VARIABLES INFLUENCING FISH IMPINGEMENT AT FIVE ALABAMA POWER STEAM PLANTS

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VARIABLES INFLUENCING FISH IMPINGEMENT AT FIVE ALABAMA POWER STEAM PLANTS

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VARIABLES INFLUENCING FISH IMPINGEMENT AT FIVE ALABAMA POWER STEAM PLANTS

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VITA

David Thomas Saalfeld was born in Cincinnati, Ohio on January 13, 1980. He grew up in Northern Kentucky and graduated from Newport Central Catholic High School in Newport, Kentucky in 1998. Following this, he attended Thomas More College where he worked for three years at Thomas More College's Center for Ohio River Research and Education. David graduated from Thomas More College cum laude with a Bachelor of Arts in Biology in 2002. He then began his graduate degree as a research assistant in Fisheries and Allied Aquacultures and as an intern at Alabama Power. David finished his degree requirements for a Masters of Science in Fisheries and Allied Aquacultures in May 2006.

THESIS ABSTRACT

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With increasing need for electricity, steam powered electric generating facilities are increasing across the nation. The cooling water intake structures at these plants are responsible for removing millions of fish and other aquatic organisms from U.S. waters annually. Due to recent rulings by the Environmental Protection Agency, steam powered electric generating facilities that meet certain criteria need to reevaluate Section 316(b) of the Clean Water Act of 1972. These steam plants are required to quantify fish mortality caused by impingement and determine the affects this mortality is having on local fish assemblages. Previous studies have noted numerous physical, chemical and biological variables (i.e. dissolved oxygen, water temperature, conductivity, pH, turbidity, intake velocity, intake flow, debris loading, river stage, number of screens in use, hydraulic zone of influence and river discharge) influencing impingement rates. The majority of studies found impingement rates to be most influenced by water temperature, with higher impingement rates corresponding to low water temperatures. The majority of these studies, however, were conducted in northern climates, where winter temperatures are often much lower than in Alabama. Additionally, most of the studies conducted on impingement rates were done in the 1970s. Therefore, the need to reevaluate the factors influencing impingement is great.

In this study, impingement rates were determined for five steam plants (Barry, Gadsden, E. C. Gaston, Gorgas, and Greene County Steam Plants), seasonal and monthly patterns in impingement rates were investigated, and the potential influence of several physical, chemical and biological variables (i.e. dissolved oxygen, water temperature, conductivity, pH, turbidity, intake flow velocity, intake flow volume, debris loading, river stage and river discharge) on impingement rates were determined. From this, the majority (86%) of fish impinged were comprised of threadfin shad (*Dorosoma petenense*), blue catfish (*Ictalurus furcatus*), and freshwater drum (*Aplodinotus grunniens*). In addition, impingement rates were most affected by water temperature, dissolved oxygen, hydraulic zone of influence, river discharge, and time of year. Since the majority of fish impinged were from the smaller length classes, fluctuations of these variables may have had a more dramatic effect on these smaller more easily stressed individuals, ultimately causing higher impingement rates.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. Introduction

With increasing need for electricity, steam powered electric generating facilities are increasing across the nation. These plants draw water from a natural resource, such as a river or reservoir, and use it primarily as cooling water. The physical structure and any associated waterways used to withdraw this water are referred to as the cooling water intake structure (CWIS) (U.S. EPA 2002). These structures remove millions of fish and other aquatic organisms from U.S. waters each year (U.S. EPA 2002). CWIS have the potential to impact aquatic organisms mainly through entrainment and impingement (Lohner et al. 2000). Entrainment occurs when organisms pass through the intake screens and travel through the power plant resulting in thermal stress and physical damage (Lohner et al. 2000; U.S. EPA 2002). Impingement occurs when organisms are entrapped against the traveling screens or intake structure during water withdrawal (Lohner et al. 2000; U.S. EPA 2002).

Edsall and Yocom (1972) suggested that losses of fish and other aquatic life may represent a potentially significant impact on existing fisheries depending on the species affected and the number killed. Because of this, the Clean Water Act of 1972 Section 316(b) states that the Environmental Protection Agency (EPA) must regulate the location, design, construction, and capacity of CWIS, so that it reflects the best available technology to minimize any adverse environmental impacts (Dey 2002; U.S. EPA 2002). Section 316(b) also states that individuals, populations, and communities of aquatic organisms need to be protected from any physical or chemical stress caused by a CWIS (U.S. EPA 2002). In order to regulate this, impingement and entrainment mortality rates of aquatic life must be assessed or predicted for each power plant in the United States as part of the permit renewal process for the operation of an electric power plant (Boreman et al. 1981).

Following the Clean Water Act of 1972, little research was conducted to determine effects of CWIS on aquatic populations, and enforcement was performed solely on a site-by-site basis. Because of this, there was considerable variation in compliance requirements and impacts on the environment among steam plants (Lohner et al. 2000). In the late 1990s, the Hudson Riverkeepers and several related environmental groups successfully sued the EPA for failure to uphold Section 316(b) regulations (Lohner et al. 2000). The high numbers of impinged fish at some sites and weak compliance with 316(b) requirements prompted the lawsuit and caused the EPA to now mandate assessments of impacts on the aquatic communities. Now, several decades after the introduction of the Clean Water Act of 1972, there is a new need to further study these effects and determine the environmental impacts on natural resources and aquatic life.

The full impact of the loss of fish to impingement depends on the time of year, water demand, and population densities of the organisms in question (Spigarelli et al. 1981). However, the effect that impingement mortality has on the surrounding ecosystem is poorly understood. From the few studies that have been conducted, there were few, if any, negative impacts on the fish community (Alabama Power 1977). However, most of the past data was gathered in the 1970s and has become outdated. Therefore, there is still little known concerning the current impact impingement is having on ecosystems and fish communities. Although the effects of impingement on the aquatic ecosystem are unknown, the U.S. EPA has mandated that applicable steam plants reduce impingement rates by 80 to 95% (U.S. EPA 2002). However, fish impingement rates are highly variable and therefore difficult to quantify with any statistical certainty. In a review of impingement rates at several southeastern steam plants, Loar et al. (1978) reported variations in daily impingement rates from more than 100,000 fish to less than 10 fish. These patterns could be due to many biological factors (i.e. relative abundance, life history characteristics, length, weight, and condition), water quality (i.e. temperature, dissolved oxygen, turbidity, nutrients, chlorophyll, and pH) and hydrological factors (i.e. approach velocity, sweeping velocity, and hydraulic zone of influence). However, little is known about the impacts of these variables on impingement. Additionally, we need to understand these factors in order to properly account for the organisms being removed from the ecosystem and to aid in the design of potential mitigation options (i.e. change in location of water withdrawals, or sweeping velocities). These variables are also likely specific to the location of the plant and to the various ecoregions within the United States. Therefore, understanding these variables across different ecoregions becomes essential.

In this study, I determined impingement rates and assessed the variables influencing these rates in several different physiographic regions (Coastal Plain, Alabama Valley and Ridge, and Cumberland Plateau) across Alabama. The objectives for this study were: 1) to determine impingement rates for each of five coal-fired steam plants (Barry, Gadsden, E. C. Gaston, Gorgas, and Greene County Steam Plants), 2) to determine seasonal or other temporal patterns in impingement rates, and 3) to measure several physical, chemical and biological variables (i.e. dissolved oxygen, water temperature, conductivity, pH, turbidity, CWIS flow velocity, CWIS flow volume, debris loading, river stage and river discharge) and to determine if any relationship exists with these factors and impingement rates.

II. Literature Review

Aquatic organisms drawn into CWIS are either impinged or entrained into the cooling water system (U.S. EPA 2002). Impingement takes place when organisms are trapped on the outer part of the CWIS, which, in most cases, is a screening device used during periods of water withdrawal to decrease the amount of debris and organisms drawn into power plants (Grimes 1975; U.S. EPA 2002). The impingement of organisms, which are primarily fish that are in their early life stages, usually occurs because of hydraulic forces (U.S. EPA 2002). According to the U.S. EPA (2002), impingement can cause mortality in several ways including starvation, exhaustion, asphyxiation, and physical damage. However, a possibly overlooked factor that may be affecting the number of organisms impinged is natural mortality (e.g. cold shock). Additionally, rates of impingement could depend on life history characteristics, fish movements, CWIS design and operation, source water hydrology and water quality (U.S. EPA 2002). For example, mortality rates or impingement rates were found to be higher where the CWIS was in proximity to estuaries due to the use of these areas as nursery grounds for many species (U.S. EPA 2002).

Fish Movements

Movement of fish vertically in the water column in response to environmental variables has been documented in several studies (McNaught 1968; Lifton and Storr

1978). McNaught (1968) was one of the first to document this behavior using a combination of plankton nets and echo sounding. Fish have not only been documented making vertical migrations, but also seasonal migrations. These migrations could have a substantial effect on fish impingement rates. In a study done by Lifton and Storr (1978) on the Niagara River, all species of fish impinged showed seasonal movements or changes. Therefore, they concluded that seasonal movements were one of the main reasons certain species were available to be impinged. Besides normal seasonal movements, Lifton and Storr (1978) also examined several other factors such as cloud cover, migrations, and wind that may influence impingement. Cloud cover was inversely correlated with the numbers of fish impinged (Lifton and Storr 1978), with increasing cloud cover causing daytime active fish to become less active. In addition, nocturnal fish activity patterns were also different than normal since the lack of proper twilight level failed to trigger normal activity (Lifton and Storr 1978). Lifton and Storr (1978) also concluded that wind and wind-induced effects were strongly correlated to fish impingement. Wind effects on large bodies of water (e.g. Lake Erie) can have significant effects on fish location. Wind passively moved fish toward the intake structure and therefore increased the rate of impingement (Lifton and Storr 1978). Lifton and Storr (1978) also concluded that with increasing wind, turbidity also increased, causing fish to be more vulnerable to intake structures due to decreased visibility.

Cooling Water Intake Structure

There are several factors associated with CWIS that influence impingement including location, intake design, volume of water withdrawn, intake velocity, and hydraulic zone of influence (HZI). Intakes located closer to shore tended to cause a greater ecological impact since near shore areas are usually more biologically productive and have higher concentrations of aquatic life. As temperatures dropped in early fall in Lake Erie, fish moved toward inshore areas in proximity to the CWIS and higher rates of impingement occurred (Lifton and Storr 1978). In addition, near shore CWIS in marine environments tended to impinge more fish. This is thought to occur since marine environments contain more species and a greater number of species utilize shallow habitat located close to shore for rearing young. In one particular study done by Savitz et al. (1998), on 58 sampling dates, only 93 individuals were impinged at a Lake Michigan steam plant. These low numbers were attributed to the CWIS being located offshore with a low velocity intake. Bernhard and Latvaitis (1976) also examined how intake velocity effected impingement. In their study, it was inferred that gizzard shad (*Dorosoma cepedianum*), the species found to be impinged the most in the Great Lakes, was impinged mainly due to the high intake velocities.

Water Body Conditions

Physical factors such as river discharge, elevation of the water body (stage), and the amount of debris have been found to influence impingement rates. Mathur et al. (1977) found that numbers of fish impinged increased as Susquehanna River discharge increased and pool elevation decreased. Hoyt (1979) found that impingement was greatest during winter and late fall at steam plants along the Ohio and Green Rivers following declines in water levels greater than 1 meter (14,892 individuals impinged per day) as compared to declines less than 1 meter (1,124 individuals impinged per day). In addition, suspended sediments and debris loading may cause increases in impingement rates (Hanson et al. 1977). Hanson et al. (1977) reported that accumulation of debris on intake screens can affect impingement by further serving to entrap and entangle fish and by altering the hydraulic flow and intake velocity.

Dissolved Oxygen

On the Wabash River in Indiana, Lewis and Seegart (2000) concluded that impingement rates tended to vary inversely with dissolved oxygen (DO) concentrations, where the highest impingement total coincided to the lowest DO measured during the study. DO depletion could stimulate fish movement toward higher DO concentrations in adjacent areas. This movement, however, could expose fish to other variables such as low water temperature or cause them to be displaced closer to the CWIS (Bodensteiner and Lewis 1992). Low DO concentrations could also stress fish making them more susceptible to impingement.

Temperature

Low water temperature have been reported to be the most influential factor on impingement rates, with a correlation between decreasing temperatures and number of fish impinged (Grimes 1975; Mathur et al. 1977; Lifton and Storr 1978; Hoyt 1979; LaJeone and Monzingo 2000). Cooler temperatures cause fish to be more sluggish and have reduced swimming ability, making them more susceptible to impingement (Griffith and Tomljanovich 1975; Grimes 1975; Hoyt 1979). In a study done on the Mississippi River, gizzard shad impingement increased during the autumn and remained high throughout the winter with peak impingement rates coinciding with freezing or near freezing water temperatures in January (LaJeone and Monzingo 2000). Gizzard shad, especially the young-of-the-year, seem to show increases in impingement during the cooler months due to their intolerance of cold water temperatures (Bodensteiner and Lewis 1992). At severe temperatures (i.e. < 4°C) gizzard shad are known to become severely stressed (Stone and Webster Engineering Corp 1976), and during the coldest months on the Upper Mississippi River a vast majority of this species were found dead before being impinged, presumably due to cold shock (LaJeone and Monzingo 2000).

These same trends were noted in southeastern U.S. with the impingement of threadfin shad (*Dorosoma petenense*). Impingement rates increased when the water temperature dropped below 10°C (Loar et al. 1978). In laboratory tests conducted at 9°C, threadfin shad exhibited decreased feeding activity and schooled less compactly (Griffith 1978). In addition, threadfin shad lost equilibrium and mortality occurred at temperatures at or below 4°C (McLean et al. 1985). Strawn (1965) found similar results in laboratory tests on threadfin shad in which significant mortality started occurring at 9°C and below. The effects from colder temperatures can ultimately lead to an increase in impingement rates. McLean et al. (1985) documented an increase in threadfin shad impingement on Watts Barr Reservoir in Tennessee [from 3,000 individuals per day to 5,000 individuals per day to 42,000 individuals per day] as temperatures dropped to 7°C and then to 4°C.

Life History Traits

Although there have been many studies on impinged fish composition, few have examined life history traits as a factor influencing fish impingement rates. However, certain fish species such as gizzard shad, threadfin shad, and freshwater drum *(Aplodinotus grunniens*) become impinged more than other species despite their abundance in the original water source (Hoyt 1979; LaJeone and Monzingo 2000; Lewis and Seegart 2000). Lewis and Seegart (2000) found that gizzard shad made up 59% of the impingement catch, even though they accounted for only 5% of fish abundance in the Wabash River in Indiana. On the other hand, cyprinid species made up 91% of the Wabash River population, but were almost absent from impingement with less than 1% being impinged. Although not examined in this study, life history traits could be an explanation for this discrepancy. Species that are planktonic during the early life stages, spawn in nearshore areas and are small as adults are more susceptible to impingement (U.S. EPA 2002). In one of the few studies that focused on life history traits, Lajeone and Monzingo (2000) concluded that freshwater drum were more susceptible to impingement because of its pelagic early life stages and abundance in the Upper Mississippi River. Spawning date and length of the fish may also have a crucial role in impingement. On the Cumberland River, McDonough and Hackney (1979) found that impingement increased for species that spawned earlier. Since early spawning species have young earlier, the young are able to grow larger faster and therefore become impinged easier and sooner.

Previous Alabama Power Company 316(b) Studies

Impingement studies conducted at Barry Steam Plant during 1976 and 1977 indicated an estimated annual impingement rate of 331,025 threadfin shad alone (Alabama Power 1977). This study along with studies at Gorgas, E.C. Gaston, and Green

County Steam Plants concluded that impingement of shad (threadfin and gizzard) and other species were not having an affect on the fish populations since most of the fish being impinged had high relative abundances. In particular, since only a few threadfin and gizzard shad were being impinged compared to the overall population, and since these species produce large numbers of offspring it was concluded that the loss of these fish did not affect their overall population (Alabama Power 1977). In these studies there were several factors that were thought to be influencing impingement (e.g. water temperature and debris loading) but were never statistically validated.

III. Materials and Methods

Site Descriptions

Power plants with a cooling water intake structure, National Pollutant Discharge Elimination System (NPDES) permit requirements, and an intake flow of 189 ML/day or greater are required to assess the impingement mortality rates according to 316(b) (U.S. EPA 2002). There are eight power plants currently operated by Alabama Power Company, that meet the above requirements, however, only five of these plants are up for NPDES permit renewal that requires an impingement assessment. The power plants subject to the new ruling are Barry, Gadsden, E.C. Gaston, Gorgas, and Greene County.

Barry Steam Plant. — Barry Steam Plant is located in north Mobile County, Alabama on the Mobile River. The Mobile River near Plant Barry is about 198 meters wide and reaches a maximum depth of 15 meters. The average flow volume based upon 30 years of data is about 891 m^3/s (Alabama Power 1977; Alabama Power 2005). Barry Steam Plant has five independent generating units operating on once-thru cooling with a combined manufacturer's rated capacity of 1,535 MW (Alabama Power 1977; Alabama Power 2005). The plant also has two combined cycle units with cooling towers that have a manufacturer's rating capacity of 1,000 MW. The plant utilizes two cooling water intake structures for the necessary water for the five once-through cooling water units and the two combined cycle units. These two intake structures draw water from an embayment off the Mobile River created by a barge canal (Alabama Power 1977;

Alabama Power 2005: Figure 1). The maximum depth of the canal is about 5 meters. The total rate of withdrawal of cooling water for the five units with all pumps operating is 49 m^3/s (Alabama Power 1977). One of the CWIS serves units 1, 2, and 3 and the other serves units 4 and 5. The CWIS for units 1, 2, and 3 has six traveling screens and the CWIS for 4 and 5 has five traveling screens. The vertical traveling screens have 1 cm square openings, which are positioned behind trash racks at each intake. Materials were removed from the traveling screens by high-pressure water jets into a sluiceway, that empties into a concrete basin. With all pumps operating, the average water velocity flowing through the trash racks is 0.21 m/s for units 1, 2, and 3 and 0.13m/s for units 4 and 5. While, the average through-screen velocity with all pumps operating is 0.48m/s for units 1, 2, and 3 and 0.59 m/s for units 4 and 5.

Gadsden Steam Plant. — Gadsden Steam Plant is located near the city of Gadsden in Etowah County, Alabama on Lake Neeley Henry of the Coosa River System. The plant has two independent generating units operating on once-thru cooling water with a combined manufacturer's rated capacity of 88 MW. The condenser cooling water flow with all pumps operating is about 4 m^3/s per unit. The CWIS is located on the bank of the Coosa River where it serves as an open channel for withdrawal of water (Figure 2). This intake consists of four withdrawal bays behind a trash rack with 1 cm woven wire mesh screen. Materials were removed from the traveling screens by high-pressure water jets into a sluiceway that empties into a concrete basin. The total rate of withdrawal for both units with all pumps operating is 8 m^3/s. With all pumps operating, the average water velocity through the trash racks for all units is 0.19 m/s and the through-screen water velocity is 0.32 m/s.

Gaston Steam Plant. — Gaston Steam Plant is located near Wilsonville, Alabama in Shelby County on Lay Lake of the Coosa River System near the confluence of Yellowleaf Creek. The Coosa River near the plant is about 167 m wide and at its deepest point 17 m. The plant has four independent generating units operating on once-thru cooling water with a combined manufacturer's rated capacity of 1,000 MW and one independent generating unit with a manufacturer's rated capacity of 880 MW operating on cooling towers. The condenser cooling water flow with all pumps operating for units 1 and 2 is 9 m^3/s, for units 3 and 4 it is 10 m^3/s and for unit 5 it is 23 m^3/s. The plant intake for units 1, 2, 3, and 4 as well as make-up water for the cooling towers is located on Yellowleaf Creek, which serves as an open channel for withdrawal of water from the Coosa River (Figure 3). The CWIS typically withdraws water from the Coosa River up Yellowleaf Creek. The intake consists of ten withdrawal bays behind a trash rack with a 1 cm woven wire mesh screen. Materials were removed from the traveling screens by high-pressure water jets into a sluiceway that empties into a concrete basin. The total rate of withdrawal for all five units with all pumps operating is 37 m^3/s. Units 1, 2, 3, and 4 utilize once-thru cooling and that accounts for 36 m^3/s out of the 37 cfs. Unit 5 utilizes a mechanical draft-cooling tower and uses about 1 m^3/s. With all pumps operating, the average water velocity through the trash racks for all units is 0.18 m/s and the through-screen water velocity is 0.37 m/s.

Gorgas Steam Plant. — Gorgas Steam Plant is located in Walker County, Alabama on the Mulberry Fork of the Warrior River System. This location is at the headwaters of the reservoir that is formed by Bankhead Dam. The plant currently has six independent generating units that have a combined manufacturer's rated capacity of

1,281 MW. The total rate of water withdrawal with all pumps operating ranged from 3 m^3/s – 18 m^3/s. The cooling water for these generating units is drawn from the Mulberry Fork through an inverted skimmer weir. The intake opening extends from a depth of 9 – 12 m. below the water surface. The calculated average velocity through the weir is 0.50 m/s. After the cooling water is withdrawn from the river it flows through a 1.3 km long intake canal to the intakes (Figure 4). The intake canal delivers water to two CWIS one serving units 6 and 7 and the other serving units 8 through 10. The vertical traveling screens have 1 cm square openings, which are positioned behind trash racks at the intake. Materials were removed from the traveling screens by high-pressure water jets into a sluiceway, which empties into a concrete basin. With all pumps operating, the average water velocity flowing through the trash racks is 0.27 m/s for units 6 through 7 and 0.31 m/s for units 8 through 10. While, the average through-screen velocity with all pumps operating is 0.31m/s for units 6 and 7 and 0.56 m/s for units 8 through 10.

Greene County Steam Plant. — Greene County Steam Plant is located in Greene County, Al. on the Black Warrior River. This location is near the headwaters of the reservoir that is formed by Demopolis Dam. The depths of the river at this point are greater than 14 m. The plant currently has two independent generating units that have a combined manufacturer's rated capacity of 500 MW. The cooling water for these generating units is drawn from the Black Warrior River through a 183 m canal (Figure 5). The total rate of withdrawal with all pumps operating is 9 m^3/s. The vertical traveling screens have 1 cm square openings, which are positioned behind trash racks at the intake. Materials were removed from the traveling screens by high-pressure water jets into a sluiceway, which empties into a concrete basin. With all pumps operating, the average water velocity flowing through the trash racks is 0.33 m/s and the through-screen water velocity is 0.42 m/s.

