J. Aquat. Plant Manage. 35: 69-73

Effects of Benthic Barriers on Aquatic Habitat Conditions and Macroinvertebrate Communities

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ABSTRACT

Physical and chemical conditions of sediments and benthic community composition were evaluated under synthetic fabric barriers, used to control aquatic macrophytes in confined areas. Macroinvertebrate density declined by 69% within 4 weeks at Eau Galle Reservoir, WI. Within a few weeks of placement at ponds near Dallas, TX, invertebrate densities declined by more than 90%. At Eau Galle Reservoir, benthic barriers apparently blocked sedimentation and caused an increase in NH_4 and a decline in dissolved oxygen to near zero beneath the fabric. Barriers reduced macroinvertebrate taxa richness at both locations. Community effects were most severe in warm water; Chironomidae was eliminated by barriers at the Texas ponds. Barriers substantially reduced macroinvertebrate density and altered community composition; however, biotic conditions in affected areas recovered rapidly after barrier removal.

Key words: aquatic invertebrates, Chironomidae, aquatic plant control, Bottom Line™ Benthic Barrier Fabric, bottom screens, reduced dissolved oxygen, sediments.

INTRODUCTION

Covering the hydrosoil to prevent growth of nuisance macrophytes is a management option employed since the late 1960s (Born et al. 1973, Nichols 1974). Techniques include placement of sand and gravel as well as plastic or synthetic fabric held in place by pins or weights. Barriers block light and restrict upward growth of shoots. Because material is expensive, barriers are typically used in relatively small areas such as harbors, boat lanes, or swimming areas.

The effectiveness of benthic barriers for plant control has been shown in previous studies (Mayer 1978, Cooke and Gorman 1980, Lewis et al. 1983, Engel 1984, Cooke 1986). However, only Engel (1984) examined the quantitative responses of benthic macroinvertebrates to barriers. Aquatic macrophyte control methods that eliminate macroinvertebrates can adversely affect higher trophic levels. Fishes, amphibians, and birds feed on benthic invertebrates and emerging adult insects. In addition, previous research provided little insight into the effects of benthic barriers on the physical and chemical composition of the soils they contact. The purpose of this paper is to describe the effects on physical and chemical conditions of the sediment and on macroinvertebrate density and community composition under experimentally placed benthic barriers. Studies were conducted at the U.S. Army Corps of Engineers' Eau Galle Reservoir in Wisconsin and the U.S. Army Corps of Engineers' Lewisville Aquatic Ecosystem Research Facility near Dallas, TX.

Eau Galle Reservoir is a 62-hectare impoundment on the Eau Galle River in west-central Wisconsin. A single benthic barrier, 6.1 m × 12.2 m, was deployed along the north shore on 25 August 1988 approximately 50 m from the mouth of inflowing Lousy Creek. The placement area was dominated by *Ceratophyllum* sp. and lesser amounts of *Potamogeton* spp.

Barriers were also installed in two adjacent ponds at the Lewisville facility near Dallas. Each pond had a surface area of approximately 0.3 hectare and an average depth of 2 m. On 11 June 1990, a single 6.1 m × 6.1-m barrier was placed in each pond. Dense *Najas* sp. dominated the areas where barriers were placed. Bottom Line™ Benthic Barrier Fabric, developed and marketed by Dow-Corning Corporation, Midland, MI, was used for this study. This material is no longer commercially manufactured or available.

MATERIALS AND METHODS

Physical and Chemical. Triplicate sediment cores were collected at Eau Galle Reservoir in June and again in September 1991 (approximately three years after placement). Cores were taken from beneath and next to the barrier for comparison of physical and chemical parameters. To allow comparison of physical and chemical parameters core samples were collected with a Wildco hand-held core sampler (Wildlife Supply Co., Saginaw, MI) equipped with 50-cm-long 6.5-cm-diameter acrylic liners.

Sediment cores from beneath the barrier were collected by penetrating the fabric. Only the top 10 cm of each core was retained for analysis. All samples were held at 4 C and transported to the laboratory for processing within 48 hours.

