PRELIMINARY OBSERVATIONS ON THE PRODUCTIVITY OF PERIPHYTON ATTACHED TO A FRESHWATER ARTIFICIAL TIRE REEF[1]

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ABSTRACT

Primary productivity and nutrient concentrations were compared between the periphyton community on a freshwater artificial tire reef and the littoral phytoplankton in Smith Mountain Lake, Virginia, during the months of July, August, and September 1974. Primary productivity and nutrient concentration of the periphyton community were several times greater than that of the littoral phytoplankton. The periphyton community was dominated by pennate diatoms and filamentous green algae. Productivity measurements of the reef periphyton were on the same order of magnitude as the highest periphyton production rates reported in the literature. High Productivity of the tire reef periphyton supports the hypothesis that freshwater artificial reefs support increased densities of fish and invertebrates by enhancing the productivity of aquatic environments.

Plant communities are important when determining the ultimate carrying capacity of aquatic ecosystems. Lindeman (1941) maintained that the two major groups of primary producers in lacustrine food webs were the macrophytes and phytoplankton. More recently, however, Wetzel (1964), Pieczynska (1970), Goldman and De Amezaga (1975), and Hutchinson (1976) have emphasized the potential of periphyton[4] input into lacustrine food cycles.

The importance of periphyton in the food chain of aquatic environments has been demonstrated by Wetzel (1964) and Pieczynska and Szczepanska (1966). Wetzel found that periphyton was the most important primary producer in the littoral zone in saline Borax Lake, California. Pieczynska and Szczepanska (1966) found that productivity of periphyton and phytoplankton was approximately the same in the littoral zone of several Masurian lakes. Other investigators have compared the primary productivity of periphyton and phytoplankton in the littoral zone of lakes but have obtained conflicting results (Knight et al. 1962; Pieczynska 1965; Goldman and De Amezaga 1975 and Huntsinger and Maslin 1976).

The incidence of periphyton in the littoral zone is directly dependent upon the availability of adequate substrate suitable for colonization (Pieczynska and Szczepanska 1966). In many impoundments, firm substrate in the euphotic zone may be a limiting factor for periphyton productivity (and ultimately fish production) because: (1) the littoral zone of many reservoirs was clearcut prior to impoundment; (2) standing timber

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[4] Periphyton was considered to be the total assemblage of plant and animal communities attached to any firm substrate, and also the free living micro- and macro-organisms found swimming, creeping, or lodged among the attached forms (American Public Health Association 1971).

that was not initially clearcut has decayed; and (3) silt eventually covers much of the firm substrate in the euphotic zone which results in unstable mud (muck) bottoms.

Buchanan (1972) and Lambert (1973) found that artificial reefs placed in a marine environment provided additional substrate for the attachment of fish food organisms and concentrated sport fishes making them more accessible to anglers. Mathews (1966) found that the oxygen production from periphyton communities on marine reefs was approximately 4X greater than the phytoplankton community collected over the reef. Consequently, it has been demonstrated that the ability of the oceans to support fish can be increased by constructing additional artificial reefs along the coast (Stone et al. 1974). Artificial reefs may also serve the same purpose in freshwater. Although reefs (structure) in freshwater have been shown to concentrate large numbers of sport fishes (Rodeheffer 1939, 1940, and 1945), the ability of large freshwater environments to support greater and more desirable fish biomass as a result of reef construction has not been documented (Stroud 1975). Quantitative measurements of periphyton primary productivity occurring on artificial reefs would provide insight into the potential energy available to higher tropic levels.

The objectives of this study were: (1) to identify the plant communities attached to the artificial tire reef substrates; (2) to quantify the primary productivity and nutrient concentration of periphyton communities attached to the tire reefs; and (3) to compare the contribution of the primary productivity of periphyton occurring on the tires with that of the littoral phytoplankton. Comparisons with periphyton on natural structure were not made because very little natural structure remains in the littoral zone of Smith Mountain Lake. The entire basin was clear-cut to a depth of approximately 10.0 meters prior to impoundment.

METHODS

Artificial reefs (Figure 1) were installed in Smith Mountain Lake during the summer of 1973 to determine their feasibility as a freshwater fisheries management technique (Prince and Brouha 1975). Identification of attached plant communities and quantification of the primary productivity and nutrient concentration of periphyton communities were part of the overall reef evaluation.

