ASSESSMENT OF LARVAL FISH ENTRAINMENT AT PLANT BARRY STEAM

ELECTRIC GENERATING FACILITY ON THE MOBILE RIVER, ALABAMA

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ASSESSMENT OF LARVAL FISH ENTRAINMENT AT PLANT BARRY STEAM ELECTRIC GENERATING FACILITY ON THE MOBILE RIVER, ALABAMA

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ASSESSMENT OF LARVAL FISH ENTRAINMENT AT PLANT BARRY STEAM

ELECTRIC GENERATING FACILITY ON THE MOBILE RIVER, ALABAMA

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THESIS ABSTRACT

ASSESSMENT OF LARVAL FISH ENTRAINMENT AT PLANT BARRY STEAM ELECTRIC GENERATING FACILITY ON THE MOBILE RIVER, ALABAMA

Robbie Lynn McKinney

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This study examined larval fish entrainment at Plant Barry Steam Electric Generating Facility near Mobile, Alabama with both short-term intensive (17-21 May 2004) sampling and a long-term (September 2004–June 2005) collection effort. The overall objective was to determine the best site for entrainment sampling at Plant Barry. Other objectives included quantifying the taxonomic composition and density of larval fish families being entrained.

Larval fish collections in the intensive study were performed in the intake canal, the Mobile River, the discharge tunnels, and a condenser tap inside the plant. Larval fish were captured by passing 100 m^3 of water through plankton nets (330µm mesh). All collected larval fish were transported to the laboratory where they were sorted,

identified, and counted. The long-term larval fish collections were performed in the same manner using the unit 2A condenser tap inside Plant Barry.

Both site (pair-wise) and diurnal statistical comparisons were performed for the intensive collections based on total numbers and larval fish densities by family. Major families collected throughout this portion of the study included Clupeidae, Cyprinidae, Centrarchidae, and Sciaenidae. Overall, the intake canal generally provided more liberal assessments of larval fish entrainment, while samples inside Plant Barry gave more conservative estimates. No one site could be labeled as best for the assessment of larval fish entrainment due to factors such as power plant effects and larval fish stratification.

Intake canal and Mobile River transect comparisons showed that each larval fish family was subject to introduction into the intake canal by the hydraulic zone of influence (HZI) and Mobile River. The HZI is the water drawn from the Mobile River into the intake canal due to the intake velocity of the power plant. For each larval fish family, at least one site was not statistically different to the densities in the intake canal, suggesting that the HZI had some effect on larval fish introduction into the intake canal.

Long-term collections of larval fish entrained by Plant Barry contained fish from the families of Clupeidae, Cyprinidae, Catostomidae, Centrarchidae, and Sciaenidae. Peak entrainment of larval fish occurred in April, with Sciaenidae showing a peak in May. Knowledge of the spawning characteristics of these fish families is important when performing future annual entrainment studies at Plant Barry in order to assess both the maximum and minimum entrainment values per year.

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CHAPTER I

INTRODUCTION

Electrical power plants are subject to the terms outlined in the 1972 Clean Water Act (CWA) of the United States (US EPA 2002; Bayne et al. 2003). Section 316(a) of the Clean Water Act deals with thermal discharge from power plants, while section 316(b) deals mainly with entrainment and impingement of fish in the cooling water intake of power plants (LaJeone and Monzingo 2000). Impingement involves the pinning of organisms against intake screens (Lohner et al. 2000; US EPA 2002). Organisms that pass through these screens and into the power plant are said to be entrained (Lohner et al. 2000; US EPA 2002).

The mortality rates of aquatic organisms must be assessed for each power plant under United States Public Law 92-500 section 316(b) (Boreman and Goodyear 1981). Studies must be conducted for section 316 in these areas as part of permit renewal for operation of the specific power plant (Bayne et al. 2003, LaJeone and Monzingo 2000, Spicer et al. 2000). Under section 316 (b), the cooling water intake of the power plant must represent the best available technology (BAT) to keep environmental impacts low (US EPA 2002, Dey 2002).

The past enforcement of 316 (b) rules was based on individual cases, resulting in some variation in the compliance of each power plant (Lohner et al. 2000). The

Environmental Protection Agency (EPA) was sued by various environmental groups for their failure to uphold these section 316(b) regulations (Lohner et al. 2000). The new ruling will require an individual power plant to reduce entrainment by 60-90% from the baseline determined for that particular power plant (US EPA 2002). The EPA guidance document clarifies the mortality assessment study requirements and the mitigation options for various types of generating facilities (US EPA 2002). The final ruling was made official on 9 July 2004 (Federal Register 2004). Power plants with a cooling water intake structure, National Pollutant Discharge Elimination System (NPDES) permit requirement, and an intake flow of 50 millions of gallons per day (MGD) or greater are subject to the new 316(b) ruling (US EPA 2002). Entrainment studies are not required at power plants 1) located on a lake, 2) that withdraw 5% or less of the mean annual flow of a freshwater river or stream, or 3) have a capacity utilization rate of less than 15%, meaning the power plant is operating at less than 15% of its full potential (US EPA 2002). Because Plant Barry does not fall under any of these exemptions, entrainment studies are required.

This entrainment study was a much more intensive study than any that had been conducted over the past 20 years at Plant Barry. The intensity of this study ensured better statistical results and more intensive analyses, including diel comparisons of larval fish families entrained at Plant Barry. The main objective of this research was to determine the location of the optimum site at Plant Barry for future studies of larval fish entrainment. Other objectives included:

1) Quantifying the taxonomic composition and statistical density comparisons of larval fish collected during the intensive study;

2) Comparing larval fish sampled in the intake canal with those collected in a Mobile River transect located at Mobile River Mile (MRM) 31.0 by both larval fish family and total numbers sampled; and

3) A long-term assessment of sampled larval fish by month at the Unit 2A condenser tap located inside Plant Barry. This included total larval fish sampled and total larval fish families sampled.

CHAPTER II

LITERATURE REVIEW

Many entrainment and impingement studies were performed by the electric utility industry in the 1970s to assess the impacts of power plants on the aquatic environment as required by the then relatively new Clean Water Act (CWA), but fewer studies were published in the two decades that followed. Most early studies focused on the impacts of impingement. Like most biological organisms, larval fish abundance distributions in the water column are patchy and exhibit a normal distribution according to the life history (i.e., stage of growth) unique to the species of fish. Therefore, there is little information available on power plant effects on ichthyoplankton and fish eggs in warmwater fish (Travnichek et al. 1993).

Alabama Power (1977) conducted 316 (b) testing on Barry Steam Plant entrainment of fish larvae between 1974 and 1976. Ichthyoplankton were collected using two 500-µm mesh plankton nets towed behind a boat for 15 minutes, yielding the necessary 100 m^3 volume (personal communication, Ed Tyberghein, Alabama Power Company). These nets were also equipped with General Oceanics flow meters to record the volume of water filtered by each net. Samples were collected at a depth of 1.52 m during 1975, and at depths of 1.52 m, 3.05 m, and 4.57 m in 1976. Samples were collected in both the Mobile River and in the discharge canal at Plant Barry. Larval fish densities reached maximum levels on 28 May 1975 and 24-25 May 1976 (Alabama Power 1977). Larval fish of the families Clupeidae and Cyprinidae were dominant across all samples. No significant effects from entrainment were found on larval fish communities, and the effects of entrainment mortality on larval fish passing through the cooling systems were considered insignificant based on the river flow percentage used for cooling the condenser (Alabama Power 1977).

A larval fish entrainment study was conducted from 1974 to 1977 near Fort Calhoun Station on the Missouri River (King 1977). This study was initiated to determine the impact of entrainment on a drifting larval fish community and to provide data necessary for a National Pollutant Discharge Elimination System (NPDES) permit. Collections of larval fish were preformed using two 571-µm mesh nitrex plankton nets suspended from the booms on each side of a boat with a General Oceanics flowmeter attached in the mouth of each net to measure velocity and volume of the sampled water. Samples were taken from the intake, discharge, and plume locations of the plant and were collected from the surface, at mid-depth, and at 1 m above the bottom with collection durations between 3 to 7 minutes. Peak larval fish density occurred when water temperature was between 21 to 25 ^{o}C, from mid-June through mid-July. All larvae collected were preserved and identified to species. Freshwater drum and catostomids combined for 95.4 % of the total collected larvae. The station entrained an estimated 2.1 to 12.4 % of the passing larval fish. Entrainment losses at the plant ranged from 2.6% to 5.3% of the entire assemblage in the river. The freshwater drum *Aplodinotus grunniens* was most affected, with 96 % mortality upon passage through the condenser. The impact of these losses could not be determined due to lack of information on larval fish standing crop and natural mortality.

Entrainment studies also were conducted at a hydroelectric facility at Pensacola Dam on Grand Lake reservoir in Oklahoma in 1988 and 1989 (Travnichek et al. 1993). This study used two 2.5-m bridled ring nets with 0.5-m diameter mouth openings and 0.5-mm mesh and flowmeter towed from a boat for 7.5 minutes. Samples were collected in the daytime at the surface and at a depth of 8 m weekly from March through August, twice monthly from September through November, and monthly during January, February, and December in 1988. All samples were identified to species, and the densities were determined by dividing the number collected by the volume of water sampled. The most collected larvae were sunfishes, followed by gizzard shad *Dorosoma cepedianum*, freshwater drum, and white crappie *Pomoxis annularis*. The authors concluded that the amount of entrainment experienced at the hydroelectric facility was low compared to the total abundance of larval fish inhabiting Grand Lake (Travnichek 1993).

Savitz et al. (1998) conducted entrainment studies at a low velocity, high volume intake at a power plant on Lake Michigan, located at Northwestern University in Evanston, Illinois. The intake forebay was monitored for entrained fish eggs and larvae during system operations. Monitoring occurred during pre-dawn and pre-dusk, each day, three times per week. Plankton nets with 0.5-m diameter opening and 520 µm mesh size were placed at two depths for 20 minutes each in both the north and south forebay. A water volume of 53.3 m^3 was filtered each day of the study. No ichthyoplankton were found in the study. The authors stated that because the intake was in a zone of deep water there would be few ichthyoplankters located there, thus yielding no entrainment (Savitz et al. 1998).

LaJeone and Monzingo (2000) studied the entrainment of larval fish through an open-cycle operating facility on the Upper Mississippi River. An open-cycle operating facility withdraws water from a nearby body of water to be used in the power plant condenser. A net barrier across the intake forebay, along with rotenone and haul seine sampling, were used in the collection of larval fish for the entrainment study. Freshwater drum was selected for a special study that determined the effect of this plant operation on the population levels with regard to entrainment in Pool 14 of the Upper Mississippi River. Population levels, growth, fecundity, sex ratios, and survival of the drum were observed, and no changes in the local fishery or drum population were evident after 14 years of monitoring.

Lewis and Seegert (2000) sampled entrainment at select stations on the Wabash River in Indiana. Ichthyoplankton were sampled inside the power plant using a tap in the cooling water lines that were coming in from the cribhouse intake. Twelve hour duration samples were collected from May to October 1987 and 1988 from the tap into 560 µm mesh plankton nets and also using near-surface plankton net tows at 4 points along a river transect. All ichthyoplankton were identified to the lowest taxon possible, with gizzard shad dominating the collection. Low river discharge caused the worst-case conditions for entrainment in spring and summer of 1987 and 1988. Because relatively low entrainment numbers existed at this time, it was determined that entrainment had no adverse effect on fish communities in the river.

Wisconsin Electric conducted entrainment studies on steam electric plants in 1975 and 1976 as required by the US EPA under the conditions of the NPDES permits for their facilities (Michaud 2000). The power plants used in the study were all located on either the Great Lakes or major tributaries to them. In this study, 24-hour entrainment samples were collected once every four days between April 15 and October 31, 1975 at the Oak Creek, Point Beach, and Valley Plants. Entrainment was examined for 24-hours every 4 days at Presque Isle station using a suspended net in the forebay of the intake pipe. Submersible pumps were used at 20 and 80% depth levels directed into suspended 350-µm mesh nets, and the samples were examined and quantified. Rainbow smelt *Osmerus mordax* and alewife *Alosa pseudoharengus* composed the majority of the entrained fish found in the study. Michaud (2000) concluded that the impact of entrainment on rainbow smelt and alewife was insignificant due to their abundance in lakes Michigan and Superior and that the rate of entrainment exceeded the annual impingement rates.

The Comanche Peak Steam Electric Station in Texas was the focus of field entrainment studies from 6 April to 24 August 1994 (Spicer et al. 2000). This time period was chosen because it coincided with the spawning activities of representative important species in Squaw Creek Reservoir. Sampling occurred on a weekly basis in front of the cooling water system intake structure, using three plankton nets with 500 µm mesh deployed from a 4.88 m boat. Spatial distribution of ichthyoplankton was determined by samples collected from 0.91 m, 7.62 m, and 15.24 m depths to ensure validity based on bathymetric differences in distribution and abundances of ichthyoplankton. Jude et al. (1986) found that stratification of larvae can occur due to factors such as the density differences of entering water masses, seiches, and larval fish behavior. The genus *Aplodinotus* (drums) and *Labidesthes* (silversides) experienced the greatest egg entrainment; drum, gizzard shad *Dorosoma cepedianum* and threadfin shad *Dorosoma petenense*, sunfish, crappie, and white bass *Morone chrysops* larvae were dominant among entrained juvenile samples (Spicer et al. 2000). Drum were most abundant in the entrainment samples, but the annual loss of this species came to less than 100 adults when taking into account the natural mortality and fecundity of the species. The study showed the importance of the consideration of the unique characteristics of manmade reservoirs as a whole.

The primary literature describes various methods that have been used in ichthyoplankton entrainment collection. Plankton nets have been found to be extremely effective tools for larval fish sampling. The use of flow meters is also important to estimate the volume of water filtered through plankton nets. Sampling for larval fish for purposes of entrainment monitoring is generally conducted in or around the power plant itself. The peak of the spawning period is the most important time of year for intensive larval fish sampling because it gives a good estimate of the highest entrainment by a power plant. Transect collections in riverine systems near the power plant intake provide a good estimate of the impact of entrainment on the fish communities because they will reveal which larvae inhabit the river, and these collections can also be used in comparison with entrained samples to assess the impact that entrainment has on the riverine communities. Larval fish collections should occur regularly, although more intensive sampling (e.g. weekly or daily) would provide better statistical results. Proper identifications of larval fishes are needed to determine which taxa are experiencing the highest entrainment. All of these aspects are important parts of a high quality experimental design that can be used to conduct larval fish entrainment sampling at any power plant.

CHAPTER III

MATERIALS AND METHODS

Overview

The Southern Company has seven steam-electric generating facilities located throughout the state of Alabama that are owned and operated by Alabama Power Company. These steam-electric facilities include Greene County, Gorgas, Gadsden, E. C. Gaston, Miller, Harris, and Barry. Of these, only Greene County, Gorgas, Gadsden, E. C. Gaston, and Barry require 316 (b) monitoring since these facilities do not meet the exemption criteria.

Plant Barry Site Description

Until recently, the Barry Steam Electric Generating Plant (Plant Barry) was solely a coal fired facility. However, in 2000 and 2001, two additional 500 MW gas combustion turbine units with cooling towers went into operation (Bayne et al. 2003). The cooling water withdrawals for the coal fired units exceed 5 percent of the mean Mobile River flow and are the focus of entrainment studies for section 316(b) because it does not meet the exemption qualifications listed by the EPA (US EPA 2002). Plant Barry is located on the Mobile River in Mobile County, Alabama (Bayne et al. 2003). Five generating units operate with a once-through cooling system for a combined overall capacity of 1,525 MW (Alabama Power 1977).

