (8.86)	198.0 (11.9)	176.0 (8.17)	41.2
Site Mean		39.3 (20.9)	153.4 (43.8)	139.6 (51.9)	33.2 (9.8)

[a]BPC-C = Sum of Protein-C, Carb-C, TLE-C expressed relative to total POC

[b]Data are expressed as mean (±standard deviation) for each site

Table 4. Correlation coefficents (R-value) of Pearson Product Moment analyses of lipid biomarker and biochemical data from the three shallow water habitats

(A) Little Holland Tract

	POC	SPM	Chl a	Phytol	C27	C28	C29	PUFA	BrFA	LCFA
SPM	0.08									
Chl a	-0.18	0.22								
Phytol	-0.45	-0.57*	0.34							
C27	0.16	-0.10	0.25	0.65*						
C28	-0.20	-0.85**	0.06	0.85**	0.40					
C29	-0.14	-0.07	0.57*	0.75**	0.90**	0.38				
PUFA	-0.46	-0.53	0.31	0.75**	0.42	0.49	0.66*			
BrFA	-0.50	-0.65*	0.41	0.96**	0.45	0.88**	0.63*	0.74**		
LCFA	0.02	-0.01	0.84*	0.61*	0.72**	0.32	0.88**	0.50	0.58*	
BPC	-0.54	-0.10	0.12	0.60*	0.56*	0.18	0.71**	0.80**	0.47	0.36

(B) Mildred Island

	POC	SPM	Chl a	Phytol	C27	C28	C29	PUFA	BrFA	LCFA
SPM	0.36									
Chl a	0.62*	-0.37								
Phytol	0.14	0.45	0.17							
C27	-0.44	-0.05	-0.59*	-0.11						
C28	0.21	0.53	-0.08	0.78**	0.42					
C29	0.27	-0.09	0.01	-0.29	0.42	0.13				
PUFA	-0.77**	-0.61*	-0.01	0.19	0.05	-0.16	-0.41			
BrFA	-0.59*	-0.48	-0.43	-0.83**	0.12	-0.81**	0.08	0.02		
LCFA	-0.95**	-0.49	-0.41	-0.03	0.35	-0.18	-0.18	0.88**	0.51	
BPC	0.52	0.63*	0.22	0.85**	0.20	0.91**	0.02	-0.30	-0.97**	-0.47

(C) Franks Tract

	POC	SPM	Chl a	Phytol	C27	C28	C29	PUFA	BrFA	LCFA
SPM	0.95**									
Chl a	-0.46	-0.49								
Phytol	-0.91**	-0.85**	0.71**							
C27	-0.80**	-0.60*	0.08	0.71**						
C28	-0.88**	-0.90**	0.76**	0.98**	0.59*					
C29	-0.67*	-0.55	0.03	0.60*	0.88**	0.45				
PUFA	-0.71**	-0.64*	0.78**	0.84**	0.43	0.90**	0.12			
BrFA	-0.22	-0.20	0.59*	0.24	0.01	0.24	0.03	0.25		
LCFA	0.04	0.24	0.35	0.17	0.25	0.04	0.24	0.13	0.60*	
BPC	-0.85**	-0.82**	0.27	0.82**	0.72**	0.82**	0.56	0.67*	-0.29	-0.32

Significant r-values are in bold; * $=p<0.05$; ** $=p<0.01$

Fig. 1. Map showing location of shallow-water sampling sites in the Sacramento-San

Joaquin River Delta, CA. Little Holland Tract (LH) is located in the northern Delta,

while Franks Tract (FT) and Mildred Island (MI) are located in the southern Delta.
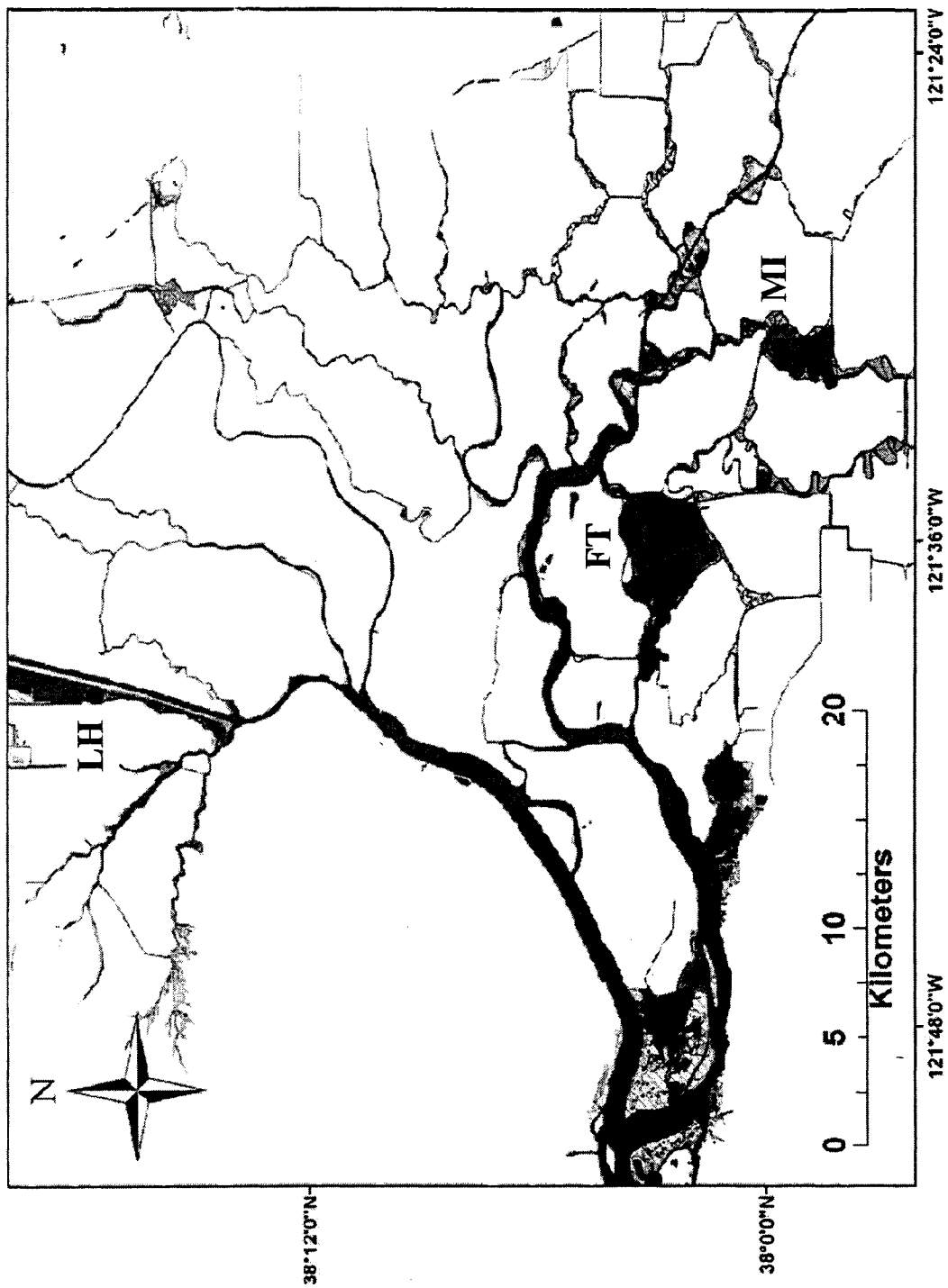
Fig. 2. a) Loadings and b) score plot for PC 1 and 2 from PCA analysis of fatty acid, alcohol and sterol data for the three shallow water habitat sites. PC 1 accounted for 47% of the variability in the dataset while PC 2 accounted for 23%. Sterols: STIG = 24-ethylcholest-5,22-dien-3β-ol; C29D5 = 24-ethylcholest-5-en-3β-ol; CAMP = 24-methylcholest-5-en-3β-ol; CHOL = cholest-5-en-3β-ol; BRAS = 24-methylchol-5,22-dien-3β-ol. Fatty acids are described in the text.

(A)

16:3/2

STIG ◆   ◆ C₂₉Δ⁵

16:4

14:0

22:6ω3   20:5ω3

16:1ω7   18:1ω9

CAMP ◆

CHOL ◆   18:0   18:4
16:0
18:3/2

Phytol △

BRAS ◆

PC 2

PC 1

| STEROL ◆ | ALCOHOL △ | FATTY ACID ◉ |

(B)

LH0799 LH0700 LH0400   △ MI1098   MI0599 △
LH1098   ◉ FT0599
LH0599   FT0799 ◉ LH1099   △ MI0799

MI1099 △
FT1099 ◉   ◉ FT1098
MI0700 △

◉ FT0700

△ MI0400
◉ FT0400

PC 2

PC 1

| LH ◆ | MI △ | FT ◉ |
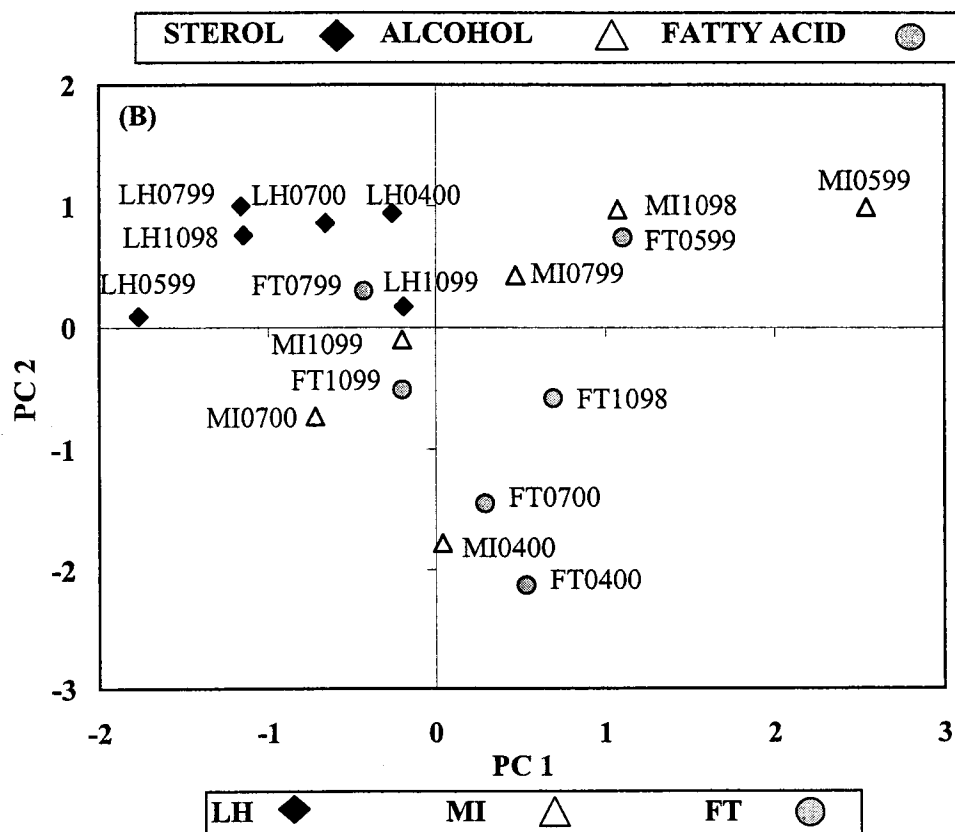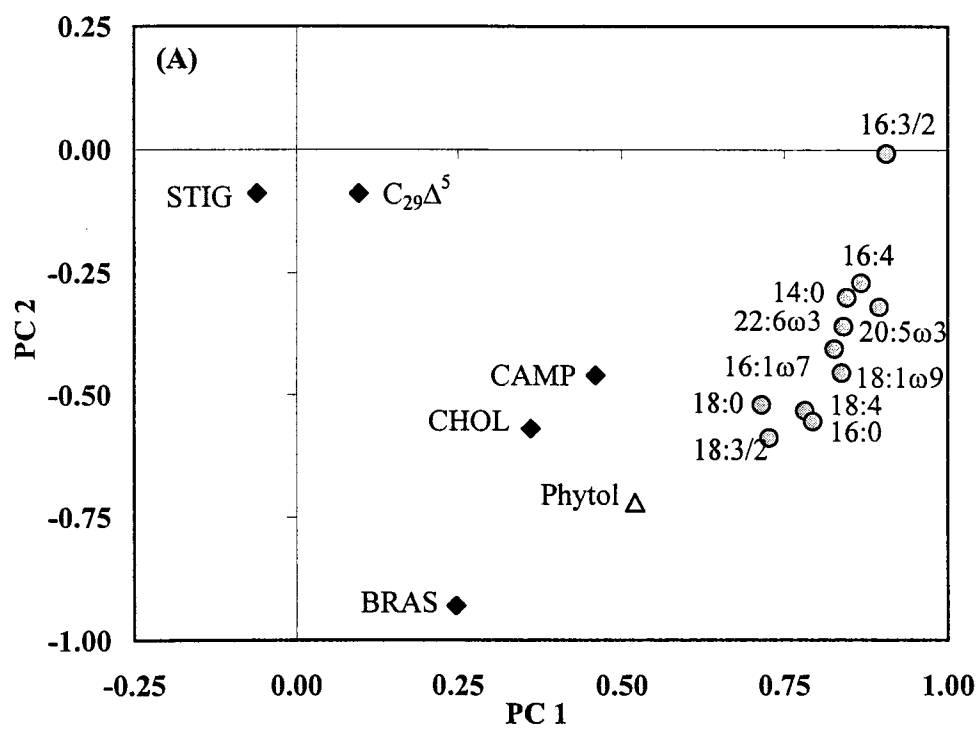
Fig. 3. Carbon-normalized concentrations of lipid compound classes associated with

POM at the three shallow-water sites, including (a) total sterols (ΣST), (b) total fatty

acids (ΣFA) and (c) total alcohols (ΣALC).
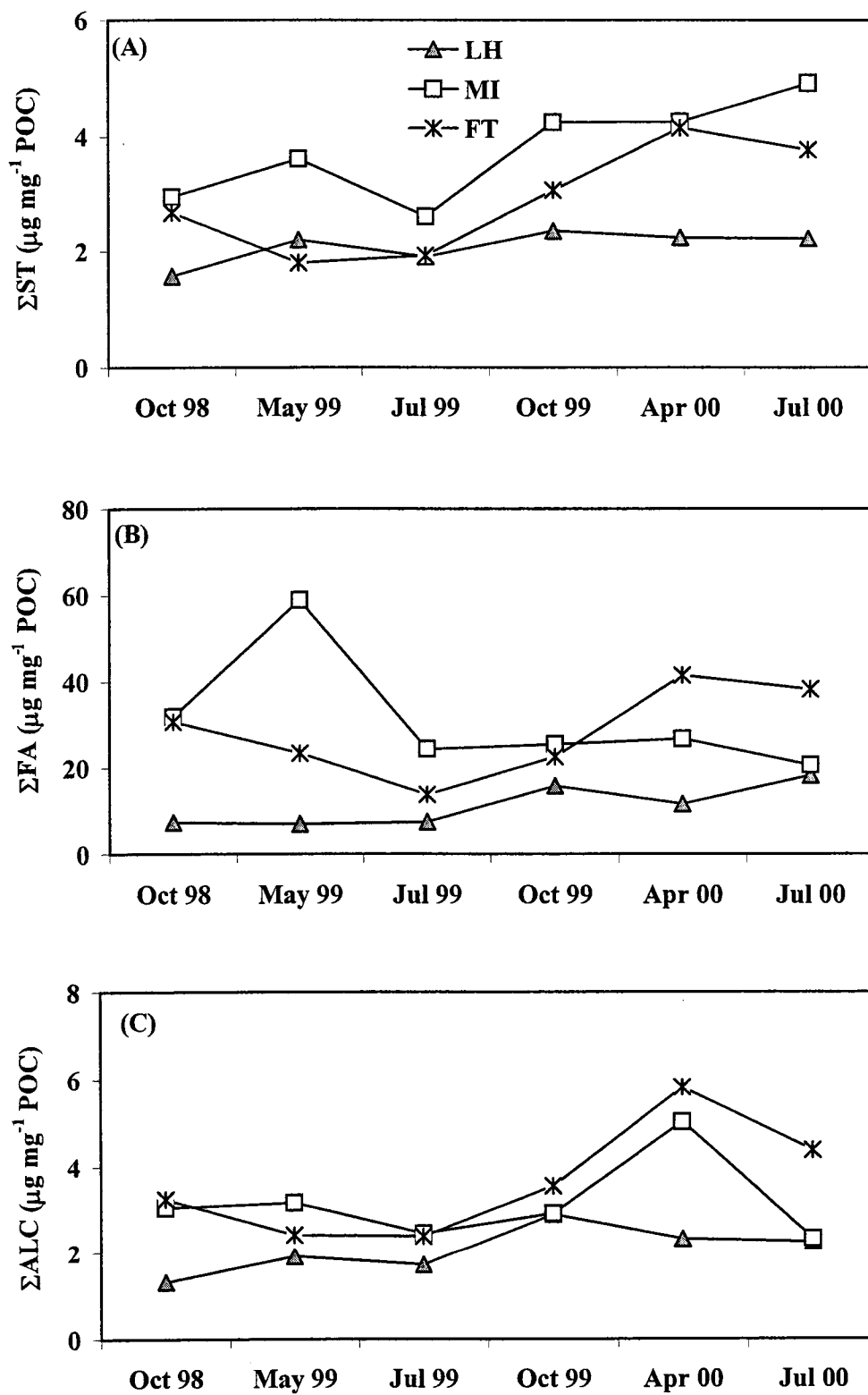
Fig. 4. Carbon-normalized concentrations of (a) C_{27} sterols, (b) C_{28} sterols and (c) C_{29} sterols, expressed as $\mu g\ mg^{-1}$ POC. C_{27} sterols are dominant in crustaceans and phytoplankton, C_{28} sterols are most abundant in phytoplankton, and C_{29} sterols are generally higher in vascular plants (Huang and Meinschein 1979).
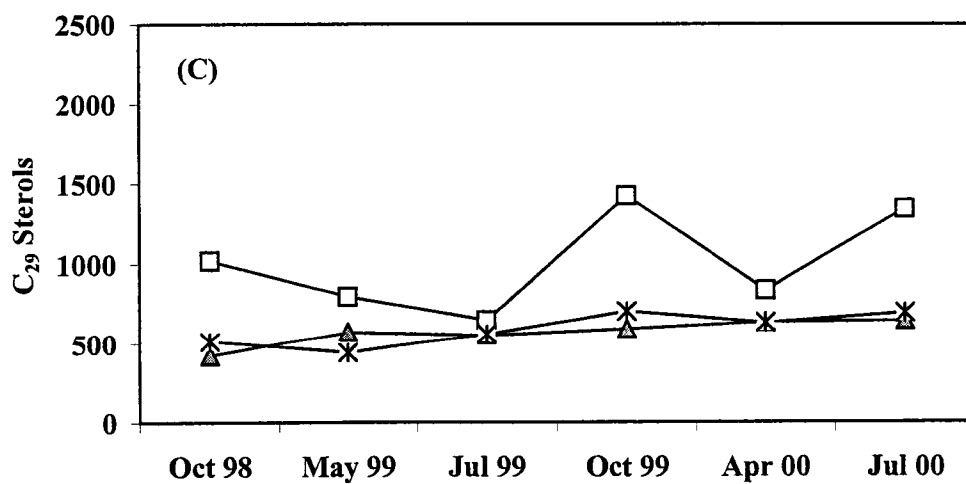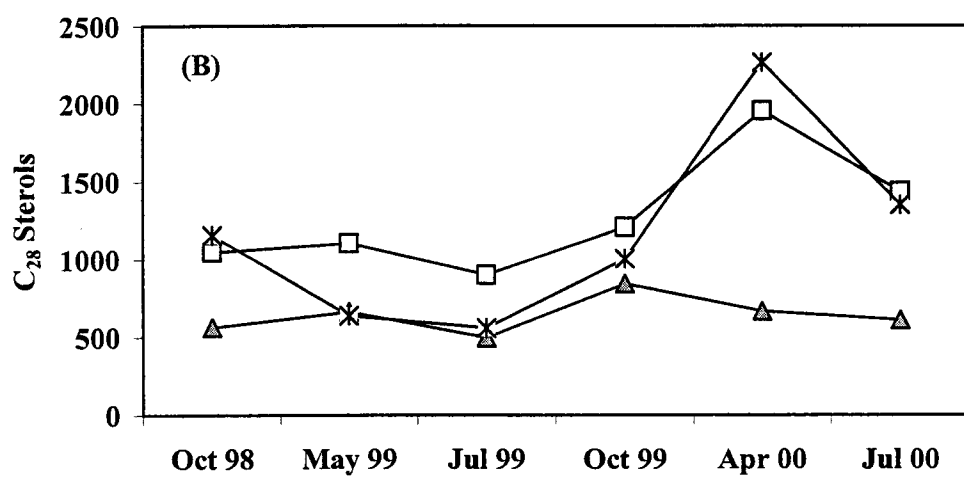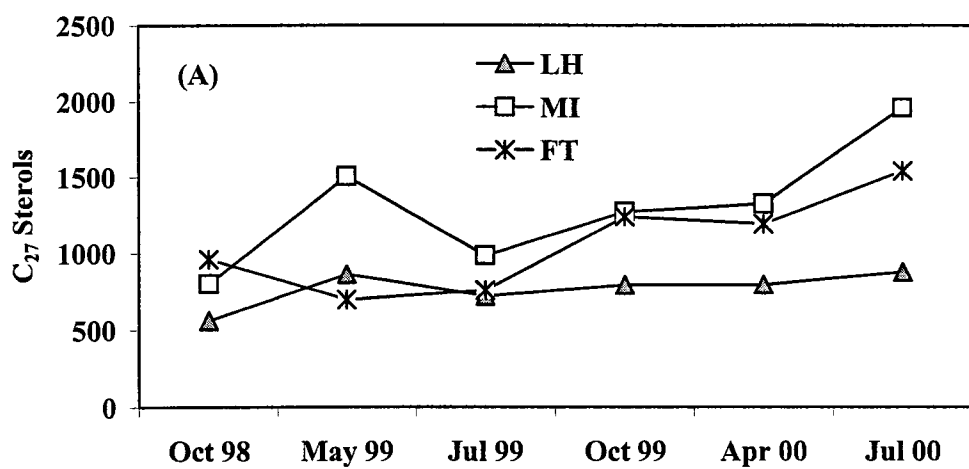
Fig. 5. Carbon-normalized concentrations of fatty acid groups, including short-chained saturated fatty acids (SCFA), long-chained saturated fatty acids (LCFA), monounsaturated fatty acids (MONO), polyunsaturated fatty acids (PUFA) and branched fatty acids (BrFA) for (a) LH, (b) MI and (c) FT. Compounds comprising each group are presented in Table 2.
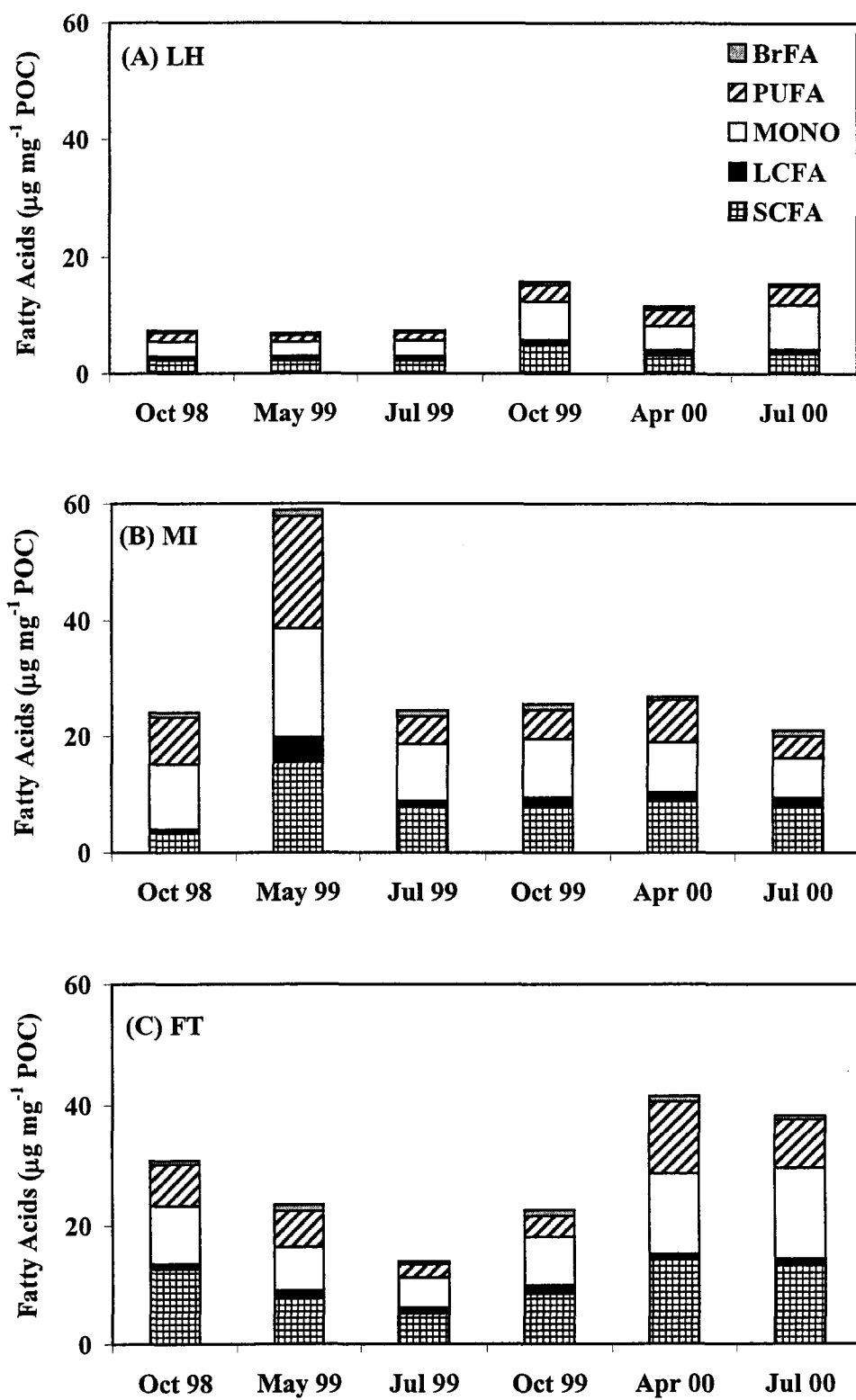
CHAPTER 4

SOURCES OF PARTICULATE AND SEDIMENT ORGANIC MATTER IN
SHALLOW-WATER HABITATS OF THE SACRAMENTO-SAN JOAQUIN RIVER
DELTA, CA

ABSTRACT

Restoration of shallow-water habitat in the Sacramento-San Joaquin River Delta (Delta) is expected to lead to increased productivity and improve aquatic food web processes. In order to examine carbon dynamics in shallow-water habitat, we characterized suspended particulate and sediment organic matter in two shallow tidal lakes (breached levee sites) in the Delta – Mildred Island (MI) and Franks Tract (FT). Organic carbon and nitrogen, biochemical compounds (total proteins, total carbohydrates and total lipid extract) and lipid biomarkers (fatty acids and sterols) were measured over three time periods (October 1999, April 2000 and July 2000). Most bulk parameters in suspended particles and sediments reached maxima in MI in October, during a phytoplankton bloom. Carbohydrates were the dominant biochemical fraction in suspended POM and sediment POM, followed by proteins and lipids. Carbohydrates and lipids were maximized at FT, and proteins at MI. Fatty acids and sterols indicated that diatoms and zooplankton were dominant sources of organic carbon for suspended POM at both sites, with macrophytes contributing to suspended POM in FT. Sediments were characterized by elevated levels of long-chain saturated fatty acids, indicative of terrestrial inputs, and branched fatty acids, indicative of bacteria, were enriched in sediments. The percent loss of fatty acids and sterols in sediments relative to POM was greater than percent losses for biochemical compounds. Results indicate that sources and mineralization processes are different between the two sites, and that benthic-pelagic coupling is weak to non-existent at both sites throughout the year. However, based on the shallowness of the sites, some coupling would be expected. Therefore our sampling regime was likely too limited (sampling of only three time periods), and results should be viewed as preliminary. Future work studying organic carbon within the Delta should include studies on finer spatial and temporal scales, particularly in rehabilitated shallow-water habitats. These sites exhibit high spatial and temporal variability, even within sites, and a thorough understanding of the quality of organic carbon at these sites will only be

possible when short-term factors such as tidal action are investigating concurrently with indicators of quality.

INTRODUCTION

Understanding the sources and dynamics of organic matter delivery and accumulation in estuarine and coastal ecosystems has been a long-standing question in the fields of aquatic ecology and geochemistry (Odum, 1984; Jassby et al., 1993; Hedges and Keil, 1999). Due to the shallow nature of these regions, a focus of these studies has been to understand the interactions between the pelagic and benthic components of these environments (i.e, benthic-pelagic coupling) and their influence on organic matter delivery and remineralization (Graf et al., 1983; Hopkinson et al., 1999; Vidal and Morgui, 2000). This coupling plays an important role in the ecology of shallow-water environments as delivery of organic matter to surface sediments has implications for the nutritional requirements of benthic organisms, nutrient regeneration, benthic oxygen demand, and organic matter accumulation. Addressing the role of benthic-pelagic coupling in river-estuarine systems is challenging due to physical and biological complexities of these ecosystems. In addition, shallow-water systems are generally characterized by strong spatial and temporal variability in physical and chemical gradients as well as in patterns of primary production (Newell 1982).

Within some estuarine systems are shallow-water environments that are semi-enclosed, lake-like environments influenced by tidal actions. Although these systems are not "lakes" in the traditional sense of a completely enclosed freshwater inland body, many of the same geographic and whole-lake perspectives of benthic-pelagic energy and nutrient flows still apply (Jeppesen et al. 1997; Vadeboncoeur and Lodge 2000; Vander Zanden et al. 2002). These semi-enclosed environments are better constrained than entire estuarine systems, with clearly defined boundaries and identifiable connections with adjacent systems (Findlay et al. 1996). These sites are useful systems in which to study the varied sources of organic matter, as well as biotic and abiotic processes controlling mineralization and benthic-pelagic coupling of organic carbon components, such as

proteins, carbohydrates and lipids. Like other shallow-water habitats, much of the organic matter produced in shallow lakes is thought to be consumed by heterotrophic processes occurring in the water column and at the sediment-water interface. The extent to which organic matter reaching the bottom is remineralized during early diagenesis or buried affects the quality of overlying water (Meyers and Ishiwatari 1993). However, as in more open tidal systems, pelagic processes such as zooplankton feeding and physical processes such as wind- and tidal-induced hydrodynamics must also be considered when assessing organic matter transfer to bottom sediments.

The Sacramento-San Joaquin River Delta, CA (Delta, hereafter) includes several shallow tidal lakes. These systems have become the focus of recent studies due to restoration efforts aimed at increasing the amount of shallow-water habitat to increase system productivity, particularly at higher trophic levels (CALFED 2000). Previous studies have focused on hydrodynamics (Lucas et al. 2002; Monsen et al. 2002; Stacey 2003), geological aspects (Simenstad et al. 2000), and select biological factor, such as fish abundances (Grimaldo et al. 2004) and aquatic macrophytes (Toft et al. 2003) in Delta shallow-water habitats. Studies of the benthic environment in these habitats have been few, with existing studies focusing on benthic biomass and grazing rates (Lucas et al. 2002) rather than organic carbon input. Previous studies of organic carbon in the Delta have utilized a variety of techniques to assess sources and mineralization processes controlling the composition of POM and sediments. Bulk POC (Jassby and Cloern 2000), stable isotopes (Cloern et al. 2002), bioassays and (Sobczak et al. 2002, 2005) have been employed to identify the sources, and bioavailability of organic carbon in San Francisco Bay and Delta environments. Lipid biomarker approaches (sterols and fatty acids) have also been useful in providing information about the sources, diagenetic alteration, and food web incorporation of organic carbon in the San Francisco Estuary (Canuel et al. 1995; Canuel and Cloern 1996; Canuel 2001).

In this paper, we present results from a study that examined the bulk biochemical (total proteins, carbohydrates and lipids) and lipid biomarker (sterol and fatty acid) composition of POM and surficial sediments in Franks Tract and Mildred Island, two breached-levee shallow-water habitats in the Sacramento-San Joaquin River Delta, CA. These sites were selected because they have been well-studied in terms of chemical

parameters such as chlorophyll (Lucas et al. 2002a,b), biological parameters such as
zooplankton and fish abundances (Orsi 2002; Grimaldo et al. 2004), and hydrodynamics
(Monsen et al. 2002; Stacey 2003), characteristic of the Delta ecosystem. Therefore, they
offer the chance to examine overall spatial and temporal variability in the composition of
of POC and sediment organic matter (SOM) in important Delta habitats. The goals in
this study were to: (1) determine the sources and composition of POM and SOM for each
site, and (2) examine patterns of organic matter degradation/accumulation.

MATERIALS AND METHODS

Study Sites

The study sites selected for this work were Franks Tract (FT) and Mildred Island (MI), both located in the southern region of the Sacramento-San Joaquin River Delta (Fig. 1a). FT and MI are former agricultural tracts that were flooded when their dikes were breached in response to storms and have never been reclaimed. Both have tidal connections to the surrounding river channels, with maximum tidal currents on the order of 0.1 m s^{-1} (Lucas et al., 2002). The mean depths of FT and MI are 5 m and 3 m, respectively, with surface areas of 12.9 km^2 for FT and 4.1 km^2 for MI (Lucas et al. 2002). FT was flooded in 1938 and MI in 1983, and they have likely reached a relatively steady state, with respect to leaching dissolved substances from the soils (Lucas et al. 2002). FT and MI represent a large portion of Delta water volume (Monsen et al. 2002) and processes in these tracts may have Delta-scale effects. The hydrodynamic regimes and pelagic and benthic productivity in FT and MI have been studied recently (Lucas et al. 2002, Monsen et al. 2002, Stacey 2003).

Within each lake, three locations were sampled in order examine spatial variability within the lakes, with northwest (FT-1, FT-2), and mid-lake (FT-3) sites represented in FT (Fig. 1b) and southeast cove (MI-1), central lake (MI-2) and western cove (MI-3) sites represented in MI (Fig. 1c). During the spring and summer FT is dominated by the invasive aquatic macrophyte *Egeria densa* (Grimaldo et al. 2004), and also hosts large populations of the freshwater clam *Corbicula fluminea* (Lucas et al. 2002). *Egeria densa* and *Corbicula fluminea* are also present in MI, but vegetation is generally limited to the perimeter of the lake, and *Corbicula* is generally found in the northern region of MI (Lucas et al. 2002, Lopez et al. in press).

Sample Collection

Suspended particle and sediment samples were collected during cruises in October 1999, April 2000 and July 2000. These time periods were chosen to represent different physical and biological conditions (phytoplankton blooms, SAV growth and senescence) contributing to variability in organic matter composition (Lucas et al. 2002). To collect particulate samples for lipids (sterol, fatty acid, total lipid extract (TLE)), 20-

30 L of water were collected from each site at a depth of 1 m above bottom, and initially filtered through 100 micron mesh to eliminate larger zooplankton. These water samples were subsequently filtered through pre-combusted (450°C, 4 hours) 142 mm diameter Gelman glass fiber filters (1 μm nominal pore size) under low pressure with nitrogen gas. For the analysis of total particulate protein and carbohydrate, water samples (200-1200 ml) were filtered onto pre-combusted 25 mm and 47 mm Gelman glass fiber filters, respectively (n=3 for each analysis) under a gentle vacuum. Sediment samples were collected concurrently using a bottom grab, and surface sediments (0-0.5 cm) were removed representing recent accumulation. Suspended particle and sediment samples were stored immediately on dry ice in the field and transferred to a -80°C freezer for long-term storage in the lab.

Additional measurements conducted by the U.S.G.S. during sampling were temperature and salinity, reported in Sobczak et al. (2005) and Chapter 3. Additional water samples (1m above bottom) were collected for ancillary analyses including chlorophyll *a* (chl *a*), phaeophytin and suspended particulate matter (SPM) following standard methods (see methods in Lucas et al. 2002). Separate aliquots of water were filtered onto GF/F filters for particulate organic carbon and nitrogen (POC and PN). Chlorophyll *a* (chl *a*), phaeophytin (phaeo), SPM, POC and PN, and dissolved oxygen analyses were conducted at the U.S. Geological Survey in Menlo Park, CA (Sobczak et al. 2005). Total organic carbon (TOC) and total nitrogen (TN) content was determined after acidification of replicate dry sediment samples (Hedges and Stern 1984). Samples were dried (60 °C for 3 days) and ground and transferred (approximately 18-22 mg) to precombusted silver capsules. Inorganic carbon was removed using 1-2 drops 10% HCl in each capsule. Samples were dried again and the TOC and TN concentrations were analyzed using a Fisons Instruments Model EA1108 CNS-O elemental analyzer.

Biochemical Analyses

The total protein content of suspended particles and sediments was analyzed using the bicinchoninic acid method described by Nguyen and Harvey (1994). Modifications to the method were made for sediments to remove compounds that may interfere with the analysis, such as free amino acids, carbohydrates and chlorophyll (Nguyen and Harvey

1994). Sediment samples (10-30 mg) were weighed into 1.8 ml microcentrifuge tubes and incubated with 0.5 ml of 10% trichloroacetic acid (TCA) solution in acetone. The sample was sonicated using an ultrasonic probe and another 0.5 ml of TCA solution was added. Samples were incubated for 30 minutes at -20°C, centrifuged, and the supernatant removed by pipet. Cold acetone (1 ml) was then added to the samples, the sample was incubated at –20°C, and the supernatant removed by pipet. This acetone extraction was repeated two to three times until the supernatant was clear. The sediment pellet was then dried and 1 ml of 0.1 N NaOH was added. A small volume (0.1 ml) was then pipeted into 15 ml centrifuge tubes. The method proceeded with the same incubation and spectrophotometric reading as described in Nguyen and Harvey (1994). Protein-carbon equivalents were calculated using a conversion factor of 0.49 μg C μg^{-1} protein (Fichez 1991).

Total carbohydrates were quantified using the Pakulski and Benner (1992) method for suspended particles. A modified version of this method was used for sediment samples (Burdige et al. 2000). Carbohydrate-carbon equivalents were calculated using a conversion factor of 0.40 μg C μg^{-1} carbohydrate (Fichez 1991).

Total lipids (TLE) were quantified using a gravimetric method following extraction. A portion of the extract from the lipid biomarker analyses was dried and resuspended in a known volume of dichloromethane (generally, 500 μl). From this, 9-10 μl aliquots of each sample were transferred to pre-weighed foil cups using a syringe and weighed on a microbalance. Samples were weighed in triplicate to obtain the amount of total lipid extract (TLE) in mg (Haddad et al. 1991; Canuel and Martens 1993). Lipid–carbon equivalents were calculated using a conversion factor of 0.75 μg C μg^{-1} lipid (Fichez 1991).

Lipid Biomarker Analyses

Prior to extraction, filters were shredded into small pieces using forceps rinsed with methanol, 2:1 methanol/dichloromethane, and hexane. The shredded filters were placed into a pre-rinsed Teflon liner and spiked with surrogate standards of myristyl arachidonate, methyl nonadecanoate and nonadecanol prior to microwave extraction (CEM MSP100) at 80°C and 200 psi for ten minutes. Samples were extracted twice

using a modification of the method of Bligh and Dyer (1959) with 2:1 (v:v) methylene chloride: methanol. Samples were centrifuged and the solvent decanted to a separatory funnel following each extraction. Water and methanol were added to create a mixture 2:2:1.9 ($MeCl_2$: MeOH: H_2O; v:v:v) and the samples were shaken. Samples were allowed to separate into two phases and the lower (organic) phase was collected to a round-bottomed flask. The aqueous phase was back-extracted with hexane and the hexane phase was collected into the round-bottomed flask. A portion of the lipid extract (generally 50%) was saponified (base hydrolyzed) using 1N KOH in aqueous CH_3OH, to cleave ester linkages. During saponification, samples were heated to 110°C using a dry heating block for 2 hr. Neutral lipids were extracted into hexane (nC_6) under basic conditions, and acidic lipids were extracted into nC_6 under acidic conditions (pH=2) (Canuel and Martens 1993). The neutral fraction was subsequently separated into lipid classes using column chromatography (5% deactivated silica), and solvents of increasing polarity from hexane through 20% ethyl acetate in hexane. The alcohol/sterol fraction was eluted with 15% and 20% ethyl acetate in hexane. The acid fraction was methylated using 3% BF_3-CH_3OH and purified by column chromatography. Sterols and fatty acid methyl esters (FAMEs) were analyzed by gas chromatography (Canuel and Zimmerman 1999). Internal standards (methyl heneicosanoate and 5α-cholestane) were added to the fatty acid and alcohol/sterol fractions, respectively and used for quantification. Sterols and FAMEs were analyzed by gas chromatography using a 30 m x 0.32 mm i.d. DB-5 fused silica capillary column with a flame ionization detector. Sample injection temperature was 60 °C with a helium gas (carrier gas) flow rate of 2.3 ml min^{-1}. Following an initial fast ramp to 110 °C (FAMEs) and 225 °C (sterols), temperature was increased at 3 °C min^{-1} to 280 °C (FAMEs) and 310 °C (sterols/alcohols). Individual peaks were identified based on relative retention times of known standards and peak areas were quantified relative to internal standards. Mass spectrometry using a Hewlett Packard 5972 mass selective detector interfaced with a HP 6890 GC was used to confirm compound identifications.

Plant Lipid Biomarker Analyses

In order to aid in our interpretation of the biomarker composition of POM and SOM, we examined the composition of four macrophytes. One emergent macrophyte species (Common tule: *Scirpus acutus*), and three submerged macrophyte species (Brazilian waterweed: *Egeria densa*, Watermilfoil: *Myriophyllum spicatum*, and water hyacinth: *Eichhornia crassipes*), were collected concurrently with POM and sediment samples. These plant species are abundant in the Delta (Cloern et al. 2002). Lipid samples were extracted from dried plant tissues in microwave vessels, using the same procedures used to extract suspended particle and sediment samples. In addition, two samples of wet tissues were analyzed for comparison.

Statistical Analyses

Data were analyzed statistically using MiniTab (Minitab Inc.: release 13.32, 2003). Within Minitab, the General Linear Model analysis of variance (ANOVA) was used. Because our data sometimes violated the assumptions for parametric tests, that all data be normally distributed and display homogeneity of variance, a nonparametric test was used when appropriate. For these data, the Fisher's least significant squares test (Fisher's LSD) was employed to test the differences of means, after rejecting the null hypothesis using ANOVA. All data were log-transformed prior to data analysis to minimize effects from outliers, but untransformed data are presented in the figures.

RESULTS

Bulk Composition of SPM

      Measures of SPM and its bulk composition over the three sampling periods are presented in Table 1. Data for SPM parameters (i.e. Secchi depth, SPM, POC were presented in Sobczak et al. (2005), although not by location within habitat as presented here. Concentrations of chl *a*, phaeophytin, POC and PN were significantly higher in SPM collected from MI vs. FT (Table 1). While concentrations of these parameters were similar across all sub-sites and all time periods in FT, concentrations were more variable in MI both spatially and temporally. The highest values of chl *a*, POC and PN were found at MI-1 in October 1999. This site is located in the southeast corner of MI, which is an area known to exhibit slower hydrodynamic flow and stagnant water conditions (Lucas et al. 2002; Grimaldo et al. 2004). Chl *a* at MI-1 reached a maximum of 23.90 µg L^{-1}, while POC and PN reached maxima of 1.35 mg L^{-1} and 0.25 mg L^{-1}, respectively. Maximum phaeophytin concentrations also occurred at MI-1, in April 2000 (7.80 µg L^{-1}) and July 2000 (6.10 µg L^{-1}). Calculations of % chl *a*, as a percentage of total pigments measured (chl *a* + phaeophytin), indicate that chl *a* made up roughly 50% of pigments during all sampling periods and locations in FT (50.09±4.00%), while MI, particularly MI-1 exhibited greater variability. Values for % chl *a* at MI-1 ranged from a maximum of 82.70% in October 1999 to 36.46% in July 2000 (average = 62.20±23.57%). Percentages at MI-2, the mid-lake site, were always between 50-60% during the sampling period (55.69±4.68%), while % chl *a* at MI-3 averaged 45.10±9.46%, and was >50% only once, in April 2000 (55.84%). Carbon:nitrogen ratios (C:N_a) were also calculated from POC and PN data. Although there was a trend of lower values at MI, C:N_a ratios were statistically similar at the two sites (Table 1). C:N_a ratios in FT were more variable than in MI due to significantly higher values in July 2000 (9.33±0.42).

Bulk Composition of Sediments

      Similar to SPM, TOC and TN of surficial sediments were significantly higher in MI (Table 2). TOC and TN concentrations averaged 64.10±23.11 mg g^{-1} and 4.78±1.24 mg g^{-1}, respectively in MI, compared to 32.26±3.49 mg g^{-1} and 3.03±0.21 mg g^{-1}, respectively in FT. Similar to SPM, bulk sediment characteristics were less variable in

FT (Table 2). Similar to POC and PN, the highest values of TOC and TN were found at MI-1 for all three sampling periods. Unlike $C:N_a$ ratios in SPM, sediment $C:N_a$ ratios were significantly higher in MI (15.23±1.77, p=0.03) than FT (12.46±0.89). The highest $C:N_a$ ratios were consistently found at MI-1 during all sampling periods, with a maximum of 17.31 in October 1999, coinciding with high chl a, POC and PN levels in SPM.

Biochemical Composition of SPM and Sediments

In general, carbohydrate was the dominant biochemical class associated with SPM at both sites (12-35% of POC), followed by lipid (10-22% of POC) and protein (3-11% of POC). These patterns were similar in the sediments, although the contributions to sediment OC were significantly smaller (6-15%, 2-7% and 2-5% for carbohydrates, lipids and proteins, respectively). The total fraction of OC that could be characterized by the biochemical classes was similar as FT and MI, ranging from 25-58% in SPM and 11-22% in sediments, indicating that a large fraction of SPM and sediments in these environments is uncharacterizable.

Seasonal and spatial variations in total protein, carbohydrate and lipid associated with SPM and sediments are shown in Fig. 2(a-f). When the temporal and spatial data for each site were pooled, characterizable biochemical classes were enriched in SPM relative to sediments (ANOVA, p<0.001). In general, concentrations of biochemical classes associated with SPM were similar at FT and MI (Figs. a,c,e) but were significantly different than sediments. Total carbohydrate and lipid (Figs. 2d,f) were higher in sediments from FT relative to MI (101.66± 20.75 µg carb mg^{-1} OC, p=0.03 and 53.29±7.98 µg TLE mg^{-1} OC , p=0.04, in FT respectively), while protein concentrations (Fig. 2b) were higher in MI vs FT sediments (34.76±9.80 µg mg^{-1} OC vs. 24.22±1.11 µg mg^{-1} OC, p=0.02).

When the data were examined by location, patterns of spatial and temporal variability in biochemical composition emerged. At FT, the protein content of SPM was significantly higher at all locations in April 2000 (Fig. 2a; 61.78± 16.06 µg mg^{-1} OC), vs _____ at other time periods but was similar across locations and sampling periods in the sediments (25.21±1.11 µg mg^{-1} OC). In contrast, SPM and sediments at MI displayed

both spatial and temporal variability. Proteins were significantly higher for both SPM and sediments in October 1999 than during other sampling periods. This was due to higher protein concentrations associated with SPM at MI-1 (109.37±11.56 μg mg^{-1} OC), and higher sediment concentrations at MI-1 (51.28±9.60 μg mg^{-1} OC) and MI-3 (47.95±10.25 μg mg^{-1} OC) (Fig 2b).

The carbohydrate content of SPM exhibited the same temporal pattern at FT as seen for proteins (Fig. 2c), with significantly higher concentrations in April 2000 than for other time periods(214.04±31.52 μg mg^{-1} OC vs. 162.81±21.44 μg mg^{-1} OC). Carbohydrate concentrations in SPM were significantly higher at FT-3, due to higher values in April 2000. Carbohydrates concentrations in FT sediments were similar at all sites during all time periods, although a maximum of 146.07 μg mg^{-1} OC was observed at FT-3 in July 2000 (Fig. 2d). At MI, spatial and temporal patterns in the carbohydrate content of SPM were evident. Overall, the maximum carbohydrate values at MI occurred in April 2000 (349.01 μg mg^{-1} OC), and SPM collected from MI-1 was enriched in carbohydrates compared to MI-2 and MI-3 (Fig. 2c). While there were no significant temporal changes in MI sediments, MI-2 exhibited significantly higher carbohydrate concentrations (109.20±22.34 μg mg^{-1} OC) than the other MI locations.

There were no significant patterns in the TLE-C composition of SPM and sediments collected from FT. TLE-C contents were 158.69±31.62 μg mg^{-1} OC in SPM, and 53.29±7.98 μg mg^{-1} OC for the sediments (Figs. 2e,f). At MI, the TLE-C composition of SPM and sediments was similar over time, but displayed spatial variability, with higher concentrations at MI-1 and MI-2 than MI-3.

In FT, the biochemical composition of sediments did not appear to track the patterns observed in SPM. Biochemical components in SPM did not correlate with concentrations in sediments at either FT or MI. However, there was positive a relationship between the biochemical components of SPM and sediments during the October sampling period in MI (r=0.67). Proteins, carbohydrates and TLE were elevated in MI-1 sediments at the same time that concentrations were elevated in SPM. Elevated protein concentrations were also seen in SPM and sediments at MI-3 in October.

Protein/carbohydrate ratios (PROT/CARB ratio) can be used as an indicator of the level of organic matter degradation in SPM and surface sediments (Tables 1,2).

PROT/CARB ratios of <1 are generally indicative of the presence of aged OC (Pusceddu et al. 2003) and a detrital-heterotrophic environment (Danovaro 1996). PROT/CARB ratios were <1 at both FT and MI in SPM and sediments during all sampling periods (Tables 1,2). There was little variability between ratios in SPM and sediments in FT (0.25±0.05), and ratios were similar between sites and sampling periods. While PROT/CARB ratios were similar among all sites for SPM in MI (0.31±0.15), there was greater temporal variability, with higher ratios in October 1999 (0.47±0.02). PROT:CARB ratios at MI-2 (mid-lake site) were similar in SPM and sediments (Fig. 3), but ratios were significantly higher in sediments at MI-1 (0.53±0.05) and MI-3 (0.54±0.11), the cove sites, relative to SPM.

Fatty acids

Across all samples, a total of fifty-seven different fatty acids were identified. A select group of sixteen fatty acids, making up >90% of fatty acids in all samples, is presented in Table 3. The detailed lipid composition in SPM is discussed in chapter 3. Briefly, saturated (SAT) and monounsaturated (MONO) fatty acids were roughly equal at both sites, comprising 33-45% and 31-41% of the total fatty acids, respectively. PUFAs were similar between the sites (15-32%), as were BrFAs (1-5%).

General trends in fatty acid composition in sediments were the dominance of SATs (49-66% in FT, 60-73% in MI) followed by MONOs (23-32% in FT, 10-20% in MI). In sediments at FT, PUFAs were generally more abundant than BrFAs (8-14% vs 5-7%, respectively), but were roughly equal in abundance in MI sediments (6-10% and 5-9%, respectively).

The prominent trends observed in the relative abundance of fatty acids at both sites were general increases in LCFAs and BrFAs in sediments compared to SPM, and a general decrease in PUFAs and SATs (Table 3). Relative abundances of BrFA and LCFA were significantly higher in MI sediments than FT sediments. Fatty acids associated with algal/microbial sources (14:0, 16:0, 16:1ω7) were depleted in sediments, relative to the SPM in MI, as was 18:0 in FT and 18:1ω9c in both FT and MI. Saturated fatty acids, particularly 15:0 were enriched in sediments at both sites, as was 16:1ω9. Saturated 18:0 was enriched in MI sediments relative to SPM, particularly MI-1 and MI-

3, as was PUFA 18:3/2. The relative abundance of 18:1ω9t increased at all FT sediments relative to SPM.

Sterols

As with fatty acids, sterol concentrations were significantly higher in SPM than in sediments by an order of magnitude (Fig. 3). In the SPM, C_{29} sterols (24-ethylcholest-5-en-3β-ol and 24-ethylcholesta-5,22-dien-3β-ol), generally associated with plant sources, were the only sterols that differed in their abundance across sites (0.49 ± 0.03 µg mg^{-1} OC vs. 0.91 ± 0.24 µg mg^{-1} OC, for FT and MI, respectively). Concentrations of C_{29} sterols, cholesterol (cholest-5-en-3β-ol) and diatom sterols (24-methylcholesta-5,22-dien-3β-ol and 24-methylcholest-5,24(28)-dien-3β-ol) were significantly higher in FT sediments than MI sediments (Fig. 3).

Diatom sterols in SPM were the only group to exhibit temporal variability at FT, with significantly higher concentrations in April 2000 at all locations compared with other sampling periods (2.10 ± 0.68 µg mg^{-1} OC vs. 0.80 ± 0.14 µg mg^{-1} OC, Fig.3a). Diatom, cholesterol and C_{29} sterols were similar in SPM at all FT locations. In MI, C_{29} sterols associated with SPM changed over time, with significantly higher concentrations in October 1999 (Fig.3e). Diatoms sterols were significantly higher at MI-1, particularly during October 1999 and April 2000.

In FT, diatom sterols and cholesterol were higher in sediments collected in July 2000 than during other sampling periods (0.19 ± 0.04 µg mg^{-1} OC and 0.13 ± 0.03 µg mg^{-1} OC; vs.0.09 ± 0.03 µg mg^{-1} OC and 0.06 ± 0.03 µg mg^{-1} OC, respectively). C_{29} sterols were the only group that differed among FT locations, with higher concentrations at FT-1 and FT-2 (closer to shore). Sterols in MI sediments were not variable between sampling dates, and only cholesterol exhibited spatial variability, with higher abundances in MI-2 sediments (mid-lake site).

Stanol/stenol ratios were also quantified for FT and MI in order to assess microbial transformations of stenols to stanols and the extent of organic matter alteration (Fig. 4). In general, stanol/stenol ratios were higher in surface sediments than in suspended particles, consistent with increased degradation of organic matter in sediments.

Overall, stanol/stenol ratios for SPm and sediments collected from FT were significantly higher than in MI.

Plant Lipids

Each of the four plants analyzed were dominated by a few fatty acid and sterol compounds that made up 80-93% and 76-100% of total compositions of each lipid class, respectively (Table 4). Fatty acid distributions were dominated by 16:0 (21.3-44.2%), 16:1ω7 (0.45-7.85%), and C_{18} PUFAs (36.6-59.8%). The saturated fatty acid 16:0 was highest in brazilian waterweed (*Egeria densa*), while PUFAs (18:3 and 18:2) were highest in eurasian watermilfoil (*Myriophyllum spicatum*) and water hyacinth (*Eichhornia crassipes*). Common tule (*Scirpus acutus*) and *E. densa* had similar fatty acid compositions, despite being an emergent and submerged species, respectively. Sterol distributions in each of the four plants were dominated by three sterols, 24-ethylcholest-5-en-3β-ol, 24-ethylcholesta-5,22-dien-3β-ol, and 24-methylcholest-5-en-3β-ol. The emergent species, *S. acutus* was dominated by 24-ethylcholest-5-en-3β-ol (91.17%), while submerged species had greater contributions of 24-ethylcholesta-5,22-dien-3β-ol. The simplicity of fatty acid and sterol composition in plants contrasts with the more complex SPM and sediment compositions (Table 3), which are indicative of a diversity of sources rather than a predominant plant source.

Delivery of OC to Sediments

Changes in the concentrations of bulk OC and biochemical and lipid components between SPM and sediment sampled were also assessed. In FT, FT-1, the nearshore site, was characterized by accumulation (Fig. 5). The offshore sites, FT-2 and FT-3, exhibited net removal of OC although small amounts of OC accumulated at FT-3 in July 2000. Lipid biomarker compounds exhibited the greatest differences between water column and sediments (>75%), while protein-C, carbohydrate-C and C_{29} sterols exhibited differences of <70% (Table 5). Compared to FT-2 and FT-3, FT-1 generally had lower percentages of compound loss.

