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Larval Fish Use of Dike Structures on a Navigable River

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Abstract.—In rivers, velocity shelters are thought to serve as limiting factors in the retention and recruitment of young fish. Such shelters are formed in backwaters and tributaries; however, these areas are limited in many North American rivers. In response to this concern, several dike sites that serve as low-velocity zones were placed within the Kanawha River (West Virginia), a sixth-order tributary of the Ohio River. This study was conducted to evaluate whether the dike sites (finger and zipper dikes) provided velocity shelters that are used by larval fish. Larval fish were sampled during 2002 and 2003 using larval light traps. Larval fishes collected were typical of large river systems; Cyprinidae, Percidae, and Centrarchidae were the most abundant families. Results show that larval abundances peaked during late June in 2002 and early July in 2003. Overall taxonomic composition did not differ between dike sites and reference sites. Throughout the study, larval fish were captured at significantly higher rates ($P < 0.001$) at dike sites than at high- and low-quality reference areas. Water velocities were significantly lower ($P < 0.001$) at dike sites than at reference areas, suggesting that the greater larval fish use of dike sites may be attributed to reduced velocity provided by the structures. This study suggests that dike sites can serve as velocity shelters and retention areas for larval fish in navigationally impacted rivers.

The development of rivers for navigation tends to decrease habitat heterogeneity by eliminating multiple channels and backwaters, which are important to larval fish (Brookes 1988; Dister et al. 1990). Heterogeneous habitats provide cover and increased foraging opportunity that may be crucial for the survival of young fish, which are highly susceptible to predation (Pretty et al. 2003). Larval fish prefer littoral and backwater habitats with plentiful food and cover (Aggus and Elliott 1975; Scott 1988; Lobb and Orth 1991; Rountree and Able 1992; Skov and Berg 1999). Increasing habitat heterogeneity in rivers that are highly impacted by human alterations may increase larval fish survival (Letcher et al. 1997).

Habitat enhancement structures are added to aquatic systems when natural habitat is perceived to be lacking or insufficient (Prince et al. 1977), with the goal of providing cover; concentrating fish; and increasing recruitment, survival, growth, and angler catch rates (Johnson and Stein 1979). Of the variety of habitat structures placed in freshwater systems, dikes have been used frequently in North American rivers. About 440 dikes have been constructed on the lower Mississippi River (Baker et al. 1991), and these structures and the regions of reduced velocity near them have been shown to be important habitats. The ichthyofauna of these dike fields is similar to that of the main channel during high flows and to that of lentic habitats during lower flows (Baker et al. 1991). Burress et al. (1982) conducted a study on nine riverine habitats in the Missouri River. Of all habitats sampled, dike fields had the most diverse fish community, which was attributable to the presence of shelter and diverse habitat.

Finger dikes, spur dikes, wing dikes, groynes, hard points, and similar structures have been placed in a variety of large rivers for mitigation and restoration purposes (Li et al. 1984; Beckett and Pennington 1986; Shields 1995). These structures are regions of high heterogeneity, containing a mix of rock structure, woody debris, sandbars, eddies, plunge pools, scour holes, and other habitats (Beckett and Pennington 1986). The placement of these structures as part of a mitigation program or restoration project may help to increase the habitat available to all life stages of fish. Finger (spur) dikes have been recognized as riparian structures that may slow velocities and diversify flow near the riverbank (Shields 1995). A finger dike is an elongated structure with one end on the bank of a river and the other projecting towards the thalweg (0.6 of bottom depth). These structures typically extend from shore into the stream or river and are usually used in series, with the first (most upstream) structure positioned at the greatest downstream angle and the latter ones situated more perpendicular to the bank. Finger dikes extend further into the stream and deflect flows well away from the bank. River engineers originally designed dikes for shoreline stabilization so that the low-velocity zones near them would fill with sediment (Anding et al. 1968). However, these low-velocity zones adjacent to and between dikes have been

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shown to provide valuable habitats for fishes (Pennington and Shields 1993; Shields 1995; Pitlo 1998).

Several studies have examined the effects of dike sites on fish populations, but few have focused on larval fish. In the Missouri River, Burress et al. (1982) did not appear to adequately sample for larval fish as only 63 fish larvae were encountered. Previous work by Li et al. (1984) determined that spur dike habitat was intermediate in quality between natural banks and continuous rip-rap revetments. However, the study did not account for temporal changes in the community because sampling was conducted during only part of a single year. Beckett and Pennington (1986) found that dike fields supported high densities of centrarchids and atherinids and had distinctive species compositions. However, their study did not fully address the spatial and temporal aspects of larval fish distributions and habitat use.

In 2004, the U.S. Army Corps of Engineers (USACE) Huntington District initiated a project to renovate its locks and dams in the Kanawha River, West Virginia, to allow for greater barge traffic. The increased traffic was expected to negatively affect fish populations, especially larval and juvenile stages (Scott and Nielsen 1989; Rider and Margraf 1997). To mitigate such impacts, five fields of dike sites were constructed in Marmet Pool during 2000. In this study, we sought to compare larval fish abundance and taxonomic composition between areas of low water velocity associated with dike sites (dike structures) and two types of natural reference sites (high and low quality) in the Kanawha River.