Under a nitrogen atmosphere within a glove box, each core sample was homogenized and subsampled for physical and chemical analysis. Moisture content, density, and organic matter content were measured by drying a known volume to a constant weight at 105 C, then combusting at 550 C (Allen et al. 1974). Total Kjeldahl nitrogen (TKN) and total phosphorus (TP) concentrations were measured colori-

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metrically after digestion with H_2SO_4, K_2SO_4, and red HgO (Plumb 1981). Particle size determinations were made using a modification of a hydrometer method (Patrick 1958) first described by Day (1956).

Plexiglas samplers, after a design of Hesslein (1976), were used to collect interstitial, or pore water. Sampler operation is based on the equilibration of a contained quantity of water with the surrounding water through a dialysis membrane (2 µm polycarbonate, Nucleopore Corporation, Cambridge, MA). Samplers remained in place for about 14 days, sufficient time to allow equilibration (Carignan 1984).

Upon retrieval, the contents of the samplers were removed, filtered (0.45 µm, Nalgene CA syringe filters), and preserved with H_2SO_4 to pH < 2. Interstitial water was analyzed for NH_4-N and soluble reactive PO_4-P, using methods described above for TKN and TP. Iron and Mn were analyzed by direct atomic absorption spectrometry (APHA 1985).

Surficial water samplers were deployed on the sediment surface beneath each barrier. These were Plexiglas dialysis chambers (10.2-cm width, 5.1-cm height) containing about 400 ml of deoxygenated and deionized water. Upon retrieval, water from the surficial samplers was transferred to 300-ml biological oxygen demand bottles and fixed for later determination of dissolved oxygen by the azide-modified iodometric method (APHA 1985).

Data were evaluated using the Statistical Analysis System (SAS Institute 1985). Comparisons of means were performed using the Student's *t*-test. Statements of statistical significance refer to $p < 0.05$.

Biological. Macroinvertebrate samples were collected at Eau Galle Reservoir on 27 September 1988 (1 month after barrier placement) and again on 28 July 1989. Biological studies were conducted a full year before the physical and chemical studies; however, all work was done during the growing season. Basic water quality measurements, specifically dissolved oxygen and temperature, were taken during all study years at Eau Galle Reservoir and Lewisville Lake.

At the Lewisville ponds, macroinvertebrate samples were collected when placed (unaffected by barriers), and at 7, 16, 39, and 94 days after placement. Barriers were removed from the Lewisville ponds on 16 November 1990, and a final set of samples was collected on 2 July 1991 to evaluate recolonization.

At each location, five replicate 5-cm cores were taken under each barrier and at an adjacent reference site using a sampler that excluded all live plants (Miller and Bingham 1987). Only the upper 5 cm of each core was analyzed. Sediments were fixed in the field in a 5% formalin solution containing Rose Bengal stain. Samples were returned to the laboratory and sieved through a 0.5-mm mesh screen. All macroinvertebrates were sorted from material on the sieve and enumerated by major taxa.

At the Lewisville ponds, no significant macroinvertebrate density differences were evident among barriers or reference sites. Thus, these sites were pooled for statistical analysis. In addition, no significant density differences (analysis of variance, $p > 0.05$) between barrier and adjacent reference sites were evident before barrier placement, so these sites were also pooled.

Statistical analyses were conducted using either standard spreadsheet programs or the Statistical Analysis System (SAS) on personal computers. For analysis of variance, biological data were grouped by treatment and comparisons were made through time.

RESULTS

At both sampling locations, barriers were highly effective at preventing plant growth. Under the barriers, a considerable gas buildup from plant decomposition (Gunnison and Barko 1992) was noted within the first 2 weeks. The gas was removed by rolling a large-diameter polyvinyl chloride pipe over each mat. Subsequent gas buildups were not a problem.

From June to September 1990, temperature at the Texas ponds was 25 C (± 2 C) at the near-bottom and water surface. Water temperature was usually 1 to 2 C less immediately under the barrier. Typical water temperature between June and September at Eau Galle Reservoir is 22 C (± 2 C) at a depth of 50 cm.