Lipid compounds also exhibited removal at MI sub-sites, with TFA, SAT, MONO, PUFA, zooplankton and diatom sterol differences generally similar to FT sub-sites. Percentages of removal for C_{29} sterols were higher in MI than in FT, and MI-1

generally exhibited the greatest differences from SPM to sediments, while MI-2 generally exhibited the smallest differences. Exceptions included smaller differences for PROT-C and TLE-C at MI-3.

DISCUSSION

Sources of organic matter

Estuarine habitats, including shallow-water tidal lakes, receive both living and detrital POC from a variety of sources, including phytoplankton, zooplankton and zooplankton fecal pellets, bacterioplankton, terrestrial and aquatic vascular plants, and resuspended microalgae. Additional sources to sediments may include bacteria, benthic invertebrates and vertebrates and their byproducts. Within FT and MI, aged organic detritus is a dominant source of POC to SPM and sediments. Several studies have indicated that the Delta and its sub-habitats are inherently oligotrophic (Jassby and Cloern 2000; Müller-Solger et al. 2002; Sobczak et al. 2005), with low productivity despite adequate nutrient supplies (Jassby et al. 2002; Sobczak 2002, 2005). POC is usually <5% of TSS in the Delta (Schemel and Hager 1996; Müller-Solger 2002), and in FT and MI, it generally constituted less than 8% during our study. In oligotrophic lakes, the ratio of detrital to live plankton biomass is likely to be highest (Meil et al. 1992) with live plankton of oligotrophic lakes usually dominated by bacteria and zooplankton, while phytoplankton often comprise only a small fraction of all living matter (del Giorgio and Gasol 1995: del Giorgio and France 1996).

In the Delta, algal biomass accounts for <10% of organic matter (Müller-Solger et al. 2002: Jassby et al. 2002: Sobczak et al. 2005). FT exchanges water with the surrounding river systems through numerous levee breaches (Lucas et al. 2002, Stacey 2003). The surrounding rivers are known to carry aged, refractory OC to the Delta and northern San Francisco Bay (Jassby and Cloern 2000; Jassby et al. 2002; Chapter 2 of this dissertation). Sediments in FT are less variable in OC content (3.0-3.5% TOC) compared to MI (3.5-8.9% TOC), but values at both sites agree well with other shallow coastal sites (Cowie and Hedges 1994; Gremare et al. 1998; Canuel and Zimmerman 1999; Cividanes et al. 2002). $C:N_a$ was higher in MI sediments vs. FT sediments. Higher ratios generally indicate that sediment OM is more refractory. Recent studies have found that the most organic-rich sediments can have significantly higher C:N ratios than samples with lower organic matter (Calvert et al. 2004). C:N ratios are also influenced by remineralization with preferential recycling of N. Therefore, C:N ratios are of limited use in determining the sources of organic matter to sediments in the Delta.

The similarity in concentrations of biochemical compounds across sites indicated their limited use in determining SPM sources. Higher values of proteins, carbohydrate and lipids in April 2000 at FT and in October 1999 are MI indicates that higher quality POM was present. Protein and lipids make up significant percentages of phytoplankton biomass, but carbohydrates can be high in phytoplankton (Cowie and Hedges 1984; Meyers and Ishiwatari 1993) primarily as non-structural carbohydrates used as energy storage (Vichkovitten and Holmer 2004).

Fatty acid and sterol biomarkers were used to examine the sources of organic matter in greater detail. Sterol compositions in FT and MI indicate that contributions from phytoplankton, particularly diatoms and zooplankton contribute to the suspended OM. This is corroborated by contributions from fatty acids such as 14:0, 16:1ω7 and 20:5ω3 (Table 3), which are indicative of phytoplankton (Arzayus and Canuel 2004) and 18:1ω9, which is a dominant fatty acid in zooplankton (Prahl et al. 1984; Wakeham and Canuel 1986; Harvey et al. 1987). High cholesterol and 18:1ω9 could also be indicative of contributions from zooplankton fecal pellets (Wakeham et al. 1995). Several studies (Jassby and Cloern 2000; Sobczak et al. 2005; Sobczak et al. 2002; Müller-Solger et al. 2002; Jassby et al. 2002; Sobczak et al. 2005) have indicated that algal-derived organic matter is important to the Delta's pelagic food webs. Higher cholesterol concentrations in FT sediments, particularly in July, likely reflected increased input of algal, zooplankton and zooplankton faeces. Zooplankton have been shown to be significantly associated with E. densa (Mazzeo et al. 2003; Grimaldo et al. 2004), which was abundant in July.

The increase in LCFAs in sediments suggesterrigenous/vascular plant sources are important to sediments at both sites (Table 3). San Joaquin River POM, which has significant LCFAs (see Chapter 3), is a likely source for terrestrial vascular plant detritus. Although insignificant in submerged aquatic vegetation (Table 3), LCFAs can account for 11% of TFAs in the emergent marsh plant S. acutus, which grows around both FT and MI. However, whether an increase in LCFAs constitutes a significant input to sediment is questionable. An accumulation of LCFAs can also come from the preferential decay of short chain FAs with higher degradation rates (Reemstma et al. 1990). Likewise, there is a possibility that increases of BrFAs in sediments may be due to simple accumulation,

rather than an increase in bacterial biomass in sediments, as bacterial biomass is not necessarily related to BrFA concentration (Harvey and Macko 1997).

An inherent problem with using sterols for source assignments is that some compounds are not unique to algal or higher plant sources. This is particularly true for the sterols normally assigned to vascular plants. 24-Ethylcholest-5-en-3β-ol ($C_{29}\Delta^5$) and 24-ethylcholesta-5,22-dien-3β-ol ($C_{29}\Delta^{5,22}$) are the dominant sterols in aquatic and terrestrial vascular plants (Volkman 1986, Canuel et al. 1997), but can also occur in significant abundance in some phytoplankton (Volkman 1986; Volkman et al. 1998). Other studies have attempted to correlate C_{29} sterols to lignin phenols or use ratios of $C_{29}\Delta^5/ C_{29}\Delta^{5,22}$ sterols. In FT and MI, $C_{29}\Delta^5/ C_{29}\Delta^{5,22}$ ratios were <6, which would indicate a mix of algal and terrestrial sources (Volkman 1986). To determine more definitive source assignments, we examined correlations between C_{29} sterols and LCFAs, SCFAs (indicative of an algal source), diatom sterols, plankton fatty acids (14:0, 16:0 and 20:5w3) and macrophytes (18:3/2). Correlations for SPM in FT and MI would indicate that C_{29} sterols came from different sources in each system. A lack of correlation between C_{29} sterols and LCFA or any diatom/plankton/SFCA components may indicate that these C_{29} sterols may come from a source other than terrestrial plants or phytoplankton, possibly aquatic macrophytes. The relative abundance of C_{29} sterols in macrophytes in FT during sampling (Table 4) indicate that is a probable source, as macrophytes generally have a low abundance of LCFAs. For MI SPM, C_{29} sterols lacked any correlation with LCFAs, but were strongly correlated with all algal components ($p<0.05$). In sediments at FT, C_{29} sterols were strongly correlated with LCFAs, indicating that there is a input of terrestrial plant material. The origin of these sterols to sediments in MI appeared to be mixed, as they correlated with both LCFAs and algal components.

Mineralization of Organic Matter

In order to initially determine any relationships between SPM and sediments, correlation analyses were carried out on biochemical and sterol data plotted in Figs. 2 and 4, as well as TFA concentrations from Table 3 (all sites and sampling dates were run). Correlation analyses indicated that there were no correlations between SPM and

sediments for any of the biochemical or lipid biomarker data, thereby indicating that benthic-pelagic systems at FT and MI may be uncoupled.

A myriad of processes can control the amount, transformation and packaging of POC supply to sediments. These include factors controlling delivery of POC to sediments, including phytoplankton bloom development and decay, zooplankton feeding and fecal pellet production, and hydrodynamics. Several factors also control the fate of organic matter once material is deposited, including bacterial mineralization, benthic feeding, and resuspension. While FT and MI share many of the same general processes controlling OM supply to sediments, they appear to yield different results. FT generally showed a loss of carbon from SPM to surface sediments, while MI tended to accumulate OC, particularly in the southern region (excluding MI-1 in October 1999) (Fig.5). This is in agreement with Lucas et al. (2002), who categorized FT as a region where of phytoplankton carbon was exported or lost from the system, and MI as a net sink.

Patterns in FT are likely the results of two primary processes 1) hydrodynamic removal of POC with tidal action and 2) removal of OC through filtering by *Corbicula fluminea*. These processes affect the open lake sites FT-2 and FT-3, while nearshore site FT-2 experiences OC accumulation. Several levee breaks around FT provide for continuous water exchange between FT and neighbouring channels. In addition, during periods when *E. densa* is abundant, the flood tide is channelized by vegetation, which produce jets that extend into the center of FT, where FT-2 and FT-3 are located. The residence time of a particle in one of these jets would be extremely short (Lucas et al. 2002; Stacey 2003), not allowing POC to sink and accumulate in sediments. In addition, FT is known to support large populations of the filter-feeder *Corbicula fluminea*, which may reduce POC accumulation. Benthic grazing rates for *C. fluminea* reached 4 $m^3m^{-2}d^{-1}$ a rate capable of removing any labile carbon reaching sediments (Lucas et al. 2002). This is reflected in the higher rates of loss of lipid and biochemical compounds at FT-2 and FT-3 (Table 5). Export of nearby emergent marsh vegetation and deposition of *E. densa*, coupled with slow hydrodynamic flow in the area of FT-1 is the likely cause of this accumulation during all sampling periods. Terrestrial OC appears to be exported to FT-1, perhaps from outside FT, based on the higher relative abundances of LCFAs in SPM. Differences in lipid biomarkers and biochemical compounds at FT-1, while still

significant, are lower than the more hydrodynamic and biologically active open water sites (Table 5).

MI can be considered as two separate systems in terms of its hydrodynamic regime. The northern section is connected to the main levee breach in the northern western quadrant and actively exchanges water with the outside channel. The southern section experiences less tidal exchange and therefore slower water movement (Lucas et al. 2002, Stacey 2003). The accumulation observed at MI-1 (except in October 1999) and MI-3 likely results from slower water movement at these cove sites. Benthic feeding and reworking of sediments is not likely a major factor, as Simenstad et al. (2000) reported the lowest benthic invertebrate densities in MI compared to other shallow water habitats. Another possible accumulation mechanism may be the sorption of compounds onto the fine-grained sediments found at these sites. The large loss of POC at MI-1 in October probably results from high bacterial degradation of labile compounds sinking out of the water column during the phytoplankton bloom, which was in an exponential growth phase at the time of sampling (83 % chl a/total pigments).

The differences in lipid classes (Table 5) in POM and sediments may be indicative of differing rates of degradation for fatty acids and sterols, as has been shown in Cape Lookout Bight, NC (Canuel and Martens 1996). Fatty acids associated with phytoplankton have also been shown to degrade more quickly than C_{29} sterols and BrFAs. The lower rates of loss of proteins, carbohydrates and TLE are likely the result of the "packaging" of these compounds in the water column. These compounds are more complex in structure than their monomers (Jorgensen and Jensen 1994; Nguyen and Harvey 1997), and are likely incorporated into structures that degrade far less quickly, and at different rates (Harvey et al. 1995). Carbohydrates are major components of plant cell walls, and proteins are known to degrade more slowly than individual amino acids (Opsahl and Benner 1999). TLE measures not only fatty acids and sterols, but other lipid compounds such as hydrocarbons which degrade more slowly than fatty acids. The total of measured compounds in TLE (fatty acids, sterols and alcohols) comprised only 45% of the total lipid in SPM, and 30% in sediments. Therefore, much of the measured TLE extract may in less degradable fractions.

Benthic-pelagic coupling implies that there is a transfer of POC from the overlying water to the sediments, and vice versa through sediment-water interactions. Based on our data, benthic-pelagic coupling is not strong within these two systems, and absent when it comes to certain compounds. Correlation analyses indicated that there is no relationship between biochemical compounds (Fig.2), and sterols (Fig.4) in SPM and sediment at MI and FT sites, except at MI-1 in October 1999. This indicates that water column processes are largely decoupled. Sources also appear to be different between SPM and overlying sediments. The hydrodynamics of each system are likely the primary process causing this uncoupling. Areas with more active hydrodynamic regimes do not exhibit any type of benthic-pelagic coupling (FT-2, FT-3, MI-2), while an area in MI known to experience only local water movement exhibits coupling of biochemical compounds, and the coupling only occurs during a period of an active bloom, as evidenced by a higher % chl a (83%) during this time. Given the shallowness of the sites, it would be expected that benthic-pelagic coupling would occur on some scale. However, benthic-pelagic coupling is not an inherent property of all shallow systems, and can be strong in some shallow coastal systems (Giordani et al. 2002; Danovaro et al. 1999), but can be weak in other (Nagata et al. 1996; Giordani et al. 2002). Our data was collected during three seasons, but may not have been collected on a time scale appropriate to observe benthic-pelagic coupling of chemical compounds.

Hydrodynamic Effects on SPM and Sediments

The primary physical factor affecting FT and MI circulation are tidal currents, which have been extensively studied in FT and MI (Lucas et al. 2002; Monsen et al. 2002; Stacey 2003). Hydrodynamics in MI and FT have been shown to strongly affect the distribution of chlorophyll, dissolved oxygen patterns, and particle transport (Lucas et al. 2002; Monsen et al. 2002). Northern MI, where MI-2 was located, experiences significant tidal action, with particles carried in during flood tide, and the majority carried out during ebb. Our sampling in October 1999 and July 2000 in MI took place during the ebb tide, while April 2000 sampling occurred during the flood. Carbohydrate and diatom sterols were highest during the April 2000 sampling compared to the rest of the year, and may indicate the influx of riverine POM and phytoplankton from the San Joaquin River

and Middle Rivers. In southern MI, there is exchange with the southern channel, but because the opening to the southern channel is much smaller than the northeast opening, there is generally less exchange of water and particles than what is found with northern channels in northern MI. Also, the location of MI-1 is in a cove which is isolated from levee breaks, and particle transport is localized (Lucas et al. 2002). In FT, particles are carried in during ebb tide, and returned to channels during flood tide. However, many particles are retained within FT during flood tide (Lucas et al. 2002). Our samplings occurred in October 1999 and April 2000 at flood or slack tide, while July 2000 sampling occurred during ebb tide. Higher protein, carbohydrate and diatom sterols were observed during April 2000, when particles would be moving out of the lake. However, our sampling sites were located in the interior at FT, away from channel openings, so that tidal action may not have influenced particles at the site. Alternatively, particles carried in during ebb tide were retained in the mid-lake regions, leading to higher concentrations of certain biochemicals and sterols.

REFERENCES

ARZAYUS, K. M., and E. A. CANUEL. 2004. Organic matter degradation in sediments of the York River estuary: Effects of biological vs. physical mixing. Geochim. Cosmochim. Acta 69: 455-463.

BURDIGE, D. J., A. SKOOG, and K. GARDNER. 2000. Dissolved and particulate carbohydrates in contrasting marine sediments. Geochim. Cosmochim. Acta 64: 1029-1041.

CALFED. 2000. California's water future: a framework for action. CALFED Bay-Delta Program.

CANUEL, E.A. 2001. Relations between river flow, primary production and fatty acid composition of particulate organic matter in San Francisco and Chesapeake Bays: a multivariate approach. Org. Geochem. 32: 563-583.

CANUEL, E. A., and J. E. CLOERN. 1996. Regional differences in the origins of organic matter in the San Francisco Bay ecosystems, p. 305-324. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

CANUEL, E. A., J. E. CLOERN, D. B. RINGELBERG, J. B. GUCKERT, and G. H. RAU. 1995. Molecular and isotopic tracers used to examine sources of organic matter and its incorporation into the food webs of San Francisco Bay. Limnol. Oceanogr. 40: 67-81.

CANUEL, E. A., and C. S. MARTENS. 1993. Seasonal variations in the sources and alteration of organic matter associated with recently-deposited sediments. Org. Geochem. 20: 563-577.

CANUEL, E. A., and C. S. MARTENS. 1996. Reactivity of recently deposited organic matter: Degradation of lipid compounds near the sediment-water interface. Geochim. Cosmochim. Acta 60: 1793-1806.

CANUEL, E. A., and A. R. ZIMMERMAN. 1999. Composition of particulate organic matter in the Southern Chesapeake Bay: Sources and reactivity. Estuaries 22: 980-994.

CIVIDANES, S., M. INCERA, and J. LOPEZ. 2002. Temporal variations in the biochemical composition of sedimentary organic matter in an intertidal flat of the Galician coast (NW Spain). Oceanol. Acta. 25: 1-12.

CLOERN, J. E., E. A. CANUEL, and D. HARRIS. 2002. Stable carbon and nitrogen isotope composition of aquatic and terrestrial plants of the San Francisco Bay estuarine system. Limnol. Oceanogr. 47: 713-729.

COWIE, G. L., and J. I. HEDGES. 1984. Carbohydrate sources in a coastal marine environment. Geochim. Cosmochim. Acta 48: 2075-2087.

COWIE, G. L., and J. H. HEDGES. 1996. Digestion and alteration of the biochemical constituents of a diatom (*Thalassiosira weissflogii*) ingested by a herbivorous zooplankton (*Calanus pacificus*). Limnol. Oceanogr. 41: 581-594.

DANOVARO, R. 1996. Detritus-bacteria-meiofauna interaction in a seagrass bed *(Posidonia oceanica)* of the NW Mediterranean. Mar. Biol. 127: 1-13.

DANOVARO, R., A. DINET, G. DUINEVELD, and A. TSELEPIDES. 1999. Benthic response to particulate fluxes in different trophic environments: a comparison between the Gulf of Lions-Catalan Sea (western-Mediterranean) and the Cretan Sea (eastern-Mediterranean). Prog. Oceanog. 44: 287-312.

DEL GIORGIO, P.A., and J.M. GASOL. 1995. Biomass distribution of freshwater plankton communities. Am. Natural. 146: 135-152.

DEL GIORGIO, P.A., and R.L. FRANCE. 1996. Ecosystem-specific patterns in the relationship between zooplankton and particulate organic matter on microplankton δ^{13}C. Limnol. Oceanogr. 41: 359-365.

FICHEZ, R. 1991. Composition and fate of organic matter in submarine cave sediments; implications for the biogeochemical cycle of organic carbon. Oceanol. Acta 14: 369-377.

GIORDANI, P., W. HELDER, E. KONING, S. MISEROCCHI, R. DANOVARO, and A. MALAGUTI. 2002. Gradients of benthic-pelagic coupling and carbon budgets in the Adriatic and Northern Ionian Sea. J. Mar. Systems 33-34: 365-387.

GRAF, G., R. SCHULTZ, R. PEINERT, and L.A. MEYER-REIL. 1983. Benthic responses to sedimentation events during autumn and spring at shallow-water stations in the Western Keil Bight. 1. Analysis of processes on a community level. Mar. Biol. 77: 235-246.

GREMARE, A., J.-M. AMOUROUX, F. CHARLES, C. MEDERNACH, E. JORDANA, C. NOZAIS, G. VETION, and J.-C. COLOMINES. 1998. Temporal changes in the biochemical composition of particulate organic matter sedimentation in the Bay of Banyuls-sur-Mer. Oceanol. Acta. 21: 783-792.

GRIMALDO, L. F., R. E. MILLER, C. M. PEREGRIN, and Z. P. HYMANSON. 2004. Spatial and temporal distribution of native and alien ichthyoplankton in three habitat types of the Sacramento-San Joaquin Delta. Am. Fish. Society Symp. 39: 81-96.

HADDAD, R. I., C. S. MARTENS, and J. W. FARRINGTON. 1992. Quantifying early diagenesis of fatty acids in a rapidly accumulating coastal marine sediment. Org. Geochem. 19: 205-216.

HARVEY, H. R., and S. A. MACKO. 1997. Kinetics of phytoplankton decay during simulated sedimentation: changes in lipids under oxic and anoxic conditions. Org. Geochem. 27: 129-140.

HARVEY, H. R., J. H. TUTTLE, and J. T. BELL. 1995. Kinetics of phytoplankton decay during simulated sedimentation: Changes in biochemical composition and microbial activity under oxic and anoxic conditions. Geochim. Cosmochim. Acta 59: 3367-3377.

HARVEY, H.R., G. EGLINTON, S.C. O'HARA, E.D.S. CORNER. 1987. Biotransformation and assimilation of dietary lipids by *Calanus* feeding on a dinoflagellate. Geochim. Cosmochim. Acta. 51: 3031-3040.

HEDGES, J.I., and J.H. STERN. 1984. Carbon and nitrogen determination of carbonate -containing solids. Limnol. Oceanogr. 29: 657-663.

HEDGES, J.I. and R.G. KEIL. 1999. Organic geochemical perspectives on estuarine processes: Sorption reactions and consequences. Limnol. Oceanogr. 29: 657-663.

HOPKINSON, C. S. J., A. E. GIBLIN, J. TUCKER, and R. H. GARRETT. 1999. Benthic metabolism and nutrient cycling along an estuarine salinity gradient. Estuaries 22: 863-881.

JASSBY, A. D., and J. E. CLOERN. 2000. Organic carbon sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic. Conserv: Mar. Freshw. Ecosyst. 10: 323-352.

JASSBY, A. D., J. E. CLOERN, and B. E. COLE. 2002. Annual primary production: Patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnol. Oceanogr. 47: 698-712.

JASSBY, A. D., J. E. CLOERN, and T. M. POWELL. 1993. Organic carbon sources and sinks in San Francisco Bay: variability induced by river flow. Mar. Ecol. Prog. Ser. 95: 39-54.

JEPPESEN, E., J. P. JENSEN, M. SONDERGAARD, T. LAURIDSEN, L. J.
PEDERSEN, and L. JENSEN. 1997. Top-down control in freshwater lakes: the
role of nutrient state, submerged macrophytes and water depth. Hydrobiol.
342/343: 151-164.

JORGENSEN, N.O.G., and R.E. JENSEN. 1994. Microbial fluxes of free
monosaccharides and total carbohydrates in freshwater determined by PAD-
HPLC. FEMS Microb. Ecol. 14: 79-94.

LOPEZ, C.B., J.E. CLOERN, T.S. SCHRAGA, A.J. LITTLE, L.V. LUCAS, J.K.
THOMPSON, J.R. BURAU. In press. Ecological values of shallow-water
habitats: Implications for restoration of disturbed ecosystems. Ecosystems.

LUCAS, L. V., J. E. CLOERN, J. K. THOMPSON, and N. E. MONSEN. 2002.
Functional variability of habitats within the Sacramento-San Joaquin Delta:
Restoration implications. Ecol. Appl. 12: 1528-1547.

MAZZEO, N. and others 2003. Effects of *Egeria densa* Planch. beds on a shallow lake
without piscivorous fish. Hydrobiol. 506-509: 591-602.

MEYERS, P.A., and R. ISHIWATARI. 1993. Lacustrine organic geochemistry- An
overview of indicators of organic matter sources and diagenesis in lake sediments.
Org. Geochem. 20:867-900.

MÜLLER-SOLGER, A. B., A. D. JASSBY, and D. C. MÜLLER-NAVARRA. 2002.
Nutritional quality of food resources for zooplankton (*Daphnia*) in a tidal
freshwater system (Sacramento-San Joaquin River Delta). Limnol. Oceanogr. 47:
1468-1476.

NAGATA, T., T. OGAWA, J. J. FRENETTE, L. LEGENDRE, and W. F. VINCENT.
1996. Uncoupled responses of bacterial and algal production to storm-induced
mixing in Lake Biwa. Jpn. J. Limnol. 57: 533-543.

NEWELL, R.C. 1982. The energetics of detritus utilization in coastal lagoons and
Nearshore waters. Coastal Lagoons. 5: 347-355.

NGUYEN, R. T., and H. R. HARVEY. 1994. A rapid micro-scale method for the
extraction and analysis of protein in marine samples. Mar. Chem. 45: 1-14.

NGUYEN R.T. and H.R. HARVEY. 1997. Protein and amino acid cycling during
Phytoplankton decomposition in oxic and anoxic waters. Org. Geochem. 27: 115-
128.

ODUM, W. E. 1984. Dual-gradient concept of detritus transport and processing in
estuaries. Bull. Mar. Sci. 35: 510-521.

OPSAHL, S., and R. BENNER. 1999. Characterization of carbohydrates during early diagenesis of five vascular plant tissues. Org. Geochem. 30: 83-94.

ORSI, J.J. 2002. Zooplankton production in shallow water and channel habitats: an example from Mildred Island. IEP Newsletter 15: 27-32.

PAKULSKI, J. D., and R. BENNER. 1992. An improved method for the hydrolysis and MBTH analysis of the dissolved and particulate carbohydrates in seawater. Mar. Chem. 40: 143-160.

PRAHL, F.G., G. EGLINTON, E.D.S. CORNER, S.C.M. O'HARA, and T.E.J. FORSBERG. 1984. Changes in plant lipids during passages through the gut of *Calanus*. J. Mar. Biol. Assoc. U.K. 64: 317-334.

PUSCEDDU, A., A. DELL ANNO, R. DANOVARO, E. MANINI, G. SARA, and M. FABIANO. 2003. Enzymatically hydrolyzable protein and carbohydrate sedimentary pools as indicators of the trophic state of detritus sink systems: a case study in a Mediterranean coastal lagoon. Estuaries 26: 641-650.

REEMSTMA, T., B. HAAKE, V. ITTEKOT, R.R. NAIR, and U.H. BROCKMANN. 1990. Downward flux of particulate fatty acids in the Central Arabian Sea. Mar. Chem. 29: 183-202.

SARGENT, J.R., R.J. PARKES, I. MUELLER-HARVEY and R.J. HENDERSON. 1987. Lipid biomarkers in marine ecology, p. 119-138. In M.A. Sleigh [ed.], Microbes in The Sea. Ellis Horwood Limited, Chichester, England.

SCHEFFER, M., and E. JEPPESEN. 1998. Alternate stable states. Ecol. Studies. 131: 397-406.

SCHEMEL, L. E., S. W. HAGER, and J. CHILDERS, D. 1996. The supply and carbon content of suspended sediment from the Sacramento River to San Francisco Bay, p. 237-260. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

SIMENSTAD, C., J. TOFT, H. HIGGINS, J. CORDELL, M. ORR, P. WILLIAMS, L. GRIMALDO, Z. HYMANSON, and D. REED. 2000. Sacramento/San Joaquin Delta Breached Levee Wetland Study (BREACH), 45 pp. University of Washington.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, and A. B. MÜLLER-SOLGER. 2002. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. Proc. Nat. Acad. Sci. 99: 8101-8105.

SOBCZAK, W.V., J. E. CLOERN, A. D. JASSBY, B. E. COLE, T. S. SCHRAGA, and
A. ARNSBERG. 2005. Detritus fuels ecosystem metabolism but not metazoan
food webs in San Francisco Estuary's freshwater Delta. Estuaries. 28: 124-137.

SOMMER, T., B. HARRELL, M. NOBRIGA, R. BROWN, P. MOYLE, W.
KIMMERER, and L. SCHEMEL. 2001. California's Yolo Bypass: Evidence that
flood control can be compatible with fisheries, wetlands, wildlife, and agriculture.
Fisheries 26: 6-16.

STACEY, M. T. 2003. Hydrodynamics of shallow water habitats in the Sacramento-San
Joaquin Delta, p. 13. UC Water Resources Center.

SUN, M.-Y., W.-J. CAI, S. B. JOYE, H. DING, J. DAI, and J. T. HOLLIBAUGH. 2002.
Degradation of algal lipids in microcosm sediments with different mixing
regimes. Org. Geochem. 33: 445-459.

TANNER, C.C., J.S. CLAYTON, D.S. WELLS. 1993. Effects of suspended solids on
the establishment and growth of *Egeria densa*. Aquat. Bot. 45: 299-310.

VADEBONCOEUR, Y., M. J. VANDER ZANDEN, and D. M. LODGE. 2002. Putting
the lake back together: reintegrating benthic pathways into lake food web models.
Bioscience 52: 44-54.

VANDER ZANDEN, M. J., and Y. VADEBONCOEUR. 2002. Fishes as integrators of
benthic and pelagic food webs in lakes. Ecology 83: 2152-2161.

VICHKOVITTEN, T., and M. HOLMER. 2004. Contribution of plant carbohydrates to
sedimentary carbon mineralization. Org. Geochem. 35: 1053-1066.

VIDAL, M., and J.-A. MORGUI. 2000. Close and delayed benthic-pelagic coupling in
coastal ecosystems: the role of physical constraints. Hydrobiol. 429: 105-113.

VOLKMAN, J. K. 1986. A review of sterol markers for marine and terrigenous organic
matter. Org. Geochem. 9: 83-99.

WAKEHAM, S.G., and E.A. CANUEL. 1986. Lipid composition of the pelagic crab
Pleuroncodes planipes, its feces, and sinking particulate organic matter in the
Equatorial North Pacific Ocean. Org. Geochem. 9: 331-343.

WAKEHAM, S. G. 1995. Lipid biomarkers for heterotrophic alteration of suspended
particulate organic matter in oxygenated and anoxic water columns of the ocean.
Deep-Sea Res. I. 42: 1749-1771.

ZIMMER. K.D., M.A. HANSON, and M.G. BUTLER. 2003. Interspecies relationships,
community structure, and factors influencing abundance of submerged
macrophytes in prairie wetlands. Wetlands. 23: 717-728.

ZIMMERMAN, A.R., and E.A. CANUEL. 2001. Bulk organic matter and lipid
biomarker composition of the Chesapeake Bay surficial sediments as indicators of
environmental processes. Est. Coast. Shelf Sci. 53: 319-341.

Table 1. Water column characteristics for each study site averaged over the three sampling periods (Oct 1999, Apr 2000, Jul 2000)

Parameters	Franks Tract			Mildred Island		
	FT-1	FT-2	FT-3	MI-1	MI-2	MI-3
Latitude (°W)	38 03.645	38 03.340	38 02.993	38 09.276	38 09.238	38 09.197
Longitude (°N)	121 35.546	121 35.686	121 35.820	121 41.281	121 41.219	121 41.093
Water Depth (m)	7.33 (1.46)[a]	2.70 (0.57)	2.95 (0.78)	4.67 (0.57)	5.00 (0.71)	3.87 (0.81)
Secchi Depth (m)[b]	1.01 (0.05)	1.35 (0.21)	1.61 (0.41)	0.82 (0.19)	0.92 (0.23)	0.73 (0.14)
SPM (mg l^{-1})[b]	12.20 (2.55)	8.20 (2.55)	9.55 (5.02)	10.73 (1.91)	9.65 (0.49)	15.33 (1.86)
chl a (µg l^{-1})[b]	2.07 (0.46)	2.40 (0.71)	2.25 (0.64)	14.53 (10.30)	4.05 (2.62)	3.30 (0.87)
Phaeophytin (µg l^{-1})[b]	2.07 (0.06)	2.35 (0.35)	2.15 (0.35)	6.30 (1.41)	3.05 (1.48)	3.97 (0.51)
POC (mg l^{-1})[b]	0.41 (0.07)	0.32 (0.06)	0.30 (0.04)	0.98 (0.33)	0.44 (0.03)	0.79 (0.03)
PN (mg l^{-1})[b]	0.05 (0.01)	0.04 (0.01)	0.04 (0.01)	0.18 (0.08)	0.06 (0.01)	0.12 (0.01)
C:N$_a$	7.85 (0.96)	7.79 (2.32)	7.88 (2.89)	5.82 (1.04)	7.05 (0.89)	6.69 (0.34)
PROT: CARB ratio	0.31 (0.06)	0.22 (0.04)	0.20 (0.05)	0.30 (0.16)	0.32 (0.13)	0.31 (0.16)

[a] Data are expressed as mean (±standard deviation) across three sampling periods

[b] Data from Sobczak et al. (2005)

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Table 2. Composition of surficial sediments at each study site averged over the three sampling periods
(October 1999, April 2000, July 2000).

Parameters	Franks Tract			Mildred Island		
	FT-1	FT-2	FT-3	MI-1	MI-2	MI-3
TOC (mg g^{-1})	35.19 (2.44)[a]	30.63 (3.68)	29.50 (1.07)	89.19 (3.64)	34.91 (0.45)	58.51 (3.46)
TN (mg g^{-1})	3.14 (0.11)	3.08 (0.28)	2.82 (0.16)	6.08 (0.37)	3.16 (0.15)	4.56 (0.18)
C:N$_a$ Ratio	13.11 (0.92)	11.57 (0.24)	12.37 (0.31)	17.13 (0.19)	12.98 (0.47)	14.82 (0.12)
PROT: CARB ratio	0.26 (0.01)	0.28 (0.03)	0.23 (0.09)	0.53 (0.05)	0.23 (0.04)	0.54 (0.11)

[a] All data expressed as mean (± standard deviation) across three sampling periods

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Table 3. Relative abundance (%) of total fatty acids for POM and SOM in FT and MI. Bold values increased in relative abundance from POM to SOM

SPM		Oct-99	Apr-00			Jul-00			Oct-99		Apr-00			Jul-00		
		FT-1	FT-1	FT-2	FT-3	FT-1	FT-2	FT-3	MI-1	MI-3	MI-1	MI-2	MI-3	MI-1	MI-2	MI-3
SAT	14:0	7.57	5.66	5.43	4.48	8.55	5.83	5.53	8.31	8.40	9.81	6.50	8.06	8.59	8.88	7.97
	15:0	1.88	1.51	1.19	0.93	0.94	0.86	0.91	0.55	0.96	0.93	1.10	1.26	1.29	1.45	1.52
	16:0	22.54	22.55	24.19	24.26	18.66	26.10	23.85	20.70	17.76	18.27	20.15	18.45	21.49	21.01	19.83
	18:0	3.99	3.39	2.77	2.55	2.03	4.81	3.24	2.14	2.48	2.97	3.75	3.83	4.22	4.76	3.40
Terrestrial	LCFA	6.19	7.33	2.27	1.60	2.63	2.74	3.62	0.24	6.69	2.91	5.89	6.63	4.69	7.57	4.15
MONO	16:1ω7	21.75	16.13	13.64	10.98	26.22	20.03	22.87	12.12	18.90	21.74	15.84	18.97	19.39	19.21	16.23
	16:1ω9	1.35	1.40	0.77	0.63	1.11	0.58	0.66	0.58	2.10	0.97	1.11	1.75	1.11	1.35	1.01
	18:1ω9c	10.75	10.75	15.56	17.90	10.82	14.29	13.50	21.00	11.95	9.26	11.80	8.24	9.09	10.99	11.21
	18:1ω9t	2.76	2.38	2.22	2.30	1.54	1.62	1.87	1.55	3.10	1.66	2.39	2.11	2.16	2.30	1.99
PUFA	16:3/2	2.70	4.12	2.87	2.23	4.58	2.15	1.29	1.91	1.56	3.95	4.05	6.09	2.76	2.58	1.58
	18:4	3.32	6.29	10.80	13.45	5.32	4.86	4.97	13.00	4.40	6.21	7.66	4.47	2.29	1.93	2.18
	18:3/2	1.84	2.06	3.09	3.57	2.75	5.28	3.16	2.98	1.82	1.67	3.46	3.05	4.30	3.56	3.62
	20:5ω3	4.69	6.88	7.13	7.18	6.36	4.92	7.90	6.66	7.15	10.27	7.23	7.42	8.54	5.39	12.34
	22:6ω3	0.74	1.34	1.67	2.04	0.71	0.65	1.11	1.78	2.45	2.51	1.69	1.37	1.45	0.76	1.96
Bacterial	BrFA	4.52	3.99	2.36	1.63	2.36	1.50	1.69	1.46	4.04	2.16	2.20	3.66	4.09	3.73	4.69
TFA (µg mg⁻¹ OC)		22.63	18.87	41.54	59.88	17.61	49.85	38.31	167.41	25.58	37.11	26.86	17.11	30.95	20.98	29.48

Sediments		Oct-99	Apr-00			Jul-00			Oct-99		Apr-00			Jul-00		
		FT-1	FT-1	FT-2	FT-3	FT-1	FT-2	FT-3	MI-1	MI-3	MI-1	MI-2	MI-3	MI-1	MI-2	MI-3
SAT	14:0	2.92	2.76	3.05	2.98	2.23	2.72	2.52	1.66	1.73	2.19	2.40	2.11	1.71	2.47	2.02
	15:0	1.35	**1.65**	**1.47**	0.68	**1.04**	**3.10**	**1.27**	**0.74**	0.75	**0.95**	0.95	0.32	0.73	0.91	0.94
	16:0	14.05	12.84	15.26	7.70	9.18	11.82	12.15	7.64	7.77	9.74	10.32	8.70	7.70	10.32	9.85
	18:0	3.62	3.28	**3.30**	1.88	0.25	3.03	3.02	**4.16**	0.47	**4.85**	3.59	**4.02**	4.18	3.82	**4.70**
Terrestrial	LCFA	**17.71**	**29.29**	**24.49**	**35.94**	**52.53**	**33.52**	**36.10**	**57.42**	**58.62**	**46.06**	**40.62**	**46.00**	**55.34**	**47.14**	**52.62**
MONO	16:1ω7	18.18	14.74	**15.30**	13.23	10.51	13.99	13.07	2.43	1.97	7.29	9.88	8.91	4.90	7.39	3.53
	16:1ω9	**3.96**	**4.41**	**4.51**	**2.32**	**2.70**	**2.94**	**3.64**	**5.51**	4.59	**2.66**	**3.45**	**3.81**	**2.23**	**2.94**	0.81
	18:1ω9c	6.34	5.51	6.14	6.95	5.68	4.18	4.83	3.05	3.72	2.06	3.12	2.30	1.69	2.55	1.99
	18:1ω9t	**4.45**	**3.80**	**4.24**	**3.65**	**2.67**	**2.72**	**3.62**	**1.66**	1.53	0.25	0.34	0.29	0.29	0.32	0.27
PUFA	16:3/2	**3.10**	2.62	2.70	**2.81**	1.58	**3.47**	**2.56**	1.20	1.08	1.58	1.77	1.41	1.18	1.61	1.36
	18:4	0.28	0.24	0.22	0.15	0.17	0.27	0.87	0.17	0.14	0.55	0.65	0.49	0.34	0.48	0.37
	18:3/2	**3.43**	2.00	2.80	0.94	0.77	2.06	1.72	2.62	**5.39**	**5.28**	**6.27**	**4.11**	4.08	3.54	**5.97**
	20:5ω3	3.62	1.49	2.21	1.15	0.82	2.78	1.71	0.44	0.47	0.95	0.93	0.66	0.48	0.74	0.57
	22:6ω3	**1.07**	0.22	0.33	**3.62**	0.09	0.40	0.30	0.10	0.12	0.20	0.26	0.12	0.10	0.12	0.08
Bacterial	BrFAs	**6.69**	**7.19**	**4.97**	**5.95**	**5.84**	**6.55**	**6.48**	**5.19**	**5.07**	**8.12**	**9.00**	**9.03**	**7.85**	**9.04**	**8.23**
TFA (µg mg⁻¹ OC)		5.19	4.31	5.55	4.24	3.41	3.26	3.70	1.56	2.55	1.15	5.72	2.99	1.41	2.85	1.11

Table 4. Relative abundances (% total concentration) of dominant fatty acids and sterols from two emergent and three submerged macrophytes. Standard deviations indicate replicate analyses of plant samples.

	Emergent	Submerged		
	Common Tule *Scirpus acutus*	Brazilian Waterweed *Egeria densa*	Eurasian Watermilfoil *Myriophyllum spicatum*	Water Hyacinth *Eichhornia crassipes*
Fatty Acids				
16:1ω7	0.64	5.95 (0.53)	7.85 (3.86)	0.45
16:0	42.15	44.20 (17.74)	21.3 (4.89)	38.41
18:3	26.91	25.37 (14.19)	32.28 (2.02)	29.69
18:2	9.69	12.72 (6.80)	23.97 (3.44)	23.95
20:5ω3	0.00	1.07 (0.95)	3.63 (3.30)	0.22
LCFA	10.56	6.55 (0.57)	2.58 (0.61)	2.92
Sterols				
24-ethylcholest-5-en-3β-ol	91.17	54.31 (4.60)	25.74 (5.56)	26.50
24-ethylcholest-5,22-dien-3β-ol	1.35	34.24 (5.17)	36.08 (12.20)	51.60
24-methylcholest-5-en-3β-ol	7.48	6.38 (0.95)	14.39 (5.08)	10.45
C:N$_a$ ratio	28.69	10.87	N/A	10.48
Total fatty acids (mg g^{-1})	1.47	4.81 (0.60)	10.64 (0.78)	10.92
Total sterols (mg g^{-1})	0.84	0.73 (0.07)	1.08 (0.36)	1.16

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Table 5. Differences in the abundance of organic carbon fractions between POM and SOM collected from FT and MI. Values are expressed as percentages of initial amount of organic carbon in POM. Italicized values represent standard deviations.

		PROT-C	CARB-C	TLE-C	TFA	SAT	MONO	PUFA	BrFA	CHOL	DIAT	C_{29}
Subsite Means	FT-1	-52.80	-50.28	-62.53	-82.39	-71.21	-81.13	-89.72	-66.41	-91.57	-78.95	-52.32
		12.15	*14.47*	*6.06*	*2.03*	*3.49*	*5.16*	*4.89*	*7.00*	*2.96*	*14.91*	*9.20*
	FT-2	-42.44	-55.14	-67.40	-90.05	-84.07	-92.36	-96.63	-71.60	-89.28	-86.85	-40.98
		11.39	*3.71*	*11.58*	*4.82*	*11.59*	*2.85*	*1.13*	*0.31*	*4.22*	*10.47*	*20.02*
	FT-3	-45.75	-38.48	-70.96	-91.63	-87.88	-93.48	-95.44	-68.57	-91.10	-90.48	-70.52
		28.85	*42.40*	*4.14*	*1.82*	*1.09*	*0.86*	*2.69*	*7.96*	*7.26*	*10.24*	*3.97*
Site Mean	FT	-43.52	-40.83	-65.40	-85.46	-79.65	-87.87	-92.50	-65.35	-90.78	-84.50	-54.28
		14.56	*21.76*	*7.86*	*7.15*	*9.56*	*7.09*	*5.39*	*7.96*	*3.97*	*11.79*	*15.70*
Subsite Means	MI-1	-42.20	-69.29	-86.32	-97.13	-94.84	-98.81	-98.95	-92.16	-96.75	-92.11	-88.79
		9.72	*10.65*	*2.95*	*1.83*	*2.93*	*0.74*	*0.80*	*4.41*	*3.02*	*7.38*	*1.21*
	MI-2	-33.83	-35.52	-77.29	-82.56	-73.55	-90.50	-91.52	-40.04	-92.23	-88.29	-64.01
		2.25	*42.54*	*3.04*	*5.47*	*9.12*	*4.75*	*1.63*	*38.30*	*2.57*	*4.99*	*7.72*
	MI-3	-26.46	-45.87	-65.17	-89.06	-81.83	-94.73	-96.79	-80.98	-95.48	-91.10	-76.43
		18.21	*9.00*	*16.63*	*6.10*	*10.44*	*4.91*	*2.61*	*20.99*	*3.13*	*9.12*	*17.60*
Site Mean	MI	-34.20	-52.07	-76.13	-90.46	-84.64	-95.20	-96.29	-74.94	-95.15	-90.78	-77.96
		13.25	*23.15*	*13.39*	*7.32*	*11.34*	*4.71*	*3.48*	*28.84*	*3.15*	*6.75*	*14.30*

PROT-C = protein-C, CARB-C = carbohydrate-C, TLE-C = lipid-C, TFA = total fatty acids, SAT = saturated fatty acids, MONO = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids, BrFA = branched fatty acids, CHOL = cholesterol, DIAT = diatom sterols, C_{29} = C_{29} sterols

Fig. 1. (a) Map of the Sacramento-San Joaquin River Delta, indicating locations of the

two shallow-water habitat sites, Franks Tract (FT) and Mildred Island (MI). Detailed

maps of Franks Tract (b) and Mildred island (c) indicating three sub-sampling sites

within each.

(A)

38°12'0"N

38°0'0"N

(B)

(C)

121°48'0"W

121°36'0"W

121°24'0"W

FT-1
FT-2
FT-3

MI-2
MI-3
MI-1
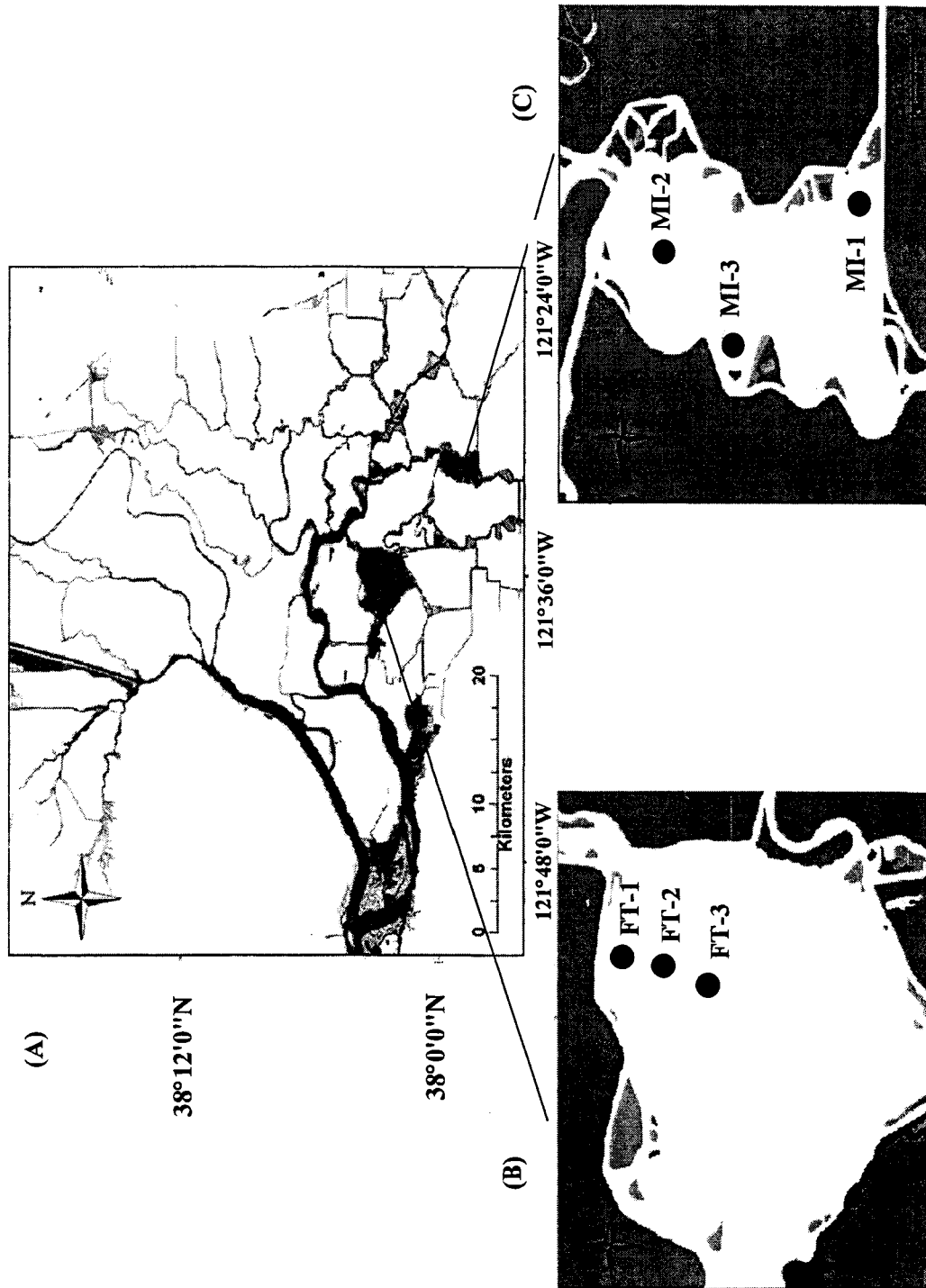
Fig. 2. Biochemical composition of POM and SOM at FT and MI, expressed relative to organic carbon (μg mg OC^{-1}). (a)-(b): total proteins; (c)-(d) total carbohydrates; (e)-(f) total lipid extract (TLE). Note scale differences for SPM and sediment data.

POM

SOM
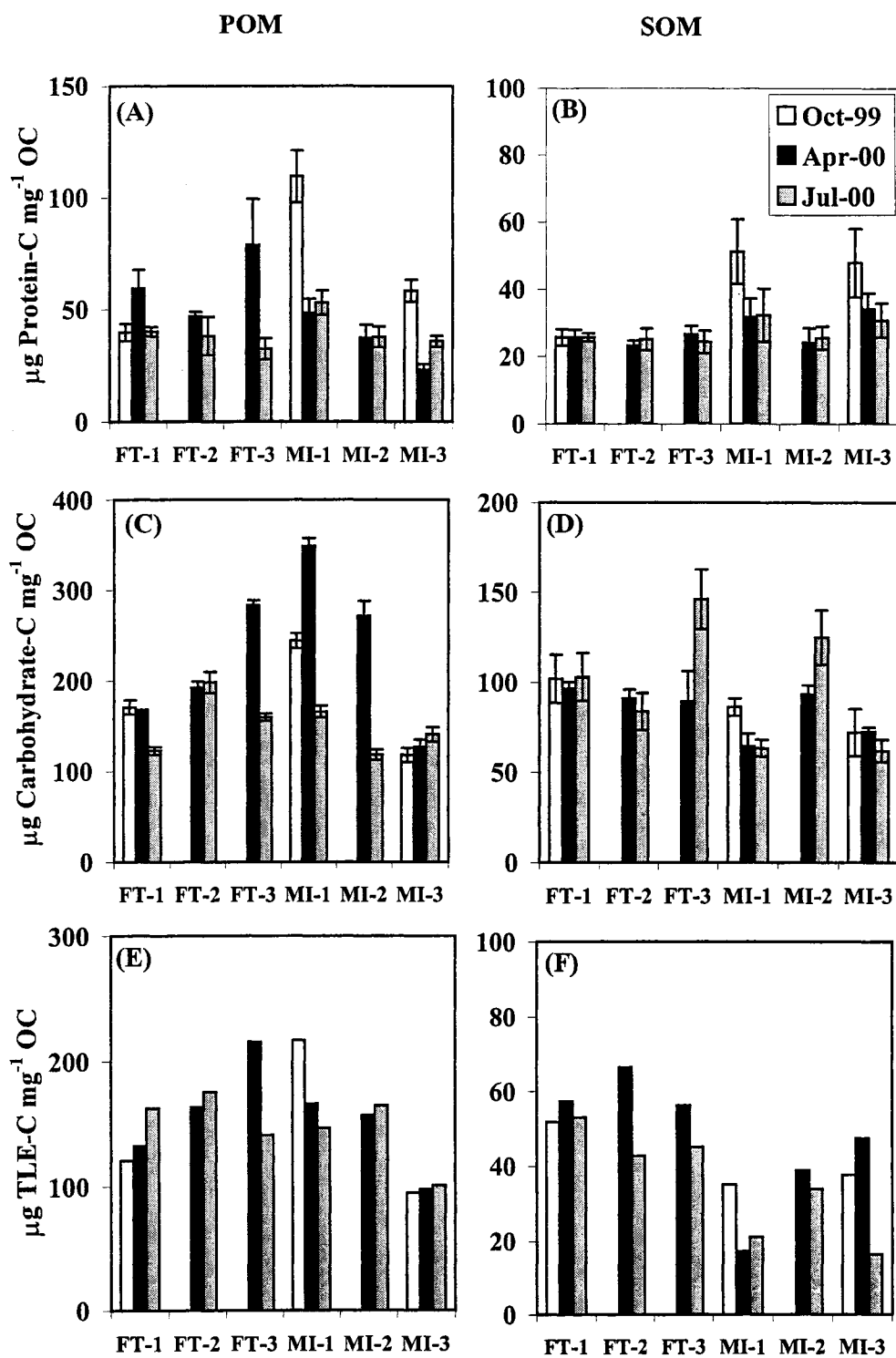
Fig. 3. Sterol biomarkers associated with POM and SOM collected FT and MI: (a)-(b)

diatom sterols, (c)-(d) cholesterol, and (e)-(f) C_{29} sterol expressed as $\mu g\ mg^{-1}$ OC.

Diatom sterols: 24-methylcholesta-5,22-dien-3β-ol (brassicasterol) + 24 methylcholesta-

5,24(28)-dien-3β-ol (24-methylenecholesterol). Cholesterol: cholest-5-en-3β-ol. C_{29}

sterols: 24-ethylcholesta-5,22-dien-3β-ol (stigmasterol) + 24-ethylcholest-5-en-3β-ol (β-

sitosterol). Note scale differences for POM and SOM.