Methods

Study area.—This study was conducted in Marmet Pool of the Kanawha River, a tributary of the Ohio River. Marmet Pool is 10 km upriver from the city of Charleston. River sections near the city are highly industrialized. The banks are steep, with a relatively short submerged bench width (area from shore to the navigational channel). Bank-full width of the river is between 195 and 205 m in the study area. Fine sediments dominate the substrate, and there are few habitats that provide cover for fish other than flooded tributary mouths (Scott and Nielsen 1989). The Marmet Pool dike sites included four sets of finger dikes (FD1–4) and one set of zipper dikes (ZD; Figure 1). Dike sites were dominated by the rocks used for construction but also had some low hanging vegetation and woody debris (Niles 2004). Two reference areas of natural composition were selected to compare with each group of dike sites: one high-quality area and one low-quality area. The reference sites were designated as high or low quality based upon velocity and the amount of potential cover available. High-quality reference areas had a larger bench width; typically had snags, woody debris, and low-hanging vegetation; and had lower water velocity (0–5 m from shoreline) in comparison with low-quality reference sites (Table 1). Low-quality reference areas had a smaller bench width; fewer snags and less woody debris; vegetation that was not as low hanging; and higher water velocity relative to high-quality reference sites. One reference area was located directly across the river from each dike site, and one reference area was randomly placed upriver (within 200 m) of each dike site. Each reference area had a shoreline length equal to that of the corresponding dike site (Niles 2004).

The dike sites consisted of a series of dike structures. All dikes were constructed of rock or rubble material positioned along the shoreline and extending into the river along the bench (Niles 2004). Finger dikes were angled from shore in an upstream direction, while the components of the ZD site were positioned parallel to shore. Although structures were different in design and length, each structure did at minimum provide greater habitat heterogeneity and a higher level of cover than what was available naturally (Titus 2004).

Field collections.—Larval fish sampling was conducted weekly at each site from June to August 2002 and from April to August 2003 when weather and river flows permitted. Safety considerations prevented sampling when river discharge exceeded 1,130 m^3/s (40,000 ft^3/s). Sampling stations were located at the dike sites and at reference sites positioned both across the river and upstream from the dike sites (Figure 1).

Light traps were used to collect larval fish. In 2002, three light traps were set per site; in 2003, five traps were set per site on each date. In 2002, we focused on several gears (light traps, benthic sled, activity traps) to assess these sites, whereas in 2003 we increased our light trap efforts as this gear type was found to be the best for sampling these sites (Niles and Hartman 2007). The light trap used was a floating, quatrefoil-type Plexiglas trap (30 × 30 × 50 cm). Each trap had four 15-mm entrance slots and used a 12-h Cyalume green chemical light stick, which originated from a central light tube (Floyd et al. 1984). We selected this light source because Gehrke (1994) showed that green light sticks glowed brighter during the first hour of sampling than other colors of light sticks. The light traps were placed and anchored within the habitat starting at 0.5 h after dusk and were left for a period of 1 h. Samples were washed into labeled jars and preserved in 10% buffered formalin. The contents of each light trap sample were washed through a 250-μm-mesh sieve and transferred to trays, where the larvae were removed from debris and counted. Samples were rechecked to ensure that all larvae had been removed. All larval fish collected were identified to the lowest possible taxon

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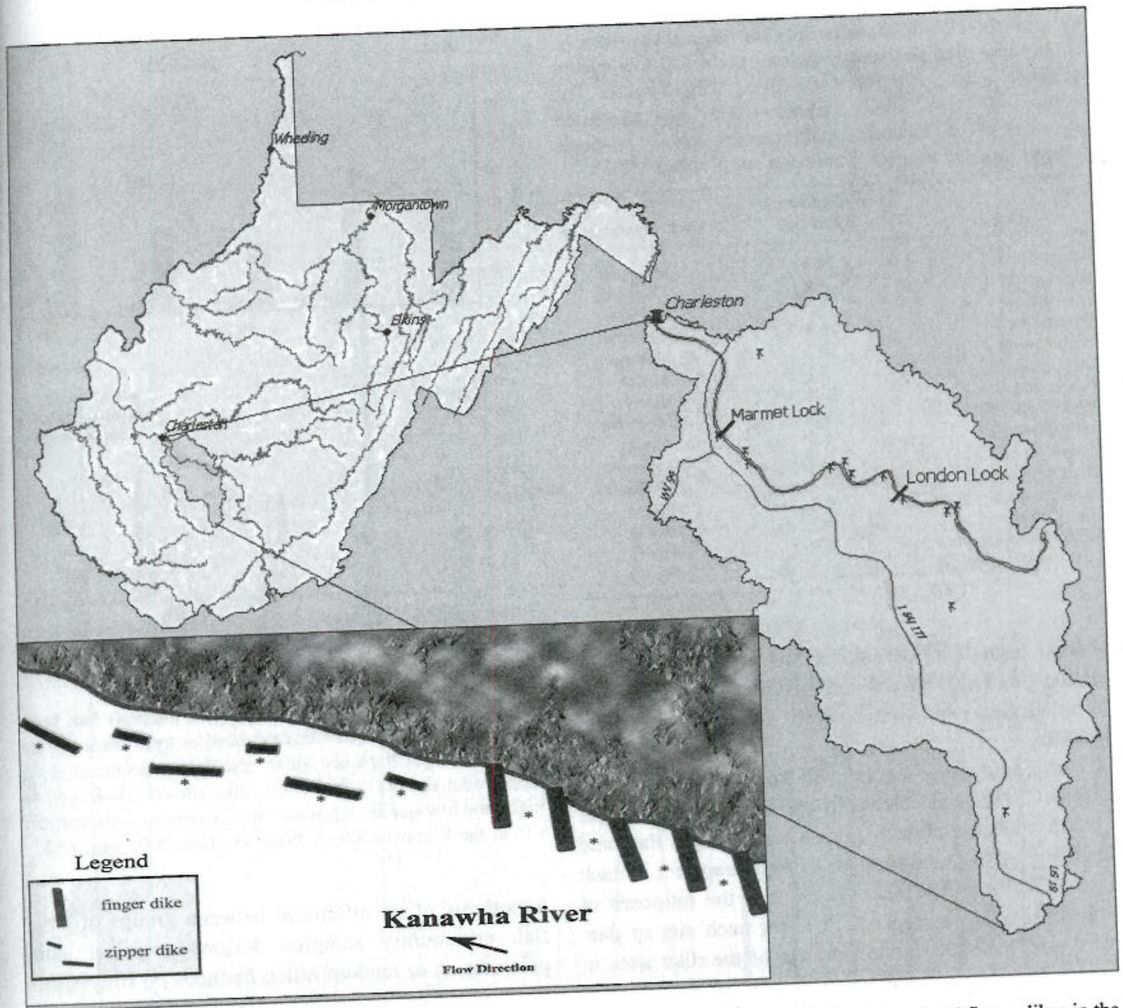