Representative scrapings of organisms attached to the reef substrate were taken and examined microscopically for qualitative evaluation of the composition of the periphyton community. Primary productivity measurements, based upon oxygen production and consumption in light and dark enclosures (American Public Health Association et al. 1971), were made in July, August, and September 1974. Individual tires, well colonized with comparable amounts of periphyton, were taken from the upper portion of the pyramid tire units at a depth of 1.7 m (Figure 1) and placed in duplicate pairs of light and dark Plexiglas boxes (Figure 2) without removing the tires from the water. Since the tires used from the upper portion of the pyramid units were the same size (33 cm rims), areas available for attachment of periphyton were homogeneous. The light and dark boxes were exposed at a depth of 0.5 m for 3 hours during mid-day. At the end of the exposure period dissolved oxygen was determined by the Winkler method (American Public Health Association 1971) from duplicate samples taken from each of the enclosures. Duplicate dissolved oxygen determinations were averaged for each box. Gross primary productivity was determined by changes in dissolved oxygen. To calculate maximum and minimum rates, the light box with the most dissolved oxygen was paired with the dark box with the least amount of dissolved oxygen. The difference in oxygen concentrations gave a maximal estimate of the gross productivity of the enclosed periphyton communities. Similarly, the light box with the least dissolved oxygen was paired with the dark box with the most dissolved oxygen to give a minimal estimate of the gross productivity of the enclosed periphyton communities. The dissolved oxygen data from the two independent light boxes and two independent dark boxes were expressed as a possible range of gross primary productivity.

For comparative purposes, duplicate light and dark 300 ml BOD (Biochemical Oxygen Demand) bottles were incubated to assess the primary productivity of phytoplankton in

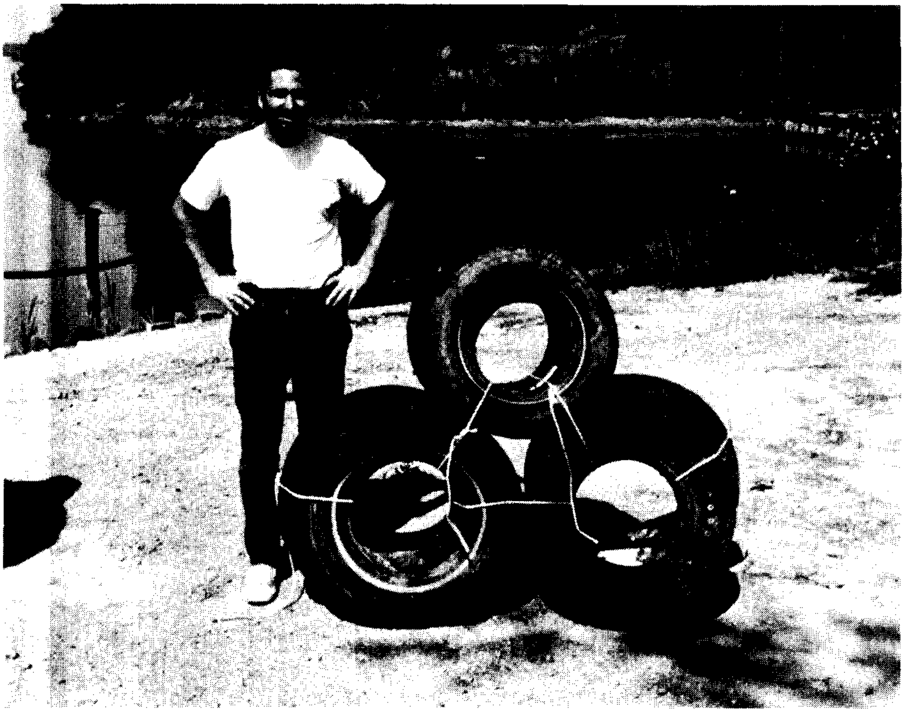

Figure 1. Pyramid tire unit used as artificial reefs in Smith Mountain Lake, Virginia. The tire unit was placed in the euphotic zone on the 3 m depth contour. The upper set of three tires were within 1.7 m of the surface and were used in measuring the primary production and nutrient concentration of periphyton communities.

littoral areas. Water samples were taken from the same depth as the periphyton communities and the bottles were placed alongside the boxes and incubated for the same period of time. Measurements of primary productivity and nutrient concentration of macrophytes were not determined because these plant communities are not generally extensive in Smith Mountain Lake.

