THE ECOLOGY OF HONEY CREEK: TEMPORAL PATTERNS OF THE TRAVERTINE PERIPHYTON AND SELECTED PHYSICO-CHEMICAL PARAMETERS, AND *MYRIOPHYLLUM* COMMUNITY PRODUCTIVITY

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Quantitative estimates of periphyton seasonal and spatial changes were made at nine stations in an Arbuckle Mountain limestone stream using a colorimetric method. Periphyton was most abundant at the unshaded, upstream stations and had autumnal and vernal blooms. Temporal changes in the periphyton were related to day length, temperature, rainfall, discharge, alkalinity, and pH. *Myriophyllum* community primary productivity, estimated by the diel oxygen curve method, was low, 1.96, 2.14, and 2.22 g/m^2 /day, and productivity/ respiration ratios were consistently less than 1.

Periphyton abundance and primary productivity have been investigated for several Arbuckle Mountain lotic systems (1, 2). The present study provides additional information on the seasonal and spatial changes of periphyton abundance and selected physico-chemical parameters as well as estimates of *Myriophyllum* community productivity for Honey Creek, Murray County,Oklahoma. This stream was selected because of its permanent flow, lack of pollution, and homogeneous substratum which facilitated the quantitative sampling of riffle periphyton.

Honey Creek is a medium-sized limestone stream originating in the Cool Creek and McKenzie Hill formations of the Arbuckle Mountains and flowing northeast into the Washita River (Figure 1). The longitudinal gradient is steep (mean = 5.7 m/km) with the greatest descent near Bridal Veil and Turner Falls. During the wetter seasons, most accrual comes from intermittent streams, which together with the upper 12 km of Honey Creek were dry from mid-summer through later fall. The most consistent sources of water were Springs 1 and 2, which drain the Arbuckle limestone aquifer (3). Land use included pasture above Turner Falls Park and below Highway I-35, recreational areas within the park, and a few houses between the park and Highway I-35. Nine stations within the zone of travertine deposition were chosen for study (Table 1, Figure 1), with Stations 1 through 7 and Stations 8 and 9 situated above and below Turner Falls, respectively.

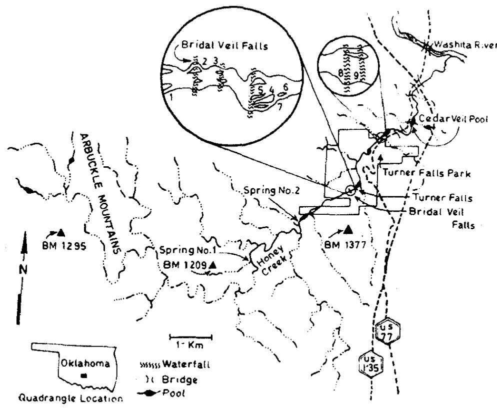

FIGURE 1. Map of Honey Creek, Murray County, Oklahoma with the locations of Stations 1 to 9 depicted within the circular enlargements. BM = bench mark.

METHODS AND MATERIALS

Selected physico-chemical variables were measured at weekly intervals below Stations 4 and 8, from 31 June 1972 through 15 August 1973. Water temperatures were measured with a mercury thermometer. Depths were measured with a 1-meter rule. Current velocities were measured at Stations 1 through 7 with a modification of Darcy's Pitot tube (4), since depth readings rarely exceeded 5 cm. Discharges were estimated just below Station 6 using the formulas and procedures described in Welch (4) with current velocities estimated by using a pigmy Gurley meter. Rainfall was collected by the U. S. Park Service at Sulphur-Platt

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TABLE 1. *Descriptions of Stations 1 through 9 including periphyton abundance (corrected optical densities), depth (cm), and current velocity (cm/sec); S.D. = standard deviation.*

