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Author

Page, Henry M

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**Sources of inorganic nitrogen utilized by salt marsh macroalgae: identification using
stable nitrogen isotope ratios**

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Henry M. Page

**Marine Science Institute
University of California
Santa Barbara, California 93106**

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Problem

Nutrients and organic matter from terrestrial sources are the most widespread pollutants impacting estuarine ecosystems (US EPA, 1996). Increases in nutrient loading of estuaries are largely the result of expanding agricultural and urban development in the coastal watershed (Peterjohn and Correll, 1984; Correll et al., 1992). These land use activities can facilitate runoff and ultimately lead to decreases in nutrient retention within the watershed through the removal of riparian vegetation, the channelization of streams, and the grading and paving of drainage basins (Beuloc and Reckhow, 1982; Yarbrow et al., 1984; Hunt et al., 1999).

Nutrient availability can control the rate of algal production in estuarine systems (Nixon and Pilson, 1983; Valiela, 1983). Anthropogenically-derived nutrients in surface runoff may contribute, in many cases, to the enhanced development of mats of filamentous green macroalgae (e.g., *Enteromorpha*) in coastal wetlands. In central and southern California, estuaries are typically small and isolated and the surrounding watersheds support extensive agricultural and urban development. Surface runoff entering estuaries from these watersheds is frequently nutrient-enriched with concentrations of nitrate nitrogen 10 to 100x values present in marine waters (Chambers et al., 1994; Page, et al., 1995)

Carpinteria Salt Marsh is typical of many small estuaries in southern California. Natural streamflow within the watershed occurs primarily in the winter and spring while irrigation runoff from adjacent agricultural activities contributes the majority of discharge during the summer and fall (Page et al., 1995). Nutrient enrichment of surface runoff from upland sources of inorganic nitrogen (nitrate and ammonium) has been identified as one of the most important management issues affecting the marsh (Ferren et al., 1997).

Project Objectives

The overall objective of this project was to provide new information on variation in the stable nitrogen isotope ratios of inorganic nitrogen and salt marsh macroalgae and to investigate the potential use of these ratios to trace the uptake of anthropogenic nitrogen by macroalgae. Specifically, we:

1. Constructed a GIS map of land use in the watershed north of Carpinteria Salt Marsh to help identify sources of inorganic nitrogen entering the marsh;
2. Measured the concentration of inorganic nitrogen in effluent entering the streambeds of two drainages (Santa Monica and Franklin Creeks) in side drains to identify the locations, concentrations and, for selected samples, $\delta^{15}\text{N}$ values of source inputs of inorganic nitrogen;

3. Explored the relationship between the stable nitrogen isotope ratios of inorganic nitrogen and the marsh macroalga, *Enteromorpha*, in the principal drainages entering the marsh;
4. Measured stream discharge and the concentration of inorganic nitrogen in stream flow entering the marsh to examine the relationship between these variables and the $\delta^{15}\text{N}$ value of *Enteromorpha*;
5. Tested the prediction that anthropogenic nitrogen in surface runoff entering Carpinteria Salt Marsh has a stable nitrogen isotope ratio distinct from inorganic nitrogen generated in the marsh and;
6. Compared the $\delta^{15}\text{N}$ values of *Enteromorpha* and the vascular plant, *Salicornia virginica*, over time and with values for nitrate-N in runoff and for ammonium-N in interstitial water to identify nitrogen sources used by these species.

Methods

Study Area

This study was conducted in Carpinteria Salt Marsh and in the watershed north of the marsh (Fig. 1). Carpinteria Salt Marsh is the site of previous and on-going studies on the source, fate, and effects of watershed-derived nutrient inputs in a coastal wetland (Galindo-Bect, 1994; Page *et al.*, 1995; Page, 1995; Page, 1997) and is typical of the small, highly urbanized estuaries of southern California. The marsh consists of channel and tidal flat, and tidal marsh vegetated predominantly by the emergent halophyte *Salicornia virginica* and mixed species assemblages at higher tidal elevations (*S. virginica*, *Distichlis spicata*, *Frankenia grandifolia*). Blooms of the macroalga, *Enteromorpha* sp., occur intermittently throughout the year in tidal channels and on tidal flats.

Freshwater runoff from the watershed enters Carpinteria Salt Marsh primarily through Santa Monica (S5) and Franklin Creeks (S6) (Figs. 1, 2, 3). The Santa Monica Creek sub-watershed extends southward from the crest of the Santa Ynez Mountains. This sub-watershed reaches an elevation of 1,175 m and drains approximately 1,561 ha. The Franklin Creek sub-watershed extends from the foothills to the marsh and lies primarily within the coastal plain. It reaches an elevation of 533 m and drains approximately 1,100 ha (Ferren, 1985; this study). The lower reaches of both creeks are artificially channelized. Four channels (S1-S4) entering the western portion of the marsh drain a much smaller sub-watershed (300 ha) that occurs entirely within the coastal plain (Fig. 1). Channels draining this sub-watershed, and those of Santa Monica and Franklin Creeks, pass through a mixture of urban and agricultural development in the coastal plain. Agricultural land uses within the coastal plain consists of greenhouses, open-fields, and orchards (Santa Barbara County, 1999). Flowers are the principal crops in greenhouses and open fields while lemons and avocados are grown in the orchards.

Potential sources of nutrients: land use within the coastal plain

We delineated the boundaries of the Carpinteria Salt Marsh sub-watersheds using a Geographic Information System (GIS) and a USGS 30 m digital elevation model (DEM). The output was created in the GRID environment, a subroutine of Arc/INFO, and then crosschecked using a topographic map of the watershed (Santa Barbara County Flood Control, 1975).

We characterized land use within each sub-watershed by combining the GIS with a recent (1999) aerial photograph of the study area. The spatial detail of the 1:12,000 aerial photograph allowed the identification of land uses within the coastal plain and we constructed GIS coverages based on these observations. Land use coverages were digitized using ESRI Arcview software with the geo-referenced aerial photo as a base map and assigned to one of five categories: (1) greenhouse agriculture, (2) open-field agriculture, (3) orchard, (4) urban/residential or (5) undeveloped.