The steam plant uses two intake structures on the Mobile River; one intake provides water for units 1-3 and the other supplies units 4-5 (Bayne et al. 2003). These intakes draw water from a barge canal constructed from the Mobile River to the plant's coal unloading facilities, and this canal has a maximum depth of 5.18 m (Figure 1). The distance water travels from the intake screens to the inside of Plant Barry is about 152.4 m. Once inside Plant Barry, water travels through circulating water pumps assigned to specific condensers. The Unit 2A circulating water pump maintains an average of 2.58 m^3/s flow through a 1.37 m diameter pipe.

Water is pulled into the intake canal by way of the hydraulic zone of influence (HZI). The HZI is the water drawn from the Mobile River into the intake canal due to the intake velocity of the power plant. Dye studies and 3 dimensional mapping at Plant Barry by the Alabama Power Company had previously determined that the HZI extended into a portion of the Mobile River (Figure 2).

The thermal discharge canal is about 3.05 m deep, 2.41 km in length, and 4.83 km downstream of the intake. The maximum depth of the Mobile River where it intersects the discharge canal is about 18.29 m in depth (Bayne et al. 2003). The Mobile River itself is about 198.12 m wide and, depending on conditions, is about 12.19 m deep.

Intensive Larval Fish Sampling

Two separate sampling activities at Plant Barry were used in this entrainment study. The first type of sampling was an intensive, short-term examination of the larval fish community and was performed during the spawning season, 17 May – 21 May 2004. This intensive study concentrated on the following sampling stations at the power

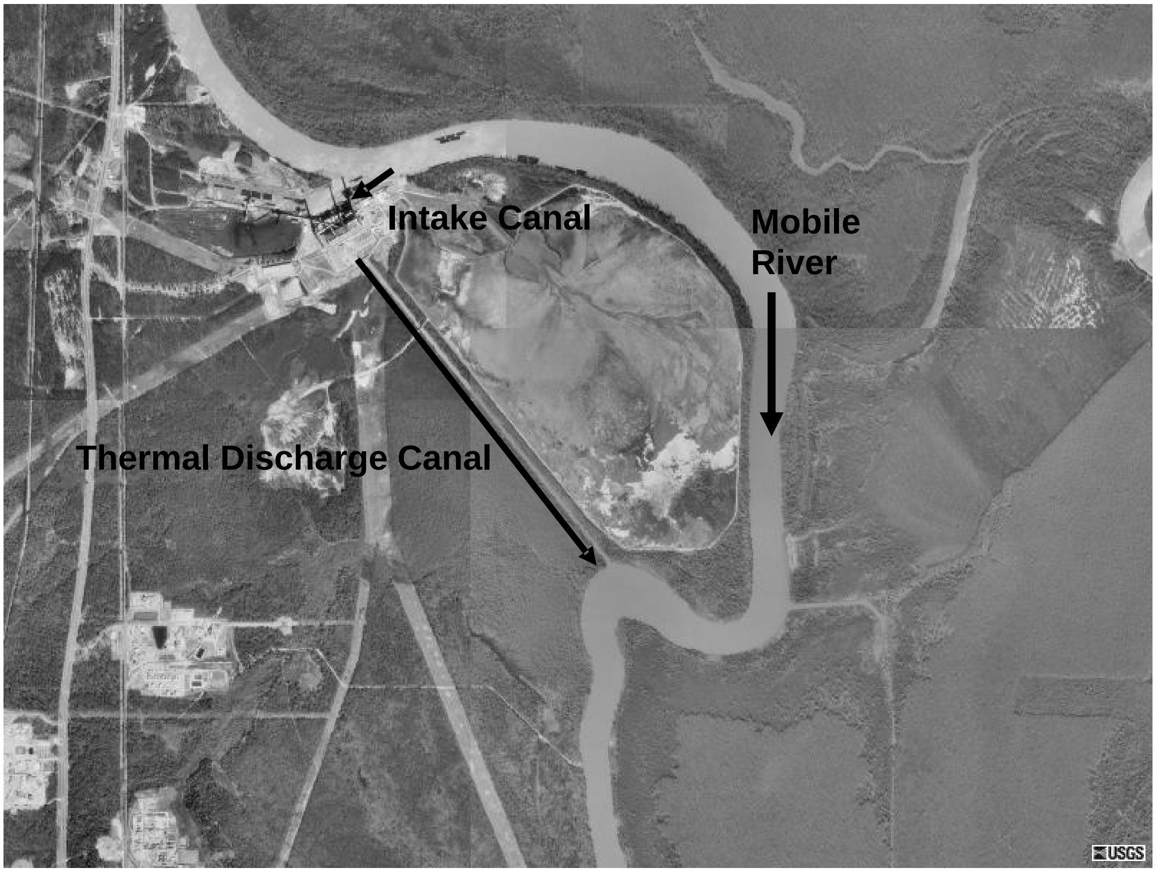

Figure 1. Aerial photograph of Barry Steam Plant showing the Mobile River, the intake canal, and the thermal discharge canal.

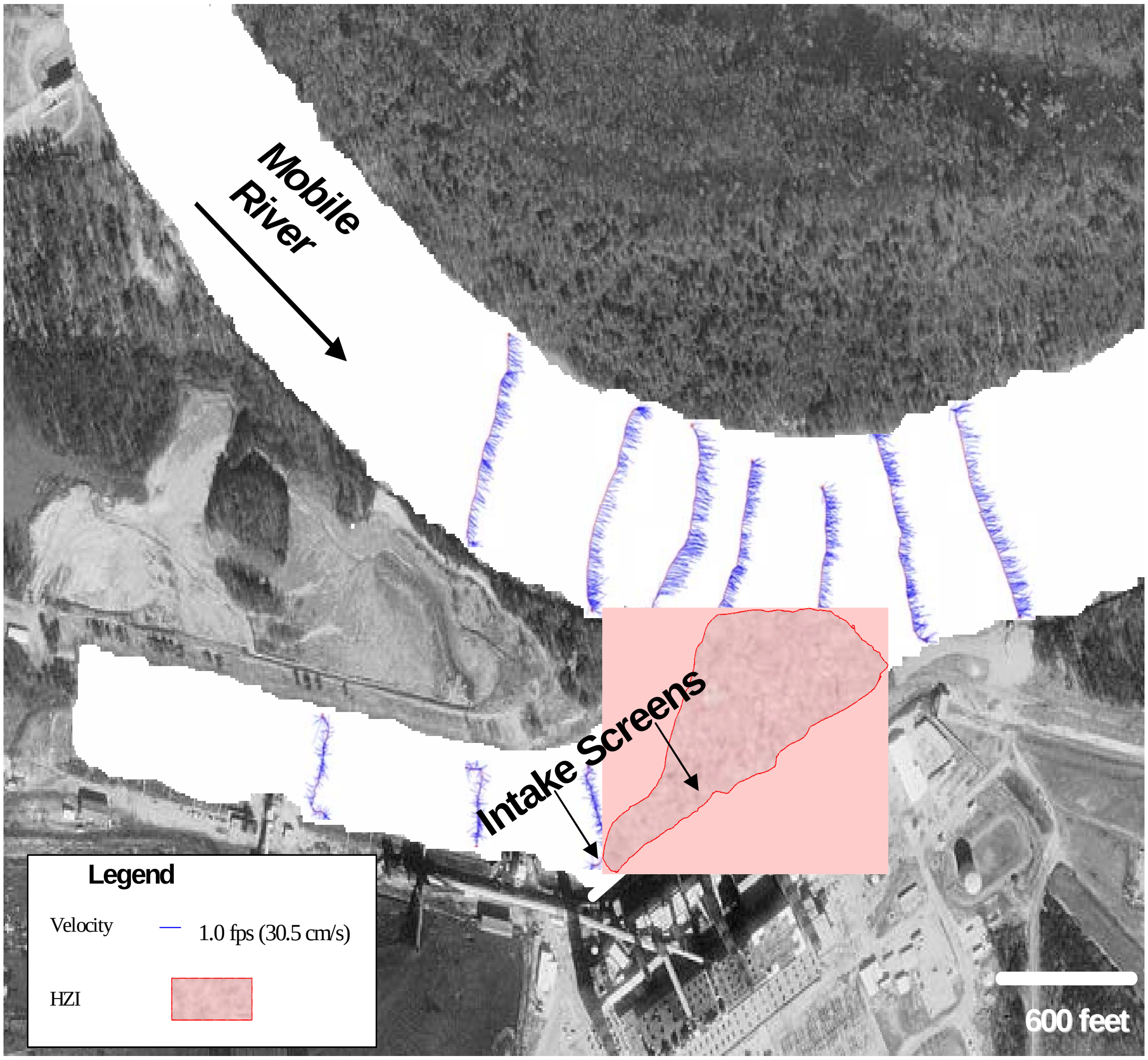

Figure 2. Aerial photograph of the Mobile River in the vicinity of Plant Barry, showing the hydraulic zone of influence (HZI) at the junction of the river and intake canal and the flow measured for various transects in the two locations.

plant: Stations 1-5 in the Mobile River at Mobile River Mile 31.0; Station 6 in the intake canal at tunnels 1 and 2 for units 1-3 and 4-5, respectively; Station 7 in-service water inside the plant from units 1-3; and Stations 8-9 in thermal discharge tunnels 1 and 2 for units 1-3 and 4-5, respectively (Figure 3). Sampling was conducted at each station every 4 hours during a 24-hour cycle. The intake sampling (station 6) and the power plant condenser (station 7) sampling took place concurrently. Samples collected from each station were labeled and preserved in a 10% formalin and Rose Bengal solution for transport back to the laboratory.

River, intake, and discharge sampling involved the use of three 4.27 m (14-ft.) boats. The boats were equipped with two 0.5-m diameter circular plankton nets located on either side of the bow of the boats. Plankton nets are the preferred tool in the capture of larger larval fish (Cada and Loar 1982). These plankton nets had a mesh size of 330µm. Nets with mesh size of 500 µm and larger do not provide accurate estimates of shad densities in entrainment studies (Tomljanovich and Heuer 1986). The plankton nets were equipped with General Oceanics flow meters to determine the volume of water sampled by the net. The boats pushed the nets upstream along the surface of the water for 0.5 km (0.3 mi) at a depth of about 0.5 m (1.6 ft). Pump sampling of larval fish was not possible in our study due to submerged debris and various other obstructions in the water column near Plant Barry. A total volume of 100 m^3 was filtered between the two nets in each sampling run (about 10-15 minutes per sampling run). A 100 m^3 volume sample is considered adequate for larval fish studies (Marcy and Dahlberg 1980). Hand-held Global Positioning Satellite (GPS) systems were used to maintain a maximum boating speed of 3.2 km/hr (2 mi/hr) along the sampling transects to ensure the proper

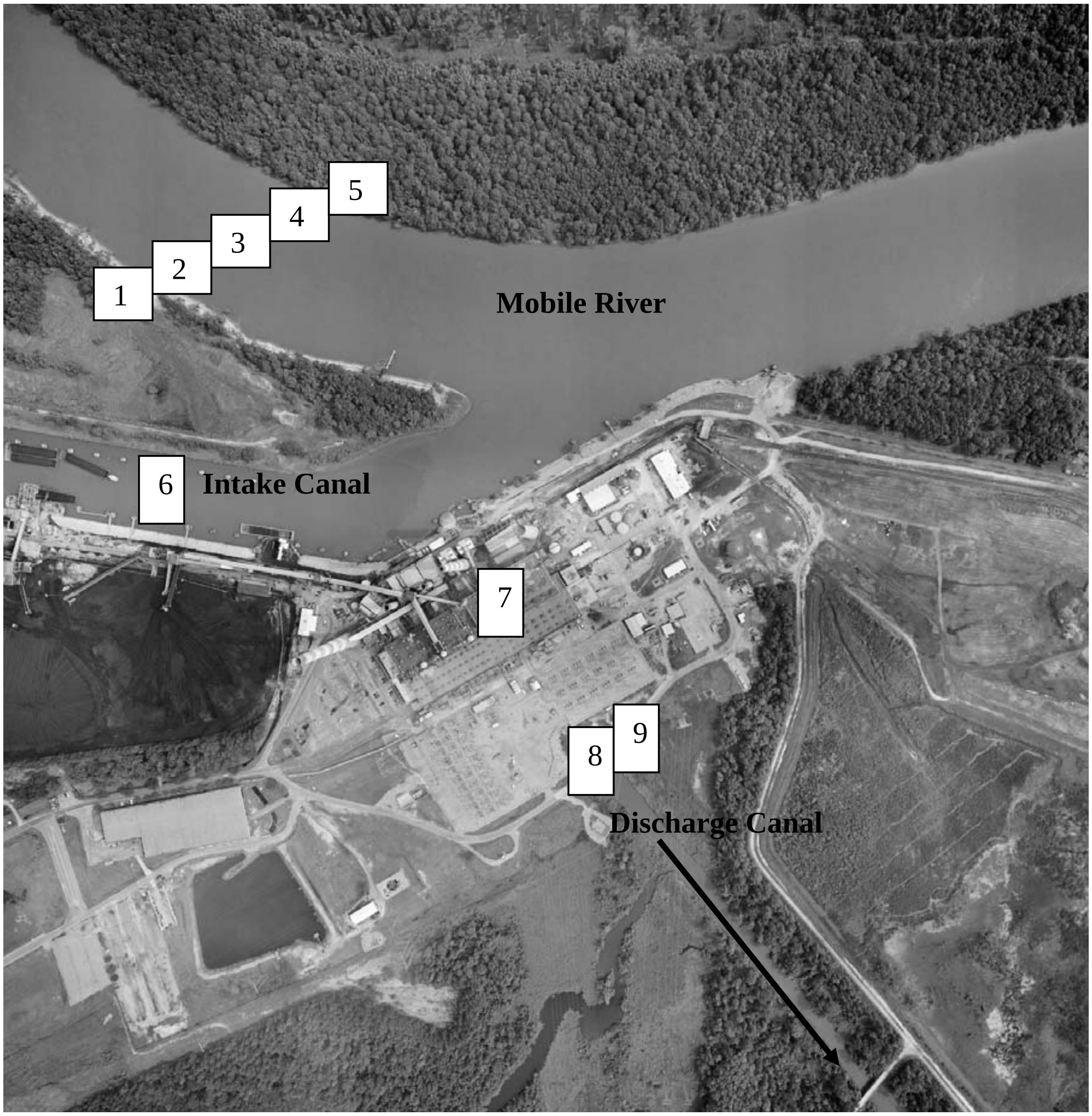

Figure 3. Aerial photograph of the sampling sites for the intensive sampling at Barry Steam Plant in Mobile County, AL for 17 May–21 May 2004.

volume was filtered. Both the boating speed and the sampling distance were pre-determined using the flow of the Mobile River.

Sampling inside the plant involved a tap in the circulation water pump drain for water entering the power plant. This water was filtered through two 0.5-m plankton nets with a mesh size of 330µm. In-line digital flow meters were used on the incoming water from the circulation water pump drain to determine the total amount of water filtered. These flow meters measured the amount of incoming water in gallons per minute. A flow rate of about 500 gallons/min (1.9 m^3/min) was maintained per net, yielding a total filtered volume of 52 thousand gallons, or 100 m^3 volume per net. All collected samples were preserved in jars with 10% formalin and Rose Bengal for transport back to the laboratory.

