FLOATING TIRE BREAKWATERS AND ECOLOGY OF COVES IN AN OKLAHOMA RESERVOIR

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Abstract: The influence of floating tire breakwaters on the ecology of coves was studied in Lake Carl Blackwell, a 1400-ha reservoir in north-central Oklahoma. Breakwaters, consisting of a single row of 18-tire modules, were installed across the mouths of 2 coves (8.5 and 9.8 ha). Wind, wave height, water temperature, transparency, suspended solids, turbidity, and sedimentation rate were measured during one 7-month period at windward and leeward sites in 2 experimental and 2 control coves. Populations of fish and benthic invertebrates were monitored in experimental and control coves for 2 years after construction of the breakwaters. At leeward sites, breakwaters reduced wave heights by 50%, increased transparency in both experimental coves and increased sedimentation rate in 1 cove. Slight differences in turbidity, suspended solids, and temperature between windward and leeward sides of the breakwaters were similar to differences between lakeward and shoreward areas of control coves. Floating tire breakwaters had little adverse environmental impact on the coves. Electrofishing suggested an increase in centrarchid fishes due to the breakwaters.

Proc. Ann. Conf. S.E. Assoc. Fish & Wildl. Agencies 33:495-506

Moorage space for pleasure boats is limited in many marine and freshwater areas by a shortage of harbors which have natural protection from destructive wave conditions. As a result, artificial protective structures are needed to expand existing harbors and to create new ones (Richey and Nece 1974). Floating, transportable structures suitable for "instant" harbors have been the focus of considerable research as alternatives to bulkheads and rock groins. Earlier research on breakwaters was reviewed by Richey and Nece (1972) and Griffin (1972), while more recent work was the subject of national conferences on floating breakwaters (Kowalski 1974) and on tire breakwater structures (R.J. Shephard 1977, National Oceanic and Atmospheric Administration, Rockville, MD. Unpublished).

Floating breakwaters have been constructed in 6 groups of geometric configurations with a variety of materials (Richey and Nece 1974). Two floating tire breakwaters (FTB) have been described--one by Noble (1969) and the other by Candle and Piper (1974). The latter design has had wider application; it provides low-cost protection against waves for marinas in exposed locations (Kowalski and Ross 1975) and is adaptable for shoreline erosion control (Candle and Fischer 1977).

The biological effects of FTB's are not well understood, however. Kowalski and Ross (1975) pointed out that FTB's, unlike many submerged reefs, are located high up in the photic zone where biological production is great, and therefore readily provide food and

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habitat for game fish. Gifford et al. (1977) found that the substrate in the wave shadow of a floating breakwater along a Florida beach rapidly became stabilized and overlain with organic debris, resulting in an apparent increase in density of burrowing worms, mollusks, and rooted submerged grasses in the protected water. On the other hand, possible adverse results of the use of these breakwaters are "down drift" erosion and the rapid silting in of the wave shadow (Gifford et al. 1977). Silting in of protected areas may have been responsible for reduction in zooplankton populations and poor survival of fishes in Lewis and Clark Lake (Benson and Cowell 1967).

FTB's were installed in coves of a wind-swept Oklahoma reservoir with the objective of providing spawning sites and nursery areas for increasing density of young-of-the-year largemouth bass, (*Micropterus salmoides*) (Clady et al. 1979). Although bass populations and diversity of the overall fish fauna were not noticeably changed by the breakwaters, more pronounced changes might conceivably occur in basic limnological characteristics of the coves and in populations of plants and animals lower in the food chain. We describe physical, chemical, and biological changes on windward and leeward sides of the breakwaters and in modified and control coves.

This paper is a contribution from Federal Aid to Fish Restoration Project F-36-R, Oklahoma.

