DRAFT
EFFECTIVENESS OF THE PINOPOLIS LOCK AT ATTRACTING ADULT BLUEBACK HERRING AND AMERICAN SHAD, SPRING 2003

(Pertains to Study Request No. 3, Part 2)

Normandeau Associates Project Number 19409.000

PREPARED FOR:
Santee Cooper
South Carolina Public Service Authority
One Riverwood Drive
P.O. Box 2946101
Moncks Corner, SC 29461-2901

PREPARED BY:
Normandeau Associates, Inc.
Drumore, PA
Westmoreland, NH

Draft

October 2003

EXECUTIVE SUMMARY

The effectiveness of the Pinopolis Lock at attracting adult blueback herring (*Alosa aestivalis*) and American shad (*Alosa sapidissima*) was investigated for a second consecutive year during spring 2003, relative to relicensing of the Santee Cooper Hydroelectric Project. The objectives of the study this year, as last year, were to estimate the efficiency of the Pinoppolis Lock in attracting blueback herring and American shad migrants for upstream passage, and to characterize their movements as they approached the Pinopolis Lock in the tailrace of the Jefferies Hydroelectric Station. Additionally, these results were compared with those reported last year.

The Project area of interest is the Pinopolis Lock and the adjacent Jefferies Hydroelectric Station, located near the town of Moncks Corner, South Carolina and approximately 77 kilometers (km) upstream from Charleston Harbor on the headwaters of the Cooper River. Beyond the Project boundary, the study area includes the approximately 6.2 km stretch of river and tailrace canal downstream of the Jefferies Hydroelectric Station to Stoney Landing. The project is owned and operated by South Carolina Public Service Authority, also known as Santee Cooper.

The Jefferies Hydroelectric Station is operated as a semi-peaking facility based on the Cooper River Rediversion Agreement (contract between the federal government and Santee Cooper). Weekly average discharge at Jefferies is restricted to 4,500 cfs. Instantaneous discharge through the five turbine units may vary from 0 to 28,000 cfs. The Pinopolis Lock is operated year round during daylight hours for navigation around Pinopolis Dam. During the spring anadromous fish migration period of approximately eight weeks, the lock is operated for fish passage in addition to navigation. Lock operation for fish passage typically includes six events between 0700 h and 1800 h. Fish passed upstream are monitored by a hydroacoustic monitoring system that provides a gross index of 'herring units' and biomass passed (Cooke and Leach 2002).

Ninety nine blueback herring and 100 American shad were collected in the Jefferies tailrace and fitted with internal coded radio transmitters supplied by Lotek Engineering Inc. The tagged fish were measured, held for short-term observation and released below the sanctuary line in the Jefferies tailrace. Tagged fish were monitored using Lotek stationary telemetry receivers set up at four stations between the dam and Stoney Landing and a portable tracking receiver. The effectiveness of the lock at attracting fish was calculated as the number of fish that entered the lock divided by the number of fish available to enter the lock (i.e., the number of fish detected in the Jefferies Hydroelectric Station tailrace).

Lock attraction effectiveness for blueback herring was 78.3%, representing 36 of 46 herring located in the tailrace more than 12 h after release. Of 36 herring located in the Pinopolis Lock on at least one occasion, 21 (58.3%) passed upstream to Lake Moultrie. For American shad, lock attraction effectiveness was 91.5%, representing 72 of 82 shad located in the tailrace more than 12 h after release. Seventy-two, or 96% of those entering the lock subsequently passed into Lake Moultrie.

Last year, lock attraction effectiveness was 48% (41 of 85) for blueback herring and 66% (49 of 74) for American shad. This represents a 62% increase in attraction effectiveness for herring and a 39% increase for shad in 2003. Passage through the lock increased for shad in 2003 (89.8% vs. 96.0% but decreased for herring (75.6% vs. 58.3%). Coming out of a five year drought, 2003 represented an exceptionally high water year for the area, providing flow to numerous tributaries that had been dry a year earlier. Some manually tracked shad and herring were found in Wadboo Creek, north-east of the lower-most stationary receiver detection zone (Old Santee Canal State Park) where alosine spawning activity was observed.

Movement of fish to the tailrace and into the lock, by flow category, for each study period was compared. Few differences were found for herring moving into the tailrace. A notable difference in shad forays was a decrease in 2003 at zero discharge (47% vs. 58%) and increase at the 15,001-20,000 cfs discharge category (22% vs. 7%). Herring and shad both entered the lock more often during zero and lower flow categories in 2003 compared to 2002 (Figures 24 and 25).

During the course of the study (13 March through 12 May), manual tracking was conducted 46 times over 29 days. The number of fish tracked manually during an event ranged from 2 to 37. Fifty-seven of the 99 herring and 84 of the 100 shad tagged were located manually. Herring were most often located in the sanctuary area of the tailrace (n=39) while shad were more often found between the Route 52 Bridge and the Railroad Bridge (n=58), and the sanctuary area of the tailrace (n=50).

At zero discharge from the powerhouse, investigators noted a relatively high percentage of forays (movement from downstream to the tailrace) and entry into the lock for both species during both years. These results indicate that semi-peaking flows do attract fish to the tailrace, and that fish do not necessarily leave the tailrace under zero discharge conditions. These results suggest that the semi-peaking operation of the Jefferies Station may not be detrimental to upstream passage, and that enhancements can be focused on getting more herring and shad into the lock.

Considerations for improvement in the effectiveness of the Pinopolis Lock include: a) lock operations over a greater portion of the day because herring and shad were present in the tailrace during all hours of the day; b) continuing or improving attraction flow via the siphon or perhaps by other means near the lock entrance, particularly at zero and low discharge conditions when lock attraction flows would likely be most effective.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION AND BACKGROUND

South Carolina Public Service Authority, also known as Santee Cooper, is in the process of relicensing the Santee Cooper Hydroelectric Power Project (the Project) (FERC No. 199-SC). The Project is located in southeast South Carolina on the Santee and Cooper Rivers in Berkeley, Calhoun, Clarendon, Orangeburg, and Sumter Counties and operates in accordance with a Federal Energy Regulatory Commission (FERC) license that expires on 31 March 2006.

In the First Stage Consultation phase of the FERC relicensing process, Santee Cooper received study requests from the following state and federal agencies: South Carolina Department of Natural Resources (SCDNR), U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS) and the South Carolina Department of Health and Environmental Control (DHEC). After consultation between the licensee and the agencies, Santee Cooper synthesized the request to a list of sixteen. This study addresses elements of Study Request 3, "Pinopolis Dam fish passage facility feasibility study." The intent of the request is to determine whether Pinopolis Lock attracts and passes upstream migrating fish at an acceptable rate.

The Santee Cooper Project area encompasses Lakes Marion and Moultrie and their appurtenant impounding and electric generating structures. Lake Marion drains to the Santee River and the canal connecting the two lakes, and Lake Marion drains to the Cooper River. A five-mile long canal diverts water from Lake Marion to Lake Moultrie for power production at the Jefferies Hydroelectric Station (130 MW). A small generating unit at the Santee Dam provides a constant minimum flow of at least 500 cfs to the Santee River and has a generating capacity of 1.92 MW with a rated net head of 46 feet.

Due to concerns with sedimentation buildup in Charleston Harbor, in the 1980s the United States Army Corps of Engineers (USACE) re-diverted approximately 70% of the project waters released from Lake Moultrie back into the Santee River via a constructed re-diversion canal. The St. Stephen Project, including a 90 MW hydroelectric station, was constructed by the USACE on the re-diversion canal. Location of a fish passage facility at the St. Stephen Project resulted in upstream passage availability on both the Cooper (via the lock) and Santee rivers.

The Project area of interest for this study is the Pinopolis Lock and adjacent Jefferies Hydroelectric Station located near the town of Moncks Corner and approximately 77 kilometers (km) upstream from Charleston Harbor on the headwaters of the Cooper River. Beyond the Project boundary, the study area includes an approximate 6.2 km segment of the river from the Jefferies Hydroelectric Station tailrace downstream to Stoney Landing (Figure 1).

The Jefferies Hydroelectric Station operates as a semi-peaking facility based on the Cooper River Rediversion Agreement (contract between the federal government and Santee Cooper). Weekly average discharge at Jefferies is restricted to 4,500 cfs with an instantaneous discharge range of 0 to 28,000 cfs. The Pinopolis Lock operates year round during daylight hours for navigate on around Pinopolis Dam. During the spring anadromous fish migration period of approximately eight weeks, the lock operates for fish passage in addition to navigation. Lock operation for fish passage typically includes six events between 0700 h and 1800 h. Fish passed upstream are monitored by a hydroacoustic monitoring system that provides a gross index of 'herring units' and biomass passed (Cooke and Leach 2002).

Seven species of diadromous fish occur in the Cooper River: American shad (*Alosa sapidissima*), hickory shad (*Alosa mediocris*), blueback herring (*Alosa aestivalis*), striped bass (*Morone saxatilis*), Atlantic sturgeon (*Acipenser oxyrhynchus*), shortnose sturgeon (*Acipenser brevirostrum*) and American eel (*Anguilla rostrata*). In the spring the most abundant of these migrants, American shad and blueback herring, make their way up the Cooper River to the Jefferies Hydroelectric Station where they may be passed upstream into Lake Moultrie via the Pinopolis Lock. Although there was little use of the upper Cooper River by alosines prior to construction of the Santee Cooper Project, the Project has facilitated expanded use by alosines via use of the lock for fish passage and the increased flows in the Cooper River via hydropower generation.

The objectives of this study were: 1) estimate the efficiency of the Pinopolis Lock in attracting blueback herring and American shad migrants for upstream passage, 2) characterize the movements of upstream migrating herring and shad as they approach the Pinopolis Lock in the tailrace of the Jefferies Hydroelectric Station, and 3) compare these results to those reported last year.

MATERIALS AND METHODS

Collection, Tagging, and Release of Shad and Herring

Migrating shad and herring were collected in the tailrace of the Jefferies Hydroelectric Station and the vicinity of the Pinopolis Lock entrance via electroshocking. One hundred fish of each species were targeted for the study and 100 shad were tagged. Due to a defective transmitter, 99 blueback herring were tagged this year. Collections were made weekly from 13 March to 2 April. The collection effort was temporally staggered to increase the likelihood of obtaining females.

Three to 6 fish were collected at a time; they were then tagged and transferred to a 70-gallon tank on the boat for a short observation period. During the tagging process, each fish was held immobile while a transmitter was inserted into the stomach, via the esophagus, so that the whip end of the transmitter protruded from the fish's mouth. The fish were sexed, measured using total length, transported to the holding tank and released in the tailrace, downstream of the sanctuary line.

Radio Telemetry Equipment and Operation

Coded radio transmitters supplied by Lotek Engineering Inc. (Lotek), Newmarket, Ontario, Canada were used for both species. Blueback herring were equipped with model number MCFT-3HM transmitters. These tags weighed 2.0 g, were 9.2 x 20 mm long and had a battery warranty life of 24 days. The larger model, MCFT-3BM, weighing 7.7 g and measuring 11 x 43 mm long was used for American shad and had a battery warranty life of 152 days. Both transmitter models propagated signals over five frequencies via a 455 mm whip antenna that protruded from the fish's mouth. Each of the 199 transmitters emitted a unique coded signal that allowed for individual fish identification.

Lotek SRX_400 stationary telemetry receivers and portable tracking receivers were used to monitor the fish. Prior to the release of tagged fish, floor level noise at the Jefferies Hydroelectric Station was determined and the receivers placed at or near the station were configured to reduce or exclude this background noise. The receivers were programmed to scan each of the five frequencies for specific time periods, depending on location. The internal clocks in all receivers were time synchronized so that logged data records could be compared among receivers.