Long-term Larval Fish Sampling

The long-term larval fish sampling was conducted at Plant Barry between September 2004 and June 2005. The samples were collected bi-weekly from September 2004 until March 2005 and then weekly from March 2005 through June 2005. The weekly samples were collected in three 8 hour blocks (1400-2200, 2200-0600, and 0600-1400). No samples were collected during the months of December, July, and August because of equipment malfunctions at the condenser tap. The long-term sampling methods were similar to those used in the intensive larval fish sampling, with the power plant Unit 2A condenser tap (station 7) being the sampling location (Figure 2). A total water volume of 100 m^3 was filtered through two 0.5-m plankton nets with a mesh size of 330 µm. These samples were then preserved with 10% formalin and Rose Bengal for transport back to the laboratory.

Laboratory Sorting and Identification

Laboratory processing for the intensive and the long-term monitoring directly followed the field work during the study. Larval fish were separated from other debris and placed in vials filled with 5% phosphate buffered formalin solution. A plankton splitter was used to aid in the consolidation of the Mobile River samples due to the large number of larvae collected. The equation used for the sample splitting was as 2^n, where n was the number of times the sample had been split. The numbers counted from the split sample were multiplied by the equation to attain the total sample numbers. The vials were labeled including date, time, location, final flow meter readings, and the total number of larval fish and eggs found in each sample.

The identification of larval fish began after all ichthyoplankton had been separated from debris in all samples. The larval fish from every sample were identified to family using various larval fish identification keys (Auer 1982; Scheidegger 1990; Wallus et al. 1990). Trained larval fish taxonomists employed by Alabama Power Company assisted in the identification of larval fish. They also provided the necessary quality control in the processing of samples and the identification of larval fish. The quality control consisted of the retention of processed samples for spot checking to ensure all ichthyoplankton had been removed, as well as random checks of the identified samples by the larval fish taxonomist to check for accuracy.

Statistical Analyses

Statistical analysis of the intensive study data was performed using repeated-measures split-plot analysis of variance (ANOVA) using the statistical package for the social sciences (SPSS) software (SPSS 2005). Repeated-measures ANOVA was performed on both the log-10 transformed total number per 100 m^3 and the log-10 transformed total number per 100 m^3 by larval fish family. All sites were compared among the time periods collected (000-0400, 0400-0800, 0800-1200, 1200-1600, 1600-2000, 2000-0000) for the entire intensive study to determine statistical differences among the means of each individual site.

Sites were also compared using repeated-measures analysis for day and night sampling times to compare diel differences among compared sites. Site means were also $\log_{10}$ transformed to normalize the data distribution. The time periods 2000-0000, 0000-0400, and 0400-0800 were considered the night sampling times, and the time periods 0800-1200, 1200-1600, and 1600-2000 were considered day sampling times. Hypothesis testing required a p-value to be less than or equal to 0.05 in order to show statistical differences between sites. Pair-wise site comparisons were performed using the Bonferroni correction.

Statistical analysis of the long-term larval fish collections involved one-way analysis of variance (one-way ANOVA) using SPSS 13.0 (2005). The $\log_{10}$ transformed total number of larval fish per 100 m^3 was compared among months collected for March, April, May, June, and September. This test was conducted for both the overall total of larval fish collected and the total numbers collected by family throughout the long-term routine study at Plant Barry. Because equal variances among samples were not assumed, the Games-Howell multiple range test was used for comparisons.

CHAPTER IV

RESULTS

Intensive Study Overview

A total of 138,514 larval fish and 9 eggs overall were seen in 422 samples collected during the intensive study. The eggs were omitted from this study due to the low number collected. The dominant larval fish families used in statistical analyses among sites for this study included Clupeidae (herrings and shad), Cyprinidae (carps and minnows), Sciaenidae (drum), and Centrarchidae (sunfish), which contributed a total of 99.5% of all larval fish across all samples collected in the intensive study (Table 1). Of the total number of larvae collected during the intensive study, 78.6 % were clupeids, 13.3 % cyprinids, 7.4 % sciaenids, and 0.2% centrarchids.

Plant and Vicinity Site Comparisons

There were 192 samples with a total of 27,131 fish larvae collected at sites 6-9 during the intensive study (Figure 3). The Mobile River transect (Sites 1-5) samples will be discussed later in the Results section. Sample collections in the intake canal (Site 6) had the highest percentage of larval fish collected when compared to the other sites. The intake canal yielded 11.7% of the total larval fish collected in the intensive study. Fish collected at the unit 2A condenser tap (Site 7) inside the power plant made up 3.3% of the total larval fish collected. The discharge from units 4-5 into the canal (Site 9) had

2.7% of the total, and the units 1-3 discharge (Site 8) contained 1.9% of all collected larval fish. The other 80.4% of larvae were collected in the Mobile River transect.

Table 1. Total number of larval fish collected, mean, and standard deviation by family at all sites collected at Barry Steam Electric Generating Plant during the intensive study from 17 May – 21 May 2004.

Family	**Number Collected**	**Mean Number Across Samples**	**SD**
Lepisosteidae	7	0.02	0.15
Clupeidae	108,817	257.86	605.44
Cyprinidae	18,471	43.77	105.56
Catostomidae	6	0.01	0.14
Belondae	13	0.03	0.22
Atherinidae	61	0.14	1.05
Moronidae	18	0.04	0.36
Centrarchidae	318	0.75	3.51
Percidae	4	0.01	0.10
Sciaenidae	10,243	24.27	60.27
Unidentified	556	1.32	3.71
Total	*138,514*	*328.22*	*609.4*

All sites were compared within day and night sampling times. Because diel site comparisons had higher resolution than a six, 4-hour time period comparison, diel analyses were used in this study. Statistical tests revealed a significant difference among sites ($F_{3,138}$=97.70, P<0.001), no significant effect of time period ($F_{1,46}$=0.747, P=0.747), and a significant interaction ($F_{3,138}$ =17.18, P<0.001) between time period and site. Overall, the intake canal sampling site was significantly different (P<0.001) in a pair-wise comparison with the other three sites for the six time periods (Table 2).

Table 2. Pairwise comparison of the intake canal (Site 6), the unit 2A condenser tap (Site 7), units 1-3 discharge (Site 8), and units 4-5 discharge (Site 9) means with standard error, significance, and 95% CI for the $\log_{10}$ total of larval fish collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 7	0.641*	0.059	0.000	0.479	0.804
	Site 8	0.726*	0.055	0.000	0.574	0.878
	Site 9	0.632*	0.041	0.000	0.519	0.745
Site 7	Site 8	0.084	0.050	0.596	-0.054	0.223
	Site 9	-0.010	0.035	1.000	-0.107	0.088
Site 8	Site 9	-0.094	0.044	0.221	-0.214	0.027

* denotes that the mean difference is significant at the 0.05 level.

In a comparison for diel effects, the intake canal had significantly ($P<0.001$) higher larval fish densities than the other sites in both day and night samples (Figure 4). The unit 2A condenser tap site also had significantly higher densities when compared with the units 1-3 discharge site in the day samples. The units 1-3 discharge site was also statistically different ($P=0.002$) in a comparison with the units 4-5 discharge site for the day samples. The intake canal site differed statistically ($P=0.001$) between the time periods, and also the units 1-3 discharge site also showed statistical differences ($P<0.001$) between night and day samples.

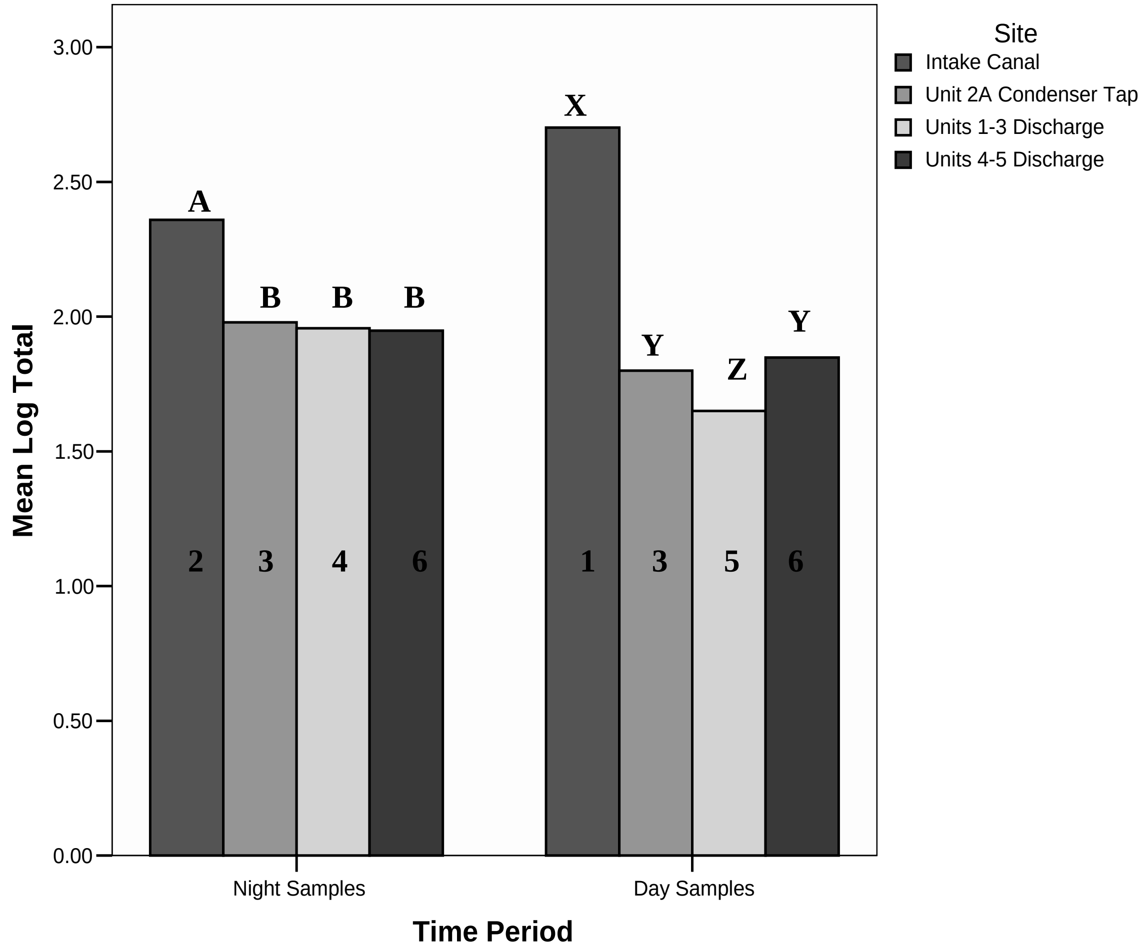

Figure 4. Comparisons among sites by time period for the overall mean $\log_{10}$ total per 100 m^3 of collected larval fish at Barry Steam Electric Generating Plant during the intensive study from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences ($P<0.05$). Different numbers across time periods within specific sites indicate statistical differences ($P<0.05$).

The log-10 total count for the family Clupeidae was compared among sites within the day and night periods. Clupeidae densities were significantly different ($F_{3,138}$=125.96, P>0.001) between sites and time periods ($F_{1,46}$=9.443, P>0.001). Pair-wise comparisons between sites showed significant differences between the intake canal and the other three sites (P>0.001) (Table 3). Statistical differences (P=0.013) were also revealed between both discharge sites.

Table 3. Pairwise comparison of the intake canal (Site 6), unit 2A condenser tap (Site 7), units 1-3 discharge (Site 8), and units 4-5 discharge (Site 9) means with standard error, significance, and 95% CI for the $\log_{10}$ total of larval fish from the family Clupeidae collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 7	0.950*	0.072	0.000	0.751	1.148
	Site 8	1.016*	0.062	0.000	0.846	1.186
	Site 9	0.828*	0.049	0.000	0.692	0.963
Site 7	Site 8	0.066	0.061	1.000	-0.103	0.236
	Site 9	-0.122	0.052	0.139	-0.265	0.021
Site 8	Site 9	-0.188*	0.058	0.013	-0.349	-0.028

* denotes that the mean difference is significant at the 0.05 level.

The interaction of Clupeidae densities and time also showed differences ($F_{3,138}$=9.443, P>0.001) among sites. The intake canal differed significantly (P>0.001) from the other three sites for both the night and day samples (Figure 5). The two discharge sites were statistically different (P=0.001) when compared for the day samples. The intake canal site yielded statistically (P<0.001) higher larval densities during the day than at night.

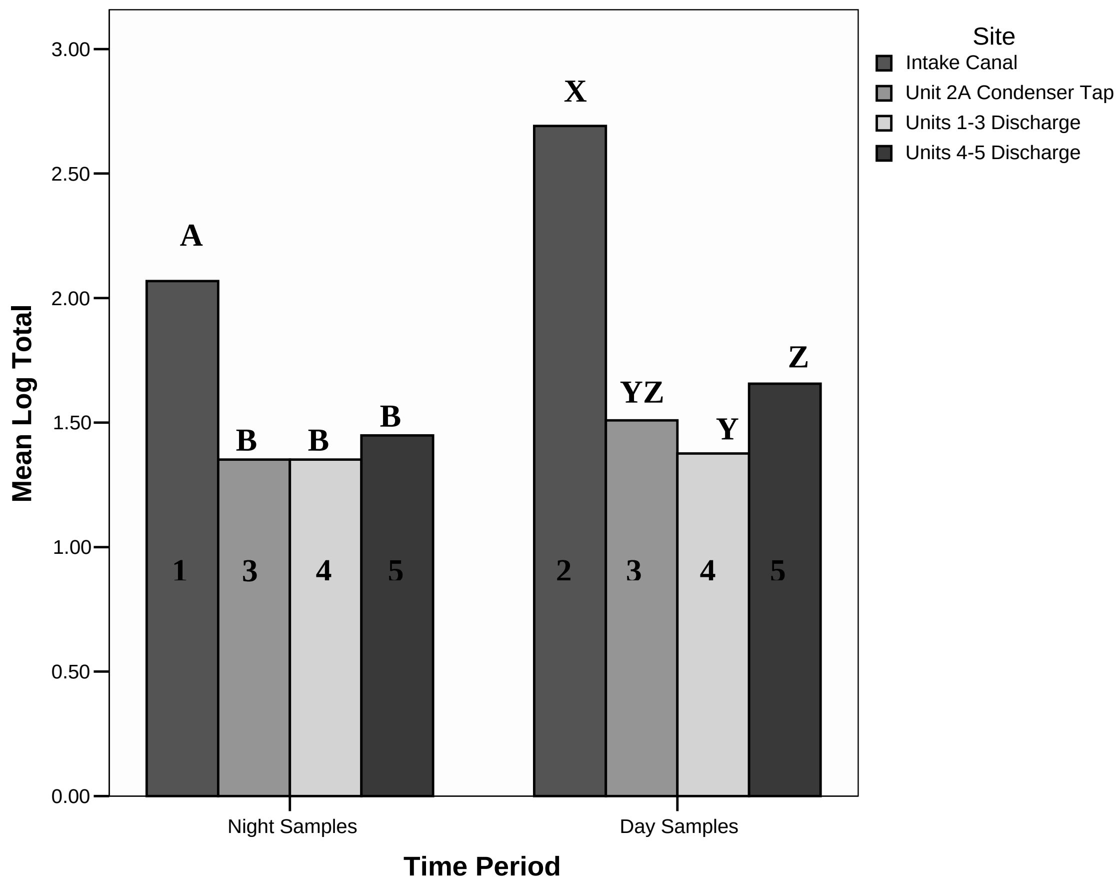

Figure 5. Comparisons among sites by time period for mean $\log_{10}$ total per 100 m^3 of collected larval fish from the family Clupeidae at Barry Steam Electric Generating Plant during the intensive study from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences (P<0.05). Different numbers across time periods within specific sites indicate statistical differences (P<0.05).

