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Seasonality of macroalgae and epilithic diatoms in spring-fed streams in Texas, USA

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Abstract

A seasonal study of two spring-fed stream systems in south-central Texas was undertaken over a 15-month period from June 1996 to September 1997. Relative abundance of the epilithic diatom flora, percent cover of macroalgae, and several physical and chemical conditions were monitored in one 20-m stretch in each of the streams at approximately two-month intervals. Six additional spring-fed stream segments were sampled in May 1996 for macroalgae and measured for the same conditions, in order to determine how representative the macroalgal floras of the study sites were of south-central and western Texas. Conditions in the two stream segments were relatively constant over the 15 months, except for maximum depth; this finding is similar those reported for other spring-fed systems worldwide. Sixty-eight diatom taxa and nine macroalgae taxa were identified from the San Marcos River, which compares to 46 diatom taxa and six macroalgae taxa from the Comal River. Several diatom and macroalgae species were significantly correlated to stream conditions (e.g. *Dichotomosiphon tuberosus* and *Hildenbrandia angolensis* with daylength, and *Amphora pediculus* with maximum depth). Twenty-one macroalgal taxa were identified from the six additional spring-fed steam segments. Conditions in these streams were very similar to those measured in the San Marcos River and Comal River, except that they had a higher average pH ($\bar{x}$ = 8.1 *versus* $\bar{x}$ = 7.6). The epilithic diatom flora of the San Marcos River and the Comal River contains many of the diatom and some macroalgal taxa commonly reported from springs globally.

Introduction

Springs represent geographically isolated systems and, as such, they have the potential to contain both relict species (once widespread species that are now more limited in distribution) or endemic species (those whose distribution is limited to the habitat in which they evolved) (Hynes, 1970). Springs provide relatively uniform conditions in areas that usually undergo great seasonal changes. Thus, organisms that have widely inhabited an area in the past due to suitable ambient climate conditions may be presently confined to springs because the spring conditions match their physiological requirements (Hynes, 1970). For example, Nielsen's (1950) study of a Danish spring revealed the presence of several species of Trichoptera that were normally characteristic of more northerly areas due to the spring waters being much cooler in the summer than other local freshwaters. It was concluded that the trichopterans represented late glacial relicts that found refuge in the spring. Examples of presumed endemic species in springs are numerous, including those from Montezuma Well, Arizona, USA: a species of amphipod, *Hyalella montezuma* Cole et Watkins, the freshwater rhodophyte *Batrachospermum carpoinvolucrum* Sheath et Vis, and the diatoms *Gomphonema montezumense* Czarnecki et Blinn, *Caloneis latiuscula* (Kütz.) Cleve var. *reimeri* Czarnecki et Blinn and *Cyclotella pseudostelligera* Hust. f. *parva* Czarnecki et Blinn (Cole & Watkins, 1977; Czarnecki & Blinn, 1979; Vis & Sheath, 1996). Several other studies have examined the algal communities of spring systems in North America, including those of Florida (Whitford, 1956), Utah (Rushforth & Kaczmarska, 1984), Texas (Christensen, 1978; Vis & Sheath, 1996) and Mexico (Cantoral-Uriza et al., 1997). These studies have also reported the presence of endemic algal taxa.

The springs along the Balcones Fault in Texas, USA, are fed by the Edward's Aquifer, which runs in a prominent line for approximately 112 km through southwestern and western Texas (Crowe & Sharp, 1997). Over the past several decades the viability of several springs of the Edward's Aquifer has been threatened due to extremely low spring flow, as a result of combined overuse and drought conditions over a number of years. The Edward's Aquifer is the sole source of freshwater for nearly two million people, including the city of San Antonio (Crowe & Sharp, 1997). Although several springs of the aquifer are perennial, such as the San Marcos Springs and the Comal Springs, some springs now flow intermittently or have ceased entirely (Christensen, 1978; Crowe & Sharp, 1997). New species have been described from the springs of the Edward's Aquifer, including several amphipods (Holsinger & Longley, 1980) and a species of red algae (Vis & Sheath, 1996). In addition, several endangered and rare species are found in the springs of the aquifer, including the Comal Springs riffle beetle and the fountain darter (Crowe & Sharp, 1997). Thus, further studies of these springs are warranted from both a resource and a biological conservation point of view.

The present study was undertaken to investigate the composition and seasonality of diatom and macroalgal communities in spring-fed streams of south-central Texas. Communities in both the San Marcos River and the Comal River (both of which are fed by the Edward's Aquifer) were monitored bimonthly for a 15-month period. No studies to date have been performed that document the macroalgal and diatom community dynamics of spring-fed streams of the Edward's Aquifer on a temporal scale. In addition, macroalgal collections were made from other spring-fed streams of the same aquifer to document spatial distribution patterns of freshwater macroalgae in south-central Texas.