Data Collection

Fish Collection, Evaluation and Identification. — Fish impingement, environmental, and operational data were collected for one year from September 20, 2004 – October 14, 2005. At each plant, adult and juvenile fish were collected every 2 weeks from basins where fish were backwashed from the traveling screens. Impingement samples were collected three times over a 24-hour period to give a day (0600-1400), afternoon/evening (1400-2200), and night (2200-0600) sample. In total, 531 8-hour impingement samples were collected from all 7 intakes combined. Fish and debris were washed off the traveling screens into a collection basket. The amount of debris washed into the basket was determined by subtracting the fish weight and basket weight from the overall weight of the sample. Most fish were enumerated, weighed, measured and identified to species (Mettee et al. 1996). If the number of individuals of a given species exceeded 50, then the first 50 were weighed and measured and the rest were enumerated and weighed as a group to assign an average weight.

Electrofishing surveys of the fish populations near each steam plant were conducted in October 2005. At each plant, fish were collected from three sites: the hydraulic zone of influence (HZI), downstream from the HZI, and upstream from the HZI. All available shoreline habitats at each site were sampled for 10 minutes of peddle time. During sampling, the electrofishing equipment was set at 60 volts and between 5-6 amps. All fish collected were enumerated, weighed, measured, and identified to species (Mettee et al. 1996).

Percent Recovery. — During each 8-hour sample period, 100 dead threadfin shad were marked using a caudal fin clip or dye (Methylene Blue, Rose Bengal, or Acridine Orange) and placed into the source water body within 1 m of the intake screens. The percentages of fish impinged or recovered during the sampling period were used as a correction factor. This was intended to provide an estimate of the number of fish impinged but not recovered due to inefficient backwash of debris and fish falling off the traveling screens.

Environmental Variables Measured. — River stage, river discharge (ML/day), dissolved oxygen (mg/l), water temperature (^{o}C), turbidity (NTU), specific conductance (µS/cm), pH, HZI (ML), and amount of debris loading (kg) were measured during each sampling event. DO, turbidity, specific conductance, pH and water temperature were measured from a surface water sample taken in front of the intake. Water in front of all CWIS was thoroughly mixed. Therefore, surface water collected was assumed to be representative of the whole water column within the HZI. All water quality variables were measured using YSI and HACH probes. The water levels in front and behind the screens were also measured in order to estimate the amount of surface area on each screen that was blocked by debris.

Information concerning HZI and river discharge was provided by Alabama Power Company personnel who used a field bathymetric measurements, and Acoustic Doppler Current Profiler (ADCP) information to calculate the volume of water within the zone of influence and the hourly river discharge upstream from the CWIS. HZI and river discharge were obtained for all plants except Gorgas. Due to lack of boat access within the intake canal and the proximity of the warm water discharge to the intake canal we were unable to measure these variables at this plant. River stage was obtained from a USGS gage located on site at Barry Steam plant and the closest USGS gage to the other steam plants CWIS.

Plant Operational Variables. — During each sampling event, the pumps withdrawing water, CWIS flow volume (ML/day), and CWIS through-screen flow velocity (m/s) were recorded for each unit. CWIS flow velocities were determined using river stage, volume of water withdrawn from the CWIS, and the amount of surface area of the screen.

Statistical Analysis

When sampling did not occur for the entire 8-hour sampling period (0600-1400, 1400-2200, and 2200-0600), impingement rates were extrapolated to eight hours. Since the one-way analysis of variance (ANOVA: PROC GLM: SAS Institute 1999b) showed no differences among periods and a two-way analysis of variance (PROC GLM: SAS Institute 1999b) showed no interaction among seasons and periods for impingement rates, all statistical tests used the impingement rate for an 8-hour period (number of fish / 8-hours). This approach greatly increased the sample size and accounted for more of the variability in impingement rates.

Overall the residuals from the analysis of variance of the impingement rates were not normally distributed. However, when the impingement rates were natural log transformed normality increased and the model r-squared values were improved.

Therefore, all statistical tests were run using natural log transformed impingement rates for each 8-hour period. Although the statistical analyses were preformed using the natural log of impingement rates, all means presented graphically are non-transformed.

Analysis of variances (PROC GLM: SAS Institute 1999b) were also used to test for differences in impingement rates among months (September and October were sampled in both 2004 and 2005, however since significant differences were not detected between years, each sampling was treated as a replicate in the analysis) and seasons to determine differences in mean number of fish impinged per 8-hour period. Impingement rates among seasons were also analyzed by grouping months according to water temperature (the coldest three months were considered winter, the next three coldest months were fall, etc.). The dominant three species were chosen for this analysis based on the overall relative abundance at all intakes. These three species were threadfin shad (69.3%), blue catfish (8.8%; *Ictalurus furcatus*), and freshwater drum (7.4%). Differences in 8-hour impingement rates for the dominant species and all species combined were tested among months and seasons using an ANOVA. This allowed for comparisons of trends among intakes for the same species. These analyses were run for all intakes combined and separately.

Eight-hour impingement rates for the three dominant species and all species combined were compared with the environmental variables (DO, pH, specific conductance, turbidity, water temperature, number of screens in use, water level difference, debris loading, cooling water intake velocity, cooling water intake volume, river stage, river discharge, and HZI) using Pearson correlation analysis (PROC CORR: SAS Institute 1999a). Among all intakes, the same variables were significantly correlated with impingement rates for both all species combined and the dominant three species. In addition, in order to determine which variables (DO, pH, specific conductance, turbidity, water temperature, number of screens in use, water level difference, debris loading, cooling water intake flow velocity, cooling water intake flow volume, river stage, river discharge, and HZI) were the best predicators of impingement rates, a simple stepwise linear regression model using various selection procedures (forward, backward, stepwise, and maxr) was used (PROC REG: SAS Institute 1999c). In these models, variables were allowed to enter at an $\alpha < 0.05$ and significantly correlated variables were not able to enter the same model. Typically a forward selection procedure produced the best r-squared values and therefore this method is reported for the results of this analysis.

IV. Results

All Intakes

Among all plants, there were 102, 24-hour sampling events, which resulted in the estimated impingement of 67,175 fish representing 23 families and 62 species. The majority of fish impinged (78%) were from Barry Steam Plant. In addition, Barry had the highest species richness with 57 fish species collected from our impingement samples, 18 of these were unique to this plant (Table 1). The five dominant species according to relative abundance for all intakes combined were threadfin shad (69.3%), blue catfish (8.8%), freshwater drum (7.4%), black crappie (3.5%; *Pomoxis nigromaculatus*), and gizzard shad (2.5%; Figure 6).

Among all plants, there were 2,893 fish collected during electrofishing sampling representing 39 species (Table 2). The five dominant species collected during electrofishing samples were bluegill (36.8%; *Lepomis macrochirus*), threadfin shad (27.3%), redear sunfish (5.2%; *Lepomis microlophus*), emerald shiner (5.0%; *Notropis atherinoides*), and gizzard shad (5.0%). However, the dominant species collected during electrofishing surveys at each plant were not always the same as the dominant species with all plants combined (Table 3).

Length class affected impingement rates, where a majority of fish impinged were comprised of small length classes (Figure 7-10). This trend was evident at most of the intakes and was especially apparent in the dominant species with over 94% of threadfin shad collected being less than 100 mm in length (Figure 11), over 64% of freshwater drum collected being less than 140 mm length (Figure 12), and over 68% of blue catfish collected being less 100 mm in length (Figure 13).

Screen efficiency data was highly variable and increased the variability in impingement rates. When impingement rates were adjusted for screen efficiency an increase in standard error occurred at every intake (Table 4). Due to this increased variability, the focus of the data analysis will be on the data that is not corrected for screen efficiency.

Comparing 8-hour impingement rates among the three time periods (0600-1400, 1400-2200, and 2200-0600) for all intakes combined and separate, resulted in no significant differences ($P > 0.05$) in number of fish impinged for all species, or for the dominant species (threadfin shad, blue catfish and freshwater drum; Figure 14).

Comparing 8-hour impingement rates among seasons for all species and intakes combined resulted in significant differences for both seasons corrected for water temperature ($F_{3,\,524} = 6.17$; $P < 0.001$) and not corrected for water temperature ($F_{3,\,524} = 8.28$; $P < 0.001$; Figure 15). However, when season was corrected for water temperature, summer impingement increased and fall impingement subsequently decreased, a trend apparent for all intakes and species.

From the correlation analysis for all intakes, pH, specific conductance, turbidity, number of screens in use, cooling water intake flow volume, debris weight, river discharge, and cooling water intake flow velocity were all significantly ($P < 0.05$) correlated with 8-hour impingement rates (Table 5). From the stepwise linear regression model, turbidity, water temperature, cooling water intake velocity, and debris weight (Table 6) were the best predictors of impingement rates for all intakes combined.

Barry U1-U3

There were 27, 24-hour sampling events at Barry Steam Plant intake for U1-U3 resulting in the impingement of 24,377 fish and 54 species (Table 1). The five dominant species for this intake were threadfin shad (75.6%), freshwater drum (7.5%), blue catfish (5.3%), black crappie (2.7%), and gizzard shad (2.0%).

Impingement rates for 8-hour periods were significantly different among months ($F_{11, 66} = 9.64$; $P < 0.001$) and seasons ($F_{3, 74} = 14.66$; $P < 0.001$) for all species combined (Figure 16). Comparing seasonal and monthly differences in 8-hour impingement rates among the dominant three species (threadfin shad, freshwater drum, and blue catfish) differences were found in blue catfish numbers among months ($F_{11, 66} = 2.77$; $P = 0.005$) and seasons ($F_{3, 74} = 4.90$; $P = 0.004$; Figure 17). Differences were also detected in freshwater drum numbers among months ($F_{11, 66} = 14.15$; $P < 0.001$) and seasons ($F_{3, 74} = 25.00$; $P < 0.001$; Figure 18). In addition, differences were also found in threadfin shad impingement rates among months ($F_{11, 66} = 18.66$; $P < 0.001$) and seasons ($F_{3, 74} = 23.71$; $P < 0.001$; Figure 19).

Based on correlation analysis river stage ($r = -0.253$; $n = 66$; $P = 0.040$), river discharge ($r = -0.262$; $n = 66$; $P = 0.033$), pH ($r = -0.302$; $n = 78$; $P = 0.007$), specific conductance ($r = 0.372$; $n = 78$; $P = 0.001$), HZI ($r = 0.388$; $n = 65$; $P = 0.001$), dissolved oxygen ($r = -0.568$; $n = 78$; $P < 0.001$), and water temperature ($r = 0.591$; $n = 78$; $P < 0.001$) were all significantly correlated with impingement rates for 8-hour periods. From the stepwise linear regression model, water temperature, and CWIS flow volume were the significant predictors of 8-hour impingement rates for this intake (Table 6).

Barry U4-U5

There were 27, 24-hour sampling events at Barry Steam Plant intake for U4-U5 resulting in the impingement of 27,733 fish and 49 species (Table 1). The five dominant species for this intake were, threadfin shad (60.0%), blue catfish (14.6%), freshwater drum (7.5%), black crappie (6.1%), and channel catfish (2.8%; *Ictalurus punctatus*).

Mean impingement rates for 8-hour periods were significantly different among months ($F_{11,66} = 10.12$; $P < 0.001$) and seasons ($F_{3,74} = 15.30$; $P < 0.001$) for all species combined (Figure 20). Differences were also detected among seasonal and monthly 8-hour impingement rates for the dominant three species (threadfin shad, freshwater drum, and blue catfish). The number of blue catfish impinged within an 8-hour period differed significantly among months ($F_{11,66} = 5.96$; $P < 0.001$) and seasons ($F_{3,74} = 8.28$; $P < 0.001$; Figure 21). In addition, differences were detected in number of freshwater drum impinged in 8-hours among months ($F_{11,66} = 10.50$; $P < 0.001$) and seasons ($F_{3,74} = 23.66$; $P < 0.001$; Figure 22). Threadfin shad also had significant differences in impingement numbers per 8-hour period among months ($F_{11,66} = 17.30$; $P < 0.001$) and seasons ($F_{3,74} = 21.94$; $P < 0.001$; Figure 23).

From the correlation analysis, pH ($r = -0.235$; $n = 78$; $P = 0.038$), debris weight ($r = 0.290$; $n = 78$; $P = 0.010$), HZI ($r = 0.309$; $n = 65$; $P = 0.012$), specific conductance ($r = 0.360$; $n = 78$; $P = 0.001$), water temperature ($r = 0.462$; $n = 78$; $P < 0.001$), dissolved oxygen ($r = -0.525$; $n = 78$; $P < 0.001$), CWIS flow velocity ($r = 0.533$; $n = 78$; $P <$

0.001), and CWIS flow volume ($r = 0.560$; $n = 78$; $P < 0.001$) were significantly correlated with impingement rates per 8-hours. From the stepwise linear regression model dissolved oxygen, pH, and CWIS flow volume were selected as the best predictors of 8-hour impingement rates (Table 6).

Gadsden U1-U2

There were 25, 24-hour sampling events at Gadsden Steam Plant intake for U1-U2 resulting in the impingement of 120 fish representing 9 species (Table 1). The five dominant species for this intake were, threadfin shad (69.5%), bluegill (14.0%; *Lepomis macrochirus*), channel catfish (9.3%), flathead catfish (8.4%; *Pylodictis olivaris*), and blue catfish (4.2%).

Differences in 8-hour impingement rates were detected among months ($F_{11, 63}$ = 4.59; $P < 0.001$) and seasons ($F_{3, 71}$ = 6.69; $P < 0.00$) for all species combined (Figure 24). Differences were also detected in seasonal and monthly 8-hour impingement rates for the dominant three species (threadfin shad, freshwater drum, and blue catfish). Differences in impingement rates per 8-hour among months ($F_{11, 63}$ = 4.65; $P < 0.001$) and seasons ($F_{3, 71}$ = 4.77; $P = 0.004$) were found for threadfin shad (Figure 25). However, there were no significant monthly ($F_{11, 63}$ = 1.27; $P = 0.263$) or seasonal ($F_{3, 71}$ = 1.26; $P = 0.294$) differences for blue catfish. Not enough freshwater drum were impinged to perform statistical analysis.

From the correlation analysis, CWIS flow volume ($r = 0.228$; $n = 72$; $P = 0.050$), HZI ($r = 0.237$; $n = 72$; $P = 0.045$), dissolved oxygen ($r = 0.249$; $n = 75$; $P = 0.031$), and water temperature ($r = -0.404$; $n = 75$; $P < 0.001$) were significantly correlated with impingement rates per 8-hours. From the stepwise linear regression model, water temperature, and CWIS flow volume were selected as the best predictors of 8-hour impingement rates (Table 6).

Gaston U1-U5

There were 25, 24-hour sampling events at E.C. Gaston Steam Plant intake for U1-U5 resulting in the impingement of 6,235 fish and 16 species (Table 1). The five dominant species for this intake were, threadfin shad (91.0%), blue catfish (3.1%), gizzard shad (2.8%), channel catfish (1.0%), and bluegill (0.7%).

Differences were detected in impingement rates per 8-hours among months ($F_{11, 63} = 18.77$; $P < 0.001$), but not among seasons ($F_{3, 71} = 22.45$; $P < 0.001$) for all species combined (Figure 26). Comparing seasonal and monthly differences for the dominant three species (threadfin shad, freshwater drum, and blue catfish), differences were found in impingement rates per 8-hours among months ($F_{11, 63} = 8.61$; $P < 0.001$) and seasons ($F_{3, 71} = 14.76$; $P < 0.001$) for blue catfish (Figure 27). However, there were no differences detected among seasons ($F_{3, 63} = 1.62$; $P = 0.193$) but there were monthly differences ($F_{11, 63} = 3.12$; $P = 0.002$) in impingement rates for freshwater drum (Figure 28). In addition, threadfin shad had significant differences among months ($F_{11, 63} = 18.27$; $P < 0.001$) and among seasons ($F_{3, 71} = 19.12$; $P < 0.001$; Figure 29).

HZI ($r = -0.263$; $n = 72$; $P = 0.027$), river discharge ($r = 0.340$; $n = 72$; $P = 0.004$), water level ($r = 0.478$; $n = 75$; $P < 0.001$), specific conductance ($r = -0.494$; $n = 75$; $P < 0.001$), dissolved oxygen ($r = 0.695$; $n = 75$; $P < 0.001$), and water temperature ($r = -0.760$; $n = 75$; $P < 0.001$) were significantly correlated with impingement rates per

8-hours. From the stepwise linear regression model, water temperature, and CWIS flow velocity were selected as the best predictors of 8-hour impingement rates (Table 6).

Gorgas U6-U7

There were 25, 24-hour sampling events at Gorgas Steam Plant intake for U6-U7 resulting in the impingement of 517 fish and 20 species (Table 1). The five dominant species for this intake were threadfin shad (76.3%), channel catfish (5.5%), gizzard shad (5.1%), bluegill (4.4%), and bullhead minnow (1.8%; *Pimephales vigilax*).

Differences were not detected in impingement rates per 8-hours among months ($F_{11,60} = 1.52$; $P = 0.149$) nor among seasons ($F_{3,68} = 2.31$; $P = 0.084$) for all species combined (Figure 30). Comparing seasonal and monthly differences in 8-hour impingement rates for the dominant three species (threadfin shad, freshwater drum, and blue catfish), no differences were found among seasons ($F_{3,68} = 0.44$; $P = 0.723$) or months ($F_{11,60} = 0.64$; $P = 0.790$) for blue catfish. Differences were detected among months ($F_{11,60} = 2.50$; $P = 0.012$), and among seasons ($F_{3,68} = 2.76$; $P = 0.049$) for freshwater drum. There were also differences among months ($F_{11,60} = 2.48$; $P = 0.012$) and seasons ($F_{11,68} = 3.86$; $P = 0.013$) for threadfin shad (Figure 31).

Debris weight ($r = 0.305$; $n = 71$; $P = 0.010$), water level ($r = 0.329$; $n = 72$; $P = 0.005$), and water temperature ($r = -0.332$; $n = 72$; $P = 0.004$) were significantly correlated with 8-hour impingement rates. From the stepwise linear regression model, water temperature, turbidity, and water level were selected as the best predictors of impingement rates per 8-hours (Table 6).

Gorgas U8-U10

There were 25, 24-hour sampling events at Gorgas Steam Plant intake for U8-U10 resulting in the impingement of 3,624 fish and 31 species (Table 1). The five dominant species for this intake were, threadfin shad (47.5%), freshwater drum (20.7%), gizzard shad (13.8%), skipjack herring (4.5%; *Alosa chrysochloris*), and channel catfish (3.4%).

Significant differences were found in 8-hour impingement rates among months ($F_{11,63} = 4.64$; $P < 0.001$) and seasons ($F_{3,71} = 6.41$; $P < 0.001$) for all species combined (Figure 32). Comparing seasonal and monthly differences in impingement rates per 8-hours for the dominant three species (threadfin shad, freshwater drum, and blue catfish), no differences were detected in seasonal ($F_{3,71} = 1.68$; $P = 0.180$) or monthly ($F_{11,63} = 1.63$; $P = 0.112$) impingement rates for blue catfish (Figure 33). There were, however, seasonal ($F_{3,71} = 24.39$; $P < 0.001$) and monthly ($F_{11,63} = 7.52$; $P < 0.001$) differences in impingement rates for freshwater drum (Figure 34). In addition, there were also significant seasonal ($F_{3,71} = 10.26$; $P < 0.001$) and monthly ($F_{11,63} = 4.47$; $P < 0.001$) differences for threadfin shad (Figure 35).

pH ($r = -0.238$; $n = 75$; $P = 0.040$), water temperature ($r = -0.263$; $n = 75$; $P = 0.023$) and dissolved oxygen ($r = -0.378$; $n = 75$; $P = 0.001$) were significantly correlated with impingement rates per 8-hours. In addition, from the stepwise linear regression model, dissolved oxygen and CWIS flow volume were selected as the best predictors of 8-hour impingement rates (Table 6).

Greene Co. U1-U2

There were 25, 24-hour sampling events at Greene Co. Steam Plant intake for U1-U2 resulting in the impingement of 4,569 fish and 21 species (Table 1). The five dominant species for this intake were, threadfin shad (80.0%), blue catfish (6.0%), freshwater drum (5.8%), gizzard shad (2.1%), and channel catfish (1.8%).

Differences were found in 8-hour impingement rates among months ($F_{11, 63}$ = 9.19; $P < 0.001$) and seasons ($F_{3, 71}$ = 5.96; $P = 0.001$) for all species combined (Figure 36). Comparing monthly and seasonal differences in impingement rates per 8-hours for the dominant three species (threadfin shad, freshwater drum, and blue catfish), differences were found among seasons ($F_{3, 71}$ = 6.09; $P = 0.001$) and months ($F_{11, 63}$ = 7.43; $P < 0.001$) for blue catfish (Figure 37). In addition, freshwater drum impingement rates were significantly different among seasons ($F_{3, 71}$ = 4.39; $P = 0.007$) and months ($F_{11, 63}$ = 3.63; $P = 0.001$; Figure 38). There were also significant differences in impingement rates among seasons ($F_{3, 71}$ = 11.73; $P < 0.001$) and months ($F_{11, 63}$ = 3.63; $P < 0.001$) for threadfin shad (Figure 39).

Based on correlation analysis turbidity ($r = 0.329$; $n = 75$; $P = 0.004$), water temperature ($r = -0.333$; $n = 75$; $P = 0.004$), HZI ($r = -0.412$; $n = 72$; $P < 0.001$), and river discharge ($r = 0.442$; $n = 72$; $P < 0.001$) were significantly correlated with impingement rates per 8-hours. From the stepwise linear regression model, river discharge, and water temperature were selected as the best predictors of 8-hour impingement rates (Table 6).