Day versus night statistical analysis of the family Cyprinidae revealed significant differences among sites ($F_{3,138}$=15.45, P<0.001) and a significant effect of time period ($F_{1,46}$=184.13, P<0.001). Overall, the intake canal sampling site was statistically different (P<0.001) than the unit 2A condenser tap and statistically different (P=0.001) than Units 4-5 discharge site. The unit 2A condenser tap site was also statistically different (P<0.001) than the units 1-3 discharge site. Both units 1-3 and units 4-5 discharge sites were statistically different (P=0.020) (Table 4).

Table 4. Pairwise comparison of the intake canal (Site 6), unit 2A condenser tap (Site 7), units 1-3 discharge (Site 8), and units 4-5 discharge (Site 9) means with standard error, significance, and 95% CI for the $\log_{10}$ total of larval fish from the family Cyprinidae collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 7	0.334*	0.064	0.000	0.157	0.511
	Site 8	0.060	0.050	1.000	-0.078	0.198
	Site 9	0.226*	0.054	0.001	0.077	0.376
Site 7	Site 8	-0.274*	0.060	0.000	-0.440	-0.108
	Site 9	-0.108	0.045	0.127	-0.233	0.017
Site 8	Site 9	0.166*	0.054	0.022	0.016	0.316

* denotes that the mean difference is significant at the 0.05 level.

A significant interaction between time period and site ($F_{3,138}$=4.72, P=0.004) also existed for the family Cyprinidae (Figure 6). At night, the intake canal had higher (P<0.001) larval densities than the other three sample sites. The unit 2A condenser tap was also statistically different (P<0.001) than the units 1-3 discharge canal site in the day samples. Day samples for the intake canal site differed statistically (P=0.005) with only the unit 2A condenser tap site. The unit 2A condenser tap differed statistically from both the units 1-3 discharge canal site (P<0.001) and the units 4-5 discharge canal site (P=0.004). The units 1-3 discharge and units 4-5 discharge canal sites differed statistically (P=0.011) during the day samples. All sites were statistically different (P<0.001) across time periods.

Total numbers of the Family Sciaenidae were statistically analyzed using both day and night periods (Table 5). There were statistical differences seen between sites ($F_{3,138}$=90.14, P<0.001), no significant effect of the time period ($F_{1,46}$=3.48, P=0.068), and a significant interaction between time period and site ($F_{3,138}$=12.29, P<0.001). Each site was statistically different (P<0.001) than every other site, with the exception of the unit 2A condenser tap and the discharge from units 4-5.

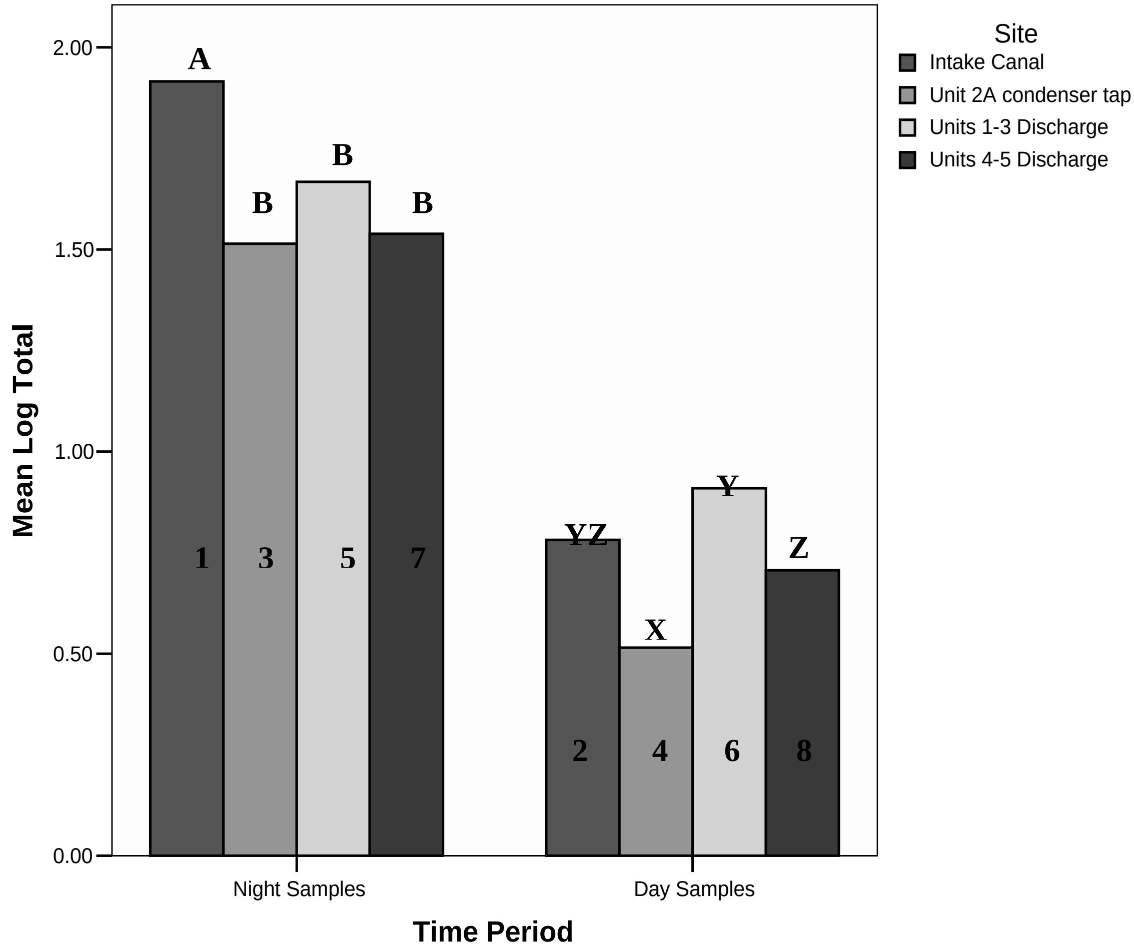

Figure 6. Comparisons among sites by time period for mean $\log_{10}$ total per 100 m^3 of collected larval fish from the family Cyprinidae at Barry Steam Electric Generating Plant during the intensive study from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences ($P<0.05$). Different numbers across time periods within specific sites indicate statistical differences ($P<0.05$).

Table 5. Pairwise comparison of the intake canal (Site 6), unit 2A condenser tap (Site 7), units 1-3 discharge (Site 8), and units 4-5 discharge (Site 9) means with standard error, significance, and 95% CI for the $\log_{10}$ total of larval fish from the family Sciaenidae collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 7	-0.762*	0.061	0.000	-0.930	-0.593
	Site 8	-0.411*	0.060	0.000	-0.576	-0.246
	Site 9	-0.680*	0.055	0.000	-0.833	-0.527
Site 7	Site 8	0.350*	0.045	0.000	0.227	0.474
	Site 9	0.082	0.036	0.163	-0.017	0.181
Site 8	Site 9	-0.268*	0.044	0.000	-0.391	-0.146

* denotes that the mean difference is significant at the 0.05 level.

Differences among time for Sciaenidae densities by site were also apparent (Figure 7). At night, the intake canal site yielded significantly ($P \leq 0.010$) fewer larval fish than the other three sites. The unit 2A condenser tap and units 1-3 discharge sites were significantly different ($P=0.001$) at night. Both discharge sites were statistically different ($P<0.001$) at night. For the day samples, all four sites differed statistically ($P \leq 0.001$). At the intake canal site, higher ($P<0.001$) larval fish densities were collected at night.

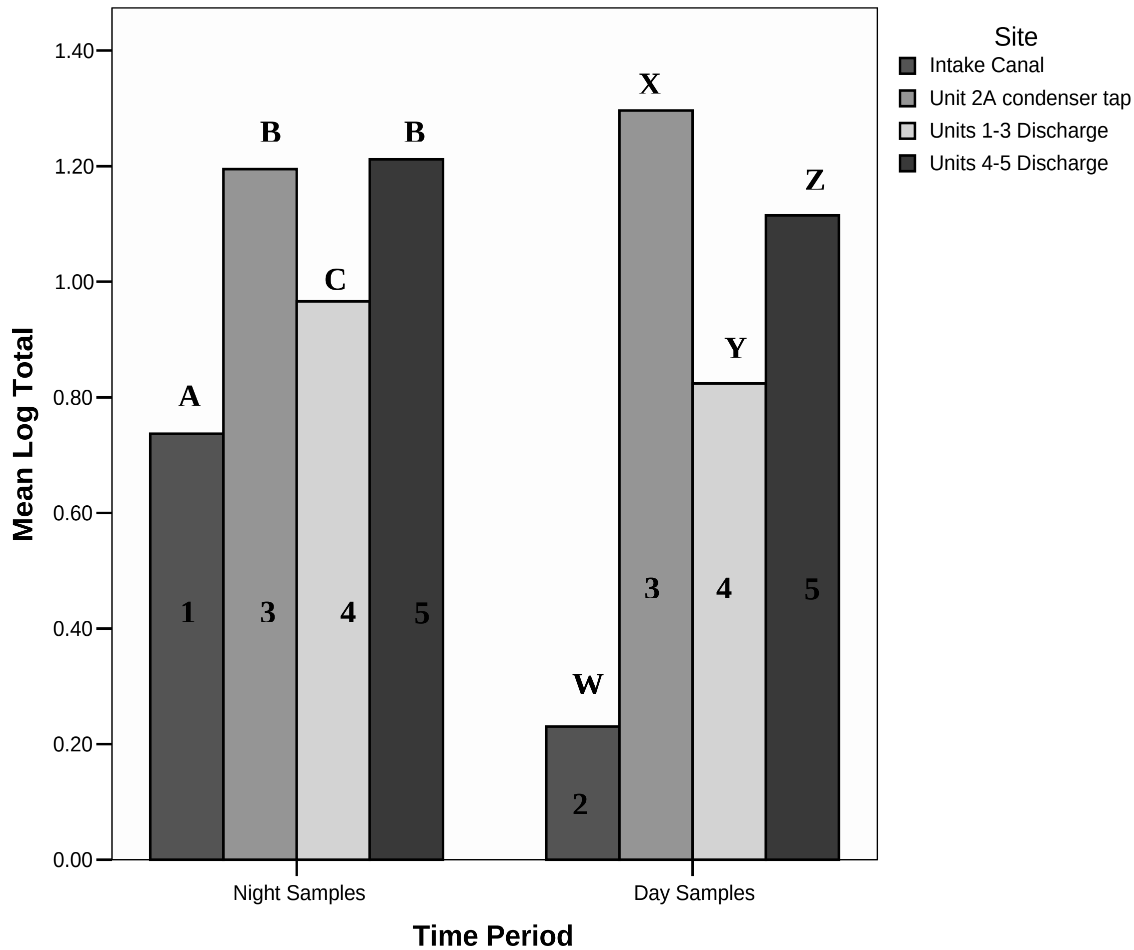

Figure 7. Comparisons among sites by time period for mean $\log_{10}$ total per 100 m^3 of collected larval fish from the family Sciaenidae during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences ($P<0.05$). Different numbers across time periods within specific sites indicate statistical differences ($P<0.05$).

The analysis for the family Centrarchidae revealed a significant difference in site ($F_{3,138}$=16.11, P<0.001) and no effect of time period ($F_{1,46}$=0.211, P=0.648). The intake canal was statistically higher than the unit 2A condenser tap (P<0.001), units 1-3 (P<0.001), and units 4-5 discharge canal sites (P=0.001). All other sites showed statistical similarity in comparisons (Table 6).

Table 6. Pairwise comparison of the intake canal (Site 6), unit 2A condenser tap (Site 7), units 1-3 discharge (Site 8), and units 4-5 discharge (Site 9) means with standard error, significance, and 95% CI for the $\log_{10}$ total of larval fish from the family Centrarchidae collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 7	0.272*	0.057	0.000	0.115	0.430
	Site 8	0.266*	0.057	0.000	0.109	0.424
	Site 9	0.215*	0.054	0.001	0.067	0.363
Site 7	Site 8	-0.006	0.027	1.000	-0.081	0.069
	Site 9	-0.057	0.032	0.475	-0.146	0.031
Site 8	Site 9	-0.051	0.033	0.739	-0.141	0.039

* denotes that the mean difference is significant at the 0.05 level.

There was also no overall significant ($F_{3,138}$=0.541, P=0.655) interaction between time period and site for the family Centrarchidae (Figure 8). At night, the intake canal had significantly (P=0.006) higher larval centrarchid densities than the other three sites.

During the day, the intake canal had significantly ($P<0.001$) higher densities than the other three sites, and the unit 2A condenser tap was statistically different ($P=0.045$) than the units 4-5 discharge site. All sites had statistically similar means across time periods.

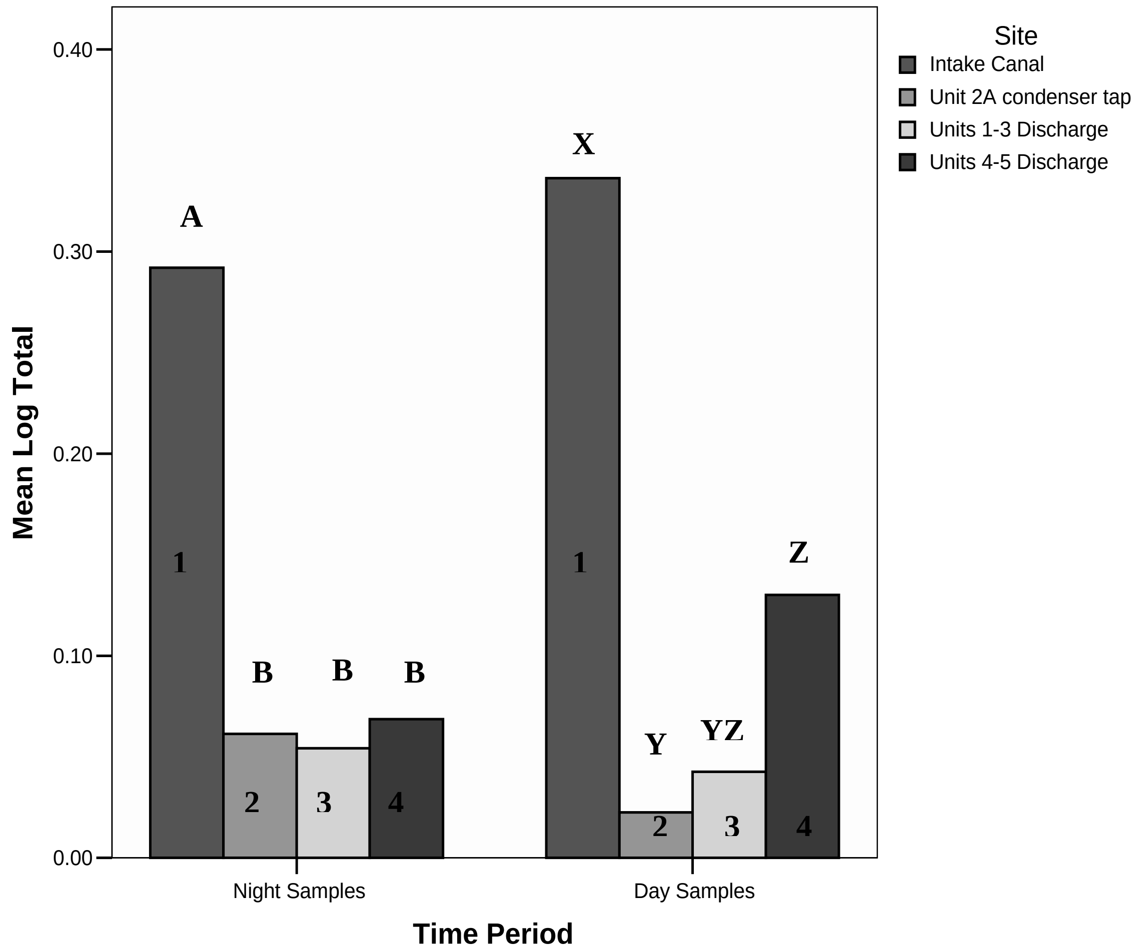

Figure 8. Comparisons among sites by time period for mean $\log_{10}$ total per 100 m^3 of collected larval fish from the family Centrarchidae at Barry Steam Electric Generating Plant during the intensive study from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences ($P<0.05$). Different numbers across time periods within specific sites indicate statistical differences ($P<0.05$).