Materials and methods

One 20-m stream segment in each of the San Marcos River and the Comal River, Texas, was sampled approximately every two months from June 1996 to September 1997 for macroalgae and diatoms. The sampling period was limited to 15 months due to accessibility, but this time frame encompassed the stream and algal community variation from an entire year due to overlap in the summer season. The sampling site along the San Marcos River was located on the north side of the intersection of the San Marcos River and Aquarena Springs Drive (29° 54′ N, 97° 54′ W), while the sampling site in the Comal River was located in Landa Park, New Braunfels, approximately 150 m downstream from the spring source (29° 42′ N, 98° 6′ W). The entire area of the stream along each of the 20-m segments was thoroughly searched for macroalgae and cover for each species was estimated as described previously (Sheath and Cole, 1992, and references therein). Representative specimens were preserved in 2.5% $CaCO_3$-buffered glutaraldehyde for later microscopic confirmation of identification. Stream segments were also measured for maximum width and depth, mean current velocity, water temperature, pH and specific conductance using the following instruments: Lufkin red folding rule, General Oceanics 2030 flow meter, Fisher pocket thermometer, and Fisher Accumet 1001 pH meter, and a TDSTestr™ (0–1990 μS cm^{-1}) conductance meter, respectively. Daylength data were obtained from the Astronomical Applications Department of the U.S. Naval Observatory (internet web site). Six additional segments of spring-fed streams in Texas were sampled for macroalgae in May 1996, and were measured for the same physical and chemical factors. These additional sites represent a broad geographical area of southwest Texas, and provide a comparative macroalgal flora for spring-fed systems of this region of Texas (Table 1). These sites were included to determine how typical the macroalgal floras of the San Marcos River and the Comal River are of southwestern Texas.

To test for heterogeneity of diatom distribution in the stream segments, five randomly distributed collections of five rocks each were brushed for an approximate area of 2 × 2 cm, from each stream segment. It was determined that 83–91% of the taxa identified were present within the first 1000 frustules counted of 5000, and so total counts of 1000 frustules were employed for the remainder of the study. Diatoms were cleaned in 50% H_2O_2 for 24 hours, followed by 4–5 rinses in distilled water. Diatom suspensions were dried onto glass coverslips and mounted in Naphrax®. Five replicate slides were made for each sample and 200 frustules were counted on each coverslip, to give

Table 1. Locations of six spring-fed stream segments sampled from southwestern Texas for macroalgae

Sampling site	Specifics of sampling location, collectors and date
TX31	Cypress Creek at Highway 12, town of Wimberley. Alison Sherwood and Robert Sheath, 30 May 1997
TX32	Highway 12, 2.7 km north of Gatlan Creek Rd. A. Sherwood and R. Sheath, 30 May 1997
TX33	Intersection of Highway 12 and Gatlan Creek, 1.0 km north of County Rd. 170. A. Sherwood and R. Sheath, 30 May 1997
TX34	Intersection of Rio Frio and County Road 1050, off Highway 83. A. Sherwood, R. Sheath and John Kingston, 31 May 1997
TX35	Highway 337 east of Leakey (0.2 km west of city limits), tributary of Rio Frio. A. Sherwood, R. Sheath and J. Kingston, 31 May 1997
TX36	Intersection of Bauerlein Creek and Highway 337, 0.2 km west of Cazey Creek Rd. A. Sherwood, R. Sheath and J. Kingston, 31 May 1997

a total count of 1000 per sample. Macroalgae and diatoms were examined and identified using an Olympus BH-S compound microscope equipped with an Olympus PM-10AK camera system.

Abundance of macroalgae and the dominant diatom taxa ($\geq$ 5% in at least one sample) from the San Marcos River and the Comal River were tested for correlation with physical and chemical conditions using the Spearman measure of rank correlation ($p < 0.05$) (Conover, 1971) and the SigmaStat statistical package (Jandel Scientific, 1994).