MATERIALS AND METHODS

At spillway elevation of 287.8 m (m.s.l.), Lake Carl Blackwell (Fig. 1) has a surface area of 1400 ha, a shoreline length of 90 km, a shoreline development index of 6.8, and a

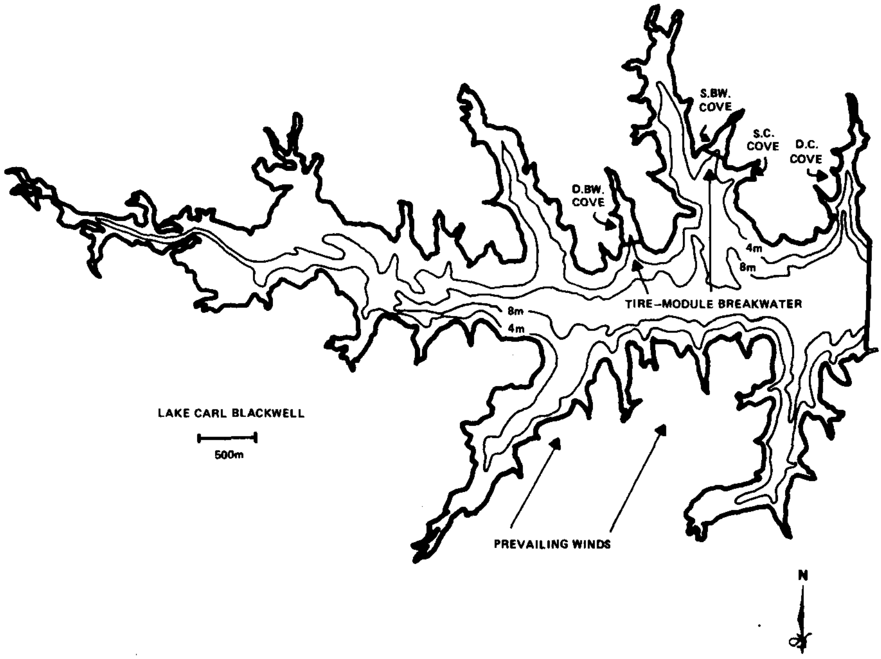

Fig. 1. Lake Carl Blackwell, Oklahoma, showing study coves. BW = breakwater; C = control; D = deep; S = shallow.

maximum depth of 10 m. Because the reservoir is oriented with its long axis in an east-west direction, much of the shoreline is exposed to prevailing southwesterly winds. Turbulence induced near shore by wind and waves associated with frontal systems has been shown to transport sediments (Norton 1968; Hysmith 1975), and to affect fish adversely (Summerfelt 1975) and probably also aquatic plants and benthos (Smith 1975; Wetzel 1975). A more detailed description of the reasons for choosing Lake Carl Blackwell as the study area were given by Clady et al. (1979).

After a preliminary investigation (Summerfelt 1977), breakwaters were installed along the northeast shore in two of four coves exposed to prevailing southwesterly winds (Fig. 1; Table 1). The breakwater in cove 3 was closed during September 1976 and that in cove 2 during April 1977. Single-row floating tire breakwaters, 2 m wide, were constructed by interconnecting a series of the basic 18-tire modules (Fig. 2) described by Candle and Piper (1974), Kowalski (1974), Kowalski and Ross (1975), and Candle and Fischer (1977). Enough modules were connected to block each cove. Breakwaters were placed in the lake in 2 overlappng sections to permit boats to pass in and out of the cove.

TABLE 1. Length of breakwaters and physical characteristics of coves of Lake Carl Blackwell with and without breakwaters in spring 1977.

Cove	Breakwater length (m)	Area (ha)	Max depth (m)	Wind direction and fetch (m) SE	S	SW	Volume (m^3)	Length of shoreline (m)	Shoreline development index
1	None	4.25	3.50	80	1800	575	65,000	810	1.10
2	125	8.50[a]	3.25	400	2000	600	114,900	1185	1.14
3	225	9.75	6.25	1500	1100	1400	186,050	1698	1.53
4	None	3.65	7.25	100	2200	150	113,475	789	1.17

[a]Area behind breakwater = 6.55 ha.

Physicochemical data were collected at 8 sites, 4 in 2 control coves without breakwaters and 4 in 2 coves with breakwaters. Sample sites were 20 m on the leeward and windward sides of the breakwater in the 2 experimental coves and in similar positions in the 2 control coves.