Discharge

We estimated stream discharge in the four smaller channels (S1-S4) entering the western portion of the marsh and in Santa Monica (S5) and Franklin (S6) Creeks on each sampling date from the equation, $Q = VA$, where Q =discharge ($\text{m}^3 \text{min}^{-1}$), V =current velocity (m min^{-1}), and A = wetted channel cross-sectional area (m^2). Current velocity was measured at a depth of approximately 0.6 times the total depth using a flow meter (Global Flow Probe) (Fetter, 1994). The data reported here were collected during non-storm flows from May through October 1999. Wetted cross-sectional area (m^2) was calculated from measurements of channel width and water depth using planimetry.

Inorganic nitrogen concentrations in surface runoff

We measured the concentrations of dissolved inorganic nitrogen in the runoff of the above drainages (S1-S6). Water samples were collected approximately every 10 days from May 1999 through October 1999. The six stations sampled along the northern border of the marsh are also described in Page et al. (1995).

Water samples were returned on ice to the laboratory and filtered through GF/F filters. The concentrations of dissolved nitrate-N+nitrite-N ($\text{NO}_x\text{-N}$, hereafter nitrate-N) and ammonium-N ($\text{NH}_4\text{-N}$) were determined using a Lachat nutrient autoanalyzer.

Nutrient sources

Surface runoff from land use activities adjacent to Santa Monica and Franklin Creeks is discharged into these creeks through a series of subsurface drains located within the sides of the channels. In August 1998 and July 1999, we collected water samples from all significant sources of runoff entering the creeks through these side drains (Figs. 2, 3). The drains were mapped and geo-referenced to the GIS. By correlating drain locations with the water samples, we were able to identify the most likely sources of

inorganic nitrogen entering the creeks, thereby linking potential point source inputs to a specific land use activity within the coastal plain.

Spatial variation in $\delta^{15}\text{N}$ values of inorganic N in runoff and *Enteromorpha*

To examine the relationship between $\delta^{15}\text{N}$ values of nitrate-N and location, we collected water samples for isotopic analysis from the six drainage channels entering the marsh in June, August and October 1999. We also determined the $\delta^{15}\text{N}$ values of nitrate-N and ammonium-N entering Santa Monica and Franklin Creek from selected side drains. Water samples were filtered through GF/C filters and the pH of the sample lowered to 2.0 with concentrated HCl. Samples were kept refrigerated ($\sim 4^\circ\text{C}$) until analysis. Coastal Science Laboratories in Austin, Texas, determined the isotopic composition of the inorganic nitrogen. Nutrient concentrations were also determined in these samples using a Lachat nutrient autoanalyzer.

To test the hypothesis that the nitrogen isotopic composition of marsh macroalgae reflects the isotopic composition of the inorganic nitrogen in the channels entering the marsh, we collected samples of *Enteromorpha* sp. in June, August, and October 1999 from the tidally influenced upper reaches of drainages that receive inorganic nitrogen in freshwater runoff. One sample of the green macroalgae, *Ulva*, was also collected near the inlet and samples of a freshwater filamentous green alga were collected above tidal influence from S1, S2, and S5 in August. Algal samples were frozen until analysis. Thawed samples were carefully rinsed to remove adhering organisms and sediment, dried at 60°C and ground to a fine powder with mortar and pestle. Stable nitrogen isotope ratios were determined on replicate portions of the ground sample in the UCSB Marine Science Institute Analytical Laboratory using a Europa Tracermass isotope ratio mass spectrometer.

Temporal variation in $\delta^{15}\text{N}$ values of *Enteromorpha* and *Salicornia*

To examine temporal variation in the $\delta^{15}\text{N}$ value of *Enteromorpha* and the rooted vascular plant, *Salicornia virginica* (pickleweed), and to test the hypothesis that these producers use different nitrogen sources (stream-derived versus interstitial water-derived inorganic nitrogen), samples of these species were taken at random along a transect parallel to the lower edge of the distribution of *Salicornia* in Carpinteria Salt Marsh Nature Park (Fig. 1) from April 1999 to March 2000. Tidal exchange to the Nature Park is provided through culverts that connect the Nature Park to Franklin Creek. The $\delta^{15}\text{N}$ values of ammonium in interstitial water from each sampling site were determined in March 2000. Interstitial water was collected by coring to a depth of ~ 10 cm and sampling water diffusing into the hole from the sides using a 60 ml syringe. Water samples for isotopic analysis were treated as above. In addition, triplicate water samples for isotopic analysis were taken on the same day from Franklin Creek and treated as above.

Findings

Land use within the coastal plain

Land use cover varied among sub-watersheds from the more intensely developed Franklin and western sub-watersheds to the relatively undeveloped Santa Monica Creek sub-watershed (Table 1). The Franklin Creek sub-watershed has the greatest area of agricultural and urban land (667 ha), followed by the western (240 ha) and Santa Monica Creek (60 ha) sub-watersheds. The western sub-watershed has the highest percentage of agricultural and urban development (80%), followed by Franklin (57%), and Santa Monica Creek (6%).

Discharge and concentration of inorganic nitrogen in surface runoff

Mean discharge from May through October varied over two orders of magnitude among drainages, ranging from $\sim 0.1 \text{ m}^3 \text{ min}^{-1}$ at S3 and S4 to $>10 \text{ m}^3 \text{ min}^{-1}$ at S5 (Fig. 4a).

Nitrate-N was the most concentrated nutrient species in runoff from all drainages with mean concentrations ranging from $2098 \pm 344 \text{ } \mu\text{M}$ ($x \pm 1\text{SE}$) at station S6 (Franklin Creek) to $175 \pm 15 \text{ } \mu\text{M}$ at S5 (Santa Monica Creek) (Fig. 4b). Dissolved ammonium-N concentrations were much lower than nitrate-N (Fig. 4c). However, the pattern of variation among drainages in the mean concentration of this nutrient was similar to that for nitrate-N. Generally, the highest concentrations of both nitrate-N and ammonium-N occurred at stations S1, S2, and S6 and lowest concentrations occurred at stations S3, S4 and S5.