Results

Water temperature and pH were relatively constant in the San Marcos River (temperature range 21.0–24.4 °C, pH range 7.0–7.8) and the Comal River (temperature range 22.0–25.0 °C, pH range 7.2–7.4) (Figure 1a, b). Specific conductance in the San Marcos River was also reasonably constant (550–620 μS cm^{-1}) as well as in the Comal River (500–570 μS cm^{-1}), except for a peak in July 1996 of 760 μS cm^{-1} in the San Marcos River and 660 μS cm^{-1} in the Comal River (Figure 1c). Current velocity varied more in the San Marcos River (31–102 cm s^{-1}) than the Comal River (15–50 cm s^{-1}), although both exhibited quite large fluctuations over the sampling period (Figure 1d). Maximum depth strongly varied in both stream segments (San Marcos River 60 - >100 cm, Comal River 43 - >100 cm) (Figure 1e), and daylength followed typical seasonal trends with a peak of 14 h in June to a miniumum of 10.3 h in December (Figure 1f).

A total of 68 diatom taxa and nine macroalgal taxa were identified from the San Marcos River (Tables 2 and 3). The six most abundant diatom taxa in the San Marcos River contributed the majority of diatoms counted for every sampling period (Figure 2). *Achnanthidium minutissimum* (authorities in Tables 2 and 3) was clearly the most abundant taxon, accounting for up to 98% of the diatoms identified in a sample. Other dominant taxa included *Amphora pediculus*, *Cocconeis placentula* var. *lineata*, *Denticula tenuis*, *Synedra famelica* and *Synedra ulna*. Maxima in the relative abundance of *Achnanthidium minutissimum* were evident in the October 1996, November 1996, December 1996 and April 1997 collections, and *Cocconeis placentula* var. *lineata* had a peak abundance in the February 1997 collection. In terms of the macroalgae, several taxa were observed at only one sampling time (the rhodophytes *Sirodotia huillensis* and *Audouinella pygmaea*, and the chlorophyte *Hydrodictyon reticulatum*). Among those species that were present in multiple collections, the green alga *Cladophora glomerata* was quite constant in abundance; among the red algae, *Hildenbrandia angolensis* peaked in abundance from February 1997 – September 1997 and *Thorea violacea* had a dip in abundance in November and December 1996 (Figure 3).

A total of 46 diatom taxa and six macroalgal taxa were identified from the Comal River (Tables 2 and 3). In the Comal River the taxa *Achnanthidium minutissimum*, *Cocconeis placentula* var. *lineata* and *Denticula tenuis* contributed the majority of diatoms counted (Figure 4). Other common taxa included *Encyonopsis falaisensis*, *Caloneis bacillum* and *Nitzschia amphibia*. The relative proportions of diatom taxa were much more consistent over the sampling period in the Comal River than in the San Marcos River. Among the macroalgae, the cyanophyte *Lyngbya taylorii* and the tribophyte *Tribonema regulare* also showed quite constant abundance, while *Hildenbrandia angolen-*