Data were stored in the receivers as either a single event or a period of multiple events. If a fish was detected in the reception area and remained there for a period of up to 10 minutes, depending on the station, it was recorded as a continuous event (known as a continuous time out record). Single events or events occurring further apart than the set continuous record time out were recorded individually. Data stored for each event included: start date, start time, frequency, average pulse rate, average signal strength, interval standard deviation, number of events, number of suspect events and date, and end time.

A portable receiver was used aboard a boat to track individual fish. Although the entire study area was monitored, the tailrace below the lock was the focus of the manual tracking effort. For each manual tracking event, an attempt was made to first locate and record all tagged fish in the study area before commencing detailed tracking of up to ten (10) of the located fish. When a tagged fish was identified, its estimated location (approximate latitude, longitude, and a written description) was recorded along with the time of day. Generation status (i.e., generating or not) at the Jefferies Hydroelectric Station was recorded in the field when discernable from where the boat was positioned at that moment, or noted from the station generation log.

Stationary Receiver Stations

Four fixed locations, continuous monitoring stations were located within the study area as described below and illustrated in Figures 1 and 2. Data was downloaded from the receivers, on average, four times per week (range of one to six times per week) during the 9.5-week duration of the study.

Old Santee Canal State Park (Stoney Landing)

This station formed the downstream boundary of the study area monitored with fixed receivers and was equipped with a receiver and a four-element yagi aerial antenna. The equipment was configured to monitor the full width and depth of the river from the dock at the Old Santee Canal State Park across to the opposite bank. The detection zone (the area within which transmitters were detectable by the antenna) was generally an elliptical shape spanning the width of the river as approximated in Figure 1.

Gilligans Restaurant (formally The Dock Restaurant)

Located approximately mid-way between the Jefferies Hydroelectric Station and the Old Santee Canal State Park, this monitoring station allowed for the detection of fish moving upstream and downstream within the study area. The station was equipped with a receiver and a four-element yagi aerial antenna that monitored the full width and depth of the river from the dock to the opposite bank. The detection zone spanned the width of the river as approximated in Figure 1.

Jefferies Powerhouse

This monitoring station detected fish entering or leaving the near field area of the Jefferies Hydroelectric Station tailrace. Three, four-element yagi aerial antennas and one receiver were configured at the Jefferies Hydroelectric Station to form a roughly rectangular detection zone the length of the powerhouse extending to approximately the downstream end of the lock wing-wall. In addition to recording general fish movements within the tailrace area, the three-antenna array allowed for delineation of three sections, or use areas immediately downstream of the discharge, one directly in front of each antenna (Figure 2). This made it possible to track fish more precisely within the tailrace of the Jefferies Hydroelectric Station.

Entrance to Pinopolis Lock

The receiver and antenna array at this station monitored the entrance and exit of the Pinopolis Lock. Two, four-element yagi aerial antennas and one receiver were configured to detect fish movement into and out of the lock (Figure 2).

Jefferies Hydroelectric Station and Pinopolis Lock Operation

This study was conducted under normal operating conditions at the Jefferies Hydroelectric Station. Generation data recorded at the station over the 9.5-week duration of this study were obtained from Santee Cooper (Tables 1 and 2; Figure 3). The data were used to describe the effect operational parameters may have had on observed fish movements. Flows were categorized into seven flow conditions or ranges to facilitate further evaluation (Table 2). Additional data, provided by unit, but compiled for only a portion of the study period, were used to provide a general assessment as to whether normal operational variances (e.g., not running one unit) affected fish movement.

Locking operations for annual fish passage at the Pinopolis Lock were scheduled for six times a day; approximately 0700 h, 1000 h, 1200 h, 1400 h, and 1800h. Deviations from the schedule occurred when the lock was operated for boat traffic (which increased the number of locks per day), or inclement weather (high wind or waves that can cause safety related problems), resulting in fewer to no lock in a day. Lock operation for fish passage occurs annually from late February through mid-to-late-April.

Analysis

Raw data from the stationary monitoring sites were compiled in a PC based database and critically analyzed to determine the validity of records. Data for individual fish within 12 h of release, those records determined as erroneous events, and records with a power level below 100 were excluded in calculations. Derived lock passage values were based on final, multiple, detections of fish within the lock monitoring zones that were not detected subsequently through stationary or manual monitoring within the study area.

The effectiveness of the lock at attracting fish was calculated as the number of fish that entered the lock divided by the number of fish available to enter the lock (i.e., the number of fish detected in the Jefferies Hydroelectric Station tailrace).

Ninety-nine blueback herring and 100 American shad were released for the study. Other than a description of initial movement following release (which consisted primarily of initial direction of movement), data collected through remote monitoring within 12 h of release were excluded from subsequent analysis because it is common for initial movements of tagged fish to be in a downstream direction due to the stress response related to handling and tagging (Legget 1976, RMC 1994, Moser et al. 2000). Based on experience, the 12 h period was considered a reasonable period of recuperation and acclimation after handling and tagging.

RESULTS

Blueback Herring

Tagging and Initial Herring Movement

Blueback herring were tagged and released downstream of the Jefferies Hydroelectric Station in ten separate groups from 13 March to 2 April (Table 3). All herring were collected in the evening via electrofishing inside the Pinopolis Lock entranceway. After tagging, all fish were released below the sanctuary line.

Following release, 46 fish (46.5%) moved downstream and exited the study area within 12 h; seven fish remained in the lower portion of the study area (upstream of Stoney Landing) for more than 12 h but were never detected in the tailrace. These 53 fish were excluded from subsequent data analysis relative to lock effectiveness. However, the seven remaining in the study area were considered in the manual tracking assessment (see below).

Forty-six herring were monitored in the vicinity of the tailrace and, or lock, comprising the effective sample for estimating the effectiveness of the Pinopolis Lock at attracting upstream migrating blueback herring (Table 4).

Herring Forays

A foray is defined as a fish leaving the lower river sites (Gilligan's Restaurant or Stoney Landing) and moving upstream to the Jefferies Hydroelectric Station tailrace. Thirty herring made forays between the downstream monitoring sites and the Jefferies Hydroelectric Station tailrace (Table 5). The majority (76.7%; n=23) made one foray between the downstream and upstream sites, six (20.0%) herring made between two and five forays, and one (3.3%) made greater than five forays. Herring forays most often occurred between 1500 h and 2400 h (Figure 4). Although movement out of the tailrace peaked at 0700 h, representing 15.4% of the herring, no discernable temporal pattern was identified.

The percent of forays herring made during the seven flow conditions evaluated were generally consistent with the percent of time those flow conditions occurred (Table 6). Blueback herring made forays into the Jefferies tailrace at all discharge levels. The majority (87.3%) of herring forays to the tailrace occurred at discharge flows of 0 to 15,000 cfs, with nearly half (44.7%) of all forays occurring during no discharge (Table 6). Comparing the proportion of forays to the proportion of time a given discharge range occurred suggests that flows between 0 and 15,000 cfs (based on the seven discharge ranges evaluated) may influence upstream behavior. However, because nearly half of the forays occurred when the Jefferies Hydroelectric Station was not generating power, it appeared that a continuous flow was not necessary to attract herring to the tailrace.

Herring in the Jefferies Hydroelectric Station Tailrace

The presence of herring by time of day was examined for the 46 herring monitored in the tailrace on at least one occasion. All 46 herring were present at some point during daily lock operations and therefore were theoretically available for passage. The number of fish detected in the tailrace or lock by hour of day ranged from 26 and 29 at 2000 h and 0700 h, respectively, and 60 and 72 at 1700 h and 1800 h, respectively (Figure 5). The number of herring in the tailrace generally remained constant through the day except in early evening when numbers peaked. Comparing the presence of herring in the tailrace with station operation categories revealed no apparent relationship. Forays to the tailrace occurred over all flow categories but most often (44.7%) during zero flow (Figure 6). Residency time within the tailrace and the lock detection zones (Figure 2) ranged from less than one minute at all monitoring zones, to 10 h 48 min at the Lock Entrance monitoring zone (Table 7).

Pinopolis Lock Effectiveness - Herring

Thirty-six herring were located in the lock on at least one occasion (Table 8), thus the effectiveness estimate for the lock at attracting herring was 78.3% (36 of 46). The percentage of fish attracted to the lock, by release group, varied from 25.0% to 100%. Of the 10 release groups, only two had effectiveness percentages below 75.0%, the second group (33%) released 14 March 2003, and the last (25%) released 2 April 2003. Median residency time of herring near the Lock Entrance was 23 min, and ranged from 8 min to 34 min (Table 7).

Herring were detected entering the lock on 104 occasions and during each of the seven flow conditions considered (Figure 7). Entrance into the lock occurred most often (32.7%) under zero discharge. For each of the other six flow categories, the percentage of herring entrances into the lock was <21% (Table 9). The number of herring in the lock on any given hour was fairly consistent through the 24 h period, ranging from six to 14 fish.

Of the 36 herring entering the lock, 58.3% (n = 21) subsequently passed upstream to Lake Moultrie (Table 8). The percentage of fish passed by release group ranged from 33.3% to 100%.

American Shad

Tagging and Initial American Shad Movement

One hundred American shad were tagged and released downstream of the Jefferies Hydroelectric Station. Fish were released in ten groups between 13 March and 2 April 2003 (Table 10). Shad were collected most often in the evening via electrofishing near the Pinopolis Lock wing-wall. After tagging, all fish were released below the sanctuary line.

Following tag and release, one (1.0%) shad from release group 7 was never detected. Four (4.0%) tagged fish moved downstream and exited the study area within 12 h. Thirteen shad remained in the lower portion of the study area (upstream of Stoney Landing) for >12 h but remained in the lower reach and were never detected in the Jefferies tailrace or the lock. These 18 shad were excluded from subsequent data analysis related to lock effectiveness. However, the 13 shad remaining in the study area were considered in the manual tracking assessment.

Eighty-two shad remained in the study area for >12 h and were detected in the Tailrace/Lock Entrance monitoring zones. These fish comprise the effective sample for estimating the effectiveness of the Pinopolis Lock at attracting upstream migrating American shad (Table 11).

American Shad Forays

As stated previously, a foray is defined as a fish leaving the lower river sites (i.e., Gilligans Restaurant or Stoney Landing) and moving upstream to the Jefferies Hydroelectric Station tailrace. Seventy-nine shad made forays between the downstream monitoring sites and the Jefferies Hydroelectric Station tailrace (Table 12). Thirty-nine shad (49.4%) made a single foray, thirty-six shad (45.6%) made between two and five forays, and three shad (3.8%) made greater than five forays. Forays from downriver and arrival at the tailrace revealed no obvious pattern relative to time of day and Jefferies operation except that peak arrival at the tailrace occurred around mid-day. Departures generally began late morning, peaked early evening and diminished by late night (Figure 8). Shad forays to the tailrace occurred over the range of flow conditions observed, including 47.3% of forays occurring at zero generation and 21.6% during 15,000-20,000 cfs (Figure 9). The percentage of shad forays by discharge flow range approximated the percentage of time that a particular discharge level occurred (Table 13).