Land use, point and non-point sources of inorganic nitrogen

The location of >200 side drains entering Santa Monica and Franklin Creek were mapped in August 1998 and July 1999. In August 1998, nine drains in Santa Monica Creek and 15 drains in Franklin Creek had enough flow to permit the collection of water samples.

In Santa Monica Creek, nitrate-N concentrations ranged from a low of $71 \text{ } \mu\text{M}$ in a drain just south of the 101 Freeway to $>7000 \text{ } \mu\text{M}$ in a drain adjacent to greenhouses. The highest nitrate-N concentrations were found in drains adjacent to greenhouse development. The lowest nitrate-N concentrations were found in drains between the railroad bridge and Highway 101 (Table 2, Fig. 2). Ammonium concentrations ranged from 1 to $3000 \text{ } \mu\text{M}$ in the side drains with the highest concentrations in drains adjacent to greenhouse development (Table 2).

In Franklin Creek, nitrate concentrations ranged from $35 \text{ } \mu\text{M}$ in a drain south of the 101 Freeway to $20,000 \text{ } \mu\text{M}$ in a drain adjacent to greenhouse development (Table 2, Fig. 3). Ammonium concentrations ranged from 1 to $2780 \text{ } \mu\text{M}$ in the side drains (Table 2). Although the highest concentration of nitrate-N ($20,000 \text{ } \mu\text{M}$) was found at drain L

adjacent to greenhouse development, the overall association between elevated nitrate-N concentration and land use was less clear along Franklin Creek than along Santa Monica Creek. Greenhouses were located adjacent to 6 flowing drains, but in two cases (I, K), the drain was located on the side opposite the greenhouse. The water flowing from drains D through H, which were not obviously associated with greenhouse development, had high levels of nitrate-N.

Fewer drains were flowing in July 1999 (two drains in Santa Monica Creek and 10 drains in Franklin Creek) compared with August 1998. Again, the association between elevated concentrations of nitrate-N and ammonium-N and land use was less clear along Franklin than along Santa Monica Creek. In Santa Monica Creek, elevated concentrations of nitrate-N were found in water from two flowing drains adjacent to greenhouse development (4, 5). In Franklin Creek, elevated concentrations of nitrate-N were found in 7 drains adjacent to urban development (C, D, F, G, H, I, K) as well from 3 drains adjacent to greenhouses (J, L, M). However, the highest concentration of nitrate-N (15,900 μM) was again were found at drain L adjacent to greenhouse development.

Stable nitrogen isotope values of inorganic N and macroalgae in drainage channels: spatial patterns

The $\delta^{15}\text{N}$ values of nitrate-N and ammonium-N in samples collected from selected drains entering Santa Monica and Franklin Creeks ranged from -4.7 to $+1.7$ ‰ (Table 3). Nitrate-N concentrations in this drainage water ranged from 3340 to 15,900 μM while ammonium-N concentrations ranged from 40 to 3700 μM (Table 2).

The $\delta^{15}\text{N}$ values of nitrate-N in water samples collected in June, August, and October along the northern border of the marsh were averaged over time for each location (Fig. 5). Mean values varied significantly among locations ($P < 0.001$, One-way repeated measures ANOVA). Values were lowest in Santa Monica and Franklin Creeks (< 5 ‰) and highest in the smaller drainages of S3 and S4 (> 15 ‰). Mean $\delta^{15}\text{N}$ values of the macroalgae, *Enteromorpha* sp., also varied among drainages and were not significantly different from those of nitrate-N ($P > 0.1$, Paired t-test) (Fig. 5). $\delta^{15}\text{N}$ values of the green macroalga, *Ulva*, at the inlet (~ 8 ‰) were intermediate between values for *Enteromorpha* from Santa Monica and Franklin Creeks and drainages S3 and S4.

Relationships between the $\delta^{15}\text{N}$ values of *Enteromorpha* sp., nitrate-N and ammonium-N concentration, $\delta^{15}\text{N}$ values of nitrate, and discharge were evaluated using multiple correlation analysis. The $\delta^{15}\text{N}$ values of *Enteromorpha* sp. were strongly correlated with the $\delta^{15}\text{N}$ values of nitrate-N in runoff ($P < 0.001$, $r = 0.75$) and negatively correlated with discharge rate ($r = -0.59$, $P < 0.05$; Table 4). There was no correlation ($P > 0.1$) between the $\delta^{15}\text{N}$ values of *Enteromorpha* sp. and the concentration of nitrate-N or ammonium-N (Table 4).

Variation in $\delta^{15}\text{N}$ values of *Enteromorpha* and *Salicornia*

The mean $\delta^{15}\text{N}$ values of *Enteromorpha* were significantly lower (by 2-5‰) than values of *Salicornia* (Paired t-test, $P < 0.001$: Fig. 6). $\delta^{15}\text{N}$ values of *Enteromorpha* ranged from 9.3 ± 0.6 to 11.3 ± 0.1 ‰ while values of *Salicornia* ranged from 11.5 ± 0.6 to 14.7 ± 0.4 ‰. In addition, there was significant temporal variation in the $\delta^{15}\text{N}$ values of *Salicornia* ($P < 0.001$, One-way ANOVA). Highest values were found in March and April, a period of typically rapid growth of this species, while lowest values were found in January and February, a period of slow growth.

There was a significant correlation between the $\delta^{15}\text{N}$ values of *Enteromorpha* and nitrate-N in water samples ($P < 0.001$, $r = 0.76$: Fig. 7). In addition there did not appear to be a consistent fractionation of nitrogen isotopes on nitrogen uptake by this macroalga (Fig. 7). However, the $\delta^{15}\text{N}$ values of an unidentified filamentous green macroalga collected above the region of tidal influence in drainages S1, S2, and S5 were ~ 8 ‰ lower than values for *Enteromorpha*, suggesting fractionation of nitrogen isotopes during nitrogen uptake by that macroalga. There was a very strong correlation ($P < 0.001$, $r = 0.95$) between the $\delta^{15}\text{N}$ values of *Salicornia* and of ammonium-N in interstitial water (grouped data from this study and Page, 1995: Fig. 8).