Wave height was measured with a meter stick attached to a pole about 2 m long driven into the lake bottom in 1.5 m of water on the most windswept side of each cove. Meter sticks were placed on the windward and leeward sides of the breakwater in experimental coves and in similar positions in control coves. Waves heights were measured as the difference between the highest crest and lowest trough during a 30 to 45-second observation period. Wind velocity and direction were measured by a continuously monitoring anemometer located on the south shore of the lake. Water temperature was measured in water samples taken at the surface and 0.5 m off the bottom with a brass Kemmerer water sampler. Suspended solids were measured in milligrams per liter from the same samples as water temperature, with a spectrophotometer. Turbidity was measured from the same water as suspended solids with a turbidimeter and reported in Jackson Turbidity Units (JTU). We used a standard Secchi disc to measure transparency.

During the period 30 May to 7 November 1977, wind, wave height, water temperature, transparency, suspended solids, and turbidity were each measured at the 8 sites on 84 days when winds were from the south, southeast, and southwest. The data were categorized according to the direction of the wind during sampling and analyzed with a paired t-test to determine differences between windward and leeward areas of coves.

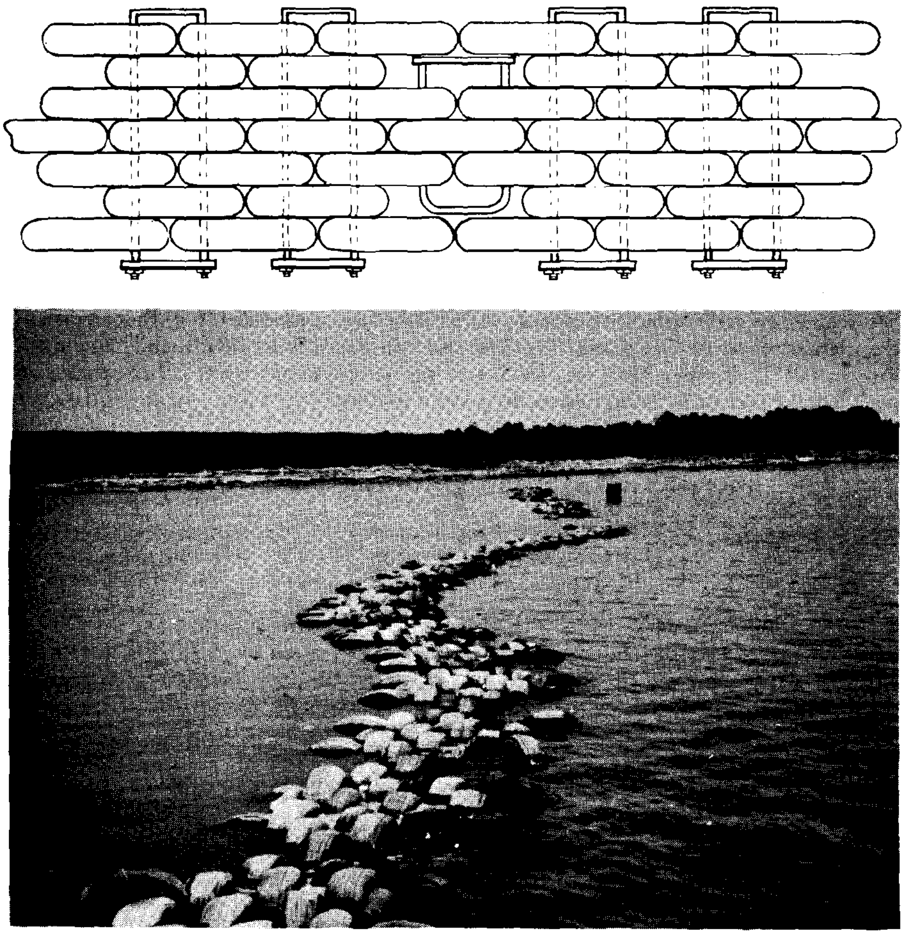

Fig. 2. Arrangement of two 18-tire modules and interconnecting U-bolts (above) and a completed breakwater in a cove in Lake Carl Blackwell (below).

Sedimentation rate was measured, also from May to November 1977, with a sampler similar to that described by White and Wetzel (1973). The water in each sample was filtered through preweighed glass fiber filters (Gelman type A-E). The filters were dried (105C for 1 hour) and reweighed. The dry weight of the samples was reported in grams per square meter per day ($g/m^2/day$). Sedimentation rates were tested non-parametrically for differences between leeward and windward sites.