Station Number	Dates Sampled	Periphyton Mean	Periphyton S.D.	Depth Mean	Depth S.D.	Current Velocity Mean	Current Velocity S.D.	Remarks
1	15 Jul — 5 Aug 72 28 Oct 72—15 Aug 73	0.32	0.19	5.54	3.02	162.22	37.69	45° slope; 40 m upstream from Bridal Veil Falls; dry from 5 Aug to 28 Oct; too deep to sample again until mid-Nov.
2	8 Jul—5 Aug 72	0.25[a]	—	5.00[a]	—	136.05	53.27	Just below Bridal Veil Falls; park visitor disturbance necessitated abandonment.
3	17 Aug 72—15 Aug 73	0.45	0.56	5.40	4.01	169.63	33.17	15° slope; 30 m below Bridal Veil Falls.
4	11 Nov 72—15 Aug 73	0.31	0.19	4.08	2.87	204.36	47.83	35° slope; 60 m below Sta. 3.
5	23 Sep 72—15 Aug 73	0.59	0.53	7.67	5.53	193.06	41.27	60° slope; adjacent to Sta. 4.
6	15 Aug 72—15 Aug 73	0.54	0.52	3.66	2.69	220.09	36.50	40° slope; 15 m below Sta. 5, 50 m above Turner Falls.
7	7 Aug 72—11 Nov 72	0.07	0.02	2.78	3.45	113.81	31.94	65° slope; 10 m adjacent to Sta. 6; denuded by spate in Nov 72 and abandoned.
8	31 Jun 72—15 Aug 73	0.14	0.12	6.00[a]	—	—	—	Lip of 50 cm waterfall; 2½ km downstream from Turner Falls.
9	23 Sep 72—23 May 73	0.13	0.13	—	—	—	—	20° slope; 6 m downstream from Sta. 8; inundated by damming on 23 May 73.

[a]Single measurement.

National Park and was expressed as the average amount of rainfall in cm/day between sampling dates. Light was measured in foot-candles during each of the primary productivity estimates using a Weston illumination meter (Model No. 756). Day lengths were determined from sunrise and sunset tables (5). A Coulter particle counter was used to estimate the numbers of suspended particles (6, 7). Triplicate counts were made on duplicate 5-ml water samples diluted in 100 ml of commercial Isotone solution. Dissolved oxygen concentrations were determined using the alkali-azide modification of the Winkler method (8) with samples titrated within ½ hour of collection. pH was measured with a portable, battery-operated Beckman pH meter (Model 210). Total alkalinities were measured by titration with dilute HCl to a pH of 4.3 (8). Orthophosphates, nitrate-N's, sulfates, turbidities, and conductivities were estimated at monthly intervals below Stations 4 and 8 using a portable Hach Chemical Company water chemistry kit (9).

Periphyton abundance was estimated at Stations 1 through 9 using a colorimetric technique modified for the analysis of stored samples. Portions of the travertine substratum of known areas were collected at weekly intervals and immediately extracted with between 50 and 100 ml of 80% ethanol without mechanically rupturing the algal cell walls; the extracts were stored at room temperature. Since samples were not processed immediately, a regression function was calculated to correct the time-induced degradation of the optical density of the extracted pigments. Using a Hach kit with a red color filter (No. 2408), the reciprocal fraction of the maximum optical density (y) was observed to be a sigmoid function of time (x). This function was partitioned into its exponential and asymptotic portions. A regression equation ($\log y = -0.034 + 0.012 x$, $r = 0.982$) provided a significant fit for the data and was used to correct results from samples processed between 15 and 50 days after collection; readings from older samples were corrected by multiplying by the suggested upper asymptote, 3.5. Corrected optical densities (O.D.$_c$) were then standardized for the volume of the extract (1) and the area sampled (cm^2). The O.D.$_c$ obtained using this method were comparable to those of samples processed by acetone extraction with grinding and were observed to fluctuate in proportion to visual changes in periphyton abundance.

Primary productivity was estimated at the effluence of a *Myriophyllum*-choked pool (dimensions: mean depth = 0.6 m; width = 11.0 m; length = 57.6 m) located about 50 m upstream from Station 1 using the single-station modification of the diel oxygen curve method (10). Since the affluent of this pool was a small waterfall, it was assumed that dissolved oxygen concentrations were initially near saturation and that the changes in the oxygen concentrations measured at the effluence were due mostly to the metabolic activity of the *Myriophyllum.* Mean community respiration ($\bar{r}$) was assumed to be constant (10), and was calculated using the following expression: $r = (-1 \sum_{i=1}^{n} (q - d)/n$

where q = rate of change in the dissolved oxygen concentration in ppm; d = amount of dissolved oxygen added or lost by diffusion (10); and n = the number of nocturnal sampling periods. Since q was usually negative during the periods of darkness, the expression was multiplied by –1. It was felt that the average of the nocturnal samples was more representative than a single "best estimate" value.