There was a significant difference between the mean $\delta^{15}\text{N}$ values of nitrate-N from Franklin Creek and of ammonium-N in interstitial water in the Carpinteria Salt Marsh Nature Park ($P < 0.001$, Student's t-test). The mean $\delta^{15}\text{N}$ value of *Enteromorpha* was not significantly different from the mean value of nitrate-N in March 2000, suggesting uptake of nitrate-N from the water column by this alga. In contrast, the mean $\delta^{15}\text{N}$ value of *Salicornia* was not significantly different from the mean $\delta^{15}\text{N}$ value of ammonium-N in interstitial water, suggesting that this was the principal nitrogen source used by this plant.

Conclusions

1. Two principal drainages, Santa Monica and Franklin Creek, convey runoff into the marsh from the coastal plain and from the foothills and the upper reaches of the Santa Ynez Mountains. Four smaller drainages convey flows from the coastal plain into the western portion of the marsh. Elevated levels of nutrients (principally as nitrate-N) were present in each of the drainages entering the marsh.
2. Although open fields and orchards are the dominant land use activities within the watershed, greenhouse operations were a point source of nutrient inputs during the summer. The association between greenhouse operations and nutrient inputs was most apparent in Santa Monica Creek. Although greenhouse effluent contributed point source inorganic nitrogen to Franklin Creek non-point sources were also present.

3. Variation in $\delta^{15}\text{N}_{\text{NO}_3}$ values (3.3 to 16.4 ‰) in runoff among drainages provides evidence of varying degrees of nutrient retention and transformation within the landscape north of Carpinteria Salt Marsh. The $\delta^{15}\text{N}_{\text{NO}_3}$ values in Santa Monica and Franklin Creeks, closer to values reported for chemical fertilizer than the other four drainages (Kohl et al., 1971; Heaton, 1986), are also consistent with less retention and transformation of nitrate-N in these cement-lined channels compared with the other drainages. Denitrification of water column nitrate-N can occur when surface waters contact soils under anaerobic conditions, resulting in a concomitant ^{15}N enrichment of the residual nitrate-N (Kellman and Hillaire-Marcel, 1998). Enrichment of $\delta^{15}\text{N}_{\text{NO}_3}$ values, relative to effluent source values was more evident in Franklin Creek, where several non-point inputs were identified, compared with Santa Monica Creek.

4. Nutrient retention and transformation was more evident in the four smaller drainages where $\delta^{15}\text{N}_{\text{NO}_3}$ values ranged from 7.1 to 16.1 ‰. The enriched $\delta^{15}\text{N}_{\text{NO}_3}$ values may reflect the seepage of varying amounts of perched groundwater into the surface flow of these channels. Denitrification in groundwater can leave the residual nitrate-N enriched in ^{15}N (Heaton, 1986; Mariotti et al., 1988; Sutherland et al., 1993). Page (1995) reported that $\delta^{15}\text{N}_{\text{NO}_3}$ values in perched groundwater along the northern border of the marsh ranged from 6.5 to 54.6 ‰ with the most depleted values closest to greenhouse development and most enriched values in pore water along the marsh boundary. The enriched $\delta^{15}\text{N}_{\text{NO}_3}$ values along the marsh boundary were postulated to result from the denitrification of nitrate-N in the perched water table on contacting the anaerobic, organic carbon rich marsh soils. Nitrate-N in the runoff from open fields may also be enriched in ^{15}N and could contribute to the elevated $\delta^{15}\text{N}_{\text{NO}_3}$ values observed in these drainages. However, there was little surface runoff from fields during our study.

5. There was no correlation between $\delta^{15}\text{N}_{\text{NO}_3}$ values and nitrate-N concentrations in runoff. For example, mean nitrate-N concentrations in Santa Monica Creek from May through October were low; nitrate-N inputs were diluted by natural discharge from the mountainous watershed. In contrast, mean nitrate-N concentrations in Franklin Creek were high. Although nitrate-N concentrations differed nearly 10-fold between these drainages, the mean $\delta^{15}\text{N}_{\text{NO}_3}$ value in Santa Monica Creek was not significantly different from that in Franklin Creek. The lack of correlation between $\delta^{15}\text{N}_{\text{NO}_3}$ and nitrate-N concentration is similar to that found in other studies (McClelland and Valiela, 1998) and supports the view that source, and history of microbial transformation, rather than concentration of nitrate *per se*, determines nitrate $\delta^{15}\text{N}_{\text{NO}_3}$ values in ground and surface water. This is particularly evident when comparing our data to the much larger Waquoit Bay system in Massachusetts, where wastewater was the dominant source of anthropogenic nitrogen (McClelland and Valiela, 1998). $\delta^{15}\text{N}$ values for nitrate

and ammonium in ground water from a forested watershed, considered representative of uncontaminated groundwater, ranged from -1.5 to 4.5 ‰. In contrast, similar values in our study were characteristic of nitrogen-enriched greenhouse effluent.

6. Marsh macroalgae may assimilate dissolved inorganic nitrogen (DIN) from several sources, including tidal waters, sediments, and freshwater runoff. The elevated concentration of nitrate-N in all drainages, relative to concentrations in tidal waters, suggests that the DIN from the coastal plain subsidizes algal growth in marsh channels. The strong correlation between the $\delta^{15}\text{N}$ values of *Enteromorpha* and of inorganic nitrogen in the tidally influenced upper reaches of tidal channels supports this contention.
7. Although some authors have reported net isotopic enrichments or depletions in algae or plants of from 0.5 to 4 ‰ relative to source inorganic nitrogen (reviewed in Handley and Raven, 1992), a consistent fractionation effect across a range of source $\delta^{15}\text{N}$ values was not found for either *Enteromorpha* sp. or *Salicornia virginica*.
8. The intermediate $\delta^{15}\text{N}$ values of the green macroalga, *Ulva*, at the inlet suggest that nutrient dynamics at this location is characterized by inputs from several sources, including Santa Monica and Franklin Creeks and the four smaller drainages.
9. Our study provides baseline data for monitoring direct inputs into the marsh from greenhouse effluent. Over time, the modernizing of greenhouse facilities should reduce inputs from this source as return waters are recycled or processed to removed nutrients. These changes should be detectable in the $\delta^{15}\text{N}$ values of macroalgae, which should increase with decreased greenhouse inputs to reflect background non-point source inputs.