American Shad in the Jefferies Hydroelectric Station Tailrace

All 82 American shad detected in the tailrace were present at some point during daily lock operations and therefore were theoretically available to enter the lock and be passed upstream to Lake Moultrie. Six fish were identified as passing during 0600 h, though lock operation is recorded as beginning at 0700 h on each day. Two factors likely explain the discrepancy: 1) the recorded 0700 h lock operation may have occurred just before the allotted time on some occasions, and 2) time of passage was assigned as the last time the fish was recorded on a receiver, with many fish in the lock, this time could have been 10 minutes or more. Detections in the tailrace by hour of day ranged from 22 during 2000 h and 2100 h to 67 during 1100 h (Figure 10). As with herring, no apparent pattern was observed when generation by hour was compared to presence in the tailrace by hour. While in the tailrace, shad were located either at the lock entrance or at one of the three tailrace monitoring zones (Figure 2). The number of fish detected in each monitored zone ranged from 79 in the left-tailrace to 74 at mid-tailrace. Residency time within the tailrace and lock detection zones ranged from <1 min to 11 h 57 min (Table 14).

Pinopolis Lock Effectiveness - American Shad

Seventy-five shad were located in the lock on at least one occasion, thus the effectiveness of the lock at attracting fish was 91.5% (75 of 82). For all release groups, the percentage of fish attracted to the lock was 70.0% or higher (Table15). Median residency time for American shad in the Lock Entrance zone was 48 min and ranged from 4 min to 41 min in the tailrace monitoring zones (Table 14).

American shad entered the lock under all seven flow conditions considered (Table 16, Figure 11). Entrance into the lock occurred most often (56.3%) under zero flow. For each of the other six flow ranges, the percentage of shad entrances to the lock was > 12% (Table 16).

Of the 75 shad entering the lock, 96.0% (n = 72) subsequently passed upstream to Lake Moultrie (Table 15). The percentage of fish passed by release group was high, ranging from 77.8% for group 1, 85.7% for group 6 and 100% for all other release groups. Passage was greatest between 1200 h and 1400 h when 32 (44.4% of the 72 passed) shad moved into Lake Moultrie.

Manual Tracking

During the course of the study (13 March through 12 May), manual tracking of tagged fish was conducted 46 times over 29 days, between two and five times per week and one to four hours per event. Tracking events covered morning, afternoon, and evening periods, with three events occurring during early morning hours (i.e., 0000 h to 0300 h), 25 events occurring between sunrise and sunset (0631 h - 1830 h) and 21 between sunset and sunrise (1801 h - 0630 h). The number of fish tracked manually during an event ranged from 2 to 37.

Fifty-seven of the 99 herring and 84 of the 100 shad tagged were located manually. For the purpose of data review, the study area was divided into five segments: below Santee Canal State Park, the Park to the Route 52 Bridge, the Route 52 Bridge to the railroad bridge, the railroad bridge to the sanctuary in the tailrace, and the sanctuary portion of the tailrace. The number of each species identified in each segment was tallied. Because an individual fish could have been identified in each or none of the river segments, the total number of fish identified in all locations is greater than the number of fish manually tracked for each species.

Herring were most often located in the sanctuary portion of the tailrace (n=39) while shad were more often found between the two bridges (n=58) and the sanctuary line (n=50) (Figure 12). When viewed from a diel perspective, a similar trend emerged. Both species were found in each segment more often during daylight hours except that a few more herring were found between the railroad bridge and the sanctuary line, and a few more shad were found from the Route 52 Bridge to the railroad bridge at night compared to daytime (Figure 13).

Seventeen percent of the shad and 2% of the herring that were manually tracked were found in Wadboo Creek. Alosine spawning behavior was frequently observed while tracking these fish in Wadboo Creek.

Two Year Comparison

Reported descriptive analyses were compared with 2002 results to assess differences and similarities between the years. Average daily discharge from the Jefferies Hydroelectric Station during the periods of study were similar (Figure 14); because the station operates under weekly flow restrictions, differences were not expected. An additional flow category was used this year to report fish movement relative to flow. However, the percentage of time that each flow category occurred remained similar between years (Table 17), as was expected. Climatically, spring monthly water temperature varied little between years (Figure 15), but precipitation was more than two times greater in 2003 (Table 18).

Lock effectiveness was greater for both species in 2003. For shad, lock effectiveness (the number of shad detected in the lock divided by the number detected in either the tailrace or lock zones) increased from 66% in 2002 to 92% in 2003 (Table 19). Lock effectiveness for herring increased from 48% to 78% from 2002 to 2003, respectively (Table 19). Fewer of the herring remaining in the study area were detected in either the tailrace or lock zones this year (47%) compared to last year (84%)(Tables 20 and 21).

The number of forays fish made to the Jefferies tailrace from the lower stations was similar in both years for shad but changed for herring (Figures 16 and 17, respectively). In 2003 a higher percentage of herring (77% vs. 43% in 2002) made just one foray, and a lower percentage (20% vs. 53% in 2002) made 2 to 5 forays. No difference was found in the percentage of herring making more than five forays (Figure 17).

The location of fish within the tailrace monitoring zones did not vary greatly from 2002 to 2003 (Tables 20 and 21). However, residency times were slightly greater in 2003 for both species. For shad, mean residency time in the tailrace and lock zones was 2 h 01 min in 2003 and 56 min in 2002. Mean residency time for herring was 1 h 11 min in 2003 and 23 min in 2002.

Movement of fish to the tailrace and into the lock was compared by flow category. The flow categories chosen for 2002 and 2003 were slightly different, as shown on Figures 18 and 19, and may account for a portion of the variance in those flow categories. Few differences were found for herring moving into the tailrace (Figure 18). A notable difference in shad forays to the tailrace was a decrease in 2003 at zero discharge (47% vs. 58%) and increase at the 15,001-20,000 cfs flow category (22% vs. 7%)(Figure 19). Herring and shad both entered the lock more often during zero and low flow categories in 2003 compared to 2002 (Figures 20 and 21).

This year discharge by unit was examined during normal operations to determine if operational changes effected fish movement into the lock. Operations data was provided by Santee Cooper for the period 10 March through 16 April. During that time, Unit 1, located closest to the lock, did not run during A.M. generation from 17 March through 20 March and did not run during P.M generation from 14 March through 17 March and 24 March through 27 March. No observable change in fish movement occurred during these times and no other significant alterations in generation were observed.

DISCUSSION

The primary objective of the study, estimation of the effectiveness of the Pinopolis Lock at attracting blueback herring and American shad, was achieved. Lock attraction effectiveness for herring was 78.3%, representing 36 of 46 herring located in the tailrace >12 h after release. Of the 36 herring located in the Pinopolis Lock on at least one occasion, 58.3% (21 of 36) passed upstream to Lake Moultrie. Of the 82 shad monitored in the tailrace >12 h after release, 75 were located in Pinopolis Lock on at least one occasion; therefore, the estimate of effectiveness of the Pinopolis Lock for American shad was 91.5%. Seventy-two, or 96.0% of those entering the lock, subsequently passed up into Lake Moultrie.

As observed last year, a relatively high percentage of forays and relatively high entry into the lock occurred at zero discharge from the powerhouse for both species. These results indicate that semi-peaking flows do attract fish to the tailrace, and that fish do not necessarily leave the tailrace under zero discharge conditions. Based on two years of data, it appears that the semi-peaking operation of the Jefferies Station may not be detrimental to upstream passage. Lock attraction effectiveness increased by 40% for herring and more than 60% for shad in 2003. Passage into the lake also increased for shad in 2003, but decreased for herring.

The effectiveness of the Pinopolis Lock at passing blueback herring and American shad was similar, again this year, to other sites with engineered upstream fish passage facilities. Two years of study at the Cataract Fishway, Saco River, ME, provided telemetered American shad passage effectiveness values of 66% and 53% (RMC 1995 and 1996). At the Holtwood Hydroelectric Station, Susquehanna River, PA, 63% of radio tagged American shad observed in the tailrace entered the fish lift entrance (Normandeau Associates 2001). A calculated ten year running average of effectiveness, based on mark-recapture for American shad through 2001 at the Conowingo Dam fish lift, Susquehanna River, MD was 39% (MDNR 2002). During a three year study of American shad passage at Lock and Dam 1 on the Cape Fear River, NC, Moser et al. (2000) found lock passage efficiency ranged from 18% to 50%. Using their passage efficiency equation (number returning to the dam after tagging divided by the number passed), passage at the Pinopolis Lock is more efficient at 59% in 2002 and 87% in 2003.

The difference in passage effectiveness between the two species, as well as temporal differences might be explained by climatic conditions and biology. Monthly water temperature during spring did not vary much between the two years, but precipitation did. More than twice the amount of rain fell during spring 2003 (Table 18), resulting in flooded tributaries downstream of the Pinopolis Dam. This year a significant portion (46.5%) of the tagged herring population did not return to the study area after tagging, compared to last year's 10%. Based on observations, we believe herring found adequate spawning habitat below the Jefferies Hydroelectric Station and therefore did not continue migrating upstream. In the southeast, herring spawn in a variety of habitats including shallow vegetated areas, rice fields, swampy areas, and small tributaries (Rulifson et al. 1982). Shad, on the other hand, prefer freshwater areas dominated by extensive flats and spawn over sandy or rocky shallows (Jones et al. 1978). Tributaries within the study area downstream of the tailrace (ex., Wadboo Creek and Biggin Creek) were inundated this year and numerous tagged fish were located in and around Wadboo Creek. NAI employees tracking the fish observed alosine spawning behavior in the creek.

Most herring (76.7%) made just one foray into the tailrace, while the majority of shad made one foray(49.4%) with a nearly equal amount making two to five (45.6%) forays. The proportion of forays by flow categories evaluated was generally similar to the proportion of time that a particular flow condition occurred, indicating that fish moved into the tailrace regardless of discharge condition. This suggests that pulsed flows may be adequate for attracting blueback herring and American shad to the tailrace. As was observed last year, most forays to the Jefferies tailrace by both species occurred under the zero generation condition. It is possible the attraction water flow from the siphon pipe in the Pinopolis Lock or release of water from the lock following an upstream locking cycle is adequate to stimulate upstream movement, especially under non-generation conditions. During a similar study at Holtwood Hydroelectric Station, Normandeau Associates personnel noticed a marked increase in detections of shad present in the tailrace during the nighttime hours at a discrete detection zone while the station was not operating (Normandeau Associates 2001). It was determined that fish were attracted to a small volume of water coming out of a downstream passage bypass pipe. On the Cape Fear River, Moser et al. (2000) found that shad most often entered the lock chamber during daylight hours (0600-2000 h).

In general, shad and herring spent more time in the tailrace in 2003 compared to 2002. Considering that lock effectiveness was higher in 2003, the reason for the difference is not clear. Of the fish that passed this year, over 50% of each species did so within 10 days of being tagged.

Considering two years of data, suggestions for improvement in the effectiveness of the Pinopolis Lock remain as stated in 2002: a) perform lock operations over a greater portion of the day. Because herring and shad were present in the tailrace during all hours of the day; Normandeau Associates recommends a detailed analysis of the two years of data on a day by day basis to identify when expanded operations might be most useful; b) continue or improve attraction flow via the siphon or perhaps by other means near the lock entrance, particularly at zero and low discharge conditions when lock attraction flows would likely be most effective.

LITERATURE CITED

Cooke, D.W. and S.D. Leach. 2002, Santee Cooper anadromous fish studies, rediversion project. Draft annual progress report SCR 1-24, October 1, 2000 – September 30, 2001.

Jones, P.W., F.D. Martin and J.D. Hardy, Jr. 1978. Development of fishes of the mid-Atlantic Bight. An atlas of egg, larval and juvenile stages. Vol. I. Acipenseridae through Ictaluridae. U.S. Fish and Wildlife Service FWS/OBS-78/12.

Legget, W. C. 1976. The American shad (*Alosa sapidissima*), with special reference to its migration and population dynamics in the Connecticut River. Pages 169-225. In Am. Fish. Soc. Monogr. No. 1.1-mm,PS.