POM   SOM
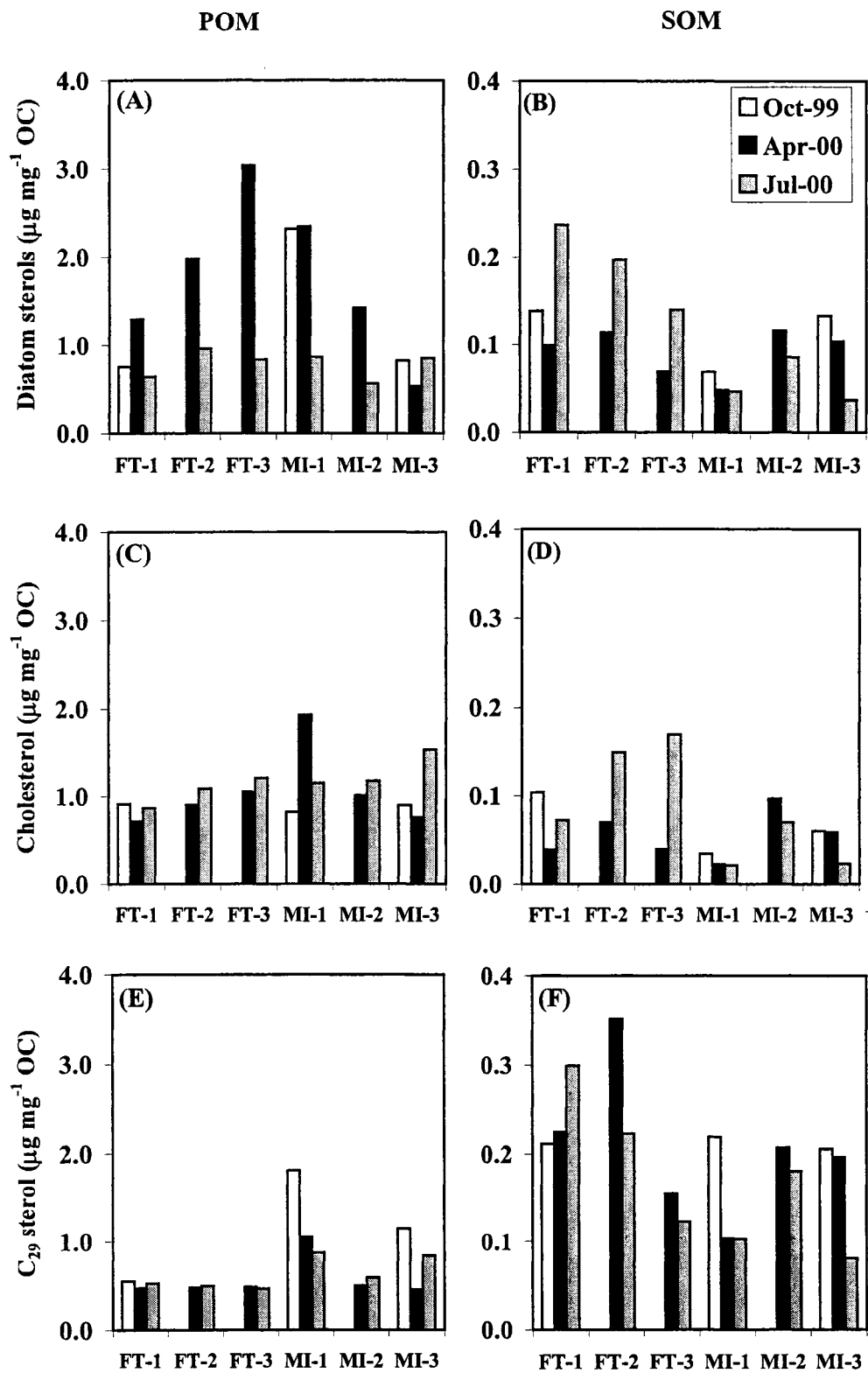
Fig. 4. Stanol/stenol ratios, (a) 5α(H)-cholest-22-en-3β-ol: cholest-5,22-dien-3β-ol; (b)

24-ethyl-5α(H)-cholest-3β-ol: 24-ethylcholest-5-en-3β-ol from POM and SOM of FT

and MT during the sampling periods (October 1999-July-2000).
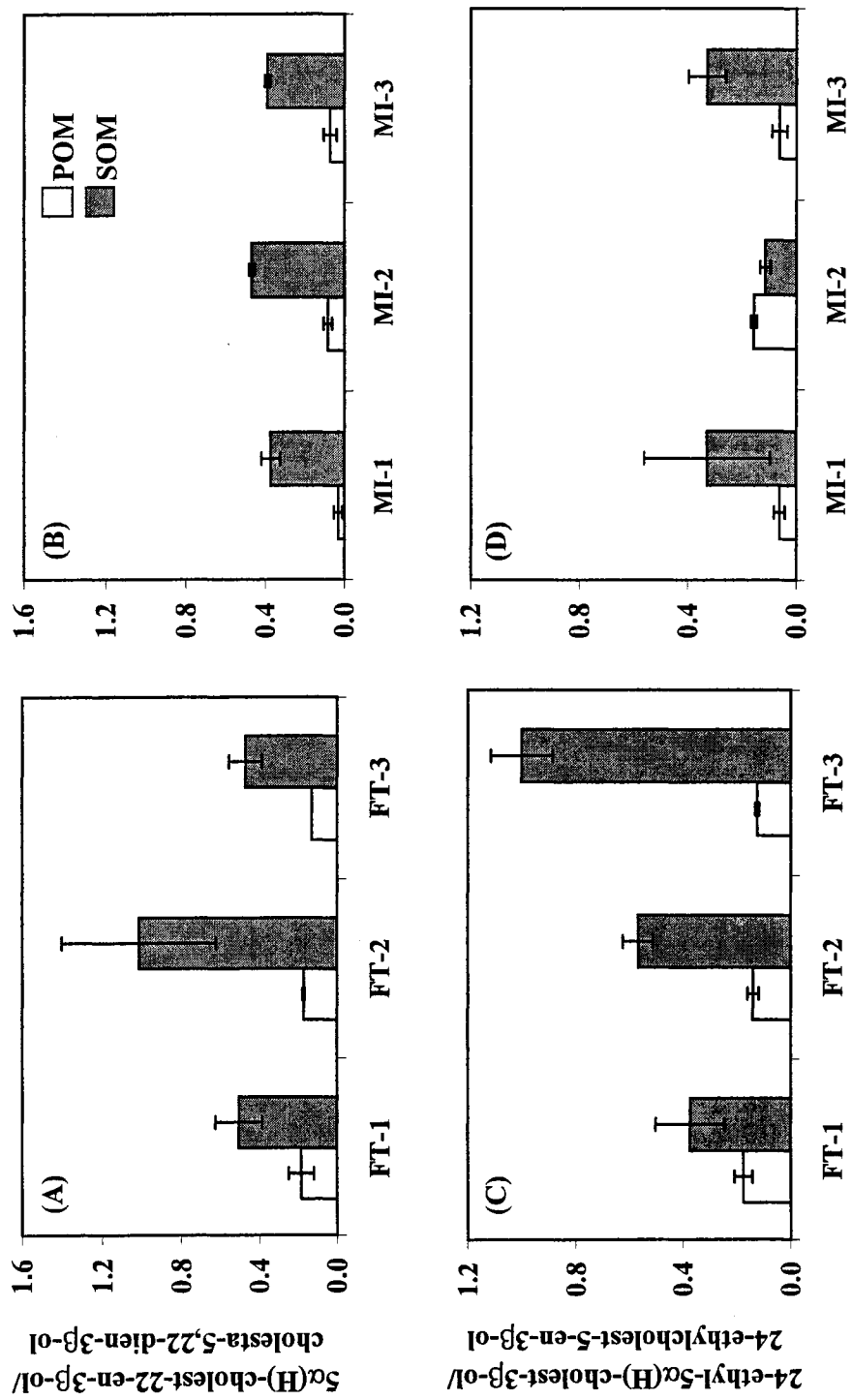
Fig. 5. Difference between sediment TOC and water column POC (TOC (mg g^{-1}) – POC (mg g^{-1} TSS)) for samples collected from (a) FT and (b) MI. Values greater than zero indicate accumulation of organic carbon in surface sediments while values less than zero indicate water column removal. Note the differences in scale.

(A)

Accumulation in
Sediments

Water Column
Removal

Oct-99
Apr-00
Jul-00

FT-1   FT-2   FT-3

(B)

MI-1   MI-2   MI-3
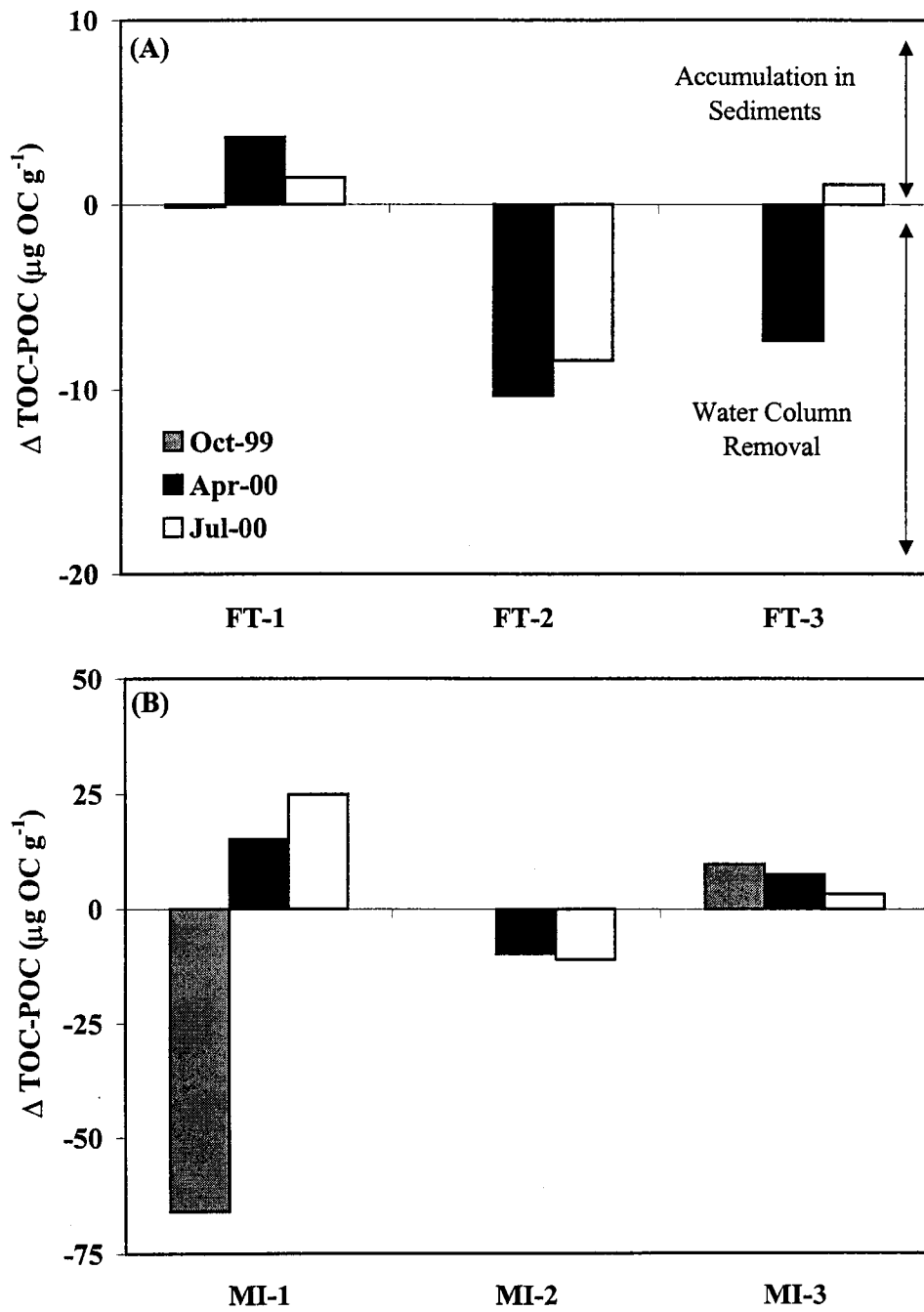
CHAPTER 5

SPATIAL VARIABILITY IN AMINO ACID COMPOSITION AND ORGANIC
MATTER DEGRADATION OF SUSPENDED PARTICLES AND SEDIMENTS IN
THE SACRAMENTO-SAN JOAQUIN RIVER DELTA, CA

ABSTRACT

Amino acids make up a significant fraction of organic nitrogen and organic carbon pools in estuaries and coastal regions. We measured total hydrolysable amino acids and individual protein and non-protein amino acids to determine spatial differences in organic matter compositon/degradation state in the Sacramento-San Joaquin River Delta. Particulate organic matter (POM) and sediment organic matter (SOM) from ten sites were collected during eight cruises between January 1999 and July 2000 representing the Sacramento and San Joaquin Rivers, shallow-water habitats, tidal marshes and open bay environments. Concentrations of total hydrolysable amino acids, as well %THAA-C and %THAA-N in POM and SOM indicated that POM from shallow-water habitats was less degraded than river sites, whereas tidal marsh and open bay sites exhibited intermediate degradation states. SOM had significantly lower amino acid concentrations at all sites compared to POM, indicating removal prior to sediment deposition. Dominant amino acids in both fractions were glycine, alanine, aspartic acid and glutamic acid, although SOM were enriched in glycine, alanine, serine, threonine and non-protein amino acids relative to POM. Other measures of POM degradation, including %non-protein amino acids, ratios of protein/non-protein amino acids, and degradation indices based on principal components analysis indicated that organic matter in the shallow-water sites was consistently less degraded than that found in riverine environments. Amino acids were correlated to biochemical and lipid biomarker measures of organic matter quality, indicating general agreement across different measures of organic matter degradation state in estimating the labile fraction for secondary producers in the Delta.

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INTRODUCTION

Estuaries receive significant amounts of organic matter (OM) from river discharge and runoff, in addition to in situ production. The study of the sources, transformation and regeneration pathways of OM in estuaries and coastal regions is important for understanding the global carbon budget (Hedges and Keil 1995, 1999) and nutrient dynamics. Small and mid-sized rivers play a vital role in biogeochemical cycles along the estuary-coastal ocean continuum, as they can carry a sediment load one to two orders of magnitude larger than that of major river systems (Cauwet et al. 1990).

Nitrogen is an important component of organic matter entering estuaries through natural and anthropogenic sources. The nitrogen cycle, incorporating organic and inorganic forms of nitrogen, plays an important role in aquatic systems, affecting the production of plants, algae and bacteria (Ryther and Dunstan 1971; Vitousek and Howarth 1991). Between 10-80% of riverine nitrogen is in the form of dissolved organic nitrogen (DON) (Meybeck 1982; Seitzinger and Sanders 1995; Perakis and Hedin 2002), with a lesser fraction attributed to particulate organic nitrogen (PON). Amino acids, including proteins, polypeptides, and combined and free amino acids, are the major classes of characterizable organic nitrogen (Parson et al. 1977), and essential components of living organisms (Lehninger 1972). Amino acids form part of the labile constituents of riverine and estuarine organic matter (Degens 1982).

The distribution of amino acids in aquatic habitats provides information on the sources and the degradation pathways of organic matter in the aquatic environment (Degens and Mopper 1976; Lee and Cronin 1984; Ittekot and Arain 1986; Cowie and Hedges 1992a; Dauwe and Middelburg 1998). Sub-fractions of POM in rivers and estuaries are degraded at different rates, and the loss of labile compounds alters the biochemical composition of POM (Tegelaar et al. 1989; Cowie and Hedges 1994) and reduces its nutritional value (Tenore et al. 1984). Amino acids are generally degraded faster than nitrogen-poor compounds, such as lipids (Wakeham et al. 1997). As a result, amino acids provide a useful class of compounds for studying the labile fraction of OM.

Previous studies have employed a suite of diagenetic indicators of POM, including bulk measurements such as C/N ratios, chlorophyll a (for short-term changes in

diagenetic status), to non-protein amino acids, which indicate diagenetic changes over a longer time scale (Cowie and Hedges 1994; Wakeham et al. 1997). Previously, the use of degradation indices based on principal components analysis (Dauwe and Middelburg 1998; Dauwe et al. 1999) have been employed in a variety of habitats including open ocean (Ingalls et al. 2003), coastal (Grutters et al. 2001; Pantoja and Lee 2003), and lake environments (Meckler et al. 2004).

The Sacramento-San Joaquin River Delta (Delta, hereafter) is a complex series of river, tidal marsh, and shallow-water habitats that delivers 90% of the freshwater input to San Francisco Bay. The Delta is characterized by extremely low productivity (Jassby et al. 2002), and hence food limitation to upper trophic levels (Muller-Solger et al. 2002). Previous work by Sobczak et al. (2002, 2005) indicated that while 70-95% of organic carbon within the Delta is in the dissolved form (DOC), particulate organic carbon (POC) was the more bioavailable fraction, and POC bioavailability was controlled by the proportion of phytoplankton biomass. Therefore, Delta habitats that support higher phytoplankton levels such as marsh sloughs and shallow-water lakes may have more bioavailable POC than other habitat types, such as rivers. Studies of amino acid composition and the degradation state of particulate organic matter has generally focused on marine environments (Dauwe and Middelburg 1998; Jennerjahn and Ittekot 1999; Pantoja et al. 2004), and less on freshwater and estuarine systems, and their diverse sub-habitats. Our goal in the present study was to compare amino acid composition and degradation at ten sites across multiple sub-habitat types in the Delta including riverine, natural tidal marsh and restored shallow-water sites. We examined total hydrolysable amino acids and individual protein and non-protein amino acids in sub-habitats of the Delta. In particular we used amino acid composition, ratios based on protein and non-protein amino acids, to develop degradation indices for POM and SOM to determine patterns in organic matter degradation state among habitat types. In addition, we compared amino acid indices of OM degradation state to other measures such as lipid biomarkers. Characterizing habitats in terms of POM degradation state will aid in predicting whether POM produced within sub-habitats can be utilized by microorganisms as well as secondary producers such as zooplankton in this low-productivity system.

METHODS

Sampling sites

Our sampling design parallels that outlined in Sobczak et al. (2002, 2005). Upstream sites Hood (HD) and Mossdale Marina (MM) were selected to represent inputs from the northern Sacramento River and southern San Joaquin River drainage basins, respectively (Fig. 1). Rio Vista (RV) on the lower Sacramento River was selected as a deep-channel site, integrating inputs from the northern Delta. Twitchell Island (TI) on the lower San Joaquin River was originally selected to represent lower San Joaquin inputs, but was later found to be influenced by both Sacramento and San Joaquin waters, thereby representing a "confluence" of river waters (Monsen 2001). Little Holland Tract (LH) in the northern Delta, and Franks Tract (FT) and Mildred Island (MI) in the southern Delta were chosen to represent restored shallow-water sites of varying ages and influence from each of the major rivers. Clifton Court Forebay (CC) in the Southern Delta is a site that receives a mix of Sacramento and San Joaquin River waters, as well as agricultural drainage that is exported to Southern California via the Delta-Mendota and California Aqueducts. Cutoff Slough (CS), located in Suisun Marsh, represents a natural, undisturbed *Scirpus acutus* marsh, the ancestral condition of much of the Delta. X2 represents the estuarine turbidity maximum, or the confluence of export from the Delta and the adjacent northern San Francisco Bay estuary. It is operationally defined as the location where bottom salinity is 2 psu, and can be located from upstream of Chipps Island to west of Suisun Bay (Kimmerer and Schubel 1994). The site is generally correlated with high concentrations of phytoplankton, zooplankton, benthic invertebrates, and larval and adult fish of several species (Jassby et al. 1995). Suspended particle-characteristics at each of these sites are well-characterized in terms of bulk parameters (Sobczak et al. 2005, Table 1), DOC, POC and lipid biomarkers (previous chapters, except for CC, CS and X2).

Field Sampling

POM and SOM samples were collected during eight cruises in January, February, May, July and October 1999; and February, April and July 2000. These time periods were chosen to represent different physical and biological conditions (high/low river

flow, spring larval fish recruitment, phytoplankton blooms) contributing to variability in organic matter composition. For POM samples, water was collected from each site at a depth of 1 m above bottom, and pre-filtered through 100 micron mesh to eliminate larger zooplankton. For amino acid analyses, 100-2500 ml was subsequently filtered through pre-combusted (450°C, 4 hours) 42 mm diameter Gelman glass fiber filters (1 μm nominal pore size) under low vacuum. Sediment samples for SOM analyses were collected concurrently using a bottom grab, and sediments (0-0.5 cm) was removed representing recent accumulation. POM and SOM samples were stored immediately on dry ice in the field and transferred to a -80°C freezer for long-term storage in the lab. At each site, duplicate samples were generally collected from one location, except for MI and FT, where samples were collected at n=3 sites in April 2000 and July 2000. Bulk parameters were collected at n=3 sites.

Additional water samples were collected for chlorophyll *a* (chl *a*) and suspended particulate matter (SPM) following standard methods (see methods in Lucas et al. 2002). Separate water samples were filtered onto GF/F filters for particulate organic carbon and nitrogen (POC and PN). Chl *a*, phaeophytin, SPM, POC and PN analyses were conducted at the U.S. Geological Survey in Menlo Park, CA (Sobczak et al. 2005). Sediment total organic carbon (TOC) and total nitrogen (TN) content was determined after acidification of replicate dry sediment samples (Hedges and Stern 1984). TOC and TN concentrations were analyzed using a Fisons Instruments Model EA1108 CNS-O elemental analyzer.

Total Hydrolyzable Amino Acids (THAA)

THAA were analyzed using a modified version of methods outlined in Cowie and Hedges (1992b) for analysis of POM and SOM samples. Briefly, POM samples collected on pre-combusted (450°C, 4 hours) GF/F filters, or 0.1-100 mg sediment (depending on known organic carbon content), were transferred to 8-ml glass vials. A charged-matched recovery standard mixture was added to each vial (200 μl of a 25 μM mixture) the day prior to hydrolysis and samples were dried in a vacuum dessicator overnight. This standard, composed of neutral (γ-methylleucine), acidic (α-aminoadipic acid), basic (δ-hydroxylysine) and intermediate (1-methylhistidine) amino acids, allows losses of _

specific charge groups via adsorption and hydrolysis to be quantified (Cowie and Hedges 1992b). Vials were transferred to a N_2-filled collapsible-frame glove bag. For hydrolysis, 2.0 ml of degassed 6N HCl was added to each vial; samples were flushed with N_2 and sealed with Teflon-lined caps. Vials were then placed in a heating block and maintained at 150 °C under a plexiglass shield within the glove bag for 70 min. Vials were then removed and cooled in an ice bath. Unopened vials were centrifuged for 10 min at 2500 rev/min and the supernatant was transferred to 10-ml glass culture tubes. Samples were then dried in a centrifuge evaporator, redissolved in 50 μl of distilled water followed by a second rapid evaporation to allow for complete acid and moisture removal. Residue was then dissolved in 2 ml of distilled water and filtered into 2 ml HPLC vials using 0.45 μm Gelman syringe filters (low protein binding).

Prior to high performance liquid chromatography (HPLC) analysis, each vial was spiked with a known volume of 1 μM o-methylthreonine immediately before chromatography, which was used as an absolute recovery standard. Pre-column derivatization of amino acids with o-phthaldialdehyde reagent (100 mg o-pthaldialdehyde, 1 ml MeOH, 100 μl mercaptoethanol, 1.0 M boric acid adjusted to pH 10.5 with KOH) was then used to form fluorescent derivatives of the amino acids (Lindroth and Mopper 1979). The HPLC system was composed of a Rheodyne syringe loading sample injector, and a dual pump Rainin HPLC with a Shimazdu RF-530 fluorescence detector. A heated (30 °C) reverse-phase Alltech Adsorbosphere C_{18} column with C_{18} guard inserts and a binary solvent system were used to separate amino acids during a 40 minute run. The binary solvent system consisted of sodium acetate buffer (8.2 g sodium acetate into 2L distilled water, adjusted to pH 6.8 with 200-300 μl acetic acid, 3.5 ml tetrahydrofuran), and HPLC-grade methanol. Amino acids were detected at 340 nm, with an emission wavelength of 450 nm.

A standard composed of seventeen amino acids (Pierce Amino Acid Standard H) and the charged-matched standards was run after every 5th sample to calculate response factors of amino acids relative to standards in the charge group. This method does not allow for the determination of cysteine, proline, or tryptophan (Lindroth and Mopper 1979, Cowie and Hedges 1992b). All samples were analyzed in duplicate, and individual amino acids were calculated from peak areas. Analytical precision was typically ±7% for

total amino acid yields, ±7% for neutral and acidic amino acid groups, and ±9% for basic and intermediate amino acids. Non-protein amino acids such as β-alanine, γ-aminobutyric acid, and ornithine were detected with lower precision (±12%).

The list of abbreviations of amino acids is as follows: aspartic acid (Asp), glutamic acid (Glu), serine (Ser), histidine (His), glycine (Gly), threonine (Thr), arginine (Arg), β-alanine (β-ALA), alanine (ALA), tyrosine (Tyr), γ-aminobutyric acid (g-ABA), methionine (Met), valine (Val), phenylalanine (Phe), isoleucine (Ile), leucine (Leu), ornithine (Orn), and lysine (Lys).

Statistical Analyses

Data were analyzed statistically using MiniTab (Minitab Inc.: release 13.32, 2003). Within Minitab, the General Linear Model analysis of variance (ANOVA) was used to analyze between site-differences in amino acid abundance and composition (%mole, %THAA-C, %THAA-N), by habitat type. Significant results were indicated if $p < 0.05$. The Fisher's least significant squares (Fisher's LSD) was employed to test the differences of means, after rejecting the null hypothesis using ANOVA. All data were log-transformed prior to data analysis to minimize effects from outliers. The interdependence of variables was tested using the Pearson Product Moment Correlation and coefficient (calculated using Minitab) to measure the degree of linear relationship. Specifically, the relationships between amino acids and chl *a*, protein and lipid biomarkers were examined.

RESULTS AND DISCUSSION

Total Hydrolyzable Amino Acids

THAA concentrations associated with Delta POM averaged 2.15±0.73 mg g TSS^{-1} (Fig.2), with the exception of MI, which averaged 10.02±7.91 mg g TSS^{-1}. The percentage of total organic carbon represented by total hydrolysable amino acids (%THAA-C) and the percent of total nitrogen present as THAA (%THAA-N), which are inversely related to diagenetic state (Cowie and Hedges 1994), were similar in POM among sites (Fig. 3). Ranges in %THAA-C and %THAA-N in POM overlapped among Delta habitats (2-26% and 15-94%, respectively). Cowie and Hedges (1992a) indicated that the %THAA-N values in all phytoplankton, zooplankton, bacteria and macrophytes were higher than 38%, while values of %THAA-N for woody vascular plant of %THAA-N were generally below 38%. %THAA-N is considered to be diagenetically sensitive, with lower values indicative of increased degradation of POM (Cowie and Hedges 1992a). The range %THAA-N of most Delta habitats was above 38%, although it did fall below 38% at sites during some time periods (Fig. 3). TI, the lower San Joaquin river site that receives both Sacramento and San Joaquin River flows, fell below 38% in January, February and May 1999. This reflects the degraded material that characterizes downstream river sites (Ittekot and Laane 1991). Previous studies have indicated that primary production in the Delta is dominated by phytoplankton rather than macrophytes or benthic microalgae (Jassby and Cloern 2000), but that this production is significantly lower than in most estuaries (Cloern 2001). Most Delta habitats are characterized by low chlorophyll concentrations (Table 1, Sobczak et al. 2005) and low phytoplankton concentrations (Jassby et al. 2002). Higher THAAs in POM and SOM were found at sites with higher chlorophyll (Table 1, Fig. 2), and a correlation between THAA and chl *a* (Table 2) indicates that phytoplankton are likely the dominant source of amino acids in the Delta.

SOM in the Delta exhibited similar patterns for THAA, although average concentrations were lower than for POM. River sediment were primarily coarse-grained with low C and N concentrations and generally high C/N ratios (Table 2). THAA in these sediments averaged 0.23±0.11 mg g^{-1} (Fig. 2). Decreased amino acid concentrations in the water column relative to the sediments have been observed in other

aquatic systems (Cowie and Hedges 1992; Sigleo and Schultz 1993; Lee et al 2000) and is likely due to several factors. Observed patterns may reflect the utilization of amino acids by pelagic organisms such as zooplankton, as well as utilization by sediment bacteria and benthic animals (Sigleo and Shultz 1993; Unger et al. 2005). Differences between POM and SOM amino acids may be caused by the selective removal of labile components by zooplankton/grazers, water column removal via fecal pellets and finer particles in the POM may be exposed to further degradation by bacteria (Unger et al. 2005). Lower concentrations of amino acids in SOM may also be the result of degradation at the sediment-water interface and a dilution by terrestrial amino acids which are poor in nitrogenous compounds (Jennerjahn et al. 2004). Previous studies of lipid biomarkers in SOM indicated a relative increase in terrestrial plant material in SOM, as evidenced by enrichments in long-chained fatty acids (Chapter 4). .

Sites with fine-grained sediments, including FT, MI and CS, had higher THAA concentrations, averaging 3.80 ± 2.29 mg g^{-1}. Between-site differences in THAA concentrations reflected both nitrogen concentrations ($r=0.79$), as well as sediment grain size. Sediments that have higher organic content and finer grain size (silts to clays) have a higher capacity for adsorption than coarser grained sediments (Ding and Henrichs 2002; Keil et al. 1998; Wang and Lee 1993). SOM also exhibited differences in the %THAA-C and %THAA-N (Fig. 3). The SOM at shallow-water habitat (SWH) sites (FT, LH and MI), tidal marsh (CS) and X2 exhibited a higher percentage of THAA-C than river SOM. Median THAA-N values were also higher at SWH (MI,FT), CS and X2. These observations are consistent with higher chl a indicating higher contributions from phytoplankton (Müller–Solger et al. 2002; Sobczak et al. 2002, 2005). Despite lower THAA concentrations in SOM at X2 (Fig.2), higher %THAA-C and %THAA-N suggests that fresher material reaches sediments at this site, albeit a small fraction (Fig. 3) The position of X2 changes (Fig.1), and periods when fresher material was delivered to X2 sediments coincided with X2 positioned seaward, in the western region of Suisun Bay. X2 is closely correlated with higher concentrations of phytoplankton, zooplankton and various larval and adult fish species (Jassby et al. 1995), suggesting a portion of this organic material likely reaches sediments.

% Mole Composition

The relative composition of amino acids change during early diagenesis of organic matter, allowing amino acid composition to be used as a proxy for the degradation state of OM (Ittekot et al 1984, Cowie and Hedges 1994, Chen et al. 1999). In the Delta, the composition of THAAs in POM was relatively uniform among sites (Table 3). The dominant amino acids in POM, in descending order, were Gly, Ala, Asp, Glu, Val, Ser, Thr, and Ile, each having a mole% of >5%. In general, the dominant amino acid composition is similar to that found in other coastal (Degens and Mopper 1979; Cowie and Hedges 1992a) and estuarine systems (Sigleo and Shutlz 1993; Unger et al. 2005). Despite similarities in the composition of amino acids between sites, some amino acids showed large variations in their mole percentages among habitat types. Mole percentages of Asp and Glu in POM were significantly lower at river sites ($p \leq 0.05$, Table 3) compared to shallow water sites FT and MI, whereas Gly, β-ALA, g-ABA and ornithine showed an opposite pattern, with higher values in the rivers ($p < 0.05$, Table 3). Higher amounts of glycine are generally indicative of an advanced state of decay (Kerner and Yasseri 1997, Dauwe and Middelburg 1998), while Glu is a significant component of intracellular protein, and decreased mol% Glu may indicate removal of labile cytoplasmic material relative to more refractory cell wall components. Differences in percent mole composition of between river and shallow-water sites may be due to differences in sources of POM. River sites receive more degraded terrestrial material from upstream, while shallow-water sites are subject to phytoplankton and macroalgal blooms. At river sites (HD, RV, MM and TI), non-protein amino acids comprised >2% of THAA, also indicative of the advanced degradation state of riverine OM, with smaller percentages at other Delta sites. In comparison, , non-protein AAs comprise <2% of THAA in the Potomac and Delaware estuaries (Sigleo and Shultz 1993, Mannino and Harvey 2000).

Amino acid composition in SOM differed from that of POM (Table 3). Delta SOM was characterized by higher percentages of Gly, Ala, Ser and Thr, and significantly lower abundances of Asp and Glu relative to POM. Asp and Glu are among the most labile amino acids, and are rapidly lost during degradation (Kerner and Yasseri 1997). Enrichment in Gly, Ser and Thr during degradation has been observed in several studies

of POM (Siezen and Mague 1978, Unger et al. 2005) and SOM (Burdige and Martens 1988, Dauwe et al. 1999, Pantoja and Lee 2003). Gly, Ser and Thr are enriched in cell walls of diatoms (Hecky et al. 1973, Siezen and Mague 1978). Therefore, SOM enrichment of these compounds is generally ascribed to the preferential preservation of these amino acids in the matrix of diatom cell walls, which generally possess varying degrees of resistance to degradation (Nguyen and Harvey 2003). Enrichments of Gly in SOM may also be due to production of bacterial biomass within sediments (Sigleo and Shultz 1993). Higher Gly, Ser and Thr abundances in sediment collected from shallow-water habitat sites (MI, FT), which were characterized by lower concentrations in SPM, may reflect the settling of diatoms known to be abundant at the sites (Sobczak et al. 2005). Enrichment in alanine may occur because it is the breakdown product of more complex amino acids, or because it accumulates as a residual (Macko and Estep 1983). Non-protein amino acids also increased in SOM (Table 3), indicative of the greater degree of degradation for sediment OC than SPM (Lee and Cronin 1982, Cowie and Hedges 1994).

Based on mole% composition, amino acid functional groups of POM and SOM were relatively invariant across Delta habitats (Fig. 4). On average, neutral amino acids dominated (50-52%), followed by acidic (17-22%), hydroxyl (16-18%), basic (7-10%) and aromatic groups (4-7%) (Fig. 4). Generally, acidic amino acids are preferentially remineralized (Sigleo and Shultz 1993). Similar amounts of acidic and neutral amino acids are indicative of relatively intact plankton protein, whereas a greater proportion of neutral amino acids is indicative of degraded material (Sigleo and Shultz 1993). The percentages of these functional groups found in the Delta are in agreement with other studies of coastal environments (Burdige and Martens 1988), although Mannino and Harvey (2000) found higher percentages of hydroxyl amino acids relative to acidic amino acids. Dittmar et al. (2001) found that the mole composition of amino acids was similar across a diverse array of habitats, including river, nearshore, surface, halocline, and deepwater ocean sites (neutral at 50%, acidic at 20%, hydroxyl at 20%, basic and aromatic at >10%). The composition of the POM based on functional groups was statistically similar to SOM, although a small decrease in acidic amino acids in SOM was evident (Fig. 4). Diagenesis usually results in decreases in acidic and aromatic amino

acids (Brown et al. 1972; Burdige and Martens 1988). Similar proportions of basic amino acids between the two substrates was surprising as studies of other estuarine systems have demonstrated increases in basic amino acids in SOM (Sigleo and Shultz 1993; Henrichs and Sugai 1993; Pantoja and Lee 2003). Basic amino acids become relatively enriched during decomposition (Parson and Tinsley 1975), as they adsorb easily onto mineral surfaces (Hedges and Hare 1987; Henrichs and Sugai 1993; Wang and Lee 1993) and are thus less susceptible to microbial degradation (Schuster et al. 1998).

Degradation Indices of POM

A number of degradation indices based on amino acid composition have been utilized to assess POM (Fig. 5). Non-protein amino acids β-ALA and γ-ABA are the decarboxylation products of aspartic and glutamic acids, respectively (Lee and Cronin 1982). They are formed through microbial mediation and have been used as indicators of organic matter degradation state because they reflect the microbial reworking of POM (Lee and Cronin 1982; Cowie and Hedges 1994). The relative abundance of non-protein amino acids may increase to percentages as high as 40% following lengthy diagenesis (Cowie and Hedges 1994). The ratios of Asp/β-Ala and Glu/γ-ABA have also been used as a measure of degradation with increasing values indicative of fresher material state (Degens and Mopper 1976; Ittekot et al. 1984; Hashimoto et al. 1998). Other studies have employed a reactivity index (RI), which is the ratio of (Tyr+Phe)/ (β-ALA+γ-ABA) to indicate the degree of degradation. Because Tyr and Phe are labile and decrease as degradation progresses, decreasing RI values are indicative of more degraded material (Jennerjahn et al. 2004).

In the Delta, the four degradation measures indicated that POM was less degraded at shallow-water sites (MI, FT) than other sites. %Non-protein AA %(β-ALA+ γ-ABA+Orn) were generally similar for POM samples collected across the Delta, averaging $3.0 \pm 1.4\%$ (Fig. 5a). However, values at SWH were on average lower $(1.1 \pm 0.02\%, p=0.04)$ than river sites $(3.1 \pm 0.6\%)$. β-ALA+γ-ABA pools in bacteria and diatoms are generally less than 2% (Cowie and Hedges 1992a, Nguyen and Harvey 1997). Therefore, sites where phytoplankton biomass is higher generally exhibit lower %

non-protein AA ratios. Also, non-protein amino acids have been found to be enriched in fine-grained sediments and clays (Keil et al, 1998); this sediment type is more characteristic of FT, MI and LH than river sites. Similarly, ratios of Asp/β-Ala, Glu/γ-ABA, and RI were higher for POM collected at shallow-water sites, consistent with less degraded organic matter (Ittekot and Arain 1986, Jennerjahn et al. 2004). RI values for POM and SOM were similar to those found in suspended particles and sediments of temperate rivers (Jennerjahn et al. 2004). Ratios of Asp/β-Ala and RI for sediments were similar among sites (Figs.5b,d). There were however significant between-site differences in the ratios Glu/γ-ABA of SOM, with higher values at SWH sites compared to other sites (p<0.05, Fig. 5c).

We applied the Degradation Index (DI) developed by Dauwe and Middelburg (1998) to the amino acid composition of POM and SOM collected from the Delta (mole%). Briefly, the DI is based on the principal that biodegradation of organic matter results in relative depletion or enrichment of individual amino acids (Lee and Cronin 1984, Cowie and Hedges 1992a, Lee et al. 2000), presumably due to their availability, as well as associations with cell wall structural components and cytoplasm (Henrichs and Sugai 1993). The DI uses the loadings of the first axis from principal component analysis (PCA). The site score summarizes the 18 amino acids analyzed in this study. Normalized values of each amino acid were obtained by subtracting the average amino acid mole % of all samples (n=58) from each individual mole% and dividing by their standard deviation. Coefficients for standardized PC scores of individual amino acids were multiplied with their normalized mole% to calculate the site score for each sampling station (Grutters et al. 2001). Results for both POM and SOM indices separated Delta habitats based on degradation state, with more positive values indicating fresher organic matter. The quality of POM in the Delta appears to follow the sequence: MI>FT>LH>CC>CS>X2>TI>MM>RV>HD (Table 4, Fig. 6). The pattern for the SOM was slightly different than for POM, with MI>FT>LH>CS>CC>MM> X2>RV>HD. Based on the DI, sites can be characterized in terms of low, intermediate and high degradation state. Both POM and SOM collected from the river sites were characterized lower values on the DI (Table 4). The low quality of POM at MM, a site with strong phytoplankton blooms in the summer (Jassby et al. 2002) was not expected. However,

these blooms are episodic and may not reflect the average condition at this site MM exhibits lower food quality during much of the year (Chapter 2). Sites such as CS and CC exhibited intermediate values on the DI, indicative of material less degraded than rivers. Less degraded OM at CC, a water export site, may result from entrainment of phytoplankton and fish at the site (Arthur et al. 1996). SWH sites had the least degraded POM, as indicated by the highest DI values. The DI results are consistent with previous studies in the Delta, which indicated that shallow-water habitats can provide higher-quality POM for utilization by zooplankton (Müller-Solger et al. 2002; Schemel et al. 2003; Sobczak et al. 2005). In contrast, studies have indicated that river sites rarely sustained chl a concentrations above 10 µg L^{-1}, a critical threshold for sustaining zooplankton growth in the Delta (Müller-Solger 2002). Organic matter at the river sites is largely recalcitrant and exhibited low rates of utilization in bioassays (Sobczak et al. 2005). Our study is consistent with the notion that POM carried in rivers has been degraded by the time it reaches estuaries (Raymond and Bauer 2001), with nutritional values too low for metazoan consumption (Muller-Solger et al. 2002).

Plots of DI vs. selected degradation indices for POM resolve the river and the shallow-water sites (Fig.6a-b). Shallow-water habitats, characterized by the highest DI values, also had the highest Asp/β-ALA and Glu/γ-ABA values. In contrast, river sites had low DI and lower ratiosAsp/β-ALA and Glu/γ-ABA values. Differences in these ratios were not as apparent in SOM (not shown), suggesting POM was more variable in its degraded state across Delta sites than SOM. Alternatively, to examine the lability of SOM, we plotted DI against %THAA-N and %THAA-C (Fig 7a-b). %THAA-C and %THAA-N had a range of values in SOM, and also provided an index of organic matter degradation state. Sites with higher DI values in SOM also exhibited higher percentages as TOC and TN. Together, these results indicate that shallow-water habitats, such as FT and MI, have the least degraded, hence highest potential quality POM and SOM. These findings are relevant to the ecosystem functioning of the Delta, as shallow-water habitats are important sites for larval fish recruitment (Grimaldo et al. 2004). These sites can be dominated by macrophytes and have higher concentrations of zooplankton and phytoplankton relative to other Delta habitats (Müller-Solger et al. 2002; Sobczak et al. 2002, 2005). In contrast, our finding regarding the more degraded state of POM at sites

in the Sacramento and San Joaquin Rivers is consistent with the notion that rivers deliver POM that is old and refractory (Raymond and Bauer 2001), and of limited use to bacteria and secondary producers (Sobczak et al. 2005).

The calculation of the DI is based on the PC 1 loading coefficients for individual amino acids. However, the DI does not indicate which amino acids are contributing to the DI values for different habitats. For this, we can examine individual PC 1 coefficients (Table 4), as well as plots of DI vs. %mole for select amino acids (Fig. 8). Factor coefficients for amino acids indicated that the highest negative loading were for Gly, non-protein amino acids, Ala, and Thr. which were enriched in riverine sample, and depleted in shallow-water samples. Coefficients for amino acids were similar to those for Dauwe and Middelburg (1998) and Unger et al. (2005), which used DI indices to examine coastal sediments. Plotting DI values vs. select amino acids that displayed the highest mole percentages (Gly, Ala, Glu and Asp) helped to elucidate the role of specific amino acids in influencing the DI values (Fig. 8a-d). Higher mole% of Gly and Ala are found at sites with lower DI values (i.e. river sites), while higher mole% of Glu and Asp were found at sites with higher DI values (shallow-water sites, particularly MI and FT). POM at LH, another shallow-water site was generally characterized as more degraded than FT and MI. This may be due to the fact that LH was breached only recently, and is still in the process of reaching system equilibrium. LH is characterized by lower amounts of aquatic vegetation and phytoplankton than FT and MI (Chapter 3). LH also receives water from the upper Sacramento River (HD), which has been demonstrated through DI values, AA ratios and THAA concentrations to have more degraded, lower quality organic matter.

Comparison with Other Systems

Concentrations of THAA in POM from the Delta appear to be lower than found in many river and estuarine systems (Table 5). This is particularly true for North American estuaries, with Delta values 6-8 times lower than those previously measured in the Potomac and Delaware estuaries (Harvey and Mannino 2000; Sigleo and Shultz 1993). The closest values were found in large rivers such as the Huanghe River (Zhang et al. 1992). The %THAA-C was also lower than most estuaries and rivers, although values

were comparable with some major world rivers characterized by lower quality POM (Ittekot and Zhang 1989). The Delta is characterized as a low-productivity system in comparison to other world estuaries (Jassby et al. 2002). THAA concentrations in Delta sediments were comparable to those found in other rivers and estuaries (Table 5). The lowest THAA concentrations were associated coarse sediment with highly degraded material in the Sacramento and San Joaquin Rivers, and higher values were found in shallow-water sediments. The ranges of values observed for the indices of OM quality such as %non-protein AA and RI for both POM and SOM were within range of other systems, and are consistent with the diversity of habitats measured in this study.

It is puzzling that values for amino acids are different from other systems in the POM, but similar to other systems in sediments. However, while POM reflects the short period during sampling, sediments reflect an integrated signal over longer time periods (Unger et al. 2005). Therefore, differences in THAA in POM and SOM may reflect sources whose signals are modified during transit to the sediments due to intense degradation or mineralization of POM in the water column. Sources of POM in the Delta may also be different from other shallow systems, resulting in differences in POM composition. The low phytoplankton component of POM is consistent with this and supports differences between the Delta and eutrophic systems such as the Chesapeake Bay.

Comparison with Measures of POC Quality

Previous studies in Delta habitats have utilized biochemical compounds such as proteins and lipids to determine POM quality (potentially useful for secondary producers). While THAAs do not provide a measure of food "quality" per se, the measures of degradation state calculated from amino acid composition can be used to infer a measure of carbon quality, as they imply the "freshness" of POM. One would expect that "fresher", less degraded organic matter would be more useful as a food source to higher organisms. Specifically in the case of %THAA-C we are measuring the amount of OC that is considered potentially metabolizable (by bacteria, or by suspension-feeders if it is adsorbed onto particles). THAA concentrations from this study correlated well with previous measurements of total protein across Delta habitats (correlation coefficient

of r=0.94, Table 6). In general, patterns in THAA concentrations were similar to protein concentrations, with higher THAA values at sites such as FT and MI, where the highest protein concentrations were found in the Delta (Chapters 2-4). This is not surprising, since proteins comprised 70-94% of THAA in this study, values similar to those found in other systems (Nguyen and Harvey 1998).

Correlation of THAA to lipid biomarkers in the Delta was also strong. Lipid biomarkers such as total fatty acids (TFA), polyunsaturated fatty acids (PUFA) and the essential polyunsaturated fatty acid 20:5ω3 have been used to estimate POM food quality (Canuel et al. 1995; Müller-Navarra et al. 1995). Concentrations of THAA and acidic amino acids (Asp and Glu), and calculated DI values were strongly positively correlated with all three groups (Table 6). Negative correlations with lipid biomarkers with neutral amino acids may reflect the more refractory nature of this functional group in relation to Delta POM. Together, these data indicate that regions/habitats in the Delta with higher quality POM, such as phytoplankton, are also regions with fresher, less degraded POM overall (e.g SWH). Our results are also consistent with findings from previous studies indicating that Delta POM in SWH is more bioavailable as measured through incubations (Sobczak 2002, 2005).

CONCLUSIONS

The measures of organic matter degradation state based on amino acid composition indicate that Delta habitats display a wide range in the degree to which OM is degraded. Riverine POM is highly degraded with low THAA concentrations, higher %mole of Gly and Ala, lower ratios for Asp/β-ALA and Glu/γ-ABA, and low DI index values. Shallow-water habitats FT and MI, which are important habitats for fish recruitment, had the freshest OM, with the highest THAA concentrations, higher %Asp and Glu, and the highest values for the DI index. Amino acid measures of OM degradation state were consistent with other measures of OM lability such as chl a, protein content and fatty acid composition. Compared to other systems, however, amino acid concentrations are low, consistent with previous studies indicating that the Sacramento-San Joaquin River Delta is a low-productivity food-limited system.

REFERENCES

ARTHUR, J. F., M. D. BALL, and S. Y. BAUGHMEN. 1996. Summary of federal and state water project environmental impacts in the San Francisco Bay-Delta Estuary, California, p. 445-495. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

BERDIE, L., J. O. GRIMALT, and E. T. GJESSING. 1995. Combined fatty acids and amino acids in the dissolved + colloidal and particulate fractions of the waters from a dystrophic lake. Org. Geochem. 23: 343-353.

BROWN, F.S., M.J. BAEDECKER, A. NISSENBAUM, and I.R. KAPLAN. 1972. Early diagenesis in a reducing fjord, Saanich Inlet, British Columbia. III. Changes in organic constituents of sediment. Geochim. Cosmochim. Acta. 36: 1185-1203.

BURDIGE, D. J., and C. S. MARTENS. 1988. Biogeochemical cycling in an organic -rich coastal marine basin: 10. The role of amino acids in sedimentary carbon and nitrogen cycling. Geochim. Cosmochim. Acta 52: 1571-1584.

CANUEL, E. A., J. E. CLOERN, D. B. RINGELBERG, J. B. GUCKERT, and G. H. RAU. 1995. Molecular and isotopic tracers used to examine sources of organic matter and its incorporation into the food webs of San Francisco Bay. Limnol. Oceanogr. 40: 67-81.

CAUWET, G., F. GAGEL, MMde SOUZA SIERRA, O. DONARD, and M. EWALD. 1990. Contribution of the Rhone River to organic carbon inputs to the northwestern Mediterranean Sea. Cont. Shelf Res. 10: 1025-1037.

CHEN, J.F., M.G. WEISNER, and H.K. WONG. 1999. Vertical changes of POC flux and indicators of early degradation of organic matter in the South China Sea. Science in China. Series D. 42: 120-128.

CLOERN, J.E. 2001. Our evolving conceptual model of the coastal eutrophication problem. Mar. Ecol. Prog. Ser. 210:223-253.

COWIE, G. L., and J. I. HEDGES.1992a. Sources and reactivities of amino acids in a coastal marine environment. Limnol. Oceanogr.: 703-724.

COWIE, G. L., and J. I. HEDGES. 1992b. Improved amino acid quantification in environmental samples: charged-matched recovery standards and reduced time analysis. Mar. Chem. 37: 223-238.

COWIE, G. L., and J. I. HEDGES. 1994. Biochemical indicators of diagenetic alteration in natural organic matter mixtures. Nature 369: 304-307.

DAUWE, B., and J. J. MIDDELBURG. 1998. Amino acids and hexosamines as indicators of organic matter degradation state in North Sea sediments. Limnol. Oceanogr. 43: 782-798.

DAUWE, B., J. J. MIDDELBURG, P. M. J. HERMAN, and C. H. R. HEIP. 1999. Linking diagenetic alteration of amino acids and bulk organic matter reactivity. Limnol. Oceanogr. 44: 1809-1815.

DEGENS, T. 1982. Riverine carbon – an overview of transport of carbon and minerals in world rivers. Part 1/SCOPE-UNEP. Hamburg-FRG. Carbon Unit. No. 52. 1-112.

DEGENS, E.T. and K. MOPPER. 1976. Factors controlling the distribution and early diagenesis of organic material in marine sediments, p. 59-113. In J.P. Riley and R. Chester [eds.], Chemical Oceanography. Academic.

DING, X., and S. M. HENRICHS. 2002. Adsorption and desorption of proteins and polyamino acids by clay minerals and marine sediments. Mar. Chem. 77: 225-237.

DITTMAR, T., H. P. FITZNAR, and G. KATTNER. 2001. Origin and biogeochemical cycling of organic nitrogen in the eastern Arctic Ocean as evident from D- and L-amino acids. Geochim. Cosmochim. Acta 65: 4103-4114.

EMERSON, S.E., and J.I. HEDGES. 1990. Processes controlling the organic carbon content of open ocean sediments. Paleoceanogr. 3: 621-634.

GRIMALDO, L. F., R. E. MILLER, C. M. PEREGRIN, and Z. P. HYMANSON. 2004. Spatial and temporal distribution of native and alien ichthyoplankton in three habitat types of the Sacramento-San Joaquin Delta. Am. Fish. Society Symp. 39: 81-96.

GRUTTERS, M., W. VAN RAAPHORST, and W. HELDER. 2001. Total hydrolysable amino acid mineralisation in sediments across the northeastern Atlantic continental slope (Goban Spur). Deep-Sea Res. I 48: 811-832.

HASHIMOTO, S., Y. MAITA, M. YANADA, and K. TAKAHASHI. 1998. Annual and seasonal variations of amino acid and hexosamine fluxes in the deep Bering Sea and the deep central Subarctic Pacific. Deep-Sea Res. I 45: 1029-1051.

HECKY, R.E., K. MOPPER, P. KILHAM, and. E.T. DEGENS. 1973. The amino acid and sugar composition of diatom cell-walls. Mar. Biol. 19:323-331.

HEDGES, J.I., and P.E. HARE. 1987. Amino acid adsorption by clay minerals in distilled water. Geochim. Cosmochim. Acta. 51: 255-259.

HEDGES, J. I., and R. G. KEIL. 1995. Sedimentary organic matter preservation: an assessment and speculative synthesis. Mar. Chem. 49: 81-115.

HEDGES, J. I., and R. G. KEIL. 1999. Organic geochemical perspectives on estuarine processes: sorption reactions and consequences. Mar. Chem. 65: 55-65.

HENRICHS, S.M., and S.F. SUGAI. 1993. Adsorption of amino acids and glucose by sediments of Resurrection Bay, Alaska, USA; functional group effects. Geochim. Cosmochim. Acta. 57: 823-835.

INGALLS, A. E., C. LEE, S. G. WAKEHAM, and J. H. HEDGES. 2003. The role of biominerals in the sinking flux and preservation of amino acids in the Southern Ocean along 170 W. Deep-Sea Res. II 50: 713-738.

ITTEKOT, V., and R. ARAIN. 1986. Nature of particulate organic matter in the river Indus, Pakistan. Geochim. Cosmochim. Acta 50: 1643-1653.

ITTEKKOT, V., and S. ZHANG. 1989. Patterns of particulate nitrogen transport in-world rivers. Global Biogeochem. Cycles. 3: 383-391.

ITTEKOT, V. and R.P.W.M. LAANE. 1991. Fate of riverine particulate organic matter. pp. 233-243. In E.T. Degens, S. Kempe, and J.E. Richey. [eds.]. Biogeochemistry of Major World Rivers. Wiley, Chichester, SCOPE 42.

ITTEKOT, V., W.G. DEUSER, and E.T. DEGENS. 1984. Seasonality in the fluxes of sugars, amino acids, and amino sugars to the deep ocean: Sargasso Sea. Deep-Sea Res. 31: 1057-1069.

JASSBY, A. D., and J. E. CLOERN. 2000. Organic carbon sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic. Conserv: Mar. Freshw. Ecosyst. 10: 323-352.

JASSBY, A. D., J. E. CLOERN, and B. E. COLE. 2002. Annual primary production: Patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnol. Oceanogr. 47: 698-712.

JASSBY, A. D., W.J. KIMMERER, S.G. MONISMITH, C.ARMOR, J.E. CLOERN, T.M. POWELL, J.R. SCHUBEL, T.J. VENDLINSKI. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecol. Appl. 5: 272-289.

JENNERJAHN, T. C., and V. ITTEKKOT. 1999. Changes in organic matter from surface waters to continental slope sediments off the Sao Francisco River, eastern Brazil. Mar. Geol. 161: 129-140.

JENNERJAHN, T. C, V. ITTEKOT, S. KLOPPER, S. ADI, S.P. NUGROHO, N. SUDIANA, A. YUSMAL, PRIHARTANTO, and B.GAYE-HAAKE. 2004. Biogeochemistry of a tropical river affected by human activities in its catchment: Brantas River estuary and coastal waters of Madura Strait, Java, Indonesia. Est. Coast. Shelf Sci. 60: 503-514.

KEIL, R. D., E. TSAMAKIS, J. C. GIDDINGS, and J. I. HEDGES. 1998. Biochemical distributions (amino acids, neutral sugars, and lignin phenols) among size-classes of modern marine sediments from the Washington coast. Geochim. Cosmochim. Acta 62: 1347-1364.

KERNER, M., and S. YASSERI. 1997. Utilization of phytoplankton in seston aggregates from the Elbe estuary, Germany, during early degradation processes. Mar. Ecol. Prog. Ser. 158: 87-102.

KIMMERER, W. J., and J. R. SCHUBEL. 1994. Managing freshwater flows into San Francisco Bay using a salinity standard: results of a workshop, p. 411-416. In K. R. Dyer and R. J. Orth [eds.], Changes in fluxes in estuaries: implications from science to management. Olsen & Olsen.

LEE, C., and C. CRONIN. 1982. The vertical flux of particulate organic nitrogen in the sea: decomposition of amino acids in the Peru upwelling area of the equatorial Atlantic. J. Mar. Res. 40: 227-251.

LEE, C., S. G. WAKEHAM, and J. H. HEDGES. 2000. Composition and flux of particulate amino acids and chloropigments in equatorial Pacific seawater and sediments. Deep-Sea Res. I 47.

LEHNINGER, A.L. 1972. Biogeochemistry. Worth Publishers, Inc. New York, 833 p.

LINDROTH, P., and K. MOPPER. 1979. High performance liquid chromatographic determination of subpicomole amounts of amino acids by precolumn fluorescence derivatization with 0-phthaldialdehyde. Analyt. Chem. 51: 1667-1674.

MACKO, S.A., and M.F. ESTEP. 1983. Microbial alteration of stable nitrogen and carbon isotopic compositions of organic substrates. Carnegie Inst. Wash. Geophysical Lab. Yrbk. 82: 394-398.

MANNINO, A., and H.R. HARVEY. 2000. Biochemical composition of particles and dissolved organic matter along an estuarine gradient: sources and implications for DOM reactivity. Limnol. Oceanogr. 45: 775-788.

MAYER, L. M., P. A. JUMARS, G. L. TAGHON, S. A. MACKO, and S. TRUMBORE. 1993. Low-density particles as potential nitrogenous foods for benthos. J. Mar. Res. 51: 373-389.

MECKLER, A.N., C.J. SCHUBERT, G.L. COWIE, S. PEIFFER, and M. DITTRICH. 2004. New organic matter degradation proxies: Valid in lake systems? Limnol. Oceanogr. 49: 2023-2033.

MEYBECK, M. 1982. Carbon, nitrogen and phosphorous transport by world rivers. Am. J. Sci. 282: 401-450.

MONSEN, N.E. 2001. A study of sub-tidal transport in Suisun Bay and the Sacramento-San Joaquin Delta, California. Ph.D. Dissertation, Stanford University, Stanford, California. 335 pp.

MÜLLER-NAVARRA, D. 1995. Evidence that a highly unsaturated fatty acid limits *Daphnia* growth in nature. Arch. Hydrobiol. 132: 297-307.

MÜLLER-SOLGER, A. B., A. D. JASSBY, and D. C. MÜLLER-NAVARRA. 2002. Nutritional quality of food resources for zooplankton (*Daphnia*) in a tidal freshwater system (Sacramento-San Joaquin River Delta). Limnol. Oceanogr. 47: 1468-1476.

NGUYEN, R., and H. R. HARVEY. 2003. Preservation via macromolecular associations during *Botryococcus braunii* decay: proteins in the Pula Kerogen. Org. Geochem. 34: 1391-1403.

NGUYEN, R. T., and H. R. HARVEY. 1998. Protein preservation during early diagenesis in marine waters and sediments, p. 88-112.

NGUYEN, R. T., and H. R. HARVEY. 1997. Protein and amino acid cycling during phytoplankton decomposition in oxic and anoxic waters. Org. Geochem. 27: 115-128.

OCHIAI, M., M. OGINO, K. SASAKI, and T. OKAZAWA. 1988. Behavior of particulate carbohydrates and amino acids in the estuary of the Tama River. Mar. Chem. 25: 265-278.

PANTOJA, S., and C. LEE. 2003. Amino acid remineralization and organic matter lability in Chilean coastal sediments. Org. Geochem. 34: 1047-1056.