V. Discussion

All Intakes

Over 85% of fish impinged were comprised of threadfin shad, blue catfish and freshwater drum. Length frequency histograms showed that a majority (80%) of these three species were from smaller length classes, indicating most impingement was comprised of young fish (Figures 11-13). LaJeone and Monzingo (2000) reported the same trend in the Upper Mississippi River in which most impinged fish were young-of-the-year fish. Young fish exhibit higher natural mortality rates, and the stress that causes high mortality rates could make fish more vulnerable to impingement (Lifton and Storr 1978). In addition to mortality, weakened swimming ability can also result from the various factors that stress young fish. Examples of these stresses include extreme water temperatures (Griffith and Tomljanovich 1975; Hoyt 1979), low dissolved oxygen (Bodensteiner and Lewis 1992), strong intake flow velocities, physical damage (Griffith and Tomljanovich 1975), and infectious disease (Foster and Wheaton 1981).

Highest overall impingement rates were detected in late summer and early fall. In addition, cooling water intake flow velocity was one of the best predictors of impingement rates according to the stepwise linear regression model. The prevalence of young fish in impingement samples could be explained by this variable. Young fish often are not capable of swimming faster than the intake velocity. During late summer and early fall, young-of-the-year fish become large enough to be impinged but have not grown strong enough to swim against the intake velocity (Griffith and Tomljanovich 1975). Often, increases in impingement occur during this time of year and continue to remain high until their swimming ability and strength has increased enough to avoid impingement. Our electrofishing sampling further documented the absence of small length class threadfin shad near the CWIS large enough to be impinged in May. In laboratory tests, threadfin shad tried to escape from a cooling water intake by swimming upstream away from the intake, but fighting the intake velocity eventually caused exhaustion. When exhaustion set in, these fish continually hit the intake screen and were eventually impinged due to exhaustion or physical damage (Griffith and Tomljanovich 1975).

Another reason impingement rates might have increased in late summer and early fall relates to water temperatures and DO concentrations. Several of the lowest dissolved oxygen readings came when Hurricanes Katrina (August 2005) and Ivan (September 2004) came through Alabama, washing a great deal of organic material into these river systems and causing a decrease in dissolved oxygen levels. On the Wabash River, in Indiana Lewis and Seegart (2000) found that impingement rates tended to vary inversely with DO concentrations, with the highest impingement totals coinciding with the lowest DO concentrations. They concluded that lower DO levels, even if not reaching lethal levels, could still trigger fish movements that are out of the ordinary and could possibly displace them to an area where they are more susceptible to impingement (Lewis and Seegart 2000). Water temperatures also influence impingement rates, with extreme cold and warm water temperatures causing mortality or stress in fish. In Lake Erie, Lifton and Storr (1978) documented an inverse relationship between impingement rates and temperature, however, they did not document increases in impingement in summer. Since their study was conducted in the northern United States, their temperatures never approached the warmer summer water temperatures observed in Alabama, which apparently increase impingement in the summer. At Barry Steam Plant, when water temperatures peaked in August and September (28-30°C), impingement rates increased to over 500 fish per 8-hour period (Figures 16 & 20).

To understand how many impinged fish were not collected, screen efficiency sampling was conducted. Impinged fish were documented falling off screens, not getting washed off screens (ending up in the plant), being eaten by predators (blue crabs, flathead catfish, etc.), landing on cross beams within the intake structure, and having too much physical damage for identification. The narrow (8 cm) ledges on the screens often were not wide enough to keep fish from falling off the screens (Figure 40). Due to the small size of the ledge, our impingement samples were probably biased toward smaller fish. In addition, screen wash water usually was not contained within the intake screen housing. Because of this, water missed the sluiceway and cascaded down onto the screens. Impinged fish that were stuck on the narrow ledge often were knocked off because of the wash water. Screen efficiency fish were also documented never getting washed off the screens, causing fish to be pulled into the plant. Screen efficiency fish were recently observed sinking to the bottom of the intake and also congregating in eddies within the CWIS (Alabama Power Company, unpublished data). The loss of fish that occurred between being impinged and being collected in our basket could be one reason why impingement rates were highly variable and hard to explain. However, when trying to account for some of this variability with screen efficiency data, more variation was actually introduced into the data, and therefore this correction was not used. Another problem with using screen efficiency numbers occurred when no screen efficiency fish were recovered but numerous fish were impinged. Therefore, the use of screen efficiency fish to document the number of fish lost produced questionable results

The fish collected in this study showed no differences in impingement rates among the three 8 hour periods (0600-1400, 1400-2200 and 2200-0600). In Watts Barr Reservoir, Hoyt (1979) found similar results in which no differences in fish numbers between day and night were observed. However, another study has reported increases in impingement after dark. After dark fish are known to move up in the water column or closer to shore (Lifton and Storr 1978). It is speculated that this movement makes fish more susceptible to impingement (Lifton and Storr 1978).

Barry U1-U3

In Lake Erie, Lifton and Storr (1978) observed more fish being impinged in late spring when young-of-the-year fish grew large enough to no longer be entrained. In addition, they also noted increased impingement in late fall when the first cold water temperatures (< 10^{o}C) of the year occurred. However, others studies documented increased impingement in fall and remaining high throughout winter and spring (Hoyt 1979; LaJeone and Monzingo 2000). At Barry U1-U3 increases in impingement rates occurred in late summer and early fall (August, September, and October). However, during these three months there was not always an increase in impingement rates for the three dominant species (freshwater drum, blue catfish and threadfin shad). Though freshwater drum and threadfin shad did follow this trend, blue catfish impingement peaked in January. This increase in blue catfish numbers coincided with the coldest temperatures recorded at this intake.

When impingement rates were at their highest (late summer and early fall; Figure 16), the lowest dissolved oxygen concentrations and highest water temperatures of the year occurred, as expected during this time of year. However, in 2004-2005, the DO concentrations were much lower than expected due to the several hurricanes that hit the Gulf Coast that year. Strong winds and large amount of precipitation associated with these storms washed large amounts of organic matter into the Mobile River causing decreases in DO levels. On September 27, 2004, about two weeks following Hurricane Ivan, DO levels were recorded between 2-3 mg/L (below 2 mg/L is considered lethal). The associated fish kills with Hurricane Ivan were not included in our study since this sampling event was an outlier (> 4,000 fish per 8-hour period). However, other hurricanes hit the Alabama coast causing similar decreases in DO concentrations with less dramatic fish kills, and were therefore not removed. After Hurricane Katrina, impingement rates also increased (> 1,500 fish per 8-hour period) with a corresponding drop in DO concentrations (< 4.8 mg/l).

The stepwise linear regression model selected water temperature, and cooling water intake flow volume as the best predictors of impingement rates. Increases in impingement in late summer and early fall (especially threadfin shad and freshwater drum) coincided with the warmest water temperatures of the year. On the Cumberland River in Tennessee, McDonough and Hackney (1979) found similar results for threadfin shad impingement, where impingement rates increased in the warmer summer months. In our study, the increase in fish numbers in the summer and fall was probably caused by the combination of low DO concentrations and warm water temperatures stressing the smaller length class fish before they became strong enough to escape from the intake flow.

Hurricane Ivan caused large numbers of fish to be impinged (> 16,000 fish in one 24 hr sampling event). This large impingement event could have shifted what influences impingement rates and the associated stress may have made fish more susceptible to disease, which in turn could effect impingement (J. Baker, unpublished data). This storm could have killed many of the small length class fish, decreasing the potential impingement rate for the remainder of the year. On the Clinch River in Tennessee, impingement rates decreased dramatically after the initial massive die-off of young-of-the-year fish due to water temperatures falling below lethal levels (McLean et al. 1985). Threadfin shad impingement rates on the Clinch River were observed not to increase until the following year when the young became large enough to be impinged.

Barry U4-U5

Barry U4-U5 intake is only a few hundred meters from the U1-U3 intake, but the same trends were not always observed. Increases in freshwater drum and threadfin shad impingement in late summer and fall occurred at both intakes. However, at Barry U4-U5 blue catfish numbers increased in the fall, where Barry U1-U3 blue catfish numbers were greatest in winter, corresponding to the lowest water temperature of the year.

Dissolved oxygen and water temperature were also correlated with impingement rates at this intake, similar to Barry U1-U3. In addition, hydraulic zone of influence, CWIS flow volume and CWIS flow velocity, were also significantly correlated to impingement rates for Barry U4-U5. We suspect that the close proximity of this intake to the river may have influenced the impingement rates. Barry U4-U5 hydraulic zone of influence extends out into the Mobile River, affecting a larger number of fish than Barry U1-U3. Barry U1-U3 hydraulic zone of influence is located within the intake canal, where electrofishing studies documented lower abundances of fish than the river. Barry U4-U5 impingement rates could have been influenced more than Barry U1-U3 by the CWIS flow velocity and volume, which were both greater in units 4-5.

Gadsden U1-U2

At plant Gadsden the greatest impingement rate occurred during winter, corresponding with the lowest water temperatures of the year. In February, water temperature dropped below 7.0^{o}C, and at these lower temperatures threadfin shad impingement increased. Few threadfin shad have been documented to survive in water temperatures below 9.0^{o}C (Strawn 1965; Griffith and Tomljanovich 1975; Griffith 1978). At 9^{o}C in laboratory tests, threadfin shad exhibited decreased feeding activity and schooled less compactly (Griffith and Tomljanovich 1975; Griffith 1978). Also, at cold temperatures threadfin shad were documented to lose equilibrium (McLean et al. 1985). Cold water temperatures can ultimately lead to increases in threadfin shad impingement rates due to winter mortality (Strawn 1965; Griffith and Tomljanovich 1975). When water temperatures fall below lethal levels, without a warm water refuge, threadfin shad usually do not survive these low temperatures. Contrary to what was found at Barry Steam Plant, water temperatures were negatively correlated with impingement at Gadsden. At Barry Steam Plant water temperatures remained above 10^{o}C in the winter while at Gadsden water temperatures approached 6°C. Since water temperatures dropped below lethal levels at Gadsden, this could have resulted in increased impingement rates during winter, a factor not as dramatic at Barry Steam Plant.

Gadsden U1-U2 intake location and river flow caused the hydraulic zone of influence to remain small. The location of this intake was perpendicular to the river channel in the reservoir (Figure 2). Loar et al. (1978) in reviewing impingement at several southeastern steam plants, found clupeid impingement to decrease with this type of intake location. Since the river current flowing past the intake is stronger than the intake velocity, even dead fish normally float past the intake and continue downstream. Only an event in which, enough fish were stressed or dying, would there be any significant increases in impingement rates. Along with the small HZI, CWIS flow velocity also remained relatively low compared to the other six intakes. These two variables remaining small, along with the river flow sweeping past the intake could explain the low number of fish impinged at this plant.

Gaston U1-U5

Impingement rates were highest in March at Plant Gaston. Both blue catfish and threadfin shad numbers peaked during one sampling event in early March. Heavy rains that occurred two days prior to this sampling event could have caused this high impingement rate. The heavy rains in the Birmingham area caused water levels in the Coosa River and Yellowleaf Creek to rise considerably. Although there were no noticeable changes in water temperature, dissolved oxygen, or other variables that have been documented to increase impingement, the location of the intake water was changed.

The intake at Plant Gaston usually pulls water from the Coosa River up Yellowleaf Creek using the creek as an intake canal (Figure 3). Cooling water intake flow is usually greater than the creek flow, so at normal water levels, Yellowleaf Creek flows in the opposite direction (away from the river and toward the intake). However, when water levels are high in Yellowleaf Creek, intake water no longer comes from the Coosa River, but shifts and comes from Yellowleaf Creek. Due to the high water levels, large numbers of fish could have been displaced from Yellowleaf Creek. When the intake water shifted and came from Yellowleaf Creek, these displaced fish may have been moved toward the intake. LaJeone and Monzingo (2000) observed similar increases in impingement rates during high water levels on the Mississippi River and suspected that high water events may displace fish from their normal habitats, possibly making them more susceptible to being impinged. Increases in impingement at Plant Gaston also coincided with increases in CWIS flow velocity. With these two factors combined (high intake flow velocity and displacement of fish toward the intake), the impingement rate greatly increased. In addition to these changes, river stage, river discharge, debris loading and turbidity were at their highest values during this high water event. However, not all these variables were significantly correlated with impingement rates at this plant.

Gorgas U6-U7

At Gorgas Steam Plant U6-U7, impingement rates were highest in January, with threadfin shad comprising a majority of the fish impinged. This increase in threadfin shad impingement coincided with the lowest water temperatures of the year ($< 8^{o}C$) similar to Gadsden U1-U2, when the greatest impingement rates were observed when water temperature dropped below 9°C. In addition, Gorgas U6-U7 intake location has similar characteristics to Gadsden. Gorgas U6-U7 intake is situated along the intake canal (Figure 4), with a perpendicular flow of water to the intake structure. Because of this, the HZI and water volume for the intake is assumed to be small allowing most fish to follow the stronger sweeping flows inside the intake canal. Because of this, low numbers of fish were impinged throughout the year. Both Gorgas U6-U7 and Gadsden U1-U2 were the only plants that exhibited higher impingement rates during the lowest water temperatures. This similarity may be due to the similar intake placements and relatively low CWIS flow velocity and volumes.

Gorgas U8-U10

The highest impingement rates occurred in fall when dissolved oxygen levels fell below 6.0 mg/l. This same trend was apparent at both Barry intakes when impingement rates increased when dissolved oxygen levels were less than 7.0 mg/l. Dissolved oxygen and CWIS flow volume were the best predictors of impingement rates according to the stepwise linear regression. The reason CWIS flow volume was a significant predictor of impingement rates was because of the unique design of the CWIS at this plant (Figure 4). The warm water discharge of this plant is located a short distance downstream from mouth of the intake canal. Due to the difference in water temperatures between the discharge water and the river, warm water from the discharge flows over top the cold water discharged from Smith Dam. This creates flow in the river in both directions; with cold water flowing downstream and warm water creeping upstream overtop the cold water wedge. The water pulled into the canal passes under a skimmer weir, which selects for the colder, less oxygenated water discharged from Smith Lake. This unique situation could alter what species and the time of year certain species enter the intake canal. In late summer and early fall, Smith Dam was discharging large amounts of water causing dissolved oxygen levels within the intake canal to remain below 6.5 mg/l for several months (Alabama Power Company, unpublished data). No other intake we sampled had dissolved oxygen levels that remained below 7 mg/l for more than a couple of weeks. These changes in dissolved oxygen concentrations within the intake canal could stress fish and cause increased impingement. Since the water flow within the canal sweeps past Gorgas U6-U7 and dead ends into Gorgas U8-U10, more fish could have been affected at this intake rather than at Gorgas U6-U7.

Another unique factor of Gorgas U8-U10 is that the intake canal flows under the discharge canal, through a deep-water tunnel. This part of the intake canal becomes narrower, with less eddies, resulting in increased velocity. It is possible that some fish get stuck in this section of the canal with little food and over time give up fighting the current and become impinged. In order to escape this terminal section of the canal, fish would have to enter the tunnel, the velocity flowing through the tunnel could be too strong for most fish to fight against, which could also aid in trapping fish. We suspect that because of this intake design, more fish were impinged at these intakes as compared to Gorgas U6-U7.

Greene Co U1-U2

Impingement rates at Greene Co. Steam Plant were highest in winter, similar to Gadsden and Gorgas U6-U7. At all intakes, peaks in impingement were comprised mostly of threadfin shad. According to electrofishing data collected by Alabama Power Company, threadfin shad were a large percentage of the overall fish biomass around these intakes. Like Gadsden U1-U2 and Gorgas U6-U7, water temperature did influence impingement rates, however, river discharge and hydraulic zone of influence also contributed at this intake. This was similar to what was observed at Plant Gaston, where impingement increased as river discharge increased. Hoyt (1979) and Mathur et al. (1977) documented similar results where impingement rates increased during periods of high river discharge, speculating that high water was displacing fish and making them more susceptible to impingement. From an analysis of impingement data collected from this plant in the 1970s, Loar et al. (1978) attributed a low threadfin shad impingement rate during winter, to the ability of shad to avoid low water temperatures by over wintering in the discharge canal or other warm water refuges. Even though water temperatures dropped below 10^{o}C at this plant, the only peak in threadfin shad numbers occurred during a high water event. During this high water event, shad could have been displaced from their warm water refuge and washed into the colder river water. This dramatic change in water temperature could have stressed the threadfin shad enough to become more susceptible to impingement.

Summary and Future Considerations

Water temperature, dissolved oxygen, HZI, river discharge, and time of year were the variables that affected impingement rates the most during this study. Some trends among intakes were contradictory, for example, water temperatures were positively correlated with impingement at both Barry intakes and Gorgas U8-U10 but were negatively correlated at Gorgas U6-U7, Gaston U1-U5, Greene Co. U1-U2 and Gadsden U1-U2. In addition, dissolved oxygen was negatively correlated with impingement at Barry U1-U3, Barry U4-U5, and Gorgas U8-U10, with increased impingement occurring when DO concentrations declined below 6.0 mg/l. However, at Gadsden and E.C. Gaston, DO concentrations were positively correlated with impingement rates. This positive correlation could be due to the inverse relationship between water temperature and DO. High water levels, however, were positively correlated with impingement at Greene Co. U1-U2 and Gaston U1-U5. Size of HZI also was highly correlated with impingement, with the intake having the smallest HZI (Gadsden U1-U2) having the lowest impingement rates and the plants with the largest HZI (Barry U1-U3, Barry U4-U5, and Gaston U1-U5) having the highest impingement rates. Since small length class fish dominated impingement samples, time of year was probably the most influential variable in impingement. The highest impingement rates at most plants were noted in late summer and early fall when young-of-the-year fish attained a size large enough to be impinged.

Despite these trends, numerous contradictions among plants were also noted. These contradictions could be caused by numerous factors including: undetectable occurrences (i.e. plant operations including barge traffic and CWIS maintenance), failure to collect all fish that were impinged, unknown status of fish impinged (i.e. dead or alive), or infrequent sampling. Plant operation variables are hard to quantify since many activities occur around intakes without any documentation. Maintenance to the CWIS prior to our sampling events often occurred but never was documented by plant personal (i.e. changing spray nozzles, and removing debris off trash racks). Since these variables were not measured or documented during this study, the effects on impingement rates due to these variables could bias these results. Another factor that might have caused variation in impingement rates was the inability to recover all fish impinged during a sample period. This could have affected the results since highly variable estimates of impingement rates were observed. Therefore, determining which factors affect impingement the most becomes difficult. In addition, not knowing the condition of impinged fish becomes problematic. On the Upper Mississippi River in Illinois, LaJeone and Monzingo (2000) believed that the vast majority of fish impinged were dead or moribund upon arrival in the intake canal. By assuming all fish are alive and healthy prior to becoming impinged, we are able to determine which environmental factors may influence impingement rates the most. However, if some fish are dead or diseased prior to impingement our analyses may be inaccurate and result in inconsistent conclusions. Another factor that could influence the results obtained in this study was the bi-weekly sampling. By sampling infrequently many of the fluctuations in impingement rates and environmental variables went undetected, ultimately limiting the ability to detect the factors most influencing impingement.

In order to accurately estimate impingement rates and determine the factors most affecting impingement, more work needs to be done in order to estimate the exact number of fish impinged, the number of fish not collected, and the percentage of fish that are sick or dead prior to being impinged. Once these factors are better understood, influential variables that affect impingement can be determined. In addition, impingement monitoring needs to be conducted at least once a week or more in order to better account for the variability in impingement rates and associated water quality variables. Records should be kept on all repair and maintenance of CWIS while studies are being conducted. In order to determine the effects of impingement induced mortality on the natural fish assemblage, more extensive work monitoring the natural fish communities needs to be conducted. By understanding the complex interactions that occur at these CWIS, power plants may then be designed and operated to reduce the number of fish being impinged and the effects on the native fish community may also be better understood.

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TABLE 1. – Summary of the impinged fish species collected for Barry, Gadsden, E.C. Gaston, Gorgas, and Greene County Steam Plants during 316(b) sampling conducted by Alabama Power Company in 2004-2005.

Species	Barry	Gadsden	Gaston	Gorgas	Greene Co.
Paddlefish (*Polyodon spathula*)	X			X	
Spotted Gar (*Lepisosteus oculatus*)	X				X
Longnose Gar (*Lepisosteus osseus*)	X				
Alligator Gar (*Lepisosteus spatula*)	X				
Bowfin (*Amia calva*)	X			X	
American Eel (*Anguilla rostrata*)	X				
Skipjack Herring (*Alosa chrysochloris*)	X			X	
Gulf Menhaden (*Brevoortia patronus*)	X				
Gizzard Shad (*Dorosoma cepedianum*)	X	X	X	X	X
Threadfin Shad (*Dorosoma petenense*)	X	X	X	X	X
Bay Anchovy (*Anchoa mitchilli*)	X				X
Silver Chub (*Macrohybopsis storeriana*)	X			X	
Golden Shiner (*Notemigonus crysoleucas*)	X				
Emerald Shiner (*Notropis atherinoides*)	X		X		X
Silverside Shiner (*Notropis candidus*)	X				X
Longnose Shiner (*Notropis longirostris*)	X				
Fathead Minnow (*Pimephales promelus*)				X	
Bullhead Minnow (*Pimephales vigilax*)			X	X	
River Carpsucker (*Carpiodes carpio*)	X				
Quillback (*Carpiodes cyprinus*)	X			X	
Highfin Carpsucker (*Carpiodes velifer*)	X				X
Smallmouth Buffalo (*Ictiobus bubalus*)	X				
Spotted Sucker (*Minytrema melanops*)				X	

TABLE 1. – Continued.

Species	Barry	Gadsden	Gaston	Gorgas	Greene Co.
Blacktail Redhorse (*Moxostoma poecilurum*)	X			X	
White Catfish (*Ameiurus catus*)	X				
Black Bullhead (*Ameiurus melas*)	X			X	X
Yellow Bullhead (*Ameiurus natalis*)			X		
Blue Catfish (*Ictalurus furcatus*)	X	X	X	X	X
Channel Catfish (*Ictalurus punctatus*)	X	X	X	X	X
Black Madtom (*Noturus funebris*)	X				
Flathead Catfish (*Pylodictis olivaris*)	X	X		X	X
Chain Pickerel (*Esox niger*)	X			X	
Rainbow Trout (*Oncorhynchus mykiss*)				X	
Pirate Perch (*Aphredoderus sayanus*)	X				
Striped Mullet (*Mugil cephalus*)	X				
Atlantic Needlefish (*Strongylura marina*)	X				
Bayou Topminnow (*Fundulus notti*)	X				
Inland Silverside (*Menidia beryllina*)	X				
White Bass (*Morone chrysops*)	X	X		X	
Yellow Bass (*Morone mississippiensis*)	X	X	X	X	X
Striped Bass (*Morone saxatilis*)	X		X	X	
Hybrid Striped Bass (*M. chrysops x saxatilis*)	X			X	
Shadow Bass (*Ambloplites ariommus*)	X			X	X
Flier (*Centrarchus macropterus*)	X				
Green Sunfish (*Lepomis cyanellus*)	X		X	X	
Warmouth (*Lepomis gulosus*)	X			X	
Bluegill (*Lepomis macrochirus*)	X	X	X	X	X

TABLE 1. – Continued.