Physical and Chemical. At Eau Galle Reservoir, significant changes in the texture of the reference (no barrier) sediment were noted during the macrophyte growth season, from June until September 1991. Sand increased; silt and clay decreased (Table 1). Over this same time period, changes in the texture of the sediment beneath the barrier were relatively minor and limited to the sand and silt frac-

TABLE 1. MEAN (N = 3) PHYSICAL AND CHEMICAL CHARACTERISTICS WITH ASSOCIATED STANDARD ERRORS, IN PARENTHESES, OF SEDIMENT COLLECTED BENEATH BARRIERS AND ADJACENT TO (REFERENCE SITE) BARRIERS AT EAU GALLE RESERVOIR, WI. AN ASTERISK (*) INDICATES A SIGNIFICANT DIFFERENCE BETWEEN SAMPLING SITES AND A PLUS SIGN (+) BETWEEN SAMPLING PERIODS (*T*-TEST, $P < 0.05$).

Characteristics	Location	June 6, 1991		Sept. 19, 1991		
Total Sediment Texture (%)[1]						
Sand	Barrier	26		19		+
	Open	18		56*		+
Silt	Barrier	51		61		+
	Open	56		33*		+
Clay	Barrier	22		20		+
	Open	27		12*		+
Density (g/ml)[2]	Barrier	0.20	(0.02)	0.27	(0.08)	
	Reference	0.16	(0.02)	0.59*	(0.12)	+
Moisture (%)	Barrier	73.6	(2.7)	74.9	(6.1)	
	Reference	78.2	(2.4)	53.9*	(7.7)	+
Organic matter (%)	Barrier	11.5	(0.8)	10.9	(1.6)	
	Reference	13.5	(0.7)	6.1*	(1.1)	+
Total Kjeldahl Nitrogen	Barrier	4.32	(0.20)	3.64	(0.29)	
(TKN), (mg/g)[2]	Reference	5.50	(0.23)	1.75*	(0.33)	+
Phosphorus (mg/g)[2]	Barrier	1.36	(0.045)	1.08	(0.047)	
	Reference	1.74	(0.035)	0.52*	(0.075)	+
Interstitial Water						
Ammonium-N (mg/L)	Barrier	16.37*	(0.99)	22.60*	(2.21)	+
	Reference	24.73*	(1.47)	35.00*	(2.33)	+
Phosphate-P (mg/L)	Barrier	0.61*	(0.061)	0.06*	(0.086)	+
	Reference	1.15*	(0.511)	0.29*	(0.179)	
Iron (mg/L)	Barrier	13.6	(1.9)	13.8	(1.3)	
	Reference	16.0	(3.1)	26.4*	(6.0)	
Manganese (mg/L)	Barrier	0.2	(0.0)	3.2*	(0.1)	+
	Reference	0.3	(0.1)	4.2*	(0.5)	+

[1]Based on a composite of three replicate samples.
[2]Based on sediment mass.

tions. From June to September sediment density increased significantly beneath the barrier, whereas organic matter remained unchanged.

In June, TKN and TP concentrations in the reference sediment were significantly greater than beneath the barrier. Between June and September, TKN declined significantly. From June to September, TP declined significantly only at the reference location.

In June and September, interstitial water ammonium-N (NH_4-N) was significantly greater at the reference location than beneath the barrier. However, sediment interstitial water phosphate-P (PO_4-P) did not differ significantly between reference and barrier locations for either sampling period. No significant differences in interstitial water Mn were evident between the reference sediment and sediment beneath the barrier. From June to September, significant increases in NH_4-N and Mn were noted at both the reference and barrier sites.

Dissolved oxygen concentrations in the surficial water collected beneath the barrier from May through September 1991 were consistently near zero.

Macroinvertebrate Density. On 27 September 1988, 1 month after barrier placement at Eau Galle Reservoir, densities below the barrier had declined by 69%. Density beneath the barrier was not significantly different from the reference site because of a high variance (t = 1.31; d.f. = 8; p > 0.2). However, nearly one year later, on 28 July 1989, density at the reference site was 5,710 individuals/m^2 compared with 791 individuals/m^2 under the barrier, a reduction of 86%.