PANTOJA, S., J. SEPULVEDA, and H. E. GONZALEZ. 2004. Decomposition of sinking proteinaceous material during fall in the oxygen minimum zone off northern Chile. Deep-Sea Res. I 51: 55-70.

PARSON, J.W. and J. TINSLEY. 1975. Nitrogenous compounds. p. 263-304. In J.E Gieseking [ed.], Soil Components. I. Organic Components. Springer-Verlag, Berlin.

PARSONS, T.R., W.H. THOMAS, D. SEIBERT, J.R. BEERS, P. GILLESPIE, C. BAWDEN. 1977. The effect of nutrient enrichment on the plankton community in enclosed water columns. Int. Rev. Ges. Hydrobiol. 62: 565-572.

PERAKIS, S.S., and L.O. HEDIN. 2002. Nitrogen loss from unpolluted South American forests mainly via dissolved organic compounds. Nature. 415: 416-419.

RAYMOND, P. A., and J. E. BAUER. 2001. Riverine export of aged terrestrial organic matter to the North Atlantic Ocean. Nature 409: 497-499.

RESCHKE, S., V. ITTEKKOT, and N. PANIN. 2002. The nature of organic matter in the Danube River particles and North-western Black Sea sediments. Est. Coast. Shelf Sci. 54: 563-574.

RYTHER, J.H., and W.H. DUNSTAN, 1991. Nitrogen, phosphorus and eutrophication in the coastal marine environment. Science: 1008-1013.

SCHUSTER, S., J.M. ARRETA, and G.J. HERNDL. 1998. Adsorption of dissolved free amino acids on colloidal DOM enhances colloidal DOM utilization but reduces amino acid uptake by orders of magnitude in marine bacterioplankton. Mar. Ecol. Prog. Ser. 166: 98-108.

SEITZINGER, S.P. and R.W. SANDERS. 1997. Contribution of dissolved organic nitrogen from rivers to estuarine eutrophication. Mar. Ecol. Prog. Ser. 159-1-12.

SIEZEN, R.J. and T.H. MAGUE. 1978. Amino acids in suspended particulate matter from oceanic and coastal waters of the Pacific. Mar. Chem. 6: 215-231.

SIGLEO, A. C., and D. J. SHULTZ. 1993. Amino acid composition of suspended particles, sediment-trap material, and benthic sediment in the Potomac Estuary. Estuaries 16: 405-415.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, and A. B. MÜLLER-SOLGER. 2002. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. Proc. Nat. Acad. Sci. 99: 8101-8105.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, B. E. COLE, T. S. SCHRAGA, and A. ARNSBERG. 2005. Detritus fuels ecosystem metabolism but not metazoan food webs in San Francisco Estuary's freshwater Delta. Estuaries 28: 124-137.

TEGELAAR, E.W., J.W. DE LEEUW, S. DERENNE, and C. LARGEAU. 1989. A reappraisal of kerogen formation. Geochim. Cosmochim. Acta. 53: 3103-3106.

TENORE, K.R., R.B. HANSON, J. McCLAIN, A.E.MACCUBBIN, and R.E. HODSON. 1984. Changes in composition and nutritional value to a benthic deposit feeder of decomposing detritus pools. Bull. Mar. Sci. 35: 299-311.

UNGER, D., B. GAYE-HAAKE, K. NEUMANN, A. C. GEBHARDT, and V. ITTEKKOT. 2005. Biogeochemistry of suspended and sedimentary material in the Ob and Yenisei rivers and Kara Sea: amino acids and amino sugars. Cont. Shelf Res. 25: 437-460.

VITOUSEK, P.M. and R.W. HOWARTH. 1991. Nitrogen limitation on land and in the sea: How can it occur? Biogeochem. 13: 87-115.

WAKEHAM, S. G., C. LEE, J. I. HEDGES, P. J. HERNES, and M. L. PETERSON. 1997. Molecular indicators of diagenetic status in marine organic matter. Geochim. Cosmochim. Acta 61: 5363-5369.

WANG, X. C., and C. LEE. 1993. Adsorption and desorption of aliphatic amines, amino acids and acetate by clay minerals and marine sediments. Mar. Chem. 44: 1-23.

ZHANG, S., W. B. GAN, and V. ITTEKOT. 1992. Organic matter in large turbid rivers: the Huanghe and its estuary. Mar. Chem. 38: 53-68.

Table 1. Study site water column parameters. Values represent the mean (±standard deviation) across all samplings.

Site	Abbreviation	Chl a µg L^{-1}	TSS mg L^{-1}	POC mg L^{-1}	PN mg L^{-1}	C:N$_a$ ratio
Sacramento River						
Hood	HD	3.02 (1.78)	32.04 (10.81)[a]	0.74 (0.28)[a]	0.10 (0.03)[a]	7.44 (1.87)
Rio Vista	RV	2.17 (0.91)	31.92 (14.35)[a]	0.70 (0.24)[a]	0.09 (0.04)[a]	7.90 (1.67)
San Joaquin River						
Mossdale Marina	MM	23.40 (32.24)	51.10 (21.24)[a]	1.62 (0.97)[a]	0.29 (0.26)[a]	7.10 (2.36)
Twitchell Island	TI	1.45 (0.80)	24.20 (7.06)[a]	0.79 (0.28)[a]	0.09 (0.04)[a]	8.60 (1.71)
Shallow-Water Tidal Lakes						
Little Holland Tract	LH	5.32 (1.64)	108.95 (34.45)[a]	1.87 (0.57)[a]	0.24 (0.07)[a]	7.77 (1.15)
Mildred Island	MI	6.99 (7.10)	12.40 (2.77)[a]	0.76 (0.25)[a]	0.12 (0.05)[a]	6.58 (0.78)
Franks Tract	FT	2.10 (0.47)	11.93 (4.35)[a]	0.44 (0.18)[a]	0.06 (0.03)[a]	7.76 (1.66)
Middle River						
Clifton Court Forebay	CC	3.87 (1.74)	30.20 (10.99)[a]	0.99 (0.37)[a]	0.12 (0.03)[a]	8.14 (1.41)
Tidal Marsh - Undisturbed						
Cutoff Slough	CS	6.41 (3.45)	88.34 (31.21)[a]	2.96 (1.36)[a]	0.34 (0.12)[a]	8.53 (1.48)
Northern SF Bay Estuarine Turbidity Maximum						
X2	X2	5.00 (8.26)	84.29 (51.76)[a]	1.73 (0.90)[a]	0.21 (0.15)[a]	9.55 (3.12)

[a] = data from Sobczak et al. (2005)

Table 2. Sediment characteristics for sampling sites throughout the Delta. Values represent the mean (±standard deviation) across all samplings.

Site	Sediment Description	POC mg g^{-1}	PON mg g^{-1}	C:N$_a$ Ratio
HD	coarse-grained	0.21 (0.06)	0.02 (0.01)	12.10 (3.51)
RV	coarse-grained	2.90 (0.19)	0.19 (0.01)	17.83 (1.44)
MM	coarse-grained	0.40 (0.18)	0.03 (0.01)	23.04 (10.44)
TI	coarse-grained	1.09 (0.45)	0.06 (0.01)	21.73 (4.81)
LH	hard-packed clay	11.97 (2.46)	1.20 (0.19)	11.59 (1.50)
MI	fine-grained	63.64 (21.23)	4.73 (1.18)	15.36 (1.55)
FT	fine-grained	32.76 (3.00)	3.00 (0.17)	12.76 (1.12)
CC	coarse-grained	5.46 (3.74)	0.36 (0.34)	16.44 (1.68)
CS	fine-grained	33.39 (6.44)	2.60 (0.25)	15.81 (2.22)
X2	coarse-grained	1.37 (0.08)	0.09 (0.01)	18.82 (0.50)

Table 3. Composition of hydrolyzable amino acids in POM and SOM throughout the Sacramento-San Joaquin Delta. Values for individual amino acids are listed as mole% of total hydrolyzable amino acids. Italicized values indicate standard deviations of the mean (n=8).

Site	Fraction	Neutral						Acidic		Basic			Hydroxyl		Aromatic		Non-Protein		
		Gly	Ala	Met	Val	Leu	Ile	Asp	Glu	Lys	Arg	His	Ser	Thr	Phe	Tyr	β-ALA	γ-ABA	Orn
HD	SPM	16.02	13.34	0.95	7.54	7.36	5.29	9.48	7.73	3.48	5.00	1.48	6.51	6.28	4.12	2.60	1.49	0.92	0.43
		1.85	*1.02*	*0.17*	*0.62*	*0.56*	*0.99*	*1.08*	*0.50*	*1.11*	*1.15*	*0.42*	*0.72*	*0.93*	*0.60*	*0.31*	*0.93*	*0.58*	*0.16*
	Sediment	17.40	13.59	0.90	7.19	7.03	5.06	9.04	7.52	3.73	4.41	1.44	6.58	6.51	3.96	2.51	1.63	0.99	0.56
		1.04	*0.58*	*0.08*	*0.73*	*0.60*	*0.96*	*1.08*	*0.46*	*0.71*	*0.39*	*0.44*	*0.74*	*0.55*	*0.59*	*0.28*	*0.20*	*0.15*	*0.05*
RV	SPM	15.82	13.44	0.91	7.41	7.25	5.23	9.85	7.97	3.42	4.68	1.39	6.82	6.55	4.18	2.47	1.33	0.87	0.41
		1.60	*0.69*	*0.21*	*0.39*	*0.45*	*1.12*	*0.48*	*0.67*	*0.91*	*0.53*	*0.20*	*0.41*	*0.47*	*0.64*	*0.31*	*0.65*	*0.53*	*0.11*
	Sediment	17.11	14.43	0.85	7.14	6.59	4.96	9.11	7.90	3.44	4.52	1.24	7.02	6.75	3.68	2.27	1.90	0.64	0.47
		0.76	*0.95*	*0.16*	*0.42*	*0.43*	*1.06*	*0.75*	*0.69*	*0.91*	*0.81*	*0.25*	*0.38*	*0.28*	*0.49*	*0.38*	*0.25*	*0.11*	*0.13*
MM	SPM	15.97	12.58	0.95	7.28	7.01	5.19	10.96	9.05	3.22	4.87	1.29	6.36	6.05	3.87	2.52	1.49	0.92	0.43
		1.91	*1.46*	*0.17*	*0.66*	*0.76*	*0.95*	*1.61*	*1.71*	*0.98*	*0.72*	*0.19*	*0.82*	*0.78*	*0.46*	*0.42*	*0.93*	*0.58*	*0.16*
	Sediment	17.58	14.35	0.92	7.15	6.88	5.00	8.76	7.64	3.25	4.46	1.27	7.02	6.84	3.54	2.43	1.58	0.95	0.38
		0.97	*1.00*	*0.16*	*0.48*	*0.71*	*0.81*	*1.01*	*0.86*	*0.77*	*0.46*	*0.18*	*0.64*	*0.47*	*0.38*	*0.43*	*0.17*	*0.25*	*0.25*
TI	SPM	15.79	14.05	0.93	7.13	7.17	4.92	9.09	7.88	3.56	5.12	1.65	6.90	6.46	4.17	2.52	1.30	0.94	0.43
		2.14	1.46	0.15	0.45	0.87	0.98	1.12	0.50	1.16	1.72	0.32	0.53	0.86	0.59	0.38	0.61	0.53	0.15
	Sediment	17.34	15.15	0.92	6.72	6.88	4.41	7.76	7.34	3.70	4.25	1.50	7.41	6.96	3.34	2.37	2.29	1.14	0.52
		1.52	*1.04*	*0.15*	*0.41*	*0.73*	*0.68*	*0.95*	*0.68*	*0.94*	*0.82*	*0.43*	*0.16*	*0.50*	*0.33*	*0.40*	*0.19*	*0.31*	*0.12*
LH	SPM	15.40	13.41	1.14	7.65	7.65	5.90	8.95	7.44	4.12	5.04	1.72	6.70	6.89	4.45	2.54	0.47	0.37	0.17
		0.32	0.54	0.17	0.71	0.17	0.20	0.82	0.38	0.45	0.97	0.39	0.41	0.33	0.36	0.20	0.03	0.05	0.05
	Sediment	16.71	14.82	1.14	7.25	7.53	5.76	7.15	6.87	4.17	4.63	1.70	7.00	7.05	4.37	2.48	0.68	0.45	0.25
		0.45	*0.14*	*0.17*	*0.26*	*0.07*	*0.15*	*0.22*	*0.36*	*0.39*	*0.39*	*0.36*	*0.24*	*0.16*	*0.40*	*0.27*	*0.11*	*0.07*	*0.03*

Table 3. Cont'd. Composition of hydrolyzable amino acids in POM and SOM throughout the Sacramento-San Joaquin Delta. Values for individual amino acids are listed as mole% of total hydrolyzable amino acids.

Site	Fraction	Neutral						Acidic		Basic			Hydroxyl		Aromatic		Non-Protein		
		Gly	Ala	Met	Val	Leu	Ile	Asp	Glu	Lys	Arg	His	Ser	Thr	Phe	Tyr	β-ALA	γ-ABA	Orn
MI	SPM	14.52	11.95	0.95	6.92	6.87	5.37	12.16	11.20	3.54	4.53	1.33	6.85	6.59	3.97	2.38	0.46	0.30	0.13
		0.95	*0.89*	*0.20*	*0.67*	*0.68*	*0.64*	*1.06*	*1.53*	*0.45*	*0.67*	*0.10*	*0.29*	*0.28*	*0.45*	*0.36*	*0.22*	*0.09*	*0.04*
	Sediment	15.97	12.72	0.95	6.59	5.57	5.24	10.61	9.65	3.56	4.42	1.32	7.52	6.62	4.01	2.36	2.17	0.45	0.25
		0.53	*1.30*	*0.22*	*0.29*	*0.34*	*0.61*	*0.86*	*1.03*	*0.44*	*0.64*	*0.11*	*0.17*	*0.28*	*0.41*	*0.38*	*0.17*	*0.10*	*0.10*
FT	SPM	14.81	12.25	0.96	6.87	7.04	5.50	11.74	10.65	3.53	4.44	1.31	6.89	6.61	3.92	2.42	0.44	0.34	0.31
		1.09	*0.74*	*0.23*	*0.76*	*0.60*	*0.53*	*0.50*	*1.26*	*0.52*	*0.71*	*0.11*	*0.28*	*0.25*	*0.48*	*0.40*	*0.04*	*0.08*	*0.04*
	Sediment	16.09	12.86	0.94	6.68	6.82	5.15	10.05	8.97	3.67	4.44	1.31	7.48	7.00	3.41	2.30	1.99	0.52	0.34
		0.82	*0.28*	*0.24*	*0.38*	*0.49*	*0.47*	*0.52*	*0.39*	*0.54*	*0.71*	*0.11*	*0.30*	*0.38*	*0.35*	*0.40*	*0.23*	*0.11*	*0.07*
CC	SPM	14.66	13.77	0.98	7.33	7.41	5.57	8.90	8.14	4.16	5.47	1.70	6.85	6.92	4.28	2.33	0.84	0.43	0.27
		0.60	*0.62*	*0.11*	*0.51*	*0.09*	*0.09*	*1.52*	*0.97*	*0.49*	*1.80*	*0.17*	*0.44*	*0.25*	*0.34*	*0.40*	*0.26*	*0.04*	*0.06*
	sediment	16.78	15.08	0.87	6.72	7.04	5.62	7.03	6.51	4.43	4.45	1.75	7.50	7.29	3.07	2.05	2.21	1.05	0.59
		0.79	*0.99*	*0.09*	*0.40*	*0.01*	*0.03*	*0.02*	*0.08*	*0.18*	*0.07*	*0.22*	*0.12*	*0.13*	*0.25*	*0.04*	*0.04*	*0.11*	*0.10*
CS	SPM	15.97	13.62	0.95	7.47	7.29	5.31	9.86	7.98	3.60	4.73	1.40	6.86	6.50	4.16	2.50	0.90	0.58	0.31
		1.72	*0.74*	*0.19*	*0.34*	*0.39*	*1.11*	*0.47*	*0.67*	*0.75*	*0.51*	*0.19*	*0.32*	*0.45*	*0.60*	*0.29*	*0.24*	*0.22*	*0.09*
	Sediment	17.25	14.65	0.93	7.07	6.78	4.87	8.75	7.55	3.66	4.34	1.37	7.29	6.83	3.37	2.18	1.98	0.71	0.41
		0.94	*0.42*	*0.16*	*0.52*	*0.54*	*0.86*	*0.63*	*0.52*	*0.72*	*0.24*	*0.13*	*0.42*	*0.16*	*0.17*	*0.06*	*0.17*	*0.13*	*0.08*
X2	SPM	16.32	14.71	0.97	6.98	7.07	4.90	9.25	8.05	3.41	4.81	1.74	6.76	6.62	4.13	2.47	0.94	0.61	0.28
		1.93	*1.25*	*0.17*	*0.58*	*0.94*	*1.02*	*1.51*	*0.93*	*1.19*	*1.53*	*0.41*	*0.53*	*0.95*	*0.62*	*0.40*	*0.32*	*0.17*	*0.05*
	Sediment	18.20	16.81	0.89	7.28	5.89	4.55	8.34	7.51	2.94	3.57	1.11	7.67	7.74	2.99	2.11	1.40	0.69	0.35
		0.03	*0.04*	*0.31*	*0.23*	*0.00*	*1.30*	*1.36*	*0.35*	*0.23*	*0.04*	*0.14*	*0.01*	*0.07*	*0.13*	*0.04*	*0.11*	*0.04*	*0.01*

Table 4. Parameters of the PCA analysis based on data from Delta sites for (a) POM and (b) SOM. DI: Degradation Index.

(A) POM

Site	DI	Amino Acid	PC 1 Loadings
HD	-0.834	Gly	-0.132
RV	-0.682	Ala	-0.091
MM	-0.557	Met	0.072
TI	-0.375	Val	0.024
LH	0.341	Leu	0.121
MI	1.211	Ile	0.044
FT	0.872	Asp	0.092
CC	0.214	Glu	0.086
CS	0.079	Lys	0.050
X2	-0.292	Arg	-0.022
		His	0.067
		Ser	0.028
		Thr	-0.056
		Phe	0.118
		Tyr	0.104
		b-ALA	-0.129
		g-ABA	-0.114
		Orn	-0.069

(B) SOM

Site	DI	Amino Acid	PC 1 Loadings
HD	-1.623	Gly	-0.145
RV	-1.312	Ala	-0.078
MM	-0.762	Met	-0.082
TI	-1.017	Val	0.063
LH	0.550	Leu	0.097
MI	1.323	Ile	0.124
FT	0.872	Asp	0.103
CC	0.215	Glu	0.091
CS	0.341	Lys	0.067
X2	-0.834	Arg	-0.051
		His	0.033
		Ser	0.045
		Thr	-0.032
		Phe	0.126
		Tyr	0.085
		b-ALA	-0.137
		g-ABA	-0.131
		Orn	-0.119

Table 5. Concentrations of THAA, %THAA-C, %-THAA-N, %non-protein AA, and RI from rivers, lakes and marine regions

Location	AA μg L⁻¹	AA mg g⁻¹	THAA-C % of POC	THAA-N % PN	β-ALA+γ-ABA % of THAA	RI	Reference
Suspended Matter							
California Coast	119-241	27-52					Siezen and Mague 1978
Major World Rivers			14	43			Ittekot and Zhang 1989
Potomac Estuary		60-129	13-39				Sigleo and Schultz 1993
Tama River	727-1281						Ochiai et al. 1988
Huanghe River	560-11030	1.2-44.4	6-35	17-94			Zhang et al. 1992
Indus River	176-2009						Ittekot and Arain 1986
Wonokromo River, Java		16-54	19-30	47-88		8-29	Jennerjahn et al. 2004
Porong River, Java		4-74	23-42	66-100		5-24	Jennerjahn et al. 2004
Danube River	94-1643		5-32				Reschke et al. 2002
Sacramento-San Joaquin Delta		1-20	2-26	15-94	1-5	1-30	This study
Pearl River, China		10-137	13-54		1-2		Chen et al. 2004
Ob River, Siberia			22-24	53-61		11-19	Unger et al. 2005
Yenisei River, Siberia			26-31	52-63		20-22	Unger et al. 2005
Delaware Estuary	600-1400		16-35	41-64	0		Mannino and Harvey 2000
Amazon River				20-60	2-3		Hedges et al. 1994
Brazil coast			10-20	27-55	1-3		Jennerjahn et al. 1999
Skjervatjern Lake, Norway	180-260		10				Berdie et al. 1995
Surface Sediments							
Lake Zug, Switzerland			18-21				Meckler et al. 2004
Wonokromo River, Java		1-4	8-16	47-64		2-4	Jennerjahn et al. 2004
Porong River, Java		3-4	8-14	47-77		2-3	Jennerjahn et al. 2004
Black Sea (northwest)			12-43				Reschke et al. 2002
Potomac estuary		4-21					Sigleo and Schultz 1993
Pearl River, China		0.9-2.9	12-16				Chen et al. 2004
Sacramento-San Joaquin Delta		0.1-15	1-16	25-90	1-4	1-7	This study
Atlantic continental slope		0.5-1.8	10-15	20-45			Grutters et al. 2001
Mangrove Lake, Bermuda				60	5		Nguyen and Harvey 1998
Ob and Yenisei Rivers, Siberia			10	34		3	Unger et al. 2005
Dabob Bay				37			Cowie and Hedges 1992
Washington-Oregon coast		3.7-20.5			>1		Keil et al. 1998

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Table 6. Pearson Product Moment correlation coefficients for lipid and amino acid measures of lability for POM in the Sacramento-San Joaquin River Delta. Bold values indicate significant correlations (p<0.05)

	THAA	Acidic AA	Neutral AA	DI
Chl a	**0.58**	**0.57**	-0.17	**0.53**
Protein	**0.94**	**0.73**	-0.41	**0.79**
TFA	**0.56**	**0.54**	**-0.62**	**0.50**
PUFA	**0.74**	**0.73**	**-0.59**	**0.75**
20:5ω3	**0.77**	**0.77**	**-0.78**	**0.76**
22:6ω3	**0.78**	**0.76**	-0.42	**0.63**
Total ω3 FA	**0.88**	**0.72**	**-0.63**	**0.68**

TFA = total fatty acids

PUFA = total polyunsaturated fatty acid

20:5ω3 = eicosapentaenoic acid

22:6ω3 = docosahexaenoic acid

Total ω3 FA = 20:5ω3+22:6ω3+22:5ω3

Fig. 1. Map of the Sacramento-San Joaquin River Delta. Inset map indicates drainage area for Delta. Sampling sites represent an array of riverine, shallow-tidal lake, marsh and open bay habitats (see Table 1 for full site names). Modified from Sobczak et al. (2005).

Map showing the Sacramento-San Joaquin Delta and Suisun Bay, California, with sampling station locations: HD, LH, CS, RV, TI, FT, MI, X2, CC, and MM. Features labeled include the Yolo Bypass, Sacramento River, Suisun Bay, Clifton Court Forebay, California Aqueduct, and San Joaquin River. Inset map shows map location and drainage basin within California. Coordinates shown: 122°00', 121°30', and 38°00'.

Fig. 2. Concentrations of THAA associated with suspended particles (mg g^{-1} TSS) and sediments (mg g^{-1} sediment) in the Delta.
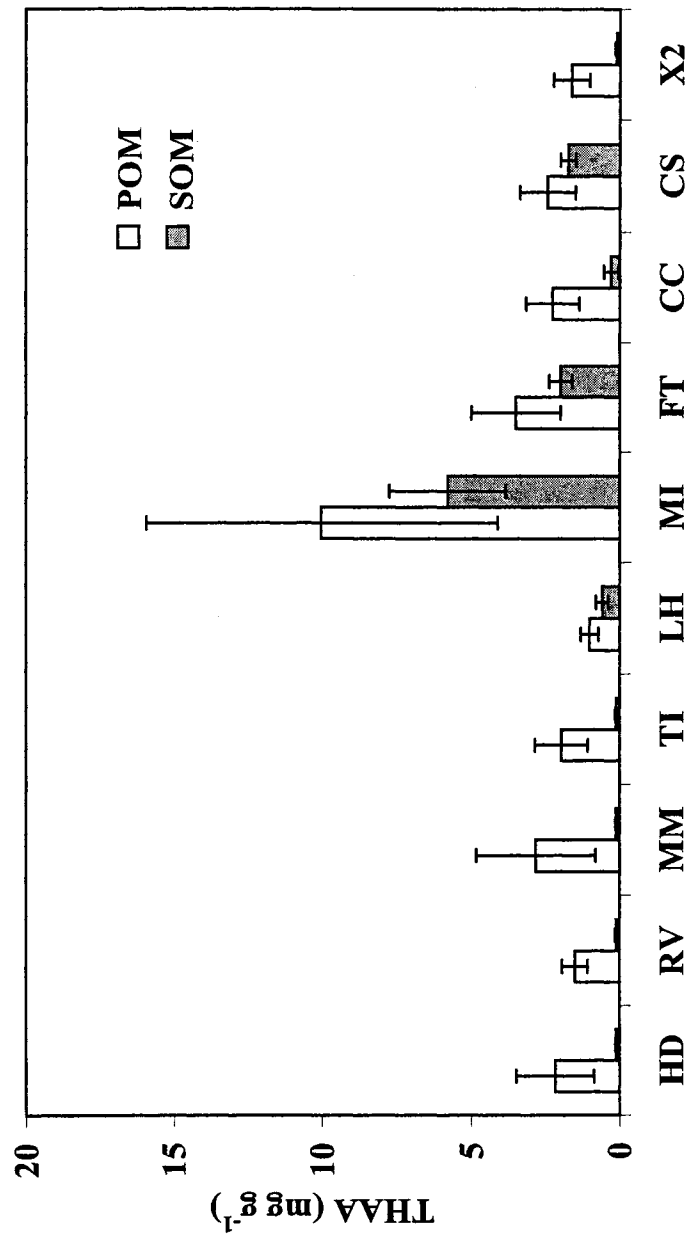
Fig. 3. Boxplots of %THAA-C and %THAA-N for POM and SOM. Plots show the median (labeled horizontal lines inside boxes) and interquartile range (25th to 75th percentiles as box ends). Whiskers indicate range from 5th to 95th percentile. Symbols within each box indicate the sample mean.
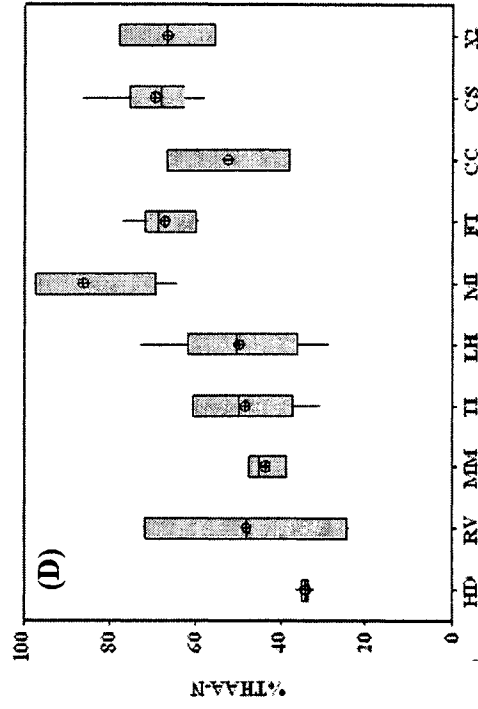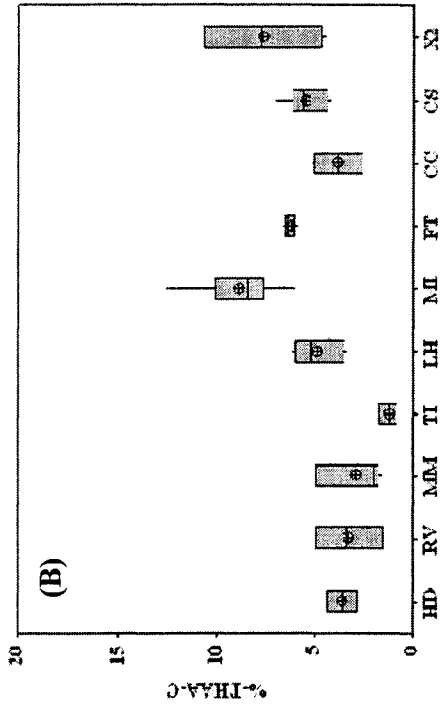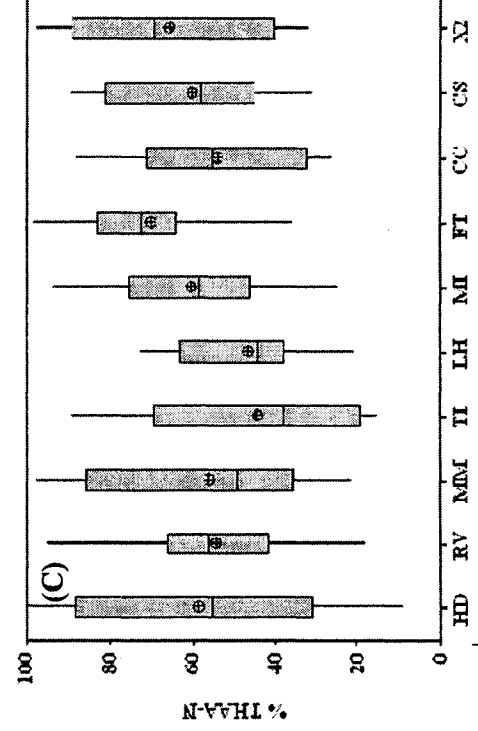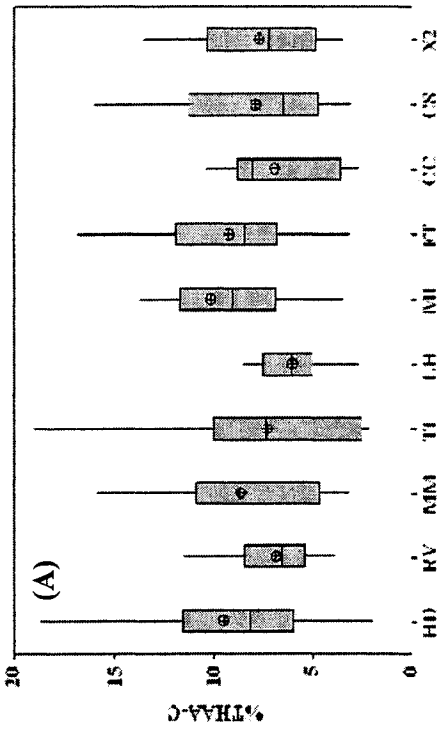
Fig. 4. Functional group composition of protein amino acids, grouped by habitat type, averaged over the entire sampling period. Sites were grouped as follows: SAC River (Sacramento River): HD+RV; SJ River (San Joaquin River + Middle River): MM+CC+TI; SWH (Shallow-water habitat): LH+MI+FT; Suisun Marsh: CS; and Suisun Bay: X2. Error bars indicate standard deviations.

(A) POM

Mole%

- □ SAC River-N Delta
- ▨ SJ River-S Delta
- ■ SWH
- ▦ Suisun Marsh
- ☰ Suisun Bay

Neutral   Acidic   Basic   Hydroxy   Aromatic

(B) SOM

Mole%

Neutral   Acidic   Basic   Hydroxy   Aromatic
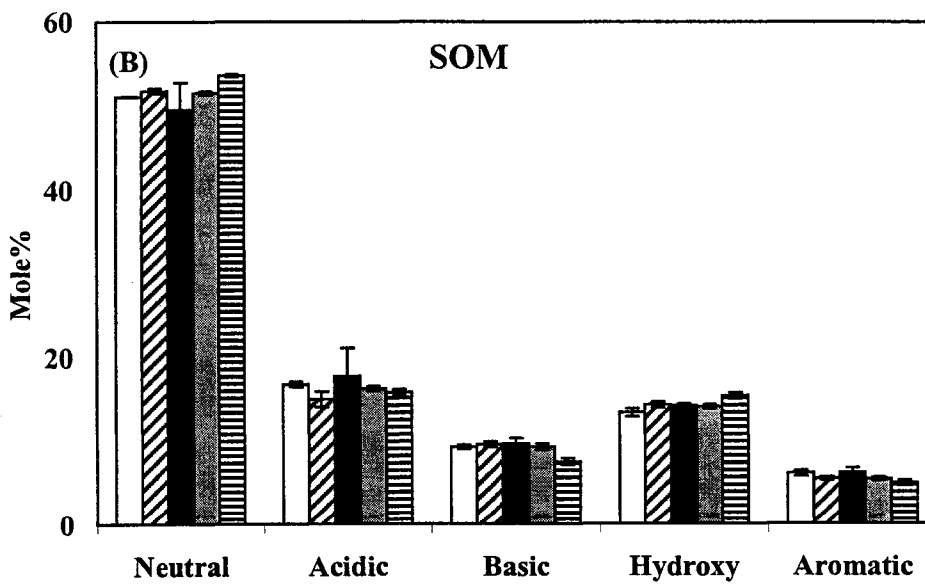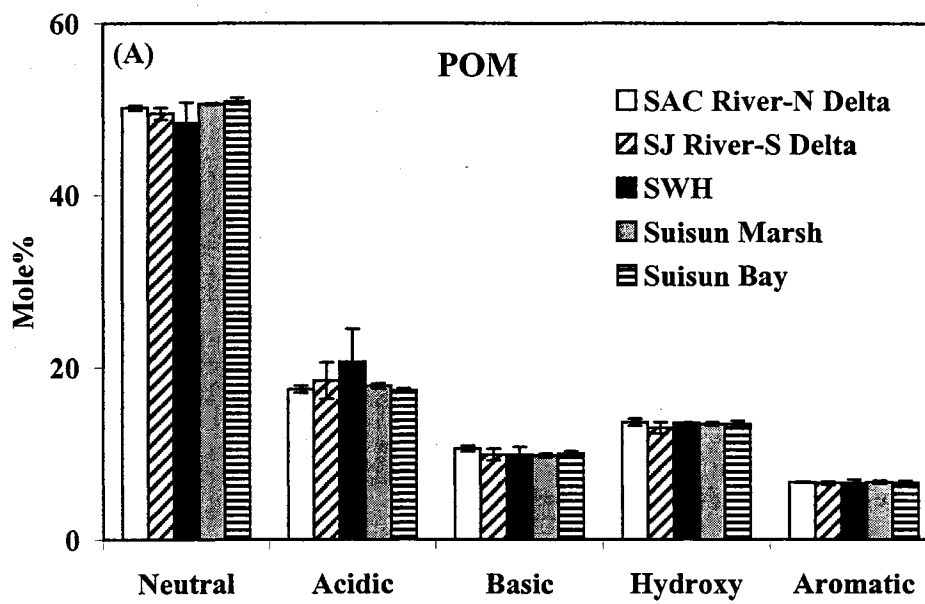
Fig. 5. Average ratios of degradation indices for POM and SOM at Delta sampling sites. % Non-protein AA: %β-ALA+%γ-ABA+%ornithine. RI: (Phe+Thr)/(β-ALA+γ-ABA). Increased % non-protein amino acids and RI values, and lower ratios of Asp/βALA, Glu/γ-ABA indicate greater degradation.
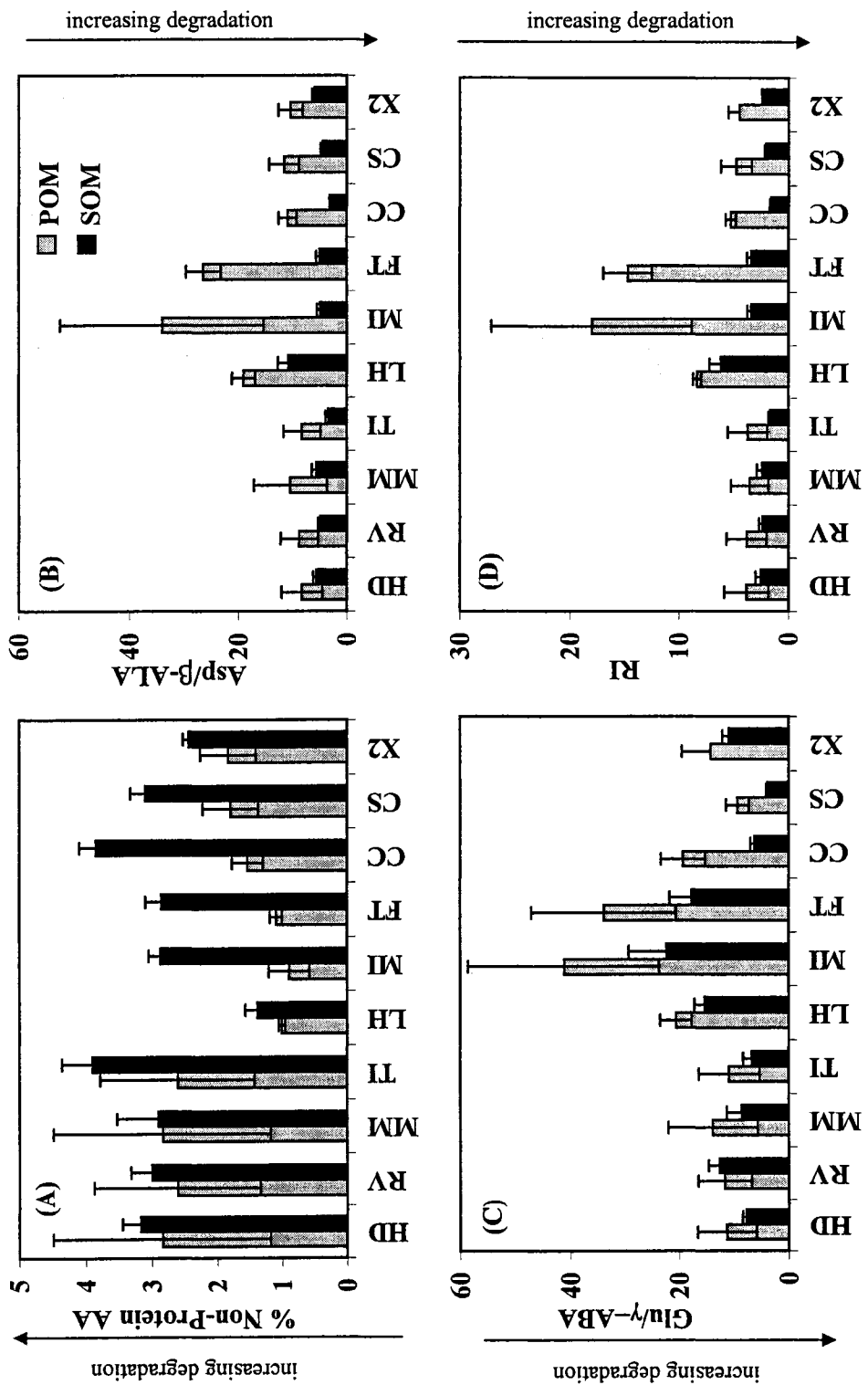
Fig. 6. Degradation index ratios (a) Asp/β-ALA and (b) Glu/γ-ABA plotted against degradation index (DI) calculated for POM at Delta sampling sites. Circles group sample points for river and SWH sites for comparison.
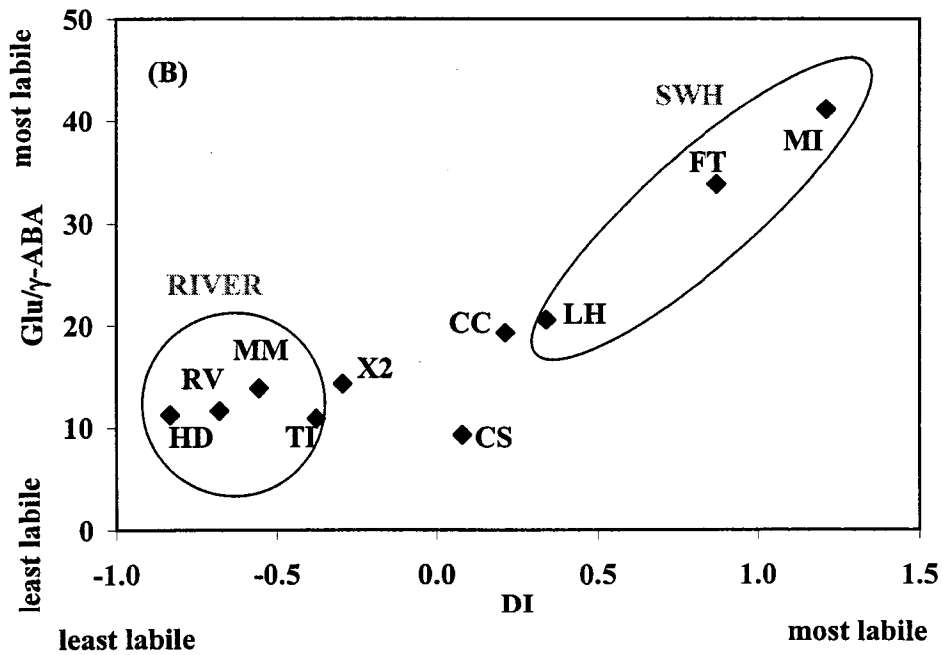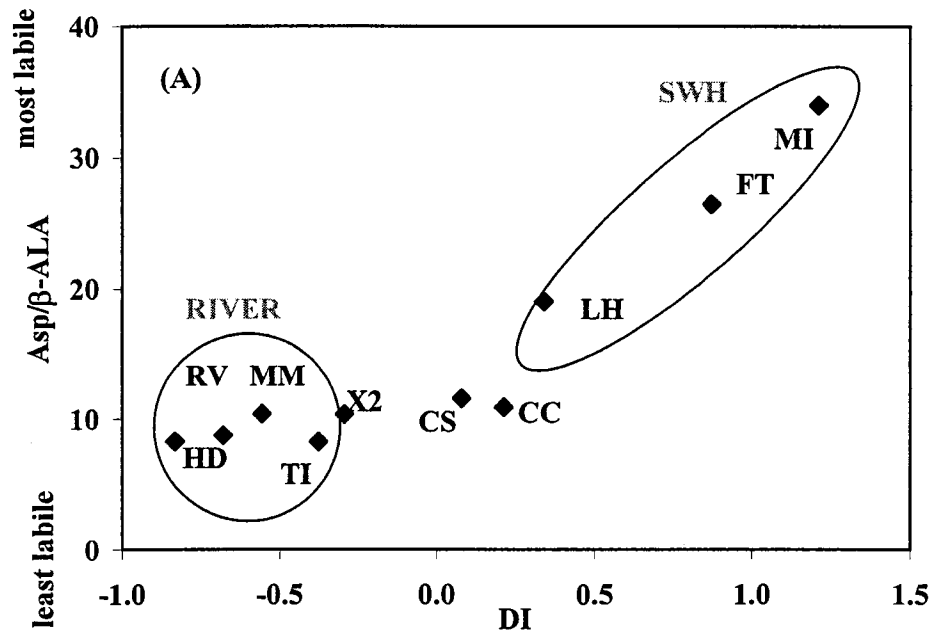
Fig. 7. Measures of organic matter degradation (%THAA-C and %THAA-N) vs. calculated degradation index (DI) values for SOM from Delta sampling sites. Circles group sample points river and SWH sites for comparison.
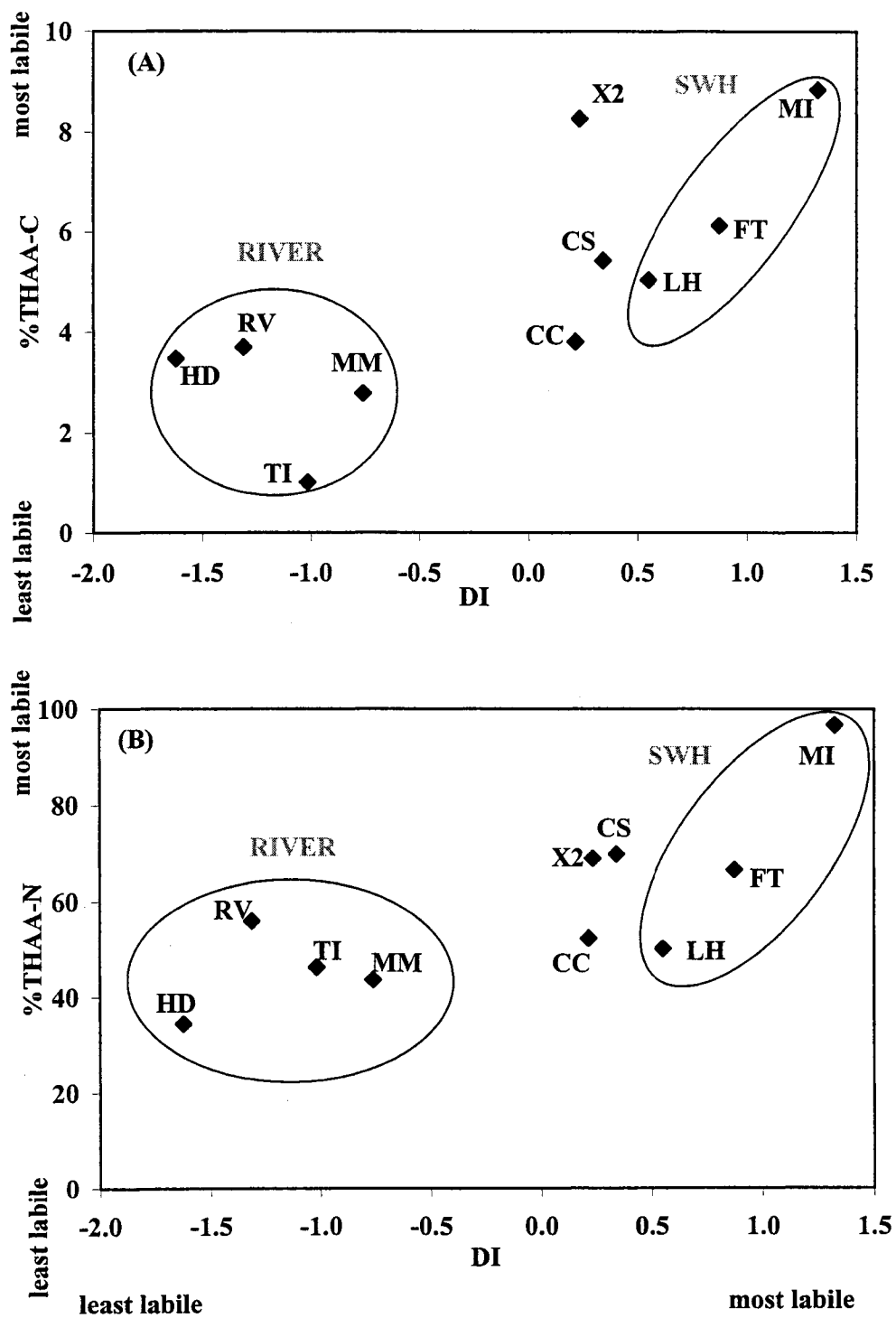
Fig. 8. Select individual protein amino acids (mole%) vs. degradation index (DI) values for Delta sampling sites. POM samples are indicated by open squares (□), and SOM samples are indicated by solid diamonds (♦). Dashed circles group sample points of POM for rivers and SWH for comparison. Solid circles group samples points of SOM for each of these regions for comparison.
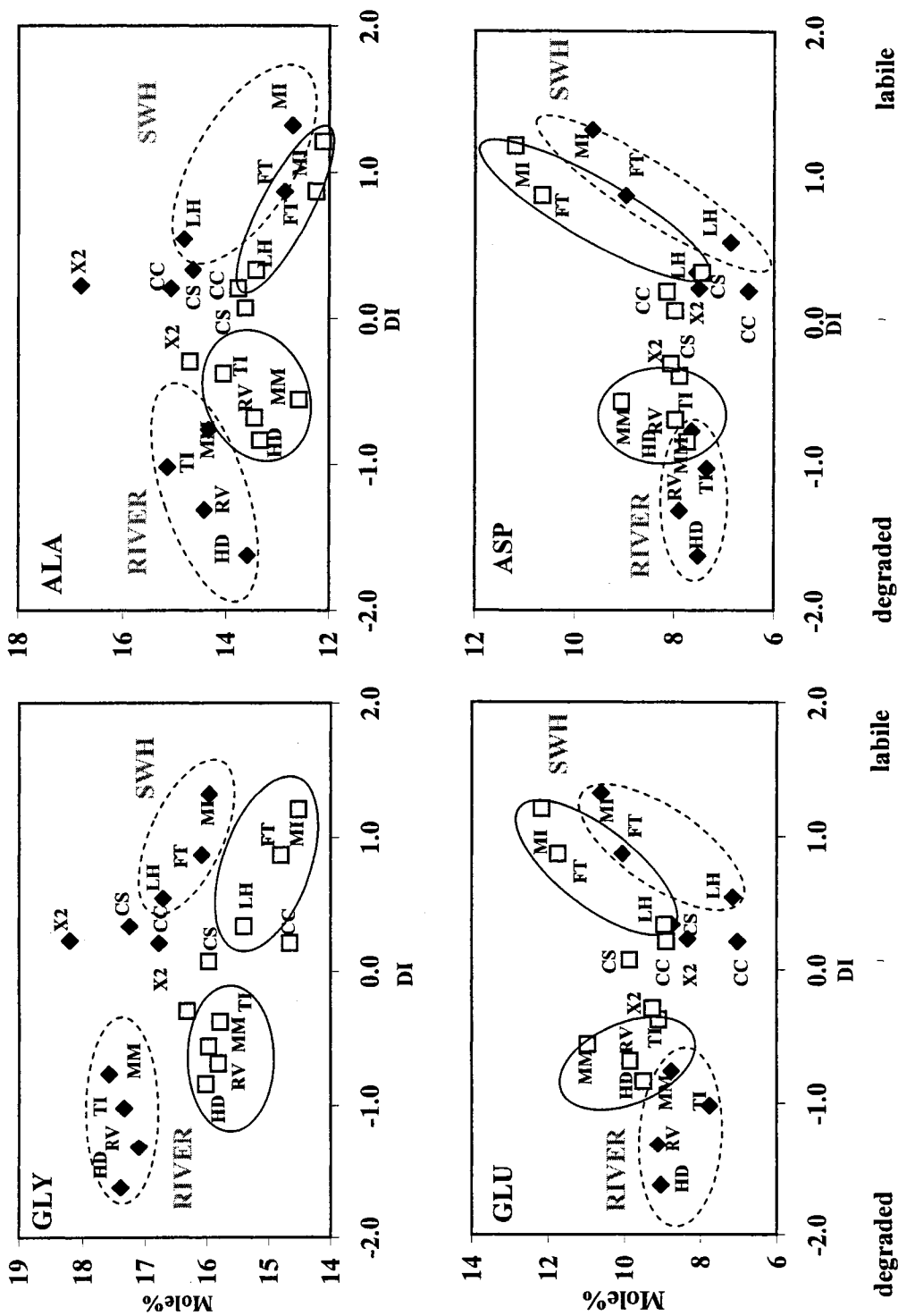
CHAPTER 6

SUMMARY AND CONCLUSIONS

Given the high levels of spatial and temporal variability in physical, chemical and biological processes along the river-estuarine continuum, a thorough examination of organic carbon dynamics is imperative for understanding the fate of autochthonous and allochthonous sources of organic carbon (Mannino and Harvey 1999). Understanding biological events, such as phytoplankton blooms and periods of high larval fish recruitment, are important for predicting the availability of organic matter for high trophic levels. Periods of high runoff and river flow can lead to increased input of soil-based contaminants, organic matter (dissolved and particulate) and nutrients to estuaries and the coastal oceans. The delivery of these materials is a response to hydrologic, climatic and anthropogenic forcings, influencing the sources, age, and potential availability of organic carbon (Lehman 2000; Kimmerer 2004). Layered upon the natural complexity of these systems are anthropogenic factors, such as human control of river flows through reservoirs, dams and export canals. Humans also affect chemical and biological conditions through agricultural inputs of nutrients, pesticide use, and the alteration of fish migration patterns through the use of fish ladders and dams (Bennett and Moyle 1996). Together, natural and anthropogenic influences can result in conditions that result in reduced ecosystem health and productivity, and the extraordinary complexity of these systems can make resource management a complex task.

The previous chapters in this dissertation examined the sources, quality and fate of particulate organic matter in a suite of habitat types that are represented in the Sacramento-San Joaquin River Delta, CA. A comparison of these habitat types is important because different sub-habitats may play unique roles as a source or sink for organic matter in the Delta (Lucas et al. 2002). Many of these sites have also been identified as habitats that have been, or will be, subject to future rehabilitation or manipulation to improve the overall health of the Delta ecosystem.

For this research project, I proposed four hypotheses:
1) Seasonal variability in the sources and quantity of POC loading in the

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Sacramento and San Joaquin Rivers will be reflected in the temporal and spatial variability of biochemical components and lipid biomarkers (Chapter 2). Higher concentrations will be associated with low-flow and phytoplankton bloom conditions.

2) Shallow-water habitats will differ in sources and quality of organic carbon due to functional variability (Chapter 3). The quality of POC will be higher at sites where phytoplankton are the primary source of POC for secondary producers.

3) Because of the shallow depth of these shallow-water habitats, there will be reduced organic matter processing in the water column, leading to surface sediments enriched in labile components, and of greater nutritional value to benthic organisms (Chapter 4).

4) Organic matter in suspended particles and sediments at shallow-water sites will be less degraded, thus higher quality, than organic matter at river sites (Chapter 5). Amino acid concentrations will be higher in shallow-water sites, and mole% composition will be enriched in more labile acids such as aspartic and glutamic acids at these sites.

Figure 1 presents the central conclusions about particulate organic carbon (POC) quality in the Delta. Organic carbon at all sites was dominated by an uncharacterizable fraction, as indicated by the analyses of biochemical classes, lipid biomarker compounds, and total hydrolysable amino acids. The San Joaquin River (MM, Table 1) and the mature shallow-water sites (FT, MI, Table 1) exhibited the highest fractions of characterizable particulate organic carbon (Chapters 2,3,5). These are sites that have higher proportions of bioavailable particulate organic carbon relative to other sites (Sobczak et al. 2002, 2005). Of the characterizable POC, concentrations of carbohydrates were higher than total hydrolysable amino acids and lipids. Exceptions included mature shallow-water habitats (FT, MI), and the water export site at Clifton Court Forebay, where lipids were the overall dominant fraction. Higher lipid fractions at these sites are likely due to phytoplankton and macrophyte abundances at mature

shallow-water sites, and phytoplankton, zooplankton and fish entrainment that occurs at Clifton Court Forebay (Bennett and Moyle 1996). This emphasizes an important underlying factor relevant to estuarine ecosystem metabolism: rivers may carry highly degraded, and on average, aged (as determined by radiocarbon) organic matter (Raymond and Bauer 2001) that is of little use for secondary producers (Sobczak et al. 2002, 2005).

Our estimates of characterizable, and potentially utilizable particulate organic carbon in the Delta, are likely conservative. Previous studies of estuaries have also identified lignin as an additional component of characterizable particulate organic carbon (Harvey and Mannino 2001). However, lignin is highly refractory, and its inclusion in our estimates would not change our overall identification of sites with higher quality particulate organic carbon. In addition, the contribution of lignin to particulate organic carbon is variable, ranging from small contributions to (Harvey and Mannino 2001) to large in coarse fractions (larger grain size) (Keil et al. 1998). Other studies of aquatic environments have indicated that many compounds are not normally measured (i.e. amino sugars, nucleic acids, lectins, uronic acids, acidic sugars, and abiotically modified proteins), and the proportion of total carbon contributed by these compounds is unknown (Bergamaschi et al. 1999; Keil and Kirchman 1993; Lee et al. 2004).

Food sources and quality were found to vary spatially and temporally between the Sacramento and San Joaquin Rivers, as well as on a temporal basis. On average, the Sacramento River exhibited lower food quality than the San Joaquin River, as result of lower contributions from phytoplankton (Chapter 2). Winter periods were characterized by the delivery of highly degraded, low-quality POC associated with higher freshwater flows. In contrast, phytoplankton blooms contributed to higher-quality organic matter, particularly on the San Joaquin River, particularly in the spring and fall. The lower San Joaquin River was influenced to some extent by the Sacramento River as well as upstream sources. Most biochemical and lipid data at the mixed site (TI) was more closely correlated to RV and HD, indicating that the site was minimally influenced by MM, or underwent processing prior to arrival at TI. However, this would also indicate that higher quality organic matter at MM was not reaching lower San Joaquin River sites, and is utilized within the Delta rather than being transported into Northern San Francisco Bay.