FIGURE 1.—Location of the Kanawha River and Marmet Pool, West Virginia, and layout of zipper dikes and finger dikes in the river. Asterisks indicate larval sampling locations associated with the structures.

by using a variety of references (Auer 1982; Holland-Bartels et al. 1990; Wallus et al. 1990; Kay et al. 1994). Larvae that could not be identified because of damage or that could not be identified at or below the family level were classified as unidentified (<0.5% of all larvae). Larvae were identified using a Leica MZ6 microscope that was retrofitted with a Cole-Parmer light ring and polarizing lens.

Water quality.—Water quality was measured with a YSI meter (Model 650 multiparameter display system, Model 6820 sonde) at each dike site and reference area on each sample date to determine if water quality varied among site types. Measurements were taken within each site at the surface and at 1-m depth. We recorded temperature (°C), specific conductivity (µS/cm), pH, turbidity (nephelometric turbidity units), and dissolved oxygen (mg/L). We deployed temperature loggers (HOBO Water Temp Pro Model H20–001) set to measure at 2-h intervals at each site. The loggers were deployed in October 2002 and retrieved in March 2004.

Velocity profile.—Velocity measurements were taken in 2002 and 2003 using a Marsh-McBirney flowmeter (Flo-Mate Model 2000) to evaluate differences among sites. In 2002, one velocity measurement was taken at each sample site on each sample date. The velocity was taken in the middle of each sample site at the thalweg using a staff gauge at a distance of 5 m and perpendicular to the riverbank near the outermost edge of the dikes. In 2003, we implemented a more thorough water velocity profile methodology. At each site and during each sample date, water velocity measurements were taken at six equidistant points at 1-m intervals along three fixed transects perpendicular to shore, and these values were averaged. Velocity profile sampling occurred on 12 dates between May and August 2003. River discharge data were obtained in cubic feet per

TABLE 1.—Habitat characteristics for finger dikes (sites 1–4), a zipper dike site, and associated high- and low-quality reference areas in the Kanawha River, West Virginia. The amount of large woody debris (LWD) was classified according to U.S. Environmental Protection Agency protocols for nonwadeable streams (Kaufmann and Robison 1998).

Site	Average bench width (m)	LWD classification
Finger dike 1	9.7	Moderate
High quality 1	9.8	Moderate
Low quality 1	3.2	Sparse
Finger dike 2	10.5	Moderate
High quality 2	10.0	Moderate
Low quality 2	3.1	Absent
Finger dike 3	10.5	Heavy
High quality 3	9.7	Moderate
Low quality 3	2.8	Absent
Finger dike 4	7.2	Moderate
High quality 4	10.2	Moderate
Low quality 4	6.1	Sparse
Zipper dike	9.7	Heavy
High quality (zipper)	9.9	Heavy
Low quality (zipper)	3.3	Sparse

second from U.S. Geological Survey (USGS) gaging station 03193000 (Kanawha River at Kanawha Falls, West Virginia) and were converted to cubic meters per second.

Data analyses.—Larval fish mean catch per unit effort (CPUE) was calculated by summing the number of fish collected at each site on each sample date and dividing by the total number of light traps set at each site (2002: $n = 3$; 2003: $n = 5$). For the purposes of statistical analysis, mean CPUE for each site or date was used to assess larval fish use of the dike sites in comparison with reference areas. Mean CPUE was analyzed using a repeated-measures analysis of variance (ANOVA) via the MIXED procedure in the Statistical Analysis System (SAS) version 9.1, with sample year treated as a co-variable (SAS Institute 2004). For each analysis, we tested for normality (skewness and kurtosis), and data that were found to be nonnormal were $\log_{10}$ transformed. The relationship between CPUE, river discharge, and velocity was evaluated using an analysis of covariance (ANCOVA) in SAS, with each sample year analyzed separately due to differences in discharge (SAS Institute 2004).

Nonmetric multidimensional scaling (NMDS; Kruskal 1964; Mather 1976) was performed to explore taxonomic composition among sample sites. We used Bray–Curtis distances for the dissimilarity matrix (Bray and Curtis 1957). The dimensionality was determined when plots of final stress versus number of dimensions showed that a greater number of axes resulted in small reductions in stress. Differences in taxonomic composition between sites were examined with an analysis of similarity (ANOSIM) model. We tested the null

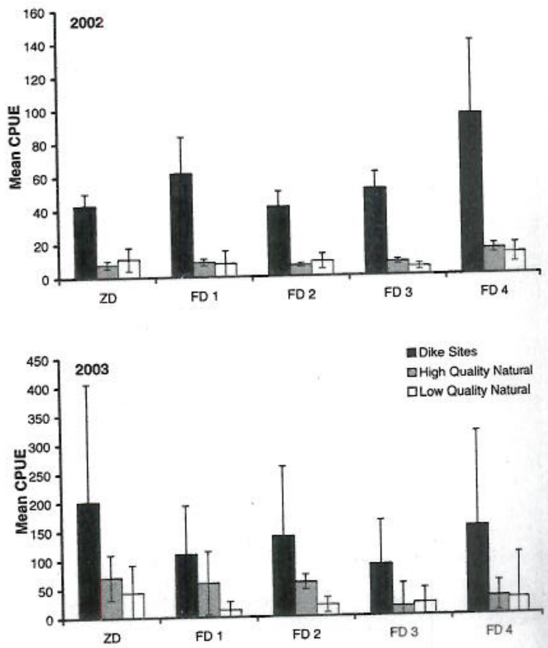


FIGURE 2.—Mean (±95% confidence interval) fish larval catch per unit effort (CPUE; calculated as total catch per site/number of light traps set; all sample dates combined) at one zipper dike site (ZD), four finger dike sites (FD1–4), and the high- and low-quality reference sites associated with each dike site in the Kanawha River, West Virginia, 2002 and 2003.