At the Lewisville ponds, macroinvertebrate density declined throughout the summer but was always lower under barriers than at reference sites (Figure 1). One week after barrier placement, density averaged 567 individuals/m^2 beneath barriers and 5,723 individuals/m^2 at reference sites. On 20 July 1990, density at reference sites averaged 1,628 individuals/m^2, which was approximately an order of magnitude more than beneath barriers (197 individuals/m^2). By 13 September, density at reference sites had declined to 888 individuals/m^2, which was not significantly different from beneath barriers (370 individuals/m^2). Barriers were removed on 16 November, the end of the growing season.

On 2 July 1991, more than 7 months after barrier removal, density at reference and ex-barrier sites was 4,495 individuals/m^2 and 2,417 individuals/m^2 (p > 0.05), respectively (Figure 1). These early summer densities were similar to those observed at reference sites during late June (3,183 individuals/m^2) and late July (1,628 individuals/m^2) during the previous year, showing that macroinvertebrate recolonization was rapid following removal.

Macroinvertebrate Community Composition. At Eau Galle Reservoir, community composition beneath the barrier was dissimilar to that in adjacent areas (Figure 2). Reference site sediments were dominated by oligochaetes (38%) and chironomids (25%). Fewer trichopterans, gastropods, and amphipods were present. Beneath the barrier the benthic macroinvertebrate community was dominated by amphipods (30%) and reduced numbers of oligochaetes, chironomids, and trichopterans.

The macroinvertebrate community before placement in the Lewisville ponds was heavily dominated by oligochaetes (82.6%) followed by chironomids, ephemeropterans, nematodes, coleopterans, and dipterans other than chironomids (Figure 3).

During treatment, Oligochaeta remained abundant at the reference sites and under the barriers. Nematodes comprised 22.8% of the community under barriers, but were about an order of magnitude less at reference sites (3.7%). Chironomidae were not found under barriers at the Lewisville ponds although they comprised 12.3% of the community at reference sites.

After removal, oligochaete abundance remained high at the reference (63.4%) and barrier (48.0%) sites. Chironomids, which were eliminated by barriers, recovered quickly after barriers were removed. In July 1991 chironomids comprised 48.9% of the community at former barrier sites and 26.1% of the community at reference sites (Figure 3).

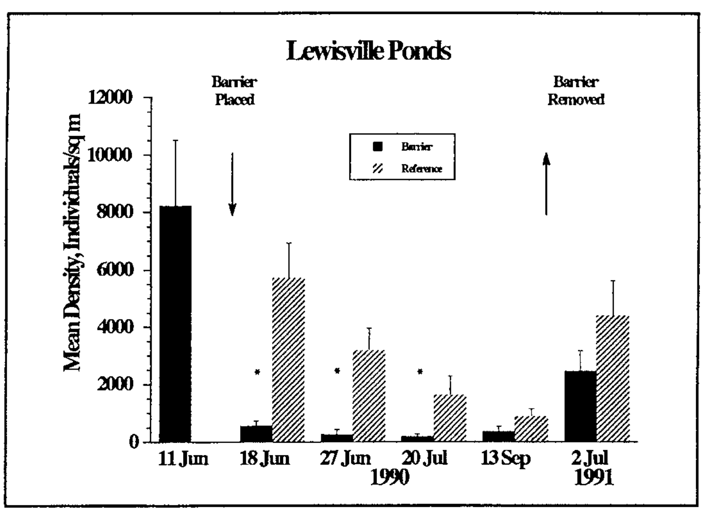

Figure 1. Macroinvertebrate density in sediments from reference and barrier sites in Lewisville ponds before placement, during placement, and after removal. Asterisks indicate a significant difference (t-test, p < 0.05) between barrier and reference sites.

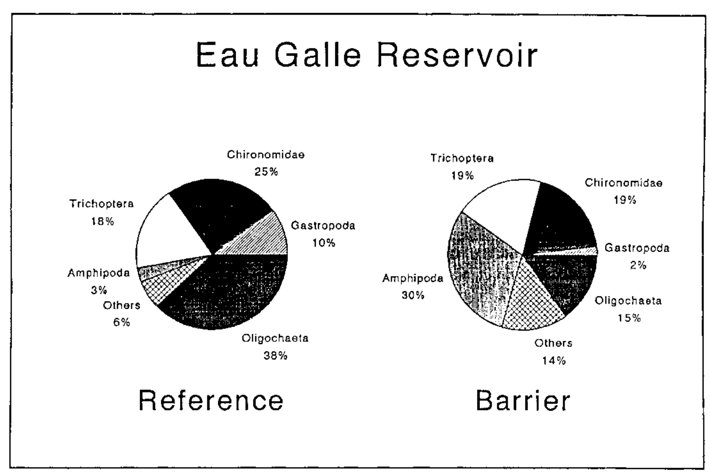

Figure 2. Macroinvertebrate community composition in sediments from a reference site and under a barrier at Eau Galle Reservoir, WI.