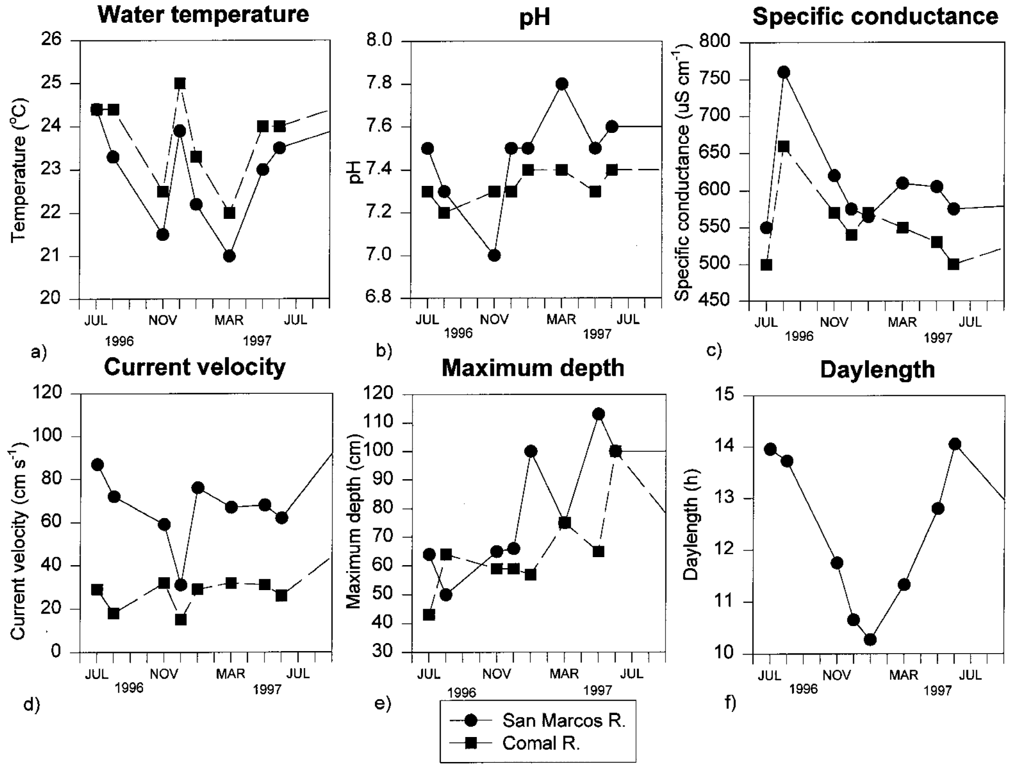

Figure 1. (a–f). Physical and chemical measurements of stream conditions in the San Marcos River (circles) and the Comal River (squares) over the sampling period: temperature (a), pH (b), specific conductance (c), current velocity (d), maximum depth (e) and daylength (f).

sis peaked in abundance in October–December 1996. The rhodophytes *Batrachospermum globosporum* and *Thorea violacea* were present in the stream segment only in May 1997 (Figure 5).

Tests of correlation of abundance values for diatoms and macroalgae to stream conditions revealed several significant correlations ($p < 0.05$). No macroalgae were significantly correlated to stream conditions in the San Marcos River, but six diatom taxa were correlated with water temperature, pH, specific conductance, maximum depth or daylength (*Achnanthidium minutissimum*, *Diploneis parma*, *Encyonema neogracile*, *Encyonopsis falaisensis*, *Encyonopsis microcephala*, *Navicula diluviana*). Six diatom and two macroalgal taxa in the Comal River were significantly correlated with pH, specific conductance, maximum depth or daylength (*Achnanthes inflata*, *Achnanthidium minutissimum*, *Amphora pediculus*, *Cocconeis placentula* var. *lineata*, *Nitzschia amphibia*, *Synedra ulna*, *Dichotomosiphon tuberosus*, *Hildenbrandia angolensis*). No taxa from either stream segment were significantly correlated with current velocity.

Twenty-one taxa of macroalgae were identified from the additional spring-fed stream segments sampled (Table 2), including four Cyanophyta, twelve Chlorophyta, one Chrysophyta and four Rhodophyta. Six of these macroalgal taxa were also identified from the San Marcos River and/or the Comal River (*Cladophora glomerata*, *Dichotomosiphon tuberososus*, *Oedogonium* sp., *Batrachospermum globosporum*, *B. involutum*, *Sirodotia huillensis*), indicating that they are quite widespread within the state. Measurements of the physical and chemical conditions of these stream segments show that they have pH values that are circumneutral to slightly alkaline ($\bar{x}$ = 8.1), moderate to high specific conductance ($\bar{x}$ = 443 μS cm^{-1}), warm temperatures ($\bar{x}$ = 24 °C) and slow to moderate current velocity ($\bar{x}$ = 28 cm s^{-1}) (Table 4). Conditions in these stream segments are very similar to those found in the San Marcos River and the Comal River at the same sampling time, except for slightly higher pH values in the additional streams sampled.

Table 2. Macroalgae taxa identified from Texas spring-fed streams

Taxon	TX7	TX9	TX31	TX32	TX33	TX34	TX35	TX36
Cyanophyta								
Lyngbya taylorii Drouet & Strickland		X						
Plectonema thomasinianum (Kütz.) Born.			X					
Rivularia minutula (Kütz.) Born. & Flah.						X		X
Schizothrix calcicola (C. Ag.) Gom.					X			
Scytonema alatum (Carm.) Borzi					X	X		X
Chlorophyta								
Chara globularis Thuill.				X	X	X	X	
unknown charophyte							X	
Chaetophora elegans (Roth) C. Ag.							X	
C. incrassata (Huds.) Hazen					X			X
Cladophora glomerata (L.) Kütz.	X					X	X	
C. cf. *glomerata* (L.) Kütz.			X					
Dichotomosiphon tubersosus (A. Br.) Ernst.	X	X	X			X		
Draparnaldia glomerata (Vauch.) C. Ag.							X	
Hydrodictyon reticulatum (L.) Lagerheim	X							
Oedogonium sp.	X						X	
Spirogyra sp.						X		
Tolypella intricata (Trent. ex Roth) Leonh.				X	X	X		X
Zygnema sp.								X
Chrysophyta (Bacillariophyceae)								
Cymbella cistula (Ehren.) Grun.							X	
Chrysophyta (Tribophyceae)								
Tribonema regulare Pascher		X						
Rhodophyta								
Audouinella pygmaea (Kütz.) Weber-Van Bosse	X							
Batrachospermum globosporum Israelson		X						X
B. involutum Vis & Sheath	X		X				X	
B. louisianae Skuja							X	
Hildenbrandia angolensis Welw. ex West & West	X	X						
Sirodotia huillensis Welw., W. & G.S. West	X						X	
Thorea violacea Bory	X	X						