River Transect and Intake Canal Comparisons

There were 276 samples collected at Sites 1-6 during the intensive study (Figure 3). Sample collections along the western shoreline upstream at MRM 31.0 (Site 1) had the highest percentage of larval fish when compared to the other sites. It accounted for 26.6% of the total larval fish collected in the intensive study. The other sites contained the following percentage of the total collected larval fish: Site 2 had 24.6%, Site 3 had 9.0%, Site 4 had 4.8%, Site 5 had 15.5%, and Site 6 had 11.7%.

Day and night comparisons among these sites revealed statistical site differences ($F_{5,220}$=20.94, P<0.001) , no effect of time period ($F_{1,44}$=0.003, P=0.956), and a significant interaction between site and time period ($F_{5,220}$=7.48, P<0.001) (Figure 9). Overall, pair-wise comparisons for sites showed the intake canal site was statistically different than Site 1 (P=0.031), Site 3 (P=0.046), and Site 4 (P<0.001) (Table 7). At night, the intake canal (Site 6) had statistically fewer larval fish than either Site 1 (P<0.001) or Site 5 (P=0.014). During the day, the intake canal had statistically higher (P≤0.012) larval densities than Sites 3, 4, and 5.

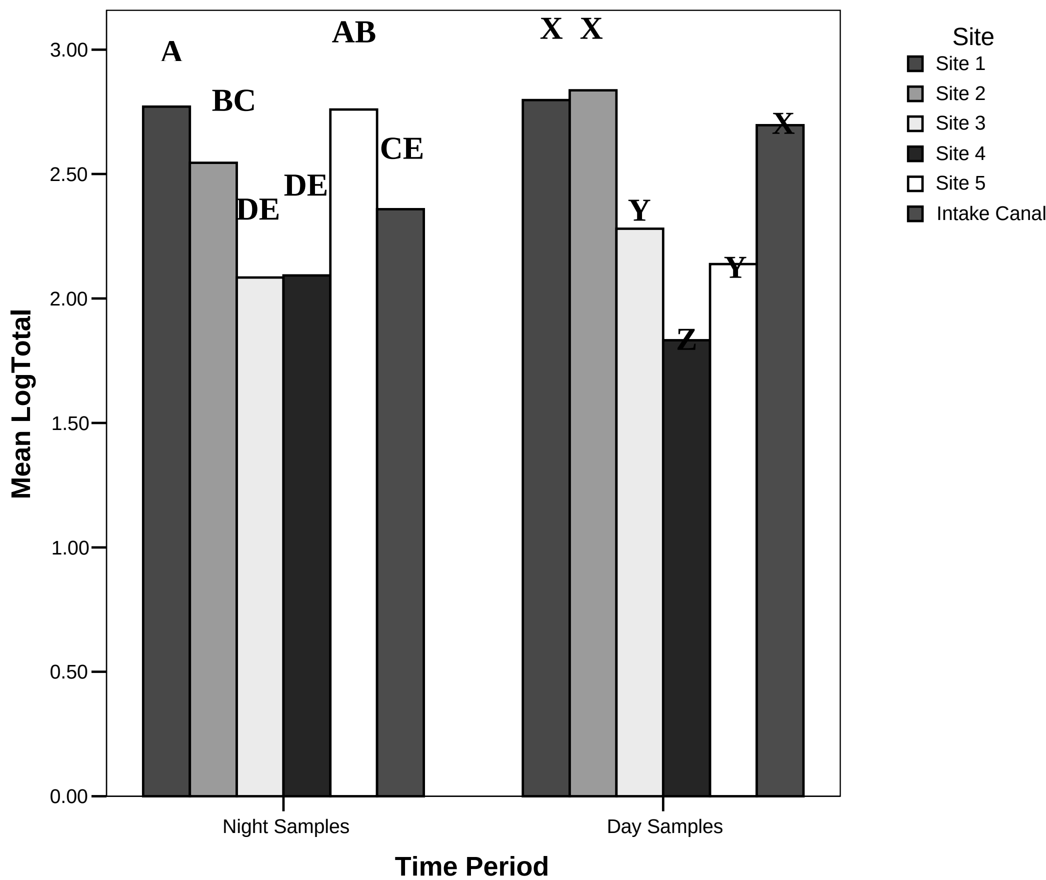

Figure 9. Comparisons among sites by time period for mean $\log_{10}$ total per 100 m^3 of collected larval fish at Barry Steam Electric Generating Plant during the intensive study from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences ($P < 0.05$).

Table 7. Pairwise comparison of the intake canal (Site 6), west shoreline upstream (Site 1), ¼ distance from the west shoreline (Site 2), mid channel (Site 3), ¼ distance from the east shoreline (Site 4), and east shoreline upstream (Site 5) means with standard error, significance, and 95% CI for the $\log_{10}$ total of larval fish collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) site	(J) site	Mean Difference	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 1	-.257*	.078	.031	-.500	-.014
	Site 2	-.164	.094	1.000	-.457	.128
	Site 3	.345*	.110	.046	.004	.686
	Site 4	.565*	.104	.000	.243	.888
	Site 5	.078	.114	1.000	-.275	.432

* denotes that the mean difference is significant at the 0.05 level.

The day and night comparison for the family Clupeidae revealed a statistical difference among sites ($F_{5, 220}$=19.84, P<0.001), a significant ($F_{1, 44}$=15.56, P<0.001) effect of time period, and a significant ($F_{5, 220}$=2.47, P=0.034) interaction between site and time period (Figure 10). For the intake canal, site pair-wise comparisons were statistically different than either Site 3 (P=0.07) or Site 4 (P<0.001) (Table 8). At night, the intake canal was significantly different than either Site 3 (P=0.002) or Site 4 (P=0.002). During the day, the intake canal was statistically higher when compared with Site 3 (P=0.042), Site 4 (P<0.001), and Site 5 (P=0.006).

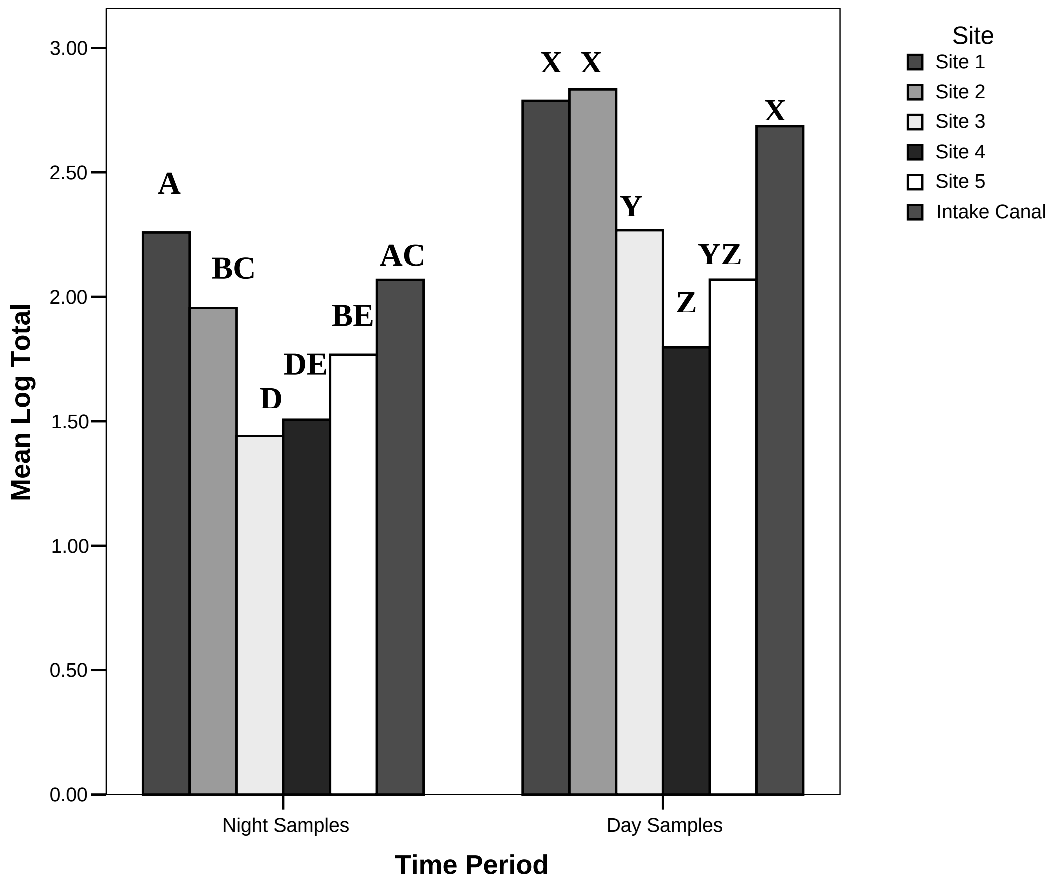

Figure 10. Comparisons among sites by time period for mean $\log_{10}$ total per 100 m^3 of collected larval fish for the family Clupeidae at Barry Steam Electric Generating Plant during the intensive study from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences ($P<0.05$).

Table 8. Pairwise comparison of the intake canal (Site 6), west shoreline upstream (Site 1), ¼ distance from the west shoreline (Site 2), mid channel (Site 3), ¼ distance from the east shoreline (Site 4), and east shoreline upstream (Site 5) means with standard error, significance, and 95% CI for the $\log_{10}$ total of larval fish from the family Clupeidae collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) site	(J) site	Mean Difference	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 1	-.146	.091	1.000	-.428	.135
	Site 2	-.017	.123	1.000	-.398	.363
	Site 3	.523*	.138	.007	.095	.950
	Site 4	.725*	.121	.000	.349	1.101
	Site 5	.459	.149	.053	-.003	.920

* denotes that the mean difference is significant at the 0.05 level.

The statistical comparison of day and night samples for the family Cyprinidae revealed significant differences between sites ($F_{5,220}$=19.33, P<0.001), a significant effect of time period ($F_{1,44}$=143.46, P<0.001), and a significant interaction between site and time period ($F_{5,220}$=3.73, P=0.003) (Figure 11). The intake canal was significantly different than Site 2 (P=0.025), Site 3 and Site 4 (P<0.001) in pair-wise comparisons (Table 9). At night, the intake canal was statistically lower than Site 1 (P=0.003) but higher than Sites 3 (P<0.001) and 4 (P<0.001). During the day, larval densities were statistically higher in the intake canal than at Sites 2 (P=0.003), 3 (P<0.001), and 4 (P<0.001).

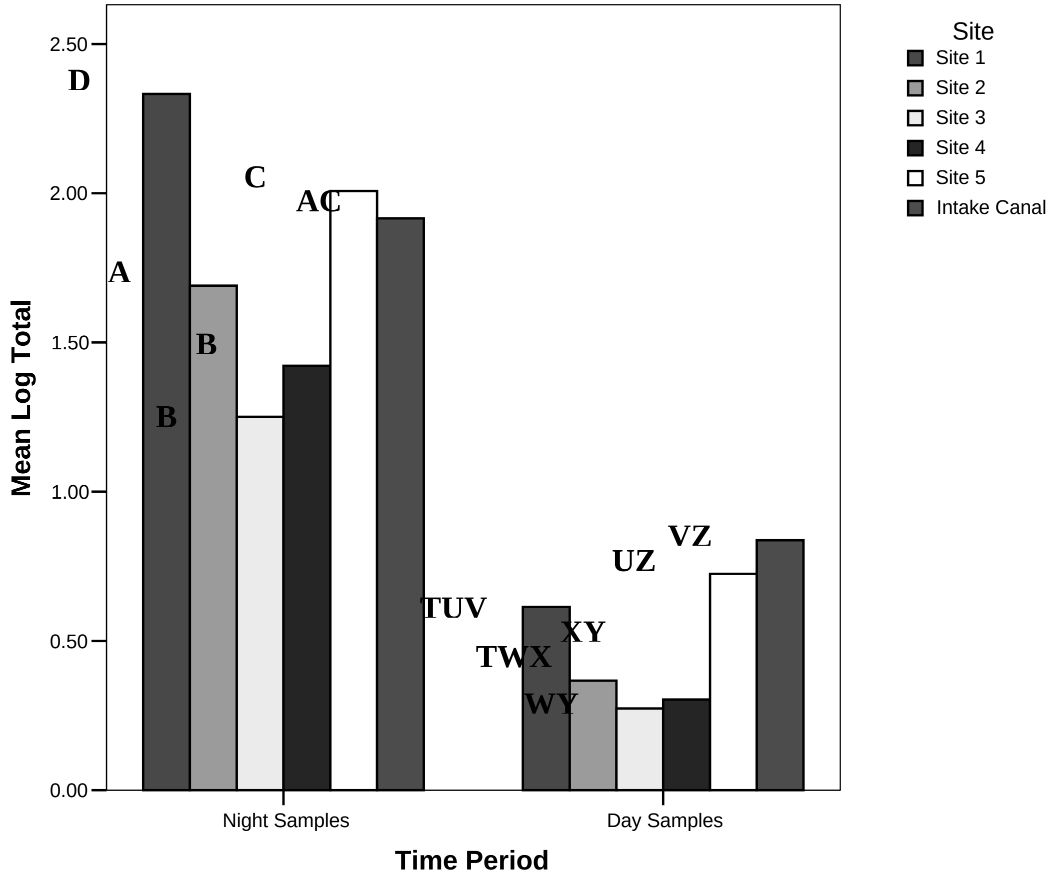

Figure 11. Comparisons among sites by time period for mean $\log_{10}$ total per 100 m^3 of collected larval fish for the family Cyprinidae at Barry Steam Electric Generating Plant during the intensive study from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences ($P<0.05$).