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Table 1. Land use in the three sub-watersheds north of Carpinteria Salt Marsh.

Sub-watershed	Greenhouse		Orchard		Open field		Total Agriculture		Urban		Undeveloped		Total ha
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	
Western	27	9	92	31	36	12	155	52	85	28	60	20	300
Franklin Creek	64	5	200	17	117	10	381	33	286	24	503	43	1170
Santa Monica Creek	10	0.6	24	1.5	12	0.8	46	2.9	14	0.9	1501	96.2	1561

Table 2. Relationship between concentration of nitrate-N and ammonium-N in water from drains entering the Santa Monica Creek and Franklin Creeks and adjacent land use from GIS (Figs 2, 3), extending from northern border of Carpinteria Salt Marsh to the base of the foothills. All flowing drains were sampled in August 1998 and July 1999. Key to land use: U=urban, G=greenhouse; na=not available, nf=no flow.

Station	Land use	Nitrate-N (μM)		Ammonium-N (μM)	
		Aug 1998	July 1999	Aug 1998	July 1999
Santa Monica Creek					
1	U	134	nf	1	nf
2	U	280	nf	1	nf
3	U	71	nf	1	nf
4	G	6851	4970	na	4
5	G	2233	3340	55	40
6	G	6979	nf	210	nf
7	G	7055	nf	211	nf
8	G	544	nf	3000	nf
9	G	3238	nf	65	nf
Franklin Creek					
A	U	93	nf	32	nf
B	U	37	nf	151	nf
C	U	1216	645	4	5
D	U	1221	1450	2	5
E	U	571	nf	3	nf
F	U	1816	1920	1	2
G	U	3035	1690	1	3
H	U	5533	4010	139	94
I	U	2774	2130	2	1
J	G	5651	6430	2780	8900
K	U	7049	8830	1	0
L	G	20110	15900	416	3700
M	G	104	6880	19	880
N	U	3576	nf	91	nf
O	G	6196	nf	255	nf

Table 3. Stable N isotope ratios of nitrate-N and ammonium-N in water from selected drains entering Santa Monica and Franklin Creeks. Locations, adjacent land use, and nutrient concentrations given in Figures 2 and 3 and Table 1. Samples collected in July 1999.

Location		$\delta^{15}\text{NNO}_3(^{\circ}/_{\text{oo}})$	$\delta^{15}\text{NNH}_4(^{\circ}/_{\text{oo}})$
Santa Monica Creek	5	-4.7	-0.5
Franklin Creek	H	0.5	1.7
	L	-3.8	1.0

Table 4. Multiple correlation coefficients derived from analysis to evaluate relationships between discharge, nutrient concentrations and $\delta^{15}\text{N}$ values of nitrate-N and the macroalga, *Enteromorpha*. *P<0.05, **P<0.01, ***P<0.001, n=17.

	Discharge	Nitrate	Ammonium	$\delta^{15}\text{N}_{\text{NO}_3}$	$\delta^{15}\text{N}_{\text{Ent}}$
Discharge	1.00	---	---	---	---
Nitrate	-0.22	1.00	---	---	---
Ammonium	0.12	0.30	1.00	---	---
$\delta^{15}\text{N}_{\text{NO}_3}$	-0.59*	0.04	-0.33	1.00	---
$\delta^{15}\text{N}_{\text{Ent}}$	-0.65**	-0.22	-0.22	0.75***	1.00

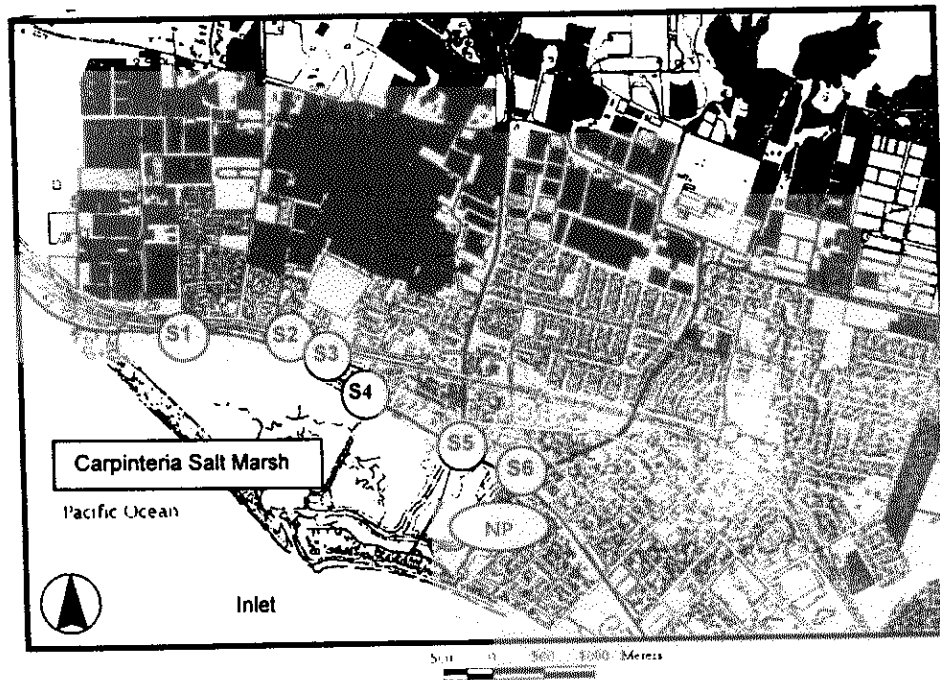


Figure 1. Map of study area that includes Carpinteria Salt Marsh and a portion of the adjoining watershed. The darkest areas represent greenhouse structures while solid lighter gray areas represent orchards and open fields. Sampling sites S1 through S6, Nature Park (NP), and the inlet into the marsh, are also indicated. S5-Santa Monica Creek, S6-Franklin Creek.