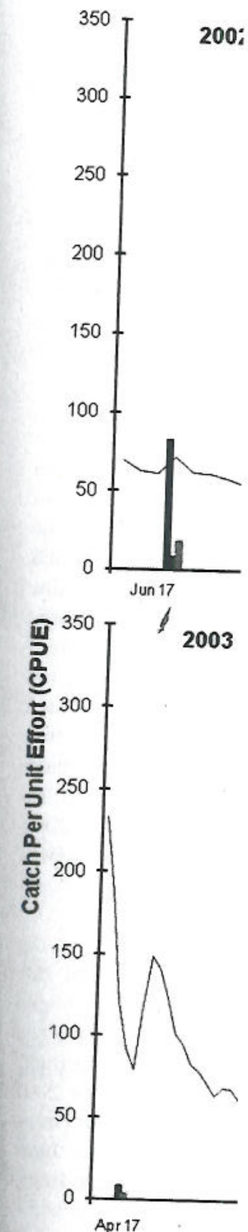
hypothesis of no difference between groups of larval fish community samples defined a priori using permutation or randomization methods on Bray–Curtis dissimilarity matrices (Clarke and Warwick 1994). The NMDS and related procedures were run in R software version 2.2.1.

Water quality data and velocity data were analyzed using repeated-measures ANOVA (MIXED procedure in SAS). The significance level was set at 0.05 for all tests. Turbidity and discharge data were analyzed using linear regression, with each year being analyzed separately.

Results

Larval fish catches were higher at dike sites than at high- and low-quality reference areas combined. A total of 65,964 larval fish were collected in the two sampling years, of which 39,212 (59.4%) were from dike sites. High-quality reference sites produced 27.2% (16,985) of the total catch, while low-quality reference sites represented 13.3% (8,767) of the total catch.

Larval fish CPUE was significantly greater at dike sites than at low-quality reference sites and high-quality reference sites (ANOVA: $F = 17.75$, df = 12, $P < 0.001$) in both 2002 and 2003 (Figure 2). Larval fish



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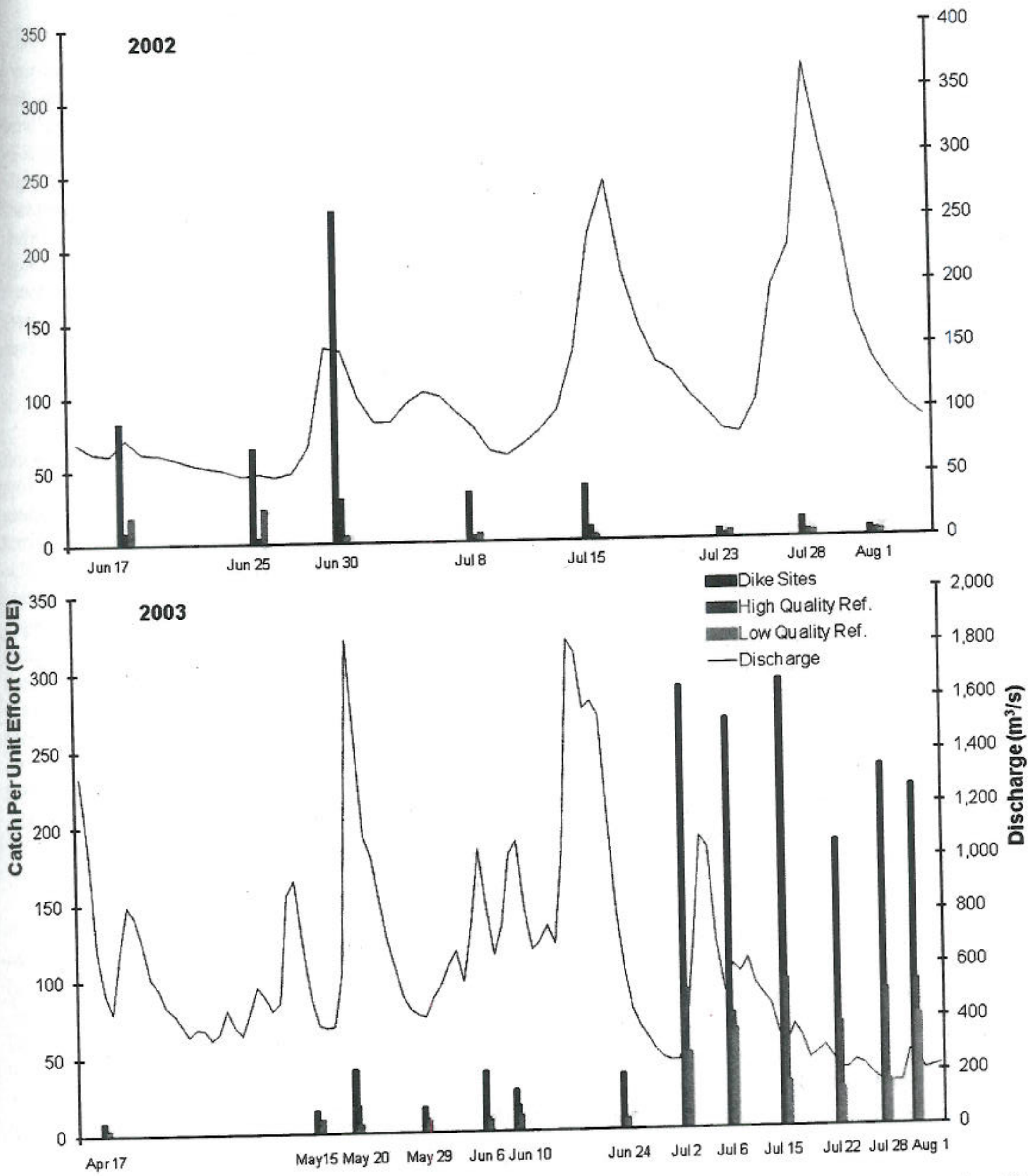