Species	Barry	Gadsden	Gaston	Gorgas	Greene Co.
Longear Sunfish (*Lepomis megalotis*)	X	X	X		
Redear Sunfish (*Lepomis microlophus*)	X			X	X
Redspotted Sunfish (*Lepomis miniatus*)	X				
Spotted Bass (*Micropterus punctulatus*)	X		X	X	X
Largemouth Bass (*Micropterus salmoides*)	X			X	X
White Crappie (*Pomoxis annularis*)	X		X	X	X
Black Crappie (*Pomoxis nigromaculatus*)	X		X	X	X
Mobile Logperch (*Percina kathae*)	X			X	X
Gulf Logperch (*Percina suttkusi*)	X				
Freshwater Drum (*Aplodinotus grunniens*)	X		X	X	X
Sand Seatrout (*Cynoscion arenarius*)	X				
Atlantic Croaker (*Micopogonias undulatus*)	X				
Spinycheek Sleeper (*Eleotris amblyopsis*)	X				
Southern Flounder (*Paralichthys lethostigma*)	X				
Hogchocker (*Trinectes maculates*)	X				X

TABLE 2. – Summary of fish species collected during electrofishing samples conducted near Barry, Gadsden, E.C. Gaston, Gorgas, and Greene County Steam Plants during 316(b) sampling conducted by Alabama Power Company in May 2005.

Species	Barry	Gadsden	Gaston	Gorgas	Greene Co.
Spotted Gar (*Lepisosteus oculatus*)	X		X	X	X
Longnose Gar (*Lepisosteus osseus*)	X		X		X
American Eel (*Anguilla rostrata*)	X			X	
Skipjack Herring (*Alosa chrysochloris*)	X			X	
Gizzard Shad (*Dorosoma cepedianum*)	X	X	X	X	X
Threadfin Shad (*Dorosoma petenense*)	X	X	X		
Common Carp (*Cyprinus carpio*)	X	X	X		X
Blacktail Shiner (*Cyprinella venusta*)			X		
Silver Chub (*Macrohybopsis storeriana*)	X				X
Golden Shiner (*Notemigonus crysoleucas*)	X				
Emerald Shiner (*Notropis atherinoides*)	X				X
Bullhead Minnow (*Pimephales vigilax*)			X		X
Smallmouth Buffalo (*Ictiobus bubalus*)	X	X			X
Spotted Sucker (*Minytrema melanops*)			X		
Blacktail Redhorse (*Moxostoma poecilurum*)			X	X	X
Blue Catfish (*Ictalurus furcatus*)	X			X	
Channel Catfish (*Ictalurus punctatus*)	X	X	X	X	X
Flathead Catfish (*Pylodictis olivaris*)			X		
Chain Pickerel (*Esox niger*)	X			X	
Striped Mullet (*Mugil cephalus*)	X				
Atlantic Needlefish (*Strongylura marina*)					X
Blackstripe Topminnow (*Fundulus notatus*)				X	
Blackspotted Topminnow (*Fundulus olivaceus*)			X		

TABLE 2. – Continued.

Species	Barry	Gadsden	Gaston	Gorgas	Greene Co.
Yellow Bass (*Morone mississippiensis*)		X			
Striped Bass (*Morone saxatilis*)		X			
Redbreast Sunfish (*Lepomis auritus*)	X		X		
Green Sunfish (*Lepomis cyanellus*)	X	X	X	X	X
Warmouth (*Lepomis gulosus*)	X		X		X
Bluegill (*Lepomis macrochirus*)	X	X	X	X	X
Longear Sunfish (*Lepomis megalotis*)	X	X	X		X
Redear Sunfish (*Lepomis microlophus*)		X	X	X	X
Redspotted Sunfish (*Lepomis miniatus*)			X		
Redeye Bass (*Micropterus coosae*)			X		
Spotted Bass (*Micropterus punctulatus*)	X	X	X	X	X
Largemouth Bass (*Micropterus salmoides*)	X	X	X	X	X
White Crappie (*Pomoxis annularis*)	X	X	X	X	X
Black Crappie (*Pomoxis nigromaculatus*)	X	X	X		X
Freshwater Drum (*Aplodinotus grunniens*)	X	X	X	X	X
Southern Flounder (*Paralichthys lethostigma*)	X				

TABLE 3. – Relative abundance (%) for the dominant five species collected during electrofishing surveys conducted near Barry, Gadsden, E.C. Gaston, Gorgas, and Greene County Steam Plants during 316(b) sampling conducted by Alabama Power Company in May 2005.

Species	Barry	Gadsden	Gaston	Gorgas	Greene Co.
Spotted Gar (*Lepisosteus oculatus*)	---	---	---	3.5	4.3
Gizzard Shad (*Dorosoma cepedianum*)	---	8.7	4.9	4.3	---
Threadfin Shad (*Dorosoma petenense*)	9.7	15.7	48.2	---	---
Emerald Shiner (*Notropis atherinoides*)	42.4	---	---	---	---
Smallmouth Buffalo (*Ictiobus bubalus*)	---	---	---	---	9.6
Striped Mullet (*Mugil cephalus*)	4.2	---	---	---	---
Green Sunfish (*Lepomis cyanellus*)	---	4.7	---	---	---
Bluegill (*Lepomis macrochirus*)	15.5	46.2	31.5	57.1	47.8
Longear Sunfish (*Lepomis megalotis*)	---	8.8	2.3	---	6.5
Redear Sunfish (*Lepomis microlophus*)	---	---	6.0	17.3	---
Largemouth Bass (*Micropterus salmoides*)	4.2	---	---	6.7	14.2

TABLE 4. – Summary of standard error (*SE*) among 8-hour impingement rates corrected for screen efficiency and the non-corrected rates, by each intake sampled in 316(b) sampling conducted by Alabama Power Company during 2004-2005.

Intake	Non-Corrected *SE*	Corrected *SE*
Barry U1-U3	121.1	212.2
Barry U4-U5	174.5	468.9
Gadsden U1-U2	2.6	8.9
Gaston U1-U5	172.5	1654.0
Gorgas U6-U7	12.8	38.5
Gorgas U8-U10	28.7	42.5
Greene Co. U1-U2	65.4	155.8

TABLE 5. – Summary of Pearson Correlation Coefficients for the combined impingement rates and the variables significantly correlated with them for the five steam plants sampled during 316(b) studies conducted by Alabama Power Company in 2004-2005.

Variable	*r*	*n*	*P*
pH	-0.287	528	<0.001
Specific Conductance	0.199	528	<0.001
Turbidity	0.325	528	<0.001
Screens in Use	0.305	528	<0.001
CWIS Velocity	0.584	513	<0.001
CWIS Volume	0.456	513	<0.001
Debris Weight	0.272	527	<0.001
River Discharge	0.475	348	<0.001

TABLE 6. – Stepwise linear regression model parameters for predicting 8-hour fish impingement rates for the five steam electric facilities sampled during 316(b) studies conducted by Alabama Power Company during 2004-2005.

Intake	Step	Parameter	R-Square	F-Value	*P*-Value
All Intakes	1	CWIS Velocity	0.343	266.67	<0.001
	2	CWIS Velocity Turbidity	0.430	191.60	<0.001
	3	CWIS Velocity Turbidity Debris Weight	0.440	133.28	<0.001
	4	CWIS Velocity Turbidity Debris Weight Water Temperature	0.453	104.77	<0.001
Barry U1-U3	1	Water Temperature	0.364	35.99	<0.001
	2	Water Temperature CWIS Volume	0.487	29.46	<0.001
Barry U4-U5	1	CWIS Volume	0.299	26.85	<0.001
	2	CWIS Volume Dissolved Oxygen	0.464	26.84	<0.001
	3	CWIS Volume Dissolved Oxygen pH	0.512	21.35	<0.001

TABLE 6. – Continued

Intake	Step	Parameter	R-Square	F-Value	*P*-Value
Gadsden U1-U2	1	Water Temperature	0.188	16.21	<0.001
	2	Water Temperature CWIS Volume	0.267	12.54	<0.001
Gaston U1-U5	1	Water Temperature	0.564	89.22	<0.001
	2	Water Temperature CWIS Velocity	0.684	73.61	<0.001
Gorgas U6-U7	1	Water Temperature	0.104	7.69	0.007
	2	Water Temperature Turbidity	0.174	6.87	0.002
	3	Water Temperature Turbidity Water Level	0.277	8.15	<0.001
Gorgas U8-U10	1	Dissolved Oxygen	0.103	8.03	0.006
	2	Dissolved Oxygen CWIS Volume	0.155	6.35	0.003
Greene Co. U1-U2	1	River Discharge	0.202	17.67	<0.001
	2	River Discharge Water Temperature	0.261	12.16	<0.001

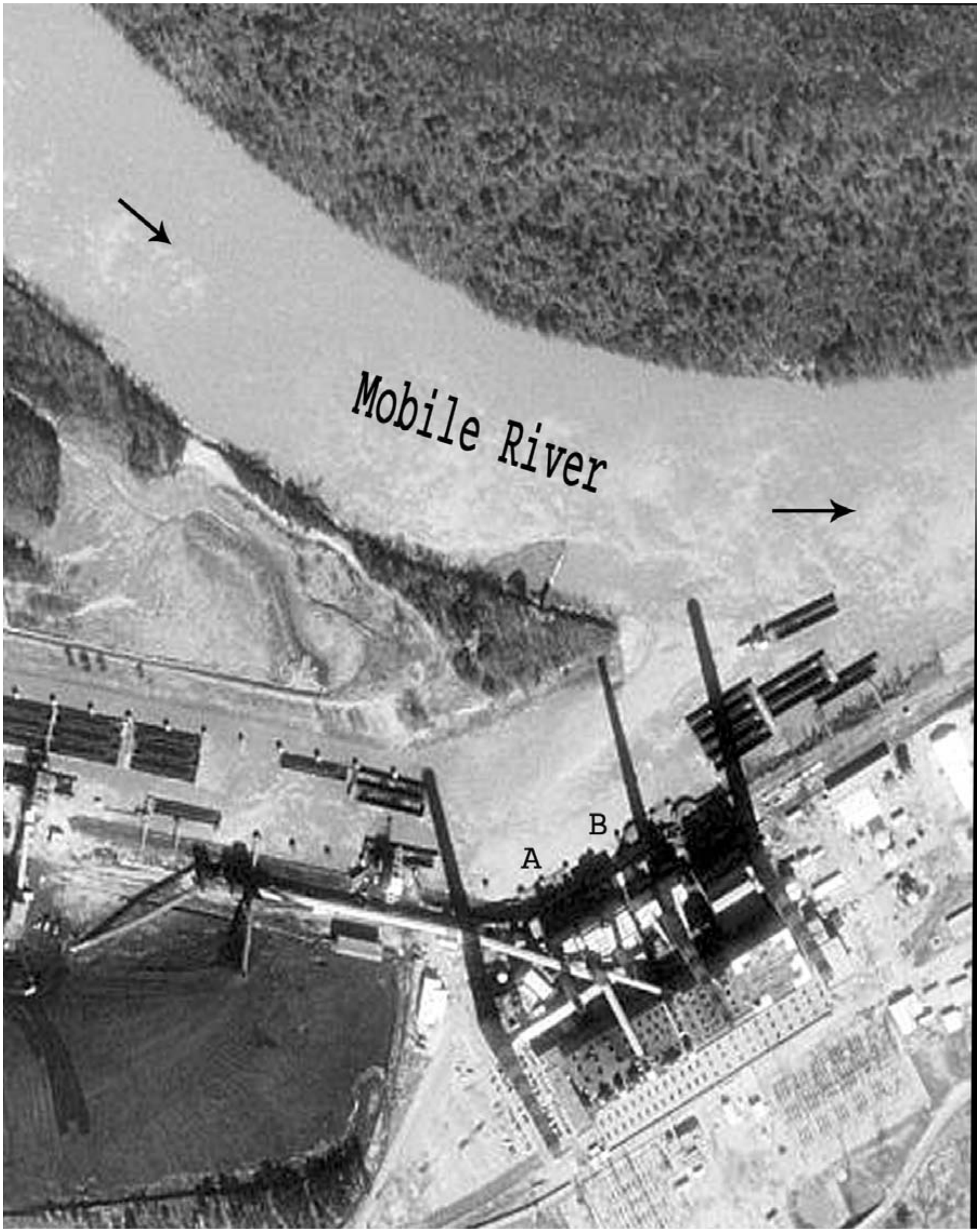

FIGURE 1. – Intake canal diagram and location of cooling water intake structures for Barry Steam Plant located on the Mobile River, Alabama (U1-U3 intake located at point A and U4-U5 intake located at point B. Arrows indicate river flow).

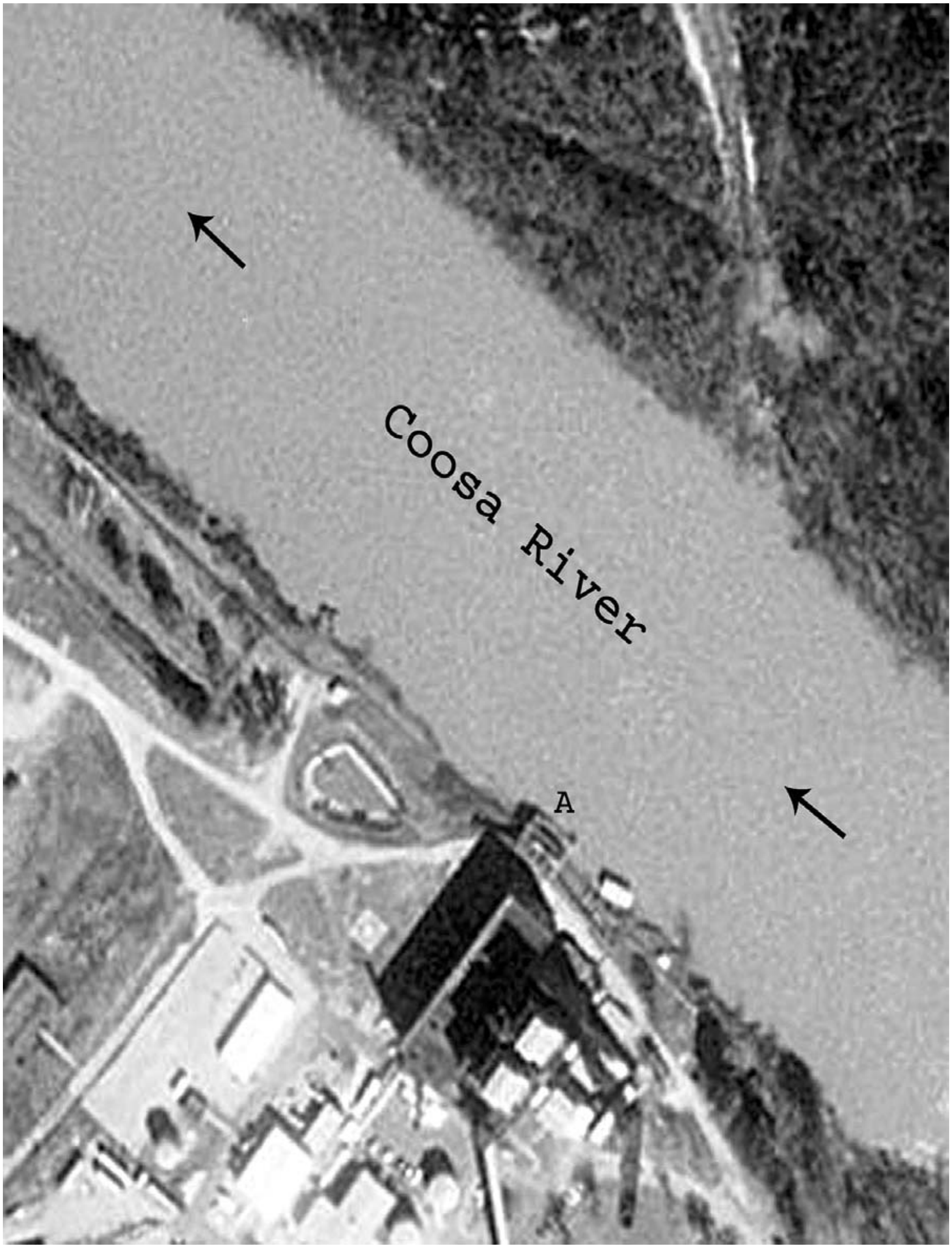

FIGURE 2. – Location of cooling water intake structure for Gadsden Steam Plant located on the Coosa River, Alabama (U1-U2 intake located at point A. Arrows indicate river flow).

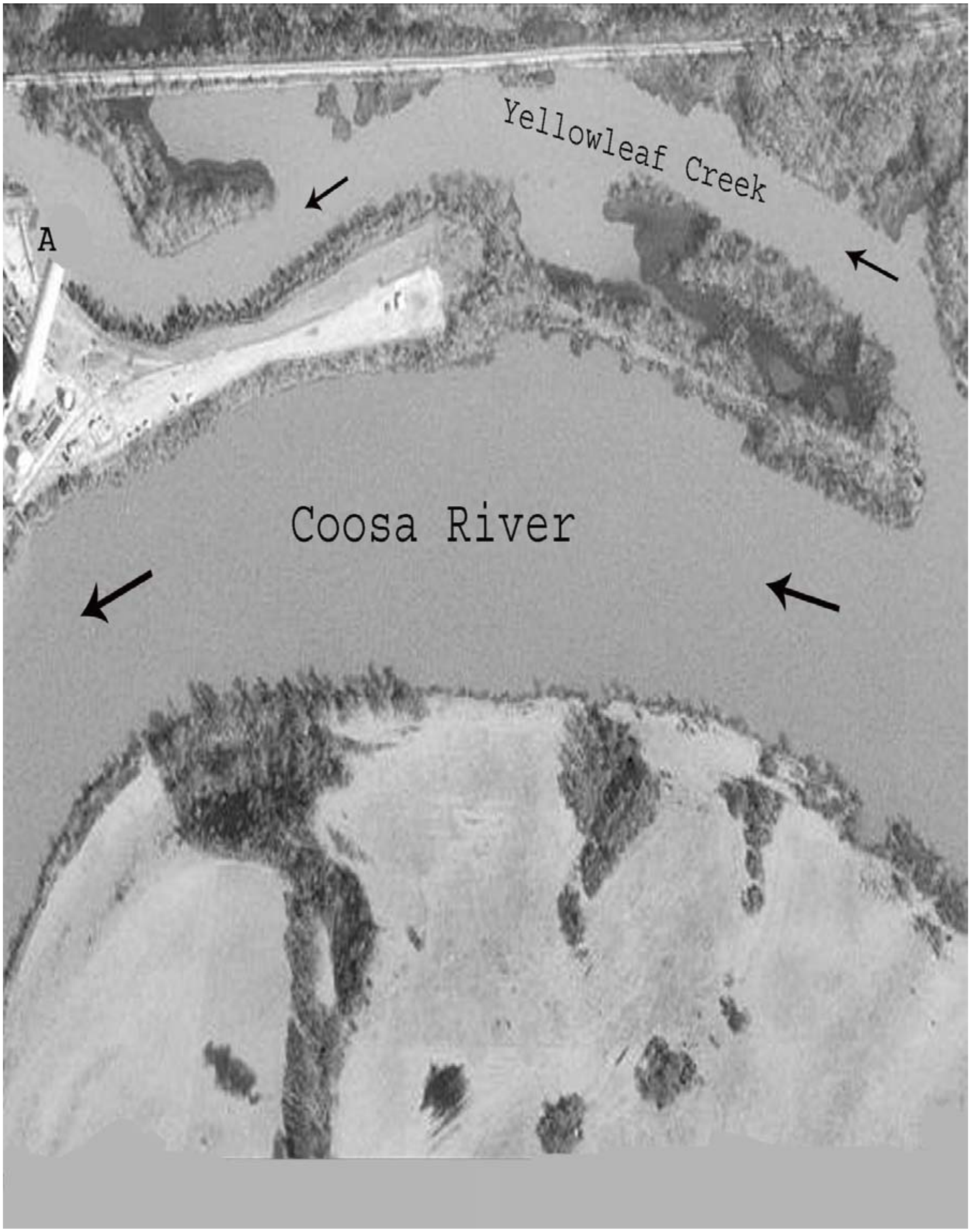

FIGURE 3. – Location of cooling water intake structure for Gaston Steam Plant located on the Coosa River, Alabama (U1-U5 intake located at point A. Arrows indicate river and creek flow).