Fish species composition in each cove was estimated in August-September of 1976, 1977, and 1978 from catches made with gill nets and electrofishing gear. Four times each year an experimental gill net--2.4 m deep and 45.7 m long, divided into six 7.6-m panels with bar mesh sizes of 1.9 to 6.4 cm--was fished ovenight on the bottom in deeper areas of each cove. Also on 4 days each year, a complete circuit of the shallower areas of each cove was made with a 240-v AC electroshocker mounted on a 4.9-m flat-bottomed boat. All fish were immediately identified and returned to the lake.

From January 1977 through September 1978, species composition and diversity of the benthic invertebrate community were estimated from organisms taken with 6 multiple-plate samplers (Hester and Dendy 1962) suspended near the bottom in 2 to 3 m of water in the northeastern corner of each cove. Samplers were removed every 6 weeks, placed in plastic bags, and returned to the laboratory. Organisms were washed from the samplers, immediately picked from the samples while still alive, preserved in 70% alcohol, and later identified. We used the Shannon-Weaver index (Wilhm 1976) to estimate species diversity for periods before and after the breakwaters were installed.

RESULTS

Limnology

Wave height, temperature, and transparency were consistently different at windward and leeward areas of coves (Table 2). Wave heights behind the breakwater in shallow cove 2 were reduced an average of 64, 65, and 63% during south, southwest, and southeast winds, respectively. The respective reductions of wave heights in deep breakwater cove 3 were 63, 57, and 48%. All wave height differences between windward and leeward sides of breakwaters were significant (Table 3). Wave heights at the shoreward site of shallow control cove 1 were also significantly lower than the lakeward site (Table 3), but the reduction was only 16%. Wave heights were similar at the windward and leeward sites in deep control cove 4. Overall, the breakwaters reduced waves up to 45 cm high by about 50% in both deep and shallow coves.

TABLE 2. Mean and standard deviation (in parentheses) of physical-chemical measurements made at windward (W) and leeward (L) sites in coves of Lake Carl Blackwell, Oklahoma, May-November 1977.

Cove, wind direction, and number of observations	Wind velocity (m/s)	Wave height (cm)		Temperature (C)				Transparency (cm)		Suspended solids (mg/l)				Turbidity (JTU)			
				Surface		Bottom				Surface		Bottom		Surface		Bottom	
		W	L	W	L	W	L	W	L	W	L	W	L	W	L	W	L
Shallow water																	
1 - Control																	
S 29	4.4			26.4	26.8	25.8	26.1	54	55	9	9	10	9	21	22	25	22
	(2.9)			(3.8)	(3.8)	(3.7)	(3.6)	(11)	(13)	(5)	(5)	(4)	(4)	(7)	(8)	(8)	(8)
SW 36	5.2	12[a]	10[a]	26.5	26.7	26.1	26.3	50	49	11	10	24	24	26	24	50	49
	(2.5)	(6)	(5)	(3.7)	(3.9)	(3.7)	(3.7)	(7)	(8)	(4)	(4)	(4)	(4)	(7)	(7)	(7)	(7)
SE 19	2.7			26.2	26.3	25.5	25.6	59	57	8	7	10	10	22	20	25	24
	(1.8)			(4.1)	(4.2)	(3.8)	(3.8)	(10)	(8)	(3)	(3)	(5)	(5)	(7)	(5)	(6)	(7)
2 - Breakwater	4.4	10	3	26.1	26.2	25.7	25.8	56	54	9	8	9	9	20	21	22	23
S 29	(2.9)	(5)	(2)	(4.0)	(3.9)	(3.9)	(3.9)	(11)	(10)	(4)	(3)	(5)	(4)	(6)	(7)	(8)	(6)
SW 36	5.2	12	4	26.3	26.4	26.0	26.2	51	49	10	10	10	11	23	22	24	23
	(2.5)	(5)	(2)	(3.8)	(3.9)	(3.7)	(3.8)	(7)	(8)	(3)	(4)	(4)	(4)	(6)	(6)	(6)	(8)
SE 19	2.7	5	2	26.1	26.0	25.6	25.6	57	57	8	8	9	10	9	21	22	22
	(1.8)	(4)	(1)	(3.7)	(4.1)	(3.8)	(3.9)	(11)	(9)	(2)	(4)	(6)	(5)	(4)	(5)	(7)	(6)
Deep water																	
3 - Breakwater																	
S 29	4.4	14	5	25.8	25.9	25.1	25.2	57	56	8	8	14	12	22	20	29	26
	(2.9)	(10)	(4)	(3.9)	(3.9)	(3.9)	(3.9)	(13)	(13)	(5)	(4)	(7)	(6)	(8)	(8)	(11)	(9)
SW 36	5.2	19	6	26.0	26.0	25.4	25.8	49	48	10	10	15	15	23	26	30	30
	(2.5)	(10)	(4)	(3.7)	(3.6)	(3.6)	(3.5)	(10)	(9)	(5)	(5)	(7)	(7)	(7)	(7)	(10)	(9)
SE 19	2.7	7	3	25.8	25.8	25.3	25.3	59	58	7	7	13	13	20	20	29	27
	(1.8)	(5)	(3)	(3.7)	(3.7)	(3.6)	(3.5)	(11)	(12)	(2)	(3)	(9)	(9)	(5)	(4)	(12)	(10)
4 - control																	
S 29	4.4			26.1	26.3	25.2	25.2	58	57	7	7	17	18	20	20	32	31
	(2.9)			(4.0)	(4.0)	(3.8)	(3.9)	(15)	(15)	(3)	(4)	(10)	(7)	(8)	(7)	(12)	(11)
SW 36	5.2	7[a]	6[a]	26.5	26.6	25.9	25.9	54	52	8	8	17	16	21	22	33	32
	(2.5)	(3)	(3)	(3.7)	(3.7)	(3.7)	(3.7)	(7)	(8)	(3)	(4)	(8)	(7)	(6)	(7)	(11)	(10)
SE 19	2.7			26.2	26.4	24.9	24.9	60	61	7	7	17	17	20	20	36	35
	(1.8)			(4.0)	(4.1)	(3.6)	(3.6)	(14)	(14)	(4)	(3)	(10)	(9)	(5)	(6)	(14)	(13)