Six 25 cm^2 patches of the periphyton community were scraped from representative sections of the tires, and water samples were collected from adjacent littoral areas for nutrient analysis. The samples were analyzed in duplicate for total phosphate, total Kheldahl nitrogen (TKN), and total solids. Phosphate samples were digested by the persulfate method (American Public Health Association 1971) and filtered. In July, an adaption of the Lucena-Conde Prat (LCP) method was used to develop indicating color in the digested samples (Hosokawa and Oshima 1973). The LCP method was found to be inadequate, and the ascorbic acid method (American Public Health Association 1971) was employed for color development in August and September. Routine methods were followed from TKN and total solids (American Public Health Association 1971). Means and standard errors were calculated from the duplicate determinations. Incident solar radiation which occurred during the experiments was measured by a recording pyrheliometer (Belfort Inst. Co., Model 5-3850A).

RESULTS AND DISCUSSION

Twenty one taxa of algae were found on the artificial reefs during this study (Table 1). The attached algae were dominated by pennate diatoms and filamentous green algae

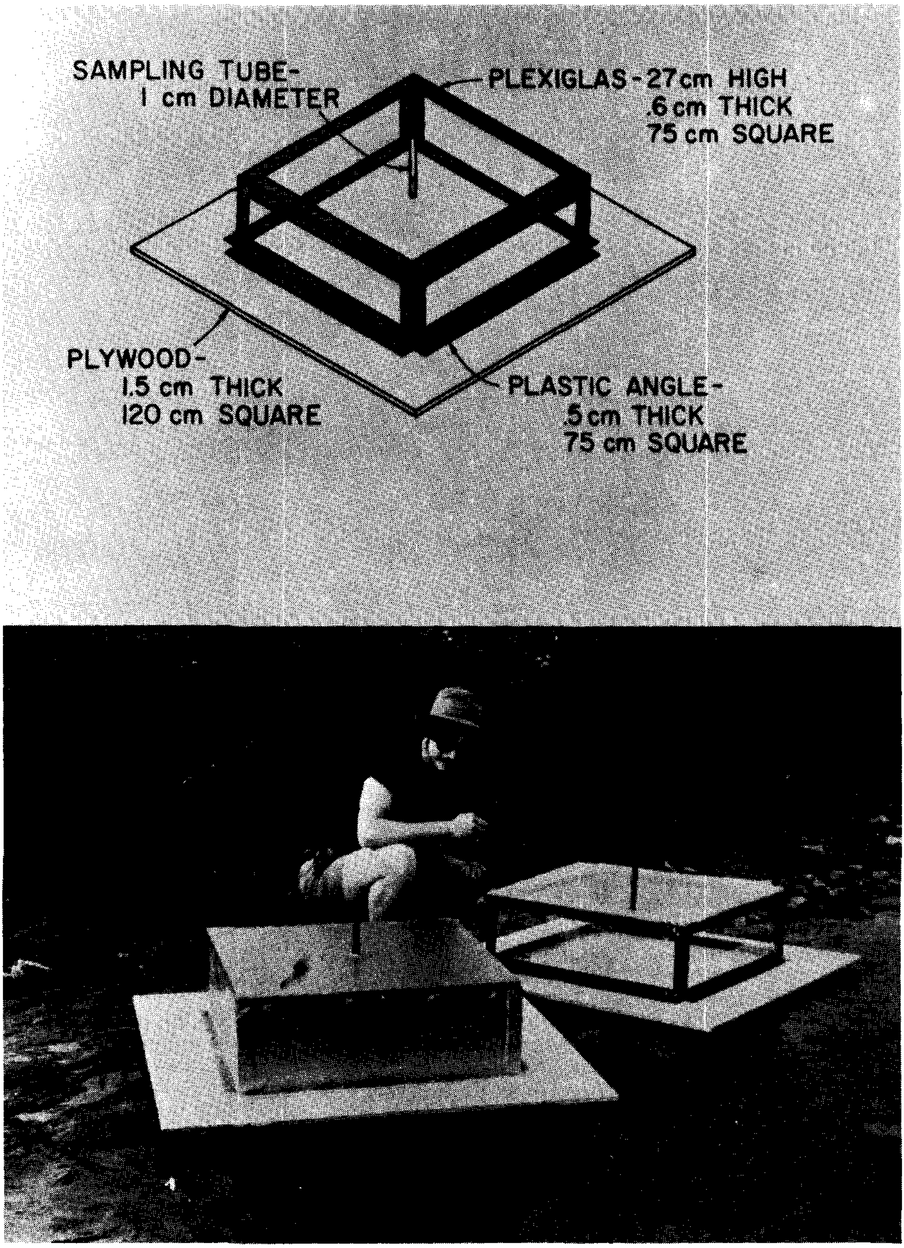

Figure 2. Schematic (top) and picture (bottom) of Plexiglas enclosures used to measure the primary production of periphyton associated with the artificial tire reefs in Smith Mountain Lake, Virginia. Water samples were taken from the tube on top of each enclosure.

Table 1. List of plant communities attached to tire reefs in Smith Mountain Lake, Virginia, in July, August, and September, 1974.

Chrysophyta (diatoms)	Chlorophyta (green algae)	Cyanophyta (bluegreen algae)
Fragilaria crotonensis[1]	*Tetraedron minimum*	*Oscillatoria nigra*
Tabellaria fenestrata	*Pediastrum Boryanum*	*Merismopedia convolota*
Meridion circulare	*Gleocapsa aeruginosa*	*Lyngbya aestuarii*
Gomphonema constrictum[1]	*Chroococcus* sp.	*Oscillatoria* sp.
Melosira granulata	*Spirogyra* spp.[1]	*Phormidium* sp.
Cyclotella stelligera	*Mougeotia* sp.[1]	
Tabellaria flocculosa		
Synedra sp.		
Cymbella sp.		
Navicula sp.		

[1] Most common taxa.