RMC. 1994. Report on the migration of telemetered shad in the tailwaters, spillage areas and forebays of the Holtwood, Safe Harbor, and York Haven Hydroelectric Projects, Susquehanna River, Pennsylvania. Report prepared for Pennsylvania Power & Light Company, Safe Harbor Water Power Corporation, and Metropolitan Edison Company.

RMC. 1995. Final report on movement and behavior of Atlantic salmon smolts, American shad, and river herring at the Cataract Fishways, Saco River, Maine, 1994. Report prepared for Central Maine Power Company, Augusta, ME.

RMC. 1996. Final report on the movement and behavior of adult American shad and river herring at the Cataract fishways, Saco River, Maine, 1995. Report prepared for Central Maine Power Company, Augusta, ME.

Rulifson, R.A., M.T. Huish and R.W. Thoesen. 1982. Anadromous fish in the southeastern United States and recommendations for development of a management plan. U.S. Fish and Wildlife Sercice, Atlanta.

Moser, M. L., A.M. Darazsdi and J.R. Hall. 2000. Improving passage efficiency of adult American shad at low-elevation dams with navigation locks. North American Journal of Fisheries Management 20:376-385.

Normandeau Associates. 2001. Adult American shad movement and behavior in the vicinities of Conowingo and Holtwood Hydroelectric Stations, Susquehanna River, during spring 2001. Report prepared for Pennsylvania Power & Light Company, Exelon Corporation, and the USFWS.

Maryland DNR. 2002. 2001 stock assessment of selected resident and migratory recreational finfish species within Maryland's Chesapeake Bay.

TABLES

Table 1

Hourly mean and median discharge flow (cfs) at Jefferies Hydroelectric Station, 10 March through 16 May, 2003.

Time of Day	Mean Discharge (cfs)	Median Discharge (cfs)
1:00	36	0
2:00	272	0
3:00	52	0
4:00	0	0
5:00	0	0
6:00	533	0
7:00	4630	808
8:00	8328	7594
9:00	6379	3919
10:00	5917	1189
11:00	4209	0
12:00	2448	0
13:00	1137	0
14:00	1269	0
15:00	2891	0
16:00	3149	0
17:00	3664	0
18:00	5662	3856
19:00	8118	8146
20:00	10554	10843
21:00	12718	14395
22:00	13391	14260
23:00	9821	10737
0:00	4909	2361

Table 2

Seven classes of discharge evaluated for the Jefferies Hydroelectric Station and associated generation duration for each class, 10 March through 16 May 2003.

Station Discharge (cfs)	Hours Generated	Percentage of Time
0	933	56.3%
1-500	23	1.4%
501-5,000	147	8.9%
5,001-10,000	193	11.7%
10,001-15,000	152	9.2%
15,001-20,000	160	9.7%
20,001-25,000	48	2.9%
Total	***1656***	***100.0%***

Table 3

Summary of tag and release times for blueback herring, spring 2003.

Release Group	Tag Date	Release Times	Number Released
1	13-Mar	18:10-18:36	10
2	14-Mar	17:52-18:20	10
3	17-Mar	9:39-18:21	10
4	18-Mar	18:14-18:39	9
5	19-Mar	16:46-17:15	11
6	24-Mar	18:24-18:34	10
7	27-Mar	18:00-18:51	10
8	31-Mar	17:47-18:22	10
9	1-Apr	17:40-18:12	10
10	2-Apr	16:58-17:10	9
Totals			***99***

Table 4

Blueback herring post tag monitoring results, spring 2003.

Release Group	Tag Date	Number Released	No. Left Study Area Within 12h		No. Remaining in Study Area		No. Detected in Tailrace/Lock Zones	
1	13-Mar	10	4	(40.0%)	6	(60.0%)	8	(80.0%)
2	14-Mar	10	5	(50.0%)	5	(50.0%)	6	(60.0%)
3	17-Mar	10	3	(30.0%)	7	(70.0%)	5	(50.0%)
4	18-Mar	9	7	(77.8%)	2	(22.2%)	6	(66.7%)
5	19-Mar	11	6	(54.5%)	5	(45.5%)	3	(27.3%)
6	24-Mar	10	7	(70.0%)	3	(30.0%)	2	(20.0%)
7	27-Mar	10	2	(20.0%)	8	(80.0%)	4	(40.0%)
8	31-Mar	10	6	(60.0%)	4	(40.0%)	6	(60.0%)
9	1-Apr	10	6	(60.0%)	4	(40.0%)	2	(20.0%)
10	2-Apr	9	0	(0.0%)	9	(100.0%)	4	(44.4%)
Totals		***99***	***46***	***(46.5%)***	***53***	***(53.5%)***	***46***	***(46.5%)***

Table 5

Number of forays blueback herring made between lower river sites and the Jefferies tailrace, spring 2003.

Release Group	Number of Fish	Number of Forays					
		1		2 to 5		>5	
1	7	5	(71.4%)	2	(28.6%)	0	(0.0%)
2	4	2	(50.0%)	1	(25.0%)	1	(25.0%)
3	3	3	(100.0%)	0	(0.0%)	0	(0.0%)
4	5	4	(80.0%)	1	(20.0%)	0	(0.0%)
5	0	NA		NA		NA	
6	1	1	(100.0%)	0	(0.0%)	0	(0.0%)
7	3	3	(100.0%)	0	(0.0%)	0	(0.0%)
8	4	3	(75.0%)	1	(25.0%)	0	(0.0%)
9	2	2	(100.0%)	0	(0.0%)	0	(0.0%)
10	1	0	(0.0%)	1	(100.0%)	0	(0.0%)
Total	***30***	***23***	***(76.7%)***	***6***	***(20.0%)***	***1***	***(3.3%)***

Table 6

Percent of forays, by discharge flow range, herring made to the Jefferies tailrace and ratio of forays per hour, spring 2003.

Station Discharge (cfs)	Percent of Hours for each Discharge	Percent of Forays	Ratio Forays/Hour	N Forays
0	56.3%	44.7%	0.79	21
1-500	1.4%	2.1%	1.53	1
501-5,000	8.9%	12.8%	1.44	6
5,001-10,000	11.7%	12.8%	1.10	6
10,001-15,000	9.2%	14.9%	1.62	7
15,001-20,000	9.7%	10.6%	1.10	5
20,001-25,000	2.9%	2.1%	0.73	1
Total	***100.0%***	***100.0%***		***47***

Table 7

Amount of time herring spent in the Jefferies tailrace and the Pinopolis Lock monitoring zones, spring, 2003.

Monitoring Zone[1]	No. of Herring	Time (day-hour:min)			
		Minimum	Maximum	Mean	Median
Left Tailrace	44	0-00:00	0-10:32	0-01:28	0-00:34
Mid Tailrace	44	0-00:00	0-09:24	0-00:46	0-00:08
Right Tailrace	44	0-00:00	0-12:55	0-01:20	0-00:32
Lock Entrance	35	0-00:00	0-10:48	0-01:09	0-00:23

[1] See Figure 2 for monitoring zone locations.

Table 8

Summary, by release group, of the number of herring detected below, in, and above the Pinopolis Lock, spring 2003.

Release Group	Tag Date	Number Released	No. Detected in Tailrace/Lock Zones	No. Detected in Lock		No. Passed[1]	
1	13-Mar	10	8	8	(100.0%)	5	(62.5%)
2	14-Mar	10	6	2	(33.3%)	1	(50.0%)
3	17-Mar	10	5	4	(80.0%)	3	(75.0%)
4	18-Mar	9	6	6	(100.0%)	4	(66.7%)
5	19-Mar	11	3	3	(100.0%)	1	(33.3%)
6	24-Mar	10	2	2	(100.0%)	2	(100.0%)
7	27-Mar	10	4	3	(75.0%)	1	(33.3%)
8	31-Mar	10	6	5	(83.3%)	2	(40.0%)
9	1-Apr	10	2	2	(100.0%)	1	(50.0%)
10	2-Apr	9	4	1	(25.0%)	1	(100.0%)
Totals		***99***	***46***	***36***	***(78.3%)***	***21***	***(58.3%)***

[1] Percentage based on number detected in the Lock.

Table 9

Percent of herring that entered the lock, by flow range, spring 2003.

Station Discharge (cfs)	Percent of Time Flow Occurred	Number and Percent (%) of Fish Entering Lock	
0	56.3%	34	(32.7%)
1-500	1.4%	9	(8.7%)
501-5,000	8.9%	17	(16.3%)
5,001-10,000	11.7%	21	(20.2%)
10,001-15,000	9.2%	13	(12.5%)
15,001-20,000	9.7%	8	(7.7%)
20,001-25,000	2.9%	2	(1.9%)
Total	***100.0%***	***104***	

Table 10

Summary of tag and release times for American shad, spring 2003.

Release Group	Tag Date	Release Times	Number Released
1	13-Mar	18:27-19:48	10
2	14-Mar	17:45-18:19	10
3	17-Mar	9:40-10:06	10
4	18-Mar	18:05-18:11	10
5	19-Mar	16:38-16:46	10
6	24-Mar	18:39-19:44	10
7	27-Mar	17:38-17:53	10
8	31-Mar	17:13-17:43	10
9	1-Apr	17:17-17:31	10
10	2-Apr	16:38-16:51	10
Totals			***100***

Table 11

American shad post tag monitoring results, spring 2003. All percentages are based on the number of shad released.

Release Group	Number Released	No. Not Detected Following Release		No. Left Study Area Within 12h		No. Remaining in Study Area		No. Detected in Tailrace/Lock Zones	
1	10	0	(0.0%)	0	(0.0%)	10	(100.0%)	9	(90.0%)
2	10	0	(0.0%)	2	(20.0%)	8	(80.0%)	6	(60.0%)
3	10	0	(0.0%)	0	(0.0%)	10	(100.0%)	9	(90.0%)
4	10	0	(0.0%)	1	(10.0%)	9	(90.0%)	6	(60.0%)
5	10	0	(0.0%)	1	(10.0%)	9	(90.0%)	7	(70.0%)
6	10	0	(0.0%)	0	(0.0%)	10	(100.0%)	8	(80.0%)
7	10	1	(10.0%)	0	(0.0%)	9	(90.0%)	9	(90.0%)
8	10	0	(0.0%)	0	(0.0%)	10	(100.0%)	10	(100.0%)
9	10	0	(0.0%)	0	(0.0%)	10	(100.0%)	9	(90.0%)
10	10	0	(0.0%)	0	(0.0%)	10	(100.0%)	9	(90.0%)
Totals	***100***	***1***	(1.0%)	***4***	(4.0%)	**95**	(95.0%)	**82**	(82.0%)

Table 12

Number of American shad that made forays between lower river sites and the Jefferies tailrace, and the number of forays made, spring 2003.

Release Group	Number of Fish	Number of Forays					
		1		2 to 5		>5	
1	9	6	(66.7%)	3	(33.3%)	0	(0.0%)
2	6	1	(16.7%)	4	(66.7%)	1	(16.7%)
3	9	6	(66.7%)	3	(33.3%)	0	(0.0%)
4	7	4	(57.1%)	3	(42.9%)	0	(0.0%)
5	7	2	(28.6%)	5	(71.4%)	0	(0.0%)
6	8	2	(25.0%)	5	(62.5%)	1	(12.5%)
7	9	5	(55.6%)	4	(44.4%)	0	(0.0%)
8	8	4	(50.0%)	3	(37.5%)	0	(0.0%)
9	8	5	(62.5%)	3	(37.5%)	0	(0.0%)
10	8	4	(50.0%)	3	(37.5%)	1	(12.5%)
Total	***79***	***39***	***(49.4%)***	***36***	***(45.6%)***	***3***	***(3.8%)***

Table 13

Percent of forays, by discharge flow range, American shad made to the Jefferies tailrace, and ratio of forays per hour, spring 2003.