Figure 2. Map showing sample locations along Santa Monica Creek. Samples collected from drains that emptied into the channel and are numbered 1 – 10. Darkest areas are greenhouse structures, medium gray areas are orchards and open fields, and light gray areas are urban development. Carpinteria Salt Marsh is located to the south of Highway 101.

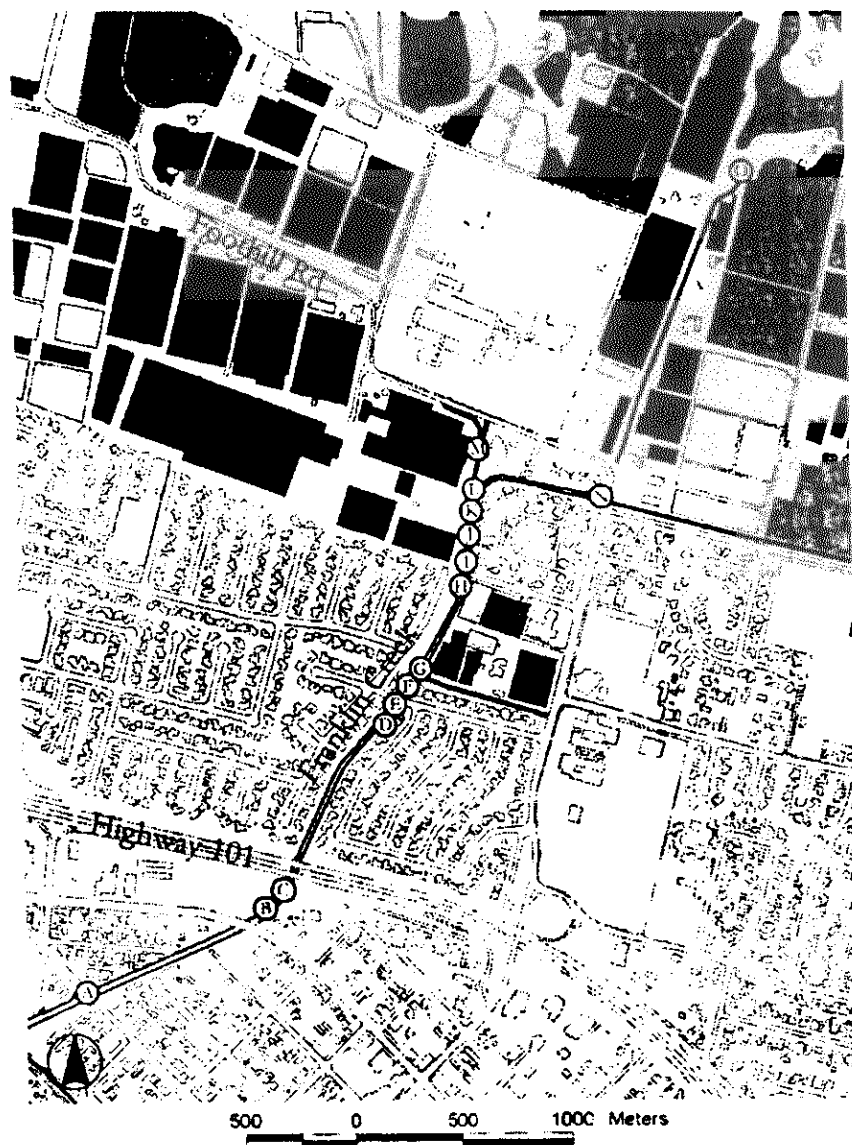


Figure 3. Map showing sample locations along Franklin Creek. Samples were collected from drains that emptied into channel and are indicated A – O. Shading as in Figure 2.

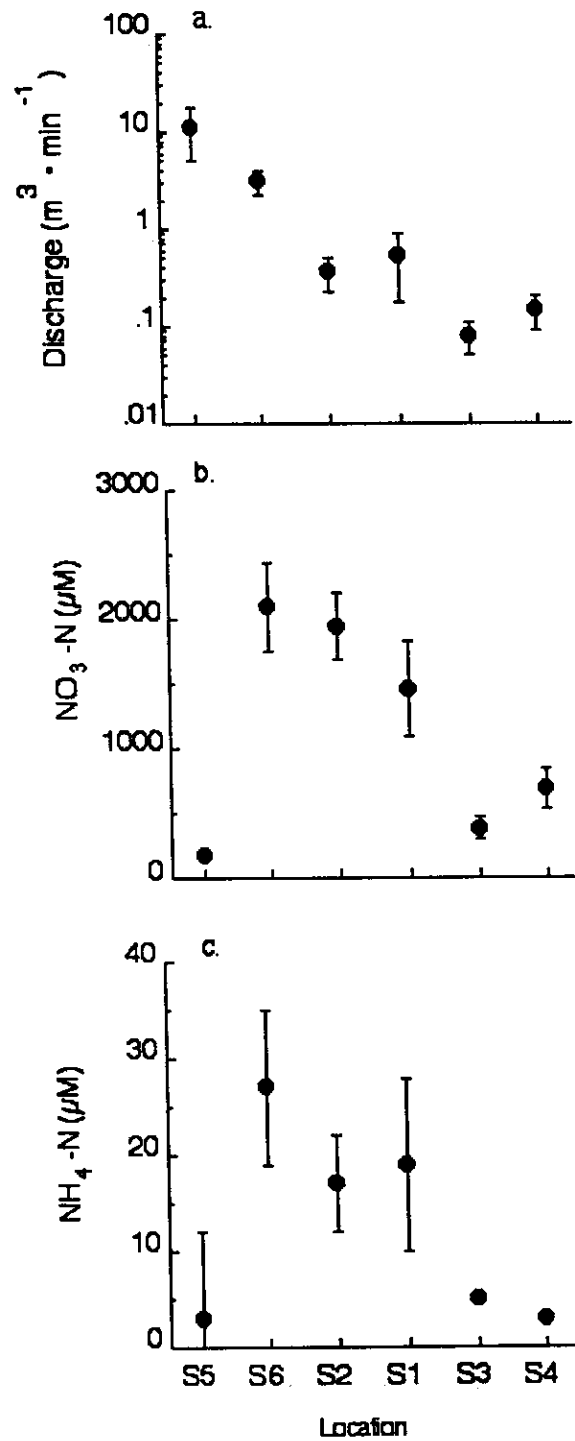


Figure 4. Variation in discharge and nitrate-N and ammonium-N concentrations among locations. Mean values ± 1 SE for samples collected from May through October 1999.