Discussion

Several physical and chemical conditions in the San Marcos River and the Comal River were relatively constant over the sampling period (water temperature, pH and specific conductance), while others varied strongly (current velocity and maximum depth). Similarly, other studies have demonstrated that most spring conditions are quite consistent over the year (e.g. Whitford, 1956; Stern & Stern, 1969), while some factors, such as current velocity, are expected to vary more on a seasonal basis in streams that are not spring-fed (Duncan & Blinn, 1989). The stronger variation in current velocity and maximum depth in the two Texas spring-fed rivers may be explained in part by fluctuations in the spring discharge, which have been occurring with increasing frequency in the past several decades due to a combination of drought conditions and overpumping by the surrounding population (Crowe & Sharp, 1997). In addition, the location of the study sites in relation to the spring sources may have influenced these measurements. The San Marcos River sampling location was several hundred metres downstream from the springs, while the site on the Comal River was less than 100 m from the spring source. Consistent with this observation, the variation

Table 3. Diatom taxa identified during a 15-month seasonality study of the San Marcos River and the Comal River, Texas

Taxon	TX7	TX9
Achnanthes curtissima Carter	X	X
A. inflata (Kütz.) Grun.		X
A. lanceolata (Bréb.) Grun. var. *rostrata* (Östrup) Hust.	X	X
Achnanthidium affine (Grun.) Czarn.	X	X
A. minutissimum (Kütz.) Czarn.	X	X
Amphipleura pellucida (Kütz.) Kütz.	X	
Amphora pediculus (Kütz.) Grun.	X	X
A. sabiniana Reimer	X	X
Aulacoseira granulata (Ehren.) Simon.	X	
A. italica (Ehren.) Simon.	X	X
Brachysira vitrea (Grun.) Ross in Hartley	X	
Caloneis bacillum (Grun.) Cleve	X	X
Cocconeis placentula Ehren.var. *lineata* (Ehren.) Van Heurck	X	X
Cymbella cistula (Ehren.) Kirch.	X	
C. microcephala Grun. var. *crassa* Reimer	X	
Denticula tenuis Kütz.	X	X
Diploneis parma Cleve	X	X
Encyonema cespitosum Kütz.	X	
E. neogracile Krammer	X	X
E. silesiacum (Bleisch in Rabenh.) Mann	X	
Encyonopsis falaisensis (Grun.) Krammer	X	X
E. microcephala (Grun.) Krammer	X	X
Eunotia bilunaris (Ehren.) Mills	X	X
E. pectinalis (Dill.) Rabenh.	X	
E. formica Ehren.	X	X
E. soleirolii (Kütz.) Rabenh.	X	X
Fragilaria capucina Desmaz.	X	X
F. capucina Desmaz. var. *mesolepta* (Rabenh.) Rabenh.	X	
F. crotonensis Kitton	X	X
F. exigua Grunow	X	
Fragilariforma virescens (Ralfs) Willams & Round	X	X
Gomphonema clavatum Ehren.	X	X
G. mexicanum Grunow	X	X
G. parvulum (Kütz.) Kütz.	X	X
G. subtile Ehren.	X	X
G. truncatum Ehren.	X	
Karayevia clevei (Grunow in Cleve & Grunow) Round & Bukhtiyarova	X	X
Meridion circulaire (Grev.) C. Ag.	X	
Navicula arvensis Hustedt	X	X
N. confervacea Kütz.	X	X
N. diluviana Krasske	X	X
N. libonensis Schoeman	X	
N. meniscullus Schumann		X
N. radiosa Kütz.	X	X
N. radiosa Kütz. var. *tenella* (Bréb.) Van Heurck	X	X
N. rhynchocephala Kütz.	X	
N. sabiniana Patrick	X	
N. schroeteri Meister	X	

Continued on p. 79

Table 3. contd.