Table 9. Pairwise comparison of the intake canal (Site 6), west shoreline upstream (Site 1), ¼ distance from the west shoreline (Site 2), mid channel (Site 3), ¼ distance from the east shoreline (Site 4), and east shoreline upstream (Site 5) means with standard error, significance, and 95% CI for the log_{10} total of larval fish from the family Cyprinidae collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) site	(J) site	Mean Difference	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 1	-.097	.095	1.000	-.392	.199
	Site 2	.348*	.104	.025	.026	.670
	Site 3	.615*	.101	.000	.300	.929
	Site 4	.514*	.076	.000	.279	.749
	Site 5	.010	.118	1.000	-.356	.377

* denotes that the mean difference is significant at the 0.05 level.

Day and night mean larval densities for the family Sciaenidae were significantly different among sites ($F_{5,220}$=10.08, P < 0.001), time period ($F_{1,44}$=163.31, P<0.001), and a significant interaction occurred between site and time period ($F_{5,220}$=15.79, P<0.001) (Figure 12). Pair-wise comparisons revealed lower larval densities in the intake canal than Sites 1 (P<0.001), 2 (P=0.005), and 5 (P<0.001) (Table 10). At night, the intake canal had statistically lower larval densities than Sites 1 (P<0.001), 2 (P< 0.001), 3 (P=0.046), and 5 (P<0.001). During the day, the intake canal was statistically similar (P>0.05) to each of the other sites in the river transect.

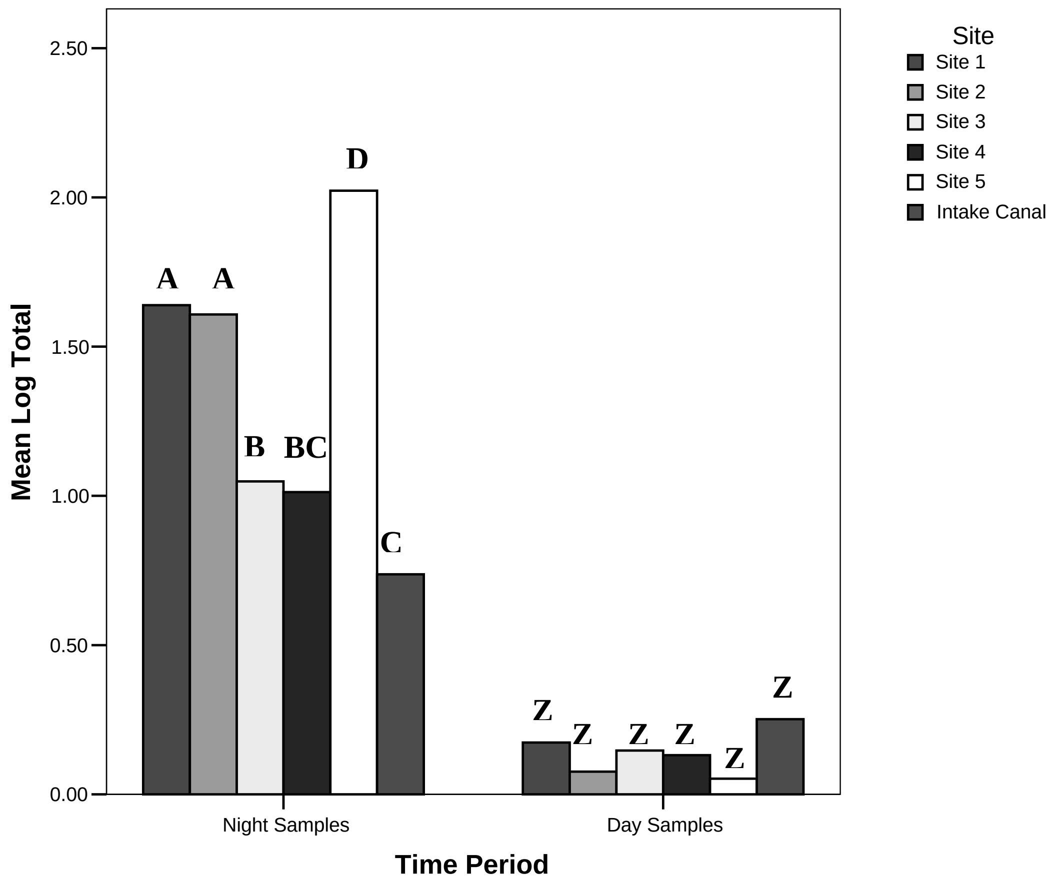

Figure 12. Comparisons among sites by time period for mean $\log_{10}$ total per 100 m^3 of collected larval fish for the family Sciaenidae at Barry Steam Electric Generating Plant during the intensive study from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences ($P<0.05$).

Table 10. Pairwise comparison of the intake canal (Site 6), west shoreline upstream (Site 1), ¼ distance from the west shoreline (Site 2), mid channel (Site 3), ¼ distance from the east shoreline (Site 4), and east shoreline upstream (Site 5) means with standard error, significance, and 95% CI for the log_{10} total of larval fish from the family Sciaenidae collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) site	(J) site	Mean Difference	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 1	-0.412*	0.071	.000	-0.631	-0.192
	Site 2	-0.348*	0.089	.005	-0.625	-0.070
	Site 3	-0.103	0.110	1.000	-0.445	0.238
	Site 4	-0.078	0.121	1.000	-0.453	0.298
	Site 5	-0.543*	0.076	.000	-0.781	-0.306

* denotes that the mean difference is significant at the 0.05 level.

The day and night comparisons for the family Centrarchidae showed a significant difference among sites ($F_{5,220}$=4.50, P=0.001), no significant effect of time period ($F_{1,44}$=1.91, P=0.174), and no significant interaction between site and time period ($F_{5,220}$=1.09, P=0.368) (Figure 13). The intake canal differed statistically from both Site 4 (P=0.010) and Site 5 (P=0.003) (Table 11). At night, the intake canal supported significantly higher larval fish densities than either Site 4 (P=0.031) or Site 5 (P=0.015). During the day, the intake canal was significantly higher than Sites 3 (P=0.018), 4 (P=0.005), and 5 (P=0.002).

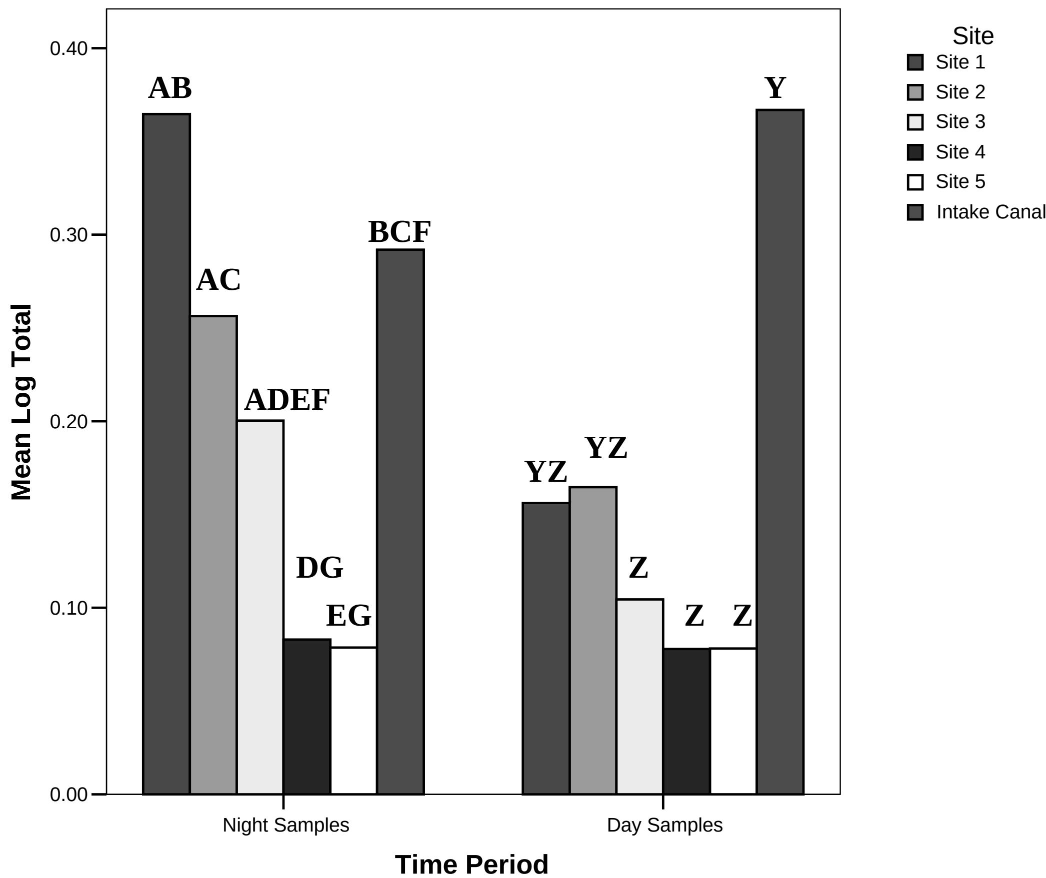

Figure 13. Comparisons among sites by time period for mean $\log_{10}$ total per 100 m^3 of collected larval fish for the family Centrarchidae at Barry Steam Electric Generating Plant during the intensive study from 17 May–21 May 2004. Sites within a specific time period with different letters indicate statistical differences (P<0.05).

Table 11. Pairwise comparison of the intake canal (Site 6), west shoreline upstream (Site 1), ¼ distance from the west shoreline (Site 2), mid channel (Site 3), ¼ distance from the east shoreline (Site 4), and east shoreline upstream (Site 5) means with standard error, significance, and 95% CI for the $\log_{10}$ total of larval fish from the family Centrarchidae collected during the intensive study at Barry Steam Electric Generating Plant from 17 May–21 May 2004.

(I) site	(J) site	Mean Difference	Std. Error	Sig.	95% CI for Difference	
					Lower Bound	Upper Bound
Site 6	Site 1	.069	.080	1.000	-.180	.318
	Site 2	.119	.074	1.000	-.112	.350
	Site 3	.177	.074	.316	-.053	.407
	Site 4	.249*	.068	.010	.038	.460
	Site 5	.251*	.061	.003	.062	.440

* denotes that the mean difference is significant at the 0.05 level.

Long-term Study

There were 8,533 larval fish and no eggs collected during the long-term study. The dominant families collected during the long term sampling period included Clupeidae (68.4%), Cyprinidae (15.2%), Catostomidae (7.5%), Sciaenidae (3.4%), and Centrarchidae (3.2%). These families combined to account for about 98.0% of the total larvae collected during the sampling (Table 12). These dominant families were used in statistical comparisons by month collected during the long-term sampling period. All numbers were $\log_{10}$ transformed to correct for normality.

Table 12. Total number collected, mean, and standard deviation by family collected at Barry Steam Electric Generating Plant during the routine larval fish collections from September 2004 to June 2005.

Family	Number Collected	Mean Number Across Samples	SD
Lepisosteidae	1	0.01	0.09
Clupeidae	5,836	46.69	76.86
Cyprinidae	1,300	10.4	29.4
Catostomidae	641	5.13	11.26
Belondae	2	0.02	0.18
Atherinidae	7	0.06	0.39
Centrarchidae	276	2.21	5.96
Percidae	21	0.17	0.45
Sciaenidae	288	2.3	5.89
Unidentified	161	1.29	2.56
Total	*8,533*	*68.26*	*100.97*

Larvae were collected inside Plant Barry (Site 7) during the months of March, April, May, June, and September (Figure 14). The months of May and June were statistically similar ($P>0.05$). All other months were statistically different ($F_{4,94}=92.83$; $P<0.001$) when compared with each other. April yielded the highest larval fish densities.

The family Clupeidae was collected in the months March, April, May, and June (Figure 15). The months of May and June were statistically similar ($P>0.05$). The lowest densities ($F_{3,82}=125.83$; $P=0.001$) were collected in March, and the highest densities ($F_{3,82}=125.83$; $P=0.001$) were collected in April.

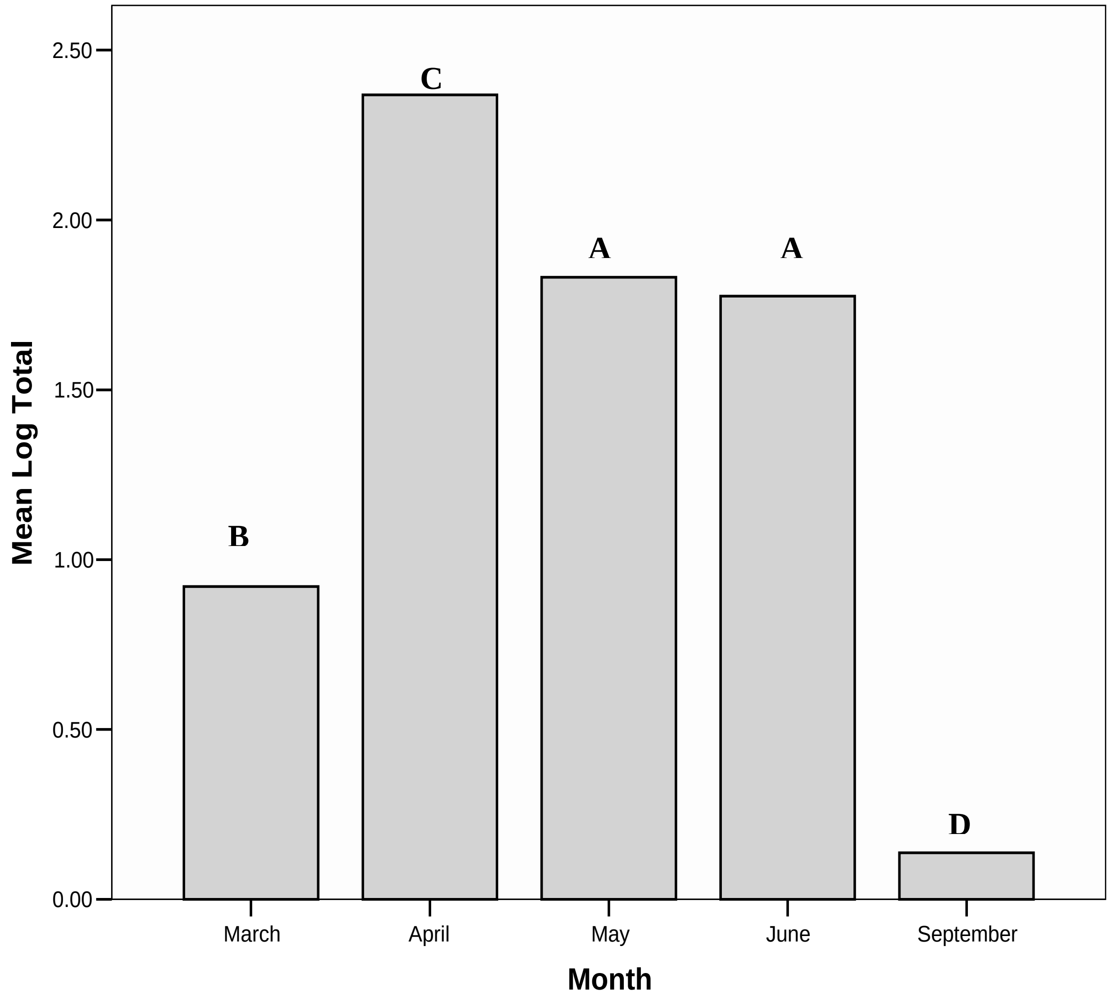

Figure 14. The $\log_{10}$ total larval fish per 100 m^3 collected by month during the long term sampling period at Barry Steam Electric Generating Plant. Months with different letters indicate statistical differences (P<0.05).