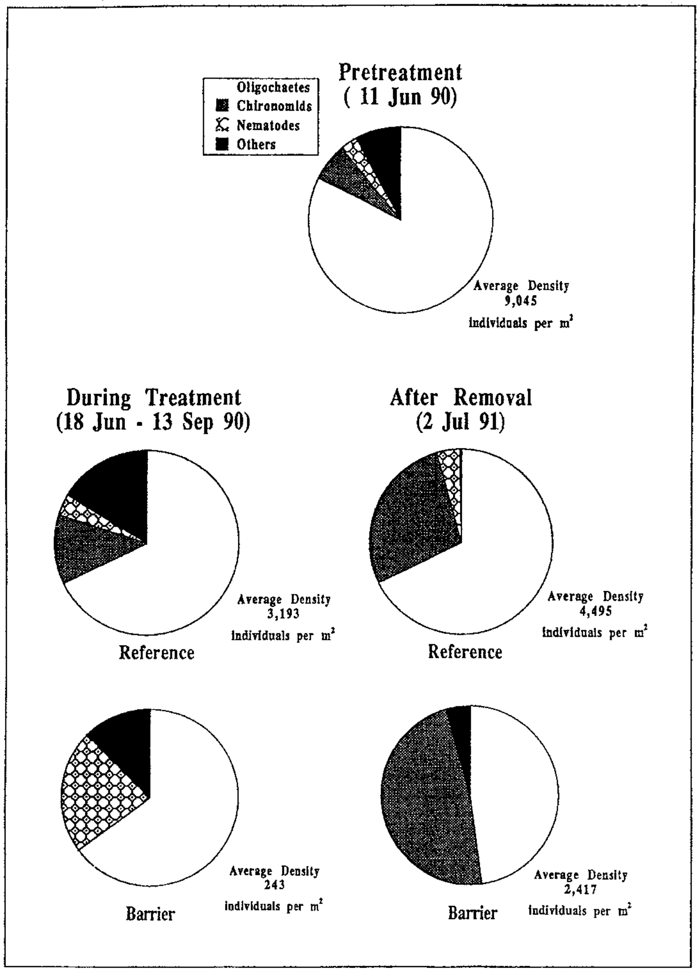

Figure 3. Macroinvertebrate community composition in sediments from reference sites and under barriers at the Lewisville ponds, TX.

DISCUSSION

The benthic barrier used at Eau Galle Reservoir affected the physical and chemical conditions of underlying sediments. Although the physical conditions of the treatment and reference sediments were quite similar in June, significant differences in the physical conditions were observed at Eau Galle Reservoir in September.

Differences in physical conditions likely resulted from erosional and/or depositional processes altering reference sediment. The location of the barrier 50 m from the mouth of inflowing Lousy Creek may have allowed high flows and suspended material loads associated with storm runoff to alter or even replace the reference sediment during the study period. In this instance, the barrier at Eau Galle could have ameliorated the effect of these processes on the physical characteristics of sediment over which it was placed.

Physical changes in the reference sediment very likely affected chemical characteristics. Thus, reductions in TKN and TP concentrations can probably be ascribed to altered physical properties, particularly decreased organic matter concentration.

Examination of dissolved oxygen concentrations, within the surficial water beneath the barrier revealed complete loss of oxygen during the study period. Loss of oxygen and increased concentrations of NH_4^+-N in the surficial water is probably responsible for the considerable reduction in viable macroinvertebrates beneath the barriers.