[a]For ten measurements at all three wind directions

TABLE 3. Paired t-statistics comparing water quality in leeward areas with that in windward areas of coves of Lake Carl Blackwell, May-November 1977.

Cove, wind direction, and number of observations	Wave height	Temperature		Transparency	Suspended solids		Turbidity	
		Surface	Bottom		Surface	Bottom	Surface	Bottom
Shallow water								
1 - Control								
S 29		4.473*	4.688*	-.648	.555	1.463	-.196	2.355*
SW 36	-2.310*[a]	3.010*	3.217*	1.502	-1.312	1.333	-.457	1.181
SE 19		1.285	1.831	1.744	.678	.259	1.502	.802
2 - Breakwater								
S 29	-10.650*	3.285*	1.162	3.604*	.774	-.716	-.812	-.304
SW 36	-13.289*	3.510*	2.539*	4.920*	-.292	-.403	.270	.287
SE 19	-4.973*	-1.000	0.000	.881	-.160	-.332	-1.603	.043
Deep Water								
3 - Breakwater								
S 29	-7.913*	1.722	1.440	2.383*	1.271	1.584	-1.735	1.421
SW 36	-13.503*	0.770	1.875	1.580	-.110	.575	-3.555*	.612
SE 19	-6.493*	0.809	1.000	1.263	.790	.268	.119	1.025
4 - Control								
S 29		2.167*	4.621*	.883	.144	-.800	.207	.173
SW 36	-0.286[a]	2.472*	1.118	2.470*	-1.850	.924	-2.047*	.325
SE 19		2.333*	0.438	.991	.162	.137	-.502	.534

*Significant difference between windward and leeward.
[a]For 10 measurements at all 3 wind directions.

Although means were nearly identical, surface water temperatures at the leeward site in shallow breakwater cove 2 were consistently and significantly higher by a fraction of a degree during south and southwest winds, but not during southeast winds (which were only 61 and 51%, respectively, of the velocity of south and southwest winds; Tables 2 and 3). A similar situation existed in shallow control cove 1, except that water temperatures at the bottom were also significantly greater during south winds. In deep breakwater cove 3, however, leeward and windward temperatures were similar; the breakwater may have reduced temperature differences that were significant between windward and leeward sites of deep control cove 4 (Table 3).