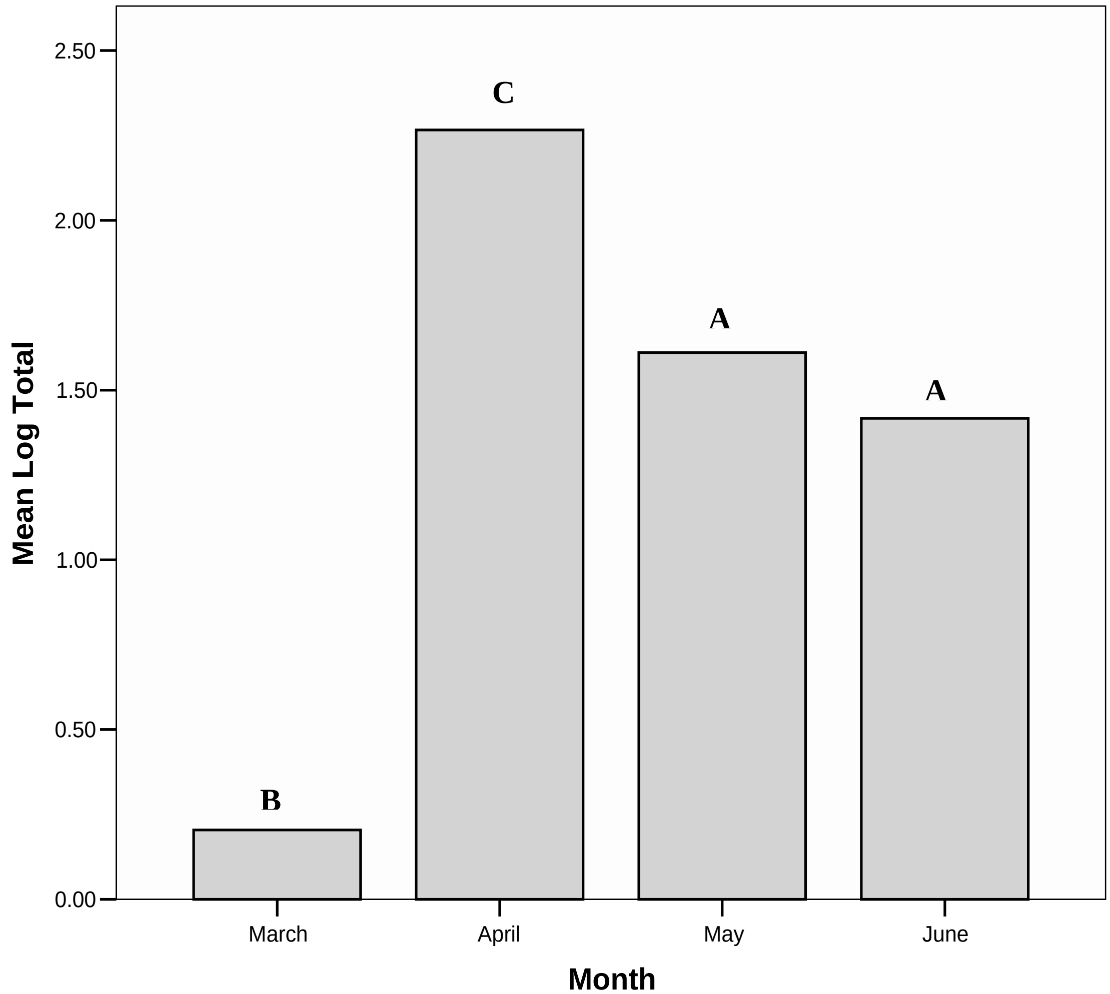

Figure 15. The $\log_{10}$ total larval fish per 100 m^3 for the family Clupeidae collected by month during the long term sampling period at Barry Steam Electric Generating Plant. Months with different letters indicate statistical differences ($P<0.05$).

Relatively small numbers of larval cyprinids were collected in March and September (Figure 16). Larval densities in April, May, and June were statistically ($P>0.05$) similar and significantly ($P<0.05$) higher than March and September.

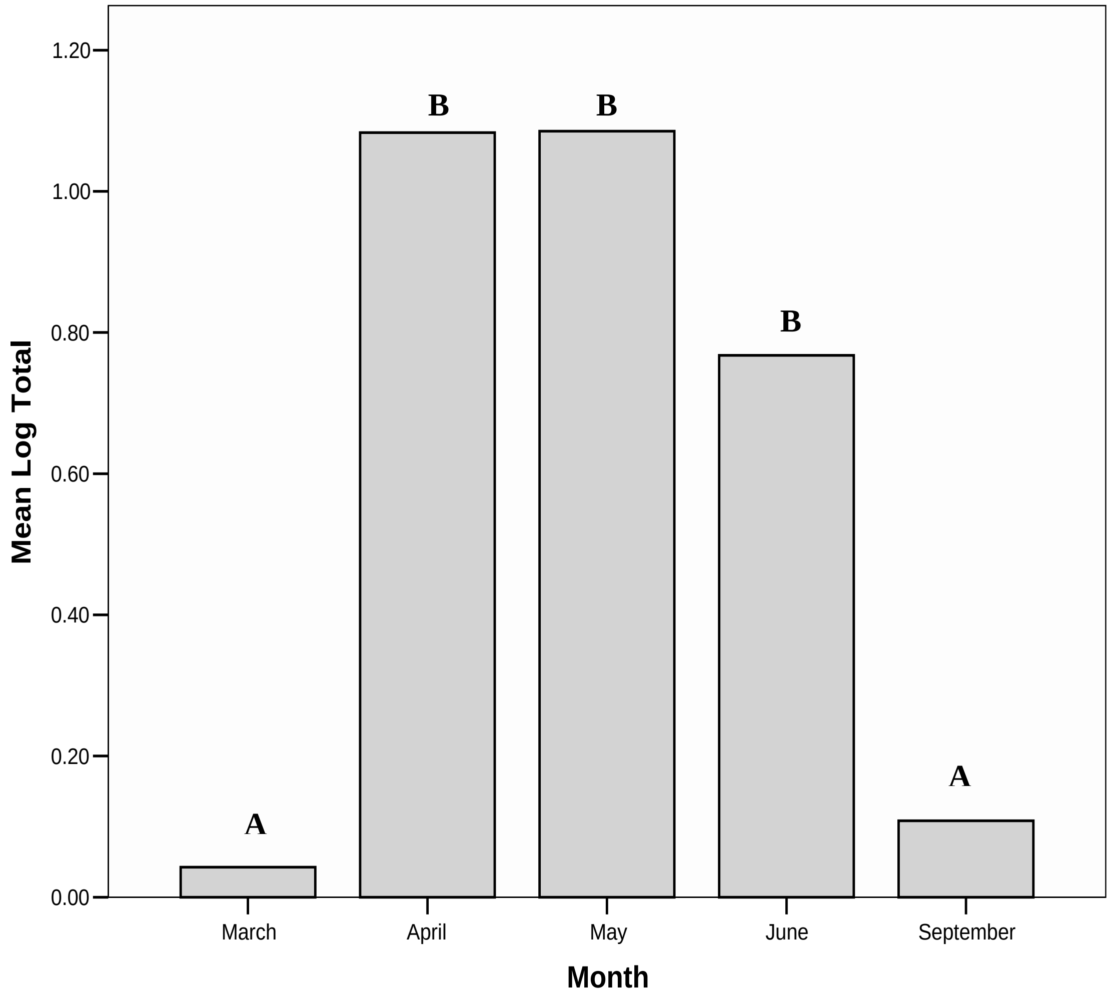

Figure 16. The $\log_{10}$ total larval fish per 100 m^3 for the family Cyprinidae collected by month during the long term sampling period at Barry Steam Electric Generating Plant. Months with different letters indicate statistical differences ($P<0.05$).

Catostomids were collected in the months of March, April, May, and June (Figure 17). Larval densities collected in May and June were relatively low and statistically ($P>0.05$) similar. A comparison between the months of March and May, April and May, and April and June showed statistical differences ($F_{3,82} = 39.31$; $P<0.001$) in means. The March and April mean comparison also yielded statistical differences

($F_{3,82}$ =39.31; P=0.007) in means. June and March showed mean statistical differences ($F_{3,82}$ =39.31; P=0.003) in comparison.

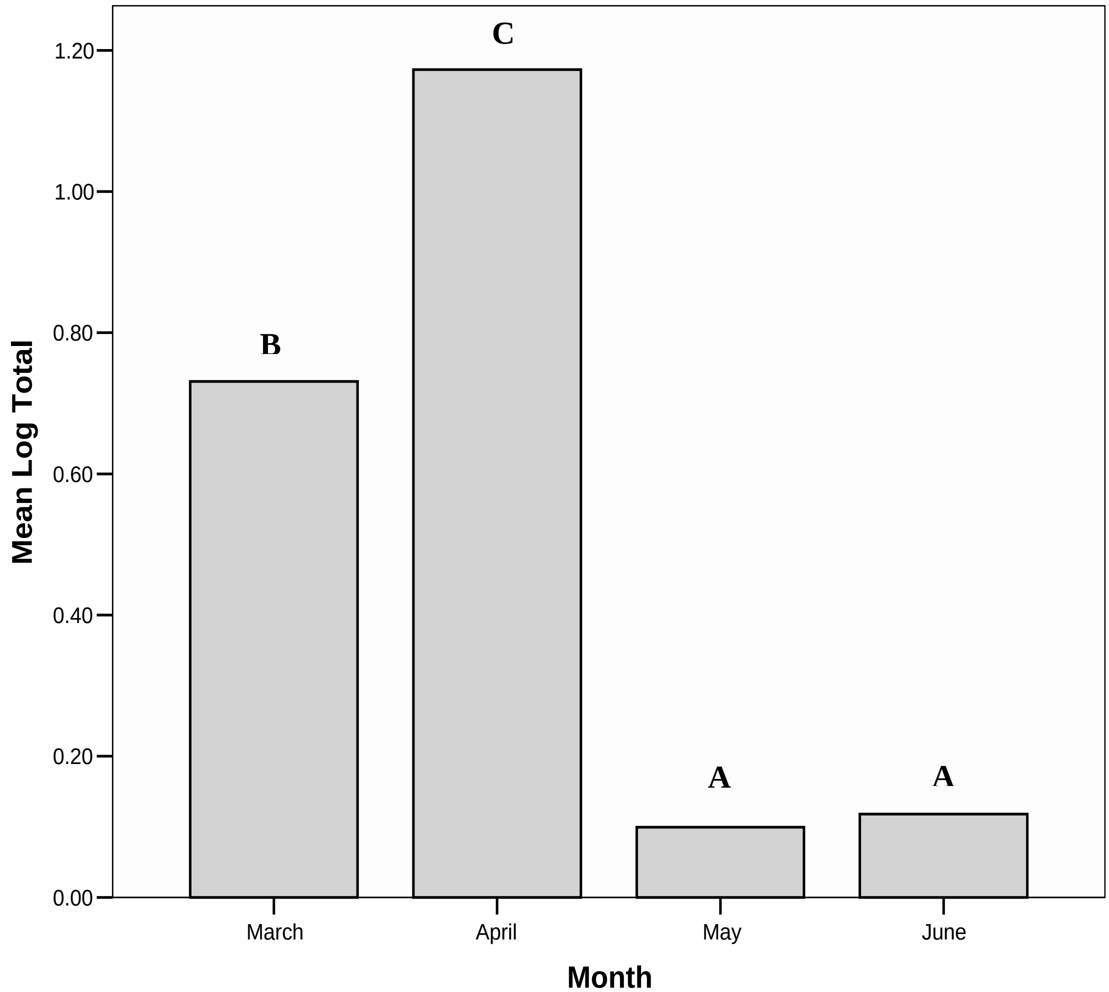

Figure 17. The $\log_{10}$ total larval fish per 100 m^3 for the family Catostomidae collected by month during the long term sampling period at Barry Steam Electric Generating Plant. Months with different letters indicate statistical differences (P<0.05).

Centrarchids were collected during the months of March, April, May, and June for the long term sampling period (Figure 18). The month comparisons of March with

April and April with May yielded statistical differences ($F_{3,82}$ =20.44; P<0.001) in means. June was statistically (P>0.05) similar to the other three months.

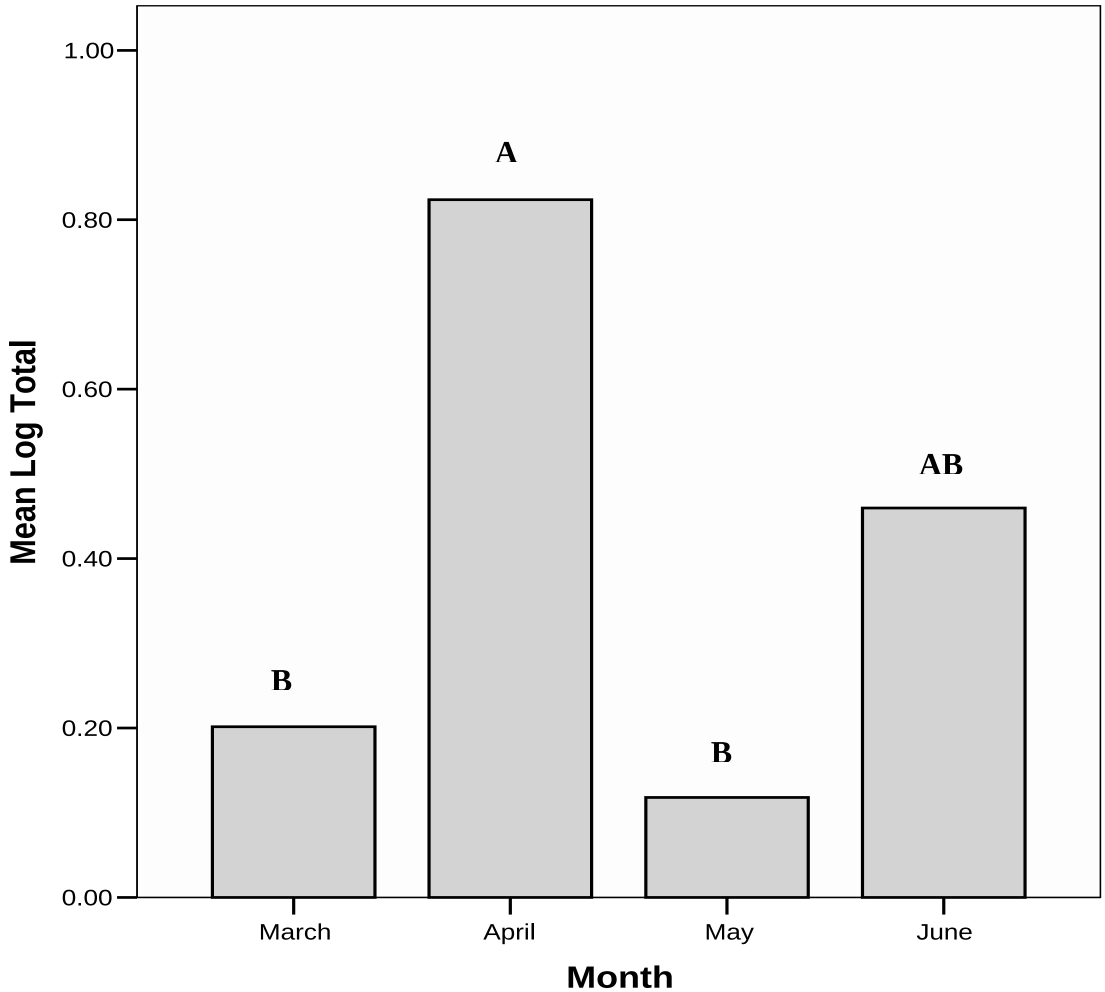

Figure 18. The $\log_{10}$ total larval fish per 100 m^3 for the family Centrarchidae collected by month during the long term sampling period at Barry Steam Electric Generating Plant. Months with different letters indicate statistical differences (P<0.05).