RESULTS AND DISCUSSION

In general, the temporal patterns (Figure 2) and the overall means (Table 2) for the physico-chemical factors agreed with data reported for Honey Creek (1) and the limestone reach of the Blue River (2). Water temperature curves corresponded to the seasonal changes in day length, although the maximum summer temperatures and the minimum winter temperatures occurred after, and prior to, the summer and winter solstices, respectively (Figure 2). Rainfall and discharge were highest in the late fall, spring, and early summer (Figure 2). Discharge was not estimated during some of the larger spates, and thus rainfall actually gave a more representative depiction of freshet occurrence and run-off. During late summer, early fall, and winter, rainfall was minimal and discharge correspondingly decreased as the upper reaches and intermittent tributaries dried up.

Coulter counts were not correlated with discharge or rainfall and did not exhibit any well defined seasonal trends (Figure 2). This variable was selected as an index of periphyton drift (11), pseudoplankton; however, microscopic examination of water samples revealed mostly inorganic particles, detritus, and bacteria (mostly gram-negative rods (6)). Coulter count samples were taken above riffles but may not have been representative of pseudoplankton abundance as simuliid larvae have been shown to significantly reduce particle counts (6).

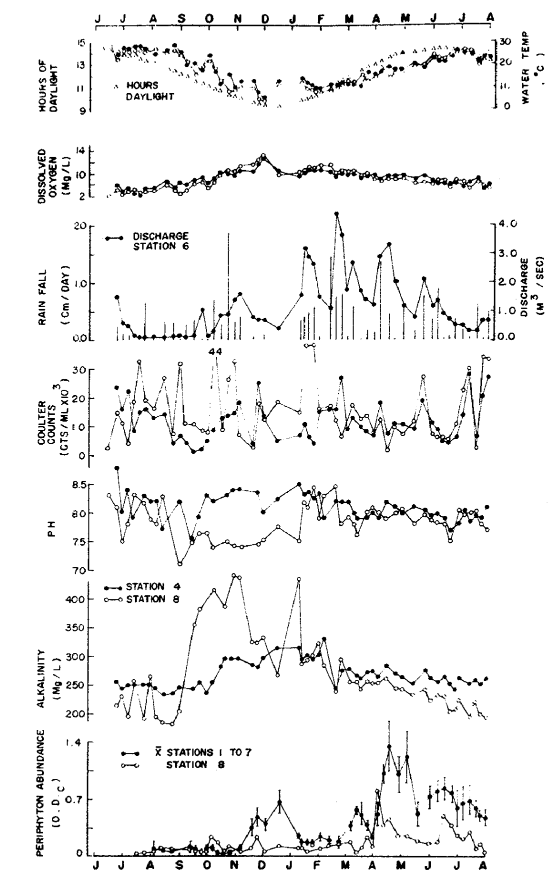

FIGURE 2. Seasonal changes in periphyton abundance (corrected optical densities) for the means of Stations 1 through 7 (brackets designate standard error of the mean) and Station 8; and selected physico-chemical parameters measured at Station 4 (•—•) and 8 (o—o).

Dissolved oxygen concentrations were measured below riffles and thus always approached saturation values; i.e., the seasonal values approximated the reciprocal of water temperatures (Figure 2). At Station 4 during the periods of lower discharge, June through December, 1972, pH values were consistently greater than 8.0. At this time, calcium and magnesium carbonates were precipitated as travertine which rapidly encrusted any allochthonous detritus. Total alkalinities at Station 4 were lower than at Station 8, where the pH remained below 8.0 and the alkalinities were presumably due to soluble bicarbonates (Figure 2). The lower pH values were attributed to lower populations of travertine-forming *Phormidium* and the accrual of more acid ground waters.