(principally *Mougeotia* and *Spirogyra*). Bluegreen algae occurred infrequently on the tire substrate and contributed very little to the periphyton community. Goldman and De Amezaga (1975) and Evans and Stockner (1972) also studied periphyton colonization of natural and artificial substrates. Goldman and De Amezaga (1975) found approximately 86 taxa (mostly identified to species) of algae with *Mougeotia* and the pennate diatoms being most common. Evans and Stockner (1972) also found that diatoms and filamentous green algae were clearly the dominant algal groups on their artificial substrates (buoys). In contrast, *Spirogyra* was found to be uncommon in both studies.

Wetzel (1964), Pieczynska and Szczepanska (1966), and Goldman and De Amezaga (1975) found that peak periods of periphyton production occurred from May through June. During the months of July to September, growth and primary productivity declined. Assuming this same pattern of periphyton productivity is characteristic in Smith Mountain Lake, the values presented in Tables 2 and 3 probably underestimate maximal production rates.

Measurements of gross primary productivity and nutrient concentration of the reef periphyton community and the littoral phytoplankton community are presented in Table 2. The different units of measurement that accompany the raw values in Table 2 make a meaningful comparison of periphyton and phytoplankton productivity difficult. Table 3 presents the data after conversion into two comparable units of measurement, one volumetric and one areal. Since the tire reef reduces limnetic habitat by the volume of water it displaces, one basis of comparison was established by presenting all periphyton values in volumetric terms (per liter of tire displacement). This procedure allows direct comparison between periphyton and phytoplankton on the basis of an identical (1 liter) volume of lake habitat. Additionally, periphyton and phytoplankton productivity values were converted to comparable areal terms (per m^2 of lake surface) based on the reef density that was tested (1 tire per enclosure or 1.7 tires per m^2). The depth of the test site was 0.5 m. This conversion compares a m^2 of lake surface with no structure in its 0.5 m water column to a m^2 of lake surface that has 1.7 tires in its 0.5 m water column. Gross productivity values in Table 3 are the median of the measured range. All converted nutrient values were based on the approximation that 2/3 of the tire's external surface was colonized. Primary productivity of the littoral phytoplankton was so low that differences in oxygen between light and dark BOD bottles were barely detectable. However, differences in oxygen between light and dark boxes enclosing periphyton communities were consistently greater than 2 mg/l.