Station Discharge (cfs)	Percent of Hours	Percent of Forays	Ratio Forays/Hour	N Forays
0	56.3%	47.3%	0.84	70
1-500	1.4%	1.4%	0.97	2
501-5,000	8.9%	4.7%	0.53	7
5,001-10,000	11.7%	12.2%	1.04	18
10,001-15,000	9.2%	11.5%	1.25	17
15,001-20,000	9.7%	21.6%	2.24	32
20,001-25,000	2.9%	1.4%	0.47	2
Total	***100.0%***	***100.0%***		***148***

Table 14

Amount of time American shad spent in the Jefferies tailrace and the Pinopolis Lock monitoring zones, spring 2003.

Monitoring Zone[1]	No. of shad	Time (day-hour:min)			
		Minimum	Maximum	Mean	Median
Left Tailrace	79	0-00:00	1-11:57	0-02:13	0-00:27
Mid Tailrace	74	0-00:00	0-12:52	0-01:08	0-00:04
Right Tailrace	77	0-00:00	1-00:39	0-02:23	0-00:41
Lock Entrance	75	0-00:00	0-18:54	0-02:19	0-00:48

[1] See Figure 2 for monitoring zone locations.

Table 15

Summary, by release group, of the number of American shad detected below, in, and above the Pinopolis Lock, spring 2003.

Release Group	Tag Date	Number Released	No. Detected in Tailrace/Lock Zones	No. Detected in Lock		No. Passed[1]	
1	13-Mar	10	9	9	(100.0%)	7	(77.8%)
2	14-Mar	10	6	6	(100.0%)	6	(100.0%)
3	17-Mar	10	9	8	(88.9%)	8	(100.0%)
4	18-Mar	10	6	6	(100.0%)	6	(100.0%)
5	19-Mar	10	7	7	(100.0%)	7	(100.0%)
6	24-Mar	10	8	7	(87.5%)	6	(85.7%)
7	27-Mar	10	9	8	(88.9%)	8	(100.0%)
8	31-Mar	10	10	7	(70.0%)	7	(100.0%)
9	1-Apr	10	9	9	(100.0%)	9	(100.0%)
10	2-Apr	10	9	8	(88.9%)	8	(100.0%)
Totals		***100***	***82***	***75***	***(91.5%)***	***72***	***(96.0%)***

[1] Percentage based on number detected in the Lock.

Table 16

Percent of American shad that entered the lock, by flow range, spring 2003.

Station Discharge (cfs)	Percent of Time Flow Occurred	Number and Percent (%) of Fish in Lock	
0	56.3%	70	(40.5%)
1-500	1.4%	6	(3.5%)
501-5,000	8.9%	39	(22.5%)
5,001-10,000	11.7%	25	(14.5%)
10,001-15,000	9.2%	16	(9.2%)
15,001-20,000	9.7%	10	(5.8%)
20,001-25,000	2.9%	7	(4.0%)
Total	***100.0%***	***173***	

Table 17

Comparison of flow ranges at the Jefferies Hydroelectric Station during shad and herring telemetry studies in spring 2002 and 2003.

2003			2002		
Station Discharge (cfs)	**Hours Generated**	**Percentage of Time**	**Station Discharge (cfs)**	**Hours Generated**	**Percentage of Time**
0	933	56.3%	0	840	55.6%
1-500	23	1.4%	N/A	N/A	N/A
501-5,000	147	8.9%	500-4,500	198	13.1%
5,001-10,000	193	11.7%	4,501-10,000	190	12.6%
10,001-15,000	152	9.2%	10,001-15,000	140	9.3%
15,001-20,000	160	9.7%	15,001-20,000	105	6.9%
20,001-25,000	48	2.9%	20,001-25,000	38	2.5%
Total	***1656***	***100.0%***		***1511***	***100%***

Table 18

Mean daily and total precipitation (cm) recorded at Orangeburg Airport during March, April and May, 2002 and 2003.

	2002		2003	
	Mean Daily	**Total**	**Mean Daily**	**Total**
March	0.36	11.02	0.86	26.62
April	0.13	4.19	0.61	18.31
May	0.18	5.72	0.51	16.03

Table 19

Post tag monitoring results and Lock attraction effectiveness for shad and herring during spring 2002 and 2003

	Number Released	No. Remaining in Study Area		No. Detected in Tailrace/Lock Zones		No. Detected in Lock[1]		No. Passed[2]	
Herring									
2002	101	91	(90.1%)	85	(84.2%)	41	(48.2%)	31	(75.6%)
2003	99	53	(53.5%)	46	(46.5%)	36	(78.3%)	21	(58.3%)
Shad									
2002	100	87	(87.0%)	74	(74.0%)	49	(66.2%)	44	(89.8%)
2003	100	95	(95.0%)	82	(82.0%)	75	(91.5%)	72	(96.0%)

[1] Percentage based on number detected in Tailrace/Lock zones.

[2] Percentage based on number detected in Lock.

Table 20

Comparison of the amount of time shad spent in the Jefferies tailrace and the Pinopolis Lock monitoring zones during spring 2002 and 2003.

Monitoring Zone	No. of shad	Time (day-hour:min) Minimum	Maximum	Mean	Median
2003					
Left Tailrace	79	0-00:00	1-11:57	0-02:13	0-00:27
Mid Tailrace	74	0-00:00	0-12:52	0-01:08	0-00:04
Right Tailrace	77	0-00:00	1-00:39	0-02:23	0-00:41
Lock Entrance	75	0-00:00	0-18:54	0-02:19	0-00:48
2002					
Left Tailrace	72	0-00:01	0-17:16	0-01:12	0-00:22
Mid Tailrace	75	0-00:00	1-06:42	0-01:32	0-00:31
Right Tailrace	68	0-00:00	0-18:55	0-00:43	0-00:15
Lock Entrance	50	0-00:00	0-01:57	0-00:18	0-00:08

Table 21

Comparison of the amount of time herring spent in the Jefferies tailrace and the Pinopolis Lock monitoring zones during spring 2002 and 2003.

Monitoring Zone	No. of Herring	Time (day-hour:min)			
		Minimum	Maximum	Mean	Median
2003					
Left Tailrace	44	0-00:00	0-10:32	0-01:28	0-00:34
Mid Tailrace	44	0-00:00	0-09:24	0-00:46	0-00:08
Right Tailrace	44	0-00:00	0-12:55	0-01:20	0-00:32
Lock Entrance	35	0-00:00	0-10:48	0-01:09	0-00:23
2002					
Left Tailrace	79	0-00:00	0-02:54	0-00:28	0-00:15
Mid Tailrace	81	0-00:00	0-05:11	0-00:35	0-00:20
Right Tailrace	64	0-00:00	0-01:16	0-00:16	0-00:08
Lock Entrance	41	0-00:00	0-00:36	0-00:14	0-00:05

FIGURES

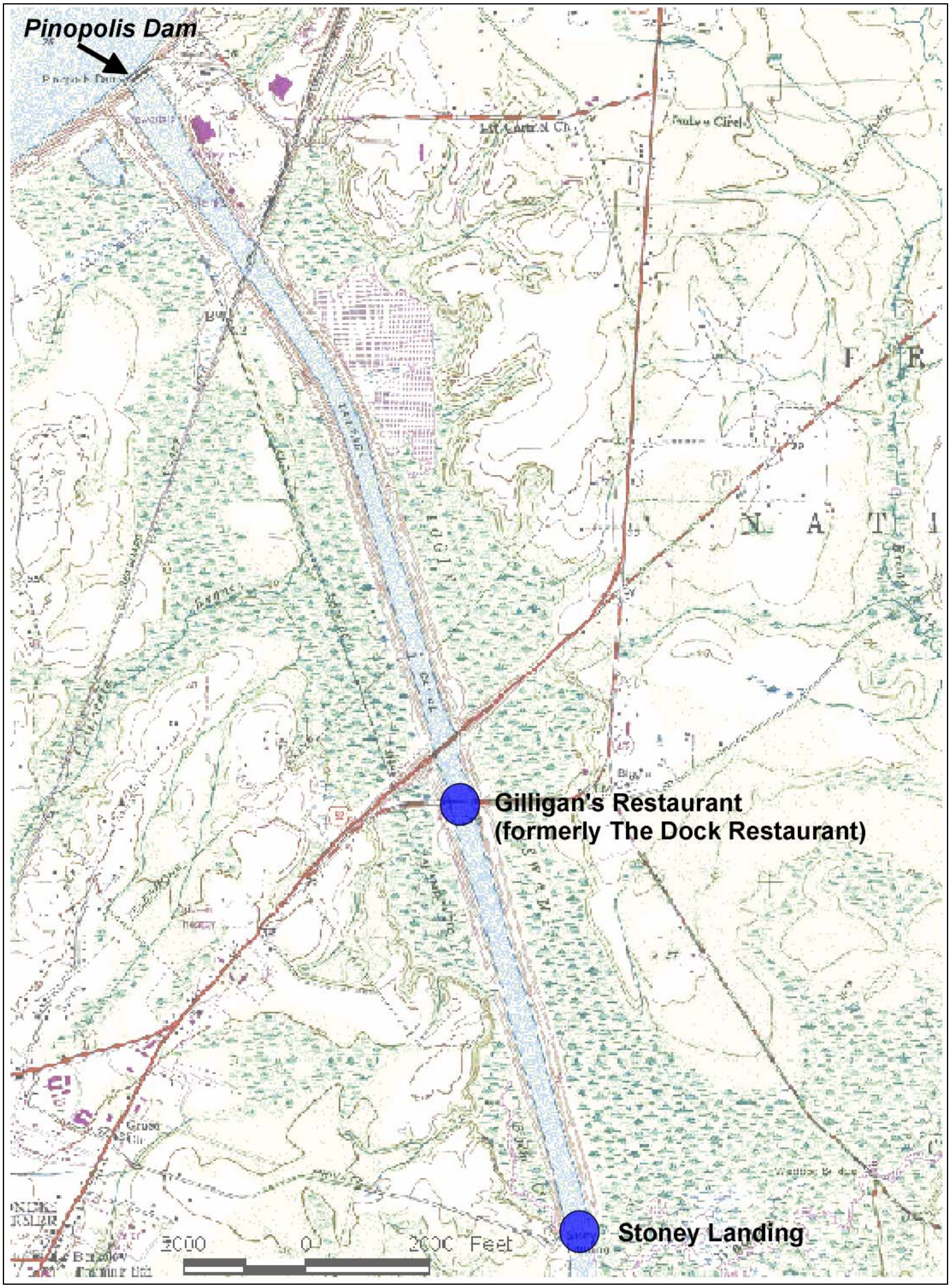

Figure 1

American shad and blueback herring, fixed station monitoring zones in the downstream portion of the study area, spring 2003.