Our investigation of organic dynamics and benthic-pelagic coupling at MI and FT, two shallow-water habitats within the Delta indicated that coupling is weak at best. In particular the hydrodynamics of each system, as well as biological influences such as zooplankton feeding and benthic grazing, contributed to this decoupling (Chapter 4). Benthic-pelagic coupling was only observed at MI in October 1999 during periods of high phytoplankton blooms. Measurements within shallow-water habitats on a finer spatial and temporal scale would likely resolve the role of hydrodynamics (tidal and wind-induced waves) and phytoplankton blooms on overall benthic-pelagic coupling at these sites. Therefore, the results and conclusions from the preliminary study at these sites must be viewed as only a preliminary assessment of benthic-pelagic coupling in these shallow-water habitats. Spatial variability was observed in lipid biomarkers between the sites, as well as in sources of organic carbon (although there was general overlap). This indicated that the functional variability observed between these two sites as indicated by measurements of chlorophyll a and primary productivity (Lucas et al. 2002; Lopez et al. in press) could also be observed in biochemical and lipid components relevant to food quality. To date, this study is the first to provide information about the sources and food quality of organic carbon in benthic environments in the Delta.

The investigation of amino acids in the Delta yielded several relevant findings. First, it corroborated findings of lipid and biomarker analyses (Chapters 2,3,4), as well as previous studies (Sobczak et al. 2002, 2005) by showing that shallow-water habitats yielded fresher, less degraded particulate organic matter, thus likely of higher quality (Chapter 5). Those finding were mirrored by amino acids in sediments from all habitat types studied in the Delta, which indicated that shallow-water habitats sediments, particularly those of mature sites, had higher food quality than sediment from less mature shallow-water and riverine habitats. This is relevant to understanding populations of benthic micro- and macroinvertebrates, which are consumed by benthic filter-feeding fish. Finally, we were able to successfully apply the use of "degradation indices", first introduced by Dauwe and Middelburg (1998) for coastal sediments, to characterize habitats in terms of organic matter degradation state, which likely reflect food quality. This method has been utilized with varying success for coastal suspended particles and sediments (Dauwe and Middelburg 1998, Pantoja and Lee 2003), as well as in lake

environments (Meckler et al. 2004). The application of the method to both suspended particles and sediments is the first along a river-estuarine continuum. Our findings indicate that the development of degradation indices may be particularly useful for ecosystems that incorporate a suite of environments, such as estuaries and deltas.

A central question during the course of this study that was not addressed in detail within chapters was how these different measures of food quality would compare to one another. Biochemical compounds, lipid biomarkers and amino acids are rarely used within the same study (Mannino and Harvey 2001). Comparison of these methods to one another, as well as to an often-used indirect indicator of food quality, chlorophyll a, provided an opportunity to assess the usefulness of chlorophyll a, as well as to examine whether the use of biomarkers and biochemical characterization provides additional insights. Our limited comparison of biochemical compounds vs. chlorophyll a (Chapters 2, 3) and lipid vs. amino acid composition (Chapter 5) indicated that these measurements are in general agreement with one another. Additionally, principal components analysis using all measurements was used to determine if these measurements were, in fact, correlated (Fig. 2). Sites loadings indicated that river (TI), X2 and tidal marsh (CS) sites (the most negative loadings of PC 1), were characterized by higher concentrations of long-chained fatty acids, 18:0 fatty acid, and four amino acids alanine, glycine, serine and threonine (Fig.2), all of which are indicative of degraded organic matter (Cowie and Hedges 1992; Dauwe and Middelburg 1998). Meanwhile the San Joaquin River (MM) and to a lesser extent the mature shallow-water sites (MI, FT), were characterized by 14:0 saturated fatty acid, and polyunsaturated fatty acids such as 20:5ω3, 16:2/3, 16:4 and 18:4 indicating higher nutritional quality (Müller-Navarra et al. 1995). The grouping of campesterol with PUFAs and chl a on the PC 1 axis indicates that this sterol, which can derive from both terrestrial and algal sources, represents algal sources in the Delta. Scores for aspartic and glutamic acid, indicative of less degraded organic matter, did not exhibit the most positive loadings, but were intermediate between indicators of fresh organic matter and higher plant/more degraded material. The plots also indicate that lipid biomarkers, particularly PUFAs agree well with chlorophyll a.

For PC 2, amino acids were most positively weighted, while PUFAs 16:4 and 18:4 were most negatively weighted (Fig. 2). Positively weighted sites on the PC 2 axis

included X2, CS, MI and MM, while negatively weighted sites included TI, LH and FT. Separation of lipid biomarkers and amino acids for PC 2 indicates that they measure different conditions of organic carbon (actual quality vs. degradation state), thus indicating that to fully understand particulate organic carbon composition and quality, the two should be measured in unison. When PCA loadings were averaged for each site, TI, X2 and CS had the most negative loadings on PC 1, while FT, MI and MM exhibited the most positive loadings. Sacramento River sites were intermediate. This indicates that in using both lipid biomarkers and amino acids, we can develop an index of organic carbon quality similar to the amino acid degradation index, but which may yield additional insights about sources of organic carbon.

An important question that acted as the impetus for this research was: How does the study of particulate organic carbon contribute to improving habitat rehabilitation and resource management efforts in the Delta, particularly at the specific level of biochemical and molecular compounds? Two of the proposed plans for habitat rehabilitation were particularly relevant for our study: 1) Increasing the number of shallow-water lakes created through the breaching of leveed agricultural tracts to increase the amount of habitat for fish recruitment available in the Delta, and 2) the construction of new canals to facilitate movement of water from the Sacramento River to the pump intakes in the southern Delta. Published studies by team members investigating Delta organic carbon dynamics have been able to identify the primary sources of organic carbon to the Delta (Jassby and Cloern 2000), and habitats that may provide high quality organic carbon for secondary production, including shallow-water habitats, and the San Joaquin River (Müller-Solger et al. 2002, Sobczak et al. 2002, 2005). Many of these relevant conclusions were obtained using measurements that are much more easily obtained (lower processing and analysis time, less costly), such as chlorophyll *a* (Jassby and Cloern 2000, Müller-Solger et al. 2002) and bulk suspended particulate matter, POC and PN (Jassby and Cloern 2000; Sobczak et al. 2002, 2005). This tends to prove the ubiquitous 20-80 rule, where 20% of the effort (in this case more easily obtained measurements), can yield 80% of the results. However, it is the additional 20% of the results (and in this case the increased efforts through longer sampling and analysis times of biochemical and molecular studies), that are vital to understanding the essential details

of a given problem. That is the niche that is filled through investigation of organic carbon in greater detail through lipid biomarker and amino acid analyses.

It is well-known that the Delta is food-limited (Jassby et al. 2002), and that primary and secondary productivity must increase in order for the Delta to sustain viable zooplankton and fish populations. However, much of the production in the Delta that could be utilized is located in the Southern Delta, in the San Joaquin River where phytoplankton blooms occur. In addition, much of this production occurs during the summer, when reverse flows that carry San Joaquin River water to export pumps are common (Jassby 2005). Therefore, most of this high quality organic matter is quickly exported out of the system, or contained upstream. One rehabilitation proposal, which has been discussed for several years, is to build channels that would carry water into the heart of the Delta, and thus enhance productivity. Two central concerns exist for this strategy. First, is the San Joaquin River water really of higher quality? Higher chlorophyll a, which has been used to characterize the San Joaquin River as such in previous studies (Jassby et al. 2002) is not always indicative of higher nutritional status, as phytoplankton species exist that are of poor nutritional quality (Müller-Solger et al. 2002). Increased frequency of toxic blooms of *Microcystis aeruginosa* (Cyanophyceae) in the San Joaquin River (Lehman et al. 2005) have also led to worries that food quality in the Delta may be adversely affected by such diversions. A second issue: do the pros of bringing in high-quality POC to the Delta outweigh the cons of potentially higher inputs of metals and pesticides from high agricultural inputs from the San Joaquin drainage basin? The first issue is easily addressed. Our findings indicate that polyunsaturated fatty acids, particularly those that are essential fatty acids for zooplankton growth and egg production, are significantly higher during summer blooms in the San Joaquin River. These results indicate that POM from the San Joaquin River is of higher quality, at least during time periods when *Microcystis* is not present in high abundances (Chapter 2). Therefore, water diverted to the Delta from the upper San Joaquin River could potentially contribute to Delta productivity. The second question is more complex and cannot be addressed using our current dataset. Our data could contribute to further understanding of this issue by developing hydrodynamic models that use data for organic carbon

quality, pesticides and metals together to estimate the effects of inputs. This type of model should be considered in future studies.

Our investigation of suspended particulate matter and sediments in shallow-water tidal habitats (Chapters 3 and 4) addressed a second strategy for Delta rehabilitation. The goal of current restoration plans is to create (10000) acres of new shallow-water habitat within the next decade (CALFED 2000), with the hopes that it will provide increased habitat for the spawning and recruitment of native fish species, such as Delta smelt and Sacramento splittail, which are in decline in the Delta (Bennett and Moyle 1996, Grimaldo et al. 2004). These sites have been the focus of intense study to determine whether rehabilitation will be able to yield consistently successful results, in terms of creating particular types of habitats (vegetated vs. open water), vegetation cover, primary productivity and subsequent habitation by native species (Lucas et al. 2002; Grimaldo et al. 2004). The findings of our study, as well as previous studies (Simenstad et al. 2000; Lucas et al. 2002; Toft et al. 2003) indicate that similar shallow-water habitats can not be created by simply re-flooding an existing agricultural tract. Shallow-water habitats are notoriously difficult to rehabilitate, as evidenced by similar restoration efforts in other systems (Florin and Montes 1999; Scasso et al. 2001; Eertman et al. 2002), with numerous factors contributing to the success of rehabilitation, including size, geomorphology, depth and interactions with outside water bodies, such as rivers (Lucas et al. 2002). The need for realistic, rather than idealized goals may therefore be a better approach to habitat rehabilitation (Ehrenfeld 2000). Other successful approaches include the use of reference sites, successional models, and functional trajectories to determine achievable rehabilitation goals (Parker 1997; Morgan and Short 2002; Neckles et al. 2002). Our research expanded previous efforts in the Delta by studying shallow-water sites that had not been previously studied (Little Holland Tract), and characterizing POC composition over longer time periods (2 years). Another unique aspect of our study was the analysis of POC and sediments. Our findings confirmed previous conclusions that shallow-water habitats in the Delta are heterogenous, dominated by different types of organic matter, and differing food quality (Lucas et al. 2002). It is important to consider the rehabilitation goals that are specific to a particular system. In the Delta, the goal is to increase system productivity, particularly at higher trophic levels (CALFED 2000).

Other restoration efforts seek to decrease productivity if eutrophication is an issue. Hence, POC and food quality are additional factors to consider in restoration efforts, as habitats with low-food quality will be of limited use in increasing fish populations. Also these sites exhibit temporal variability in POC sources and quality, thereby increasing the complexity at which shallow-water habitat rehabilitation needs to be addressed. The investigation of sediment organic carbon adds an additional dimension to rehabilitation efforts, providing information to address food quality for benthic invertebrates, and benthic-feeding native fish that may utilize these sites. It also provides an integrated view of organic matter composition and allows consideration of burial and preservation.

The sources, transformation and fate of organic carbon in estuaries are dependent on an extraordinarily complex set of factors (Hedges and Keil 1999; Kimmerer 2004). Future work studying organic carbon within the Delta should include studies on finer spatial and temporal scales, particularly in rehabilitated shallow-water habitats. These sites exhibit high spatial and temporal variability, even within sites, and a thorough understanding of the quality of organic carbon at these sites will only be possible when short-term factors such as tidal action are investigating concurrently with indicators of quality. There should also be a greater effort to characterize suspended particles and sediments concurrently in shallow lake-like systems, to determine the implications of rehabilitation efforts to the benthos and to obtain a whole-system perspective (Vadenbonceour et al. 2002). It would also be valuable to collect sediment cores in shallow-water habitats to examine past use of land and to develop restoration goals. Rehabilitated shallow-water habitats should also be measured periodically from inception, to fully understand how these sites develop, and to establish the timeframe needed for them to be established as relatively stable ecosystems (Kennison et al. 1998; Tanner et al. 2002). Few rehabilitation projects in California have been subject to post-project monitoring and evaluation (Kondolf 1998). However, monitoring and assessment of rehabilitated sites has proven to be a valuable tool in assessing rehabilitation goals in other systems (Piehler et al. 1998; Zedler and Callaway 1999; Craft et al. 2002). Finally, a thorough understanding of organic carbon dynamics in estuarine and coastal systems is essential for managing these systems and developing successful habitat rehabilitation programs in the future. The use of a multiple biomarker approach, incorporated into a

larger study of a system's biology (i.e. zooplankton, bioavailability), hydrology and chemistry is the best plan for addressing management issues in complex estuarine systems, not only the Sacramento-San Joaquin River Delta, but in estuaries world-wide.

REFERENCES

BENNETT, W. A., and P. B. MOYLE. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin Estuary, p. 519-542. In J. T. Hollibaugh [ed.], San Francisco Bay: the ecosystem. Pacific Division of the American Association for the Advancement of Science.

BERGAMASCHI, B.A., J.S. WALTERS, and J.I. HEDGES. 1999. Distributions of uronic acids and O-methyl sugars in sinking and sedimentary particles in two coastal marine environments. Geochim. Cosmochim. Acta. 63: 413-425.

COWIE, G. L., and J. I. HEDGES. 1992. Sources and reactivities of amino acids in a coastal marine environment. Limnol. Oceanogr.: 703-724.

CRAFT, C., S. BROOME, and C. CAMPBELL. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restor. Ecol. 10: 248-258.

DAUWE, B., and J. J. MIDDELBURG. 1998. Amino acids and hexosamines as indicators of organic matter degradation state in North Sea sediments. Limnol. Oceanogr. 43: 782-798.

EERTMANN, R. H. M., B. A. KORNMAN, E. STIKVOORT, and H. VERBEEK. 2002. Restoration of the Sieperda tidal marsh in the Scheldt Estuary, The Netherlands. Restor. Ecol. 10: 438-449.

EHRENFELD, J. G. 2000. Defining the limits of restoration: The need for realistic goals. Restor. Ecol. 8: 2-9.

FLORIN, M., and C. MONTES. 1999. Functional analysis and restoration of Mediterranean lagunas in the Mancha Humeda Biosphere Reserve (Central Spain). Aquatic Conserv.: Mar. Freshwat. Ecosyst. 9: 97-109.

GRIMALDO, L. F., R. E. MILLER, C. M. PEREGRIN, and Z. P. HYMANSON. 2004. Spatial and temporal distribution of native and alien ichthyoplankton in three habitat types of the Sacramento-San Joaquin Delta. Am. Fish. Society Symp. 39: 81-96.

HARVEY, H. R., and A. MANNINO. 2001. The chemical composition and cycling of particulate and macromolecular dissolved organic matter in temperate estuaries as revealed by molecular organic tracers. Org. Geochem. 32: 527-542.

HEDGES, J. I., and R. G. KEIL. 1999. Organic geochemical perspectives on estuarine processes: sorption reactions and consequences. Mar. Chem. 65: 55-65.

JASSBY, A. D., and J. E. CLOERN. 2000. Organic carbon sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic. Conserv.: Mar. Freshwat. Ecosyst. 10: 323-352.

JASSBY, A. D., J. E. CLOERN, and B. E. COLE. 2002. Annual primary production: Patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnol. Oceanogr. 47: 698-712.

JASSBY, A.D. 2005. Phytoplankton regulation in a eutrophic tidal river (San Joaquin River, California). San Francisco Estuary and Watershed Science (online serial). 3.

KEIL, R.G. and D.L. KIRCHMAN. 1993. Dissolved combined amino acids: Chemical form and utilization by marine bacteria. Limnol. Oceangr. 38:1256-1270.

KEIL, R. D., E. TSAMAKIS, J. C. GIDDINGS, and J. I. HEDGES. 1998. Biochemical distributions (amino acids, neutral sugars, and lignin phenols) among size-classes of modern marine sediments from the Washington coast. Geochim. Cosmochim. Acta 62: 1347-1364.

KENNISON, G. C. B., D. S. DUNSFORD, and J. SCHUTTEN. 1998. Stable or changing lakes? A classification of aquatic macrophyte assemblages from a eutrophic shallow lake system in the United Kingdom. Aquatic Conserv.: Mar. Freshwat. Ecosyst. 8: 669-684.

KIMMERER, W. 2004. Open Water Processes of the San Francisco Estuary: From Physical Forcing to Biological Responses. San Francisco Estuary and Watershed Science (online serial). 2.

KONDOLF, G.M. 1998. Lessons learned from river restoration in California. Aquatic Conserv.: Mar. Freshwat. Ecosyst. 8:39-52.

LEE, C., S. G. WAKEHAM, and C. ARNOSTI. 2004. Particulate organic matter in the sea: The composition conundrum. Ambio 33: 565-575.

LEHMAN. 2000. The influence of climate on phytoplankton community biomass in San Francisco Bay Estuary. Limnol. Oceanogr. 45: 580-590.

LEHMAN, P.W., G. BOYER, C. HALL, S. WALLER, and K. GERHTS. 2005. Distribution and toxicity of a new colonial *Microcystis aeruginosa* bloom in the San Francisco Bay Estuary, California. Hydrobiol. 541: 87-99.

LOPEZ, C.B., J.E. CLOERN, T.S. SCHRAGA, A.J. LITTLE, L.V. LUCAS, J.K. THOMPSON, and J.R. BURAU. In press. Ecological values of shallow-water habitats: Implications for restoration of disturbed ecosystems. Ecosystems.

LUCAS, L. V., J. E. CLOERN, J. K. THOMPSON, and N. E. MONSEN. 2002. Functional variability of habitats within the Sacramento-San Joaquin Delta: Restoration implications. Ecol. Appl. 12: 1528-1547.

MANNINO, A., and H. R. HARVEY. 1999. Lipid composition in particulate and dissolved organic matter in the Delaware Estuary: Sources and diagenetic patterns. Geochim. Cosmochim. Acta 63: 2219-2235.

MECKLER, A.N., C.J. SCHUBERT, G.L. COWIE, S. PEIFFER, and M. DITTRICH. 2004. New organic matter degradation proxies: Valid in lake systems? Limnol. Oceanogr. 49: 2023-2033.

MORGAN, P. A., and F. T. SHORT. 2002. Using functional trajectories to track constructed slat marsh development in the Great Bay Estuary, Maine/New Hampshire, U.S.A. Restor. Ecol. 10: 461-473.

MÜLLER-NAVARRA, D. 1995. Evidence that a highly unsaturated fatty acid limits *Daphnia* growth in nature. Arch. Hydrobiol. 132: 297-307.

MÜLLER-SOLGER, A. B., A. D. JASSBY, and D. C. MÜLLER-NAVARRA. 2002. Nutritional quality of food resources for zooplankton (*Daphnia*) in a tidal freshwater system (Sacramento-San Joaquin River Delta). Limnol. Oceanogr. 47: 1468-1476.

NECKLES, H.A., M. DIONNE, D.M. BURDICK, C.T. ROMAN, R. BUCHSBAUM, and E. HUTCHINS. A monitoring protocol to assess tidal restoration of salt marshes on local and regional scales. Restor. Ecol. 10: 556-563.

PANTOJA, S., and C. LEE. 2003. Amino acid remineralization and organic matter lability in Chilean coastal sediments. Org. Geochem. 34: 1047-1056.

PARKER, V. T. 1997. The scale of successional models and restoration objectives. Restoration Ecol. 5: 301-306.

PIEHLER, M.F., C.A. CURRIN, R. CASSANOVA and H.W. PAERL. 1998. Development and N_2-fixing activity of the benthic microbial community in transplanted *Spartina alterniflora* marshes in North Carolina. Restor. Ecol. 6: 290-296.

RAYMOND, P. A., and J. E. BAUER. 2001. Riverine export of aged terrestrial organic matter to the North Atlantic Ocean. Nature 409: 497-499.

SCASSO, F. and others 2001. Limnological changes in a subtropical shallow hypertrophic lake during its restoration: two years of a whole-lake experiment. Aquatic Conserv.: Mar. Freshwat. Ecosyst. 11: 31-44.

SIMENSTAD, C. and others 2000. Sacramento/San Joaquin Delta Breached Levee Wetland Study (BREACH), p. 45 pp. University of Washington.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, B. E. COLE, T. S. SCHRAGA, and A. ARNSBERG. 2005. Detritus fuels ecosystem metabolism but not metazoan food webs in San Francisco Estuary's freshwater Delta. Estuaries 28: 124-137.

SOBCZAK, W. V., J. E. CLOERN, A. D. JASSBY, and A. B. MÜLLER-SOLGER. 2002. Bioavailability of organic matter in a highly disturbed estuary: The role of detrital and algal resources. Proc. Natl. Acad. Sci. USA. 99: 8101-8105.

TANNER, C. D., J. R. CORDELL, J. RUBEY, and L. M. TEAR. 2002. Restoration of freshwater intertidal habitat functions at Spencer Island, Everett, Washington. Restor. Ecol. 10: 564-576.

TOFT, J. D., C. A. SIMENSTAD, J. R. CORDELL, and L. F. GRIMALDO. 2003. The effects of introduced water hyacinth on habitat structure, invertebrate assemblages and fish diets. Estuaries 26: 746-758.

VADEBONCOEUR, Y., M. J. VANDER ZANDEN, and D. M. LODGE. 2002. Putting the lake back together: reintegrating benthic pathways into lake food web models. Bioscience 52: 44-54.

ZEDLER, J.B., and J.C. CALLAWAY. 1999. Tracking wetland restoration: Do mitigation sites follow desired trajectories? Restor. Ecol. 7:69-73.

Table 1. Sites (listed as site abbreviations) corresponding to representative regions
of the Delta shown in Figure 1.

Representative Region	Site Abbreviation
Sacramento River	HD, RV
San Joaquin River	MM
Mixed River	TI
Recently Breached Shallow-Water Habitat	LH
Mature Shallow-Water Habitat	MI, FT
Water Export Site	CC
Natural Tidal Marsh	CS
X2	X2

Table 2. Compound names and abbreviations for compounds used for Principal
Components Analysis in Figure 2.

ID	Compound	Compound Abbreviation/ Common Name
	Biochemical	
A	Total Hydrolyzable Amino Acids/Protein	THAA/Prot
B	Total Carbohydrate	TCHO
C	Total Lipid	TLE
	Amino acids	
a	Glycine	GLY
b	Serine	SER
c	Threonine	THR
d	Alanine	ALA
e	Aspartic Acid	ASP
f	Glutamic Acid	GLU
	Lipids	
I	24-methylcholest-5-en-3β-ol	CAMP
II	24-ethylcholesta-5,22-dien-3β-ol	STIG
III	24-ethycholest-5-en-3β-ol	$C_{29}\Delta^5$
IV	cholest-5-en-3β-ol	CHOL
V	24-methylcholest-5,22-dien-3β-ol	BRAS
1	Even Long-Chained Fatty Acids (C_{22}-C_{32})	LCFA
2	Iso- and anteiso- 15:0 and 17:0 fatty acids	Br15,17
3	tetradecanoic acid	14:0
4	hexadecanoic acid	16:0
5	octadecanoic acid	18:0
6	hexadecenoic acid	16:1ω7
7	octadecenoic acid	18:1ω9c
8	hexadecadienoic and hexadecatrienoic acids	16:2/3
9	hexadecatetraenoic acid	16:4
10	octadecadienoic and octadecatrienoic acids	18:2/3
11	octadecatetranoic acid	18:4
12	eicosapentaenoic acid	20:5ω3
VI	chlorophyll a	Chl *a*

Table 3. Scores and loadings for PCA analysis shown in Fig. 2.

(a) Scores for PC 1 and 2

	PC 1	PC 2
GLY	0.07	0.96
ALA	0.03	0.97
ASP	0.35	0.74
GLU	0.48	0.75
SER	0.11	0.96
THR	0.18	0.95
THAA/Prot	0.25	0.71
TCHO	0.50	0.31
TLE	0.54	0.31
STIG	0.29	0.41
$C_{29}D^5$	0.37	0.26
CAMP	0.84	0.29
CHOL	0.41	0.22
BRAS	0.57	0.22
LCFA	0.06	0.24
BrFA	0.33	0.31
14:0	0.76	0.14
16:0	0.58	0.15
18:0	0.05	0.24
16:1w7	0.76	0.19
18:1w9	0.53	0.09
16:2/3	0.86	0.12
16:4	0.73	-0.12
18:2/3	0.75	-0.03
18:4	0.47	0.21
20:5w3	0.86	0.08
Chl a	0.94	0.08

(b) Loadings for PC 1 and 2

	PC 1	PC 2		PC 1	PC 2
HD0199	-0.25	-0.46	LH0599	-0.95	-0.17
HD0299	-0.70	-2.59	LH0799	-0.19	-0.51
HD0599	0.33	-0.28	LH1099	0.45	-0.12
HD0799	-0.23	-0.04	LH0400	0.07	-0.57
HD1099	0.02	1.67	LH0700	-0.08	0.34
HD0200	-0.30	0.98	MI0599	0.84	-1.32
HD0400	1.11	0.14	MI0799	0.12	0.27
HD0700	0.35	0.41	MI1099	0.16	2.07
RV0599	0.33	-0.72	MI0400	0.96	0.45
RV0799	-0.31	0.01	MI0700	0.03	0.32
RV1099	-0.03	-1.27	FT0599	0.40	-1.55
RV0200	-0.75	0.29	FT0799	-0.20	-0.12
RV0400	1.09	0.51	FT1099	0.17	0.19
RV0700	-0.02	-0.01	FT0400	1.29	0.46
MM0199	1.97	-0.86	FT0700	0.81	-0.38
MM0299	-0.31	1.16	CC0599	-0.30	0.37
MM0599	1.04	1.17	CC0799	-0.60	0.40
MM0799	2.53	0.73	CC0400	-0.20	0.10
MM1099	1.37	0.04	CS0199	-0.84	-1.41
MM0200	-0.56	0.65	CS0599	0.19	-0.43
MM0400	1.95	-1.08	CS0799	-0.49	-0.51
MM0700	3.01	0.69	CS1099	-0.13	1.43
TI0199	-1.24	-2.24	CS0200	-1.95	1.56
TI0299	-1.47	-2.05	CS0400	-1.35	0.10
TI0599	-0.11	-2.31	CS0700	0.28	0.08
TI0799	-0.29	0.43	X20199	-1.63	-0.69
TI1099	-0.23	-0.27	X20799	-0.81	0.11
TI0200	-1.42	1.73	X21099	-0.13	0.14
TI0700	-0.23	0.56	X20200	-1.56	0.89
			X20400	0.82	-0.51
			X20700	-1.77	1.03

Fig. 1. The fraction of POC identified, and chemical composition of POC collected in eight representative regions of the Sacramento-San Joaquin River Delta from October 1998 to July 2000. Pie charts on the left represent the characterizable (open) and uncharacterizable (filled) fractions of POC. Pie charts on the right represent portions of the characterizable fractions that can be identified as protein (THAA-Protein), carbohydrate, and lipid (TLE, of which fatty acids and sterols are components).

33.5%
Sacramento River
46.0%
66.5%

26.2%
⊞ THAA-Protein
☐ Lipid (FA+Sterol)
▨ Carbohydrate
27.8%

40.5%
San Joaquin River
47.3%
59.5%

25.2%
27.5%

29.5%
Mixed River
41.6%
70.5%

25.0%
33.4%

29.3% Recently breached
Shallow-water
habitat   42.0%
70.7%

22.4%
35.6%

48.0% Mature
Shallow-water
Habitat   36.7%
52.0%

23.3%
40.0%

31.7%
Water Export
Site   33.7%
68.3%

19.8%
46.5%

23.9%
Natural tidal
Marsh
48.0%
76.1%

28.9%
23.1%

19.5%
X2
48.8%
80.5%

32.5%
18.7%
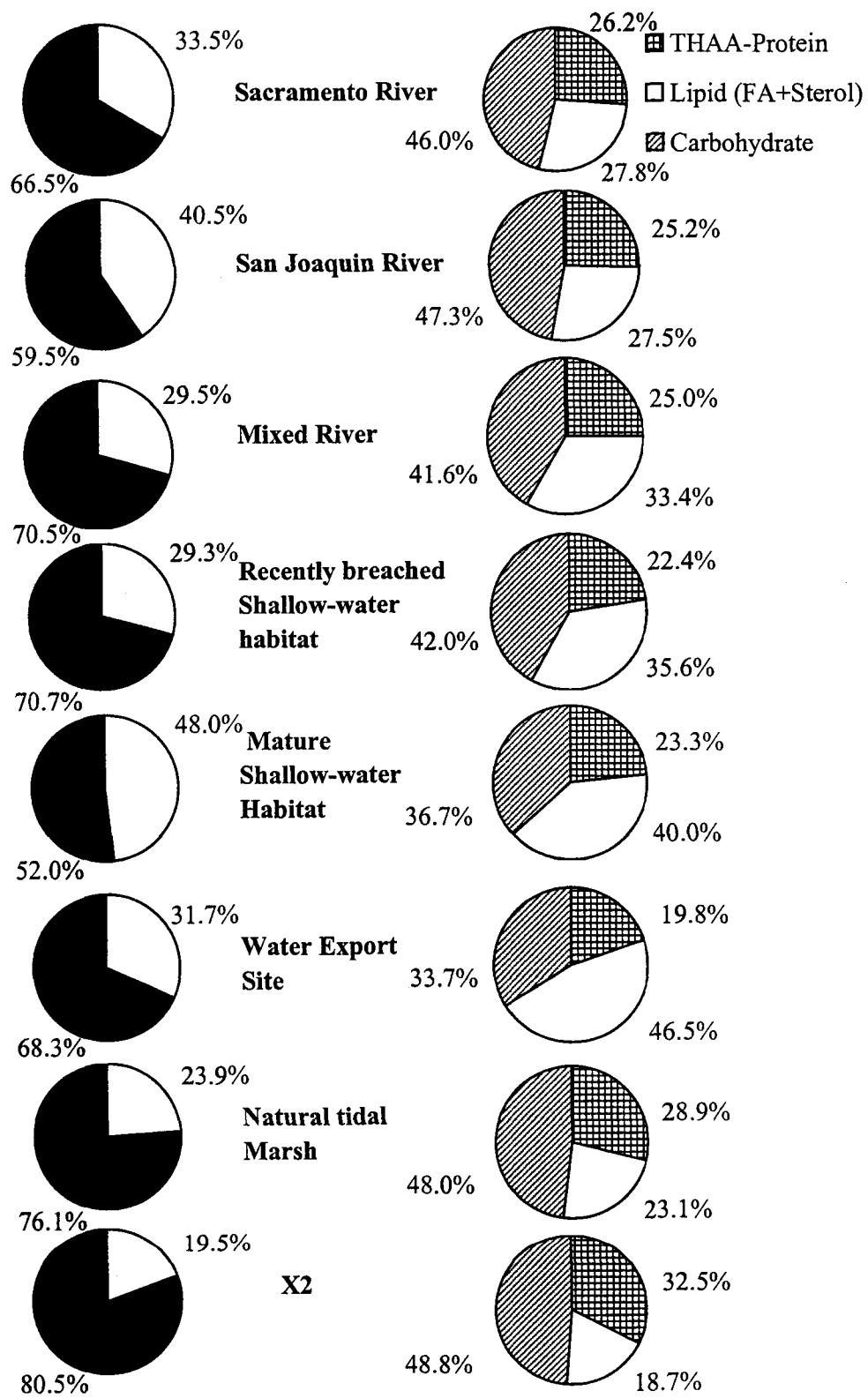
Fig. 2. (a) Loadings and (b) scores for principal components analysis of biochemical, lipid biomarker (sterols and fatty acids), chlorophyll and select protein amino acid data for all sites and sampling dates in the Delta, as $\mu g\ mg^{-1}$ OC. PC 1 accounted for 28.4% of the variability in the dataset while PC 2 accounted for 26.8%. See Table 2 for compound identification. Error bars represent standard error of the mean.

(A)

More degraded/
less nutritious

Less degraded/
more nutritious

(B)

River: ◆ HD   ◇ RV   ◆ MM   ◈ TI
SWH: ■ LH   □ MI   ▣ FT
Water Export: ○ CC
Tidal Marsh: ▲ CS
Northern Bay: △ X2
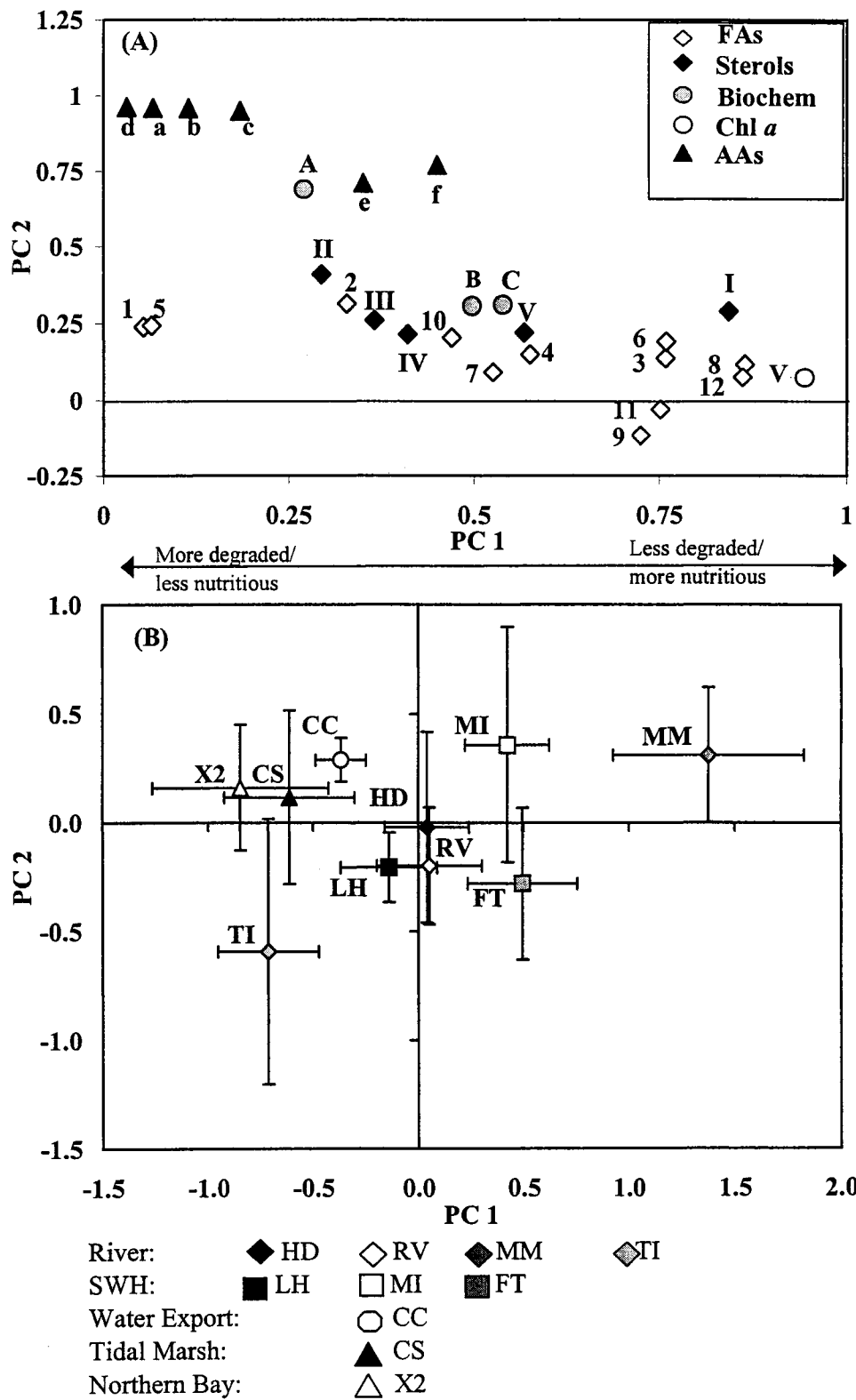
APPENDICES

Appendix A. Sterol concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

					Site HD				
Component	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
C14OH	NA	540.19	963.12	573.20	750.02	683.08	1373.72	733.77	635.85
C16OH	NA	77.28	196.22	89.21	57.74	61.60	220.16	101.43	71.36
C18OH	NA	86.05	194.16	80.74	105.02	130.06	237.32	85.94	81.96
Phytol	NA	1013.87	653.77	848.07	632.47	539.56	485.46	1654.67	961.82
C19OH	NA	1363.77	2109.65	1100.99	1586.76	1513.67	3140.05	1715.86	1437.06
C20OH	NA	29.30	91.29	24.35	37.44	21.00	66.21	28.19	35.75
C22OH	NA	114.52	386.40	138.31	129.73	117.30	555.90	49.37	59.47
C24OH	NA	40.17	102.08	21.90	42.28	25.44	64.34	44.43	52.85
C26OH	NA	46.45	171.52	20.50	44.36	25.19	124.79	54.70	55.85
5α cholestane	NA	271.11	367.89	261.43	263.78	244.00	548.24	292.80	241.98
24-norcholesta-5,22-dien-3β-ol	NA	9.42	13.35	9.13	9.20	8.57	19.68	8.56	7.95
24-nor-5α-cholesta-22-en-3β-ol	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5β-cholestan-3β-ol	NA	12.30	28.52	49.38	11.25	42.36	25.75	52.99	42.40
5β-cholestan-3α-ol	NA	4.85	25.96	22.50	5.86	3.65	30.05	5.52	6.85
27-nor-24-methylcholesta-5,22-dien-3β-ol	NA	7.51	0.00	4.14	3.03	0.00	0.00	7.94	3.47
cholesta-5,22-dien-3β-ol	NA	68.33	93.82	57.85	69.85	55.85	88.43	85.44	82.12
5α(H)-cholest-22-en-3β-ol	NA	0.00	0.00	0.00	4.80	0.00	0.00	5.44	5.76
cholest-5-en-3β-ol	NA	288.80	627.86	309.56	276.19	241.78	612.85	415.34	372.53
5α-cholestan-3β-ol	NA	33.28	151.45	38.41	37.82	38.32	112.12	51.66	86.11
24-methylcholesta-5,22-dien-3β-ol	NA	166.84	175.66	78.98	143.17	99.58	164.77	188.65	169.94
24-methylcholest-22-en-3β-ol	NA	13.56	22.98	7.10	15.84	9.86	37.79	10.72	18.41
4α-methylcholest-8(14)-3-en-3β-ol	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-methylcholesta-5,24(28)-dien-3β-ol	NA	84.70	84.22	58.92	82.17	55.43	64.51	127.45	116.58
24-methylcholest-5-en-3β-ol	NA	107.62	141.71	132.54	95.69	77.82	273.62	294.69	121.54
24-methyl-5α(H)-cholestan-3β-ol	NA	23.78	41.22	0.00	17.53	13.76	0.00	25.00	16.69
23,24-dimethylcholesta-5,22-dien-3β-ol	NA	7.34	0.00	4.15	21.85	10.73	0.00	10.76	25.12
24-ethylcholesta-5,22-dien-3β-ol	NA	125.07	158.17	89.41	100.98	72.56	174.66	135.93	148.17
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	NA	0.00	14.59	0.00	0.00	0.00	13.90	0.00	0.00
24-ethyl-5α(H)-cholest-22-en-3β-ol	NA	10.72	14.89	5.66	9.14	5.06	10.67	9.39	9.49
4-methyl-C29-D22-stanol	NA	5.12	9.83	7.95	6.84	3.07	8.22	10.24	4.44
23,24-dimethylcholest-5-en-3β-ol	NA	10.22	13.44	12.86	19.67	12.43	0.00	22.89	17.23
24-ethylcholest-5-en-3β-ol	NA	421.22	611.59	206.66	189.88	157.14	550.41	373.66	283.21
24-ethyl-5α(H)-cholest-3β-ol	NA	46.21	75.77	20.02	30.57	22.09	69.67	33.08	36.41
24-ethylcholesta-5,24(28)-dien-3β-ol	NA	29.34	60.73	15.09	26.45	18.33	38.24	46.41	41.51
4α,23,24-trimethylcholest-22-en-3β-ol	NA	15.41	0.00	10.13	18.96	9.28	39.72	18.82	21.20
24-ethylcholestan-7-en-3β-ol	NA	25.10	37.26	23.59	24.76	21.03	0.00	38.39	23.65
5α(H)-C29 stenol (possibly D7or D8)	NA	13.52	0.00	6.71	9.52	7.35	0.00	14.55	16.66
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	NA	13.28	0.00	5.59	12.59	4.64	0.00	8.46	24.64
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	NA	7.42	17.65	0.00	13.02	13.93	13.43	11.16	20.50
hopan-3β-ol	NA	3.92	15.98	0.00	5.07	3.50	9.76	7.57	12.52
extended hopanol	NA	4.36	0.00	0.00	4.58	0.00	0.00	0.00	4.53
Total Alcohols	NA	1476.08	1923.38	1280.24	1118.56	977.60	1912.22	2165.27	1407.22
Total Sterols	NA	1559.26	2436.66	1176.31	1266.30	1008.13	2358.25	2020.72	1739.63

NA= not available

Appendix A, ctd Sterol concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Site RV

Component	Oct-98	Oct-98 (2)	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
C14OH	1023.47	1003.88	NA	NA	618.39	541.58	436.03	645.40	572.74	600.07
C16OH	327.44	109.68	NA	NA	69.86	47.37	42.86	122.87	51.21	26.16
C18OH	189.94	111.86	NA	NA	68.09	60.00	66.58	94.19	54.77	201.63
Phytol	282.10	481.74	NA	NA	847.17	675.23	690.13	740.15	1267.73	654.70
C19OH	1341.04	1529.31	NA	NA	1052.20	1276.39	806.39	1010.38	1164.70	1275.27
C20OH	57.77	32.17	NA	NA	18.70	26.80	20.20	40.21	16.66	16.83
C22OH	224.39	222.03	NA	NA	266.70	211.57	208.49	429.57	100.93	104.98
C24OH	46.34	41.41	NA	NA	38.68	40.87	41.08	93.24	38.40	31.23
C26OH	31.46	18.42	NA	NA	45.67	42.49	40.16	318.93	51.02	36.59
5α cholestane	96.00	84.80	NA	NA	190.98	194.17	160.69	258.89	88.43	83.43
24-norcholesta-5,22-dien-3β-ol	8.90	13.53	NA	NA	9.08	8.13	8.03	16.86	9.30	7.44
24-nor-5α-cholesta-22-en-3β-ol	1.90	4.87	NA	NA	6.72	0.00	7.20	0.00	16.73	6.80
5β-cholestan-3β-ol	13.06	35.74	NA	NA	21.04	20.31	11.70	24.75	26.68	14.58
5β-cholestan-3α-ol	19.92	0.00	NA	NA	26.94	17.64	14.13	24.49	38.64	17.59
27-nor-24-methylcholesta-5,22-dien-3β-ol	2.08	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
cholesta-5,22-dien-3β-ol	63.74	78.28	NA	NA	80.92	116.67	69.72	106.10	116.03	108.03
5α(H)-cholest-22-en-3β-ol	1.32	4.73	NA	NA	0.00	4.55	4.14	0.00	7.62	6.22
cholest-5-en-3β-ol	373.73	301.27	NA	NA	318.65	301.49	229.59	564.43	407.03	240.99
5α-cholestan-3β-ol	45.72	51.71	NA	NA	60.22	36.05	54.10	246.67	88.51	27.73
24-methylcholesta-5,22-dien-3β-ol	115.65	140.83	NA	NA	175.45	150.37	137.35	213.30	299.50	132.87
24-methylcholest-22-en-3β-ol	22.37	10.52	NA	NA	11.97	18.31	10.89	32.80	19.69	14.26
4α-methylcholest-8(14)-3-en-3β-ol	9.40	12.30	NA	NA	0.00	5.16	0.00	0.00	11.82	10.45
24-methylcholesta-5,24(28)-dien-3β-ol	58.55	23.37	NA	NA	51.26	83.51	58.91	110.47	114.46	80.14
24-methylcholest-5-en-3β-ol	60.06	71.30	NA	NA	112.27	95.13	55.04	190.60	211.49	97.88
24-methyl-5α(H)-cholestan-3β-ol	3.52	40.30	NA	NA	0.00	18.27	14.81	69.03	25.24	18.29
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	12.40	14.05
24-ethylcholesta-5,22-dien-3β-ol	78.79	94.26	NA	NA	96.05	89.88	53.33	255.25	137.23	83.52
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	8.65	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
24-ethyl-5α(H)-cholest-22-en-3β-ol	0.00	9.10	NA	NA	0.00	7.97	0.00	22.41	11.04	10.27
4-methyl-C29-D22-stanol	0.00	5.89	NA	NA	11.48	14.93	7.62	17.54	21.44	21.67
23,24-dimethylcholest-5-en-3β-ol	1.06	9.24	NA	NA	0.00	0.00	0.00	11.28	11.75	4.55
24-ethylcholest-5-en-3β-ol	167.90	129.45	NA	NA	223.71	170.89	120.77	748.85	323.34	144.68
24-ethyl-5α(H)-cholest-3β-ol	11.12	71.02	NA	NA	24.60	18.98	19.98	104.04	31.41	26.20
24-ethylcholesta-5,24(28)-dien-3β-ol	44.15	54.08	NA	NA	19.33	18.98	23.26	79.28	44.00	23.10
4α,23,24-trimethylcholest-22-en-3β-ol	0.00	13.00	NA	NA	0.00	0.00	0.00	9.17	12.76	5.93
24-ethylcholestan-7-en-3β-ol	15.28	20.35	NA	NA	16.62	17.46	10.73	44.75	29.68	20.36
5α(H)-C29 stenol (possibly D7or D8)	1.10	3.59	NA	NA	0.00	0.00	0.00	0.00	5.21	7.82
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	1.10	6.10	NA	NA	0.00	5.25	4.75	12.43	13.45	7.62
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	5.65	6.66	NA	NA	0.00	11.09	6.32	18.62	12.04	12.40
hopan-3β-ol	1.63	4.86	NA	NA	0.00	0.00	6.28	18.47	12.69	6.13
extended hopanol	0.00	2.72	NA	NA	0.00	4.30	4.76	7.83	9.11	9.21
Total Alcohols	1245.03	1085.97	NA	NA	1424.93	1170.08	1171.32	1968.46	1637.78	1120.72
Total Sterols	1136.33	1219.10	NA	NA	1266.30	1235.33	933.39	2949.43	2080.86	1180.78

NA= not available

Appendix A, ctd. Sterol concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98	Jan-99	Feb-99	May-99	Site MM Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
C14OH	785.55	723.81	1489.89	868.76	721.77	774.26	1534.65	880.79	886.25
C16OH	107.87	152.82	27.84	74.39	145.82	115.49	198.95	133.91	170.19
C18OH	83.06	102.86	161.04	64.40	106.58	101.81	388.10	104.30	385.70
Phytol	2222.55	2760.28	975.19	1848.57	11004.50	4096.89	1037.45	6487.05	24231.95
C19OH	852.31	1062.52	2206.31	1696.01	1243.65	1594.52	3617.11	2056.52	1874.86
C20OH	37.32	33.70	47.23	32.10	36.21	49.93	94.74	59.84	56.75
C22OH	138.70	299.57	467.32	239.02	488.27	272.25	717.65	134.27	387.68
C24OH	33.34	23.95	41.95	42.94	26.63	63.45	135.47	163.56	68.45
C26OH	26.78	24.80	59.17	38.28	23.99	65.50	227.71	99.12	104.92
5α cholestane	150.53	266.29	532.57	298.24	266.29	338.91	665.71	124.59	135.42
24-norchlolesta-5,22-dien-3β-ol	12.19	11.61	19.05	10.46	21.62	13.45	23.41	21.73	23.57
24-nor-5α-cholesta-22-en-3β-ol	6.85	26.30	9.67	6.58	0.00	22.95	0.00	4.84	6.84
5β-cholestan-3β-ol	29.11	92.86	48.86	44.47	12.82	34.34	87.01	51.47	17.55
5β-cholestan-3α-ol	19.33	40.94	24.13	24.00	11.27	19.35	57.63	18.69	15.08
27-nor-24-methylcholesta-5,22-dien-3β-ol	4.43	32.36	14.03	0.00	0.00	10.75	0.00	0.00	13.21
cholesta-5,22-dien-3β-ol	42.90	121.15	79.17	80.39	122.12	133.37	106.27	168.27	165.58
5α(H)-cholest-22-en-3β-ol	26.63	12.78	0.00	8.09	0.00	12.18	12.40	0.00	0.00
cholest-5-en-3β-ol	248.05	920.32	706.11	603.11	1278.64	974.15	857.87	875.14	1184.12
5α-cholestan-3β-ol	197.43	187.66	158.80	123.61	116.05	206.30	338.90	275.96	174.06
24-methylcholesta-5,22-dien-3β-ol	167.64	280.25	249.98	360.48	784.94	535.05	239.82	695.57	1250.27
24-methylcholest-22-en-3β-ol	23.46	342.23	41.48	38.94	216.47	154.65	45.81	281.47	93.07
4α-methylcholest-8(14)-3-en-3β-ol	14.56	76.58	0.00	0.00	84.62	0.00	67.50	43.33	44.66
24-methylcholesta-5,24(28)-dien-3β-ol	131.23	219.58	37.58	22.71	775.04	272.04	180.77	207.17	53.07
24-methylcholest-5-en-3β-ol	219.08	556.30	332.49	545.63	4018.96	640.22	281.57	1122.06	7412.75
24-methyl-5α(H)-cholestan-3β-ol	203.94	285.19	217.86	180.11	0.00	145.38	423.53	91.63	0.00
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-ethylcholesta-5,22-dien-3β-ol	329.90	376.42	185.31	189.76	551.94	424.98	256.54	380.62	503.86
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	6.92	11.84	9.92	0.00	20.99	21.25	15.28	0.00	24.12
24-ethyl-5α(H)-cholest-22-en-3β-ol	16.53	54.26	15.81	32.93	38.72	47.05	45.72	57.80	35.04
4-methyl-C29-D22-stanol	42.38	85.05	22.44	37.82	89.78	79.12	33.00	163.15	169.50
23,24-dimethylcholest-5-en-3β-ol	5.66	20.30	0.00	21.47	29.99	12.85	0.00	129.09	99.98
24-ethylcholest-5-en-3β-ol	581.96	1398.50	753.84	607.34	1256.92	701.38	1067.81	991.78	2229.44
24-ethyl-5α(H)-cholest-3β-ol	123.25	250.98	177.16	140.13	99.16	126.59	265.95	122.92	70.41
24-ethylcholesta-5,24(28)-dien-3β-ol	4.60	64.82	36.79	51.31	148.41	69.42	238.82	163.03	537.10
4α,23,24-trimethylcholest-22-en-3β-ol	18.48	26.47	0.00	13.86	0.00	21.86	193.76	40.84	68.13
24-ethylcholestan-7-en-3β-ol	27.99	207.61	95.11	89.51	79.99	85.66	13.24	259.35	169.99
5α(H)-C29 stenol (possibly D7or D8)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.72	74.24
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	4.78	0.00	0.00	0.00	0.00	13.18	17.33	44.92	15.30
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	8.34	10.50	14.66	9.83	22.93	25.41	22.03	27.17	44.74
hopan-3β-ol	11.30	16.15	0.00	0.00	0.00	9.39	32.72	23.49	17.44
extended hopanol	5.10	12.39	0.00	7.98	13.45	17.71	0.00	20.56	0.00
Total Alcohols	2716.10	3521.14	1948.88	2434.01	11945.63	4870.74	3084.45	7445.57	25636.62
Total Sterols	2534.01	5741.38	3250.25	3250.52	9794.83	4830.04	4924.69	6286.77	14513.10

ND= not detectable

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Appendix A, ctd. Sterol concentrations (ng L-1) in suspended particles, seasonal sampling (1998-2000).

Component		Site TI								
	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00	Jul-00 (2)
C14OH	NA	679.94	882.79	751.78	455.95	504.53	1374.96	NA	185.05	381.26
C16OH	NA	118.93	214.78	74.40	43.86	90.38	149.89	NA	44.37	50.40
C18OH	NA	146.28	216.38	57.07	53.88	162.39	163.47	NA	93.17	107.15
Phytol	NA	493.63	343.58	612.55	359.29	471.08	308.32	NA	643.11	720.29
C19OH	NA	1590.07	1888.96	1503.98	743.02	1168.70	3229.33	NA	927.76	1102.78
C20OH	NA	53.07	84.17	20.73	16.76	42.37	64.32	NA	24.55	23.35
C22OH	NA	235.77	324.32	216.01	207.43	164.72	590.53	NA	347.96	250.87
C24OH	NA	47.35	71.16	34.25	18.72	25.53	77.13	NA	27.31	25.40
C26OH	NA	33.55	117.98	21.87	8.30	13.08	159.14	NA	19.49	16.78
5α cholestane	NA	233.00	332.86	296.25	217.10	233.11	582.50	NA	217.10	256.22
24-norcholesta-5,22-dien-3β-ol	NA	9.30	12.68	7.86	35.85	6.35	21.01	NA	13.07	8.82
24-nor-5α-cholesta-22-en-3β-ol	NA	0.00	0.00	0.00	3.82	21.70	0.00	NA	0.00	0.00
5β-cholestan-3β-ol	NA	16.85	23.11	8.50	14.35	4.56	21.50	NA	6.75	8.46
5β-cholestan-3α-ol	NA	8.85	18.49	5.33	12.06	3.39	24.93	NA	6.11	4.96
27-nor-24-methylcholesta-5,22-dien-3β-ol	NA	4.83	5.84	0.00	4.21	0.00	0.00	NA	0.00	0.00
cholesta-5,22-dien-3β-ol	NA	51.23	60.89	43.05	137.20	54.65	87.30	NA	55.70	69.04
5α(H)-cholest-22-en-3β-ol	NA	0.00	0.00	0.00	7.38	0.00	0.00	NA	0.00	7.90
cholest-5-en-3β-ol	NA	326.50	489.27	280.11	293.14	360.43	460.51	NA	323.68	350.85
5α-cholestan-3β-ol	NA	55.53	137.12	34.18	25.11	36.10	153.07	NA	46.47	45.57
24-methylcholesta-5,22-dien-3β-ol	NA	182.25	106.84	173.97	152.60	174.14	120.11	NA	164.19	195.53
24-methylcholest-22-en-3β-ol	NA	17.32	23.41	12.85	22.61	18.32	23.68	NA	20.67	21.86
4α-methylcholest-8(14)-3-en-3β-ol	NA	35.59	18.61	0.00	0.00	0.00	25.34	NA	7.07	0.00
24-methylcholesta-5,24(28)-dien-3β-ol	NA	0.00	69.44	35.51	48.59	50.63	89.32	NA	70.79	81.44
24-methylcholest-5-en-3β-ol	NA	75.10	93.04	86.81	94.73	54.78	108.38	NA	126.97	172.93
24-methyl-5α(H)-cholestan-3β-ol	NA	29.13	95.47	0.00	6.81	11.46	99.98	NA	0.00	18.68
23,24-dimethylcholesta-5,22-dien-3β-ol	NA	0.00	0.00	4.70	0.00	4.17	0.00	NA	6.47	8.01
24-ethylcholesta-5,22-dien-3β-ol	NA	78.34	121.46	41.24	78.30	45.14	171.21	NA	69.46	81.66
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	NA	5.21	7.97	0.00	0.00	0.00	13.25	NA	0.00	0.00
24-ethyl-5α(H)-cholest-22-en-3β-ol	NA	5.50	17.17	3.76	6.03	0.00	15.61	NA	0.00	0.00
4-methyl-C29-D22-stanol	NA	3.82	21.49	5.71	13.28	11.78	9.71	NA	8.15	10.32
23,24-dimethylcholest-5-en-3β-ol	NA	0.00	0.00	0.00	24.76	0.00	0.00	NA	0.00	0.00
24-ethylcholest-5-en-3β-ol	NA	246.74	402.10	125.53	162.01	111.31	477.51	NA	149.32	181.08
24-ethyl-5α(H)-cholest-3β-ol	NA	43.88	83.40	22.21	37.39	19.64	95.94	NA	26.44	30.08
24-ethylcholesta-5,24(28)-dien-3β-ol	NA	17.71	62.04	14.88	13.84	14.50	63.43	NA	18.23	24.22
4α,23,24-trimethylcholest-22-en-3β-ol	NA	0.00	8.79	0.00	8.76	0.00	42.16	NA	0.00	9.72
24-ethylcholestan-7-en-3β-ol	NA	17.33	38.32	10.26	26.33	10.72	0.00	NA	12.66	15.36
5α(H)-C29 stenol (possibly D7or D8)	NA	0.00	0.00	3.78	4.73	4.28	0.00	NA	0.00	0.00
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	NA	10.61	8.89	0.00	12.47	5.91	13.86	NA	0.00	7.01
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	NA	0.00	9.16	0.00	7.36	0.00	0.00	NA	0.00	5.51
hopan-3β-ol	NA	0.00	14.62	0.00	7.02	0.00	14.02	NA	0.00	0.00
extended hopanol	NA	6.76	0.00	3.61	19.11	5.46	0.00	NA	0.00	5.43
Total Alcohols	NA	1206.55	1516.77	1070.10	758.08	1009.42	1649.60	NA	1221.16	1220.33
Total Sterols	NA	1248.36	1949.61	923.84	1279.85	1029.42	2151.82	NA	1132.22	1364.44

NA = not available

Appendix A, ctd. Sterol concentrations (ng L⁻¹) in suspended particles, seasonal sampling (1998-2000).