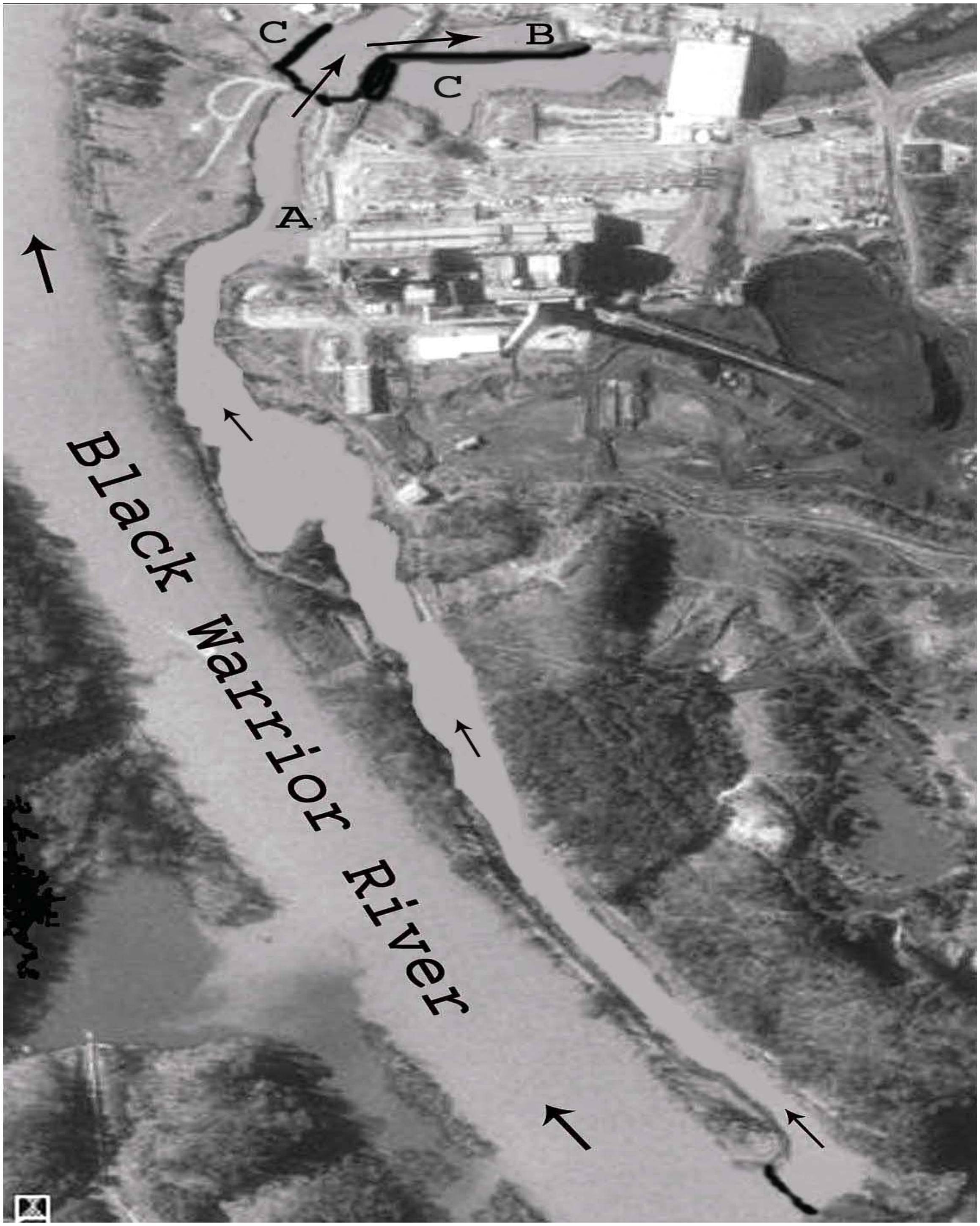

FIGURE 4. – Intake canal diagram and location of cooling water intake structures for Gorgas Steam Plant located on the Mulberry Fork of the Black Warrior River, Alabama (U6-U7 intake located at point A, U8-U10 intake located at point B and the discharge canal is located at points C. Arrows indicate river and intake flow).

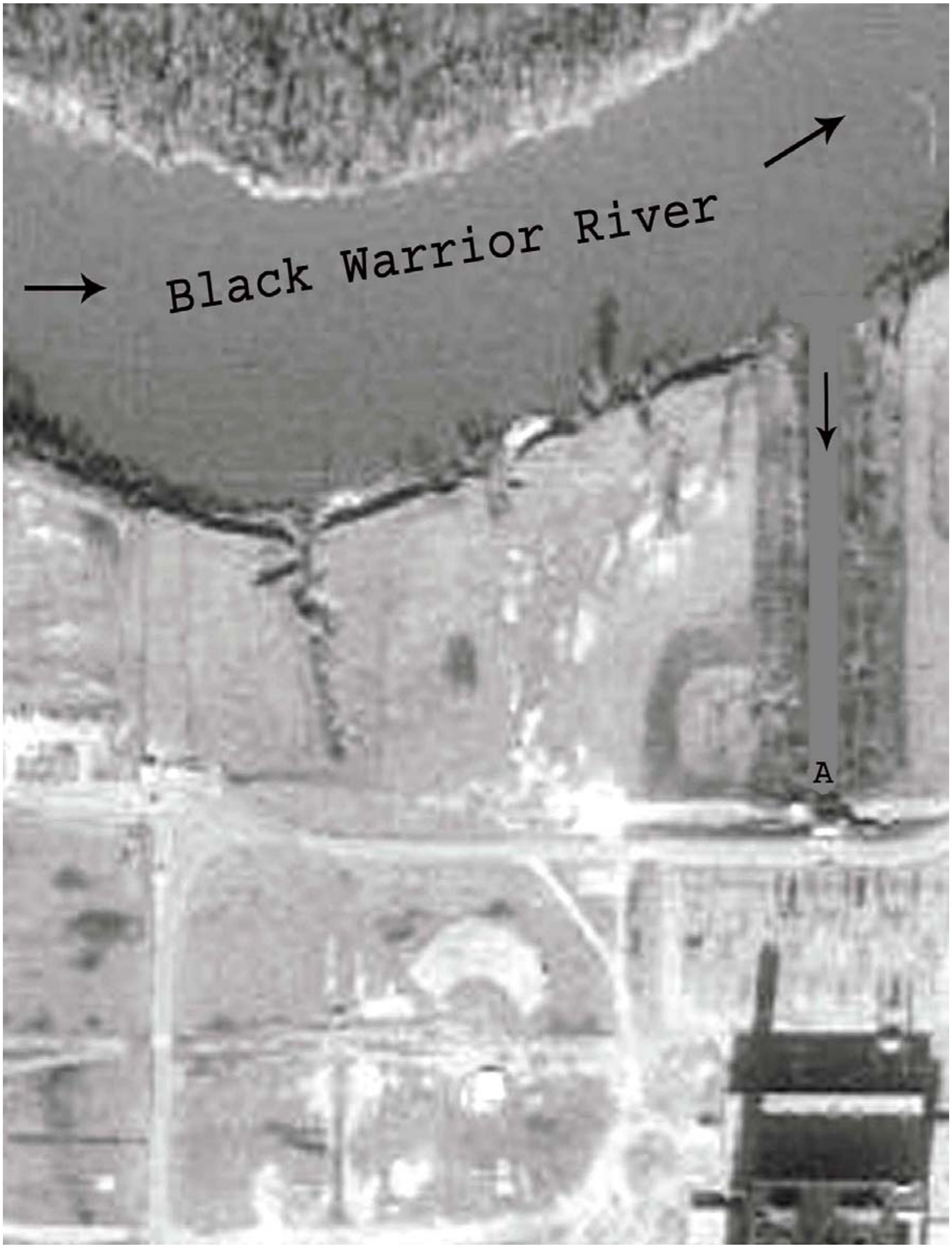

FIGURE 5. – Intake canal diagram and location of cooling water intake structure for Greene County Steam Plant located on the Black Warrior River, Alabama (U1-U2 intake located at point A. Arrows indicate river and intake flow).

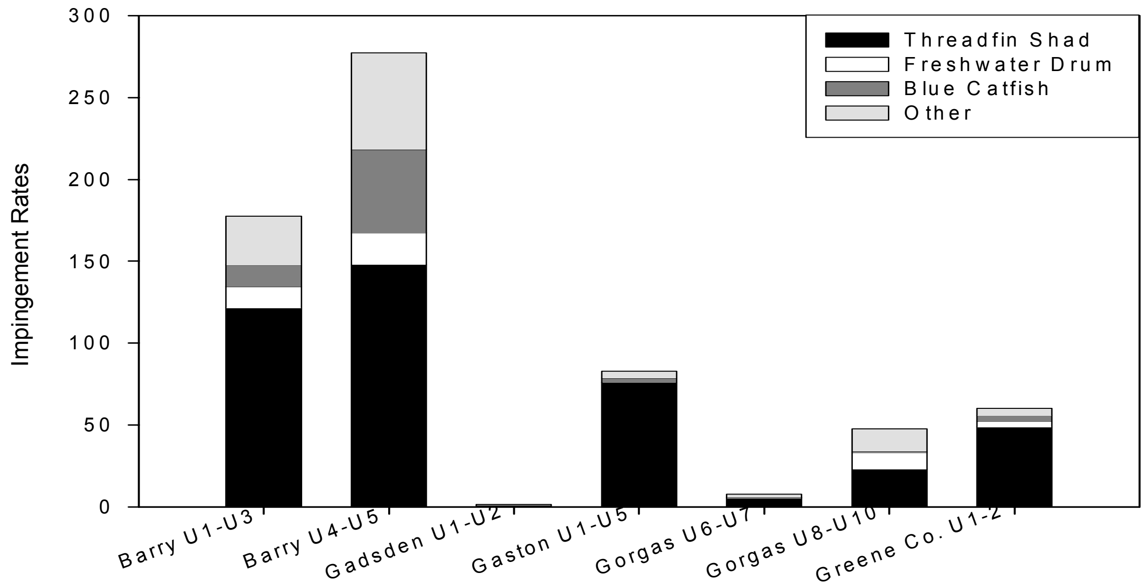

FIGURE 6. Summary of mean 8-hour impingement rates for the dominant three species (threadfin shad, freshwater drum, and blue catfish) collected during 316(b) sampling conducted by Alabama Power Company at five steam plants located in Alabama during 2004-2005.

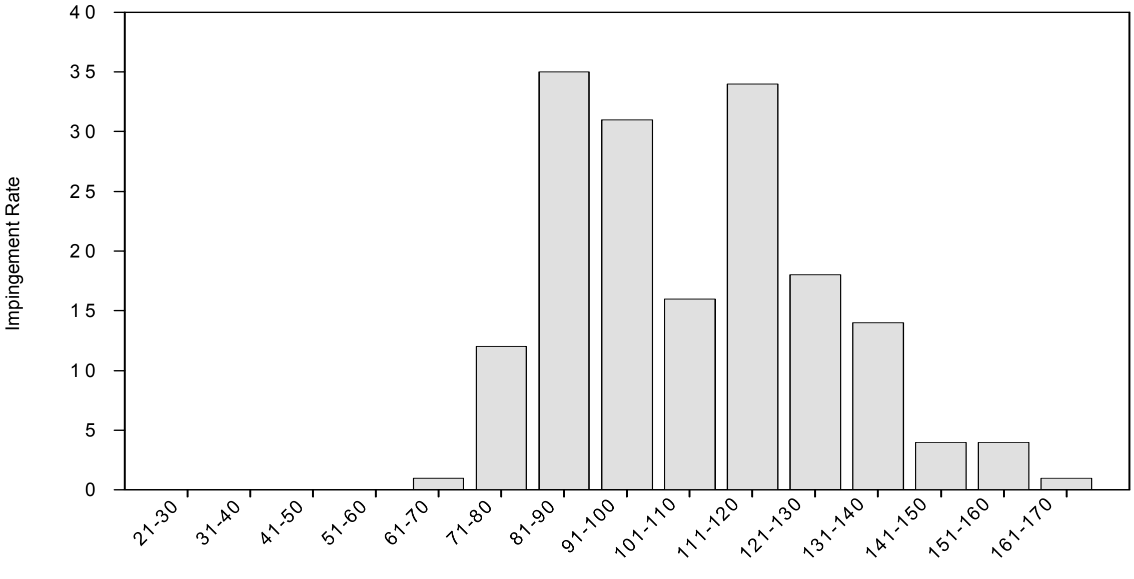

FIGURE 7. – Length class data for impinged threadfin shad (*Dorosoma petenense*) collected during spring at five steam electric facilities during 316(b) sampling conducted by Alabama Power Company (2004-2005).

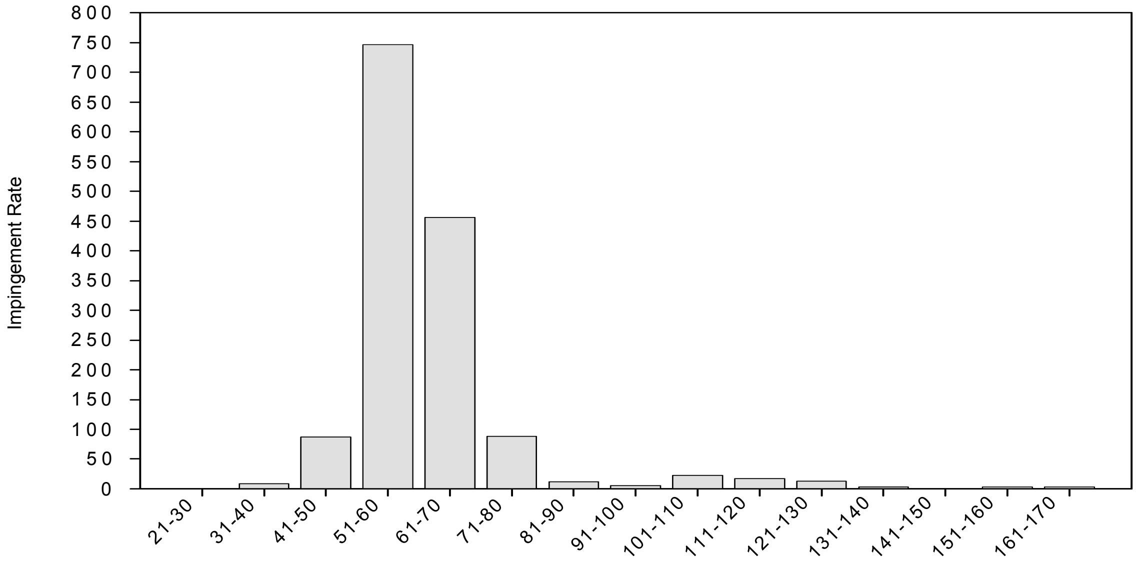

FIGURE 8. – Length class data for impinged threadfin shad (*Dorosoma petenense*) collected during summer at five steam electric facilities during 316(b) sampling conducted by Alabama Power Company (2004-2005).

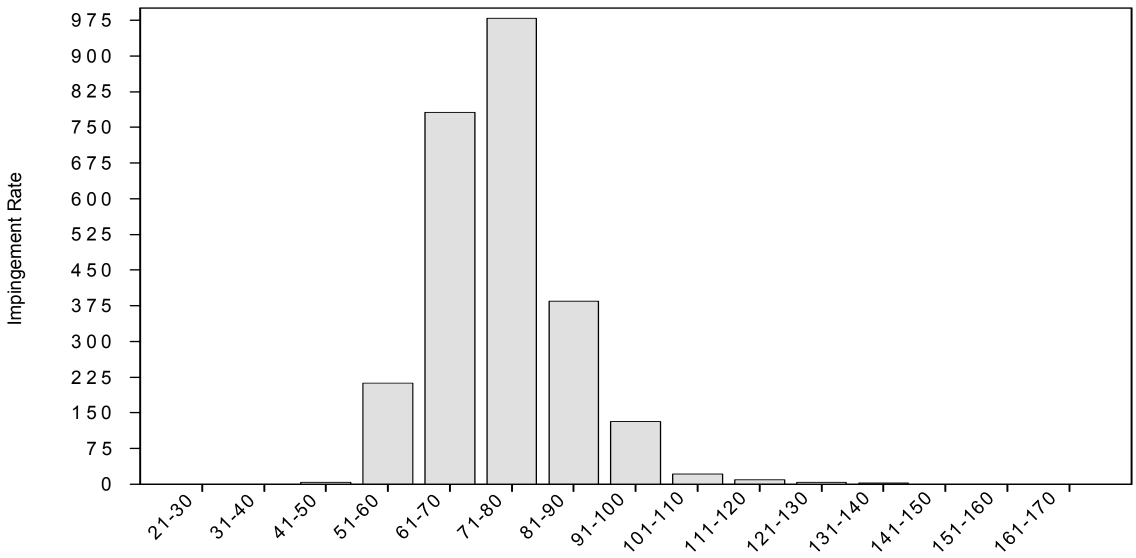

FIGURE 9. – Length class data for impinged threadfin shad (*Dorosoma petenense*) collected during fall at five steam electric facilities during 316(b) sampling conducted by Alabama Power Company (2004-2005).

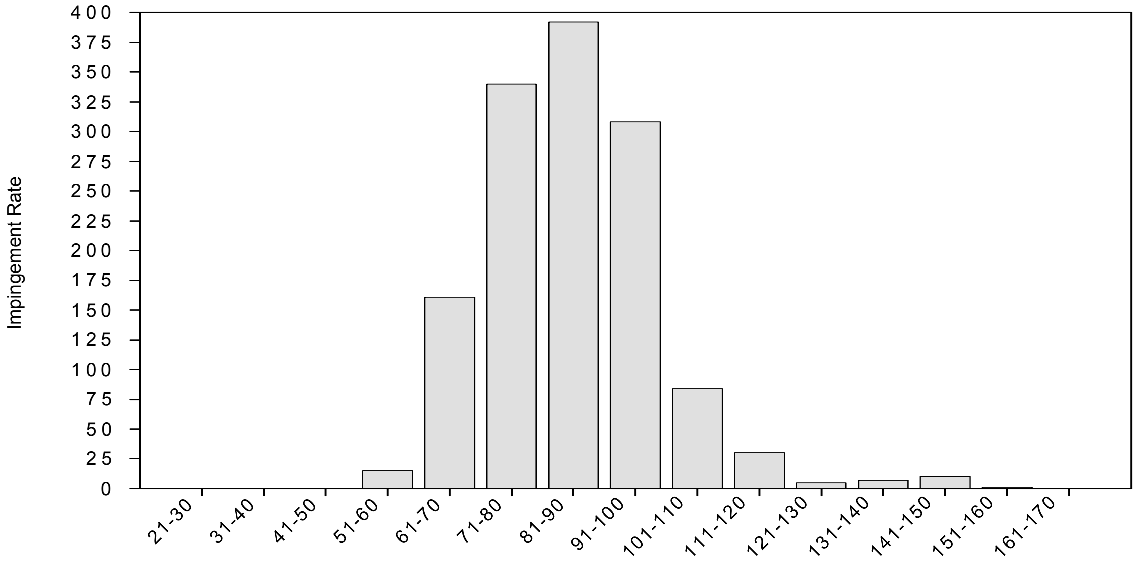

FIGURE 10. – Length class data for impinged threadfin shad (*Dorosoma petenense*) collected during winter at five steam electric facilities during 316(b) sampling conducted by Alabama Power Company (2004-2005).

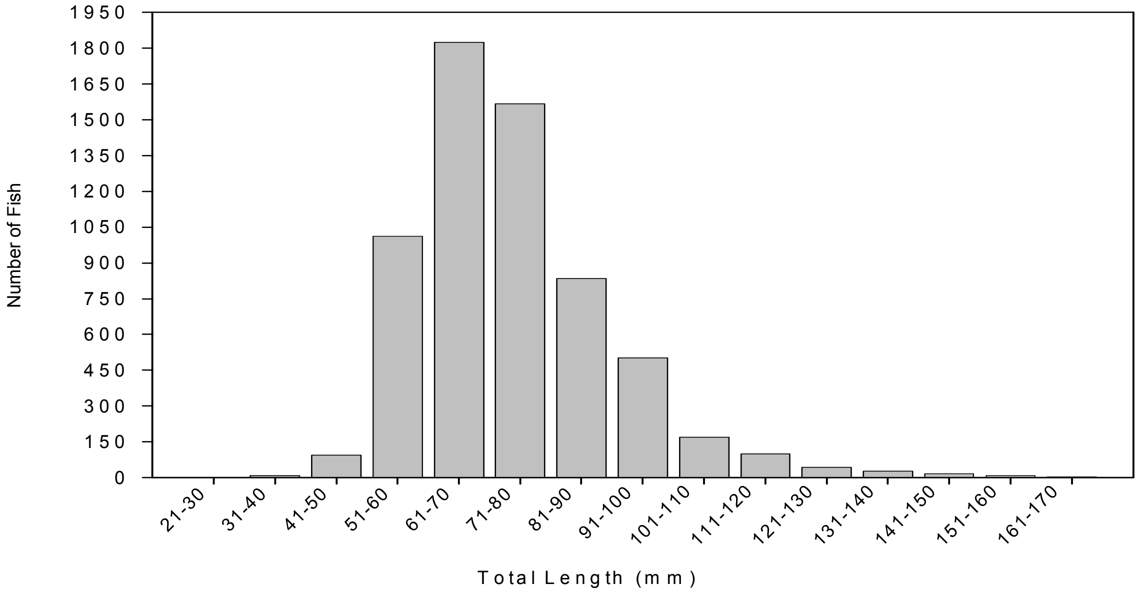

FIGURE 11. – Length class data for threadfin shad (*Dorosoma petenense*) collected at five steam electric facilities during 316(b) sampling conducted by Alabama Power Company (2004-2005).

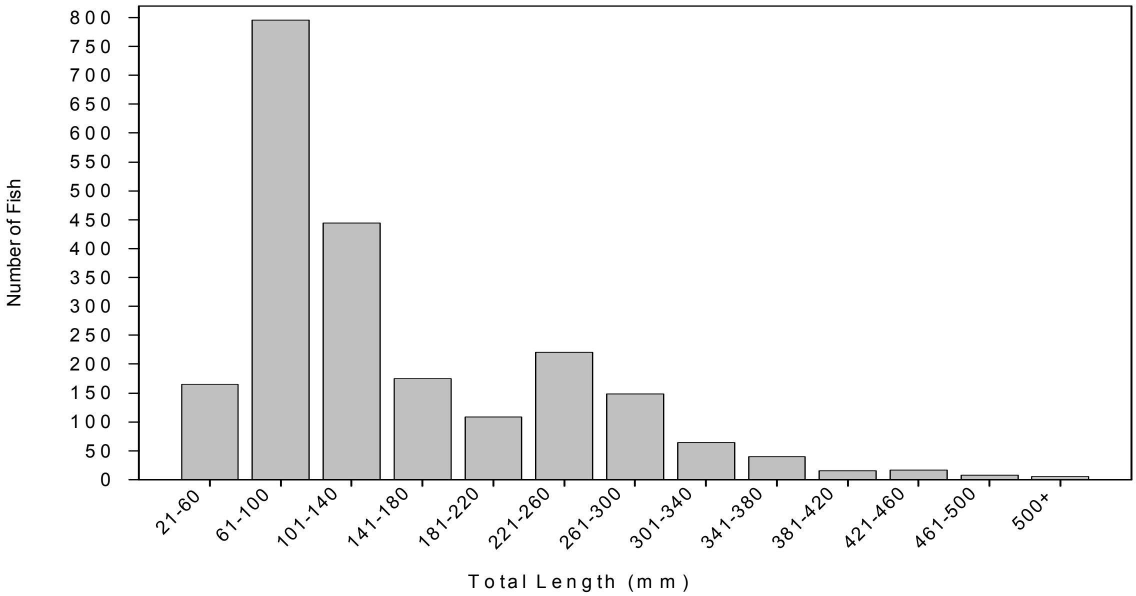

FIGURE 12. – Length class data for freshwater drum (*Aplodinotus grunniens*) collected at five steam electric facilities during 316(b) sampling conducted by Alabama Power Company (2004-2005).