FIGURE 3.—Mean fish larval catch per unit effort (CPUE; calculated as total catch per site/number of light traps set) at dike sites, high-quality reference sites, and low-quality reference sites for 2002 and 2003 sample dates in relation to Kanawha River, West Virginia, discharge (converted to m^3/s from ft^3/s values recorded at U.S. Geological Survey gaging station 03198000, Charleston).

CPUE was significantly greater at high-quality reference sites (ANOVA: $F = 10.68$, df = 2, $P = 0.002$) than at low-quality reference sites.

Significantly more fish (greater CPUE) were collected in 2003 than in 2002 at all dike sites (ANOVA: $F = 11.78$, df = 2, $P = 0.002$); however, sampling effort differed between years (five versus three light traps), resulting in a possible weakened comparison. In 2003, high-quality reference sites contained significantly more larval fish than low-quality reference sites (ANOVA: $F = 7.90$, df = 2, $P = 0.015$), but there was no difference between these two site types in 2002 (ANOVA: $F = 2.65$, df = 2, $P = 154$). Within a sample date, CPUE for larval fish was significantly greater

(ANOVA: $F = 5.88$, df = 12, $P = 0.001$) at dike sites than at low- and high-quality reference sites in both 2002 and 2003 (Figure 3).

River Discharge and Habitat Use

Mean river discharges were lower in 2002 (310.1 m^3/s) and higher in 2003 (602.5 m^3/s) compared with the 125-year average (343.7 m^3/s) for the Kanawha River (USGS gaging station 03193000). The discharge values can be considered to represent two extremes, with the 2002 discharge being extremely low during a dry year and conversely the 2003 season being characterized by high discharge with major spikes that on occasion pushed the Kanawha River to flood stage.

Larval fish CPUE was higher at dike sites than at reference sites at differing river discharge levels and in both years (Figure 3). Discharge was relatively low and consistent in 2002 (June 17–July 15), and larval fish CPUE was significantly higher at dike sites than at reference sites (ANOVA: $F = 9.34$, df = 4, $P = 0.010$). Periods of high discharge occurred in 2003 (April 17–June 24), and larval fish CPUE was overall lower than that in 2002; larval fish CPUE in 2003 also was significantly higher at dike sites than at reference sites (ANOVA: $F = 5.31$, df = 4, $P = 0.041$). Larval fish CPUE generally increased at all sites starting in early July, corresponding to declining river discharge. However, the relation between larval fish CPUE at dike sites and discharge was inconsistent between years. In 2003, CPUE at dike sites was significantly related to discharge (ANCOVA: $F = 17.41$, df = 1, $P = 0.006$) but was not related to velocity (ANCOVA: $F = 0.21$, df = 1, $P = 0.646$). For 2002, we found no significant relationship between discharge and CPUE (ANCOVA: $F = 2.83$, df = 1, $P = 0.095$) or between velocity and CPUE (ANCOVA: $F = 0.66$, df = 1, $P = 0.416$) at the dike sites. In addition, we found no correlation between river discharge and turbidity in 2002 ($r^2 = 0.0343$) but did find a correlation between river discharge and turbidity in 2003 ($r^2 = 0.6301$).

Analysis of temperature, specific conductivity, pH, and dissolved oxygen between sites (dike sites versus high- and low-quality reference sites and between structure types) showed that there was no significant difference within each sample date.

Velocity Shelters

Dike sites provided areas of lower velocity in comparison with similar areas that lacked dikes. The three site categories exhibited significantly different velocities (ANOVA: $F = 6.92$, df = 12, $P < 0.001$), with dike sites having the lowest velocities (Figure 4). For all dike sites, velocities remained low (<0.05 m/s) for most of their length. The greatest velocities were measured in the low-quality reference sites. Velocities began to increase at 5 m from shore, which for most sites corresponded to the end of the structure, and velocities measured at 6 m were highest and were closest to the main-channel flow. Velocities in low-quality reference sites began higher than in high-quality reference sites or dike sites and increased exponentially with distance away from shore. Measured points furthest from shore had extremely high velocities ranging from 0.45 to 0.55 m/s. Maximum velocities (at the furthest point from shore) were between 0.04 and 0.14 m/s at dike sites and between 0.21 and 0.36 m/s at high-quality reference sites.

Taxonomic Groups and Dike Sites

Larval fishes collected were typical of North American large river systems, with individuals from the families Cyprinidae, Percidae, and Centrarchidae being the most abundant (Table 2). Other taxa collected include Catostomidae, Atherinopsidae, Sciaenidae (drums), and Clupeidae (herrings). Overall taxonomic composition did not differ between dike sites and high- and low-quality reference sites. The NMDS ordination produced a two-dimensional solution that demonstrated no differences in larval fish taxonomic composition among dike sites and high- and low-quality reference sites (Figure 5). The ANOSIM results showed no significant taxonomic composition differences in 2002 (ANOSIM: $R = 0.014$, $P = 0.312$) or 2003 ($R = -0.048$, $P = 0.95$).