Component					Site LH				
	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
C14OH	2861.61	NA	NA	1215.90	1502.92	1176.91	NA	1471.33	1941.73
C16OH	134.61	NA	NA	153.73	142.95	97.34	NA	124.69	128.95
C18OH	101.66	NA	NA	190.81	215.71	152.89	NA	189.27	161.92
Phytol	1458.37	NA	NA	1797.71	2947.57	1923.41	NA	2353.16	2365.72
C19OH	3477.39	NA	NA	2770.32	3450.20	2757.97	NA	3119.25	3918.77
C20OH	46.74	NA	NA	94.86	101.82	48.72	NA	62.12	82.11
C22OH	655.92	NA	NA	896.35	1040.31	782.44	NA	1011.39	418.07
C24OH	79.94	NA	NA	102.14	128.97	51.81	NA	78.33	123.75
C26OH	53.21	NA	NA	70.70	66.40	31.10	NA	65.07	124.93
5α cholestane	248.20	NA	NA	406.67	488.00	375.38	NA	488.00	522.86
24-norchlolesta-5,22-dien-3β-ol	43.42	NA	NA	18.81	20.79	14.31	NA	19.31	23.07
24-nor-5α-cholesta-22-en-3β-ol	0.00	NA	NA	28.94	18.33	6.08	NA	49.01	11.71
5β-cholestan-3β-ol	34.37	NA	NA	19.13	15.02	9.40	NA	14.64	20.37
5β-cholestan-3α-ol	0.00	NA	NA	18.24	22.26	16.53	NA	26.65	7.66
27-nor-24-methylcholesta-5,22-dien-3β-ol	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
cholesta-5,22-dien-3β-ol	227.81	NA	NA	234.27	548.31	168.08	NA	212.82	379.23
5α(H)-cholest-22-en-3β-ol	0.00	NA	NA	15.92	24.89	11.13	NA	13.24	0.00
cholest-5-en-3β-ol	690.91	NA	NA	1152.22	1283.71	607.83	NA	1017.36	813.65
5α-cholestan-3β-ol	135.71	NA	NA	151.51	174.58	79.69	NA	143.35	223.99
24-methylcholesta-5,22-dien-3β-ol	499.25	NA	NA	564.48	620.11	482.59	NA	513.35	382.04
24-methylcholest-22-en-3β-ol	91.03	NA	NA	92.31	93.02	41.12	NA	70.57	66.12
4α-methylcholest-8(14)-3-en-3β-ol	0.00	NA	NA	287.38	252.48	176.99	NA	340.41	205.40
24-methylcholesta-5,24(28)-dien-3β-ol	146.93	NA	NA	60.04	83.11	36.70	NA	66.21	27.91
24-methylcholest-5-en-3β-ol	298.59	NA	NA	223.02	386.83	216.16	NA	210.18	329.59
24-methyl-5α(H)-cholestan-3β-ol	63.83	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	11.57
24-ethylcholesta-5,22-dien-3β-ol	194.20	NA	NA	216.54	458.59	165.44	NA	239.91	236.99
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	0.00	NA	NA	20.08	31.21	19.53	NA	27.00	12.95
24-ethyl-5α(H)-cholest-22-en-3β-ol	0.00	NA	NA	33.65	51.55	20.42	NA	34.31	35.68
4-methyl-C29-D22-stanol	0.00	NA	NA	59.87	118.92	53.21	NA	64.86	24.43
23,24-dimethylcholest-5-en-3β-ol	0.00	NA	NA	26.39	18.17	7.45	NA	30.81	23.54
24-ethylcholest-5-en-3β-ol	481.75	NA	NA	562.10	745.07	330.88	NA	592.38	540.42
24-ethyl-5α(H)-cholest-3β-ol	149.04	NA	NA	100.97	146.14	62.39	NA	98.53	100.39
24-ethylcholesta-5,24(28)-dien-3β-ol	0.00	NA	NA	43.03	55.63	33.71	NA	55.91	86.88
4α,23,24-trimethylcholest-22-en-3β-ol	0.00	NA	NA	0.00	45.06	0.00	NA	26.21	11.27
24-ethylcholestan-7-en-3β-ol	0.00	NA	NA	60.16	90.86	31.73	NA	69.97	17.94
5α(H)-C29 stenol (possibly D7or D8)	0.00	NA	NA	0.00	29.46	13.06	NA	9.21	0.00
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	0.00	NA	NA	15.79	20.47	13.06	NA	19.77	10.84
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	0.00	NA	NA	33.25	55.03	22.52	NA	32.94	16.87
hopan-3β-ol	0.00	NA	NA	10.71	33.09	9.17	NA	12.41	20.02
extended hopanol	0.00	NA	NA	25.45	34.51	12.50	NA	23.51	32.54
Total Alcohols	2562.57	NA	NA	3534.66	4938.78	3274.28	NA	4192.31	3733.45
Total Sterols	3056.84	NA	NA	4074.26	5477.20	2661.68	NA	4034.84	3673.10

NA = not available

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Appendix A, ctd. Sterol concentrations (ng L⁻¹) in suspended particles, seasonal sampling (1998-2000).

Site MI

Component	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct 99-1	Oct 99-3	Feb-00	Apr-00-1	Apr-00-2	Apr-00-3	Jul-00-1	Jul-00-2	Jul-00-3
C14OH	822.13	NA	NA	563.54	649.07	682.17	708.71	NA	1114.05	726.08	880.78	868.26	988.96	890.63
C16OH	130.39	NA	NA	64.45	99.16	123.41	64.08	NA	103.53	107.56	86.52	71.81	63.92	121.20
C18OH	96.87	NA	NA	59.73	97.09	97.93	62.50	NA	134.77	105.35	85.74	261.74	82.35	100.17
Phytol	1904.70	NA	NA	1109.39	967.03	8758.82	1709.41	NA	6935.56	1581.55	1863.07	1662.55	1050.97	1189.47
C19OH	949.20	NA	NA	1159.99	1141.61	1588.84	1623.04	NA	2637.48	1592.77	1989.64	1955.08	2142.21	2041.40
C20OH	38.69	NA	NA	36.37	27.46	31.62	34.48	NA	45.70	29.91	35.23	30.62	28.69	38.02
C22OH	259.66	NA	NA	191.47	219.73	507.75	233.42	NA	173.89	124.31	158.06	150.49	176.11	153.52
C24OH	245.41	NA	NA	133.51	64.99	32.61	50.81	NA	146.39	65.37	95.00	59.98	57.02	65.74
C26OH	12.03	NA	NA	14.64	38.32	28.96	43.33	NA	63.73	41.08	67.21	39.13	43.26	48.79
5α cholestane	84.80	NA	NA	248.53	271.13	273.61	281.36	NA	271.11	252.41	305.00	305.00	344.47	301.86
24-norcholesta-5,22-dien-3β-ol	10.88	NA	NA	36.37	10.81	21.25	18.83	NA	21.70	9.54	12.13	11.67	11.11	16.97
24-nor-5α-cholesta-22-en-3β-ol	2.25	NA	NA	0.00	0.00	0.00	11.08	NA	1.18	0.00	0.00	0.00	0.00	0.00
5β-cholestan-3β-ol	4.05	NA	NA	4.35	6.24	0.00	3.61	NA	15.23	7.97	6.16	9.07	10.58	13.29
5β-cholestan-3α-ol	5.09	NA	NA	6.27	0.00	0.00	11.25	NA	0.00	7.78	20.03	6.68	4.69	8.43
27-nor-24-methylcholesta-5,22-dien-3β-ol	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
cholesta-5,22-dien-3β-ol	73.31	NA	NA	62.50	103.75	127.99	108.45	NA	288.43	58.60	108.10	118.90	67.97	157.56
5α(H)-cholest-22-en-3β-ol	7.05	NA	NA	0.00	0.00	0.00	11.45	NA	12.22	0.00	4.40	5.40	0.00	11.29
cholest-5-en-3β-ol	570.24	NA	NA	665.30	492.27	1107.16	698.54	NA	1661.66	422.88	621.09	851.17	534.96	1179.81
5α-cholestan-3β-ol	59.82	NA	NA	56.34	80.36	206.59	157.79	NA	118.35	58.33	89.84	88.01	44.40	135.69
24-methylcholesta-5,22-dien-3β-ol	305.99	NA	NA	176.95	329.53	2661.39	516.54	NA	1720.79	532.66	366.82	392.75	178.98	521.87
24-methylcholest-22-en-3β-ol	111.77	NA	NA	128.69	25.00	95.11	43.34	NA	45.76	15.85	23.27	29.74	19.88	42.92
4α-methylcholest-8(14)-3-en-3β-ol	23.38	NA	NA	24.35	10.07	29.68	17.09	NA	9.69	10.19	13.52	10.60	6.82	11.01
24-methylcholesta-5,24(28)-dien-3β-ol	150.85	NA	NA	60.56	114.56	468.84	122.70	NA	297.50	63.53	70.60	245.27	78.49	132.83
24-methylcholest-5-en-3β-ol	331.91	NA	NA	186.43	120.80	716.33	194.55	NA	1127.79	173.42	290.97	341.52	117.71	348.73
24-methyl-5α(H)-cholestan-3β-ol	18.22	NA	NA	6.07	24.28	40.90	45.80	NA	20.04	22.65	0.00	31.51	23.92	47.68
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
24-ethylcholesta-5,22-dien-3β-ol	245.59	NA	NA	60.21	154.99	984.49	309.90	NA	286.02	65.66	110.41	208.07	105.69	246.50
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
24-ethyl-5α(H)-cholest-22-en-3β-ol	10.93	NA	NA	15.76	0.00	35.84	19.84	NA	26.84	8.75	14.12	11.89	0.00	21.32
4-methyl-C29-D22-stanol	4.21	NA	NA	29.18	19.32	27.60	68.59	NA	41.83	0.00	10.11	0.00	0.00	0.00
23,24-dimethylcholest-5-en-3β-ol	25.04	NA	NA	33.22	0.00	56.39	6.90	NA	50.28	30.00	23.29	56.03	28.11	59.22
24-ethylcholest-5-en-3β-ol	540.78	NA	NA	215.98	207.15	1460.49	591.95	NA	616.77	143.71	258.76	437.68	163.46	397.59
24-ethyl-5α(H)-cholest-3β-ol	27.98	NA	NA	17.27	25.20	56.33	54.02	NA	43.09	23.42	37.95	32.94	24.29	45.93
24-ethylcholesta-5,24(28)-dien-3β-ol	40.50	NA	NA	48.37	38.91	129.59	76.12	NA	192.50	57.26	78.17	124.67	26.61	198.26
4α,23,24-trimethylcholest-22-en-3β-ol	9.48	NA	NA	21.90	0.00	48.63	36.12	NA	44.01	16.42	6.95	25.94	5.49	34.66
24-ethylcholestan-7-en-3β-ol	27.11	NA	NA	31.02	24.51	49.95	48.95	NA	68.76	21.79	34.63	46.01	31.04	62.16
5α(H)-C29 stenol (possibly D7or D8)	1.93	NA	NA	0.00	0.00	0.00	17.32	NA	0.00	4.79	14.54	0.00	0.00	0.00
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	8.77	NA	NA	3.12	0.00	17.60	23.95	NA	16.68	10.83	13.08	12.45	10.58	20.71
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	26.92	NA	NA	4.05	11.20	49.88	59.55	NA	25.23	9.67	16.62	18.11	7.71	21.68
hopan-3β-ol	7.82	NA	NA	4.28	0.00	0.00	17.21	NA	15.67	8.37	13.19	14.19	15.15	21.10
extended hopanol	1.64	NA	NA	6.69	9.51	0.00	15.56	NA	12.05	0.00	14.93	12.37	0.00	25.81
Total Alcohols	2754.29	NA	NA	1675.10	1708.81	9697.01	2276.96	NA	7708.77	2106.29	2465.66	2350.45	1571.90	1798.31
Total Sterols	2653.50	NA	NA	1905.26	1808.47	8392.05	3307.00	NA	6780.06	1784.05	2273.67	3142.65	1517.65	3783.03

NA = not available

Appendix A, ctd. Sterol concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00 (Site FT)	Apr-00-1	Apr-00-2	Apr-00-3	Jul-00-1	Jul-00-2	Jul-00-3
C14OH	1006.80	NA	NA	746.27	832.04	711.46	NA	720.10	543.23	781.03	753.18	734.33	803.14
C16OH	173.34	NA	NA	87.61	92.02	70.15	NA	72.14	59.48	57.39	70.34	78.97	83.30
C18OH	122.96	NA	NA	124.75	97.41	97.02	NA	75.71	76.94	90.62	101.99	89.47	258.01
Phytol	725.96	NA	NA	1037.99	1084.68	767.23	NA	929.11	1103.30	993.20	1033.51	1069.07	985.04
C19OH	1144.73	NA	NA	1710.86	1933.42	1702.09	NA	1891.74	1392.97	1868.80	1756.25	1716.28	1911.99
C20OH	25.94	NA	NA	38.12	44.70	35.31	NA	29.87	29.11	31.99	43.74	43.87	49.34
C22OH	225.99	NA	NA	301.18	278.68	266.81	NA	280.06	212.95	267.94	129.10	134.71	152.43
C24OH	26.22	NA	NA	78.19	101.70	45.30	NA	70.20	54.78	50.12	50.09	49.93	49.37
C26OH	6.61	NA	NA	49.58	62.63	35.26	NA	55.36	26.38	22.06	37.15	30.77	31.29
5α cholestane	84.80	NA	NA	254.18	249.64	231.07	NA	247.43	199.71	254.18	236.13	240.00	244.00
24-norcholesta-5,22-dien-3β-ol	2.71	NA	NA	9.39	9.78	8.67	NA	9.75	7.06	8.31	7.47	10.42	8.05
24-nor-5α-cholesta-22-en-3β-ol	0.00	NA	NA	0.00	0.00	9.55	NA	0.00	0.00	0.00	0.00	0.00	0.00
5β-cholestan-3β-ol	2.20	NA	NA	12.35	14.87	8.61	NA	10.31	4.74	0.00	9.51	8.46	8.14
5β-cholestan-3α-ol	0.93	NA	NA	6.30	7.38	5.43	NA	8.47	4.97	0.00	10.75	7.13	5.94
27-nor-24-methylcholesta-5,22-dien-3β-ol	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
cholesta-5,22-dien-3β-ol	14.04	NA	NA	36.50	60.65	49.91	NA	36.99	28.09	25.46	50.88	42.50	45.78
5α(H)-cholest-22-en-3β-ol	14.81	NA	NA	0.00	4.63	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
cholest-5-en-3β-ol	232.43	NA	NA	390.64	442.99	356.77	NA	246.75	251.32	227.51	412.67	396.42	461.81
5α-cholestan-3β-ol	162.36	NA	NA	73.44	55.59	65.61	NA	72.99	43.71	38.22	72.10	32.58	66.40
24-methylcholesta-5,22-dien-3β-ol	324.18	NA	NA	273.29	235.94	231.82	NA	397.76	522.43	635.06	237.55	305.01	272.14
24-methylcholest-22-en-3β-ol	13.12	NA	NA	20.70	23.01	15.42	NA	19.31	11.62	12.19	25.90	21.48	22.38
4α-methylcholest-8(14)-3-en-3β-ol	7.55	NA	NA	0.00	0.00	0.00	NA	5.48	0.00	0.00	7.73	9.55	5.28
24-methylcholesta-5,24(28)-dien-3β-ol	81.56	NA	NA	59.00	72.76	63.18	NA	49.02	30.05	22.65	67.70	44.31	46.87
24-methylcholest-5-en-3β-ol	82.91	NA	NA	124.88	96.88	65.24	NA	74.52	67.81	58.61	144.46	140.95	156.16
24-methyl-5α(H)-cholestan-3β-ol	3.79	NA	NA	0.00	5.89	17.55	NA	22.90	0.00	0.00	19.46	16.09	13.55
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	NA	NA	6.35	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
24-ethylcholesta-5,22-dien-3β-ol	71.00	NA	NA	56.03	83.24	63.01	NA	43.84	32.13	27.24	73.49	58.72	50.53
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
24-ethyl-5α(H)-cholest-22-en-3β-ol	2.67	NA	NA	9.77	7.30	0.00	NA	4.23	0.00	0.00	0.00	8.49	0.00
4-methyl-C29-D22-stanol	0.00	NA	NA	0.00	0.00	9.44	NA	0.00	3.63	0.00	0.00	3.26	27.70
23,24-dimethylcholest-5-en-3β-ol	16.78	NA	NA	17.72	38.67	0.00	NA	0.00	0.00	0.00	22.20	26.13	6.74
24-ethylcholest-5-en-3β-ol	74.69	NA	NA	157.26	206.66	151.66	NA	119.69	101.75	77.16	177.95	122.35	126.49
24-ethyl-5α(H)-cholest-3β-ol	48.06	NA	NA	35.62	33.39	25.01	NA	25.42	12.65	9.18	26.41	18.86	16.34
24-ethylcholesta-5,24(28)-dien-3β-ol	10.00	NA	NA	32.21	36.29	23.43	NA	32.56	22.77	19.16	40.26	36.66	39.83
4α,23,24-trimethylcholest-22-en-3β-ol	7.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	11.29	8.98	8.63
24-ethylcholestan-7-en-3β-ol	5.34	NA	NA	16.26	30.67	13.15	NA	12.27	7.59	8.81	26.49	24.89	26.33
5α(H)-C29 stenol (possibly D7or D8)	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	6.94	8.39	7.35
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	0.00	NA	NA	0.00	5.33	0.00	NA	0.00	0.00	0.00	6.65	4.41	4.22
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	3.27	NA	NA	0.00	7.78	4.87	NA	0.00	0.00	0.00	8.32	4.79	5.19
lopan-3β-ol	1.47	NA	NA	0.00	5.26	6.04	NA	0.00	5.51	7.86	6.15	7.52	7.45
extended hopanol	5.31	NA	NA	7.99	9.26	6.17	NA	0.00	0.00	0.00	9.49	4.14	0.00
Total Alcohols	1444.69	NA	NA	1809.77	1857.74	1391.35	NA	1591.29	1621.62	1577.08	1525.70	1555.63	1671.68
Total Sterols	1188.17	NA	NA	1345.68	1494.22	1200.52	NA	1192.27	1157.83	1177.44	1481.80	1372.46	1439.30

NA = not available

Appendix A, ctd. Sterol concentrations (ng L⁻¹) in suspended particles, seasonal sampling (1998-2000).

Component					Site CC				
	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
C14OH	1114.75	NA	NA	645.25	718.32	NA	NA	558.37	NA
C16OH	91.71	NA	NA	87.10	82.45	NA	NA	85.98	NA
C18OH	89.13	NA	NA	88.79	86.62	NA	NA	94.83	NA
Phytol	1420.95	NA	NA	1195.25	1036.87	NA	NA	1562.84	NA
C19OH	1296.46	NA	NA	1574.25	1664.64	NA	NA	1689.87	NA
C20OH	56.18	NA	NA	51.70	80.83	NA	NA	76.68	NA
C22OH	246.13	NA	NA	113.10	110.59	NA	NA	123.55	NA
C24OH	28.71	NA	NA	61.28	73.98	NA	NA	116.33	NA
C26OH	39.50	NA	NA	25.58	42.49	NA	NA	68.57	NA
5α cholestane	91.68	NA	NA	287.06	271.11	NA	NA	281.54	NA
24-norcholesta-5,22-dien-3β-ol	11.92	NA	NA	7.97	7.98	NA	NA	16.08	NA
24-nor-5α-cholesta-22-en-3β-ol	11.95	NA	NA	6.42	3.70	NA	NA	7.70	NA
5β-cholestan-3β-ol	41.99	NA	NA	32.06	5.99	NA	NA	4.41	NA
5β-cholestan-3α-ol	1.80	NA	NA	6.95	12.25	NA	NA	10.88	NA
27-nor-24-methylcholesta-5,22-dien-3β-ol	17.58	NA	NA	0.00	3.25	NA	NA	0.00	NA
cholesta-5,22-dien-3β-ol	44.68	NA	NA	88.10	81.72	NA	NA	61.60	NA
5α(H)-cholest-22-en-3β-ol	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
cholest-5-en-3β-ol	446.37	NA	NA	521.36	379.79	NA	NA	494.40	NA
5α-cholestan-3β-ol	101.38	NA	NA	40.68	103.65	NA	NA	92.99	NA
24-methylcholesta-5,22-dien-3β-ol	373.98	NA	NA	275.71	286.40	NA	NA	593.55	NA
24-methylcholest-22-en-3β-ol	77.45	NA	NA	34.66	45.54	NA	NA	32.49	NA
4α-methylcholest-8(14)-3-en-3β-ol	60.51	NA	NA	141.09	71.75	NA	NA	0.00	NA
24-methylcholesta-5,24(28)-dien-3β-ol	147.59	NA	NA	192.94	71.39	NA	NA	78.86	NA
24-methylcholest-5-en-3β-ol	352.24	NA	NA	197.60	111.72	NA	NA	248.58	NA
24-methyl-5α(H)-cholestan-3β-ol	88.14	NA	NA	0.00	33.30	NA	NA	31.46	NA
23,24-dimethylcholesta-5,22-dien-3β-ol	1.55	NA	NA	8.76	8.61	NA	NA	8.31	NA
24-ethylcholesta-5,22-dien-3β-ol	295.26	NA	NA	126.69	200.48	NA	NA	122.77	NA
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	91.19	NA	NA	3.96	8.23	NA	NA	0.00	NA
24-ethyl-5α(H)-cholest-22-en-3β-ol	38.35	NA	NA	15.44	9.10	NA	NA	14.67	NA
4-methyl-C29-D22-stanol	14.01	NA	NA	21.71	74.21	NA	NA	37.72	NA
23,24-dimethylcholest-5-en-3β-ol	52.87	NA	NA	19.39	7.66	NA	NA	0.00	NA
24-ethylcholest-5-en-3β-ol	524.85	NA	NA	388.07	316.16	NA	NA	322.39	NA
24-ethyl-5α(H)-cholest-3β-ol	100.25	NA	NA	43.95	68.37	NA	NA	81.75	NA
24-ethylcholesta-5,24(28)-dien-3β-ol	22.71	NA	NA	9.26	34.43	NA	NA	28.90	NA
4α,23,24-trimethylcholest-22-en-3β-ol	8.39	NA	NA	8.58	24.08	NA	NA	7.31	NA
24-ethylcholestan-7-en-3β-ol	17.78	NA	NA	40.62	26.36	NA	NA	24.24	NA
5α(H)-C29 stenol (possibly D7 or D8)	51.97	NA	NA	0.00	10.10	NA	NA	0.00	NA
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	10.32	NA	NA	0.00	7.44	NA	NA	10.01	NA
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	6.93	NA	NA	8.26	14.43	NA	NA	19.54	NA
hopan-3β-ol	4.00	NA	NA	6.52	13.67	NA	NA	24.35	NA
extended hopanol	11.62	NA	NA	9.07	17.32	NA	NA	19.24	NA
Total Alcohols	2060.41	NA	NA	1686.68	1615.09	NA	NA	2192.26	NA
Total Sterols	3029.64	NA	NA	2255.83	2059.09	NA	NA	2394.19	NA

NA = not available

Appendix A, ctd. Sterol concentrations (ng L⁻¹) in suspended particles, seasonal sampling (1998-2000).

Site CS

Component	Oct-98	Jan-99	Jan-99 (2)	Feb-00	May-99	Jul-99	Oct-99	Oct-99 (2)	Feb-00	Feb-00 (2)	Apr-00	Apr-00 (2)	Jul-00	Jul-00 (2)
C14OH	589.07	787.04	1352.51	NA	1081.81	1695.40	1028.97	670.85	1339.11	2150.64	1067.03	1666.34	956.13	585.28
C16OH	346.13	119.23	155.49	NA	83.51	69.11	58.46	42.25	527.07	155.23	68.19	93.12	82.53	49.59
C18OH	212.11	136.68	184.44	NA	94.40	99.10	67.95	76.23	331.08	155.94	85.57	106.79	99.39	61.04
Phytol	3702.71	1343.89	1786.67	NA	2479.86	1751.12	1180.43	854.41	1398.61	1060.89	1028.77	972.06	3249.48	1280.78
C19OH	502.93	765.25	2979.56	NA	1391.78	1824.77	1281.33	1453.11	1923.56	4541.05	2548.35	3382.37	2182.04	1295.83
C20OH	106.89	62.17	90.78	NA	79.02	51.45	55.91	31.25	157.28	98.61	66.35	74.60	67.62	35.19
C22OH	605.31	251.23	409.29	NA	155.11	222.35	235.98	219.06	1262.77	468.84	180.92	310.74	149.30	171.54
C24OH	156.53	249.83	95.68	NA	300.91	199.75	249.53	44.41	372.11	141.13	152.18	78.13	254.10	76.02
C26OH	90.14	245.07	54.07	NA	176.76	133.97	143.48	25.61	671.07	185.36	128.94	46.88	87.89	21.67
5α cholestane	237.66	327.27	325.33	NA	327.27	450.00	303.16	177.45	601.29	627.43	166.86	439.20	116.80	141.68
24-norcholesta-5,22-dien-3β-ol	313.55	176.13	281.76	NA	104.38	101.63	55.63	67.16	53.39	44.55	23.45	130.48	124.58	55.28
24-nor-5α-cholesta-22-en-3β-ol	10.04	24.41	22.70	NA	11.81	13.61	7.52	10.83	25.49	16.73	98.10	16.94	12.93	7.21
5β-cholestan-3β-ol	20.09	12.09	30.22	NA	9.52	0.00	4.43	3.15	56.93	84.12	25.24	21.59	10.02	3.95
5β-cholestan-3α-ol	11.86	33.88	17.23	NA	23.06	12.29	19.13	0.00	0.00	21.11	17.74	15.82	8.24	2.71
27-nor-24-methylcholesta-5,22-dien-3β-ol	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	5.45	0.00	0.00	0.00
cholesta-5,22-dien-3β-ol	591.52	163.18	276.44	NA	133.59	111.57	99.76	78.18	177.14	214.70	182.17	222.62	214.00	94.46
5α(H)-cholest-22-en-3β-ol	35.18	13.42	258.84	NA	12.56	13.70	12.34	8.60	0.00	20.60	22.86	20.07	19.20	7.43
cholest-5-en-3β-ol	948.48	562.53	848.35	NA	939.51	671.82	643.38	445.98	1239.19	1275.50	609.13	844.19	1330.32	593.96
5α-cholestan-3β-ol	261.41	275.65	170.58	NA	218.38	244.48	125.55	68.53	498.87	261.52	225.99	168.95	208.10	72.91
24-methylcholesta-5,22-dien-3β-ol	1505.99	409.85	346.42	NA	791.87	335.62	286.77	193.97	394.27	460.38	340.40	453.50	574.15	246.20
24-methylcholest-22-en-3β-ol	132.75	50.23	80.60	NA	116.14	92.53	92.19	53.68	139.43	150.89	97.06	123.09	126.28	53.49
4α-methylcholest-8(14)-3-en-3β-ol	24.08	0.00	19.73	NA	21.59	30.07	16.38	9.18	0.00	19.12	23.82	13.78	16.50	4.47
24-methylcholesta-5,24(28)-dien-3β-ol	569.33	217.22	296.73	NA	234.38	232.39	172.50	141.94	302.60	309.31	156.11	181.36	282.33	117.17
24-methylcholest-5-en-3β-ol	573.86	309.87	396.62	NA	334.22	329.35	213.06	178.02	331.94	412.02	228.68	274.76	284.58	126.25
24-methyl-5α(H)-cholestan-3β-ol	102.35	20.54	82.89	NA	16.22	13.91	12.55	31.93	125.01	123.42	30.65	92.28	20.67	19.84
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-ethylcholesta-5,22-dien-3β-ol	1336.01	665.12	893.69	NA	237.89	467.87	145.22	249.68	567.01	652.81	386.16	529.55	207.23	89.98
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-ethyl-5α(H)-cholest-22-en-3β-ol	54.96	67.18	92.49	NA	44.09	50.94	26.38	32.66	55.23	70.89	65.64	77.87	34.74	13.36
4-methyl-C29-D22-stanol	75.71	22.57	33.89	NA	31.61	18.10	11.84	20.55	25.04	36.02	54.00	24.55	83.22	35.07
23,24-dimethylcholest-5-en-3β-ol	16.60	41.34	70.86	NA	64.61	21.87	47.18	19.51	45.57	61.45	24.35	59.67	40.64	14.96
24-ethylcholest-5-en-3β-ol	1850.54	1118.19	1535.76	NA	584.71	449.44	369.74	251.32	1355.11	1529.98	1614.73	658.99	417.87	185.58
24-ethyl-5α(H)-cholest-3β-ol	275.31	163.91	218.20	NA	148.74	107.60	107.60	58.20	264.33	282.22	512.12	185.17	99.94	42.85
24-ethylcholesta-5,24(28)-dien-3β-ol	69.79	140.03	80.58	NA	108.92	468.76	95.17	264.79	181.66	126.67	107.67	85.51	161.74	55.65
4α,23,24-trimethylcholest-22-en-3β-ol	116.98	24.98	64.32	NA	32.67	36.85	29.61	118.43	48.50	82.87	82.44	61.33	14.08	15.53
24-ethylcholestan-7-en-3β-ol	19.48	259.58	112.83	NA	74.92	200.64	23.30	23.67	104.68	149.26	88.09	87.12	83.89	29.61
5α(H)-C29 stenol (possibly D7 or D8)	0.00	61.42	120.17	NA	0.00	12.70	4.74	18.66	0.00	31.57	45.53	0.00	19.27	2.28
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	19.89	18.52	34.38	NA	15.83	0.00	10.69	7.42	25.52	43.01	64.44	23.23	19.42	2.15
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	28.68	25.95	35.93	NA	47.10	17.78	37.88	8.98	34.75	50.32	60.84	25.80	23.21	8.12
hopan-3β-ol	19.80	63.08	54.60	NA	43.76	32.82	40.83	12.97	64.33	42.27	80.56	33.97	35.78	12.48
extended hopanol	93.65	32.11	47.34	NA	44.97	35.44	34.86	20.00	48.37	51.93	42.29	55.53	36.35	15.70
Total Alcohols	5472.55	2573.40	2935.38	NA	3528.77	2656.90	2115.61	1356.70	5113.72	2456.38	1845.42	1817.61	4146.75	1763.61
Total Sterols	9077.88	4972.97	6524.13	NA	4447.06	4123.77	2746.25	2398.03	6164.37	6625.21	5315.74	4487.72	4509.29	1928.65

NA = not available

Appendix A, ctd. Sterol concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Site X2

Component	Oct-98	Jan-99	Jan-99 (2)	Feb-99	May-99	Jul-99	Oct-99	Oct-99 (2)	Feb-00 (NF)*	Feb-00 (F)*	Apr-00	Jul-00
C14OH	731.67	1065.64	721.56	NA	801.76	960.60	648.20	619.69	1210.92	1158.86	871.79	705.60
C16OH	141.69	100.97	134.06	NA	108.94	96.74	38.72	45.03	314.32	91.58	133.93	45.81
C18OH	114.74	349.18	148.22	NA	115.23	88.54	67.25	58.95	282.19	107.66	121.00	78.31
Phytol	871.80	755.38	444.81	NA	1519.32	934.25	527.73	441.72	361.03	376.61	3820.17	441.61
C19OH	665.58	1174.84	1414.59	NA	1582.45	1880.05	1422.11	1295.57	2458.09	1994.11	1371.93	1641.96
C20OH	62.63	34.87	56.25	NA	49.10	63.58	31.45	29.48	97.16	44.67	69.59	49.05
C22OH	355.93	162.23	272.25	NA	616.58	546.35	325.68	351.66	648.17	843.00	1821.94	147.49
C24OH	83.95	82.93	75.09	NA	67.87	75.80	34.33	19.87	61.10	74.05	117.58	87.24
C26OH	41.99	89.20	56.84	NA	41.74	17.88	20.22	16.06	45.70	94.28	77.32	75.52
5α cholestane	177.42	342.86	331.38	NA	185.18	148.25	111.54	108.44	209.14	216.96	399.08	129.78
24-norcholesta-5,22-dien-3β-ol	55.02	54.75	68.95	NA	47.71	15.35	11.49	13.57	14.70	68.79	46.57	6.97
24-nor-5α-cholesta-22-en-3β-ol	197.05	17.37	0.00	NA	18.92	63.62	91.35	82.83	327.29	22.37	372.77	78.10
5β-cholestan-3β-ol	42.97	21.87	25.09	NA	26.42	36.94	12.94	11.01	38.48	44.54	63.70	21.59
5β-cholestan-3α-ol	50.22	11.77	9.45	NA	14.41	12.27	15.91	14.61	24.45	26.52	56.24	13.86
27-nor-24-methylcholesta-5,22-dien-3β-ol	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cholesta-5,22-dien-3β-ol	213.04	43.40	55.49	NA	140.85	128.01	81.20	76.66	307.70	181.86	313.15	93.26
5α(H)-cholest-22-en-3β-ol	23.93	0.00	0.00	NA	6.36	16.19	8.74	7.44	19.09	19.09	24.64	8.95
cholest-5-en-3β-ol	561.95	216.45	353.63	NA	524.67	472.79	334.33	321.94	1190.68	572.85	1866.73	340.77
5α-cholestan-3β-ol	114.15	95.09	82.67	NA	73.49	110.73	61.35	48.54	134.16	138.94	195.45	122.55
24-methylcholesta-5,22-dien-3β-ol	328.29	140.06	157.73	NA	342.89	229.26	185.16	153.95	190.83	219.98	404.70	171.55
24-methylcholest-22-en-3β-ol	50.90	16.80	25.14	NA	29.03	58.18	30.22	23.81	175.21	39.36	304.94	36.67
4α-methylcholest-8(14)-3-en-3β-ol	37.83	0.00	0.00	NA	16.99	14.17	15.42	11.53	48.97	23.84	65.79	31.26
24-methylcholesta-5,24(28)-dien-3β-ol	24.70	55.30	47.09	NA	98.23	164.53	103.29	91.58	172.75	65.78	514.78	70.53
24-methylcholest-5-en-3β-ol	260.99	59.19	58.75	NA	325.53	289.68	126.87	109.12	364.91	151.22	1060.00	102.85
24-methyl-5α(H)-cholestan-3β-ol	206.63	0.00	36.62	NA	30.20	20.14	21.89	20.00	31.30	22.66	174.67	28.33
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	0.00	0.00	NA	0.00	0.00	0.00	13.83	0.00	0.00	41.85	16.55
24-ethylcholesta-5,22-dien-3β-ol	170.62	60.94	72.08	NA	92.28	121.55	69.79	62.71	184.27	189.04	246.05	90.05
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-ethyl-5α(H)-cholest-22-en-3β-ol	28.74	0.00	0.00	NA	17.43	25.61	15.43	12.96	5.64	31.45	38.06	90.05
4-methyl-C29-D22-stanol	0.00	0.00	0.00	NA	10.04	18.86	7.58	0.00	11.55	38.60	23.06	16.97
23,24-dimethylcholest-5-en-3β-ol	34.53	0.00	0.00	NA	7.62	15.06	30.48	10.85	79.73	16.84	47.60	14.68
24-ethylcholest-5-en-3β-ol	376.27	188.62	209.80	NA	258.69	185.00	149.53	137.50	642.31	543.30	1041.42	220.47
24-ethyl-5α(H)-cholest-3β-ol	152.47	41.34	45.89	NA	53.23	132.76	45.77	42.94	43.41	103.01	201.75	72.76
24-ethylcholesta-5,24(28)-dien-3β-ol	43.47	83.52	48.96	NA	37.43	20.07	43.36	36.65	150.79	44.08	230.30	102.76
4α,23,24-trimethylcholest-22-en-3β-ol	14.37	0.00	0.00	NA	30.65	22.05	29.12	24.28	18.19	32.69	101.49	64.59
24-ethylcholest-7-en-3β-ol	90.29	0.00	13.43	NA	28.60	34.32	26.96	21.53	34.92	44.22	74.88	39.28
5α(H)-C29 stenol (possibly D7or D8)	0.00	0.00	0.00	NA	25.90	10.90	27.49	21.32	10.21	24.55	42.40	37.65
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	44.99	9.04	0.00	NA	10.47	9.02	14.56	12.62	8.97	22.93	21.86	31.09
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	26.84	7.69	0.00	NA	13.08	14.44	19.02	16.54	17.34	25.47	44.35	20.41
hopan-3β-ol	30.32	24.48	0.00	NA	18.33	32.04	11.38	12.10	16.16	27.26	67.46	60.29
extended hopanol	50.58	7.49	8.94	NA	20.41	38.72	19.23	21.64	26.51	21.03	77.27	38.12
Total Alcohols	1876.96	1671.52	1283.98	NA	2673.60	1996.32	1129.55	1047.19	2005.28	1860.78	6510.59	1036.96
Total Sterols	3231.16	1155.16	1319.71	NA	2319.83	2312.28	1609.86	1434.06	4290.53	2762.24	7763.90	2042.94

NA = not available

Note: (F)* = filtered through 100 micron mesh, (NF)* = not filtered

Appendix A, ctd. Sterol concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
					Site PS				
C14OH	660.19	1323.81	1129.22	945.74	NA	NA	994.65	NA	NA
C16OH	132.47	174.57	107.19	84.88	NA	NA	31.66	NA	NA
C18OH	102.39	214.88	148.64	116.46	NA	NA	146.60	NA	NA
Phytol	2164.95	657.87	1346.03	1555.05	NA	NA	625.16	NA	NA
C19OH	619.69	3145.41	2563.18	2457.10	NA	NA	2140.06	NA	NA
C20OH	34.27	69.11	43.42	60.42	NA	NA	45.30	NA	NA
C22OH	553.37	478.29	404.78	407.77	NA	NA	337.68	NA	NA
C24OH	44.55	63.86	36.69	72.39	NA	NA	50.22	NA	NA
C26OH	26.13	75.28	24.43	42.88	NA	NA	64.95	NA	NA
5α cholestane	203.70	444.38	418.24	364.62	NA	NA	360.00	NA	NA
24-norchlolesta-5,22-dien-3β-ol	6.30	11.71	9.53	7.66	NA	NA	6.33	NA	NA
24-nor-5α-cholesta-22-en-3β-ol	30.69	0.00	21.80	25.99	NA	NA	0.00	NA	NA
5β-cholestan-3β-ol	9.40	8.07	32.06	20.95	NA	NA	4.14	NA	NA
5β-cholestan-3α-ol	0.00	7.96	7.38	10.86	NA	NA	4.16	NA	NA
27-nor-24-methylcholesta-5,22-dien-3β-ol	0.00	8.52	37.69	13.29	NA	NA	4.59	NA	NA
cholesta-5,22-dien-3β-ol	115.39	80.54	105.35	160.88	NA	NA	49.26	NA	NA
5α(H)-cholest-22-en-3β-ol	204.10	0.00	0.00	10.25	NA	NA	393.14	NA	NA
cholest-5-en-3β-ol	525.67	567.00	622.45	731.41	NA	NA	393.14	NA	NA
5α-cholestan-3β-ol	415.37	87.77	97.46	102.25	NA	NA	82.31	NA	NA
24-methylcholesta-5,22-dien-3β-ol	824.21	199.76	424.04	418.83	NA	NA	161.33	NA	NA
24-methylcholest-22-en-3β-ol	50.71	27.84	34.39	53.46	NA	NA	19.00	NA	NA
4α-methylcholest-8(14)-3-en-3β-ol	40.11	0.00	5.27	6.47	NA	NA	0.00	NA	NA
24-methylcholesta-5,24(28)-dien-3β-ol	245.67	98.57	133.72	174.10	NA	NA	62.12	NA	NA
24-methylcholest-5-en-3β-ol	317.58	186.55	156.09	212.90	NA	NA	167.83	NA	NA
24-methyl-5α(H)-cholestan-3β-ol	109.28	21.58	30.75	41.35	NA	NA	0.00	NA	NA
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	5.25	7.21	11.98	NA	NA	0.00	NA	NA
24-ethylcholesta-5,22-dien-3β-ol	300.60	160.80	186.73	164.09	NA	NA	171.21	NA	NA
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
24-ethyl-5α(H)-cholest-22-en-3β-ol	10.42	9.63	4.84	21.05	NA	NA	0.00	NA	NA
4-methyl-C29-D22-stanol	81.98	0.00	18.49	11.89	NA	NA	5.44	NA	NA
23,24-dimethylcholest-5-en-3β-ol	10.42	9.63	0.00	35.57	NA	NA	0.00	NA	NA
24-ethylcholest-5-en-3β-ol	693.12	613.20	724.84	415.46	NA	NA	50.75	NA	NA
24-ethyl-5α(H)-cholest-3β-ol	39.11	62.34	60.05	67.91	NA	NA	52.48	NA	NA
24-ethylcholesta-5,24(28)-dien-3β-ol	134.10	50.13	26.87	25.98	NA	NA	50.35	NA	NA
4α,23,24-trimethylcholest-22-en-3β-ol	39.66	21.77	11.27	12.60	NA	NA	13.68	NA	NA
24-ethylcholestan-7-en-3β-ol	15.50	32.22	36.83	34.60	NA	NA	32.15	NA	NA
5α(H)-C29 stenol (possibly D7or D8)	21.19	10.16	9.60	12.00	NA	NA	9.10	NA	NA
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	7.03	9.17	11.00	23.18	NA	NA	31.51	NA	NA
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	11.70	11.88	0.00	10.73	NA	NA	8.76	NA	NA
hopan-3β-ol	12.84	21.43	19.61	7.81	NA	NA	7.08	NA	NA
extended hopanol	17.42	71.77	8.31	12.26	NA	NA	0.00	NA	NA
Total Alcohols	3225.20	1809.54	2183.19	2409.45	NA	NA	1361.04	NA	NA
Total Sterols	4289.55	2395.26	2843.62	2857.79	NA	NA	1779.89	NA	NA

NA = not available

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Appendix B. Fatty acid concentrations (ng L⁻¹) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98	Jan-99	Feb-99	Site HD May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
12:0	NA	31.18	121.51	36.66	35.42	47.45	128.35	27.55	0.00
i13	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
a13	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13:1	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13:0	NA	10.53	0.00	12.59	8.12	9.26	0.00	11.60	6.14
i14	NA	40.16	123.27	32.17	11.02	17.47	144.44	17.31	20.36
14:1	NA	16.49	0.00	39.03	11.02	10.99	0.00	24.44	15.25
14:0	NA	613.48	1113.19	982.35	410.59	384.24	1115.36	833.05	525.70
i15	NA	177.49	410.90	168.78	93.21	92.49	494.27	189.33	139.35
a15	NA	152.73	404.21	119.28	65.20	67.30	436.44	117.11	96.00
15:1	NA	14.20	0.00	14.37	0.00	0.00	0.00	16.04	0.00
15:0	NA	117.83	392.46	186.27	100.30	98.45	415.51	160.29	126.69
16:4	NA	254.15	222.08	445.38	130.74	107.27	220.19	578.11	205.48
16:3	NA	464.97	369.57	805.09	290.07	278.75	461.16	0.00	482.77
16:2	NA	0.00	0.00	0.00	0.00	0.00	0.00	1250.42	0.00
16:1ω7	NA	1795.69	3499.19	2902.81	1186.65	1134.80	4277.89	3087.47	2157.55
16:1ω9	NA	125.87	285.86	147.42	90.46	60.74	279.67	161.85	107.32
16:0	NA	1749.15	3959.49	3346.06	1581.08	1674.76	4168.29	3199.12	2311.63
10Me17Br	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
i17	NA	36.10	80.86	66.64	35.42	36.07	86.86	74.72	50.71
a17	NA	79.66	253.87	116.45	57.34	67.53	278.14	118.68	95.31
17:1	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17:0	NA	80.90	158.08	130.39	89.56	83.22	190.04	167.97	93.96
18:4	NA	462.75	510.16	600.53	201.31	247.85	395.06	665.47	429.56
18:3	NA	460.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18:2	NA	0.00	596.85	795.23	242.84	476.80	906.02	803.28	412.31
18:1ω9c	NA	1099.37	2070.24	2141.37	674.97	1220.42	2623.61	2236.45	1423.63
18:1ω9t	NA	408.82	618.97	670.87	219.65	361.38	892.14	622.99	429.37
18:0	NA	465.95	1009.56	752.98	532.90	573.14	954.45	591.14	423.91
19:0	NA	1645.49	1209.76	1468.16	2642.24	1367.22	1631.55	2021.84	1376.19
20:5ω6	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:4ω6	NA	68.41	155.94	92.06	68.52	53.39	165.95	120.35	149.65
20:5ω3	NA	748.76	640.05	1203.74	413.53	331.16	568.03	1832.07	810.73
20:3	NA	0.00	0.00	19.06	0.00	0.00	0.00	33.09	10.01
20:2	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:1	NA	58.00	0.00	97.33	36.90	41.63	0.00	125.69	64.22
20:0	NA	1062.47	858.21	937.27	1684.72	868.09	1116.39	1330.47	888.38
21:0	NA	588.52	806.67	748.15	572.61	529.67	1202.09	635.60	525.29
22:6ω6	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:6ω3	NA	145.62	168.47	206.87	64.60	64.90	101.78	308.48	146.24
22:5ω6	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:5ω3	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:2	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:1ω9	NA	55.05	0.00	65.93	22.64	27.77	0.00	72.53	25.95
22:0	NA	126.79	200.65	108.83	97.46	83.56	192.69	176.77	113.04
23:0	NA	39.51	70.71	24.32	29.07	15.22	0.00	29.37	27.67
24:1	NA	19.26	0.00	13.63	7.30	8.14	0.00	19.80	11.00
24:0	NA	184.38	278.39	132.86	153.77	84.94	261.73	159.40	147.54
25:0	NA	40.41	0.00	23.14	30.79	54.71	0.00	67.90	37.57
26:0	NA	110.83	139.18	72.92	100.61	53.06	148.26	92.74	93.65
27:0	NA	18.55	0.00	12.24	16.44	7.34	0.00	14.85	13.84
28:0	NA	102.53	95.76	54.52	80.93	46.56	106.59	84.10	75.73
29:0	NA	21.46	0.00	9.70	14.40	8.81	0.00	16.20	13.24
30:0	NA	81.39	89.58	36.78	58.51	33.99	0.00	61.38	53.01
31:0	NA	0.00	0.00	18.93	0.00	0.00	0.00	26.92	21.07
32:0	NA	40.30	0.00	15.88	24.06	9.40	0.00	29.05	23.59
Total	NA	10519.25	18039.05	16721.44	7287.41	7974.97	20012.92	18225.10	11390.74

NA= not available

Appendix B, ctd. *Fatty acid concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).*

					Site RV					
Component	Oct-98	Oct-98 (2)	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
12:0	40.16	21.80	NA	NA	63.79	24.42	32.44	53.34	48.11	0.00
i13	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
a13	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
13:1	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
13:0	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	14.12	0.00
i14	18.80	22.37	NA	NA	58.41	39.07	35.51	123.09	62.43	12.64
14:1	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	22.65	9.84
14:0	297.77	248.18	NA	NA	748.20	447.56	393.91	559.78	836.56	293.87
i15	59.45	80.02	NA	NA	193.22	152.85	125.04	429.06	226.59	66.40
a15	51.91	51.70	NA	NA	126.54	85.32	70.45	339.41	121.16	38.81
15:1	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
15:0	101.87	63.84	NA	NA	116.84	82.71	77.51	186.29	111.12	79.08
16:4	0.00	29.92	NA	NA	329.52	144.02	141.00	181.60	329.42	137.93
16:3	65.65	91.42	NA	NA	638.65	283.35	263.23	361.47	717.63	229.19
16:2	0.00	0.00	NA	NA	0.00	92.08	115.20	0.00	213.16	127.56
16:1ω7	730.45	669.68	NA	NA	2015.59	1245.52	1055.73	2779.95	2318.41	1357.95
16:1ω9	32.15	44.39	NA	NA	123.83	97.82	87.66	336.27	169.33	101.89
16:0	1462.41	1123.02	NA	NA	2003.37	1307.10	1209.24	2291.28	2139.40	1566.26
10Me17Br	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
i17	38.62	18.33	NA	NA	40.86	32.15	23.00	86.75	38.55	19.86
a17	51.48	30.39	NA	NA	65.56	0.00	0.00	157.33	61.82	21.64
17:1	0.00	0.00	NA	NA	0.00	0.00	0.00	77.07	0.00	26.91
17:0	64.17	44.14	NA	NA	115.93	61.90	56.09	117.27	60.71	76.39
18:4	94.14	172.23	NA	NA	542.47	186.10	275.46	333.66	570.57	318.57
18:3	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
18:2	171.25	133.31	NA	NA	335.36	157.37	147.71	432.05	432.99	174.86
18:1ω9c	522.14	554.91	NA	NA	1468.14	806.73	900.40	1405.47	1644.15	976.53
18:1ω9t	205.08	197.56	NA	NA	506.71	240.15	264.76	743.76	537.58	306.15
18:0	850.42	460.96	NA	NA	572.00	248.47	265.18	662.30	312.61	402.01
19:0	1664.65	727.28	NA	NA	1761.44	1649.61	749.38	2402.73	1267.01	3765.48
20:5ω6	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
20:4ω6	0.00	33.32	NA	NA	111.46	72.12	56.73	159.04	142.34	89.95
20:5ω3	151.61	228.93	NA	NA	1193.38	482.36	522.44	547.13	1471.51	812.06
20:3	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	15.66	0.00
20:2	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
20:1	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	80.17	0.00
20:0	1133.02	483.08	NA	NA	1230.06	968.83	463.48	1520.00	830.61	2804.11
21:0	275.77	243.60	NA	NA	621.02	632.50	523.45	843.33	437.79	1428.57
22:6ω6	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
22:6ω3	0.00	70.16	NA	NA	223.34	82.94	92.12	109.00	275.48	130.96
22:5ω6	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
22:5ω3	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
22:2	0.00	0.00	NA	NA	455.02	0.00	0.00	0.00	0.00	0.00
22:1ω9	0.00	15.70	NA	NA	0.00	0.00	0.00	0.00	24.58	16.53
22:0	53.40	61.60	NA	NA	127.96	104.57	92.05	243.28	126.76	169.98
23:0	0.00	18.93	NA	NA	30.28	29.75	26.08	80.66	25.02	63.95
24:1	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	14.50	0.00
24:0	70.41	89.38	NA	NA	155.99	148.37	134.47	298.17	130.90	231.25
25:0	0.00	18.16	NA	NA	0.00	0.00	26.47	0.00	22.73	44.03
26:0	40.84	68.61	NA	NA	104.28	120.48	107.31	203.56	95.05	185.72
27:0	0.00	0.00	NA	NA	140.17	0.00	0.00	0.00	16.69	33.04
28:0	27.52	63.67	NA	NA	96.47	120.94	106.55	183.04	96.94	172.84
29:0	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	14.37	0.00
30:0	0.00	33.12	NA	NA	55.25	61.09	50.76	166.19	51.35	69.15
31:0	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
32:0	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00	0.00	0.00
Total	5201.68	4759.77	NA	NA	12758.57	6957.30	6754.50	13647.26	13593.12	8363.81

NA= not available

Appendix B, ctd. Fatty acid concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
				Site MM					
12:0	41.40	75.45	48.63	37.69	176.18	84.62	200.61	114.87	NA
i13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
a13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
13:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
13:0	19.02	26.83	0.00	0.00	78.35	35.04	0.00	45.17	NA
i14	90.53	67.67	36.74	23.29	811.09	149.14	255.42	165.90	NA
14:1	26.26	0.00	25.34	0.00	110.34	30.75	0.00	47.84	NA
14:0	1025.29	1680.83	658.57	497.73	11014.35	2379.63	1676.98	3180.28	NA
i15	318.78	239.63	132.49	84.49	937.92	408.92	806.56	517.43	NA
a15	182.81	161.84	118.27	59.41	635.40	249.00	730.85	262.46	NA
15:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
15:0	224.09	252.20	186.75	105.80	1772.60	496.62	693.26	428.14	NA
16:4	596.44	1125.31	242.68	279.07	952.49	781.87	382.21	2091.56	NA
16:3	2152.73	2131.37	376.86	658.43	23074.78	3628.82	768.59	4629.76	NA
16:2	0.00	0.00	0.00	0.00	0.00	293.16	0.00	852.61	NA
16:1ω7	3728.63	4388.94	1863.24	1533.33	25861.49	6715.83	5786.86	9346.96	NA
16:1ω9	233.32	228.48	146.61	87.18	699.96	336.97	460.41	429.55	NA
16:0	3466.84	3915.20	2330.22	1483.21	14455.63	5341.67	6873.37	9044.54	NA
10Me17Br	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
i17	50.26	40.48	34.92	19.08	102.65	114.32	158.63	113.77	NA
a17	113.21	88.66	73.01	36.71	664.85	162.92	461.56	194.60	NA
17:1	0.00	0.00	31.39	24.11	0.00	0.00	0.00	0.00	NA
17:0	150.41	101.59	101.71	52.50	180.82	147.27	290.65	170.87	NA
18:4	1263.17	1607.37	467.42	215.29	3267.96	1102.79	628.00	2508.95	NA
18:3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
18:2	498.09	588.45	284.95	202.00	1619.24	465.82	755.61	1239.31	NA
18:1ω9c	1195.08	2921.99	1369.66	711.15	4223.00	2814.05	3114.70	6747.03	NA
18:1ω9t	636.96	832.96	453.20	311.96	1366.55	1011.56	1055.93	1230.95	NA
18:0	795.52	1219.72	1567.52	358.97	778.70	698.93	3254.35	138.15	NA
19:0	1204.03	1739.93	3490.20	2665.77	1250.87	2430.33	1680.67	1929.38	NA
20:5ω6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
20:4ω6	82.02	163.89	71.67	48.51	2450.22	431.30	280.46	357.91	NA
20:5ω3	3424.47	3953.00	688.64	1007.97	25844.64	4616.46	1029.62	903.54	NA
20:3	0.00	0.00	0.00	0.00	112.65	54.11	0.00	83.28	NA
20:2	0.00	0.00	0.00	0.00	372.87	0.00	0.00	110.70	NA
20:1	245.31	79.57	0.00	0.00	1142.49	53.89	0.00	248.55	NA
20:0	775.85	1267.62	2527.28	1872.20	1932.65	1748.74	985.91	1342.42	NA
21:0	608.61	857.14	1714.29	1500.00	690.00	1090.91	1445.71	556.91	NA
22:6ω6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
22:6ω3	655.89	782.41	178.50	175.88	2983.32	686.63	216.33	1834.85	NA
22:5ω6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
22:5ω3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
22:2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
22:1ω9	530.83	97.75	27.74	0.00	267.06	29.29	0.00	192.04	NA
22:0	140.74	212.90	203.18	77.21	1670.33	238.26	291.79	393.24	NA
23:0	44.77	5.28	6.45	0.00	54.83	7.16	0.00	72.33	NA
24:1	22.81	0.00	0.00	0.00	78.95	47.30	0.00	68.21	NA
24:0	207.19	260.78	297.20	120.44	179.56	363.05	435.48	506.07	NA
25:0	35.84	41.68	57.12	0.00	122.33	59.51	0.00	53.51	NA
26:0	132.44	152.45	198.96	70.68	85.15	252.40	244.87	249.61	NA
27:0	21.97	0.00	0.00	0.00	0.00	0.00	0.00	29.88	NA
28:0	104.43	130.18	183.56	73.39	0.00	196.30	220.81	195.32	NA
29:0	17.27	0.00	0.00	0.00	0.00	0.00	0.00	25.19	NA
30:0	92.65	113.36	171.42	0.00	0.00	145.08	254.40	120.48	NA
31:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
32:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
Total	22567.47	27688.24	12634.63	8355.46	128148.73	34630.45	31328.32	48945.41	NA