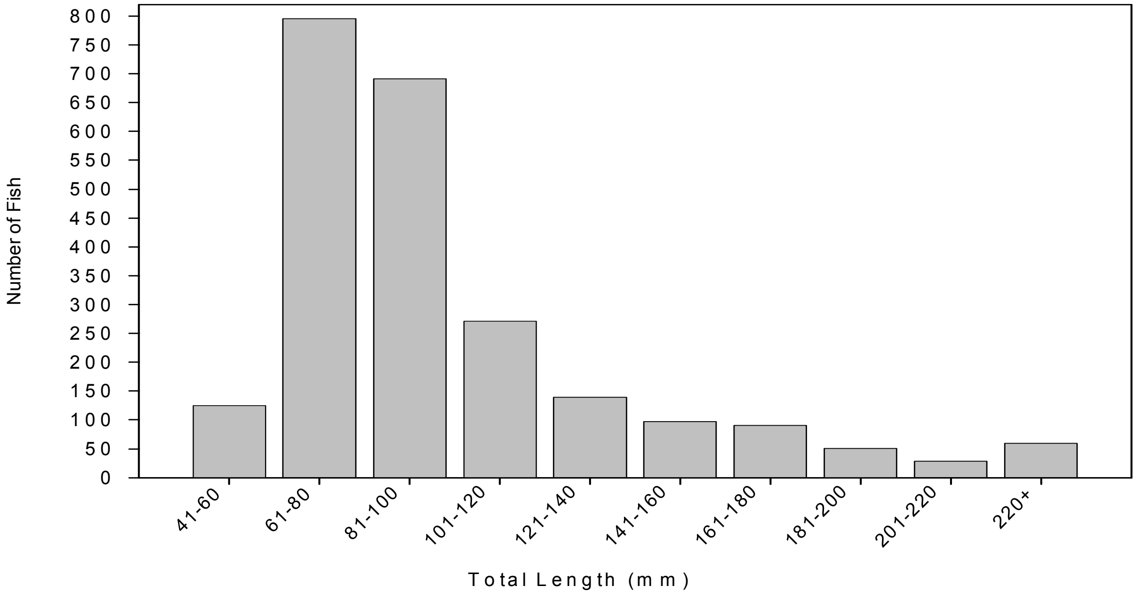

FIGURE 13. – Length class data for blue catfish (*Ictalurus furcatus*) collected at five steam electric facilities during 316(b) sampling conducted by Alabama Power Company (2004-2005).

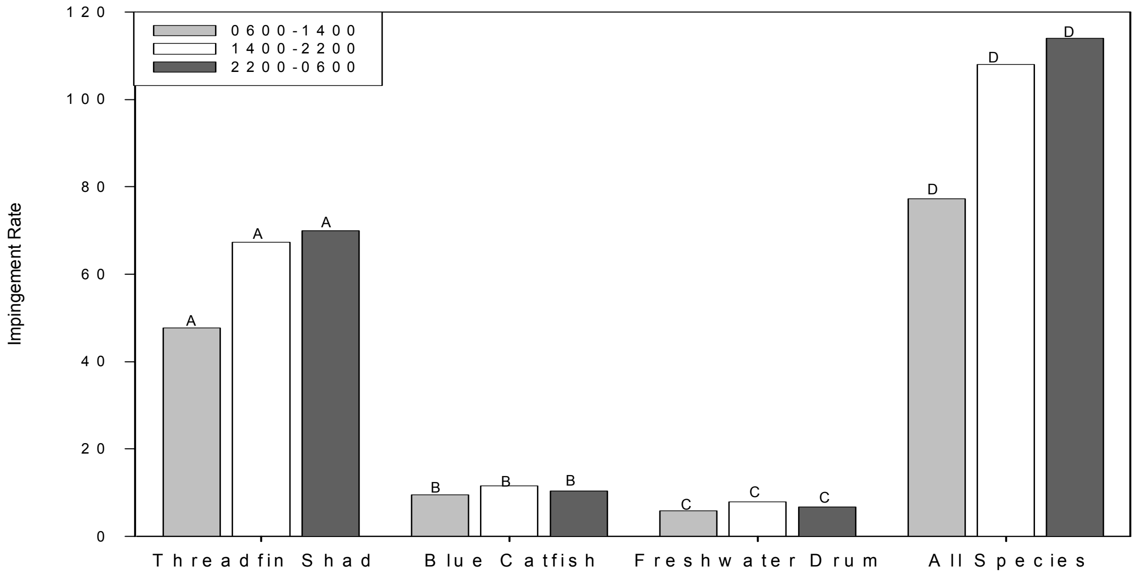

FIGURE 14. – Mean number of fish impinged during each 8-hour period for the dominant three species (threadfin shad, blue catfish and freshwater drum) and all species combined collected at five Alabama Power Company Steam Plants during 2004-2005. Means with the same letter among seasons or months are not different (*P* > 0.050).

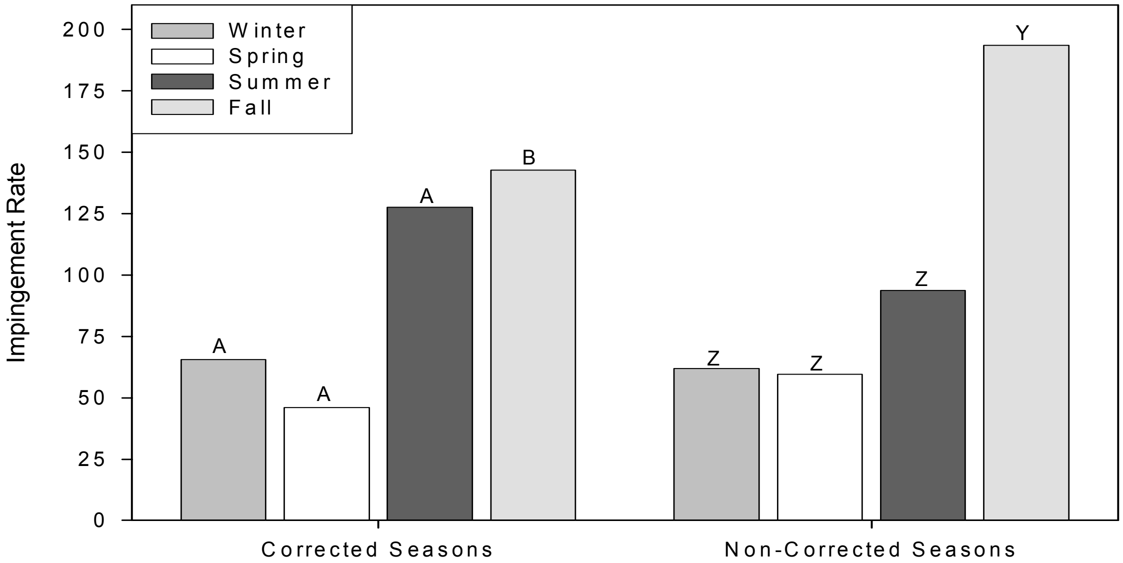

FIGURE 15. – Mean number of fish impinged for 8-hour periods among corrected seasons (seasons grouped by water temperature) and non-corrected seasons for all species collected at five Alabama Power Company Steam Plants sampled during 2004-2005. Means with the same letter among seasons or months are not different (*P* > 0.050).

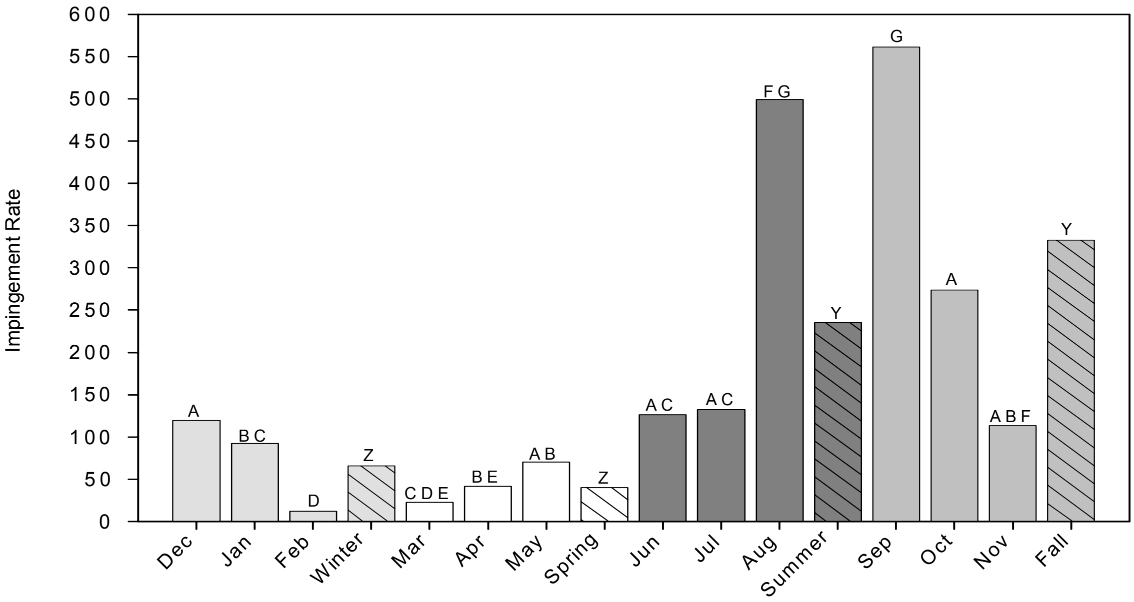

FIGURE 16. – Mean number of fish impinged for 8-hour period among seasons and months for all species at intake units 1-3 for Barry Steam Electric on the Mobile River, Alabama (2004-2005). Means with the same letter among seasons or months are not different (*P* > 0.050).

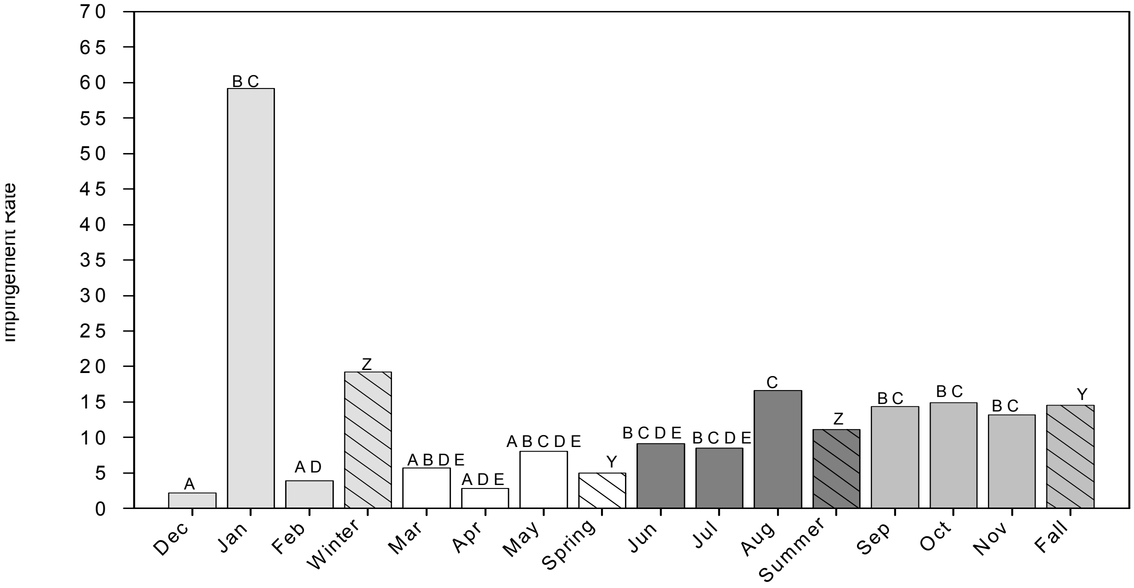

FIGURE 17. – Mean number of fish impinged for 8-hour period among seasons and months for blue catfish (*Ictalurus furcatus*) at intake units 1-3 for Barry Steam Electric on the Mobile River, Alabama (2004-2005). Means with the same letter among seasons or months are not different (*P* > 0.050).

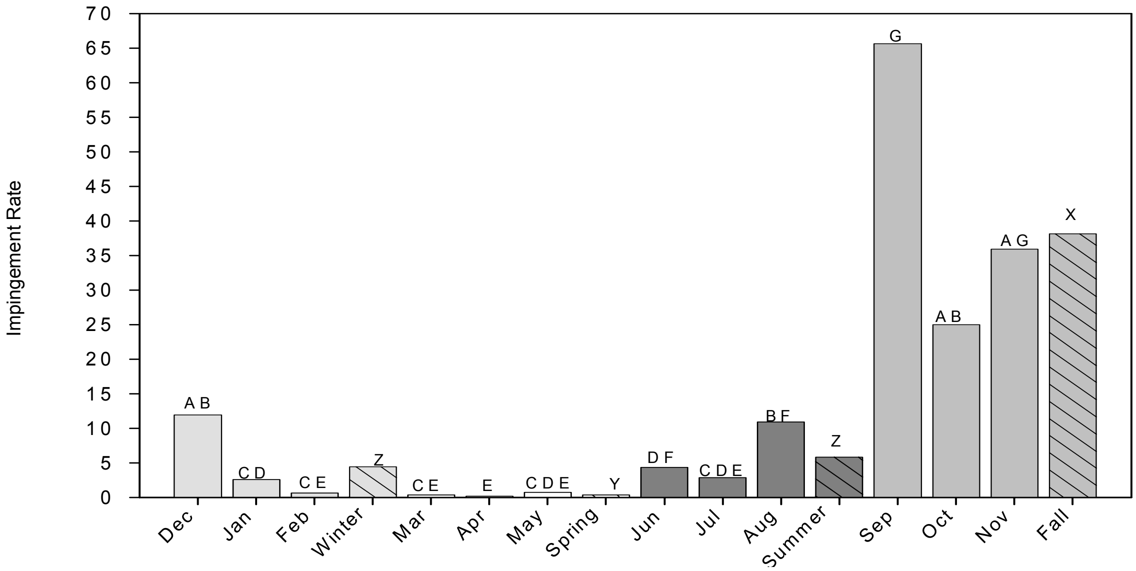

FIGURE 18. – Mean number of fish impinged for 8-hour period among seasons and months for freshwater drum (*Aplodinotus grunniens*) at intake units 1-3 for Barry Steam Electric on the Mobile River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

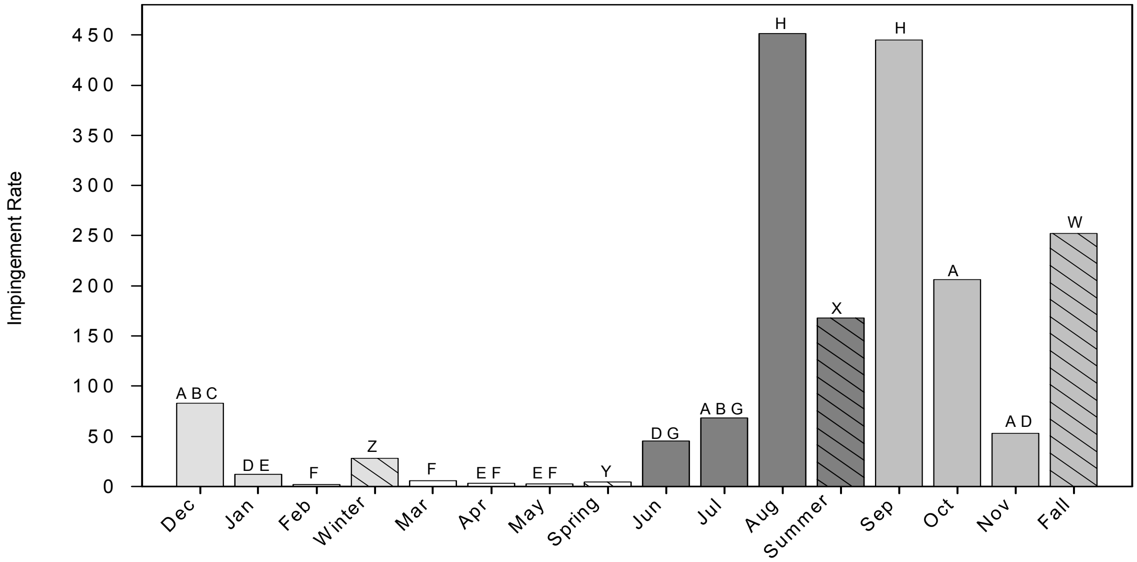

FIGURE 19. – Mean number of fish impinged for 8-hour period among seasons and months for threadfin shad (*Dorosoma petenense*) at intake units 1-3 for Barry Steam Electric on the Mobile River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

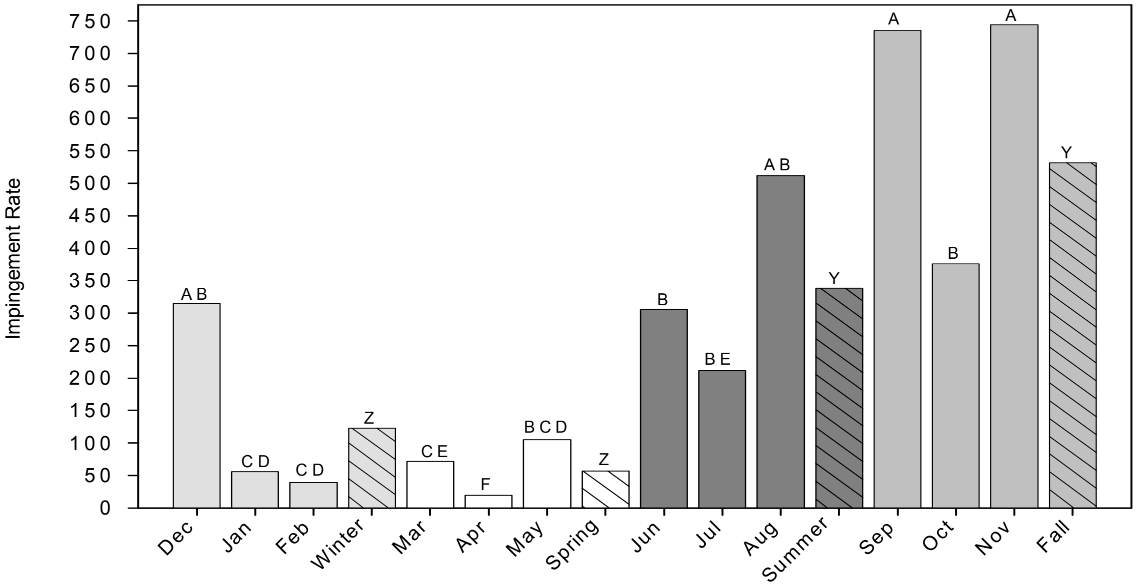

FIGURE 20. – Mean number of fish impinged for 8-hour period among seasons and months for all species at intake units 4-5 for Barry Steam Electric on the Mobile River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

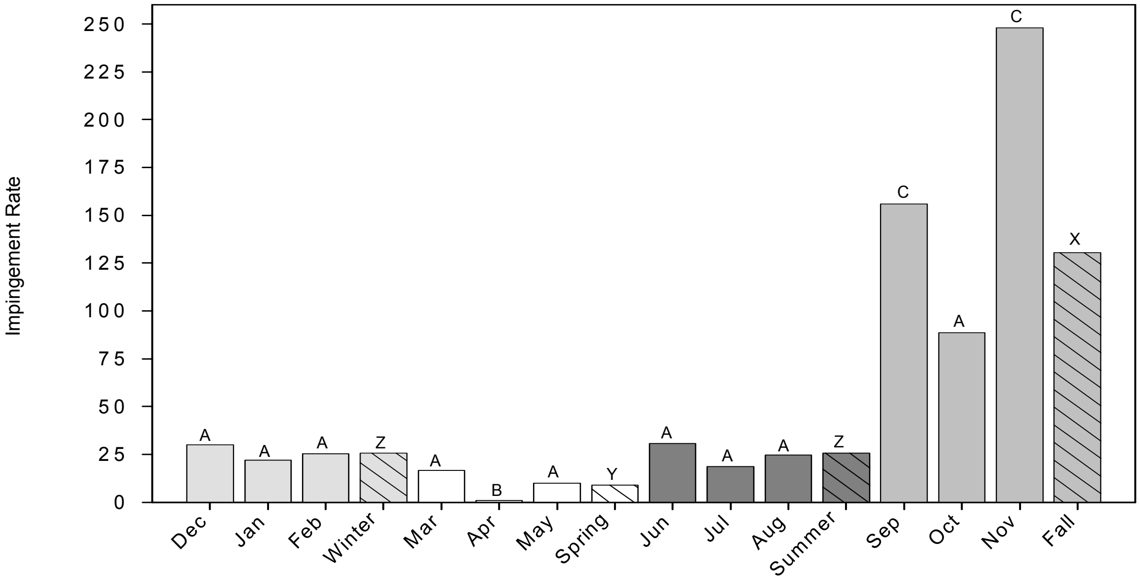

FIGURE 21. – Mean number of fish impinged for 8-hour period among seasons and months for blue catfish (*Ictalurus furcatus*) at intake units 4-5 for Barry Steam Electric on the Mobile River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