Pieczynska and Szczepanska (1966) found that during periods of mass appearances of periphyton, productivity amounted to approximately 84 mg $0_2/m^2/hr$; whereas, during periods of medium growth, productivity was approximately 22 mg $0_2/m^2/hr$. Wetzel

Table 2. Unconverted measurements of solar radiation (SR), Gross production (GP), total phosphate (Total PO_4), total Kjeldahl nitrogen (TKN), and total solids from tire reef periphyton and littoral phytoplankton from Smith Mountain Lake, Virginia, 1974. Gross production is given as a range (see text). Nutrient values are means of duplicates plus or minus one standard error (X±SE).

	July	*August*	*September*
SR (kcal/cm²/hr at mid-day)	53	51	54
GP (mg O_2/hr at mid-day)			
Periphyton, per tire-enclosure	108-130	84-140	30-188
Phytoplankton, per liter	0.03-0.10	0.00	0.00
Total PO_4 (mg PO_4–P) ± SE			
Periphyton, per 25 cm²	0.029±0.003	0.016±0.004	0.033±0.001
Phytoplankton, per liter		0.02±0.00	0.04±0.01
TKN (mg N) ± SE			
Periphyton, per 25 cm²	2.82±0.39	0.84±0.22	1.08±0.09
Phytoplankton, per liter	0.44±0.01	0.21±0.02	0.06±0.06
Total solids (mg dry wt) ± SE			
Periphyton, per 25 cm²	366.5±14.9	174.6±14.9	291.4±87.1
Phytoplankton, per liter	107.0±12.0	89.7±10.3	120.8±17.2

(1964), utilizing a Carbon-14 technique found the annual mean periphyton productivity in Borax Lake to be approximately 731 mg C/m²/day. During August 1961, the rate in Borax Lake was approximately 1200 mg C/m²/day. Using the general equilibrium equation for photosynthesis (Odum 1971) and allowing a 50% difference between net and gross primary productivity values, Carbon-14 rates (net productivity) should be multiplied by a conversion factor of 2.25 to approximate oxygen rates (gross productivity). Using this conversion factor, the values from Borax Lake then become 1658.3 and 2700.0 mg O_2/m²/day, respectively. If the areal data in Table 3 from Smith Mountain Lake are expanded to approximate a full sun day (using pyrheliometer data) the values become 2220.0, 1710.0, and 1539.0 mg O_2/m²/day. Even though error is introduced by such "conversions" and "expansions," the productivity data gathered from the tire reef periphyton community were on the same order of magnitude as the highest periphyton production rates reported in the literature.

Goldman and De Amezaga (1975) found that periphyton productivity in oligotrophic Lake Tahoe, California, in July (the last month of their study) was only 9.5 mg C/m²/day. It appears, therefore, that the trophic status of a lake may affect production rates of periphyton, as well as phytoplankton communities.

Tables 2 and 3 also show that the photosynthetic rate of the periphyton community was several times greater than the littoral phytoplankton community. In most oxygen light and dark studies of primary productivity, the bottles remain in the water for 24 hours (Odum 1971). Therefore, the oxygen values in this study probably underestimated the littoral phytoplankton productivity values by a considerable amount. However, Simmons and Neff (1969), using the Carbon-14 light and dark bottle technique within 0.5 km of the reef site, reported limnetic phytoplankton primary productivity values which ranged between 36-23 mg C/m²/day in the surface waters during August 1966 and 1967. Converting these Carbon-14 values to oxygen values (81.0—51.8 mg O_2/m²/day) and comparing them with our values for August 1975, the primary production of the periphyton on the artificial tire reef still exceeded the estimates of the limnetic phytoplankton community by a factor greater than one order of magnitude (10X). Moreover, bubbles had frequently accumulated on the lid immediately above the tires in the light boxes by the end of the exposure period. The presence of these bubbles probably represented a supersaturated condition of oxygen due to the photosynthetic rates of the periphyton. The loss

Table 3. Measurements of gross production (GP), total phosphate (Total PO_4), total Kheldahl nitrogen (TKN), and total solids converted to comparable volumetric (1) and areal terms (2) (see text). Primary production and nutrient values are given as medians.