The overall means of the physico-chemical parameters at Stations 4 and 8 were not significantly different (2-way analysis of variance without replication (12), $P>0.05$) with the exception of pH and periphyton abundance (Table 2). The stations above Turner Falls (1 to 7) were generally more sunlit, while the stations below Turner Falls Park (8 and 9) were shaded throughout most of the morning and later afternoon. This difference in shading may have resulted in greater periphyton densities and photosynthetic activity which may have raised the pH.

TABLE 2. *The overall means and standard error of the means (S.E.) for the limnological parameters measured at Stations 4 and 8. N = number of measurements.*

Parameter[a]	Station number	N	Mean	S.E.
Periphyton abundance	4[b]	43	0.43	0.05
($O.D._c$)[a]	8	49	0.16	0.03
Discharge (m^3/sec)	4	36	1.06	0.04
Water temperature	4	54	19.2	0.1
(C)	8	55	18.2	0.9
Dissolved oxygen	4	54	9.24	0.17
(mg/l)	8	54	9.18	0.21
pH[a]	4	52	8.09	0.03
	8	53	7.88	0.04
Total alkalinity	4	52	266.3	6.0
(mg/l)	8	52	267.5	11.2
Orthophosphate	4	13	0.89	0.40
(mg/l)	8	13	0.43	0.19
Nitrate-N (mg/l)	4	10	0.13	0.02
	8	10	0.12	0.01
Sulfate (mg/l)	4	2	30.00	20.00
	8	2	19.50	0.50
Conductivity	4	13	2.15	0.10
(μ mhos/cm x 10^3)	8	13	2.26	0.10
Coulter count	4	52	17.03	3.27
cts/ml x 10^3)	8	52	20.94	2.85
Rainfall (cm/day)		49	0.38	0.06
Day length (hrs)		49	12.5	---

[a]Significant difference between Stations 4 and 8 ($\alpha = 0.05$)

[b]Mean of Stations 1, 3, 4, 5, 6, and 7.

The periphyton abundance curves were consistently bimodal, with fall and spring peaks (Figure 2), although the overall means varied considerably amongst the stations (Table 1). *Phormidium,* normally associated with travertine deposition (13), predominated in the fall and early winter collections, especially at Stations 1 to 7. Optical densities during the spring bloom, which consisted mostly of *Spirogyra* and *Oedogonium,* were greater than those observed during the fall bloom, agreeing with the trends in chlorophyll - a biomass observed for the Blue River (2). Both the fall and spring blooms were initiated after a period of considerable rainfall. During the fall, spates removed much of the dense *Myriophyllum* and presumably increased nutrient concentrations as the highest phosphate and nitrate-N concentrations were observed during this period. The vernal bloom occurred prior to peak *Myriophyllum* abundance and after the first spring storms. The short-term oscillations in vernal periphyton abundance were attributed to the denuding effects of spates caused by spring storms. During the periods of reduced rainfall, especially the late summer of 1972, periphyton practically disappeared and the travertine substratum appeared white in color. Although discharge exerted considerable influence on periphyton abundance, there did not appear to be any consistent spatial relationship amongst optical density, current velocity, and depth at Stations 1 to 9 (Table 1).

Selected chemical parameters were observed to change longitudinally due mostly to photosynthesis and/or diffusion (Table 3). Alkalinities were highest at the effluents of Springs 1 and 2 and decreased progressively downstream while the dissolved oxygen concentration and pH increased. Progressive oxygenation was related to both photosynthesis and mechanical aeration as the stream passed over riffles and waterfalls. Phosphate and nitrate concentrations did not exhibit consistent longitudinal patterns perhaps owing to sporadic enrichment from cattle excrement and/or rapid depletion by aquatic plants.

Primary productivity was measured previously for Honey Creek by Hornuff (1);

TABLE 3. *Longitudinal changes in selected chemical parameters.*

Parameter	Date	Spring 1	Spring 2	Below Spring 2	Station 4	Station 8
Dissolved oxygen (mg/l)	1 Apr 73	8.2	a	9.9	9.9	10.0
pH	1 Apr 73	6.9	a	7.6	7.9	8.0
	17 Jul 73	7.1	7.15	7.7	7.9	8.0
Alkalinity (mg/l)	1 Apr 73	303		274	268	247
	17 Jul 73	310	354	250	239	222
Phosphate (mg/l)	17 Jul 73	0.75	0.45	0.14	0.10	0.40
Nitrate-N (mg/l)	17 Jul 73	0.20	0.17	0.08	0.12	0.06

[a]No estimate taken.