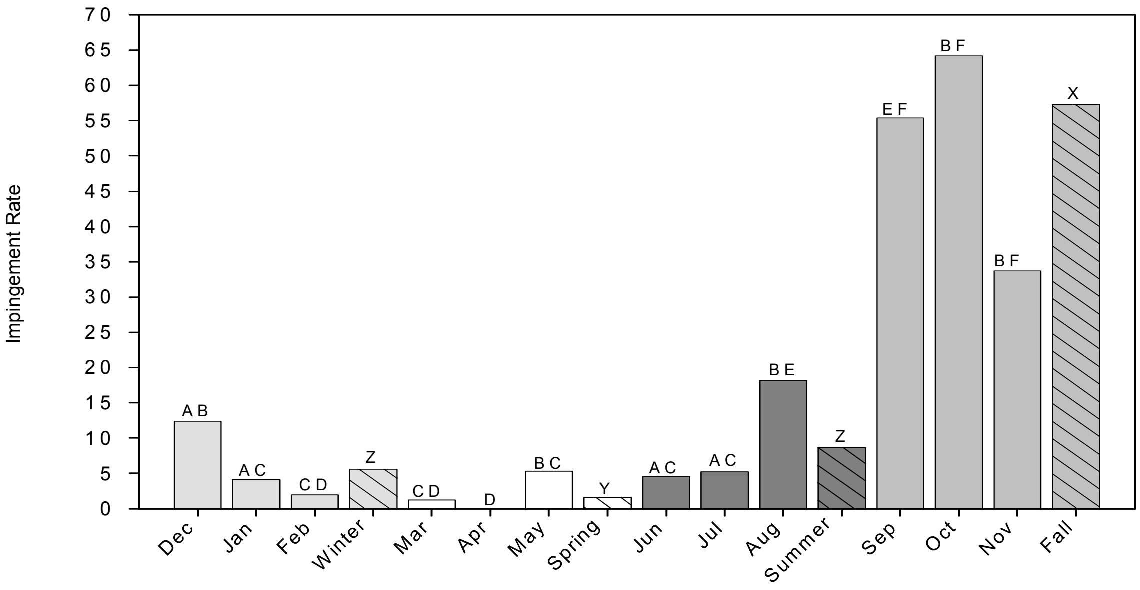

FIGURE 22. – Mean number of fish impinged for 8-hour period among seasons and months for freshwater drum (*Aplodinotus grunniens*) at intake units 4-5 for Barry Steam Electric on the Mobile River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

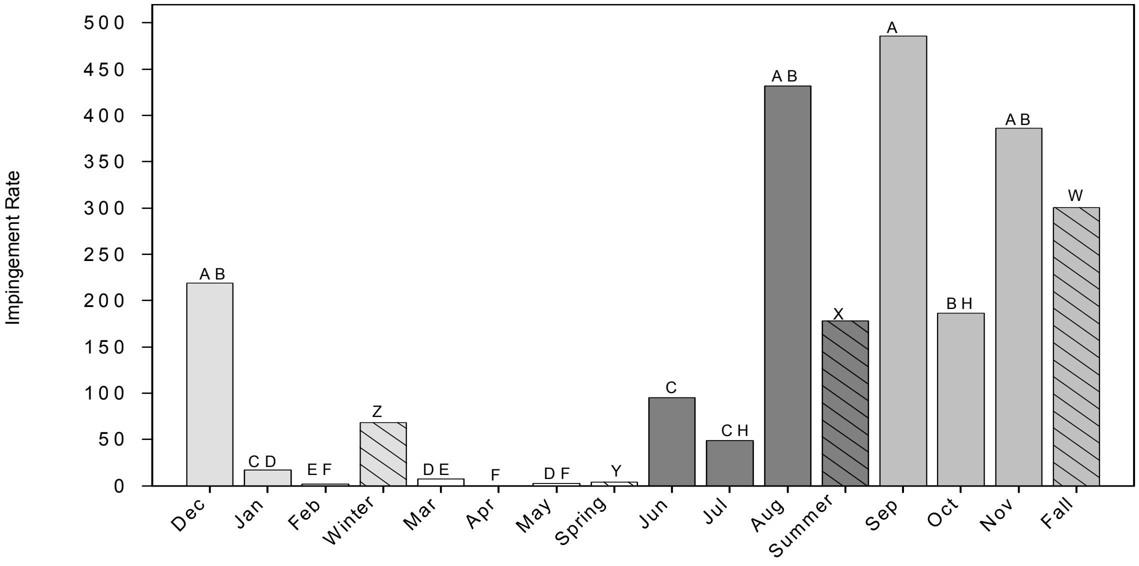

FIGURE 23. – Mean number of fish impinged for 8-hour period among seasons and months for threadfin shad (*Dorosoma petenense*) at intake units 4-5 for Barry Steam Electric on the Mobile River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

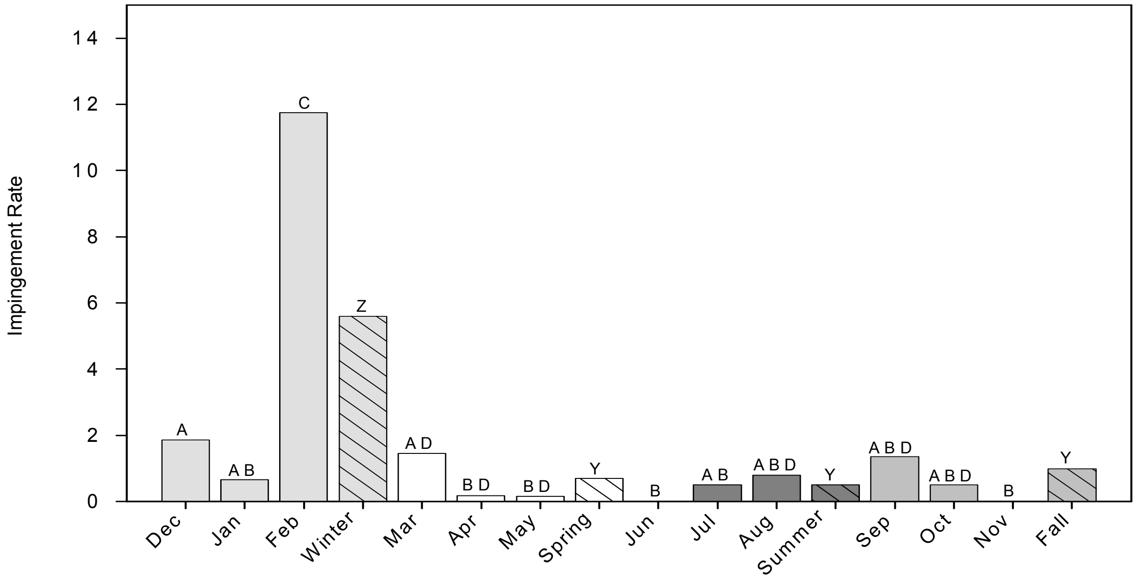

FIGURE 24. – Mean number of fish impinged for 8-hour period among seasons and months for all species at intake units 1-2 for Gadsden Steam Electric on the Coosa River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

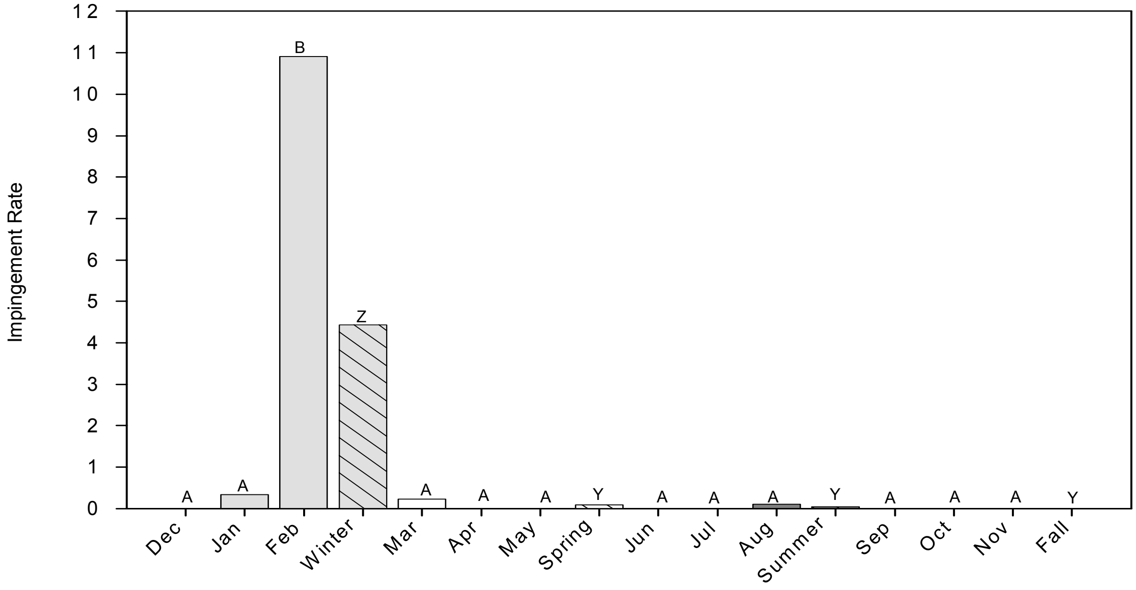

FIGURE 25. – Mean number of fish impinged for 8-hour period among seasons and months for threadfin shad (*Dorosoma petenense*) at intake units 1-2 for Gadsden Steam Electric on the Coosa River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

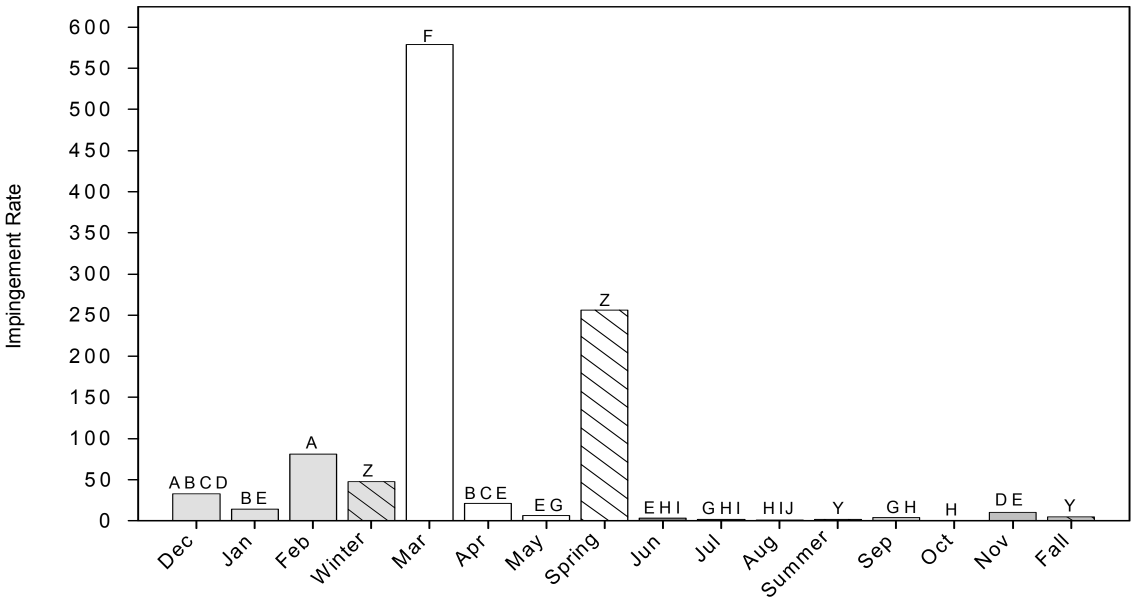

FIGURE 26. – Mean number of fish impinged for 8-hour period among seasons and months for all species at intake units 1-5 for E.C. Gaston Steam Electric on the Coosa River, Alabama (2004-2005). Means with the same letter among seasons or months are not different (*P* > 0.050).

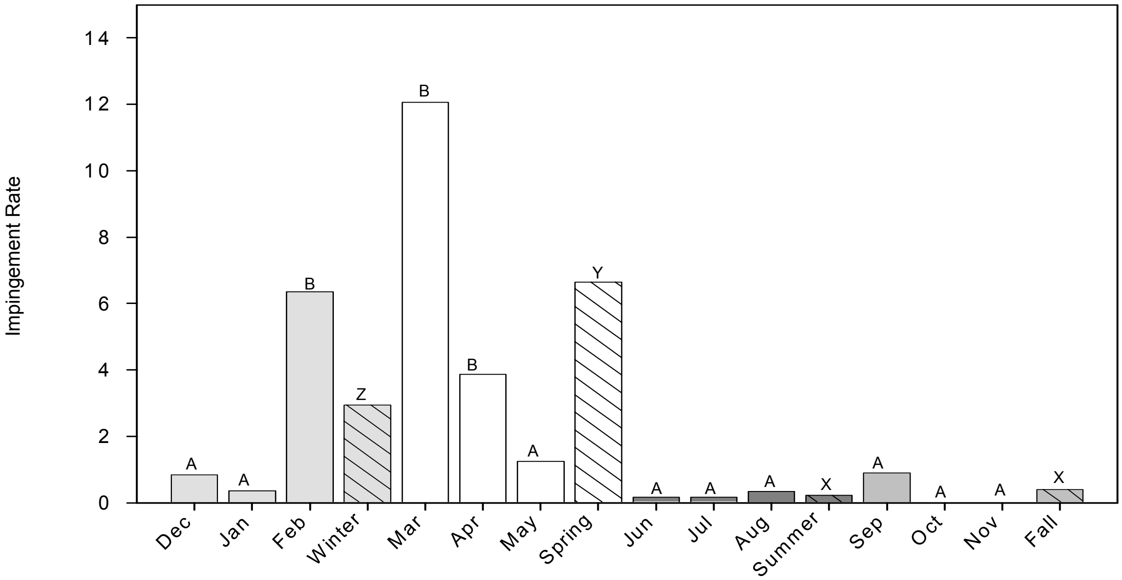

FIGURE 27. – Mean number of fish impinged for 8-hour period among seasons and months for blue catfish (*Ictalurus furcatus*) at intake units 1-5 for E.C. Gaston Steam Electric on the Coosa River, Alabama (2004-2005). Means with the same letter among seasons or months are not different (*P* > 0.050).

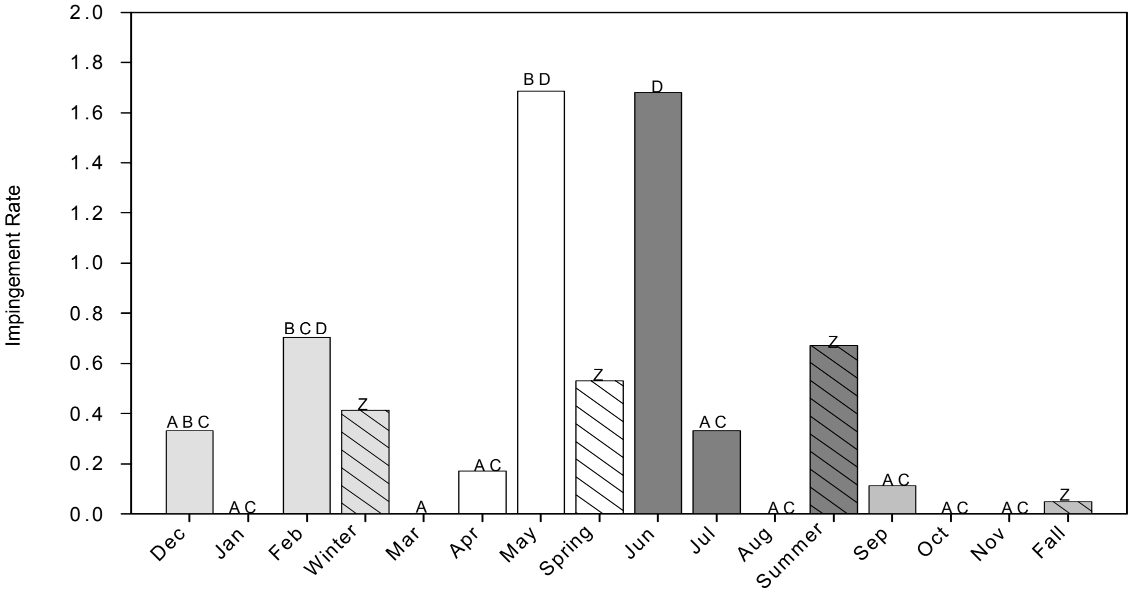

FIGURE 28. – Mean number of fish impinged for 8-hour period among seasons and months for freshwater drum (*Aplodinotus grunniens*) at intake units 1-5 for E.C. Gaston Steam Electric on the Coosa River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

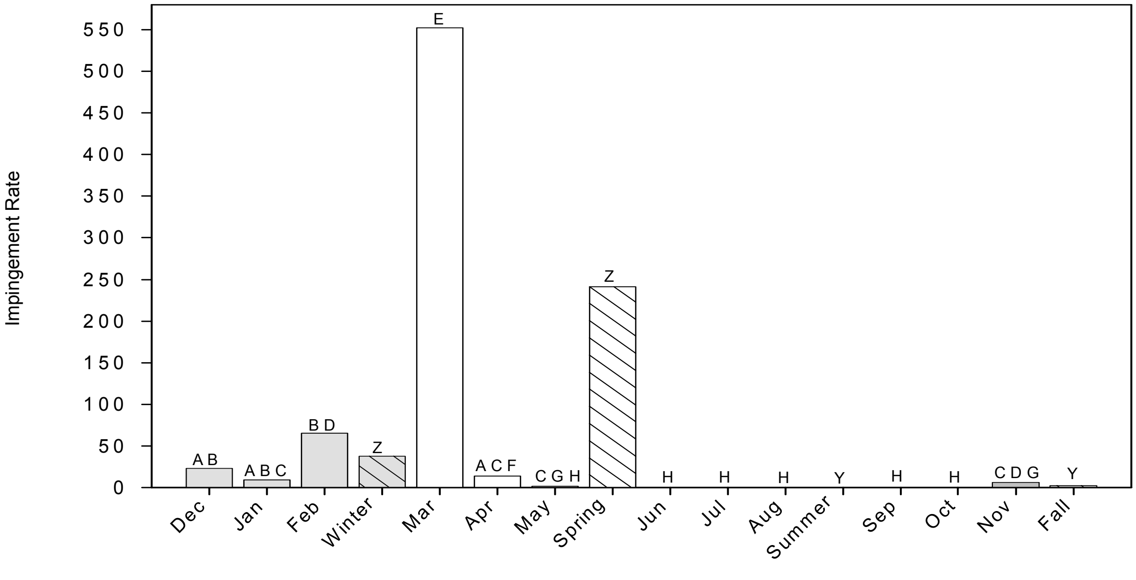

FIGURE 29. – Mean number of fish impinged for 8-hour period among seasons and months for threadfin shad (*Dorosoma petenense*) at intake units 1-5 for E.C. Gaston Steam Electric on the Coosa River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

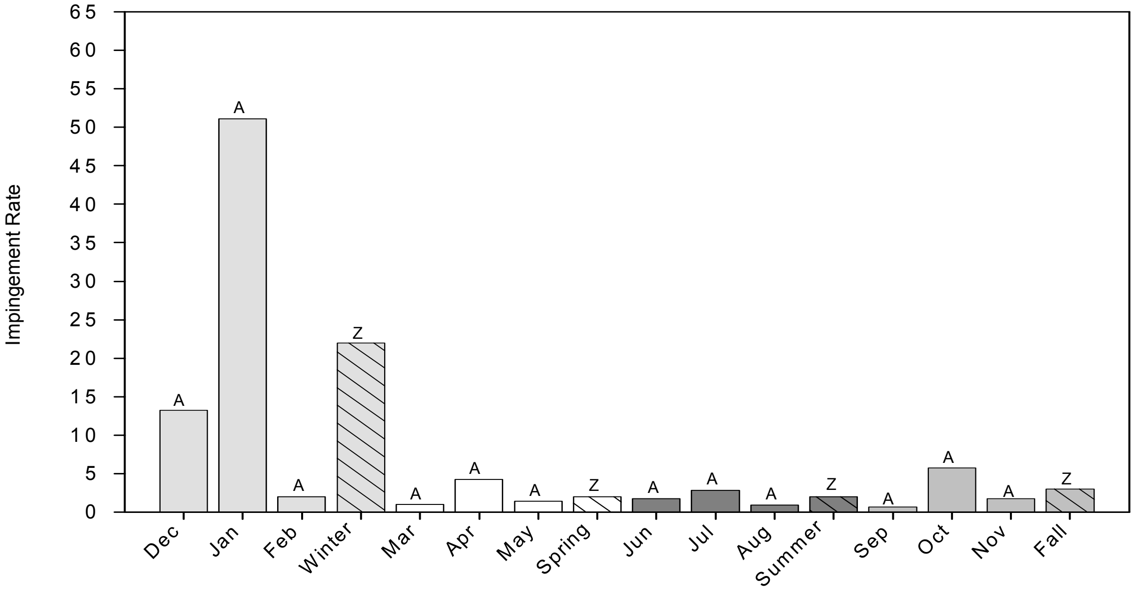

FIGURE 30. – Mean number of fish impinged for 8-hour period among seasons and months for all species at intake units 6-7 for Gorgas Steam Electric on the Black Warrior River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

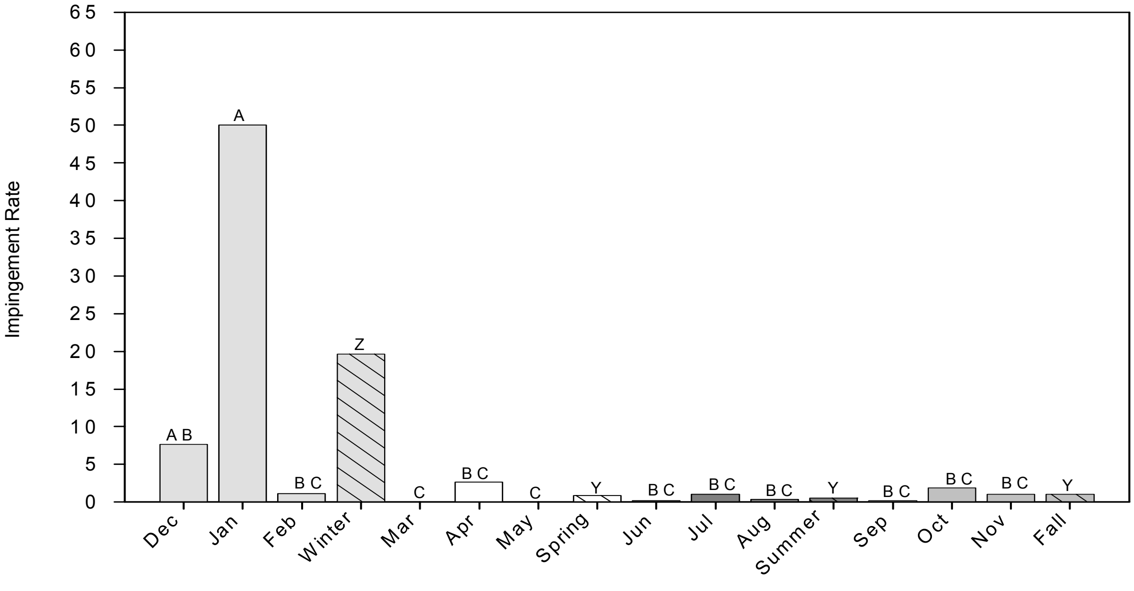

FIGURE 31. – Mean number of fish impinged for 8-hour period among seasons and months for threadfin shad (*Dorosoma petenense*) at intake units 6-7 for Gorgas Steam Electric on the Black Warrior River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