Secchi disc transparency was significantly greater on the leeward side of the breakwaters in both coves 2 and 3 during south winds and in cove 2 during southwest winds (Table 3). However, transparency was also significantly greater in leeward (shoreward) areas of control cove 4. During sampling periods when there were relatively strong winds (south and southwest) transparencies at leeward and windward sites were significantly different in 3 of 4 comparisons in coves with breakwaters but in only one of four comparisons in the control coves (Table 3).

When analyzed according to wind direction, the rest of the measurements did not indicate consistent differences in suspended solids and turbidity between windward and leeward areas in coves with breakwaters (Tables 2 and 3). The greatest difference between the means for a characteristic at the windward and leeward sites in a given cove was 14% for suspended solids on the bottom of cove 3. Generally, variation between windward and leeward means was less than 5% (Table 2).

Differences between the mean sedimentation rate at leeward and windward sites were inconsistent in both magnitude and direction and variation was large relative to the means (Table 4). Wilcoxon signed-rank tests indicate that windward and leeward sites were significantly different in breakwater coves but not in control coves (Table 4). However, the sedimentation rates were higher on the leeward side of the breakwater in shallow cove 2 but higher on the windward side of the breakwater in deep cove 3.

TABLE 4. Mean sedimentation rate ($g/m^2/da$) of 4 samplers set in leeward (L) and windward (W) areas of breakwater (2 and 3) and control coves (1 and 4) of Lake Carl Blackwell, Oklahoma, May-December 1977.

Date of sample	Cove 1		Cove 2		Cove 3		Cove 4	
	W	L	W	L	W	L	W	L
1977								
31 May	95	121	114	112	97	102	207	209
13 June	53	39	55	62	68	68	84	96
27 June	75	58	79	92	106	73	94	-
12 July	101	65	97	100	110	85	245	144
26 July	55	45	65	65	132	72	242	163
10 Aug.	42	73	106	111	137	78	-	-
24 Aug.	42	46	61	71	155	57	82	324
6 Sept.	7	38	-	5	17	3	18	6
29 Sept.	22	77	87	88	91	81	86	109
14 Oct.	164	97	117	116	113	119	147	85
26 Oct.	54	49	54	57	57	61	103	87
8 Nov.	46	43	60	56	58	50	46	31
30 Nov.	174	50	55	53	62	61	60	86
23 Dec.	108	28	25	31	33	30	38	38
Mean ± SD	74	59	75	78[a]	88	67	113[b]	115
	±49	±25	±28	±33	±41	±28	±79	+87
Wilcoxon signed rank T	37		19.5*		15*		32.5	

[a]Does not include value for 6 Sept.
[b]Does not include value for 27 June.
*Significant difference between windward and leeward.

Fish

The predominant species in virtually all samples was gizzard shad (*Dorosoma cepedianum*) (Table 5). The other major component of the catch was the Centrarchidae: green sunfish (*Lepomis cyanellus*), orangespotted sunfish (*L. humilis*), bluegill (*L. macrochirus*), redear sunfish (*L. macrolophus*), longear sunfish (*L. megalotis*), largemouth bass (*Micropterus salmoides*), and white crappie (*Pomoxis annularis*). A large catch of other species was made in gill nets in shallow cove 2 in 1978 and consisted of carp (*Cyprinus carpio*), river carpsucker (*Carpiodes carpio*), and channel catfish (*Ictalurus punctatus*).

TABLE 5. Relative abundance of fish caught by electrofishing (E) and gill nets (G) in coves with breakwaters (2 and 3) and control coves (1 and 4) in Lake Carl Blackwell, 1976-78.

Species and year	Percent of total catch							
	Cove 1		Cove 2		Cove 3		Cove 4	
	E	G	E	G	E	G	E	G
Gizzard shad								
1976	83	43	94	37	96	38	66	28
1977	96	72	91	72	83	39	90	57
1978	80	30	82	3	75	51	98	47
Centrarchidae								
1976	13	39	3	28	3	24	21	47
1977	2	14	6	15	14	33	8	20
1978	8	30	18	3	13	39	2	39
Other								
1976	4	18	3	35	1	38	13	25
1977	2	14	3	13	3	28	2	23
1978	12	40	0	94	12	10	0	14
Number of fish								
1976	72	82	69	108	157	136	44	83
1977	346	283	219	227	235	224	148	122
1978	54	89	17	37	75	300	59	250

In coves 2, 3 and 4, there was no general agreement in the trends in catch composition and relative abundance of fishes taken in the two gears and we do not believe further analysis would be justified. However, with the exception of the gill net catch in cove 2, a tendency for the centrarchid fishes to increase in abundance in the breakwater coves was not evident in the control coves (Table 5).