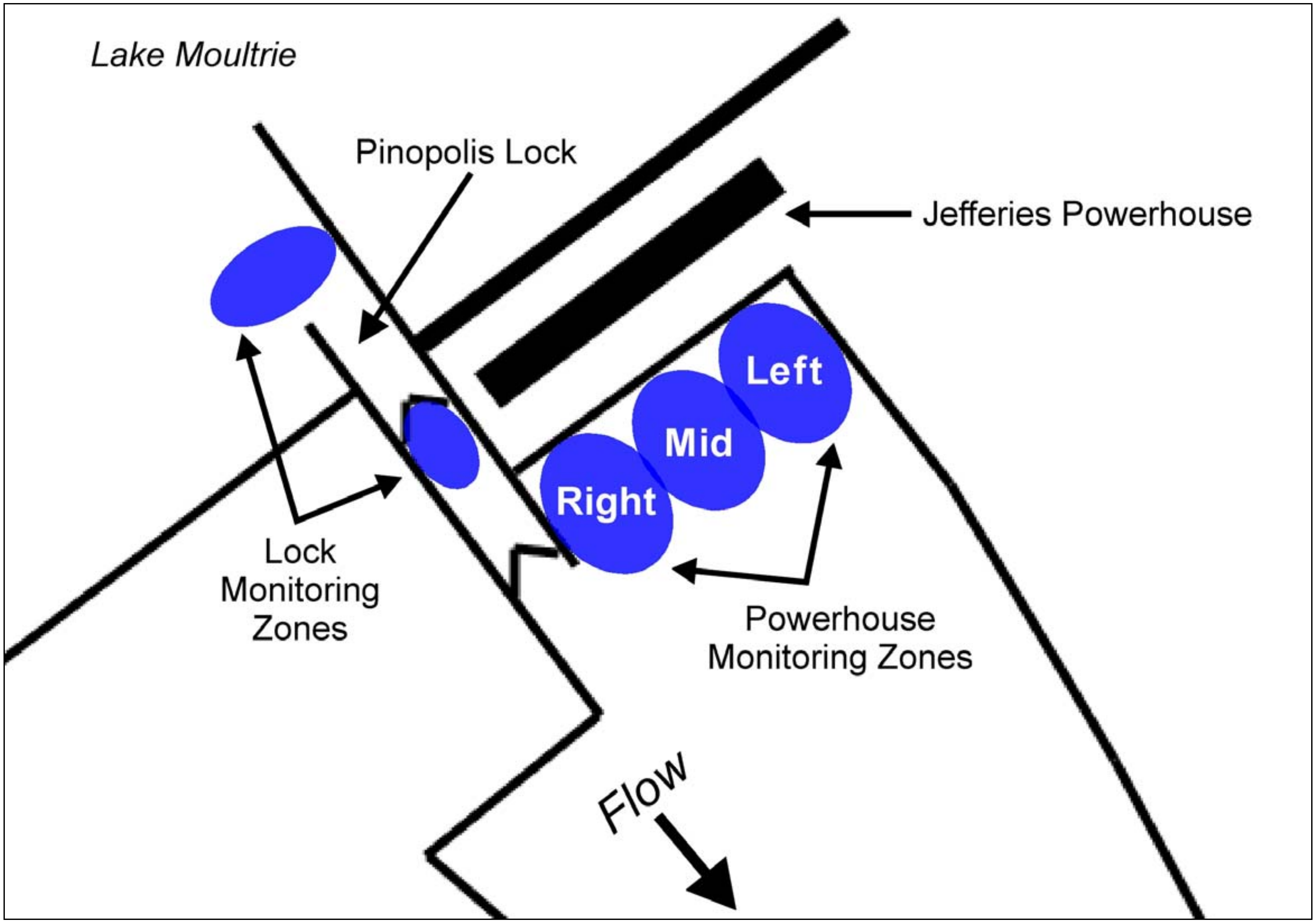

Figure 2

American shad and blueback herring, fixed station monitoring zones in the Jefferies Hydroelectric Station tailrace and Pinopolis Lock, spring 2003.

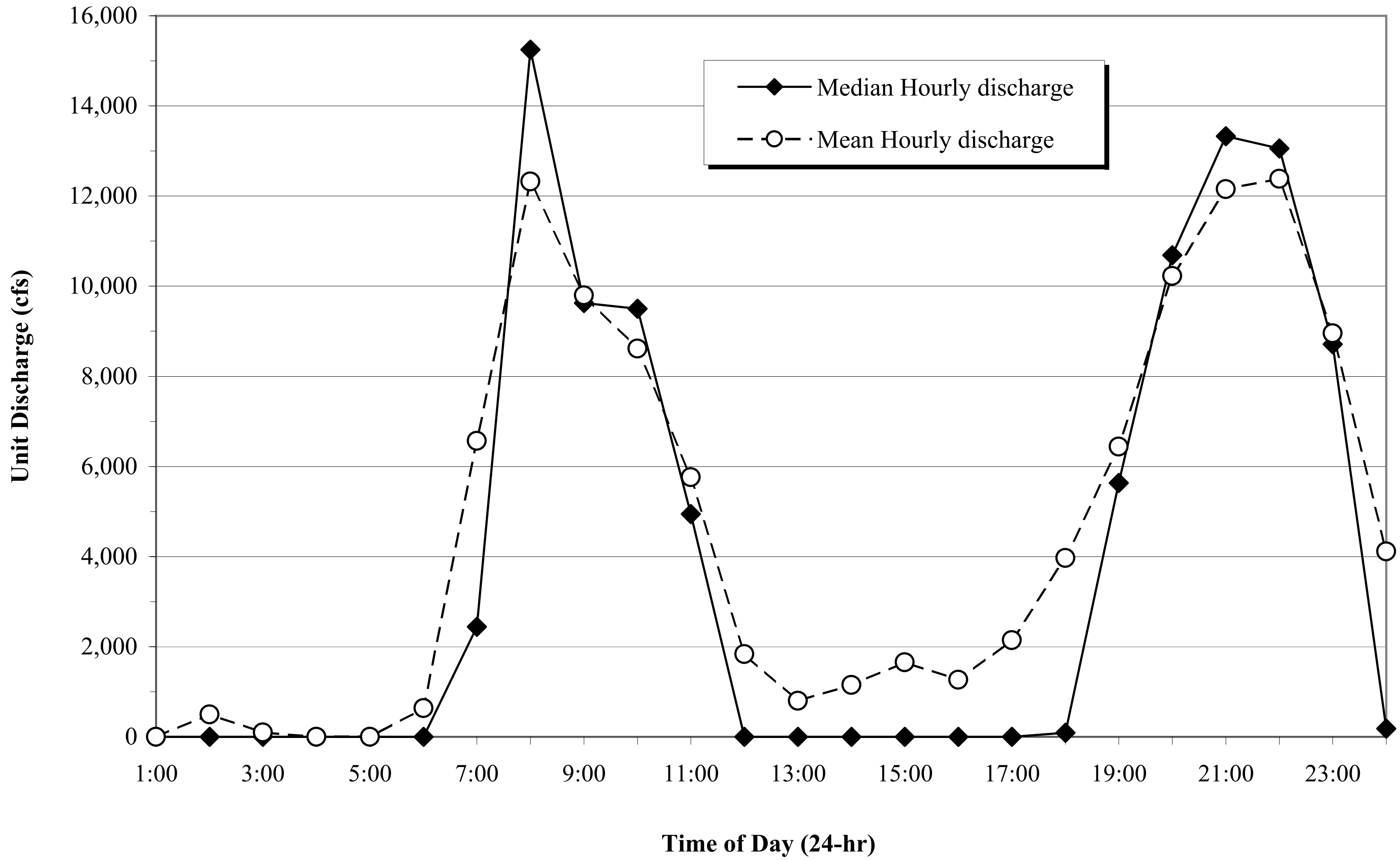

Figure 3

Median and mean hourly discharge at the Jefferies Hydroelectric Station, spring 2003.

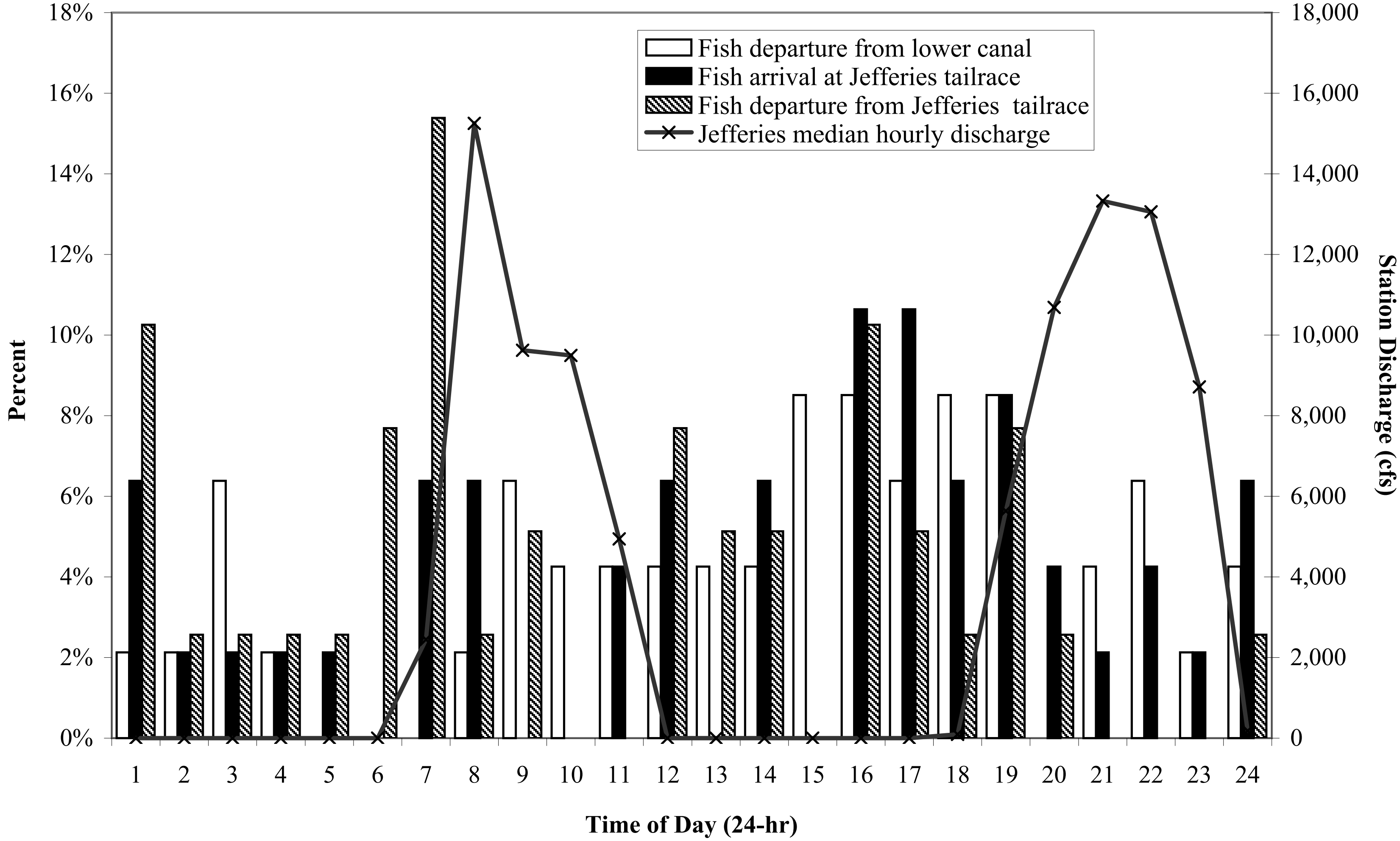

Figure 4

Forays made by herring between downstream monitoring sites and the Jefferies tailrace, spring 2003.