Temporal Composition Patterns

Temporal patterns in taxonomic composition differed between 2002 and 2003. In 2002, sampling began in mid-June, with *Lepomis* spp., *Pimephales* spp., and *Notropis* spp. being the dominant taxonomic groups. *Notropis* was the dominant taxon throughout the 2002 sampling season. *Lepomis* was the second most dominant taxon in 2002, with a peak in late June. Percidae, Clupeidae, and *Micropterus* spp. were found throughout 2002, with no peaks in distribution.

Sampling for 2003 commenced earlier (i.e., April) than in 2002. The first taxon to appear was Percidae in mid-April. Percidae was prevalent throughout all of the samples identified in 2003 and peaked in early July. Catostomidae began to appear and peak in mid-May and persisted through early July 2003 samples. Several other taxa also began to appear in mid-May, including *Pimephales*, *Notropis*, and Clupeidae. *Pimephales* was the dominant cyprinid taxon throughout June. In early July, *Notropis* began to peak and became the dominant cyprinid group. Common carp *Cyprinus carpio* began to appear in late June and peaked in early July. *Lepomis* and *Micropterus* did not appear until late June

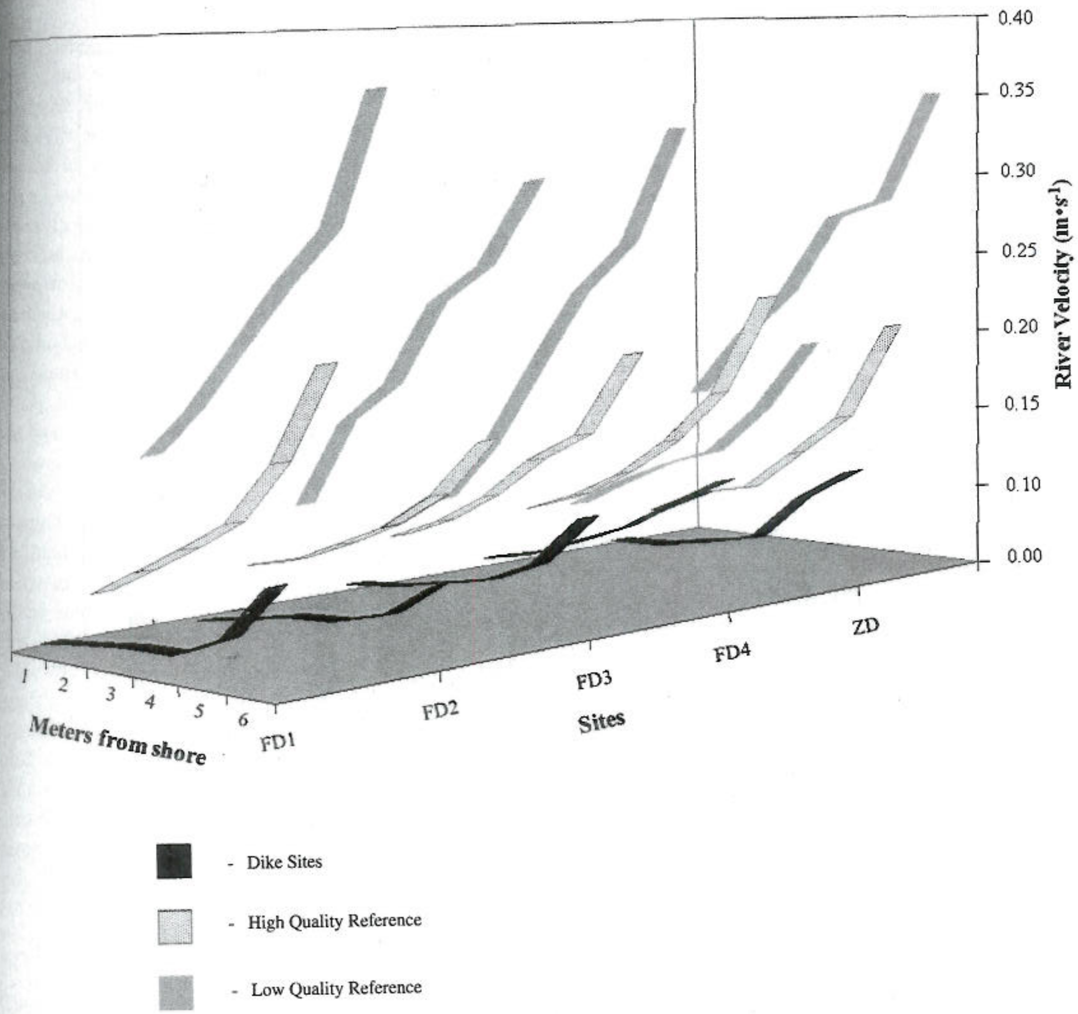

FIGURE 4.—Average velocity (m/s) within four finger dike sites (FD1–4), one zipper dike site (ZD), and the high- and low-quality reference areas associated with each dike site in the Kanawha River, West Virginia. Measurements begin near shore (1 m) and move linearly away from shore (6 m).

TABLE 2.—Taxonomic composition (%) of larval fish collected at dike sites, high-quality reference sites, and low-quality reference sites in the Kanawha River, West Virginia, 2002 and 2003.