Benthic Invertebrates

Diversity of benthic invertebrates was neither significantly different between experimental and control coves ($X^2_r = 4.32$) nor changed over time in areas behind breakwaters (Table 6). Mean diversity of the benthic populations in experimental coves 2 and 3 was the lowest in 3 samples, the highest in 4 samples, and not consistently different from the controls in 5 samples.

When the breakwaters were constructed in coves 2 and 3 during winter of 1976-77, communities of benthic invertebrates were dominated by chironomid species A and the amphipod *Hyalella azteca* (Fig. 3). By April-June 1977, benthic communities had changed little behind the breakwaters. By April 1978, chironomid species A was replaced by species B, which remained co-dominant with the Psychomyiidae through September 1978. Communities of benthic invertebrates in control coves 1 and 4 were nearly identical with those in the experimental coves. In the control coves, *Hyalella azteca* were replaced by Psychomyiidae between the first and second quarters of 1977 and chironomid species A was replaced by species B during the first quarter of 1978.

TABLE 6. Pooled diversity indices of benthic invertebrates on 6 Hester-Dendy samplers set in each cove with a breakwater (2 and 3) and control cove (1 and 4) in Lake Carl Blackwell, February 1977 - September 1978.

Date	Cove 1	2	3	4
1977				
15 Feb. - 29 March	1.22	1.14	1.07	1.46
2 Apr. - 11 May	0.71	0.80	1.21	-
13 May - 22 June	1.21	1.56	1.39	1.63
24 June - 3 Aug.	0.70	1.02	1.02	0.89
4 Aug. - 13 Sept.	1.07	1.06	1.20	1.25
19 Sept. - 31 Oct.	0.98	1.12	1.03	0.92
1 Nov. - 13 Dec.	-	1.75	1.99	2.13
1978				
4 Jan. - 5 Apr.	1.09	1.37	1.12	1.01
6 Apr. - 17 May	1.68	0.78	0.86	1.94
18 May - 29 June	0.93	1.02	0.47	0.63
1 July - 8 Aug.	0.57	0.91	0.59	1.27
9 Aug. - 25 Sept.	0.85	1.15	0.86	1.00

DISCUSSION

The basic purpose of a FTB is to suppress waves. FTB's may also provide structure and attract fish in barren reservoirs, and provide safe harbor for mooring boats. Our objective was to evaluate the use of a FTB to provide protected areas for spawning and rearing of largemouth bass (Clady et al. 1979). We found that wave height, corrected for natural windward-leeward reduction, was suppressed about 50%.

Protected areas of Lewis and Clark Lake "silted in" in the first 12 years of impoundment, adversely affecting survival of some fishes (Benson and Cowell 1967), and it has been suggested that energy loss in the wave shadow of breakwaters could similarly affect the ecology of coves (Gifford et al. 1977). Higher transparency and greater sedimentation rates in leeward areas of the shallow breakwater cove both suggest silting in of the cove and may support this concern. However, this pattern did not occur in the deep breakwater cove and turbidity and suspended solids were not consistently different between windward and leeward sides of coves with breakwaters. Some inconsistencies in our measurements in coves were probably due to differences in morphometry and substrate of the coves and to the inflow of water masses, caused by currents and seiches, that had the general characteristics of the rest of the lake. In terms of turbidity, transparency, suspended solids, and sedimentation rate, response to the reduction of waves by the breakwater may have been limited by the resuspension of unconsolidated sediments by even slight water movement in Lake Carl Blackwell (Hysmith 1975).