Taxon	TX7	TX9
N. veneta Kütz.	X	X
Nitzschia amphibia Grun.	X	X
N. hantzschiana Rabenh.	X	X
N. recta Hantzsch	X	
Opephora olsenii Möller	X	
Planothidium delicatulum (Kütz.) Round & Bukhtiyarova	X	X
P. lanceolatum (Bréb.) Round & Bukhtiyarova	X	X
Psammothidium levanderi (Hust.) Czarn. in Czarn. & Edlund	X	X
Reimeria sinuata (Greg.) Kociolek & Stoermer	X	
Rhoicosphenia abbreviata (C. Ag.) Lange-Bertalot	X	X
Rossithidium linearis (Wm. Smith) Round & Bukhtiyarova	X	X
Staurosira construens (Ehren.) Williams & Round	X	
S. elliptica (Schumann) Williams & Round	X	
Surirella angusta Kütz.	X	
Synedra amphicephala Kütz.	X	X
S. famelica Kütz.	X	X
S. parasitica (W. Smith) Hust. var. *subconstricta* (Grun.) Hust.	X	
S. tenera W. Smith	X	
S. ulna (Nitz.) Ehren.	X	X
Terpsinoë musica Ehren.	X	X

Table 4. Physical and chemical characteristics of spring-fed Texan stream segments sampled for macroalgae

Location	Temperature (°C)	pH	Specific conductance ($\mu S \cdot cm^{-1}$)	Maximum depth (cm)	Mean current velocity ($cm \cdot s^{-1}$)	Daylength (h)
TX31	23.0	8.2	475	42	55.0	14:02
TX32	25.0	8.2	490	>100	29.0	14:02
TX33	27.0	8.1	460	>100	25.7	14:02
TX34	24.5	8.2	430	>100	20.9	14:02
TX35	19.0	7.8	360	55	13.2	14:02
TX36	26.0	8.3	440	>100	25.7	14:02

in physical and chemical conditions was larger overall in the San Marcos River than in the Comal River, possibly indicating a greater influence by runoff water into the stream. No significant correlations were observed among physical and chemical conditions of the streams, such as pH and specific conductance, two factors which are commonly reported to be correlated (e.g. Sheath et al., 1988).

Of the 68 diatom taxa and nine macroalgal taxa identified from the San Marcos River, the occurrence of only six diatom taxa was significantly correlated to the physical and chemical conditions of the stream. Likewise, of the 46 diatom taxa and six macroalgal taxa identified from the Comal River, only six diatom and two macroalgal taxa showed significant correlation to stream conditions. Thus, the vast majority of algal taxa do not display seasonal variation that can be explained by fluctuations in measured stream conditions. This phenomenon may be due to the relatively constant conditions present in the streams. In the San Marcos River, most of the diatom taxa that were significantly correlated to stream conditions are known to be cosmopolitan in distribution (Patrick & Reimer, 1966; Lowe, 1974), indicating that they can

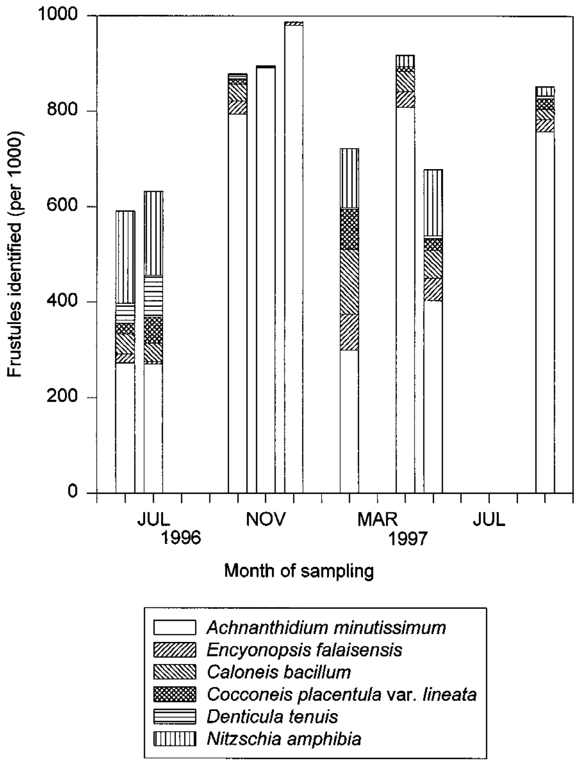

Figure 2. Relative proportions of the six most common diatoms identified from the San Marcos River over the sampling period (June 1996–September 1997). *Achnanthidium minutissimum* was the dominant diatom species in almost all seasonal samples from the San Marcos River.