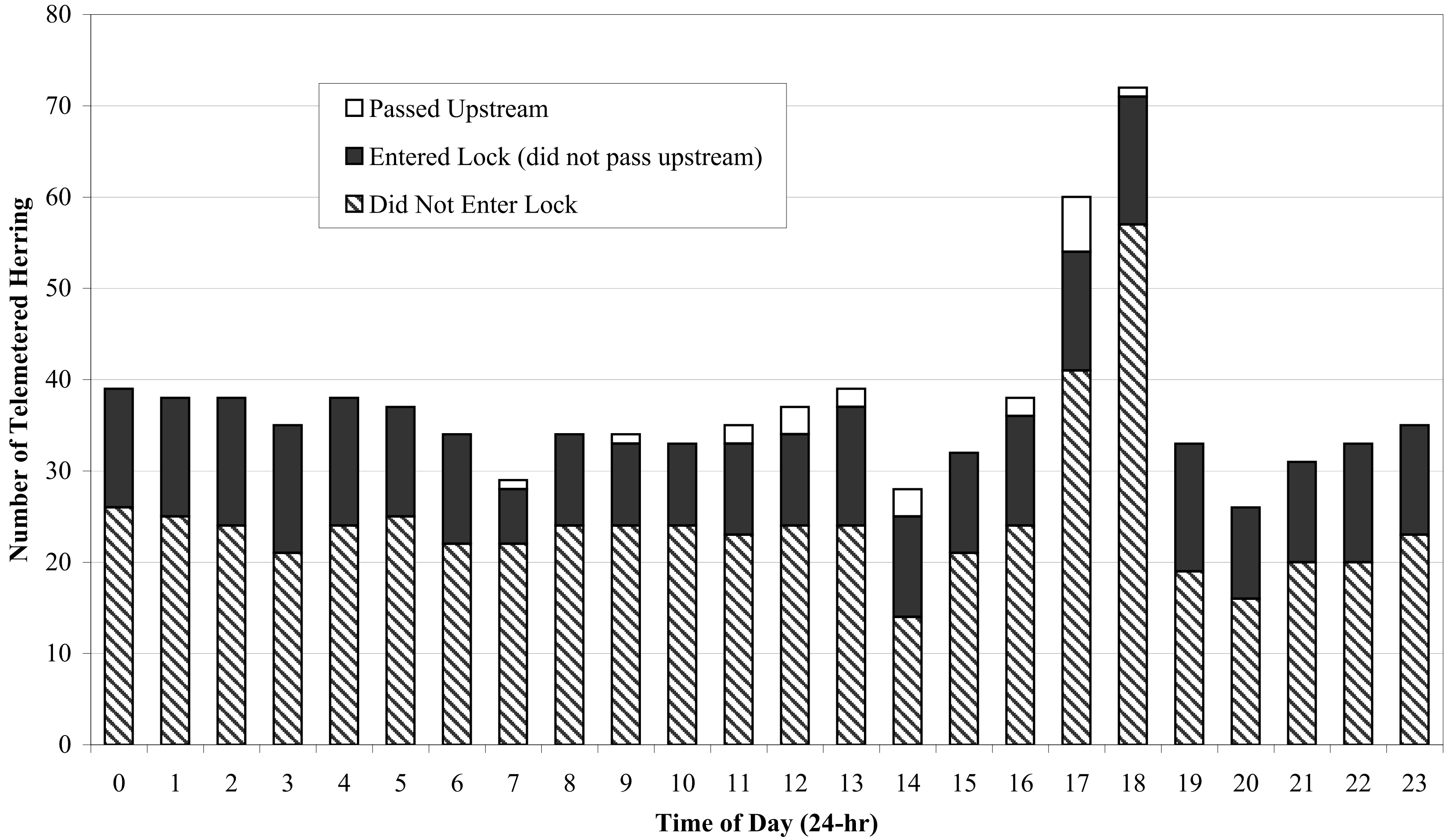

Figure 5

Breakdown of the number of herring detected in the Jefferies tailrace that entered the lock but did not pass upstream, passed upstream, and, did not enter the lock, by hour of day, spring 2003.

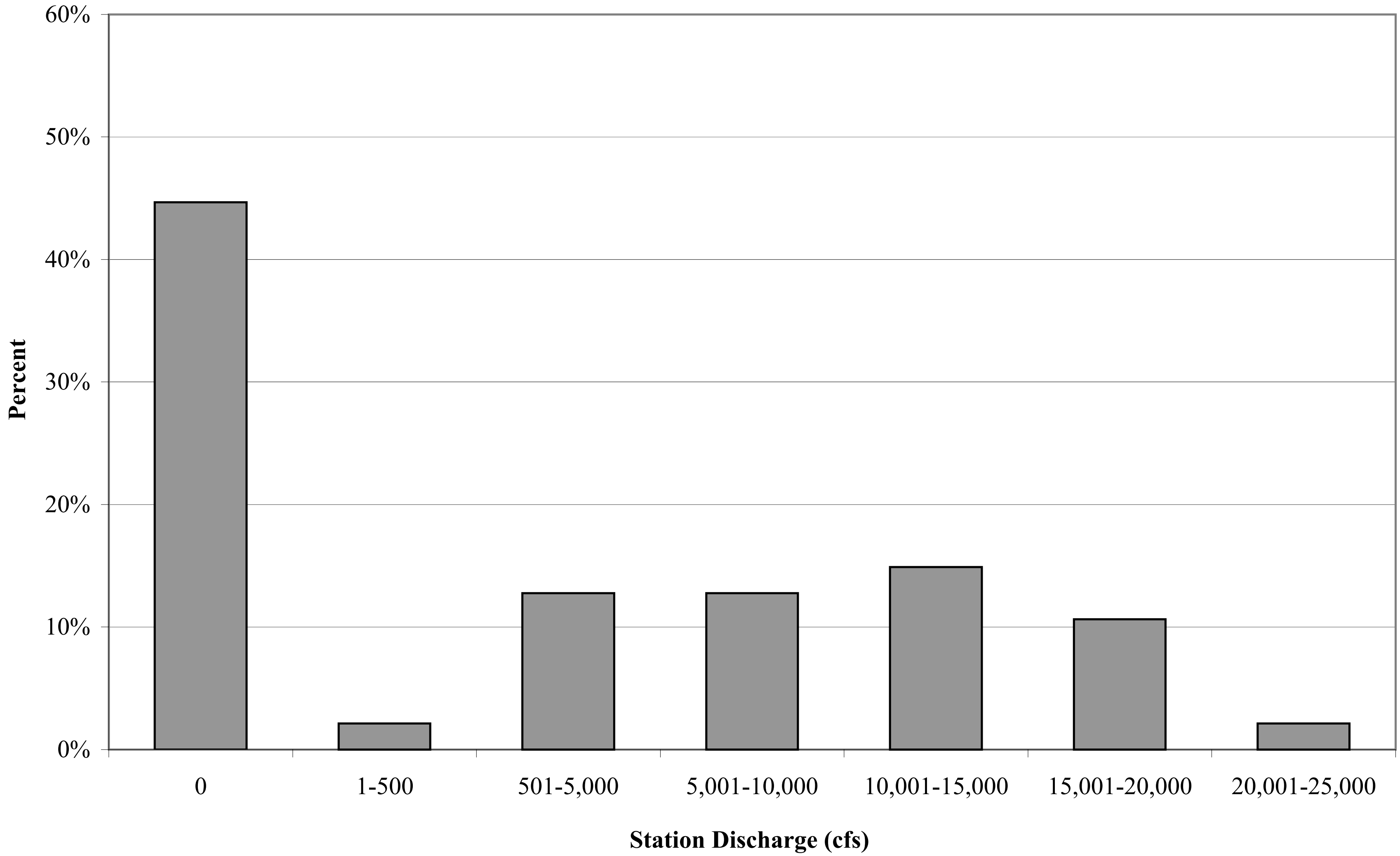

Figure 6

Percent of forays herring made to the Jefferies tailrace by flow range, spring 2003.

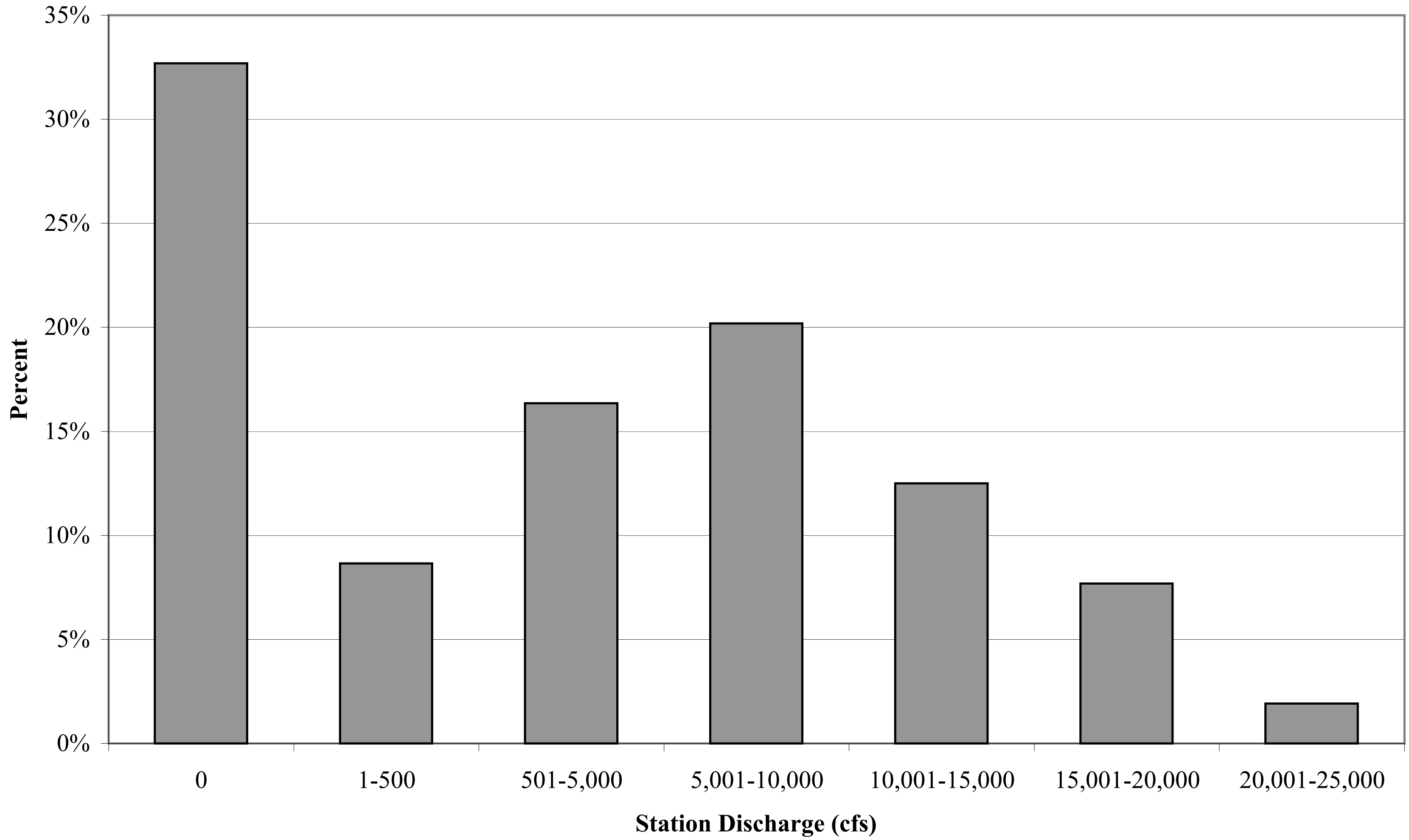

Figure 7

Percent of herring entering the Pinopolis lock by flow range, spring 2003.