In spite of statistically significant changes in 4 characteristics--wave height, transparency, temperature, and sedimentation rate--diversity and species composition of benthic macroinvertebrates, sampled with Hester-Dendy plates, were not significantly different between coves. Perhaps these physical differences, although statistically significant, were not biologically significant. With the exception of wave height in both coves and sedimentation rate in cove 3, means of the measurements at leeward sites differend by less than 10% from those at windward sites (Tables 2 and 3). Electrofishing catches, however, suggested that the relative abundance of sunfishes in experimental

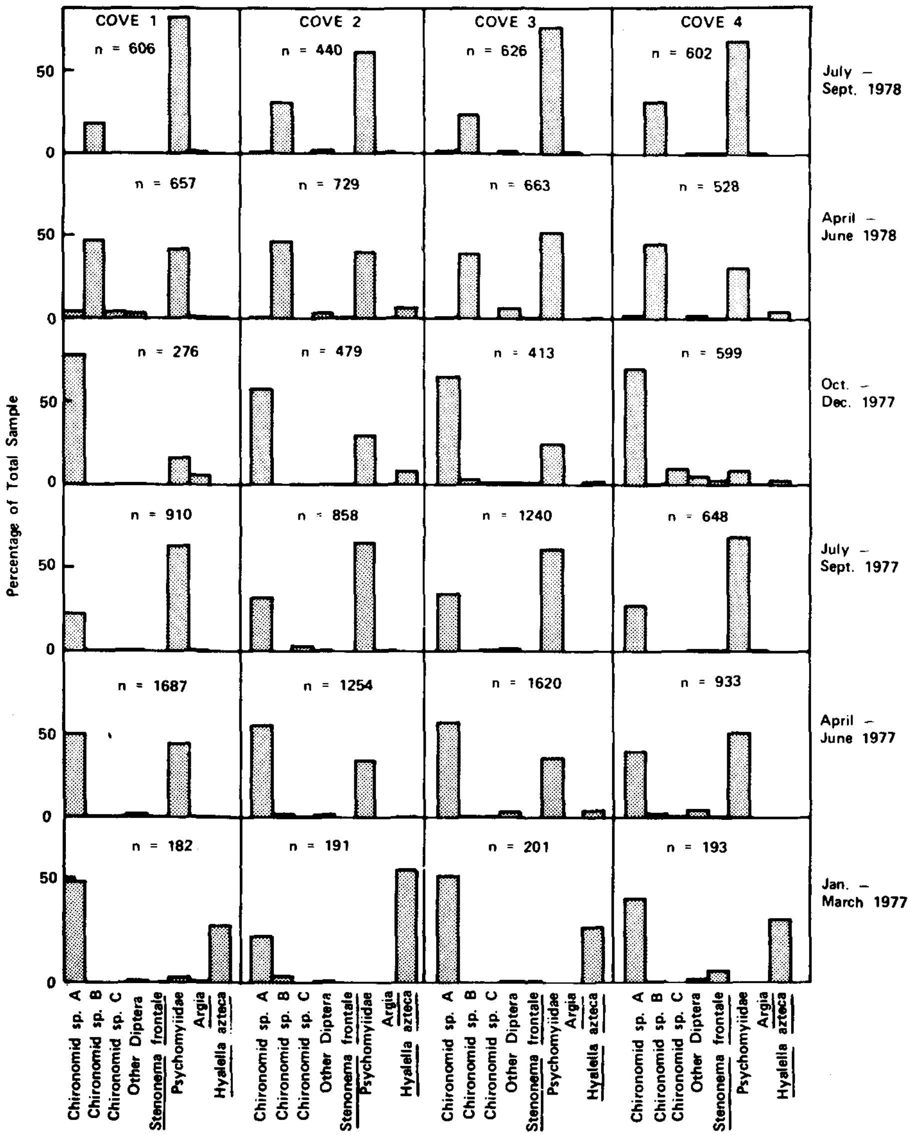

Fig. 3. Percentage of the total number of benthic invertebrates on plate samplers made up of various organisms in coves with breakwaters (2 and 3) and control coves (1 and 4) in Lake Carl Blackwell, 1976-1978.

coves increased after installation of the breakwaters while it concurrently declined in control coves. Increased abundance of centrarchid fishes in breakwater coves would not be surprising since these species readily concentrate near submerged tire reefs (Prince and Maughan 1978). Overall, the floating tire breakwaters did not have a marked ecological influence on coves in Lake Carl Blackwell over a 2 year period.

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