Mean totals for the family Sciaenidae were also analyzed for the months March, April, May, and June (Figure 19). No larvae from the family Sciaenidae were collected during the month of April, so this month was omitted from the analysis. The month comparison between March and May showed statistical differences ($F_{2,60}$ =26.69; P<0.001) in the means, and a comparison between March and June mean totals also showed statistical differences ($F_{3,82}$ =20.44; P=0.009). A mean total comparison between the months of May and June showed statistically similar (P>0.05) values.

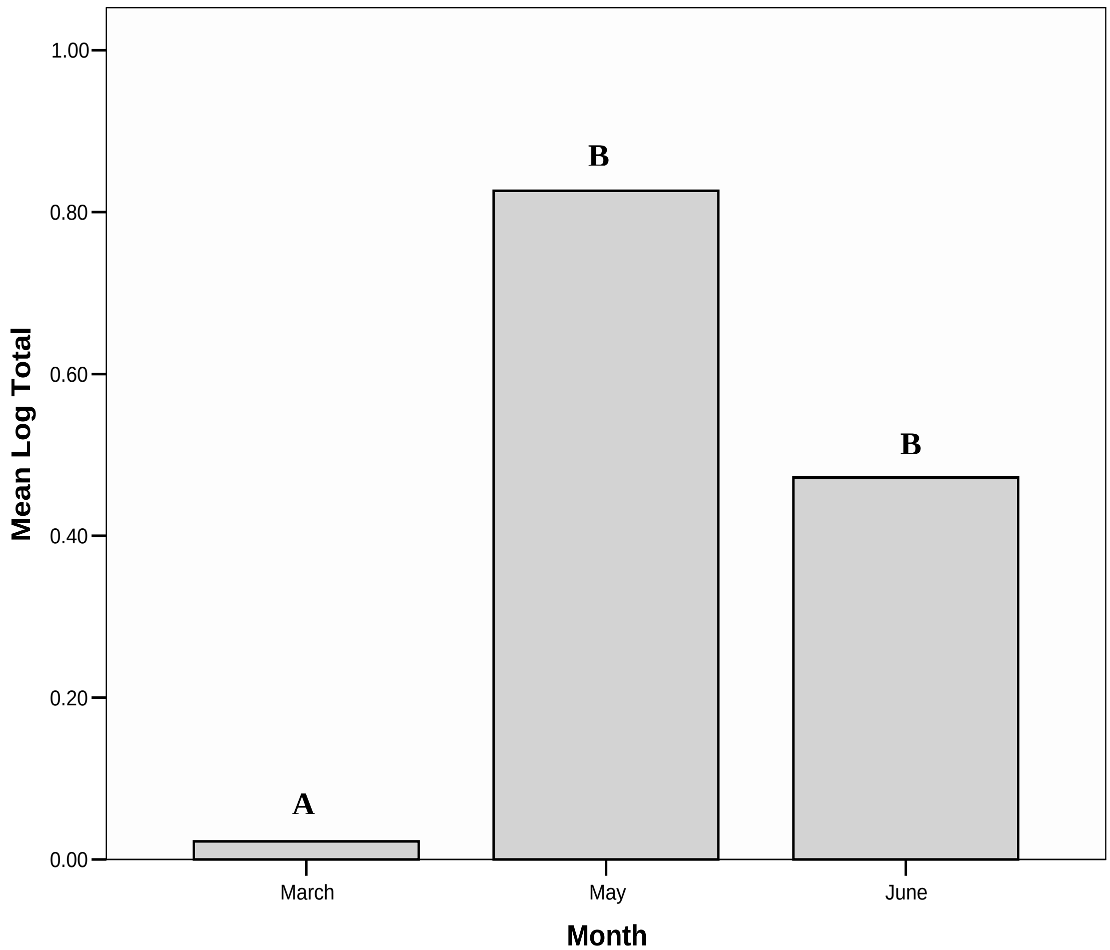

Figure 19. The $\log_{10}$ total larval fish per 100 m^3 for the family Sciaenidae collected by month during the long term sampling period at Barry Steam Electric Generating Plant. Months with different letters indicate statistical differences (P<0.05).

CHAPTER V

DISCUSSION

Plant and Vicinity Site Comparisons

Four larval fish families had the highest numbers of all families collected at Sites 6-9. During the intensive study, a total of 19,334 (71% of the total numbers sampled at the plant and vicinity) clupeid larvae were collected at these four sampling sites. Larval cyprinids sampled at these four sites numbered 4,875 (18%). The family Sciaenidae had 2,247 (8%) larvae, while a total of 90 (0.3%) larval centrarchids were sampled at these four sites during the intensive study.

Since the overall larval fish densities in the intake canal were statistically higher than those collected inside Plant Barry, future sampling protocol should take into account these differences. Estimating entrainment by sampling in the intake canal would represent a more liberal estimation of entrainment densities for Plant Barry. However, sampling inside Plant Barry at Site 7 would provide a more conservative estimate of total entrainment densities.

None of the sampled sites can be considered representative of the best possible estimate of larval fish entrainment. Larval fish entrainment losses within Plant Barry are to be expected because of the cooling water intake design. Factors such as mechanical damage and disintegration of entrained larvae make it unlikely that any site inside the plant (Site 7) or downstream of the plant (Sites 8-9) could be considered the best possible site for entrainment estimation at Plant Barry. Power plant effects on larval fish have been documented in previous studies where larval fish are damaged or killed during entrainment (Marcy 1973, Jude et al. 1986). These factors were evident at Plant Barry from a comparison of the total larval fish densities in the intake canal (60% of larvae collected among the 4 sites), to the unit 2A condenser tap (17%), and finally to the discharges from units 1-3 (10%) and 4-5 (14%). The 152.4 m distance from the intake screens to the 2A condenser (Site 7) within Plant Barry, in conjunction with the high (2.58 m^3/s) flows at the condensers, is likely to result in compression and disintegration of the fish larvae. In addition, larval contact with the walls of the 1.37 m diameter pipe probably causes considerable mechanical stress and damage to the larvae. Collections at more than one condenser site in Plant Barry may allow a better understanding of the density differences and similarities that exist among these sites.

Larval fish vertical distribution in the water column should be determined in future larval fish studies. The uncertainty concerning how larval fish are suspended in the water column at each site makes it difficult to determine the best sampling site for entrainment studies. For example, it is possible that the higher populations of larval fish were observed because larval fish were concentrated in the near surface portion of the water column where the samples were collected. This is especially true in the intake canal due to the entrance of different water masses that can cause larval fish movements due to upwelling in the water column. The location of sampling equipment should occur in uniform current and well-mixed water in order to avoid biased entrainment numbers (Jude et al. 1986).

Condenser temperature is another factor influencing larval fish entrainment losses. The initial water temperature, increase in water temperature by the plant itself, and the length of temperature exposure for the larvae are key factors in survival assessment. Seasons and even times of day influence the water temperature, along with larval fish survivability at power plants (Jinks et al. 1978).

Sampling with larval fish pumps throughout the water column at these sites should be conducted in order to obtain a better estimate of larval fish density. High volume pumps have been shown to be more effective than larval nets in high velocity intake canal waters (Leithiser et al. 1979). These larval fish pumps may also aid in answering questions concerning density differences among sites at and around Plant Barry. The use of pumps and assessing larval damage must be included in a well-rounded entrainment sampling design.

River Transect and Intake Canal Comparisons

Total larval fish densities collected from the river transect were similar to those collected in the intake canal. Both the pair-wise and diel comparisons between these sites show that, in fact, at least two river sites were similar in larval density to the intake canal. Statistical similarities between river transect sites and the intake canal suggests that larvae were imported from the Mobile River into the intake canal by way of the HZI. Larvae from points in the Mobile River were most likely swept by the river current into the intake canal, making them available for entrainment by Plant Barry. Hydraulic features greatly influence both the spatial distribution and movement in larval fish (Pavlov 1994). It is estimated that the maximum swimming speed of a larval fish in freshwater streams is around 8.4 cm/s for a 12 mm long larvae, and any current greater than the 8.4 cm/s will cause the larvae to drift in the direction of the flow (Scheidegger and Bain 1995). The current velocity inside the HZI could be as high as 30.5 cm/s.

Clupeid densities in the intake canal also showed similarities with the densities found at specific sites within the river transect. Both the pair-wise comparisons and diel comparisons revealed specific similarities between densities in Sites 1 and 2 of the river transect and the intake canal. This meant that larvae from the family Clupeidae were possibly be introduced into the intake canal by specific sites in the river for possible entrainment. Members of the family Clupeidae broadcast sperm and buoyant eggs into their surroundings during the breeding process (Mettee et al. 1996). Spawning clupeids are able to broadcast between 8,000 and 380,000 eggs during a single spawning season (Boschung and Mayden 2004). Both the fecundity and spawning characteristics of clupeids offer an explanation for the dominance of larval clupeids throughout the entire study at Plant Barry.

The Mobile River was a significant contributor of cyprinid larvae to the intake canal. Both pair-wise comparisons diel samples showed that the Mobile River contributed cyprinid larvae to the intake canal for entrainment. Since both the intake and Mobile River shorelines (Sites 1 and 5) were statistically similar, it seems likely that the intake canal also serves as a nursery area for cyprinids. Scheidegger and Bain (1995) found that the greatest concentrations of larval fish were distributed along the river margins, which are regarded as very important nursery areas to larval fish.

Comparisons of the intake canal and the river transect for the family Sciaenidae also indicated that the river was a significant source of larvae for possible entrainment by Plant Barry. At least two sites in the river transect showed statistical similarity in pair-wise comparison to the intake canal, while the diel comparisons showed at least one site was similar in comparison with the intake canal. This further illustrated the impact the Mobile River and HZI had on introduction of larval Sciaenids into the intake canal at Plant Barry.

For samples collected during this study, Sites 1-3 of the river transect showed statistically similar densities compared with the intake canal for the family Centrarchidae for both the night samples and the overall pair-wise comparisons. The Mobile River could be viewed as a significant contributor of larval centrarchid densities to the intake canal, providing for the possible entrainment of these larvae by Plant Barry.

Long-term Study

Larval fish were collected in each of the five months sampled during the study. The peak of spawning and the highest entrained densities at Plant Barry were in the month of April, which exhibited the highest density and was statistically different from each other month. Overall, the larval fish entrainment began to taper off in September since that month had the lowest density of larval fish and was statistically different than every other month.

Spawning of clupeids began in March around Plant Barry. Clupeids begin spawning in early spring and summer when water temperatures reach 18-21 ^{o}C (Mettee et al. 1996). Specific clupeids such as threadfin shad have been found to spawn in Missouri in waters reaching 21.3 ^{o}C (Pflieger 1975, Mettee et al. 1996). Mean temperatures for the Mobile River from March through June range from 17.6 to 29.4, indicating that these months are well within the preferred temperature range of clupeid spawning (Pearman et al. 2002). The month of April was the peak of entrainment and, possibly, spawning for the family Clupeidae. It also had the highest mean densities, which were statistically different than any of the other months collected.

Cyprinids began spawning near Plant Barry in March and began to decline dramatically in September, with both months being statistically similar. According to Mettee et al. (1996), spawning of cyprinids could occur any time between March and October depending on the species of cyprinid. Spawning temperatures for some cyprinids had been found in a previous study to occur at a range of 10 to 16 ^{o}C in the mid-Columbia River (Gray and Dauble 2001). In previous years, the USGS has recorded temperatures greater than this during these months for the Mobile River, allowing for the possibility of cyprinid spawning during these months (Pearman et al. 2002). Cyprinid spawning and entrainment peaked during the months of April and May, and the density of collected larvae began to decline in June.

Interestingly, larvae from the family Catostomidae were collected in larger numbers during the long term study than the intensive study. The catostomids were collected in significant densities at Plant Barry from March to June. Depending on the species, catostomid spawning occurs as early as March and as late as July (Mettee et al. 1996). An earlier intensive sampling would be needed to assess the entrainment impacts on larval catostomids. Spawning temperatures for the smallmouth buffalo, a member of the family Catostomidae, was recorded between 15 and 16 ^{o}C (Wrenn 1969). The Mobile River has historically seen temperatures higher than this during the same months in which these larvae were collected for this study (Pearman et al. 2002). The peak of catostomid entrainment at Plant Barry was in April, with May and June showing significantly lower densities in the study.

From the months of March through June, larvae of the family Centrarchidae were collected at Plant Barry. Peak entrainment densities occurred in April, with a significant decline in May and a similar density collected in June. Spawning of centrarchids in Alabama waters occurs from March until April, with some species of centrarchids (largemouth bass) spawning at water temperatures of 17 to 20 ^{o}C (Mettee et al. 1996). Other centrarchids (Genus *Lepomis*) begin spawning at temperatures of 16 to 25 ^{o}C with longer periods of daylight (Boschung and Mayden 2004). According to previous data collected in the Mobile River, water temperatures average slightly higher than 25 ^{o}C during the months in which centrarchids were collected in this study (Pearman et al. 2002).

Only 3 months of the long term study yielded entrained larvae from the family Sciaenidae. Significantly fewer sciaenids were collected in March than in either May or June. May proved to be the peak of entrainment for sciaenids at Plant Barry, but the density collected in May was statistically similar to the density collected in June. Spawning for members of the family Sciaenidae occurs at temperatures around 20 ^{o}C from May until mid-summer (Boschung and Mayden 2004; Mettee et al. 1996).

Summary

Entrainment sampling inside Plant Barry provided a conservative estimate of larval fish densities, while sampling in the intake canal resulted in a more liberal assessment. Various factors influencing larval fish sampling and entrainment would not allow for the designation of a single site as providing the best estimate of larval fish entrainment. These factors include larval fish damage due to the mechanical effects of the plant itself, stratification of larval fish in the water column, and sampling at only one condenser inside the plant. More studies need to be conducted in order to ultimately determine a better design for entrainment studies at Plant Barry

For the Mobile River transect and intake canal collections, at least one river transect site for the total larval and family-wise densities was similar to the densities collected inside the intake canal. In fact, larval densities at Sites 1 and/or 2 were statistically similar to those at Site 6 for about 80% of all the fish families collected. Both pair-wise comparisons of sites and site by time period analyses confirmed this. The Mobile River flow and the HZI functioned together to move larval fishes from the river to the intake canal. These introduced larvae had the potential to be entrained by Plant Barry due to the relatively high flow into the intake canal and through the intake screens (30.5 cm/s).

Overall, the long-term entrainment of larvae at Plant Barry closely followed the spawning patterns exhibited by the specific fish families. A working understanding of family spawning characteristics is therefore important in assessing the temporal variations at which entrainment may begin and end at Plant Barry.

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