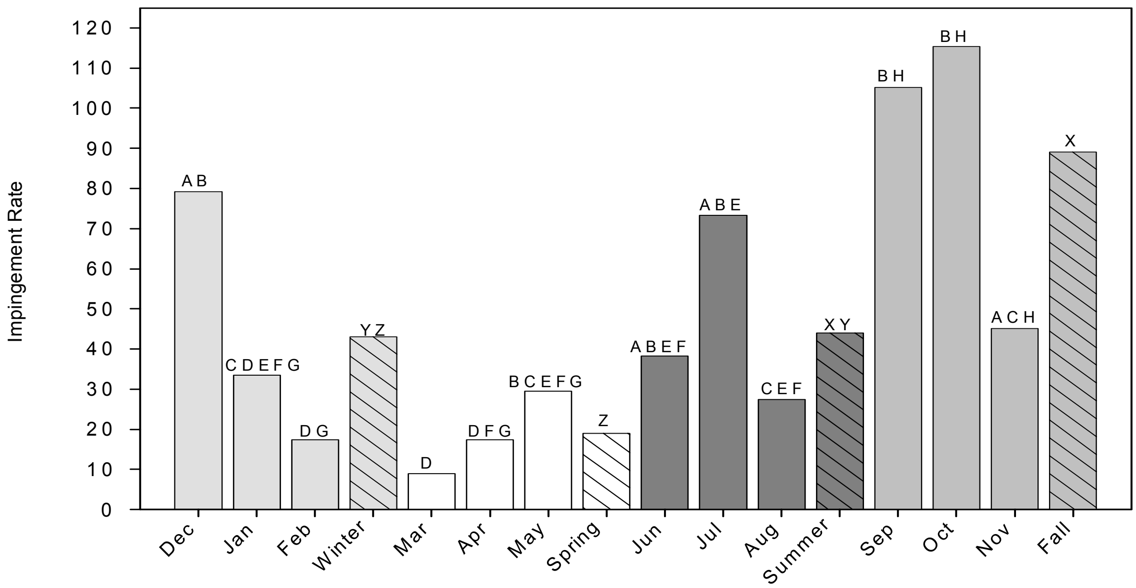

FIGURE 32. – Mean number of fish impinged for 8-hour period among seasons and months for all species at intake units 8-10 for Gorgas Steam Electric on the Black Warrior River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

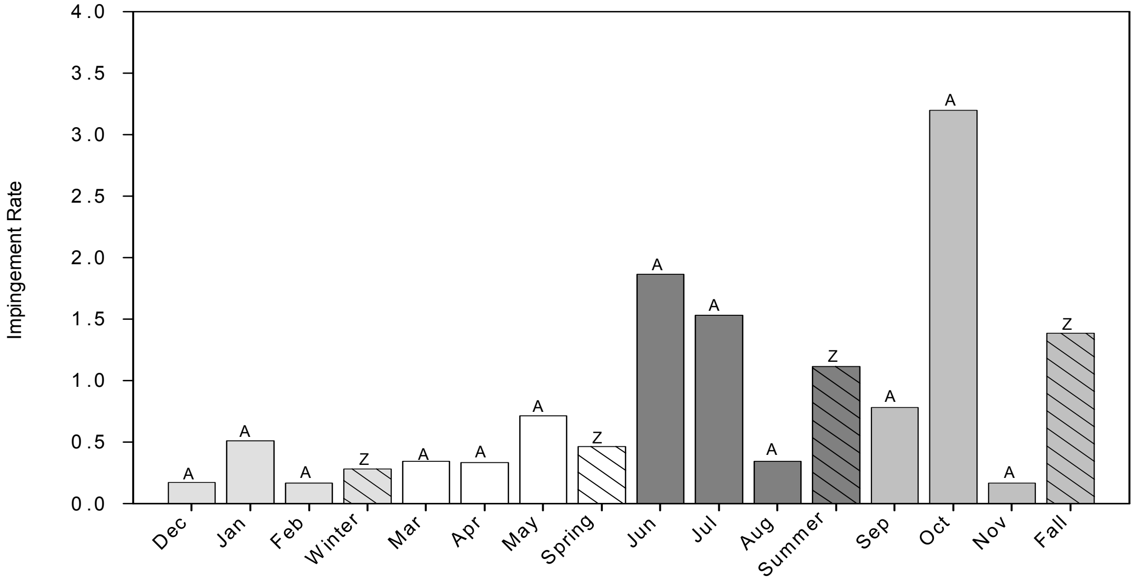

FIGURE 33. – Mean number of fish impinged for 8-hour period among seasons and months for blue catfish (*Ictalurus furcatus*) at intake units 8-10 for Gorgas Steam Electric on the Black Warrior River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

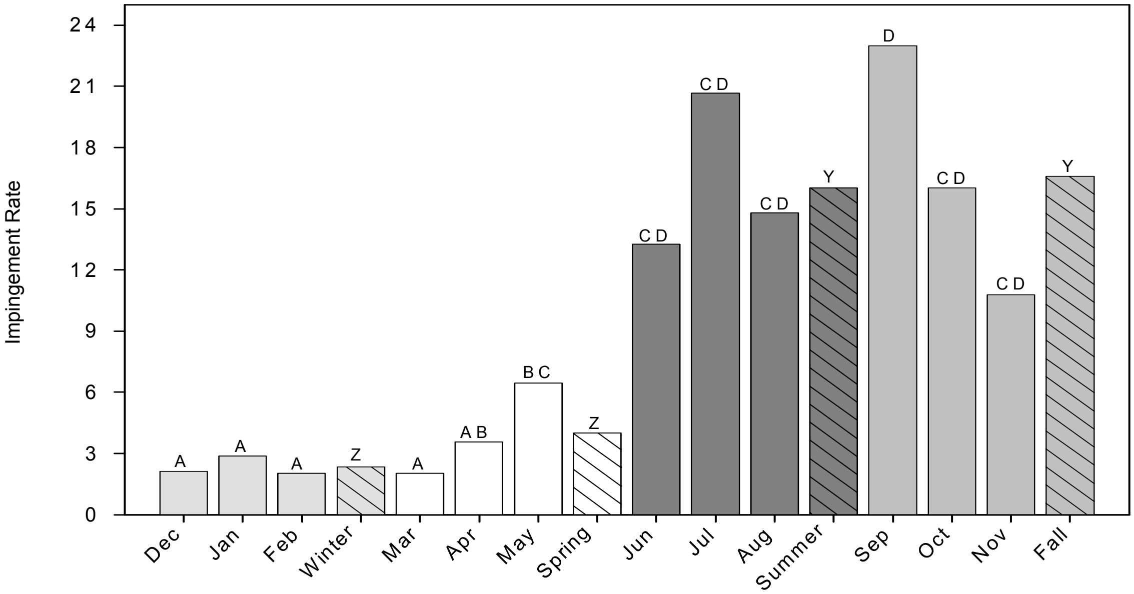

FIGURE 34. – Mean number of fish impinged for 8-hour period among seasons and months for freshwater drum (*Aplodinotus grunniens*) at intake units 8-10 for Gorgas Steam Electric on the Black Warrior River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

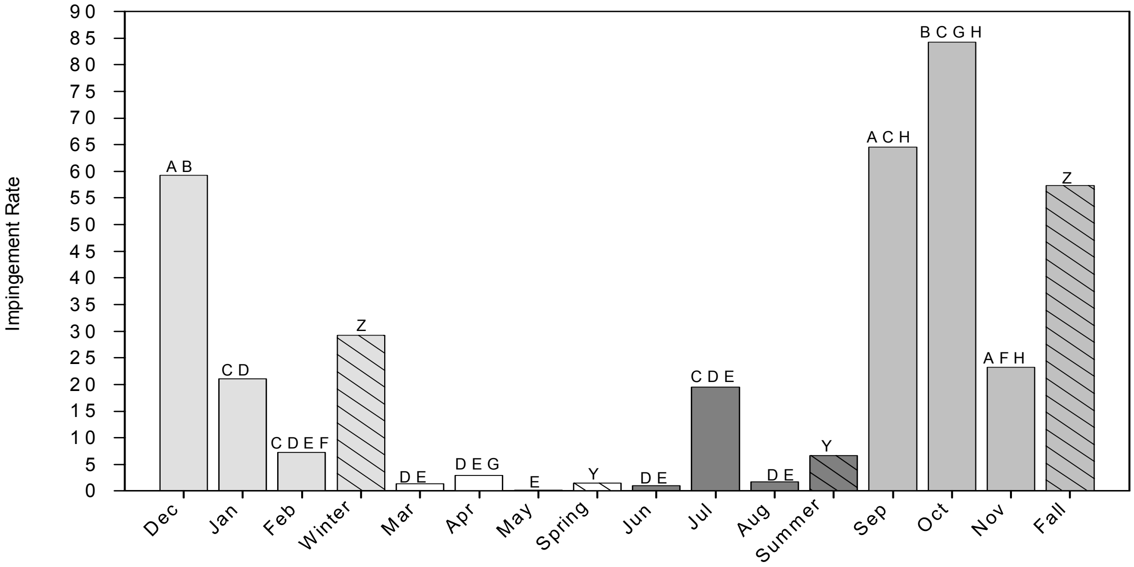

FIGURE 35. – Mean number of fish impinged for 8-hour period among seasons and months for threadfin shad (*Dorosoma petenense*) at intake units 8-10 for Gorgas Steam Electric on the Black Warrior River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

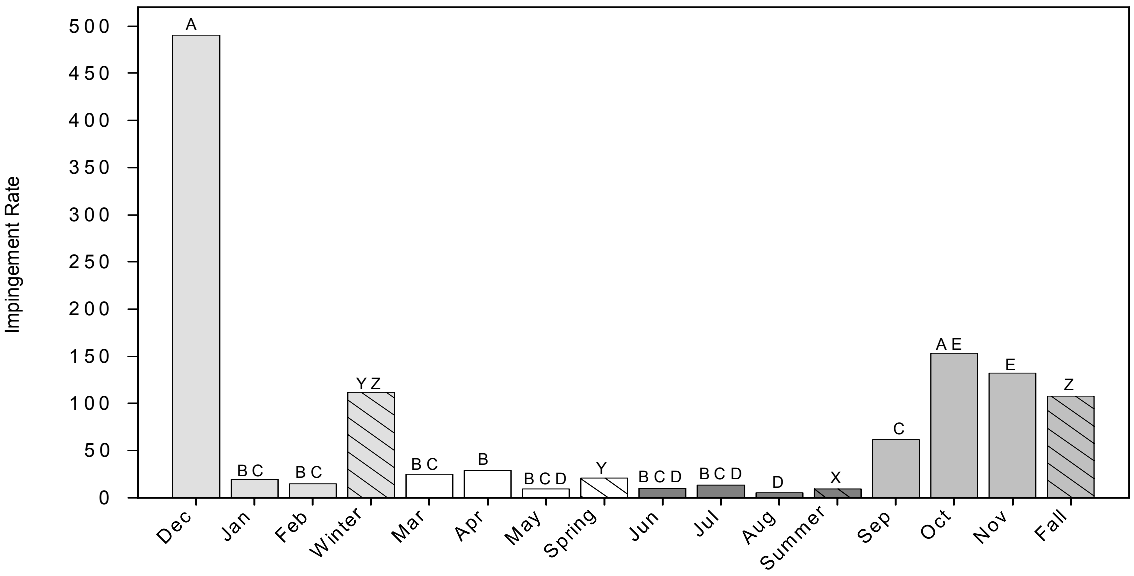

FIGURE 36. – Mean number of fish impinged for 8-hour period among seasons and months for all species at intake units 1-2 for Greene Co. Steam Electric on the Tombigbee River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

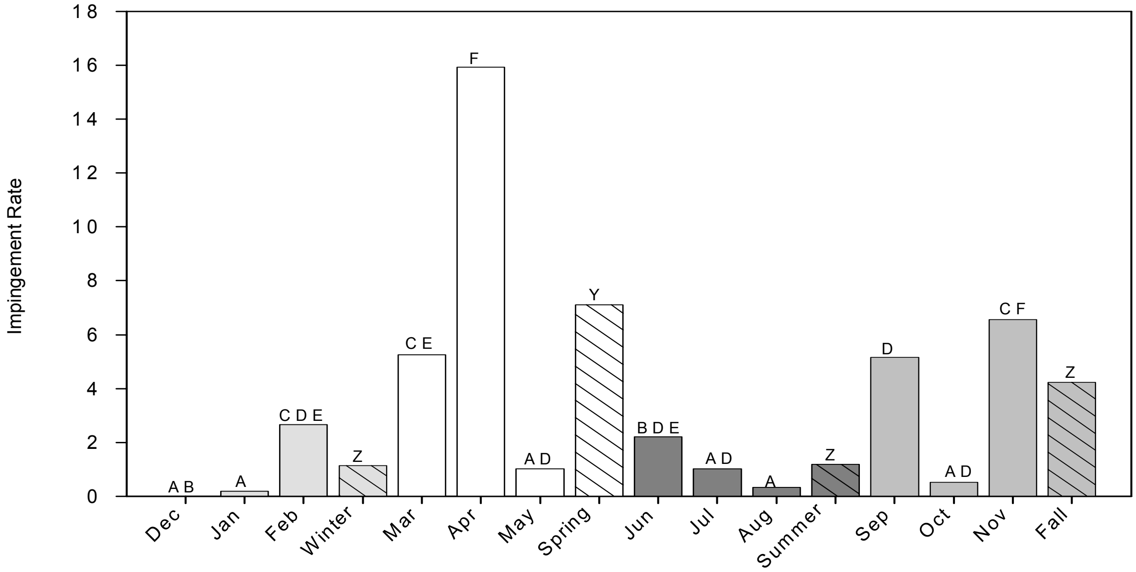

FIGURE 37. – Mean number of fish impinged for 8-hour period among seasons and months for blue catfish (*Ictalurus furcatus*) at intake units 1-2 for Greene Co. Steam Electric on the Tombigbee River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

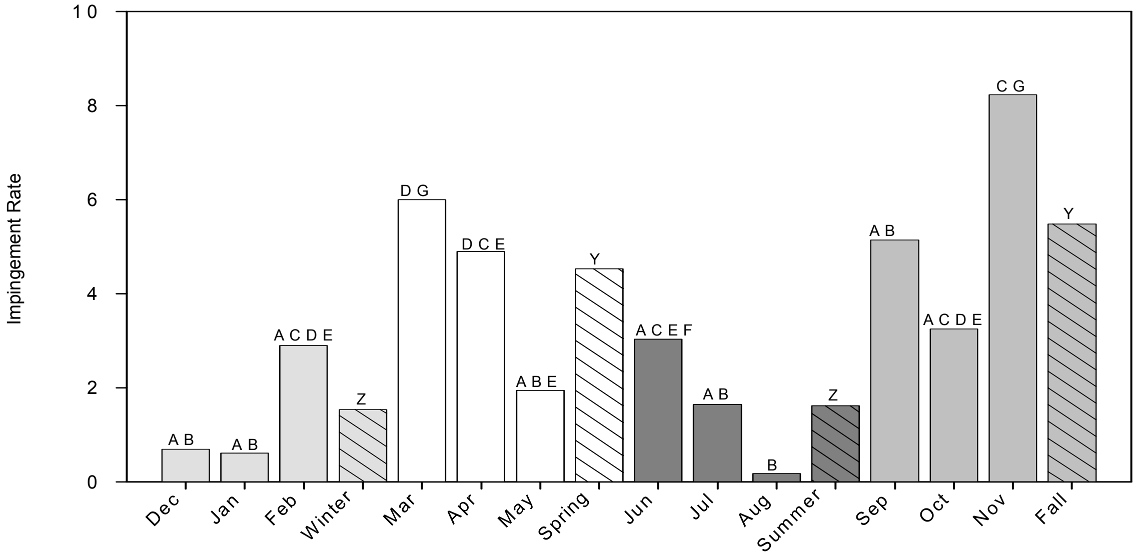

FIGURE 38. – Mean number of fish impinged for 8-hour period among seasons and months for freshwater drum (*Aplodinotus grunniens*) at intake units 1-2 for Greene Co. Steam Electric on the Tombigbee River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

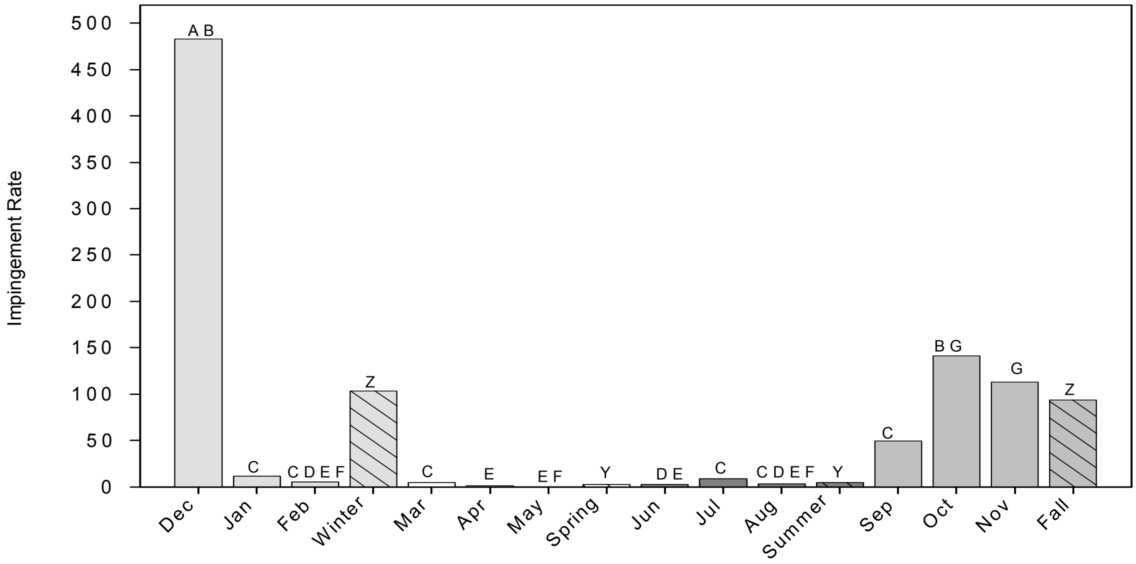

FIGURE 39. – Mean number of fish impinged for 8-hour period among seasons and months for threadfin shad (*Dorosoma petenense*) at intake units 1-2 for Greene Co. Steam Electric on the Tombigbee River, Alabama (2004-2005). Means with the same letter among seasons or months are not different ($P > 0.050$).

FIGURE 40. – Example of cooling water intake structure screen ledge for Barry, Gadsden, E.C. Gaston, Gorgas, and Greene County Steam Plants during 316(b) sampling conducted by Alabama Power Company in 2004-2005.

VII. Appendices

APPENDIX 1. Ranges of variables sampled at Barry, Gadsden and E.C. Gaston Steam Plants during 316(b) sampling conducted by Alabama Power Company during 2004-2005.

Variable	Barry 1-3	Barry 4-5	Gadsden	Gaston
Water Temperature (^{o}C)	10.4 – 30.6	10.5 – 30.7	6.3 – 33.7	7.8 – 30.6
Dissolved Oxygen (mg/l)	4.6 – 11.3	4.8 – 11.3	5.2 – 12.1	5.4 – 11.5
Specific Conductance (µS/cm)	105.0 – 216.0	106.0 – 239.0	91.0 – 159.0	52.0 – 174.0
Turbidity (NTU)	13.6 – 70.0	14.7 – 74.0	4.0 – 31.5	1.0 – 228.0
pH	6.7 – 8.0	6.7 – 7.9	6.6 – 8.8	6.6 – 8.4
CWIS Flow Velocity (m/s)	0.5 – 5.4	0.7 – 4.7	0.1 – 0.5	0.7 – 2.7
CWIS Flow Volume (MLD)	232.0 – 468.0	256.0 – 669.0	48.0 – 191.0	507.0 – 856.0
HZI (ML)	56.8 – 123.2	56.8 – 123.2	0.1 – 0.6	260.6 – 335.8
River Discharge (MLD)	5,721 – 35,790	5,721 – 35,790	1,292 – 13,872	491 – 28,135
Screens In Use	3 – 6	3 – 5	2 – 3	3 – 7
Debris Weight (kg)	874.0 – 104,970.0	2,239.0 – 58,577.0	60.0 – 41,551.0	9.0 – 210,055.0
Water Level (m)	3.1 – 9.5	6.8 – 8.2	14.1 – 24.5	12.5 – 15.0

APPENDIX 2. Ranges of variables sampled at Gorgas and Greene Co. Steam Plants during 316(b) sampling conducted by Alabama Power Company during 2004-2005.

Variable	Gorgas 6-7	Gorgas 8-10	Greene Co.
Water Temperature (^{o}C)	7.3 – 25.4	6.9 – 25.0	8.8 – 30.4
Dissolved Oxygen (mg/l)	4.0 – 11.0	4.0 – 11.2	6.8 – 12.1
Specific Conductance (μS/cm)	72.0 – 202.0	71.0 – 197.0	140.0 – 299.3
Turbidity (NTU)	3.9 – 37.0	4.0 – 18.0	5.4 – 54.2
pH	6.7 – 8.0	6.7 – 9.5	6.9 – 8.2
CWIS Flow Velocity (m/s)	0.0 – 1.5	1.4 – 3.1	0.5 – 1.4
CWIS Flow Volume (MLD)	0.0 – 245.6	172.0 – 339.0	221.0 – 434.0
HZI (ML)	--	--	16.8 – 37.2
River Discharge (MLD)	--	--	684 – 44,992
Screens In Use	2 – 3	2 – 5	3
Debris Weight (kg)	10.9 – 50,693.0	322.1 – 46,935.0	611.0 – 118,000.0
Water Level (m)	-0.9 – 1.4	6.4 – 10.2	14.8 – 20.0