Taxon	Dike sites		High quality		Low quality	
	2002	2003	2002	2003	2002	2003
Atherinidae (silversides)	1.87	0.01	7.52	0.04	2.61	0.06
Catostomidae (suckers)						
Catostomus spp.	0.00	0.51	0.00	0.78	0.00	1.85
Centrarchidae						
Sunfishes *Lepomis* spp.	6.64	0.26	7.52	0.60	5.78	0.66
Black basses *Micropterus* spp.	0.50	0.03	0.18	0.05	1.12	0.36
Cyprinidae						
Shiners *Notropis* spp.	84.74	69.23	80.24	66.05	87.41	60.08
Minnows *Pimephales* spp.	4.17	6.63	2.90	6.23	1.03	8.03
Percidae (perches)	0.58	22.04	0.73	25.06	1.03	27.49
Other taxa	0.85	0.22	0.82	0.00	1.02	0.62
Unidentifiable	0.65	1.07	0.09	0.72	0.00	0.85

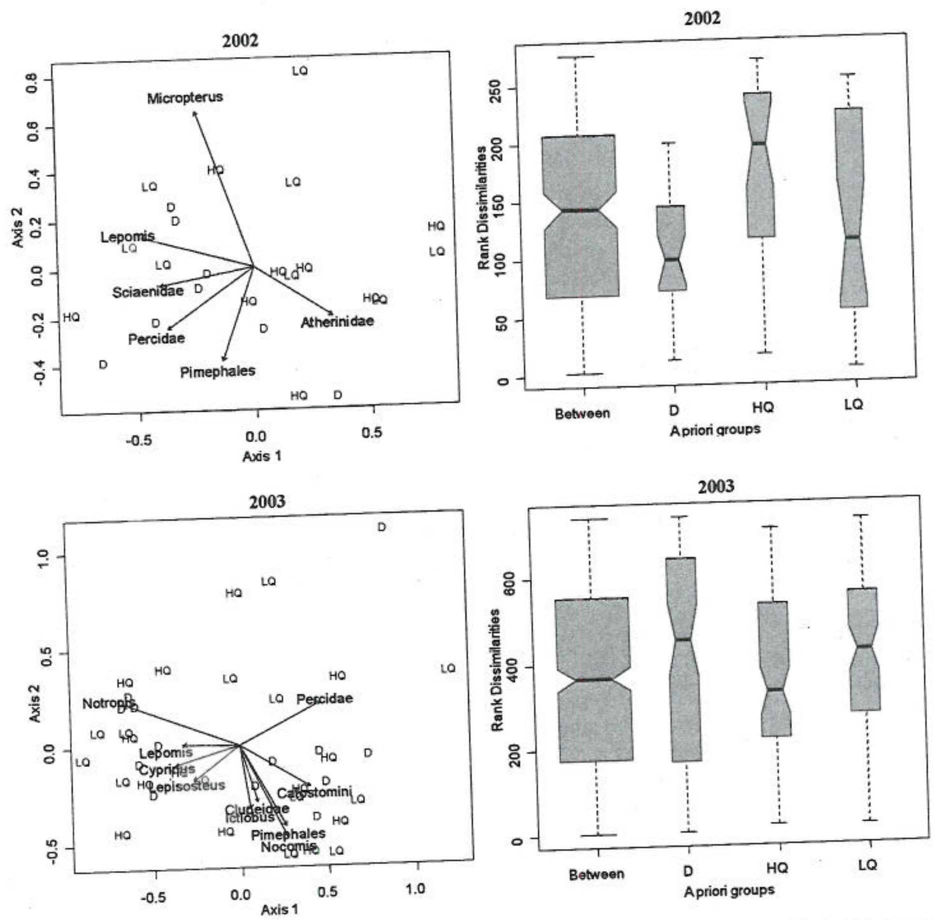

FIGURE 5.—Nonmetric multidimensional scaling (left panels) and analysis of similarity (right panels) for 2002 and 2003 larval fish taxonomic composition at three site types on the Kanawha River, West Virginia (D = dike site; HQ = high-quality reference site; LQ = low-quality reference site). Taxa include gars *Lepisosteus* spp., buffaloes *Ictiobus* spp., and chubs *Noçomis* spp. (other taxa are defined in Table 2).

and steadily increased through July, with numbers peaking at the beginning of August. Brook silversides *Labidesthes sicculus* began to appear in late June but exhibited no clear peak in abundance.

Discussion

The results of this study show that dike sites (ZD and FD) provide important habitat to larval fish in large, navigable rivers. We collected greater larval numbers and had higher larval CPUEs at all dike sites in comparison with references areas. Our findings differ from those of Li et al. (1984), who found no significant differences in larval fish abundance between dikes and reference areas in the Willamette River, Oregon. However, in the Li et al. (1984) study, natural reference zones and dikes each had lower velocities associated with them, thus eliminating the need for larval protection from higher velocities. In our case, water velocities were significantly lower within dike site habitats than at the other shoreline sites. Decreased water velocities within dike sites provide shelter to larval fish from the wave action generated by barge tows. Holland (1987) showed that passing barges can create enough wave action to dewater fish larvae and eggs. In addition to serving as low-velocity areas, dike sites were physically more diverse than other shoreline sites because woody debris accumulated and aquatic vegetation also increased between FDs (authors' personal observations). Li et al. (1984) predicted that as woody debris accumulation increased within similar structures on the Willamette River, larval fish numbers would increase. Overall, the Kanawha River dike sites are producing a combination of conditions that result in higher CPUE of larvae than at reference sites. If we assume that CPUE approximates abundance (Gulland 1969), then the dike sites in this river had higher use

than reference areas a
important larval fish
navigable rivers.
Species composition
similar to that in oth
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Percidae made up 93.8
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freshwater drum *Aplo*
Cyprinidae, and commo
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populations.

than reference areas and therefore may represent an important larval fish retention habitat in large, navigable rivers.