NA= not available

Appendix B, ctd. Fatty acid concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Component					Site TI					
	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00	Jul-00 (2)
12:0	NA	5.55	94.76	36.75	57.51	52.83	116.25	NA	14.96	23.66
i13	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
a13	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
13:1	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
13:0	NA	5.38	0.00	29.97	16.35	17.13	0.00	NA	0.00	0.00
i14	NA	6.38	87.16	27.78	58.56	63.28	105.25	NA	16.67	18.04
14:1	NA	3.13	0.00	11.21	18.72	21.09	0.00	NA	12.44	23.42
14:0	NA	128.94	902.13	400.00	541.17	678.75	878.53	NA	329.74	551.84
i15	NA	29.49	254.94	90.85	70.58	134.94	283.63	NA	62.72	121.81
a15	NA	24.54	305.24	64.58	63.61	104.41	258.41	NA	39.78	66.82
15:1	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
15:0	NA	46.60	385.20	92.34	143.08	196.28	399.71	NA	66.96	97.43
16:4	NA	83.52	0.00	262.55	90.68	147.37	142.55	NA	59.68	99.39
16:3	NA	45.83	211.33	537.40	165.57	282.13	1243.99	NA	312.49	577.17
16:2	NA	58.77	0.00	0.00	0.00	0.00	0.00	NA	0.00	106.66
16:1ω7	NA	453.05	2407.20	1208.10	1486.97	1890.94	897.09	NA	988.23	1683.01
16:1ω9	NA	61.89	152.84	83.68	68.11	115.20	168.73	NA	55.24	113.54
16:0	NA	766.23	3416.68	1394.04	1495.95	1981.39	3720.51	NA	936.98	1501.37
10Me17Br	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
i17	NA	7.62	60.40	23.73	21.06	27.91	0.00	NA	13.41	29.92
a17	NA	12.90	217.82	43.51	87.57	110.34	214.16	NA	35.26	52.17
17:1	NA	11.51	0.00	12.27	11.99	30.49	0.00	NA	7.29	17.52
17:0	NA	34.00	148.53	73.24	69.90	91.27	198.59	NA	46.21	68.84
18:4	NA	233.53	219.52	296.15	185.38	338.48	162.43	NA	111.36	198.24
18:3	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
18:2	NA	123.74	292.04	194.79	304.25	255.04	2360.22	NA	78.63	193.58
18:1ω9c	NA	428.88	1505.81	729.65	449.24	1146.77	2446.96	NA	394.08	660.00
18:1ω9t	NA	121.96	349.17	189.07	148.42	234.21	509.69	NA	116.09	212.90
18:0	NA	257.49	801.83	391.44	392.29	441.84	2697.70	NA	227.29	323.94
19:0	NA	1706.99	850.74	1682.96	1284.87	1148.67	1506.85	NA	1429.86	953.51
20:5ω6	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
20:4ω6	NA	24.86	0.00	37.97	39.50	55.69	0.00	NA	34.02	71.88
20:5ω3	NA	168.80	213.34	795.30	282.41	472.22	221.35	NA	346.46	606.70
20:3	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
20:2	NA	0.00	0.00	26.10	64.46	39.99	0.00	NA	15.96	22.71
20:1	NA	0.00	0.00	33.09	0.00	0.00	0.00	NA	12.17	49.66
20:0	NA	1252.88	569.96	1059.40	834.93	729.88	1284.97	NA	900.09	592.43
21:0	NA	666.67	670.41	662.08	485.19	520.98	1277.22	NA	485.19	572.61
22:6ω6	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
22:6ω3	NA	38.34	54.48	115.71	36.88	91.24	0.00	NA	48.26	76.86
22:5ω6	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
22:5ω3	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
22:2	NA	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00
22:1ω9	NA	13.68	0.00	22.95	23.86	27.48	0.00	NA	6.54	15.16
22:0	NA	103.06	136.76	115.80	74.63	81.57	223.74	NA	62.46	88.34
23:0	NA	37.32	0.00	28.43	20.18	23.11	0.00	NA	17.82	24.35
24:1	NA	0.00	0.00	9.73	8.61	0.00	244.95	NA	6.31	0.00
24:0	NA	130.27	202.38	176.83	140.47	150.57	293.01	NA	111.00	132.00
25:0	NA	23.77	0.00	39.82	35.29	31.70	0.00	NA	23.32	24.57
26:0	NA	103.69	127.82	129.35	93.63	105.28	151.11	NA	89.49	106.04
27:0	NA	22.31	0.00	20.30	12.60	14.96	0.00	NA	13.34	15.98
28:0	NA	98.77	139.72	122.42	83.19	89.99	148.33	NA	91.09	105.28
29:0	NA	0.00	0.00	15.06	8.78	8.40	0.00	NA	9.25	0.00
30:0	NA	42.42	0.00	60.64	35.12	38.01	0.00	NA	40.40	47.80
31:0	NA	0.00	0.00	0.00	17.72	24.19	0.00	NA	19.18	0.00
32:0	NA	0.00	0.00	158.03	11.37	12.34	0.00	NA	12.33	167.02
Total	NA	3758.22	12687.11	8100.62	6935.68	9628.82	18086.89	NA	4884.89	8295.59

NA= not available

Appendix B, ctd. Fatty acid concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
				Site LH					
12:0	55.85	NA	NA	28.77	45.53	39.69	NA	40.06	37.06
i13	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
a13	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
13:1	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
13:0	0.00	NA	NA	13.86	22.95	15.23	NA	18.77	26.78
i14	84.81	NA	NA	78.30	120.44	77.77	NA	180.71	121.48
14:1	34.78	NA	NA	19.57	76.10	57.94	NA	32.27	36.04
14:0	905.55	NA	NA	718.59	1639.23	1437.41	NA	1193.47	1679.76
i15	304.85	NA	NA	272.36	493.26	338.30	NA	358.00	121.48
a15	180.44	NA	NA	199.56	291.80	163.88	NA	210.04	164.23
15:1	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
15:0	156.03	NA	NA	192.31	265.70	182.42	NA	266.67	236.28
16:4	189.76	NA	NA	241.66	478.45	453.51	NA	571.30	130.57
16:3	441.90	NA	NA	373.62	721.00	459.36	NA	1048.26	718.44
16:2	262.51	NA	NA	194.65	533.08	436.80	NA	426.15	108.21
16:1ω7	2448.02	NA	NA	2104.57	4004.00	3888.53	NA	3634.68	3989.58
16:1ω9	166.86	NA	NA	172.06	264.95	187.47	NA	317.00	202.23
16:0	2571.33	NA	NA	2419.05	3589.97	3471.37	NA	3383.35	2933.87
10Me17Br	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
i17	73.95	NA	NA	81.64	122.73	55.65	NA	107.92	21.30
a17	71.41	NA	NA	143.49	117.81	58.43	NA	117.51	42.20
17:1	49.64	NA	NA	0.00	0.00	0.00	NA	0.00	59.18
17:0	105.03	NA	NA	120.04	173.54	104.33	NA	154.06	153.18
18:4	593.37	NA	NA	325.17	415.35	527.04	NA	665.79	249.36
18:3	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
18:2	326.68	NA	NA	284.69	515.09	449.36	NA	487.42	424.06
18:1ω9c	1660.60	NA	NA	1618.98	2616.33	2705.38	NA	2471.87	2858.26
18:1ω9t	608.92	NA	NA	477.71	766.13	530.06	NA	794.87	433.99
18:0	629.81	NA	NA	600.27	672.46	428.66	NA	603.30	630.49
19:0	3809.48	NA	NA	2043.06	2555.51	1953.14	NA	2750.64	3003.80
20:5ω6	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
20:4ω6	109.21	NA	NA	73.20	176.62	91.18	NA	157.03	150.52
20:5ω3	848.08	NA	NA	472.94	868.09	700.36	NA	1522.81	1345.66
20:3	0.00	NA	NA	0.00	15.62	17.11	NA	0.00	0.00
20:2	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
20:1	71.78	NA	NA	53.42	63.32	54.68	NA	79.65	0.00
20:0	2515.10	NA	NA	1330.16	1699.60	1230.03	NA	1797.35	1948.27
21:0	611.12	NA	NA	882.78	1059.33	814.87	NA	1059.33	1135.00
22:6ω6	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
22:6ω3	140.93	NA	NA	57.89	110.77	90.54	NA	222.10	124.06
22:5ω6	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
22:5ω3	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
22:2	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
22:1ω9	0.00	NA	NA	32.04	32.09	17.79	NA	35.07	16.37
22:0	158.98	NA	NA	245.52	339.04	133.58	NA	374.38	335.07
23:0	231.50	NA	NA	74.65	114.47	40.99	NA	78.20	117.39
24:1	0.00	NA	NA	19.40	19.04	11.50	NA	30.06	0.00
24:0	233.06	NA	NA	337.49	494.10	198.02	NA	386.53	340.41
25:0	41.33	NA	NA	73.47	112.40	42.03	NA	75.07	29.71
26:0	172.42	NA	NA	263.10	422.66	165.22	NA	289.44	147.28
27:0	0.00	NA	NA	53.25	79.13	33.33	NA	55.68	30.15
28:0	141.91	NA	NA	276.14	394.62	169.11	NA	307.19	164.68
29:0	0.00	NA	NA	36.25	51.21	24.50	NA	38.56	19.96
30:0	234.15	NA	NA	128.19	172.78	76.97	NA	139.13	140.79
31:0	0.00	NA	NA	18.52	23.83	14.60	NA	18.28	0.00
32:0	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00
Total	14305.44	NA	NA	12896.38	21435.66	17950.11	NA	20892.65	18340.07

NA= not available

Appendix B, ctd. Fatty acid concentrations (ng L) in suspended particles, seasonal sampling (1998-2000).

						Site MI					
Component	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99-1	Oct-99-3	Feb-00	Apr-00-1	Apr-00-2	Apr-00-3
12:0	191.80	NA	NA	69.00	37.33	1423.56	41.90	NA	65.54	32.07	50.47
i13	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
a13	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
13:1	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
13:0	14.78	NA	NA	49.57	16.94	180.74	0.00	NA	18.44	8.81	14.52
i14	94.01	NA	NA	60.61	51.94	229.13	84.36	NA	81.56	19.96	35.50
14:1	72.40	NA	NA	58.10	56.97	293.80	42.47	NA	53.56	14.01	19.95
14:0	2912.36	NA	NA	1963.28	1361.08	18775.43	1675.62	NA	3129.62	730.86	1124.85
i15	359.90	NA	NA	283.02	356.84	2183.48	451.60	NA	292.47	99.45	228.70
a15	163.58	NA	NA	129.99	132.73	426.09	152.18	NA	130.16	56.41	127.79
15:1	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
15:0	263.39	NA	NA	270.54	212.03	1251.94	190.94	NA	296.52	123.56	176.45
16:4	273.93	NA	NA	1819.49	273.93	6026.23	315.55	NA	678.04	300.22	373.49
16:3	1012.66	NA	NA	672.66	478.11	4325.64	310.65	NA	1258.26	455.02	849.19
16:2	0.00	NA	NA	645.72	235.87	0.00	0.00	NA	0.00	0.00	0.00
16:1ω7	5394.65	NA	NA	4604.29	3344.53	27397.13	3769.97	NA	6931.83	1781.14	2647.27
16:1ω9	368.40	NA	NA	273.73	176.33	1306.43	418.91	NA	310.79	124.42	244.82
16:0	5404.54	NA	NA	5027.26	3100.84	46781.61	3542.11	NA	5824.77	2265.52	2574.60
10Me17Br	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
i17	43.31	NA	NA	41.74	85.72	0.00	55.34	NA	69.34	21.30	42.79
a17	104.29	NA	NA	71.71	118.20	465.56	62.28	NA	114.60	50.53	75.60
17:1	22.32	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
17:0	104.65	NA	NA	127.37	134.49	597.64	106.12	NA	212.66	70.87	68.94
18:4	2057.95	NA	NA	1353.62	573.21	29391.09	878.55	NA	1980.02	860.91	624.34
18:3	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
18:2	578.60	NA	NA	677.66	451.77	6733.10	363.10	NA	531.99	389.24	426.06
18:1ω9c	3101.06	NA	NA	4309.88	1987.22	47472.96	2383.99	NA	2953.11	1326.75	1149.25
18:1ω9t	639.34	NA	NA	586.07	367.82	3497.59	618.18	NA	529.45	269.20	294.58
18:0	1186.05	NA	NA	679.06	520.64	4827.79	494.09	NA	945.82	421.44	533.99
19:0	1641.81	NA	NA	4905.21	883.08	686.67	2242.45	NA	1443.77	1210.16	1469.20
20:5ω6	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
20:4ω6	220.35	NA	NA	212.85	163.69	1249.69	170.43	NA	46.17	47.04	44.47
20:5ω3	2285.43	NA	NA	4006.31	947.67	15047.85	1426.47	NA	3274.63	813.30	1034.74
20:3	118.50	NA	NA	0.00	24.78	403.28	0.00	NA	36.63	12.50	0.00
20:2	177.43	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
20:1	275.20	NA	NA	0.00	806.76	593.75	52.74	NA	99.60	37.39	20.26
20:0	1176.02	NA	NA	3434.87	568.61	1014.40	1644.16	NA	1041.46	783.54	960.37
21:0	243.60	NA	NA	2000.00	368.00	557.06	1000.00	NA	588.52	597.24	814.36
22:6ω6	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
22:6ω3	574.18	NA	NA	759.70	163.91	4025.93	488.16	NA	800.89	190.10	191.42
22:5ω6	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
22:5ω3	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
22:2	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.00
22:1ω9	135.49	NA	NA	52.00	24.98	555.48	517.65	NA	185.58	42.42	40.66
22:0	110.14	NA	NA	462.66	144.31	162.17	221.35	NA	263.79	111.84	151.19
23:0	27.30	NA	NA	103.11	37.34	0.00	51.46	NA	50.79	21.71	35.02
24:1	82.06	NA	NA	82.36	0.00	0.00	0.00	NA	108.97	17.68	12.79
24:0	189.02	NA	NA	671.11	210.04	240.78	312.49	NA	217.41	137.47	212.92
25:0	29.46	NA	NA	74.56	43.28	0.00	51.59	NA	33.49	95.97	45.26
26:0	121.46	NA	NA	447.71	146.38	142.50	295.69	NA	149.98	95.44	183.65
27:0	0.00	NA	NA	54.05	16.79	0.00	43.38	NA	20.41	14.40	26.82
28:0	90.37	NA	NA	324.45	120.93	0.00	270.47	NA	123.41	91.19	181.86
29:0	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	11.32	9.19	17.01
30:0	30.29	NA	NA	108.43	42.66	0.00	89.05	NA	43.34	41.17	70.96
31:0	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	4.75	0.00	0.00
32:0	0.00	NA	NA	0.00	0.00	0.00	0.00	NA	8.30	43.80	0.00
Total	28830.63	NA	NA	31133.65	16968.07	226008.36	19948.82	NA	31888.00	11244.30	13952.22

NA= not available

Appendix B, ctd. Fatty acid concentrations (ng I^L) in suspended particles, seasonal sampling (1998-2000).

	Site MI		
Component	Jul-00-1	Jul-00-2	Jul-00-3
12:0	103.62	36.61	40.41
i13	0.00	0.00	0.00
a13	0.00	0.00	0.00
13:1	0.00	0.00	0.00
13:0	22.76	10.17	29.14
i14	92.42	35.81	55.89
14:1	52.13	37.96	23.30
14:0	1966.41	849.13	1805.83
i15	404.79	146.64	296.34
a15	134.45	66.34	99.39
15:1	0.00	0.00	0.00
15:0	296.04	138.65	344.61
16:4	205.88	129.89	228.11
16:3	632.96	246.69	357.71
16:2	0.00	0.00	342.54
16:1ω7	4441.02	1836.95	3675.59
16:1ω9	253.48	128.60	228.69
16:0	4920.64	2008.58	4491.19
10Me17Br	0.00	0.00	0.00
i17	175.46	44.37	189.49
a17	129.42	63.58	107.42
17:1	0.00	0.00	0.00
17:0	167.31	81.52	221.97
18:4	524.52	184.81	492.54
18:3	0.00	0.00	0.00
18:2	984.58	340.32	820.78
18:1ω9c	2081.06	1050.58	2539.08
18:1ω9t	495.34	219.80	450.19
18:0	965.89	455.25	769.84
19:0	1732.17	1820.22	995.03
20:5ω6	0.00	0.00	0.00
20:4ω6	229.92	70.97	440.92
20:5ω3	1956.76	515.68	2793.84
20:3	58.33	0.00	126.97
20:2	0.00	0.00	257.14
20:1	91.71	24.71	31.63
20:0	1174.78	1165.29	700.51
21:0	662.08	747.76	769.23
22:6ω6	0.00	0.00	0.00
22:6ω3	332.41	72.82	444.65
22:5ω6	0.00	0.00	0.00
22:5ω3	0.00	0.00	0.00
22:2	0.00	0.00	0.00
22:1ω9	72.65	24.86	0.00
22:0	208.44	106.69	195.44
23:0	48.44	27.86	56.91
24:1	32.78	16.31	0.00
24:0	247.11	174.16	213.72
25:0	70.64	39.54	40.44
26:0	205.46	139.21	190.90
27:0	25.73	20.12	0.00
28:0	184.32	122.19	182.25
29:0	17.46	10.88	0.00
30:0	67.40	50.51	60.59
31:0	0.00	0.00	0.00
32:0	0.00	32.16	0.00
Total	22899.75	9560.92	22645.47

NA= not available

Appendix B, ctd. Fatty acid concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00-1	Apr-00-2	Apr-00-3	Jul-00-1	Jul-00-2	Jul-00-3
						Site FT							
12:0	45.52	NA	NA	50.39	39.85	38.21	NA	24.61	27.37	27.35	15.65	64.98	0.00
i13	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
a13	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
13:1	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
13:0	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	8.91	0.00
i14	51.55	NA	NA	53.56	38.12	39.19	NA	21.70	20.75	17.34	26.40	23.99	28.76
14:1	24.60	NA	NA	0.00	41.03	0.00	NA	0.00	0.00	0.00	27.61	29.16	21.79
14:0	909.14	NA	NA	814.03	1034.12	670.92	NA	369.74	628.44	580.50	720.72	1059.04	808.81
i15	93.86	NA	NA	198.51	171.81	170.10	NA	103.74	105.88	98.21	79.69	86.22	88.82
a15	48.59	NA	NA	149.76	105.97	115.71	NA	65.15	73.73	49.61	45.81	57.45	51.17
15:1	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
15:0	160.49	NA	NA	201.86	170.28	166.66	NA	98.29	137.48	121.14	79.31	155.80	132.54
16:4	283.70	NA	NA	402.01	207.39	126.71	NA	161.16	280.02	330.36	155.40	204.40	190.25
16:3	298.15	NA	NA	550.14	215.87	239.16	NA	268.99	332.32	288.86	386.23	390.81	188.96
16:2	121.84	NA	NA	137.25	160.01	0.00	NA	0.00	0.00	0.00	123.85	0.00	0.00
16:1ω7	2409.17	NA	NA	2047.44	2154.75	1928.34	NA	1053.24	1578.79	1422.98	2209.20	3638.06	3346.97
16:1ω9	87.94	NA	NA	157.69	146.26	120.06	NA	91.73	89.26	82.03	93.40	105.92	96.95
16:0	3510.72	NA	NA	2334.99	2299.03	1998.38	NA	1472.75	2800.59	3144.99	1572.16	4740.29	3490.59
10Me17Br	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
i17	20.26	NA	NA	32.61	28.29	0.00	NA	20.63	15.88	0.00	13.00	21.62	12.33
a17	58.16	NA	NA	71.15	74.04	75.95	NA	49.63	56.53	46.69	34.07	82.67	66.03
17:1	107.09	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	14.64	25.40	11.12
17:0	79.15	NA	NA	78.45	74.35	74.28	NA	50.68	66.81	69.21	29.40	80.92	65.71
18:4	946.44	NA	NA	420.96	273.17	294.12	NA	410.69	1250.00	1743.65	448.38	881.77	726.74
18:3	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
18:2	240.80	NA	NA	192.99	225.77	163.14	NA	134.73	357.98	462.60	231.75	958.31	462.35
18:1ω9c	1348.81	NA	NA	1163.38	1359.59	953.39	NA	702.16	1801.94	2319.87	911.62	2594.34	1975.06
18:1ω9t	343.61	NA	NA	264.63	195.18	244.26	NA	155.11	257.14	298.56	130.16	294.86	272.97
18:0	870.79	NA	NA	359.04	359.66	354.02	NA	221.53	321.14	330.40	171.04	874.17	474.69
19:0	1693.86	NA	NA	1156.59	1125.32	655.82	NA	995.43	979.62	1175.37	1365.43	1161.34	1162.95
20:5ω6	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
20:4ω6	57.04	NA	NA	53.35	75.28	62.37	NA	38.15	48.45	38.97	53.96	88.23	120.85
20:5ω3	855.39	NA	NA	1008.32	475.73	416.06	NA	449.54	825.45	931.05	535.64	893.19	1156.77
20:3	37.10	NA	NA	0.00	0.00	0.00	NA	0.00	32.55	36.06	16.05	50.61	43.07
20:2	50.81	NA	NA	0.00	22.81	0.00	NA	0.00	0.00	0.00	0.00	64.67	34.49
20:1	28.55	NA	NA	0.00	0.00	0.00	NA	0.00	13.95	50.27	10.05	16.13	21.88
20:0	1100.21	NA	NA	697.19	807.01	382.50	NA	599.33	574.71	683.16	742.63	762.60	745.95
21:0	243.60	NA	NA	552.00	546.93	501.82	NA	537.35	433.71	552.00	512.58	520.98	715.05
22:6ω6	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
22:6ω3	181.71	NA	NA	157.36	45.49	65.66	NA	87.75	192.91	264.59	59.89	118.09	162.53
22:5ω6	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
22:5ω3	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
22:2	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00
22:1ω9	53.82	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	9.85	29.35	29.27
22:0	71.56	NA	NA	124.91	125.49	83.21	NA	90.15	67.14	53.70	30.45	71.90	62.81
23:0	20.46	NA	NA	30.05	33.95	0.00	NA	22.44	0.00	0.00	8.30	17.10	17.83
24:1	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	22.75	22.96
24:0	125.15	NA	NA	175.88	230.83	129.04	NA	136.40	102.12	82.36	46.86	119.71	112.40
25:0	21.50	NA	NA	0.00	31.04	177.17	NA	0.00	0.00	0.00	35.12	44.96	53.28
26:0	72.63	NA	NA	112.36	146.56	86.90	NA	97.09	52.34	41.15	33.38	81.22	74.98
27:0	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	9.46	8.69
28:0	48.74	NA	NA	83.68	127.24	72.84	NA	95.40	40.92	30.36	32.02	91.00	75.86
29:0	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	17.80	59.43
30:0	0.00	NA	NA	0.00	42.45	0.00	NA	37.49	0.00	0.00	15.41	23.78	54.57
31:0	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	9.75	0.00
32:0	0.00	NA	NA	0.00	0.00	0.00	NA	0.00	0.00	0.00	19.79	11.20	0.00
Total	13684.86	NA	NA	11426.74	10731.43	8865.87	NA	6530.66	11577.85	12962.86	8426.26	18159.97	14634.08

NA= not available

Appendix B. Fatty acid concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98	Jan-99	Feb-99	Site CC May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
12:0	75.93	NA	NA	33.05	22.82	NA	NA	14.83	NA
i13	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
a13	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
13:1	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
13:0	26.93	NA	NA	10.25	8.62	NA	NA	7.87	NA
i14	121.36	NA	NA	41.95	30.66	NA	NA	24.79	NA
14:1	35.04	NA	NA	13.19	30.87	NA	NA	15.16	NA
14:0	1403.78	NA	NA	455.91	646.73	NA	NA	525.50	NA
i15	62.01	NA	NA	87.70	71.30	NA	NA	73.65	NA
a15	384.18	NA	NA	141.28	139.59	NA	NA	120.99	NA
15:1	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
15:0	249.07	NA	NA	115.49	93.67	NA	NA	111.57	NA
16:4	435.09	NA	NA	206.28	116.49	NA	NA	231.63	NA
16:3	146.93	NA	NA	556.86	183.08	NA	NA	498.98	NA
16:2	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
16:1ω7	4182.03	NA	NA	1536.48	1491.02	NA	NA	1723.06	NA
16:1ω9	248.30	NA	NA	119.82	109.19	NA	NA	141.63	NA
16:0	4332.70	NA	NA	1778.76	1668.45	NA	NA	2181.87	NA
10Me17Br	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
i17	66.69	NA	NA	53.84	33.64	NA	NA	45.94	NA
a17	75.68	NA	NA	84.18	52.88	NA	NA	71.74	NA
17:1	98.84	NA	NA	51.38	25.28	NA	NA	35.98	NA
17:0	148.14	NA	NA	125.14	79.02	NA	NA	115.07	NA
18:4	1097.50	NA	NA	266.12	159.44	NA	NA	719.28	NA
18:3	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
18:2	459.94	NA	NA	284.87	235.46	NA	NA	371.52	NA
18:1ω9c	2061.19	NA	NA	924.98	872.41	NA	NA	1166.56	NA
18:1ω9t	728.56	NA	NA	373.77	257.90	NA	NA	349.45	NA
18:0	954.50	NA	NA	505.47	332.59	NA	NA	445.87	NA
19:0	2788.67	NA	NA	1568.71	1288.95	NA	NA	1258.89	NA
20:5ω6	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
20:4ω6	179.09	NA	NA	50.00	50.89	NA	NA	41.82	NA
20:5ω3	2228.63	NA	NA	745.55	266.57	NA	NA	605.15	NA
20:3	80.91	NA	NA	22.34	11.67	NA	NA	28.97	NA
20:2	118.13	NA	NA	35.48	34.78	NA	NA	47.99	NA
20:1	137.17	NA	NA	64.82	35.44	NA	NA	46.31	NA
20:0	1961.89	NA	NA	1085.33	873.17	NA	NA	891.45	NA
21:0	321.23	NA	NA	618.82	584.44	NA	NA	606.92	NA
22:6ω6	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
22:6ω3	125.14	NA	NA	110.78	28.76	NA	NA	127.62	NA
22:5ω6	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
22:5ω3	0.00	NA	NA	0.00	0.00	NA	NA	0.00	NA
22:2	26.77	NA	NA	101.16	27.84	NA	NA	55.27	NA
22:1ω9	72.89	NA	NA	18.00	0.00	NA	NA	0.00	NA
22:0	192.37	NA	NA	161.56	139.86	NA	NA	164.15	NA
23:0	63.84	NA	NA	41.31	36.99	NA	NA	39.69	NA
24:1	76.92	NA	NA	22.38	13.77	NA	NA	19.44	NA
24:0	286.84	NA	NA	223.33	237.72	NA	NA	244.06	NA
25:0	53.01	NA	NA	39.76	34.45	NA	NA	61.64	NA
26:0	202.76	NA	NA	173.14	200.24	NA	NA	207.13	NA
27:0	29.22	NA	NA	30.86	25.49	NA	NA	30.32	NA
28:0	145.74	NA	NA	227.30	190.54	NA	NA	230.53	NA
29:0	0.00	NA	NA	27.50	15.08	NA	NA	17.73	NA
30:0	67.51	NA	NA	94.51	69.08	NA	NA	86.66	NA
31:0	0.00	NA	NA	361.38	29.85	NA	NA	46.46	NA
32:0	0.00	NA	NA	35.69	22.89	NA	NA	25.92	NA
Total	21481.33	NA	NA	10353.70	8133.03	NA	NA	11119.79	NA

NA= not available

Appendix B, ctd. Fatty acid concentrations (ng L⁻¹) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98-1	Oct-98-2	Jan-99-1	Jan-99-2	Site CS May-99	Jul-99	Oct-99-1	Oct-99-2	Feb-00-1	Feb-00-2
12:0	0.00	135.45	106.72	89.93	125.16	121.79	23.86	40.20	120.65	112.35
i13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
a13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13:0	41.14	65.17	0.00	36.96	49.02	56.92	26.19	0.00	0.00	37.53
i14	184.26	210.25	256.63	159.60	323.44	189.70	42.73	56.85	246.26	267.13
14:1	77.36	49.31	0.00	58.98	119.32	48.84	0.00	30.85	0.00	76.12
14:0	2200.69	2093.79	1915.60	1213.76	2595.71	2689.16	944.21	848.14	954.30	956.49
i15	762.78	689.21	506.41	344.15	781.13	598.59	197.03	236.80	719.68	713.49
a15	465.69	415.91	578.49	343.89	870.88	421.26	147.95	182.77	587.69	577.97
15:1	0.00	0.00	0.00	33.32	0.00	0.00	0.00	0.00	0.00	0.00
15:0	633.16	547.88	574.73	332.98	468.45	524.13	186.83	158.16	392.11	332.71
16:4	1396.53	545.12	1083.49	657.54	987.19	1038.67	138.66	148.19	204.67	281.62
16:3	2401.76	1191.20	718.78	512.62	1485.06	904.69	639.32	1024.53	383.67	473.69
16:2	1025.70	0.00	870.97	655.57	687.66	931.31	152.65	158.53	0.00	0.00
16:1ω7	11184.79	7765.58	5642.72	3516.88	6971.99	7749.37	2941.68	2732.22	4318.49	4785.27
16:1ω9	815.92	533.77	837.46	657.10	729.59	469.28	159.72	159.84	586.85	755.00
16:0	10289.27	8096.95	5031.74	3908.95	5854.93	7271.79	2404.16	2097.42	4015.24	3562.58
10Me17Br	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
i17	92.42	136.97	0.00	101.01	127.88	104.80	36.72	51.18	168.78	148.43
a17	235.43	286.48	331.05	216.64	375.66	140.13	81.37	50.02	324.33	155.70
17:1	217.32	97.06	0.00	88.01	0.00	0.00	0.00	69.77	0.00	173.68
17:0	327.26	273.75	165.88	185.13	204.84	258.35	118.33	107.07	248.55	195.19
18:4	4739.68	2427.46	1429.08	1004.69	2437.30	1511.66	597.84	423.69	380.06	642.76
18:3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18:2	1649.18	6576.56	808.63	683.44	656.03	793.32	276.68	255.60	458.55	523.80
18:1ω9c	4285.65	2471.84	4607.27	3426.09	5017.14	4848.51	1058.21	872.16	2040.76	1795.68
18:1ω9t	3531.33	1767.79	1127.77	1200.12	1817.78	1986.79	754.06	697.54	1446.56	1759.48
18:0	1875.03	258.26	745.40	1169.01	941.34	807.36	344.46	402.49	915.58	904.32
19:0	740.97	2521.40	490.68	1363.02	1723.28	3669.31	1952.72	1396.31	4759.86	2745.58
20:5ω6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:4ω6	840.95	402.94	199.29	139.27	211.46	279.83	121.40	98.39	160.48	246.98
20:5ω3	5945.54	2517.71	1586.09	1022.45	2226.17	2707.05	1214.05	947.80	363.33	514.40
20:3	0.00	114.26	0.00	0.00	0.00	0.00	0.00	13.34	0.00	0.00
20:2	0.00	0.00	0.00	32.45	0.00	0.00	0.00	0.00	0.00	0.00
20:1	247.78	205.41	0.00	42.91	147.36	54.54	0.00	23.00	0.00	52.96
20:0	515.80	1776.27	237.67	918.85	528.23	2822.20	1381.03	898.36	3141.57	1760.58
21:0	1096.55	635.48	690.00	1008.89	690.00	1538.46	1000.00	613.33	1958.71	2168.57
22:6ω6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:6ω3	1788.30	707.33	675.61	372.10	564.55	726.24	505.76	333.89	167.37	256.30
22:5ω6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00	0.00
22:5ω3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:1ω9	184.06	124.14	0.00	67.67	0.00	26.32	49.75	28.72	0.00	62.19
22:0	857.77	668.86	498.30	739.68	775.51	1043.32	272.09	207.98	935.17	831.29
23:0	170.96	149.51	0.00	153.59	109.37	179.06	57.80	39.60	218.76	181.86
24:1	0.00	36.12	0.00	32.56	55.13	82.68	0.00	26.33	0.00	46.08
24:0	826.37	743.40	524.32	783.59	599.45	1146.09	295.13	246.57	1018.50	859.44
25:0	129.24	117.12	0.00	120.90	65.70	155.06	46.12	40.56	177.49	153.57
26:0	550.10	443.29	327.12	540.82	241.31	739.79	204.98	182.51	701.30	618.65
27:0	75.21	55.84	0.00	83.03	0.00	93.02	0.00	26.79	0.00	98.81
28:0	434.83	287.98	296.97	477.57	165.78	595.85	177.58	161.04	641.26	548.40
29:0	0.00	0.00	0.00	51.40	0.00	57.06	0.00	18.24	0.00	78.50
30:0	181.08	94.28	0.00	198.63	0.00	236.17	77.55	72.09	378.70	321.73
31:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.65
32:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.05	0.00	113.00
Total	60664.55	43303.95	31446.52	25454.98	38789.31	41588.50	14294.86	13306.91	23275.13	24248.81

NA= not available

Appendix B, ctd. Fatty acid concentrations (ng L⁻¹) in suspended particles, seasonal sampling (1998-2000).

	Site CS			
Component	Apr-00-1	Apr-00-2	Jul-00-1	Jul-00-2
12:0	40.27	44.99	96.48	38.28
i13	0.00	0.00	0.00	0.00
a13	0.00	0.00	0.00	0.00
13:1	0.00	0.00	0.00	0.00
13:0	0.00	23.31	50.26	19.76
i14	73.81	112.61	166.41	73.15
14:1	26.70	42.93	120.71	54.72
14:0	671.33	724.80	2873.10	1345.91
i15	241.31	348.70	534.73	240.09
a15	168.45	242.70	404.23	178.56
15:1	0.00	0.00	0.00	0.00
15:0	169.01	188.57	394.25	213.15
16:4	262.64	292.25	889.16	464.56
16:3	178.98	320.18	1156.01	575.36
16:2	0.00	230.84	723.58	349.29
16:1ω7	2491.71	2279.97	6559.71	3074.09
16:1ω9	346.26	364.37	301.74	154.75
16:0	2255.57	2393.69	5933.95	2789.63
10Me17Br	0.00	0.00	0.00	0.00
i17	47.95	73.50	95.54	55.66
a17	0.00	77.87	126.24	84.10
17:1	0.00	71.33	194.07	88.80
17:0	125.31	136.38	187.77	122.87
18:4	633.47	525.34	1366.67	670.46
18:3	0.00	0.00	0.00	0.00
18:2	216.72	265.41	771.93	393.69
18:1ω9c	1374.28	1402.93	4412.03	2099.49
18:1ω9t	864.44	880.55	1520.60	701.92
18:0	361.19	644.85	628.19	402.03
19:0	3808.51	2837.73	1798.53	1212.33
20:5ω6	0.00	0.00	0.00	0.00
20:4ω6	95.40	97.07	220.64	123.88
20:5ω3	704.16	586.87	2027.35	969.68
20:3	0.00	0.00	0.00	23.16
20:2	0.00	0.00	0.00	0.00
20:1	19.53	31.98	137.58	46.33
20:0	2768.35	1825.10	1260.80	829.39
21:0	2000.00	1518.00	635.60	489.68
22:6ω6	0.00	0.00	0.00	0.00
22:6ω3	309.30	175.06	936.83	433.02
22:5ω6	0.00	0.00	0.00	0.00
22:5ω3	0.00	0.00	0.00	0.00
22:2	0.00	0.00	0.00	0.00
22:1ω9	31.15	40.58	38.32	64.17
22:0	671.14	642.84	479.71	308.61
23:0	156.20	124.69	84.64	56.16
24:1	0.00	25.21	67.63	40.06
24:0	623.39	619.87	562.96	342.15
25:0	97.94	101.03	58.89	37.43
26:0	421.52	402.75	253.98	164.96
27:0	0.00	61.74	33.62	20.07
28:0	330.01	298.71	210.21	132.45
29:0	0.00	37.72	0.00	12.89
30:0	137.75	128.23	86.28	51.43
31:0	0.00	14.69	0.00	0.00
32:0	0.00	53.94	57.52	69.31
Total	14146.88	15131.06	34763.53	17086.04

NA= not available

Appendix B, ctd. Fatty acid concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

Component	Oct-98	Jan-99	Jan-99-2	Feb-99	May-99	Jul-99	Oct-99	Oct-99-2	Feb-00	Apr-00	Jul-00
					Site X2						
12:0	0.00	21.63	31.42	NA	13.92	53.31	18.16	46.56	58.12	69.81	44.73
i13	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
a13	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13:1	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13:0	0.00	15.42	0.00	NA	33.87	21.28	0.00	13.25	23.11	169.64	15.10
i14	30.98	17.72	19.11	NA	32.23	69.77	14.39	29.83	101.88	185.72	27.88
14:1	0.00	10.29	10.35	NA	0.00	19.17	0.00	14.39	21.54	0.00	8.90
14:0	541.64	341.13	347.27	NA	626.78	879.06	441.66	441.15	596.90	2879.42	483.80
i15	176.64	73.44	78.77	NA	103.09	263.93	86.90	153.75	324.11	390.63	115.57
a15	122.37	59.72	63.18	NA	65.85	198.65	60.27	107.83	262.02	285.98	82.15
15:1	0.00	0.00	0.00	NA	0.00	17.62	0.00	0.00	0.00	0.00	0.00
15:0	183.60	99.13	97.83	NA	147.07	195.58	99.63	107.12	193.73	557.63	108.56
16:4	105.83	111.08	119.03	NA	285.06	149.15	72.05	284.03	110.63	804.23	55.72
16:3	535.00	189.53	218.73	NA	1178.48	834.02	285.44	96.32	306.64	4826.13	128.98
16:2	0.00	0.00	0.00	NA	84.19	167.11	0.00	0.00	0.00	0.00	68.08
16:1ω7	1918.66	964.80	1045.26	NA	2167.33	2839.85	1238.13	1357.94	2068.85	8487.57	1147.67
16:1ω9	155.41	93.79	102.42	NA	113.59	243.70	84.69	102.52	271.07	461.34	77.35
16:0	2951.05	1135.50	1160.96	NA	2172.57	2576.04	1350.61	1382.58	2168.98	4544.24	1328.63
10Me17Br	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
i17	0.00	15.92	17.04	NA	29.60	64.73	27.79	37.48	80.65	50.38	25.57
a17	100.95	40.97	39.71	NA	57.79	62.03	48.48	27.97	139.61	161.72	22.47
17:1	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17:0	241.89	52.93	55.57	NA	82.42	118.66	76.83	76.73	137.36	176.94	88.20
18:4	208.54	229.01	258.52	NA	393.04	344.66	185.05	174.60	261.13	1220.27	85.62
18:3	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18:2	196.71	164.72	172.34	NA	172.52	288.65	103.17	142.82	297.69	502.89	90.76
18:1ω9c	698.42	669.29	695.49	NA	987.74	1198.72	582.22	683.83	1097.28	1590.38	425.87
18:1ω9t	808.80	241.61	268.70	NA	328.86	550.50	257.32	343.47	426.04	1055.35	253.96
18:0	1506.56	382.98	370.34	NA	400.17	471.46	274.91	294.92	584.06	805.38	314.22
19:0	1406.38	1922.87	2229.78	NA	2611.05	1140.09	1094.97	918.79	1393.14	2214.16	3378.42
20:5ω6	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:4ω6	0.00	27.24	40.62	NA	71.79	110.85	0.00	33.96	120.96	222.87	36.63
20:5ω3	739.19	330.10	400.22	NA	1431.18	1129.60	483.08	341.73	492.39	6098.01	242.35
20:3	0.00	0.00	0.00	NA	0.00	11.78	0.00	0.00	0.00	0.00	0.00
20:2	0.00	0.00	0.00	NA	0.00	0.00	0.00	28.79	0.00	0.00	0.00
20:1	0.00	0.00	0.00	NA	0.00	39.92	0.00	17.08	25.38	0.00	4.60
20:0	981.98	1435.14	1624.26	NA	1847.35	730.14	742.44	565.13	855.14	1524.55	2507.12
21:0	1025.81	909.09	909.09	NA	1250.00	459.75	769.23	336.30	672.59	1428.57	1250.00
22:6ω6	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:6ω3	136.64	137.98	156.87	NA	243.87	226.70	159.60	122.75	270.73	1355.72	85.84
22:5ω6	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:5ω3	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:2	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22:1ω9	456.57	18.41	17.09	NA	12.91	27.51	0.00	21.03	48.22	29.49	11.96
22:0	464.07	208.79	212.80	NA	239.70	340.82	130.09	130.19	258.93	494.73	298.74
23:0	114.11	5.01	4.92	NA	59.26	83.53	0.00	31.35	70.02	120.53	87.33
24:1	0.00	0.00	0.00	NA	0.00	14.01	0.00	12.00	0.00	0.00	0.00
24:0	517.70	244.85	245.07	NA	296.31	386.42	172.94	166.57	288.60	580.65	373.17
25:0	99.85	42.61	44.98	NA	51.24	60.03	0.00	34.66	51.05	109.07	68.42
26:0	370.01	178.73	175.21	NA	201.36	239.12	124.44	102.37	179.19	411.95	279.60
27:0	52.26	0.00	0.00	NA	0.00	37.71	0.00	13.38	26.48	0.00	42.40
28:0	313.12	155.98	147.78	NA	155.66	161.71	102.37	68.27	301.97	350.83	229.76
29:0	0.00	0.00	0.00	NA	0.00	17.20	0.00	21.65	23.58	0.00	29.09
30:0	137.47	76.63	70.96	NA	74.14	52.31	78.20	27.99	84.49	172.85	35.47
31:0	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	18.73
32:0	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	13884.05	6356.95	6688.58	NA	12313.61	14566.87	6558.39	7092.87	11773.42	39172.36	6843.87

NA= not available

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Appendix B, ctd. Fatty acid concentrations (ng L^{-1}) in suspended particles, seasonal sampling (1998-2000).

				Site PS					
Component	Oct-98	Jan-99	Feb-99	May-99	Jul-99	Oct-99	Feb-00	Apr-00	Jul-00
12:0	0.00	113.27	88.70	62.55	NA	NA	157.66	NA	NA
i13	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
a13	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
13:1	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
13:0	0.00	25.79	11.63	19.26	NA	NA	16.31	NA	NA
i14	87.24	139.54	52.81	100.02	NA	NA	66.77	NA	NA
14:1	0.00	27.52	14.17	43.87	NA	NA	26.54	NA	NA
14:0	974.87	1258.22	476.83	994.54	NA	NA	627.21	NA	NA
i15	301.91	285.10	144.57	316.49	NA	NA	247.30	NA	NA
a15	1835.08	256.20	148.14	227.54	NA	NA	227.61	NA	NA
15:1	0.00	22.58	0.00	26.06	NA	NA	20.03	NA	NA
15:0	182.07	273.69	149.67	228.96	NA	NA	217.09	NA	NA
16:4	599.59	410.43	141.09	440.77	NA	NA	236.01	NA	NA
16:3	1054.70	919.59	221.58	642.25	NA	NA	398.44	NA	NA
16:2	456.34	0.00	0.00	292.72	NA	NA	0.00	NA	NA
16:1ω7	3179.11	3259.71	1633.69	2752.12	NA	NA	2574.12	NA	NA
16:1ω9	227.88	309.75	148.28	243.40	NA	NA	255.68	NA	NA
16:0	3420.30	3868.47	1944.07	3224.48	NA	NA	2736.81	NA	NA
10Me17Br	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
i17	0.00	88.97	37.70	95.49	NA	NA	70.92	NA	NA
a17	68.42	186.58	99.54	160.74	NA	NA	163.34	NA	NA
17:1	0.00	0.00	38.52	0.00	NA	NA	88.83	NA	NA
17:0	141.49	160.80	82.36	154.77	NA	NA	126.29	NA	NA
18:4	1173.24	1117.27	276.67	597.55	NA	NA	359.16	NA	NA
18:3	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
18:2	410.69	775.03	659.88	485.19	NA	NA	1074.82	NA	NA
18:1ω9c	1539.06	2693.00	1170.37	2307.97	NA	NA	1566.01	NA	NA
18:1ω9t	939.93	842.96	420.97	685.92	NA	NA	726.93	NA	NA
18:0	888.46	1048.89	690.99	730.22	NA	NA	936.22	NA	NA
19:0	1170.44	3576.86	2436.90	3088.29	NA	NA	3062.58	NA	NA
20:5ω6	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
20:4ω6	191.28	182.77	49.40	143.29	NA	NA	80.47	NA	NA
20:5ω3	2420.27	1332.79	318.06	1006.65	NA	NA	527.42	NA	NA
20:3	0.00	30.22	33.66	11.56	NA	NA	0.00	NA	NA
20:2	0.00	69.74	76.26	0.00	NA	NA	84.96	NA	NA
20:1	136.64	71.56	0.00	70.59	NA	NA	0.00	NA	NA
20:0	687.49	2330.62	1593.11	2058.86	NA	NA	2021.84	NA	NA
21:0	1070.71	986.25	928.24	809.23	NA	NA	798.99	NA	NA
22:6ω6	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
22:6ω3	440.94	263.23	64.71	145.44	NA	NA	95.50	NA	NA
22:5ω6	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
22:5ω3	0.00	0.00	0.00	0.00	NA	NA	0.00	NA	NA
22:2	0.00	0.00	0.00	0.00	NA	NA	50.20	NA	NA
22:1ω9	0.00	57.88	27.06	37.38	NA	NA	0.00	NA	NA
22:0	176.21	347.72	132.88	352.32	NA	NA	236.39	NA	NA
23:0	0.00	63.18	39.24	95.86	NA	NA	67.04	NA	NA
24:1	0.00	43.69	18.60	28.92	NA	NA	32.14	NA	NA
24:0	258.76	303.83	181.84	457.21	NA	NA	283.77	NA	NA
25:0	182.53	123.56	66.32	92.71	NA	NA	82.15	NA	NA
26:0	188.16	209.80	111.30	353.42	NA	NA	167.97	NA	NA
27:0	0.00	37.49	22.60	69.22	NA	NA	32.66	NA	NA
28:0	145.50	216.63	111.08	346.99	NA	NA	167.97	NA	NA
29:0	0.00	32.44	19.91	45.74	NA	NA	33.23	NA	NA
30:0	0.00	121.56	96.43	153.38	NA	NA	140.61	NA	NA
31:0	0.00	0.00	26.82	19.92	NA	NA	14.14	NA	NA
32:0	0.00	52.49	42.40	58.35	NA	NA	310.09	NA	NA
Total	21620.66	21643.94	10090.80	18321.82	NA	NA	15326.78	NA	NA

NA= not available

Appendix C, ctd Sterol concentrations (ng g⁻¹) in surface sediments, seasonal sampling (1998-2000).

Component	Oct-98	May-99	Jul-99	Oct 99-1	Oct 99-3	Apr 00-1	Apr-00-2	Apr-00-3	Jul-00-1	Jul-00-2	Jul-00-3
						Site MI					
C14OH	2995.76	3100.83	5676.55	4143.57	3826.81	4073.40	4128.81	5178.09	3547.75	4243.89	3679.28
C16OH	2110.05	4365.97	5770.15	8294.99	9333.32	4525.89	3924.46	6227.47	4419.67	3280.59	5011.97
C18OH	1829.76	1279.99	1352.36	1911.13	1728.71	1281.90	1024.21	1694.99	1912.28	791.48	1173.79
Phytol	10438.45	41398.78	9597.26	6727.00	9581.31	3751.87	7344.76	8752.27	3909.61	5592.80	5165.40
C19OH	2309.85	8511.86	10686.76	9985.33	9433.83	9439.23	9377.86	11054.40	7856.74	9623.01	8654.58
C20OH	1553.16	1100.32	1370.85	2668.90	1668.44	1519.82	737.56	1528.22	1409.12	639.28	1132.39
C22OH	1297.68	2515.80	2351.21	2386.69	2526.09	3309.43	3399.07	3555.50	2533.49	3092.62	4509.52
C24OH	689.77	1692.93	1872.76	3631.95	2197.94	1587.34	1243.17	1489.40	1420.82	1316.00	1128.51
C26OH	0.00	207.30	236.75	622.56	104.53	694.00	0.00	0.00	76.23	139.69	299.40
5α cholestane	958.19	2091.43	2400.00	2353.70	2400.00	1706.29	1795.47	1975.18	1418.60	1612.33	2265.71
24-norcholesta-5,22-dien-3β-ol	616.44	1172.70	1707.39	4071.98	2063.39	1345.07	751.83	1297.15	1440.59	678.44	728.14
24-nor-5α-cholesta-22-en-3β-ol	0.00	29.59	41.38	55.26	44.64	56.39	31.89	76.39	31.72	44.69	87.99
5β-cholestan-3β-ol	0.00	577.33	566.96	625.89	44.98	80.86	396.20	470.89	312.28	338.36	314.64
5β-cholestan-3α-ol	0.00	167.97	120.53	65.08	1149.49	291.62	212.92	66.80	34.75	34.75	33.51
27-nor-24-methylcholesta-5,22-dien-3β-ol	0.00	0.00	0.00	94.95	0.00	56.48	222.66	126.04	90.44	138.78	67.50
cholesta-5,22-dien-3β-ol	1703.82	1061.93	570.91	492.09	697.41	321.87	626.97	600.21	321.79	450.39	391.27
5α(H)-cholest-22-en-3β-ol	0.00	317.16	259.36	204.15	283.52	103.19	300.98	232.54	122.29	207.26	147.63
cholest-5-en-3β-ol	6971.33	1255.39	3393.66	3193.73	3688.57	2062.02	3545.80	3227.82	1821.52	2415.59	2009.30
5α-cholestan-3β-ol	2985.95	3482.85	3471.54	2654.30	4950.78	2085.73	2688.99	3093.88	2321.42	2095.42	1840.98
24-methylcholesta-5,22-dien-3β-ol	3573.16	4546.70	1760.76	1651.35	2062.67	1061.62	1983.87	1950.39	936.94	1347.83	1042.44
24-methylcholest-22-en-3β-ol	1404.66	1271.34	865.99	978.39	1123.60	709.86	1096.49	867.76	409.12	609.24	527.31
4α-methylcholest-8(14)-3-en-3β-ol	0.00	239.39	186.79	0.00	243.62	23.32	135.73	210.89	116.70	121.48	119.71
24-methylcholesta-5,24(28)-dien-3β-ol	541.86	0.00	4994.44	4653.04	6072.21	3327.36	2282.68	3730.59	3031.43	1630.35	2099.81
24-methylcholest-5-en-3β-ol	8355.62	15049.18	1669.80	24605.13	2009.09	1144.95	879.18	1540.67	1083.74	657.26	1026.29
24-methyl-5α(H)-cholestan-3β-ol	2476.15	1094.33	0.00	1354.08	0.00	678.54	1005.65	1052.94	1228.38	805.24	905.99
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24-ethylcholesta-5,22-dien-3β-ol	4953.45	3081.88	2245.59	3248.95	2853.71	1775.69	1890.16	2383.36	1646.80	1563.80	1447.27
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	0.00	310.92	136.91	181.82	193.46	78.52	187.60	193.36	113.20	191.03	127.83
24-ethyl-5α(H)-cholest-22-en-3β-ol	0.00	863.29	859.78	1330.20	1265.23	685.64	497.74	784.71	737.10	463.28	619.22
4-methyl-C29-D22-stanol	0.00	594.90	776.10	2043.94	3700.95	1241.32	461.49	1155.48	1420.60	402.30	804.26
23,24-dimethylcholest-5-en-3β-ol	0.00	357.25	270.68	476.48	383.18	91.36	237.20	309.41	205.19	235.77	187.94
24-ethylcholest-5-en-3β-ol	16640.90	9668.38	8065.21	15564.16	10541.45	7625.69	5704.65	8326.90	7035.94	4674.65	5452.91
24-ethyl-5α(H)-cholest-3β-ol	7785.31	1385.90	960.89	2776.85	2806.80	4558.98	570.31	1229.87	1473.52	593.39	792.40
24-ethylcholesta-5,24(28)-dien-3β-ol	0.00	2922.19	4884.48	10437.80	6734.65	1174.28	3038.57	4769.11	4451.22	2638.80	3152.30
4α,23,24-trimethylcholest-22-en-3β-ol	0.00	742.22	633.61	15863.92	1097.58	478.35	350.51	418.32	742.74	481.31	378.10
24-ethylcholestan-7-en-3β-ol	1123.00	620.82	577.02	1437.15	1083.45	468.58	453.04	701.26	692.04	519.60	413.29
5α(H)-C29 stenol (possibly D7 or D8)	0.00	164.55	181.33	11545.80	410.33	132.42	66.33	200.04	463.44	402.77	155.50
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	0.00	385.86	323.34	1124.56	1088.14	261.40	337.83	541.83	565.87	426.90	243.78
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	0.00	1097.67	1057.58	2201.77	1439.87	858.44	785.64	1339.16	1209.54	853.23	717.97
hopan-3β-ol	0.00	585.66	351.54	840.59	1479.18	440.43	384.69	615.95	492.65	415.27	359.43
extended hopanol	856.70	846.13	1407.28	2359.18	1803.38	1143.73	641.25	1525.74	1113.51	610.10	1007.38
Total Alcohols	37450.24	55339.57	24664.63	34117.23	29200.20	19362.62	19418.40	24607.52	17764.77	16466.90	19902.39
Total Sterols	59988.34	53893.47	42340.86	116132.60	61315.31	34363.74	31768.87	43039.48	35666.46	26047.30	27202.09

Appendix C. Sterol concentrations (ng g^{-1}) in surface sediments, seasonal sampling (1998-2000)

Component	Site FT									
	Oct-98	May-99	Jul-99	Oct-99	Apr-00-1	Apr-00-2	Apr-00-3	Jul-00-1	Jul-00-2	Jul-00-3
C14OH	2188.05	2154.55	5307.11	6517.80	4270.96	4491.48	4769.60	4803.23	4347.02	4952.45
C16OH	2761.21	6271.97	3845.15	6750.70	5152.59	7478.02	4072.57	6058.61	3480.31	3574.63
C18OH	438.74	1632.00	1014.19	963.91	881.70	2655.60	869.98	842.85	680.80	757.17
Phytol	4431.41	26939.74	12112.61	8555.27	9052.74	17378.85	11559.70	11135.45	9203.87	9312.16
C19OH	1911.63	5401.42	8354.65	10797.68	9081.87	6728.63	8136.98	8322.54	8522.55	9312.36
C20OH	321.68	23844.17	13246.16	13741.55	11692.02	8638.65	10579.69	11225.31	11432.12	11687.96
C22OH	290.72	2617.11	1329.33	1509.32	1346.37	762.41	881.21	996.58	914.86	1006.24
C24OH	332.04	1866.05	948.75	1228.71	747.97	0.51	864.49	830.48	641.55	773.54
C26OH	232.82	898.24	857.07	949.54	708.58	927.11	1120.70	833.94	579.77	785.19
5α cholestane	506.91	1379.24	1720.30	2201.24	1580.00	1217.47	1416.33	1503.17	1427.71	1569.54
24-norcholesta-5,22-dien-3β-ol	284.92	238.31	133.96	170.27	134.14	157.04	111.55	126.44	87.94	110.21
24-nor-5α-cholesta-22-en-3β-ol	0.00	921.54	879.30	0.00	0.00	76.31	1084.05	806.67	560.81	759.51
5β-cholestan-3β-ol	214.94	381.17	278.08	0.00	261.55	240.97	259.52	309.67	166.29	124.04
5β-cholestan-3α-ol	215.28	1286.92	761.18	869.76	292.05	433.60	361.39	294.71	226.97	281.33
27-nor-24-methylcholesta-5,22-dien-3β-ol	0.00	0.00	0.00	0.00	119.96	128.27	0.00	0.00	0.00	0.00
cholesta-5,22-dien-3β-ol	442.10	520.86	494.06	638.34	616.81	475.63	551.88	943.83	325.29	571.90
5α(H)-cholest-22-en-3β-ol	0.00	262.98	310.95	269.67	397.14	350.53	293.54	424.34	419.78	236.21
cholest-5-en-3β-ol	2909.43	6982.76	3388.11	3937.01	1350.70	2318.42	1138.70	2395.75	4178.92	5133.58
5α-cholestan-3β-ol	1530.40	7348.38	2790.64	2405.24	1120.84	3921.60	2326.70	2634.19	2347.64	1944.98
24-methylcholesta-5,22-dien-3β-ol	1508.85	3043.54	1182.49	1188.59	1936.65	1878.43	267.84	2615.89	2168.01	2498.09
24-methylcholest-22-en-3β-ol	1052.33	1931.84	1202.34	934.25	1212.04	1791.01	1324.57	1213.42	1273.57	1121.03
4α-methylcholest-8(14)-3-en-3β-ol	0.00	0.00	0.00	0.00	47.66	92.37	0.00	96.79	88.48	0.00
24-methylcholesta-5,24(28)-dien-3β-ol	655.81	4659.55	2283.37	4051.55	1480.84	1908.62	1721.60	5227.32	3355.97	1738.24
24-methylcholest-5-en-3β-ol	2676.33	988.50	3044.06	0.00	2247.97	691.30	1130.06	0.00	0.00	591.30
24-methyl-5α(H)-cholestan-3β-ol	441.08	316.55	136.01	58.95	0.00	1419.94	876.00	0.00	929.32	591.30
23,24-dimethylcholesta-5,22-dien-3β-ol	0.00	2461.64	1948.80	1743.40	1762.13	121.17	61.93	347.43	200.90	87.47
24-ethylcholesta-5,22-dien-3β-ol	1381.60	2083.61	186.47	263.00	283.44	2928.77	1615.76	2450.49	1671.48	1525.01
23,24-dimethyl-5α(H)-cholest-22-en-3β-ol	0.00	571.47	215.21	0.00	176.61	0.00	478.68	0.00	0.00	0.00
24-ethyl-5α(H)-cholest-22-en-3β-ol	366.53	123.31	179.14	297.49	147.36	1201.66	0.00	677.70	594.74	335.40
4-methyl-C29-D22-stanol	0.00	470.85	373.00	397.35	0.00	486.99	151.11	404.27	378.45	171.40
23,24-dimethylcholest-22-en-3β-ol	197.68					870.52	527.56	1108.29	213.11	294.13
24-ethylcholest-5-en-3β-ol	3646.36	12557.63	6244.92	6257.27	6000.89	8753.87	2859.96	7459.70	4577.54	2214.87
24-ethyl-5α(H)-cholest-3β-ol	2009.54	2785.13	2830.17	1417.84	2762.71	5338.13	3095.88	3236.63	2420.95	2036.69
24-ethylcholesta-5,24(28)-dien-3β-ol	0.00	603.75	786.44	743.57	549.56	856.23	426.69	737.42	390.10	372.15
4α,23,24-trimethylcholest-22-en-3β-ol	300.88	1337.31	525.38	469.32	182.21	598.24	703.16	752.66	246.02	309.59
24-ethylcholestan-7-en-3β-ol	327.89	814.13	399.58	357.19	196.01	554.23	364.07	408.69	278.44	210.63
5α(H)-C29 stenol (possibly D7 or D8)	0.00	546.62	259.34	240.29	308.84	266.11	246.92	44.54	95.00	106.61
4α,23S,24R-trimethyl-5α(H)-cholestan-3β-ol	0.00	464.79	776.57	635.04	565.01	274.97	600.39	496.05	409.74	509.10
4α,23R,24R-trimethyl-5α(H)-cholestan-3β-ol	0.00	1288.09	638.11	543.41	155.61	483.92	439.01	405.29	277.09	309.06
hopan-3β-ol	0.00	206.76	166.38	201.20	417.87	163.07	111.01	99.18	55.11	64.43
extended hopanol	424.02	1188.15	756.36	707.00	721.07	1327.11	848.33	736.96	676.50	572.66
Total Alcohols	9141.73	66239.20	34579.17	34981.53	31453.20	39996.34	31149.49	33199.40	27893.70	28829.18
Total Sterols	20585.97	56386.16	33170.43	28796.99	25447.72	40109.03	23977.90	36454.33	28614.16	24820.93

Appendix D, ctd. Fatty acid concentrations (ng g) in surface sediments, seasonal sampling (1998-2000).