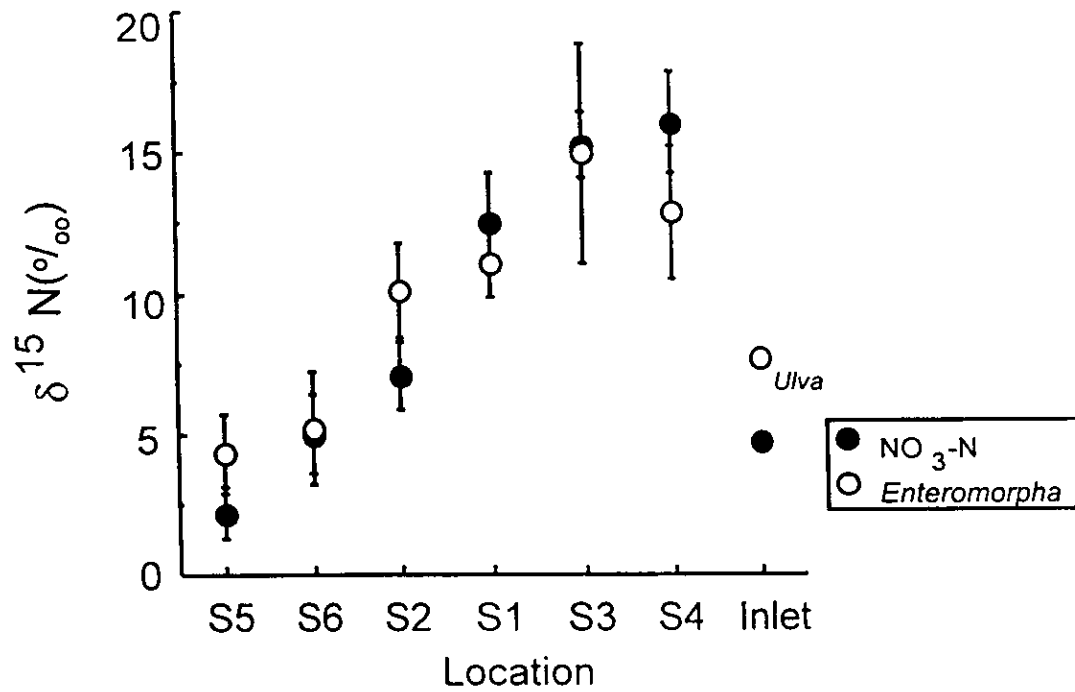


Figure 5. Variation in $\delta^{15}\text{N}$ values of nitrate-N and the macroalgae, *Enteromorpha* sp. among locations. Mean values $\pm 1\text{SE}$ for samples collected from May through October 1999.

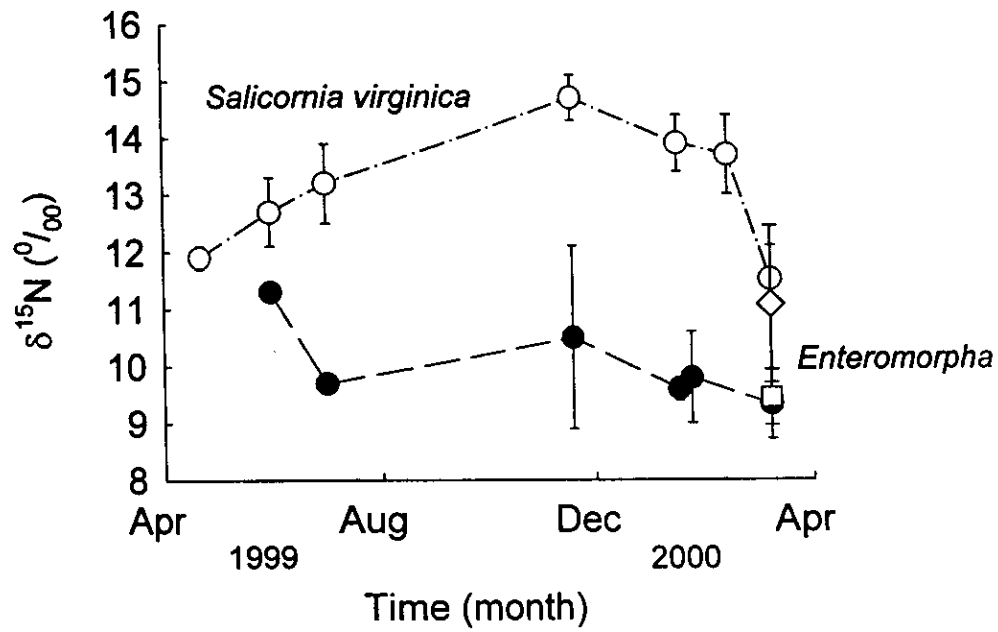


Figure 6. Temporal variation in $\delta^{15}\text{N}$ values of *Enteromorpha* sp. and *Salicornia virginica* in the Carpinteria Salt Marsh Nature Park. Diamond-porewater, square-Franklin Creek. Mean values $\pm 1\text{SD}$, $n=3-6$.