Species composition in our study was expected to be similar to that in other navigable and channelized rivers, such as the Ohio, Mississippi, and Missouri rivers. In our study, two cyprinid types and the family Percidae made up 93.8% of the total catch. Previous larval fish surveys on the Kanawha River found that freshwater drum *Aplodinotus grunniens*, Clupeidae, Cyprinidae, and common carp were the most dominant taxa, constituting 86% of the catch (Rider and Margraf 1997). In comparison, Percidae contributed 23.5% of the total catch in 2003, whereas previous studies have captured percid larvae in much smaller numbers (Odom 1987; Scott 1988; Rider 1991). Rider and Margraf (1997) found that percids made up 3.02% of the total catch from the upper Kanawha River. The dominance of Percidae was expected for the early part of the sample season (April and May). Odom (1987) first collected Percidae in early May in the lower Kanawha River. Rider and Margraf (1997) found percids in Marmet Pool as late as August 2, but this was limited to a few (12) individuals (0.71% of the total sample). The dominance of Percidae into late summer was somewhat unexpected; Percidae contributed 62.4% of the samples from June 24, 29.1% of the samples from July 1, and 11.3% of the samples from July 31. Percids spawn at a wide range of temperatures, but the percid species known to exist in the Kanawha River typically spawn at temperatures between 3.0°C and 15.0°C (Holland-Bartels et al. 1990). Water temperatures at study sites ranged from 14.7°C to 24.0°C between April 15 and July 3. However, identification of the percid species found in the Kanawha River is incomplete because a detailed taxonomic record and many species descriptions are lacking (Simon and Wallus 2006). Therefore, a need exists for possible additional research on the taxonomic composition in this region.

Given their use by vulnerable early life stages of fish, dike sites may serve as valuable tools to improve overall fish populations within large, navigable rivers. Houde (1989) demonstrated that larval fish survival and recruitment are fundamental in structuring the juvenile and adult fish community. Increasing larval fish recruitment and survival within larger rivers can thus increase fish populations as a whole. Our research shows that dike sites support higher numbers of larval fish than typical habitat in a navigationally impacted large river. The apparent success of these dike sites may be an important tool in managing navigation impacts and other anthropogenic impacts to river fish populations.

Despite lower velocities at dike sites than at reference areas and our assertion that larval fish use was related to velocity shelters, larval fish CPUE at dike sites was not associated with increased velocities. However, we did find that during our high-discharge year (2003), CPUE at dike sites increased as discharge increased. This seeming paradox may suggest that larval fish use of dike sites is also related to other factors. Several hypotheses may help to explain this observation. Larval fish CPUE may be lower under high flows due to a decreased catch efficiency of the light traps. In 2003, we found that increased river flow was related to increased turbidity, so this could be a possible explanation. Under high flows, larvae may be less active, seeking to maximize their retention in nonturbulent areas (Starnes et al. 1983). However, research showed that light traps were the best available gear for sampling these habitats (Niles and Hartman 2007). Larvae would also have reduced relative swimming ability under increased flow, which may reduce their ability to move towards artificial light sources or enter trap slots, both of which have the effect of reducing gear efficiency under these conditions. If reduced swimming ability is a factor in gear efficiency, it may also explain increased CPUE at dike sites versus reference areas, as those fish in other areas may be swept downstream and experience high mortality. Therefore, the dikes would still be important to recruitment and retention. A concurrent electrofishing survey of juvenile fish showed increased CPUE at dike sites under high flows (Titus 2004). Alternatively, lower larval CPUE under high flows could be due to altered behavior or reduced abundance due to some unquantified predatory interaction with juvenile fishes. Whatever the mechanism, larval fish CPUE remained higher at dike sites than at reference sites, even under high flows, substantiating the value of dikes as larval fish habitat in this large, navigable river.

Water velocity was lowest within dike sites and highest in low-quality reference sites. During periods of high flows, significantly more larval fish were found at dike sites than at reference sites. Since dike sites are zones of low velocity, larval fish may use them as a source of cover from swift-moving water in the main channel. These low-velocity areas may be most important to smaller and younger fish, which are susceptible to displacement during high-flow events. However, in comparison with low flows, in both years fewer fish were collected at dike sites during periods of high river discharge. This appears to be most evident in 2003 as the CPUE was low until early July. Before early July, there were large peaks in discharge and low CPUE, and when river discharge decreased the CPUE increased. This may be attributable to the fact that during low-flow events, fish can be attracted to the light traps from further away as currents and turbidity may both be lower under these conditions. In addition, differences may also be attributable to the temperature and differential spawning times of different species.

Despite clear evidence that larval fish CPUE was higher at the treatment sites than at other areas, it is still unclear whether these sites foster the production of fishes or merely aggregate them. In marine (Powers et al. 2003) and freshwater (Kelch et al. 1999) systems, it has been argued that artificial structures like dike sites only concentrate young fish. However, in river systems with turbulent flows (e.g., the Kanawha River), any areas affording velocity shelter and allowing accumulation of larvae could be considered retention areas that prevent displacement downstream and potentially lead to increased localized recruitment. Therefore, the placement of these structures may enhance rivers that lack natural retention areas.

An important yet unanswered question is whether dike sites continue to serve their intended purpose over the long term or are merely a short-term solution. Future studies should include an analysis of these sites over 10–20 years to verify the functionality of dikes as mitigation sites over the long term. Additional studies involving these sites should analyze whether differences in the design and placement of dikes and dike fields yield similar results. In our study, the four FD sites differed in the overall number of component dikes, individual dike length, orientation to the channel, and total length of shoreline. Each of these features may play a role in determining a dike's overall functionality. In addition, further study is needed to determine whether dike sites actually increase the recruitment to a system or only act as areas of short-term refuge.

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