Component	Oct-98	May-99	Jul-99	Oct-99-1	Oct-99-3	Site MI Apr-00-1	Apr-00-2	Apr-00-3	Jul-00-1	Jul-00-2	Jul-00-3
12:0	NA	1075.34	396.28	1267.06	626.95	409.58	717.90	436.10	538.29	661.10	267.98
i13	NA	140.16	58.96	38.65	63.38	0.00	0.00	62.55	55.50	35.90	0.00
a13	NA	99.02	41.40	78.36	89.31	77.76	218.67	147.27	96.89	121.75	0.00
13:1	NA	49.81	98.30	69.20	95.59	53.70	142.59	96.72	64.83	86.45	52.05
13:0	NA	311.93	156.10	154.98	133.13	120.06	216.47	159.61	116.22	116.48	66.64
i14	NA	737.84	411.63	579.21	509.67	614.00	1148.41	933.06	615.62	577.11	330.93
14:1	NA	322.70	57.07	338.40	148.12	59.99	202.90	236.58	102.35	88.16	68.33
14:0	NA	9827.43	2218.54	2460.84	2593.41	2297.35	4844.62	3434.57	2052.36	2432.03	1344.71
i15	NA	3197.70	1892.70	2082.48	2221.23	2429.81	5479.23	4252.56	2752.92	2775.88	1594.26
a15	NA	3578.42	2118.43	2245.96	2469.51	2705.69	5544.42	4925.20	2872.59	2839.29	1772.67
15:1	NA	970.63	72.97	73.59	103.60	134.23	375.28	1420.82	82.99	172.36	77.31
15:0	NA	6696.01	1163.84	1065.36	1148.19	1002.40	1906.90	520.93	874.69	892.96	625.69
16:4	NA	707.85	425.27	556.95	762.03	417.30	812.16	724.69	382.07	398.81	290.30
16:3	NA	367.33	134.39	114.55	205.25	183.61	373.85	218.49	101.87	143.14	71.75
16:2	NA	6540.75	1469.45	1423.62	1661.13	1476.54	3196.23	2072.73	1311.75	1440.93	831.87
16:1ω7	NA	5715.36	3378.71	2812.52	3783.75	7667.10	19920.21	14529.55	5884.01	7278.14	2347.77
16:1ω9	NA	40433.08	9406.54	6547.62	8595.17	2792.62	6954.69	6205.39	2674.07	2897.36	542.34
16:0	NA	25650.50	9838.13	11075.28	11905.95	10238.08	20794.08	14186.18	9241.60	10162.13	6551.61
10Me17Br	NA	0.00	0.00	846.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
i17	NA	1103.89	720.83	846.64	982.17	1031.43	2321.48	1614.37	1136.06	1085.22	679.71
a17	NA	28607.02	1051.88	1105.71	1298.67	1444.98	2719.47	2255.78	1344.68	1298.38	931.74
17:1	NA	23252.70	1137.98	1089.35	1272.55	1134.66	2015.21	1884.35	1179.92	1019.84	700.34
17:0	NA	24872.04	8737.53	980.56	1135.92	1006.13	1889.22	1538.03	977.87	890.02	666.92
18:4	NA	657.25	195.07	194.89	257.45	574.56	1311.76	792.89	412.38	472.30	243.12
18:3	NA	1390.58	521.58	446.66	535.26	1734.77	3688.15	999.17	1815.65	3052.26	1438.12
18:2	NA	7196.31	4338.59	7240.23	3551.34	3815.40	8957.77	5693.35	3078.79	437.16	2531.78
18:1ω9c	NA	7972.14	4441.95	5301.32	4754.59	2168.38	6295.87	3757.38	2033.99	2514.34	1321.51
18:1ω9t	NA	5364.33	2100.03	2175.46	2586.22	259.80	686.28	472.12	343.32	313.06	179.38
18:0	NA	5542.00	4590.50	675.63	6485.47	5095.80	7235.98	6558.75	5014.92	3758.10	3130.54
19:0	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:5ω6	NA	148.70	92.24	225.54	104.45	102.34	335.64	207.92	296.61	46.36	59.93
20:4ω6	NA	187.98	128.59	190.98	170.96	135.70	370.11	319.98	251.36	121.64	105.47
20:5ω3	NA	703.81	501.62	677.40	634.28	624.30	954.25	949.49	1568.52	445.72	314.99
20:3	NA	9111.98	7199.29	7776.49	10329.48	9046.82	13316.89	10475.96	7507.53	8013.70	5458.24
20:2	NA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:1	NA	2473.61	969.64	887.78	882.40	728.84	1867.09	1185.96	788.72	820.06	431.53
20:0	NA	3706.94	866.93	669.19	692.86	997.48	1871.69	1080.81	577.94	724.36	380.34
21:0	NA	566.65	153.70	180.50	151.73	140.64	292.45	186.82	169.88	95.45	69.12
22:6ω6	NA	379.57	170.32	177.68	254.62	415.41	1037.92	613.53	396.57	358.38	206.34
22:6ω3	NA	528.56	198.45	224.27	282.15	91.25	200.68	191.48	131.29	109.60	58.41
22:5ω6	NA	8678.51	8075.64	8339.18	8988.17	6452.72	11480.67	8497.82	6405.18	6529.62	5574.25
22:5ω3	NA	4540.00	4912.13	4822.01	4912.13	3812.21	5611.24	4406.47	3014.49	3359.19	3307.28
22:2	NA	249.80	104.46	97.31	114.46	100.47	298.70	142.96	133.40	127.69	0.00
22:1ω9	NA	583.83	169.39	174.98	156.78	215.02	530.66	201.91	124.02	122.53	50.93
22:0	NA	186.01	32.45	41.82	441.00	295.84	319.68	414.17	419.53	187.39	0.00
23:0	NA	131.23	328.09	391.15	175.83	48.65	188.92	177.70	72.43	78.06	151.29
24:1	NA	249.60	281.03	881.52	893.39	107.75	106.42	195.31	53.09	224.56	197.34
24:0	NA	228.52	108.40	281.01	161.75	844.19	456.28	802.79	775.47	233.34	342.59
25:0	NA	5601.01	6315.45	14388.88	12609.42	8456.76	6968.05	9096.66	8552.75	3383.77	4054.75
26:0	NA	1658.19	1718.84	3481.55	3561.22	2103.67	19435.98	2545.33	2153.05	874.19	1121.61
27:0	NA	897.21	711.80	831.56	1293.26	915.48	877.35	1237.40	701.92	393.91	501.08
28:0	NA	809.06	7736.72	16133.70	18331.52	405.11	11370.42	12629.40	11180.98	4646.09	5863.62
29:0	NA	1821.30	1795.56	3271.54	3213.64	2090.83	3341.39	2710.39	2777.04	1095.77	1431.78
30:0	NA	9298.10	7558.01	16763.54	16736.53	11316.36	12595.98	15453.12	14925.81	5403.48	7092.87
31:0	NA	1059.85	897.58	1735.95	2023.34	1109.09	1394.28	1660.60	1424.65	646.91	857.23
32:0	NA	10622.83	8893.88	17355.15	21497.12	12097.78	15157.88	19440.14	16939.88	6662.92	9900.38
28:0	NA	605.16	742.01	953.72	1120.71	5871.15	1010.57	1192.21	937.33	536.17	599.50
30:0	NA	3412.61	3016.78	5050.83	6673.69	3488.66	5041.20	6068.91	4849.73	20195.66	2866.63
31:0	NA	745.00	2412.43	123.48	370.24	199.82	356.28	2835.96	256.20	138.32	151.23
32:0	NA	703.46	629.44	4295.00	3389.53	1290.80	5199.16	1349.53	2430.88	2830.75	1076.61
Total	NA	259938.72	107708.49	142527.14	155911.92	105139.14	201548.84	163019.69	120047.25	98463.76	66544.92

NA = not available

Appendix D. Fatty acid concentrations (ng/g) in surface sediments, seasonal sampling (1998-2000).

Component	Oct-98	May-99	Jul-99	Oct-99	Apr-00-1	Apr-00-2	Apr-00-3	Jul-00-1	Jul-00-2	Jul-00-3
					Site FT					
12:0	0.00	156.35	213.38	260.82	319.10	159.32	111.10	96.72	0.00	71.40
i13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
a13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13:1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13:0	0.00	136.67	151.87	210.60	214.26	180.76	128.60	101.16	73.89	87.93
i14	276.76	701.25	750.60	1296.37	1197.46	966.53	678.90	695.26	529.60	464.11
14:1	0.00	142.89	116.75	0.00	176.11	201.43	130.83	88.59	82.96	68.65
14:0	1431.72	3627.00	2991.08	6000.38	4434.28	4120.35	3316.73	2849.76	2648.68	2779.19
i15	1088.32	1958.26	2298.41	3977.40	2966.60	2512.77	1904.78	1912.20	1625.52	1605.37
a15	1131.08	2201.72	2543.87	4170.08	3597.27	3212.42	2104.04	2146.98	1837.26	1827.40
15:1	0.00	324.75	381.24	466.76	1309.91	472.10	935.57	318.83	504.49	1338.72
15:0	794.87	1680.10	1782.89	2894.06	1016.27	1911.70	3781.40	1428.98	2086.78	4207.01
16:4	0.00	590.03	645.24	917.24	219.46	706.22	557.35	487.38	422.07	578.70
16:3	1300.59	453.49	246.24	468.57	764.64	264.58	236.80	250.27	206.24	355.91
16:2	0.00	3398.93	2591.69	4838.73	3417.72	2641.79	3993.92	2640.46	2631.31	3208.67
16:1ω7	6235.28	22593.41	15953.59	30054.83	19671.48	19385.38	17055.61	14760.50	14944.33	15549.06
16:1ω9	1245.85	4926.97	4768.79	8867.57	3448.89	4982.60	3589.29	4105.99	3333.36	3702.74
16:0	5941.03	17463.97	13894.13	29986.13	11455.71	16931.00	14420.66	13719.31	12823.58	14731.51
10Me17Br	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
i17	361.93	935.75	894.82	1571.20	1252.53	999.48	773.47	778.07	639.99	741.98
a17	367.33	1390.12	1325.08	2131.32	1677.33	1473.11	1796.14	1065.30	1353.12	2615.03
17:1	0.00	1501.79	1747.45	2553.65	1696.77	1315.95	1379.77	1234.33	1114.74	1728.79
17:0	410.43	1618.95	1299.42	2438.50	1759.20	1421.10	1196.31	1162.70	1073.09	1399.45
18:4	409.33	350.82	263.27	427.45	224.90	312.44	324.84	985.47	197.99	249.45
18:3	0.00	1779.29	972.15	2474.98	323.94	1092.57	1115.51	1061.58	1089.79	974.32
18:2	2863.39	2488.74	1192.06	3031.97	1070.77	328.31	1402.32	875.35	1357.46	1761.55
18:1ω9c	3712.94	7886.03	5967.99	12062.39	10334.39	10484.69	5095.50	5456.96	4902.95	5042.19
18:1ω9t	1287.41	5533.67	4111.82	8330.87	5431.52	4927.06	3317.13	4084.38	3471.23	4072.38
18:0	1772.23	4493.87	3551.53	6482.63	2790.36	454.57	3696.28	3411.25	2872.95	3359.91
19:0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:5ω6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:4ω6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:5ω3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:3	3493.70	5284.53	8296.39	5587.38	11073.42	6480.49	7303.74	6937.02	6329.00	8007.86
20:2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20:1	1030.91	2551.14	1686.23	3675.36	1938.91	1298.73	2016.88	1689.31	1693.05	2359.71
20:0	2092.71	4494.65	1612.47	4346.15	1712.55	1520.34	3389.47	1926.83	2251.48	2898.61
21:0	0.00	1870.27	88.30	192.80	426.54	128.40	164.09	86.03	150.75	193.09
22:6ω6	0.00	767.06	647.05	1333.68	0.00	1057.93	0.00	791.94	745.67	1049.50
22:6ω3	394.06	330.90	169.07	301.47	2115.25	380.61	677.69	360.09	463.62	810.96
22:5ω6	3162.66	2686.86	8125.82	5302.04	7524.97	8725.06	8540.38	7980.24	6417.29	8537.96
22:5ω3	1406.82	3090.20	4201.23	5400.00	3346.64	2727.74	3186.00	3382.17	3201.37	3501.10
22:2	0.00	0.00	0.00	0.00	0.00	155.03	0.00	0.00	0.00	377.15
22:1ω9	0.00	1336.07	239.11	650.61	5382.08	160.46	490.16	342.32	350.35	562.40
22:0	0.00	844.71	0.00	0.00	0.00	197.18	0.00	0.00	0.00	244.68
23:0	0.00	552.90	108.41	370.67	724.21	93.47	154.98	77.80	180.59	277.02
24:1	0.00	170.44	636.29	709.37	0.00	222.60	583.82	519.66	415.20	691.60
24:0	0.00	447.82	167.07	382.75	1452.15	424.76	175.43	288.56	119.98	217.14
25:0	2327.76	5043.42	5209.45	5955.29	11194.59	6393.99	5180.80	6409.10	3283.24	4591.28
26:0	527.19	1380.22	1532.04	1427.49	2705.01	1610.71	1327.47	1564.01	845.23	1167.59
27:0	0.00	576.51	515.21	473.46	768.72	469.50	383.10	347.41	292.81	220.19
28:0	2719.15	668.19	7611.03	8843.27	14811.33	8875.29	6616.55	8796.03	4587.06	6099.88
29:0	347.40	1107.14	1406.46	1444.60	2291.77	8091.89	8310.63	1663.21	2079.02	3868.34
30:0	1674.00	5343.92	6395.30	8510.26	6326.60	33450.26	5086.26	7524.18	3597.59	4858.45
31:0	256.16	567.20	692.14	1080.57	549.71	585.40	2095.98	1027.44	642.91	675.10
32:0	1420.69	5173.01	5851.94	10045.02	12036.92	21433.24	4996.01	8188.78	3387.21	4828.21
28:0	0.00	420.79	415.47	483.56	394.20	1659.87	551.77	491.86	292.86	257.13
30:0	4342.58	1833.83	1941.92	2795.80	2055.44	12171.88	1462.20	2435.87	1161.42	1428.47
31:0	0.00	111.62	176.83	7024.72	668.07	1998.34	4892.14	2212.87	2801.84	1475.27
32:0	0.00	366.32	469.04	504.65	416.71	626.40	353.02	446.92	258.92	312.92
Total	47763.09	124292.91	108226.17	196466.07	148741.61	########	#######	112908.02	91424.19	#######

Appendix E. Water content of surface sediment, sampling season 1999-2000.

Site	Date	% Water
FT-1	Oct-99	70.65
FT-1	Apr-00	62.18
FT-2	Apr-00	53.07
FT-3	Apr-00	60.05
FT-1	Jul-00	64.24
FT-2	Jul-00	60.03
FT-3	Jul-00	62.82
MI-1	Oct-99	71.20
MI-3	Oct-99	71.83
MI-1	Apr-00	60.80
MI-2	Apr-00	62.04
MI-3	Apr-00	65.74
MI-1	Jul-00	53.54
MI-2	Jul-00	58.50
MI-3	Jul-00	58.22

Appendix F. Biochemical concentrations (in $\mu g\ L^{-1}$) of suspended
particles, seasonal sampling (1998-2000).

Site	Date	Average Protein	STDEV Protein	Average Carb	STDEV Carb	Total Lipid
HD	Oct-98	NA	NA	NA	NA	NA
HD	Jan-99	48.26	8.97	95.88	7.55	107.06
HD	Feb-99	22.06	6.53	163.90	9.43	85.30
HD	May-99	49.82	5.41	83.52	3.12	100.97
HD	Jul-99	36.03	5.69	164.05	5.68	84.55
HD	Oct-99	42.81	5.16	35.06	2.81	87.86
HD	Feb-00	72.29	4.35	129.41	5.40	99.18
HD	Apr-00	45.46	6.62	116.99	3.57	122.03
HD	Jul-00	45.52	3.35	113.52	6.18	96.52
RV	Oct-98	27.46	0.51	95.96	5.77	74.57
RV	Jan-99	NA	NA	NA	NA	NA
RV	Feb-99	63.02	4.32	180.48	11.85	NA
RV	May-99	39.04	3.81	66.67	3.37	42.38
RV	Jul-99	32.13	5.15	118.95	5.39	46.63
RV	Oct-99	37.75	4.75	46.08	3.56	38.51
RV	Feb-00	89.10	9.25	171.63	2.82	48.23
RV	Apr-00	34.03	6.62	80.25	4.49	68.78
RV	Jul-00	28.70	1.95	81.37	1.90	42.99
MM	Oct-98	55.11	1.87	143.68	4.08	96.05
MM	Jan-99	72.49	8.52	157.66	7.69	163.34
MM	Feb-99	28.40	1.05	151.03	13.90	115.94
MM	May-99	104.81	8.44	276.84	19.18	98.92
MM	Jul-99	292.66	10.18	417.58	100.38	544.49
MM	Oct-99	117.45	5.24	191.53	6.07	147.11
MM	Feb-00	127.50	10.19	201.36	5.45	136.80
MM	Apr-00	63.32	2.99	226.27	11.11	218.27
MM	Jul-00	320.85	15.65	968.71	52.33	628.02
TI	Oct-98	NA	NA	NA	NA	NA
TI	Jan-99	25.73	4.66	74.72	6.28	57.27
TI	Feb-99	24.59	2.73	102.79	6.41	71.96
TI	May-99	21.17	3.57	57.35	3.46	135.01
TI	Jul-99	38.50	6.83	76.68	3.31	110.16
TI	Oct-99	38.80	3.53	65.75	4.59	107.11
TI	Feb-00	66.60	6.42	137.44	5.52	72.60
TI	Apr-00	NA	NA	NA	NA	NA
TI	Jul-00	53.86	6.26	84.03	6.11	117.77

Appendix F, cont. Biochemical concentrations (in μg L⁻¹) of suspended
particles, seasonal sampling (1998-2000).

Site	Date	Average Protein	STDEV Protein	Average Carb	STDEV Carb	Total Lipid
FT	Oct-98	27.19	0.59	67.36	3.31	121.43
FT	Jan-99	NA	NA	NA	NA	NA
FT	Feb-99	NA	NA	NA	NA	NA
FT	May-99	27.06	1.43	57.72	2.67	86.74
FT	Jul-99	46.46	0.89	125.09	5.89	82.97
FT	Oct-99	31.17	0.60	54.61	2.56	63.10
FT	Feb-00	NA	NA	NA	NA	NA
FT-1	Apr-00	37.86	1.45	58.29	0.70	61.01
FT-2	Apr-00	27.76	1.62	53.78	2.05	60.68
FT-3	Apr-00	34.16	1.41	62.37	1.21	62.24
FT-1	Jul-00	38.43	0.57	58.93	2.16	103.67
FT-2	Jul-00	27.91	1.36	71.34	4.30	85.14
FT-3	Jul-00	24.91	0.86	60.66	1.60	71.88
MI	Oct-98	48.97	2.60	102.38	7.60	173.81
MI	Jan-99	NA	NA	NA	NA	NA
MI	Feb-99	NA	NA	NA	NA	NA
MI	May-99	27.05	8.72	72.69	7.03	62.35
MI	Jul-99	62.60	9.55	109.39	5.33	70.71
MI-1	Oct-99	296.06	19.24	329.85	10.90	391.44
MI-3	Oct-99	90.86	7.73	91.99	6.06	98.53
MI	Feb-00	NA	NA	NA	NA	NA
MI-1	Apr-00	83.29	9.69	300.15	7.25	190.50
MI-2	Apr-00	31.37	5.99	113.93	7.07	87.54
MI-3	Apr-00	37.77	4.71	104.20	6.44	106.52
MI-1	Jul-00	78.52	6.82	122.72	4.81	144.83
MI-2	Jul-00	34.48	3.78	54.49	2.66	100.21
MI-3	Jul-00	55.10	4.74	108.46	6.15	103.13
LH	Oct-98	46.35	0.98	156.56	9.06	215.45
LH	Jan-99	NA	NA	NA	NA	NA
LH	Feb-99	NA	NA	NA	NA	NA
LH	May-99	105.72	11.80	196.19	12.91	130.22
LH	Jul-99	134.54	3.83	412.72	22.27	242.80
LH	Oct-99	75.50	6.48	140.07	10.23	139.18
LH	Feb-00	NA	NA	NA	NA	148.36
LH	Apr-00	79.09	6.05	240.80	13.51	NA
LH	Jul-00	117.76	10.92	246.30	12.74	258.66

Appendix F, cont. Biochemical concentrations (in $\mu g\ L^{-1}$) of suspended particles, seasonal sampling (1998-2000).

Site	Date	Average Protein	STDEV Protein	Average Carb	STDEV Carb	Total Lipid
CS	Oct-98	147.78	3.79	304.61	78.27	296.09
CS	Jan-99	136.89	12.62	558.64	39.15	120.36
CS	Feb-99	NA	NA	NA	NA	NA
CS	May-99	158.16	19.16	551.30	5.92	170.86
CS	Jul-99	155.06	14.24	431.42	62.92	157.44
CS	Oct-99	113.18	10.26	115.84	5.14	113.85
CS	Feb-00	235.17	235.17	402.08	57.35	143.83
CS	Apr-00	141.25	9.32	369.99	26.22	100.53
CS	Jul-00	119.98	4.81	208.63	15.82	148.15
X2	Oct-98	66.05	1.76	110.39	33.52	128.36
X2	Jan-99	48.49	5.51	190.99	70.56	82.07
X2	Feb-99	NA	NA	NA	NA	NA
X2	May-99	73.35	5.27	169.28	23.14	98.10
X2	Jul-99	122.42	16.07	304.77	85.31	138.77
X2	Oct-99	66.02	6.12	85.52	10.55	74.07
X2	Feb-00	82.62	3.73	121.24	46.68	74.45
X2	Apr-00	141.80	12.11	380.65	11.29	159.12
X2	Jul-00	105.41	10.00	195.83	62.05	86.42
PS	Oct-98	47.55	1.38	149.45	9.87	78.70
PS	Jan-99	34.07	9.40	154.37	15.07	197.96
PS	Feb-99	21.93	4.91	131.18	20.90	145.84
PS	May-99	124.23	9.89	353.55	44.13	210.35
PS	Jul-99	NA	NA	NA	NA	NA
PS	Oct-99	NA	NA	NA	NA	NA
PS	Feb-00	59.91	4.93	200.75	38.18	148.07
PS	Apr-00	61.27	7.93	NA	NA	NA
PS	Jul-00	NA	NA	187.84	9.43	NA

Appendix G. Biochemical concentrations (in mg g^{-1} dw) of surface sediments, seasonal sampling (1999-2000).

Site	Date	Total Protein Average	Total Protein STDEV	Total Carbohydrate Average	Total Carbohydrate STDEV	Total Lipid
FT-1	Oct-99	0.97	0.09	3.86	0.51	1.96
FT-1	Apr-00	0.89	0.08	3.31	0.10	1.98
FT-2	Apr-00	0.77	0.05	3.03	0.16	2.21
FT-3	Apr-00	0.77	0.07	2.57	0.49	1.62
FT-1	Jul-00	0.85	0.04	3.41	0.44	1.76
FT-2	Jul-00	0.70	0.09	2.35	0.29	1.20
FT-3	Jul-00	0.74	0.10	4.42	1.71	1.37
MI-1	Oct-99	4.69	0.88	7.89	0.46	3.21
MI-3	Oct-99	2.93	0.63	4.42	0.80	2.30
MI-1	Apr-00	2.89	0.51	5.89	0.62	1.58
MI-2	Apr-00	0.85	0.15	3.29	0.18	1.37
MI-3	Apr-00	1.86	0.26	3.96	0.14	2.59
MI-1	Jul-00	2.75	0.67	5.40	0.40	1.80
MI-2	Jul-00	0.89	0.12	4.32	1.86	1.17
MI-3	Jul-00	1.84	0.30	3.70	0.37	0.98

Appendix H. Amino acid composition (μg g^{-1}) in suspended particles, sampling period 1998-2000

Compound	HD Jan-99	HD Feb-99	HD May-99	HD Jul-99	HD Oct-99	HD Feb-00	HD Apr-00	HD Jul-00	RV Jan-99	RV Feb-99	RV May-99	RV Jul-99	RV Oct-99	RV Feb-00	RV Apr-00	RV Jul-00
Aspartic Acid	194.59	65.69	188.81	130.85	471.43	242.80	197.32	137.81	NA	117.96	165.77	103.10	206.71	199.72	167.59	127.93
Glutamic Acid	157.84	49.42	164.30	115.70	377.25	188.66	158.13	118.03	NA	98.67	141.98	79.27	150.35	161.41	147.44	100.70
Serine	123.00	29.71	154.09	98.81	362.76	170.46	139.22	101.68	NA	69.67	133.24	68.87	150.35	140.26	110.38	91.26
Histidine	21.52	6.33	39.71	22.41	74.00	30.50	26.71	38.91	NA	13.86	26.95	13.02	27.45	24.54	24.49	23.25
Glycine	261.99	109.13	348.11	248.91	785.03	454.16	290.91	253.55	NA	205.53	280.80	163.36	317.54	365.53	232.53	189.17
Threonine	116.72	27.93	157.72	108.91	320.33	121.28	134.34	119.50	NA	68.86	129.34	71.92	129.55	120.11	107.80	94.59
Arginine	130.04	24.32	150.68	66.45	228.21	91.49	91.06	85.66	NA	46.33	101.47	45.57	91.92	99.96	70.74	68.55
β-alanine	34.84	17.34	17.93	9.79	66.76	66.20	18.13	12.10	NA	25.30	18.77	8.19	26.83	45.69	16.60	9.83
Alanine	213.63	85.22	293.65	220.50	657.73	331.70	267.32	224.45	NA	166.14	235.27	139.85	266.18	286.32	211.74	178.81
Tyrosine	58.64	16.87	61.27	38.67	108.67	56.74	54.59	39.56	NA	33.04	50.18	25.72	43.67	42.10	44.80	30.82
γ-aminobutyric Acid	21.52	10.89	8.62	8.21	34.67	40.90	12.09	7.19	NA	17.79	8.92	5.46	13.93	34.12	11.60	5.85
Methionine	16.18	4.79	29.05	15.15	43.47	21.99	15.79	18.47	NA	8.78	22.67	8.82	13.72	15.96	14.66	15.54
Valine	138.61	42.02	167.25	131.48	437.28	187.01	134.34	113.62	NA	83.99	138.82	81.47	165.74	148.05	109.09	96.05
Phenylalanine	83.40	20.77	79.65	75.45	229.25	77.07	85.21	77.16	NA	38.36	76.56	50.50	91.50	65.84	72.67	64.03
Isoleucine	101.86	26.81	133.43	94.55	320.33	75.18	108.21	92.20	NA	52.45	105.00	61.52	130.80	60.06	88.14	77.18
Leucine	147.18	40.36	171.79	117.43	398.98	147.05	146.04	129.47	NA	77.29	142.54	76.75	152.64	131.49	119.41	102.69
Ornithine	6.28	4.50	7.72	5.05	21.22	13.95	7.60	4.74	NA	5.66	5.95	3.36	8.53	11.77	6.77	3.85
Lysine	76.16	9.71	95.54	70.08	237.53	47.05	62.78	60.65	NA	25.65	74.15	43.15	92.12	42.30	54.95	48.36
Total (mg g^{-1})	1.90	0.59	2.27	1.58	5.17	2.36	1.95	1.63	NA	1.16	1.86	1.05	2.08	2.00	1.61	1.33

Appendix H, cont. - Amino acid composition (µg g-1) in suspended particles, sampling period 1998-2000

Compound	MM Jan-99	MM Feb-99	MM May-99	MM Jul-99	MM Oct-99	MM Feb-00	MM Apr-00	MM Jul-00	TI Jan-99	TI Feb-99	TI May-99	TI Jul-99	TI Oct-99	TI Feb-00	TI Apr-00	TI Jul-00
Aspartic Acid	354.66	85.18	269.33	527.80	189.79	160.42	187.48	1025.13	172.80	85.23	73.60	206.64	169.79	350.74	NA	204.68
Glutamic Acid	303.14	64.07	242.75	506.24	151.88	124.65	150.25	767.31	154.34	68.64	73.50	181.18	148.62	281.83	NA	176.45
Serine	172.59	38.52	196.22	241.54	146.04	112.62	132.28	478.70	123.40	52.14	72.80	148.32	147.81	264.95	NA	149.86
Histidine	35.72	8.21	45.95	41.12	29.79	20.15	25.38	106.21	30.76	9.60	18.98	36.56	31.05	50.99	NA	51.76
Glycine	425.47	141.50	443.30	639.19	316.04	300.07	276.41	1171.36	248.11	144.27	142.01	354.73	297.64	661.86	NA	364.43
Threonine	193.77	36.22	200.85	256.31	128.96	80.13	127.64	461.77	123.59	40.63	71.81	159.43	131.88	187.78	NA	174.10
Arginine	184.29	31.54	162.99	208.00	91.88	60.45	86.52	403.28	137.94	28.49	75.30	103.43	93.16	111.29	NA	118.10
β-alanine	57.85	22.48	22.83	23.95	26.88	43.74	17.23	56.95	28.33	16.82	6.29	15.50	26.42	69.25	NA	20.23
Alanine	354.66	110.50	373.95	436.37	264.79	219.16	253.99	825.80	210.45	122.44	137.62	332.52	280.30	544.03	NA	324.43
Tyrosine	97.36	21.87	78.03	71.86	43.75	37.49	51.87	186.25	52.19	24.76	21.77	46.74	48.60	92.68	NA	56.46
γ-aminobutyric Acid	35.72	14.12	10.98	20.76	13.96	27.02	11.49	33.86	25.72	13.73	3.89	12.26	15.93	45.13	NA	11.06
Methionine	26.87	6.22	36.99	37.93	17.50	14.53	15.01	86.97	16.59	5.32	11.09	21.06	18.55	31.70	NA	25.64
Valine	230.12	54.48	212.98	250.32	176.04	123.56	127.64	534.89	135.14	56.42	74.30	179.79	143.78	235.32	NA	149.39
Phenylalanine	138.45	26.93	101.43	149.72	92.29	50.92	80.96	286.30	85.00	30.00	38.95	102.74	93.77	107.50	NA	111.05
Isoleucine	169.11	34.76	169.92	206.41	128.96	49.67	102.82	434.06	92.08	28.81	55.93	130.51	112.12	118.52	NA	131.75
Leucine	244.34	52.33	218.76	225.57	160.63	97.16	138.76	529.50	146.52	46.74	74.90	169.61	156.08	205.69	NA	185.86
Ornithine	10.43	5.83	9.83	12.78	8.54	9.22	7.23	22.32	9.32	5.48	3.00	7.40	10.08	14.82	NA	6.35
Lysine	126.44	12.58	92.76	136.54	95.63	31.08	59.65	285.53	71.77	14.05	42.94	105.52	90.95	71.32	NA	91.05
Total (mg g^{-1})	3.16	0.77	2.89	3.99	2.08	1.56	1.85	7.70	1.86	0.79	1.00	2.31	2.02	3.45	NA	2.35

Appendix H, cont. - Amino acid composition (μg g^{-1}) in suspended particles, sampling period 1998-2000

Compound	FT Jan-99	FT Feb-99	FT May-99	FT Jul-99	FT Oct-99	FT Feb-00	FT Apr-00	FT Jul-00	MI Jan-99	MI Feb-99	MI May-99	MI Jul-99	MI Oct-99	MI Feb-00	MI Apr-00	MI Jul-00
Aspartic Acid	NA	NA	181.06	346.95	408.81	NA	634.49	313.26	NA	NA	358.48	510.49	3162.90	NA	560.60	583.43
Glutamic Acid	NA	NA	208.08	350.87	309.83	NA	544.44	272.78	NA	NA	348.71	519.36	2965.46	NA	547.32	516.66
Serine	NA	NA	108.11	212.69	244.31	NA	364.10	178.77	NA	NA	180.05	312.95	1584.37	NA	339.97	333.30
Histidine	NA	NA	17.75	37.11	46.35	NA	70.93	38.36	NA	NA	29.56	54.60	319.84	NA	66.03	71.51
Glycine	NA	NA	263.12	483.01	468.41	NA	739.73	431.76	NA	NA	383.97	710.68	3053.03	NA	677.73	799.76
Threonine	NA	NA	111.53	193.69	215.73	NA	344.56	189.37	NA	NA	185.75	284.98	1399.03	NA	326.30	352.23
Arginine	NA	NA	75.55	157.18	118.84	NA	214.62	145.67	NA	NA	125.82	231.27	963.10	NA	205.96	271.54
β-alanine	NA	NA	6.84	15.39	13.24	NA	21.88	13.30	NA	NA	13.02	27.08	50.40	NA	14.12	37.55
Alanine	NA	NA	178.12	360.82	442.96	NA	664.54	323.14	NA	NA	296.65	530.90	2449.39	NA	613.02	595.93
Tyrosine	NA	NA	35.98	54.30	73.19	NA	144.96	66.47	NA	NA	59.93	79.90	474.63	NA	134.95	123.74
γ-aminobutyric Acid	NA	NA	3.42	9.35	11.85	NA	17.64	10.08	NA	NA	5.69	15.54	40.35	NA	15.23	20.23
Methionine	NA	NA	20.84	31.68	29.28	NA	39.67	33.85	NA	NA	34.71	46.61	189.85	NA	35.94	61.59
Valine	NA	NA	103.72	201.23	294.50	NA	338.82	194.19	NA	NA	172.73	296.08	1698.20	NA	309.61	360.16
Phenylalanine	NA	NA	53.89	113.13	154.39	NA	209.43	107.23	NA	NA	89.75	166.46	1001.25	NA	198.02	199.68
Isoleucine	NA	NA	95.74	155.97	215.73	NA	265.38	158.25	NA	NA	159.44	229.50	1014.25	NA	259.35	295.30
Leucine	NA	NA	106.97	180.41	268.71	NA	379.88	189.71	NA	NA	178.15	265.45	1357.79	NA	355.81	356.53
Ornithine	NA	NA	5.21	10.56	9.76	NA	15.90	9.10	NA	NA	2.17	5.33	32.65	NA	4.55	9.22
Lysine	NA	NA	52.27	103.18	159.97	NA	166.70	104.84	NA	NA	87.04	151.81	845.02	NA	155.20	193.77
Total (mg g^{-1})	NA	NA	1.63	3.02	3.49	NA	5.18	2.78	NA	NA	2.71	4.44	22.60	NA	4.82	5.18

Appendix H, cont. - Amino acid composition ($\mu g\ g^{-1}$) in suspended particles, sampling period 1998-2000

Compound	LH Jan-99	LH Feb-99	LH May-99	LH Jul-99	LH Oct-99	LH Feb-00	LH Apr-00	LH Jul-00	CS Jan-99	CS Feb-99	CS May-99	CS Jul-99	CS Oct-99	CS Feb-00	CS Apr-00	CS Jul-00
Aspartic Acid	NA	NA	88.87	75.43	132.46	NA	96.39	107.96	NA	155.41	191.33	181.03	379.18	346.82	150.14	318.60
Glutamic Acid	NA	NA	77.33	66.69	101.76	NA	77.24	91.38	NA	129.99	163.88	139.18	275.80	280.30	132.09	251.01
Serine	NA	NA	72.53	57.14	97.99	NA	68.00	79.23	NA	96.35	153.80	120.93	275.80	243.57	98.89	225.42
Histidine	NA	NA	18.69	13.19	21.36	NA	14.00	30.12	NA	19.94	31.10	22.86	50.35	42.62	21.94	57.42
Glycine	NA	NA	163.85	143.48	214.54	NA	142.10	197.57	NA	277.18	328.61	287.03	590.13	642.02	208.31	467.24
Threonine	NA	NA	74.24	62.78	89.19	NA	65.62	92.52	NA	90.72	149.29	120.57	237.65	208.58	96.58	233.62
Arginine	NA	NA	70.92	38.49	61.83	NA	44.48	66.32	NA	62.56	117.12	80.01	172.42	177.05	63.37	169.31
β-alanine	NA	NA	5.02	4.73	6.42	NA	4.57	5.44	NA	17.20	19.09	13.09	29.75	45.39	12.13	20.67
Alanine	NA	NA	138.22	127.02	177.69	NA	130.58	173.78	NA	221.16	271.56	245.55	507.73	510.70	192.58	441.65
Tyrosine	NA	NA	28.84	22.29	32.52	NA	26.67	30.63	NA	43.53	57.91	45.53	80.11	78.30	40.13	76.12
γ-aminobutyric Acid	NA	NA	3.31	3.00	5.86	NA	3.43	5.19	NA	10.81	9.22	17.70	17.17	24.95	5.49	14.44
Methionine	NA	NA	13.99	10.92	14.80	NA	8.38	15.57	NA	14.61	26.17	15.49	25.18	31.18	13.14	38.39
Valine	NA	NA	80.32	75.79	117.95	NA	66.58	87.96	NA	115.22	160.23	143.06	300.21	260.55	98.74	237.23
Phenylalanine	NA	NA	41.44	43.58	61.83	NA	42.38	59.74	NA	51.29	88.37	84.99	167.84	114.34	65.11	158.15
Isoleucine	NA	NA	62.81	54.50	86.40	NA	54.77	71.89	NA	70.63	121.19	108.03	239.94	106.37	84.74	190.64
Leucine	NA	NA	80.86	68.88	107.62	NA	71.34	100.24	NA	106.40	164.52	134.76	280.00	228.33	106.97	253.64
Ornithine	NA	NA	1.92	1.36	1.54	NA	2.38	1.90	NA	3.96	6.01	7.93	8.77	15.59	4.19	8.20
Lysine	NA	NA	44.97	40.58	64.07	NA	33.53	48.22	NA	35.31	85.59	75.77	176.62	108.10	49.23	119.44
Total ($mg\ g^{-1}$)	NA	NA	1.07	0.91	1.40	NA	0.95	1.27	NA	1.52	2.14	1.84	3.81	3.46	1.44	3.28

Appendix H, cont. - Amino acid composition (μg g^{-1}) in suspended particles, sampling period 1998-2000

Compound	X2 Jan-99	X2 Feb-99	X2 May-99	X2 Jul-99	X2 Oct-99	X2 Feb-00	X2 Apr-00	X2 Jul-00	CC Jan-99	CC Feb-99	CC May-99	CC Jul-99	CC Oct-99	CC Feb-00	CC Apr-00	CC Jul-00
Aspartic Acid	184.19	NA	NA	97.60	244.98	242.82	86.80	139.59	NA	NA	199.87	255.13	NA	NA	270.78	NA
Glutamic Acid	154.54	NA	NA	97.47	214.80	195.11	74.83	123.04	NA	NA	199.60	223.99	NA	NA	240.05	NA
Serine	104.65	NA	NA	93.49	175.85	183.42	63.55	103.07	NA	NA	197.43	183.13	NA	NA	178.35	NA
Histidine	18.98	NA	NA	25.16	41.15	34.82	21.95	35.38	NA	NA	51.53	45.43	NA	NA	42.18	NA
Glycine	285.23	NA	NA	188.31	420.55	458.20	154.54	251.43	NA	NA	385.64	438.27	NA	NA	375.70	NA
Threonine	81.90	NA	NA	95.21	189.02	134.77	73.83	119.79	NA	NA	194.99	196.85	NA	NA	174.18	NA
Arginine	56.33	NA	NA	99.85	122.63	77.04	50.08	81.32	NA	NA	204.48	127.71	NA	NA	114.30	NA
β-alanine	14.59	NA	NA	10.86	21.12	37.93	7.78	12.17	NA	NA	17.90	20.57	NA	NA	29.68	NA
Alanine	248.36	NA	NA	182.48	394.22	397.62	137.58	223.83	NA	NA	373.70	410.84	NA	NA	342.12	NA
Tyrosine	49.11	NA	NA	28.87	55.42	64.16	23.94	38.63	NA	NA	59.12	57.71	NA	NA	72.38	NA
γ-aminobutyric Acid	6.59	NA	NA	6.22	13.44	18.60	7.28	12.50	NA	NA	12.75	12.00	NA	NA	10.15	NA
Methionine	10.51	NA	NA	14.70	24.96	21.94	10.87	17.69	NA	NA	30.10	26.57	NA	NA	23.69	NA
Valine	111.55	NA	NA	98.53	213.16	162.91	63.35	103.07	NA	NA	201.77	221.99	NA	NA	176.27	NA
Phenylalanine	60.88	NA	NA	51.65	121.80	74.42	47.09	76.29	NA	NA	105.49	126.85	NA	NA	117.42	NA
Isoleucine	56.95	NA	NA	74.16	154.72	84.44	53.87	90.90	NA	NA	151.87	161.14	NA	NA	142.42	NA
Leucine	92.41	NA	NA	99.32	201.09	140.01	78.82	128.23	NA	NA	203.39	209.42	NA	NA	192.93	NA
Ornithine	4.39	NA	NA	3.44	9.33	7.63	2.89	3.41	NA	NA	5.70	9.14	NA	NA	7.03	NA
Lysine	27.77	NA	NA	56.94	125.10	49.37	38.61	62.82	NA	NA	116.61	130.28	NA	NA	93.99	NA
Total (mg g^{-1})	1.57	NA	NA	1.32	2.74	2.39	1.00	1.62	NA	NA	2.71	2.86	NA	NA	2.60	NA

Appendix I. Amino acid composition ($\mu g\ g^{-1}$) in surficial sediments, sampling period 1998-2000

Compound	HD Jan-99	HD Feb-99	HD May-99	HD Jul-99	RV Jan-99	RV Feb-99	RV May-99	RV Jul-99	MM Jan-99	MM Feb-99	MM May-99	MM Jul-99	TI Jan-99	TI May-99	TI Jul-99
Aspartic Acid	20.47	NA	17.03	19.90	NA	NA	24.98	25.87	23.84	NA	40.77	41.91	23.98	21.92	22.18
Glutamic Acid	16.77	NA	15.20	17.59	NA	NA	21.39	21.27	22.01	NA	34.79	36.78	24.01	21.89	21.55
Serine	15.55	NA	14.26	15.02	NA	NA	20.08	19.24	18.73	NA	33.27	22.99	20.94	22.60	23.71
Histidine	2.60	NA	3.68	3.41	NA	NA	2.80	3.64	3.28	NA	7.79	3.91	3.05	5.89	4.42
Glycine	39.05	NA	35.99	37.85	NA	NA	47.91	48.58	53.19	NA	80.07	64.64	44.40	50.28	55.71
Threonine	14.35	NA	14.60	16.20	NA	NA	19.49	20.09	19.23	NA	37.78	25.27	20.10	22.29	23.65
Arginine	11.11	NA	8.72	10.10	NA	NA	15.29	12.73	13.92	NA	22.74	19.80	15.66	16.28	12.38
β-alanine	4.12	NA	3.59	3.19	NA	NA	5.21	5.51	4.61	NA	6.52	5.81	5.89	7.29	8.35
Alanine	30.36	NA	27.17	33.53	NA	NA	38.25	41.71	35.44	NA	68.31	52.97	38.83	45.82	47.90
Tyrosine	6.67	NA	5.67	5.88	NA	NA	7.56	5.54	8.93	NA	13.23	6.84	6.96	6.76	6.46
γ-aminobutyric Acid	2.00	NA	2.08	2.26	NA	NA	1.51	2.11	2.18	NA	3.82	2.62	2.99	3.69	3.23
Methionine	1.96	NA	2.06	2.30	NA	NA	2.35	2.46	2.47	NA	6.27	3.61	2.58	3.44	2.91
Valine	16.74	NA	15.06	19.27	NA	NA	18.12	22.76	21.11	NA	36.11	23.83	21.03	19.96	22.62
Phenylalanine	7.77	NA	7.37	10.75	NA	NA	11.54	11.76	12.67	NA	17.20	14.25	10.32	8.99	10.02
Isoleucine	12.31	NA	11.51	13.42	NA	NA	14.87	17.19	15.52	NA	27.34	19.65	14.52	14.26	16.13
Leucine	17.78	NA	15.90	17.14	NA	NA	16.44	19.51	22.42	NA	37.09	21.47	22.79	23.25	22.50
Ornithine	1.20	NA	1.28	1.54	NA	NA	1.06	1.29	0.90	NA	1.18	0.65	0.99	2.08	1.70
Lysine	9.20	NA	8.84	10.66	NA	NA	11.14	12.06	9.57	NA	15.73	13.00	11.17	13.33	14.59
Total ($mg\ g^{-1}$)	0.23	NA	0.21	0.24	NA	NA	0.28	0.29	0.29	NA	0.38	0.29	0.29	NA	0.31

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Appendix I, cont. - Amino acid composition (μg g-1) in surficial sediments, sampling period 1998-2000

Compound	FT May-99	FT Jul-99	FT Oct-99	FT Apr-00	FT Jul-00	MI May-99	MI Jul-99	MI Oct-99	MI Apr-00	MI Jul-00	LH May-99	LH Jul-99	LH Oct-99	LH Apr-00	LH Jul-00
Aspartic Acid	194.97	216.18	251.35	208.66	184.85	456.20	512.72	1112.76	486.55	461.01	40.79	50.37	42.40	59.33	41.23
Glutamic Acid	187.70	196.88	214.24	184.95	165.96	440.13	439.63	1005.58	453.52	409.30	40.73	49.81	42.40	59.24	34.05
Serine	148.36	168.04	186.76	152.26	141.86	343.71	405.77	705.35	350.54	332.59	40.67	48.17	43.77	60.34	37.01
Histidine	23.30	26.67	32.05	27.67	24.12	48.66	62.34	130.53	63.01	62.04	10.18	10.30	9.15	12.42	12.70
Glycine	366.85	368.82	372.08	314.15	315.70	721.35	914.19	1452.85	730.37	718.01	95.08	119.15	97.89	147.47	91.05
Threonine	155.10	147.88	168.45	145.58	131.30	311.13	345.57	584.50	309.37	305.23	40.44	49.02	42.40	59.07	40.02
Arginine	99.19	112.97	82.18	84.97	87.95	180.34	280.01	377.67	189.99	232.67	27.00	29.70	26.49	39.47	28.69
β-alanine	36.56	39.90	41.45	41.33	41.49	98.65	131.14	205.70	101.54	89.24	3.37	5.04	4.96	6.00	3.07
Alanine	276.63	281.01	306.29	260.11	240.47	666.89	750.27	1080.49	597.91	517.57	87.22	106.29	88.08	124.32	80.64
Tyrosine	46.60	39.46	50.61	54.27	38.43	89.72	96.74	196.97	128.78	107.14	15.71	17.41	12.74	23.66	12.70
γ-aminobutyric Acid	8.12	11.71	14.22	11.24	9.68	19.19	24.18	38.07	18.73	21.38	2.39	3.69	3.17	3.46	2.14
Methionine	27.36	22.77	17.83	15.34	23.51	60.26	56.43	78.79	33.86	53.74	7.62	8.53	6.34	7.44	6.73
Valine	136.18	144.62	172.30	130.83	127.24	284.34	358.47	599.21	294.15	312.45	43.76	52.08	44.55	59.07	38.05
Phenylalanine	66.49	66.57	94.95	66.77	69.45	147.75	201.54	415.52	196.10	173.07	22.58	34.03	24.10	37.61	25.68
Isoleucine	125.70	112.10	125.07	102.00	101.83	217.83	277.86	464.96	239.96	255.12	32.47	42.56	34.62	48.59	31.10
Leucine	140.45	129.66	161.70	146.38	128.11	221.85	321.39	535.58	245.53	264.43	44.05	53.78	45.33	63.30	40.62
Ornithine	8.98	8.89	7.71	7.49	5.00	12.50	12.36	22.45	8.21	12.34	1.57	1.71	1.73	2.03	1.15
Lysine	89.15	74.15	110.61	65.34	72.15	143.29	183.80	372.71	150.94	168.30	26.24	28.85	27.87	32.28	20.86
Total (mg g^{-1})	2.14	2.17	2.41	2.02	1.91	4.46	5.37	9.38	4.60	4.50	0.58	0.71	0.60	0.85	0.55

Appendix I, cont. - Amino acid composition (μg g^{-1}) in surficial sediments, sampling period 1998-2000

Compound	CC May-99	CC Jul-99	CS Jan-99	CS May-99	CS Jul-99	CS Oct-99	CS Apr-00	CS Jul-00	X2 Jan-99	X2 Jul-99
Aspartic Acid	30.14	26.05	141.50	148.47	160.48	140.89	122.96	188.93	16.07	9.59
Glutamic Acid	27.74	24.27	115.85	124.47	138.95	117.90	124.64	148.85	13.39	9.44
Serine	32.59	27.42	112.62	138.16	120.73	116.47	120.05	147.91	13.25	9.96
Histidine	8.17	5.88	20.13	27.18	22.82	21.53	23.25	30.16	2.09	1.31
Glycine	69.75	64.16	279.78	305.93	323.36	284.88	251.26	315.99	31.41	23.70
Threonine	31.73	26.60	106.93	130.47	120.36	113.01	102.31	132.89	13.29	10.13
Arginine	19.35	16.28	63.15	89.23	79.87	73.71	67.14	80.94	6.20	4.60
β-alanine	9.63	8.07	28.88	32.06	39.94	33.92	32.27	40.08	2.56	1.72
Alanine	67.85	53.21	238.61	274.81	263.55	233.35	221.75	281.35	29.08	21.82
Tyrosine	8.94	7.47	33.49	40.68	41.78	34.24	33.34	41.25	3.68	2.71
γ-aminobutyric Acid	4.86	3.59	13.98	11.81	14.54	9.46	9.79	11.48	1.14	0.94
Methionine	3.44	3.77	14.75	22.87	15.46	11.58	13.92	19.07	1.16	1.44
Valine	27.69	25.90	108.16	140.03	141.53	110.56	103.69	121.22	12.28	9.68
Phenylalanine	12.43	11.99	53.31	58.49	59.08	55.44	53.53	69.85	5.32	3.77
Isoleucine	24.08	20.87	71.29	105.91	89.44	86.26	82.12	101.37	6.27	7.11
Leucine	30.27	26.01	92.03	143.78	126.07	103.39	107.20	136.59	10.18	7.66
Ornithine	2.84	1.92	6.30	6.00	6.81	7.18	7.95	6.03	0.62	0.44
Lysine	18.49	16.87	35.64	74.80	75.64	75.50	52.15	70.82	4.79	4.03
Total (mg g^{-1})	0.43	0.37	1.54	1.87	1.84	1.63	1.53	1.95	0.17	0.13

VITA

Born in Elliot Lake, Ontario, Canada, October 14, 1970. Grew up in Elliot Lake and attended Elliot Lake Secondary School. Attended University of Guelph, Guelph, Ontario, Canada, and graduated with a B.Sc. in Specialized Honors Marine Biology in May 1994. Worked at the Bamfield Marine Station in Bamfield, British Columbia, Canada as a research technician from 1994-1996. Received a M.Sc. from the University of New Hampshire in Earth Science: Oceanography in 1999. Entered the Ph.D. program in the Physical Sciences Department at the School of Marine Science, College of William and Mary in August 1998. Accepted a Knauss Sea Grant Fellowship in February 2003, in the Wetlands Division, U.S.E.P.A. in Washington D.C until February 2004. Worked as a program coordinator for the Reef Condition (RECON) Monitoring Program for The Ocean Conservancy in 2004.