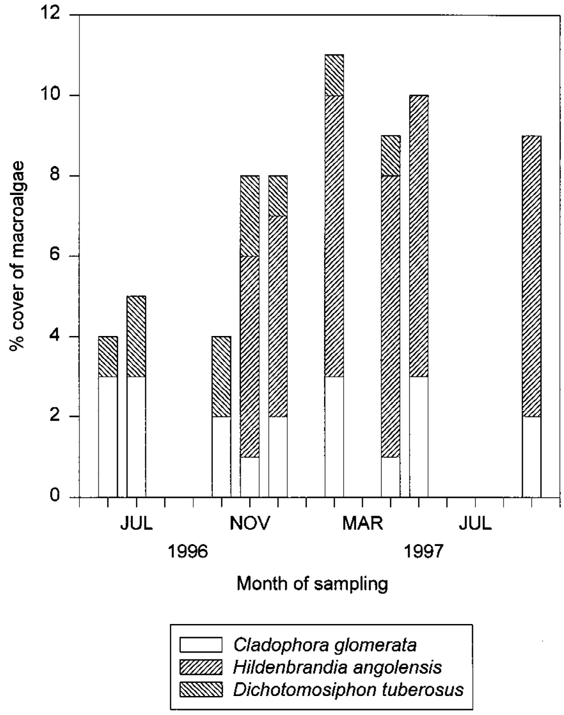

Figure 3. Percent cover of the most common macroalgae present in the San Marcos River stream segment over the sampling period (June 1996–September 1997).

most likely tolerate a variety of stream conditions. The most abundant diatom taxon in the San Marcos River, *Achnanthidium minutissimum,* reached its peak abundance in the October, November and December 1996 collections, as well as in the September 1997 collection. These sampling dates also correlated to the greatest changes in current velocity (Figure 1d). The strong presence of *A. minutissimum* at these times, then, may be explained as an early successional stage of the diatom community after scouring events (Rushforth et al., 1986). In the Comal River, several of the dominant diatom taxa exhibited significant correlations to stream conditions, such as *Nitzschia amphibia* with pH and *Achnanthidium minutissimum* with specific conductance. However, the variations in these conditions were not great. In addition, all diatoms significantly correlated with stream conditions are reported to be cosmopolitan in distribution (Lowe, 1978), rendering them unsuitable as ecological indicators. Two diatoms (*Cocconeis placentula* var. *lineata* and *Synedra ulna*) and two macroalgae (*Dichotomosiphon tuberosus* and *Hildenbrandia angolensis*) were significantly correlated with daylength. Thus, the seasonal abundances of some of the dominant algal taxa may be linked to the number of daylight hours, as has been shown in previous studies (Korch & Sheath, 1989; Hambrook & Sheath, 1991; and references therein). The red alga *Hildenbrandia angolensis* was negatively correlated to daylength, indicating that it tends to be most abundant in the winter months when fewer hours of daylight are available. This observation is consistent with other reports for the alga (e.g. Starmach, 1969), which usually describe it as being found predominantly in shady areas.

Although the need for more study on the algal communities of spring systems has been recognized in the past (Whitford, 1956; Sabater & Roca, 1990), most research to date has concentrated on the diatoms (e.g. Christensen, 1978; Cantoral-Uriza et al., 1997). The epilithic diatom flora of the San Marcos River and the Comal River contains many of the taxa commonly reported from springs around the world. For example, nine of the 57 diatom species reported from Mexican springs by Cantoral-Uriza et al. (1997) were also identified in this study, including several of the

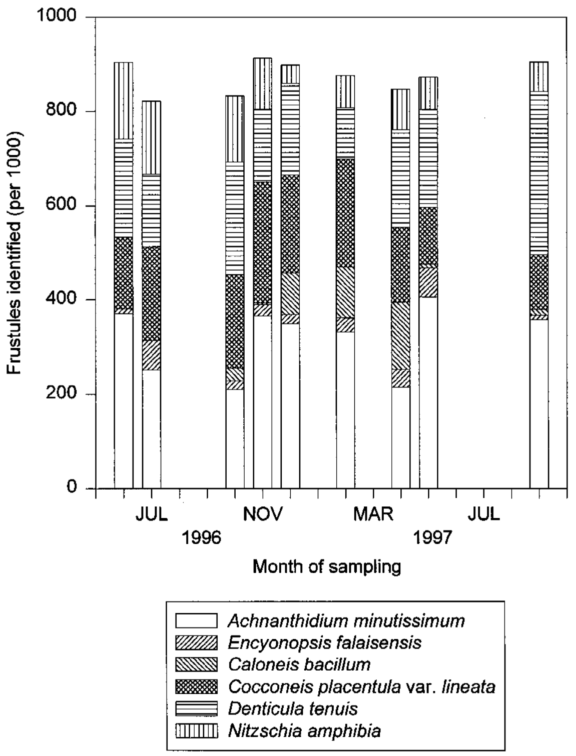

Figure 4. Relative proportions of the six most common diatoms identified from the Comal River over the sampling period (June 1996–September 1997). The assemblage in the Comal River is not as heavily dominated by a single species as it is in the San Marcos River.