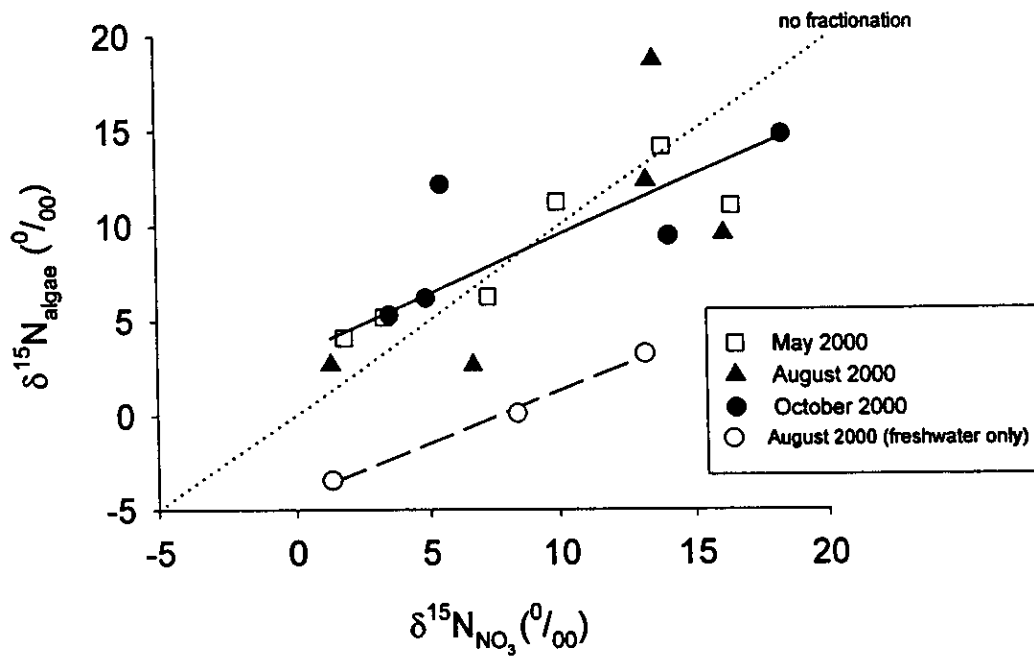


Figure 7. Relationship between values of $\delta^{15}\text{N}$ for the macroalga, *Enteromorpha* sp., and nitrate-N in the tidally influenced reaches of drainage channels S1-S6 ($P < 0.001$, $r = 0.75$, $df = 15$). Also shown is relationship between value of $\delta^{15}\text{N}$ for filamentous green algae collected from reaches above tidal influence and nitrate-N in August 2000. Predicted relationship with no isotopic fractionation during nitrogen uptake shown by dotted line.

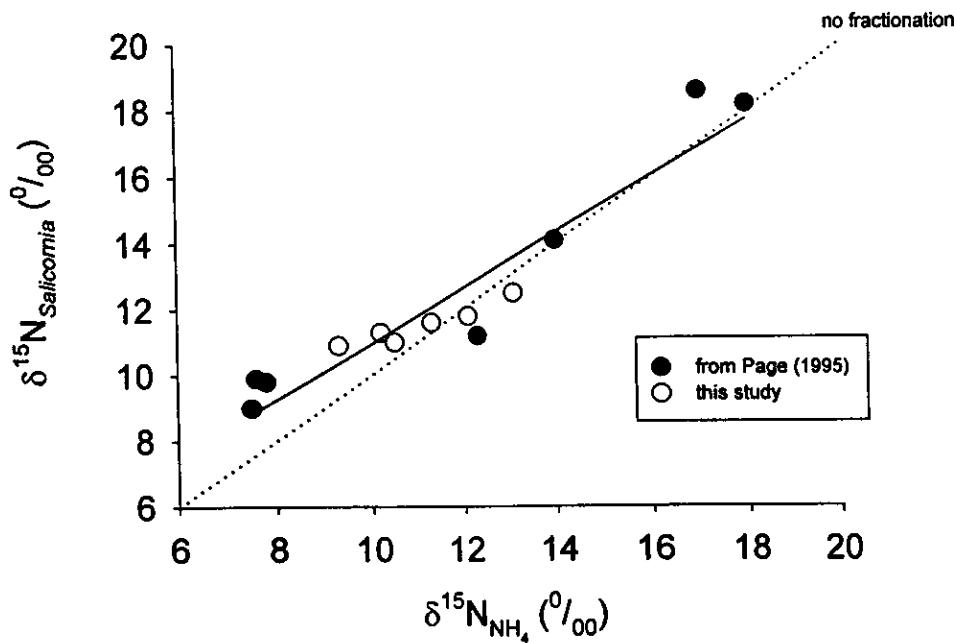


Figure 8. Relationship between values of $\delta^{15}\text{N}$ for *Salicornia virginica* and dissolved ammonium-N in pore water. $P < 0.001$, $r = 0.95$, $df = 11$.

Publications and professional presentations

Data from this study are included in a poster entitled, "Introducing the new Santa Barbara coastal system LTER" to be presented at the LTER All Scientists Meeting in Snowbird, Utah, August 2-4. Reed, D, S. Cooper, S. Gaines, S. Holbrook, J. Melack, and M. Page, authors

Data from this study were incorporated into the Carpinteria Valley Greenhouse Program. Final Environmental Impact Report, Santa Barbara County

Manuscript entitled, "Nutrient inputs into a southern California estuary: links with land use in the coastal plain", submitted to the Journal of Environmental Quality
David Court and Henry M. Page, authors

Training accomplishments

Graduate students (UCSB)

David Court, Bren School of Environmental Science and Management (supported as Graduate Research Assistant, 33% time)

Undergraduate students (UCSB)

Michael Henry (Laboratory Assistant, variable time)
Jason Clapper (Laboratory Assistant, variable time)
Mario Mirabello (Laboratory Assistant, variable time)

Application to overall research program

Data from this study were incorporated into a grant application to the EPA to establish a "Center for Wetlands Studies" at UC Davis and UC Santa Barbara. This proposal has successfully passed technical review and will be reviewed for relevancy in the near future.

Data from this study are also being used in Santa Barbara Channel LTER program to design long-term monitoring of runoff from the Carpinteria watershed into the marsh and coastal ocean.