TABLE 4. *Primary productivity estimates for selected lotic systems.*

System, time of year, source		Gas transfer constant (k)	Gross production (P) (g/m^2/day)	Respiration (R) (g/m^2/day)	P/R ratio
Honey Creek, Okla., present work	23 May 73	0.94	1.96	2.27	0.86
	21 Jun 73	0.81	2.14	2.16	0.99
	17 Jul 73	0.84	2.22	2.27	0.98
Honey Creek, Okla., summer Hornuff (1)		a	2.661	a	a
Blue River, Okla., summer, Hornuff (1)		a	1.032	a	a
Blue River, Okla., limestone reach, Duffer and Dorris (2)	Jun 63	a	6.0	10.0	0.60
	Jul 63	a	5.0	6.0	0.83
Itchen River, England, April to to October, Odum (10)		0.9—2.8	5.5—14.0	5.8—18.6	0.6—1.1
Buffalo Creek, Pa., August, McDiffett, *et al.* (14)		3.895	5.62	2.16	2.60
Oconee River, Ga., August, Nelson and Scott (15)		0.68	0.23	0.88	0.26

[a]Estimate not included.

however, his estimate was not corrected for respiration or diffusion, and was slightly higher than the present observed values (Table 4, Figure 3). Dissolved oxygen concentrations in the present study closely paralleled illumination curves (Figure 3) and were in good agreement with oxygen curves presented in the literature (10, 14). Primary productivity estimates for Honey Creek were low when it was compared with other nonpolluted lotic systems, e.g., the partially shaded, cold water trout stream investigated by McDiffet, *et al.* (14) (Table 4). Also diffusion constants and respiration estimates were generally lower than the values reported for similar systems (Table 4, also (10)).

Many lotic systems are heterotrophic and dependent upon allochthonous energy such as leaf fall (15, 16). The P/R ratios for this study were observed during the late spring and summer in the effluent of a *Myriophyllum*-choked pool, but were still slightly heterotrophic (<1). Honey Creek was not polluted and many "clean-water" invertebrates were common (17). Productivity estimates for the Itchen River, England cal-

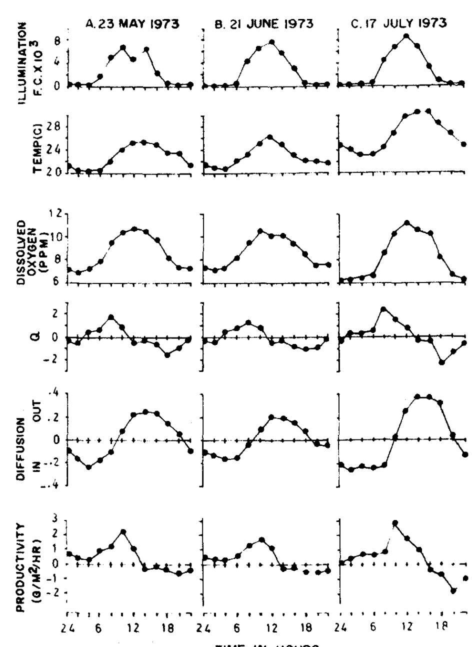

FIGURE 3. Primary productivity curves for a *Myriophyllum* community including diel changes in illumination and water temperature. Q = rate of change of dissolved oxygen.

culated by Odum (10) from data presented by Butcher, *et al.* (18) gave comparable P/R ratios as did the limestone reach of the Blue River (2), although overall productivity was higher in both systems. Streams with a lower carbonate content have yielded conflicting results; e.g., McDiffet, *et al.* (14) found *Ceratophyllum* beds to be autotrophic and fairly productive, while Nelson and Scott (15) found *Podostemum* outcrop communities to be heterotrophic with low primary productivity (Table 4).

Estimates of primary productivity for riffle periphyton using the two-station method (10) were not possible in Honey Creek because of the excessive downstream turbulence between this study area and Station 4, which resulted in estimates of negative productivity owing to oxygen losses by diffusion.

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