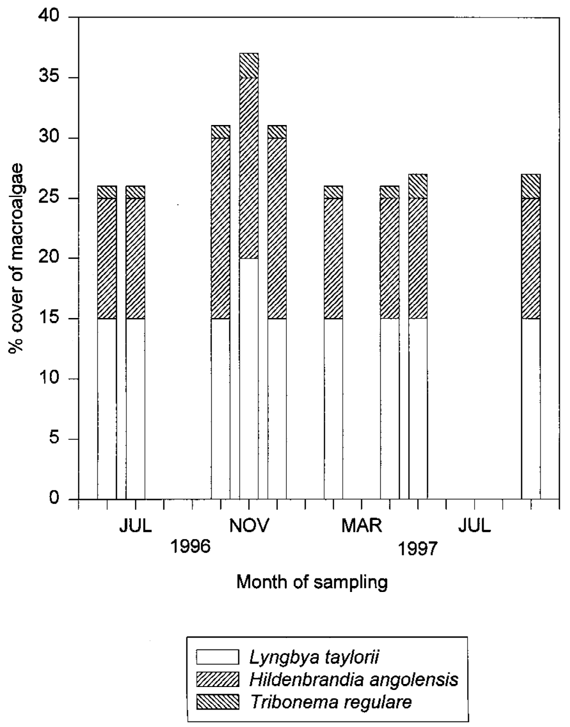

Figure 5. Percent cover of the most common macroalgae present in the Comal River stream segment over the sampling period (June 1996–September 1997).

dominant taxa (e.g. *Cocconeis placentula* var. *lineata* and *Denticula tenuis*). Cazaubon & Rolland (1995) noted some of the same taxa from springs in France (*Rhoicosphenia abbreviata*, *Gomphonema parvulum*, *Achnanthidium minutissimum* [as *Achnanthes minutissima*]), as did Sabater & Roca (1990) from springs in the Pyrenees (e.g. *Achnanthidium minutissimum* [as *Achnanthes minutissima*], *Caloneis bacillum*, *Denticula tenuis* and *Synedra ulna*). The previous study on the diatom flora of the San Marcos River and the Comal River (Christensen, 1978) reported many of the same taxa as this study. We identified several additional taxa, however, including *Amphora sabiniana*, *Brachysira vitrea*, *Encyonopsis falaisensis*, *Reimeria sinuata* and *Rhoicosphenia abbreviata*, some of them as dominant members of the flora.

Our study included a survey of the abundance of macroscopic algal taxa present in the two stream segments, as well as macroalgae identified from six additional spring-fed stream segments in Texas. In the San Marcos and Comal River a large proportion of Rhodophyta and Chlorophyta were found, with the Cyanophyta and non-diatom Chrysophyta composing relatively small proportions of the macroalgae identified. In the six additional spring-fed stream segments sampled, a large variety of Chlorophyta were collected, along with several Cyanophyta and Rhodophyta. These relative proportions of macroalgal groups are similar to those reported by Sheath & Burkholder (1985) for softwater streams in Rhode Island, and by Sheath et al. (1996) for tundra macroalgae of North America. Chlorophyta are usually dominant, and the Rhodophyta also often form a significant proportion of these floras. In Whitford's (1956) study of springs and spring-fed streams in Florida, he noted that the periphyton forms the important component of the algal springs community, but several rhodophytes, chlorophytes and cyanobacteria were also common members. Whitford (1956) reported species of *Cladophora*, *Chara*, *Thorea*, *Oedogonium* and *Lyngbya* as being widespread, and these taxa were also abundant in our survey of spring-fed stream macroalgae in Texas.

Two of the streams sampled (TX31 and TX35) contained the recently described red alga *Batrachos-*

permum involutum. This alga was described in 1996 from the San Marcos River, Texas (Vis & Sheath, 1996) and was thought to be endemic. Our observations of this alga represent the first report beyond the type locality, and thereby extend the known range of the alga to the western areas of the state of Texas.

In conclusion, this study represents the first examination of seasonal abundance trends for both diatoms and macroalgae in the spring-fed systems of Texas. Our findings are consistent with previous studies of spring-fed streams which have reported seasonal floras of springs to be quite constant, as well as having common conditions, such as high pH and specific conductance values due to bedrock geology.

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Note added in proof

We have identified a sample collected in January 1999 from Austin, Texas as the red alga *Batrachospermum boryanum* Sirodot, which is a new record.