	July	*August*	*September*
GP (mg O_2/hr at mid-day)			
(1) per liter of lake volume			
Periphyton	46	43	42
Phytoplankton	0.07	0	0
(2) per m^2 of lake surface			
Periphyton	200	190	190
Phytoplankton	33	0	0
Total PO_4 (mg $PO_4 - P$)			
(1) per liter of lake volume			
Periphyton	1.5	0.8	1.7
Phytoplankton		0.02	0.04
(2) per m^2 of lake surface			
Periphyton		14	26
Phytoplankton		10	18
TKN (mg N)			
(1) per liter lake volume			
Periphyton	140	42	54
Phytoplankton	0.44	0.21	0.06
(2) per m^2 of lake surface			
Periphyton	870	310	290
Phytoplankton	220	110	28
Total Solids (mg dry wt)			
(1) per liter of lake volume			
Periphyton	18000	8700	15000
Phytoplankton	107.0	89.7	120.8
(2) Per m^2 of lake surface			
Periphyton	140000	86000	130000
Phytoplankton	54000	45000	60000

of oxygen due to dissolution would also indicate greater primary productivity than was measured.

There have been many studies conducted which compared the photosynthetic rates of different lake plant communities. Such comparisons indicate the relative contribution of each segment of the plant community to the total photosynthetic input of the lake. Lakes with gradually sloping banks generally exhibit considerable periphyton and macrophyte growth, and these two communities usually exceed the productivity of the phytoplankton community several fold (Wetzel 1964; Pieczynska and Szczepanska 1966). In lakes with reduced littoral zone development, there is correspondingly less periphyton production (Goldman and De Amezaga 1975). Wetzel (1964) found that periphyton was the most important source of primary production in the littoral zone of Borax Lake, California. When adequate attachment surfaces were introduced into the littoral zone of Smith Mountain Lake, periphyton production showed a similar potential.

Pieczynska (1970) distinguished three types of periphyton (autotrophic; autotrophic-heterotrophic, and heterotrophic) based on the species composition of the biotic communities and their functional role in the trophic structure of the ecosystem. The relatively low species diversity of the attached biotic community and high primary productivity of reef periphyton found in this study fit Pieczynska's criteria for autotrophic periphyton. However, the characteristics of the reef periphyton probably change seasonally.

The elevated concentrations of nutrients indicated that the anions are actively accumulated on the reef by the periphyton community and/or precipitate and settle on the reef upon chelation with clay particles or other suspended materials. Assuming that biological activity on the reef contributes, in part, to the observed nutrient levels, then the periphyton community also serves to recycle nutrients which would otherwise be lost.

SUMMARY

Artificial tire reefs in the euphotic zone of Smith Mountain Lake changed the available habitat by providing additional substrate for the attachment of periphyton communities. Attached algal communities were dominated by pennate diatoms and filamentous green algae. The increase in available habitat resulted in increased primary productivity and nutrient levels of the tire reef periphyton community compared to the primary productivity and nutrient concentrations of the littoral phytoplankton community.

Primary productivity of the tire reef periphyton communities in Smith Mountain Lake were on the same order of magnitude as the highest periphyton production rates reported. The relatively low species diversity of attached biotic communities and the high primary productivity of reef periphyton found in this study fit the criteria for autotrophic periphyton. The tire reef periphyton community apparently serves to recycle nutrients which would otherwise be lost due to sedimentation on the lake bottom.

Increased primary productivity and nutrient levels at the base of the artificial tire reef food web do not necessarily indicate that this energy is being utilized by higher trophic levels (i.e., omnivorous fishes). However, Prince (1976) has recently found that periphyton (particularly attached plant material) was the most important component in the diet of tire reef bluegill. The food cycle of carnivorous reef fishes (black bass) was also shown to be ultimately dependent on the reef periphyton communities. In addition, increases in primary productivity and nutrient levels may also have contributed to increases in body condition and growth (weight) detected in artificial tire reef sunfish (Prince et al. 1975, and Prince 1976).

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