Reduction of macroinvertebrate density beneath barriers ranged from approximately 65% in 1 month at Eau Galle Reservoir to greater than 90% within 1 week in the Texas ponds. Reduction was rapid and sustained, as long as the substratum was blocked. Once barriers were removed, the macroinvertebrates recovered. Approximately 8 months after barrier removal in the Texas ponds, density had risen from just a few hundred individuals/m^2 to over 2,000 individuals/m^2. Chironomids, which had been eliminated from under barriers, became abundant once barriers were removed.

Results at Eau Galle Reservoir were similar to Engel's (1984) observations of effects of a synthetic barrier on macroinvertebrates in Cox Hollow Lake, WI. His data show that in late July, after 2.5 months of placement, density at a reference site was approximately 16,000 individuals/m^2, whereas macroinvertebrates under barriers averaged 4,000 individuals/m^2. This 75% reduction corresponds closely to 65% reduction noted at the Eau Galle Reservoir in this study (Figure 4).

The rate of decline in macroinvertebrate density at the ponds in Texas was much more rapid than observed by Engel (1984). He noted a progressive monthly decline in density from May to August. At the Texas ponds, density under the barriers declined within 1 week to near zero and remained near zero throughout the season. The slower decline in Cox Hollow Lake could have been the result of lower water temperature and higher macroinvertebrate density and diversity than in the ponds.

Not all biological effects of benthic barriers are negative. Loss of a productive invertebrate habitat can be compensated for by beneficial aspects of barriers. Sport fish forage more effectively in open areas and channels than among dense plants (Engel 1985). Benthic barriers develop their

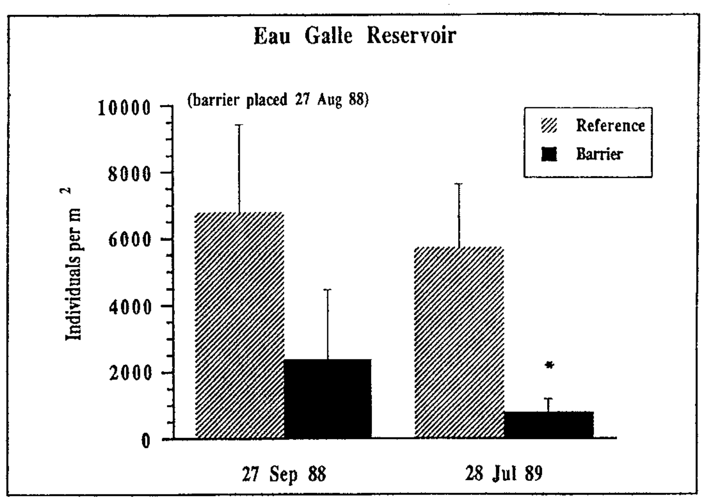

Figure 4. Macroinvertebrate density immediately after placement and 1 year later in sediments at a reference site and under a barrier at Eau Galle Reservoir, WI. Asterisks indicate a significant difference (t-test, $p < 0.05$) between sites.

own relatively dense epibenthic fauna (noted during this study and by Engel 1984). It is reasonable to expect that invertebrate-feeding fishes will more successfully exploit this epibenthic food resource.

Submersed aquatic plants are known to provide important and highly productive habitats to many benthic (Beckett et al. 1992a) and epiphytic macroinvertebrates (Schramm et al. 1987; Cyr and Downing 1988; Beckett et al. 1992b and 1992c). Based on results presented herein and by Engel (1984), barrier use causes marked reduction in density and substantial change in benthic macroinvertebrate community composition.

Barriers also limit exchanges with the overlying water column (Gunnison and Barko 1992) and appear to physically restrict erosional and/or depositional processes from affecting the sediments upon which they are placed (data presented herein). However, physical, chemical, and biological effects may be quite localized. In the studies reported herein, only macroinvertebrates directly beneath the barrier were affected, and community composition and density recovered quickly once barriers were removed. The small area affected by barriers compared with the total littoral zone should be considered in evaluations of system-wide biological, chemical, and physical effects.

ACKNOWLEDGMENTS

This research was conducted as part of the U.S. Army Corps of Engineers' Aquatic Plant Control Research Program, managed in the Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station. Permission was granted by the Chief of Engineers to publish this information. The authors acknowledge the assistance of M. Smart, W. James, D. Dressel, E. Zimmer, S. Wilkerson, E. Hubertz, S. Fox, and K. Pigott.

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