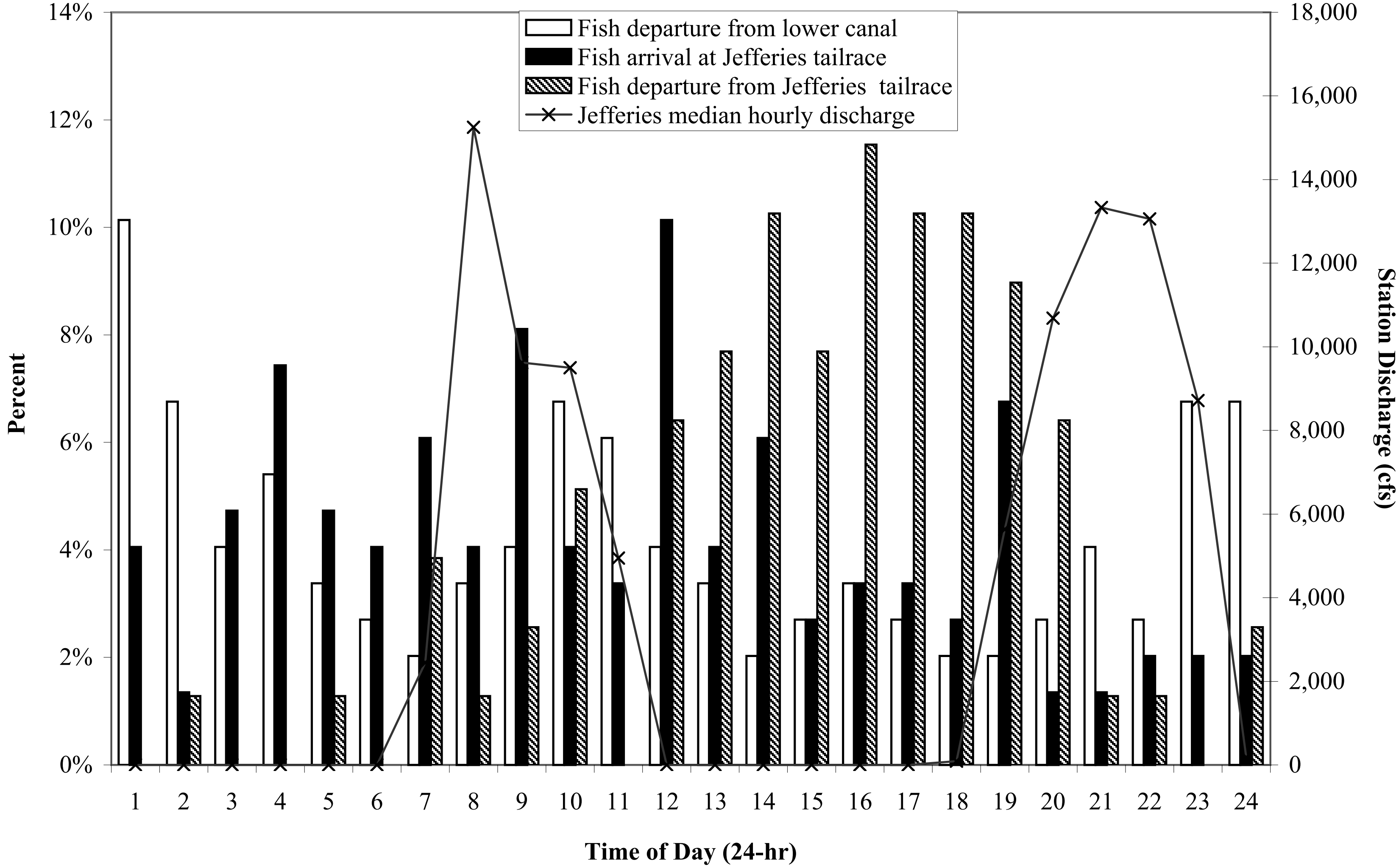

Figure 8

Forays made by American shad between downstream monitoring sites and the Jefferies tailrace, spring 2003.

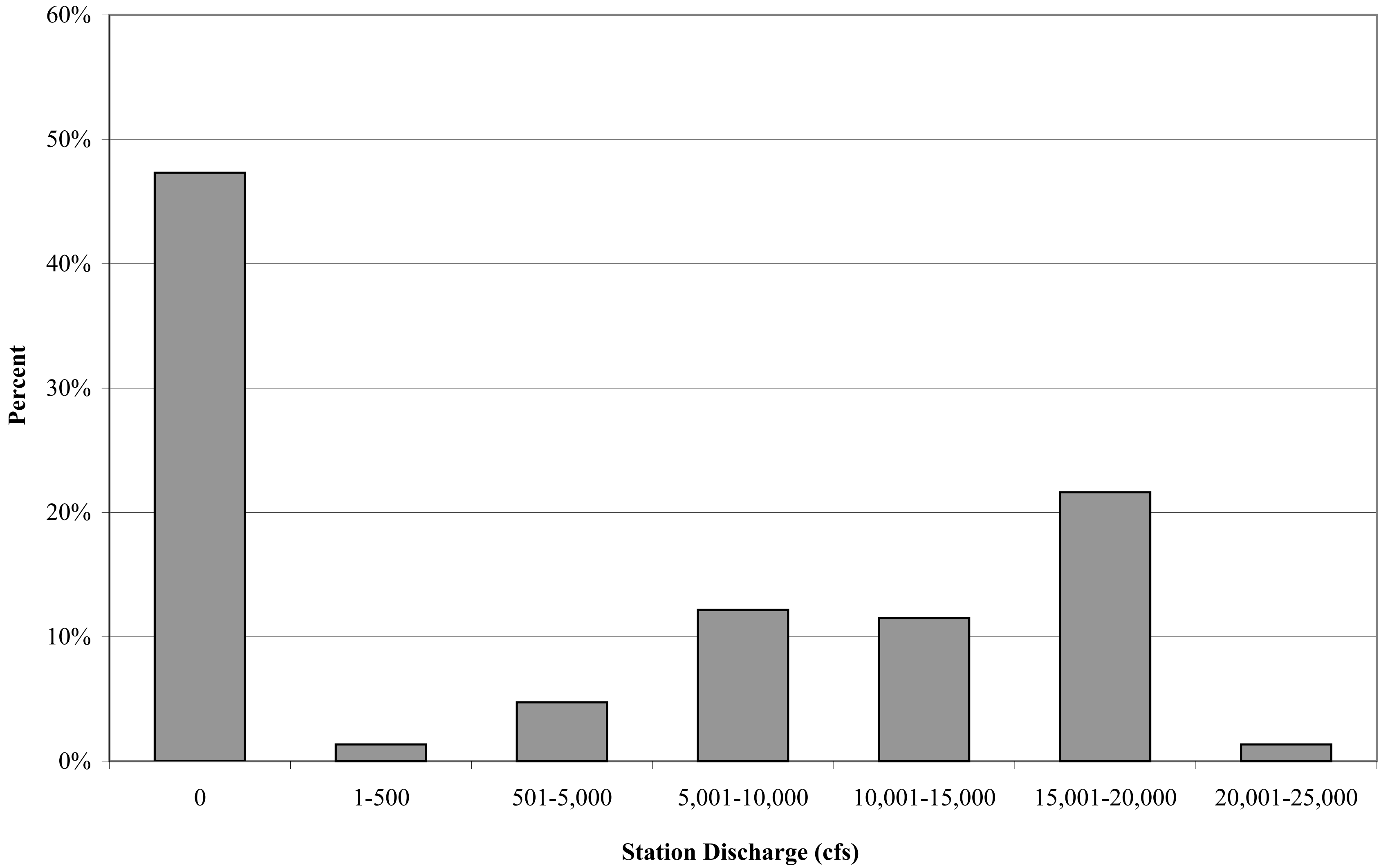

Figure 9

Percent of forays shad made to the Jefferies tailrace by flow range, spring 2003.

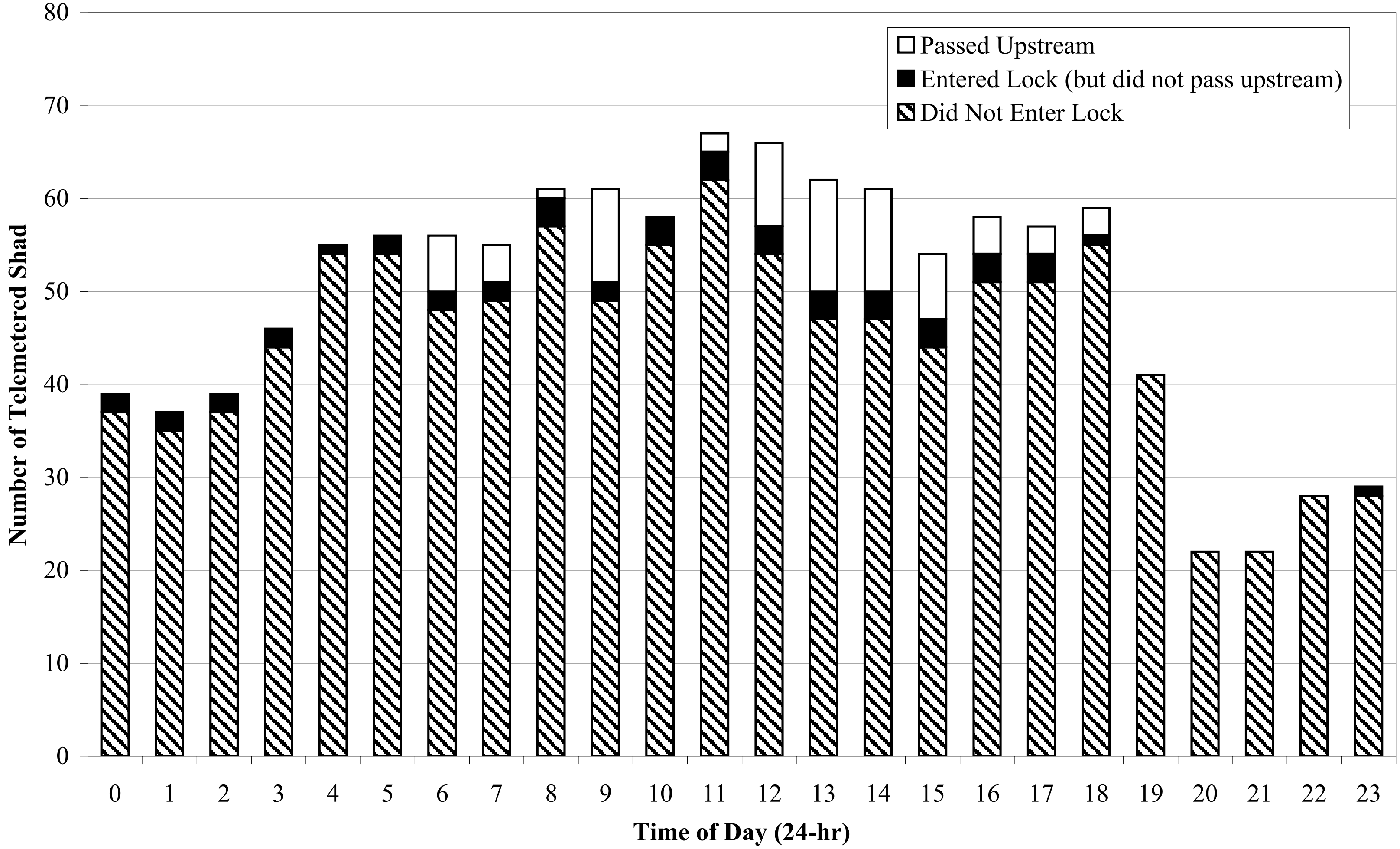

Figure 10

Breakdown of the number of shad detected in the Jefferies tailrace that entered the lock but did not pass upstream, passed upstream, and, did not enter the lock, by hour of day, spring 2003.

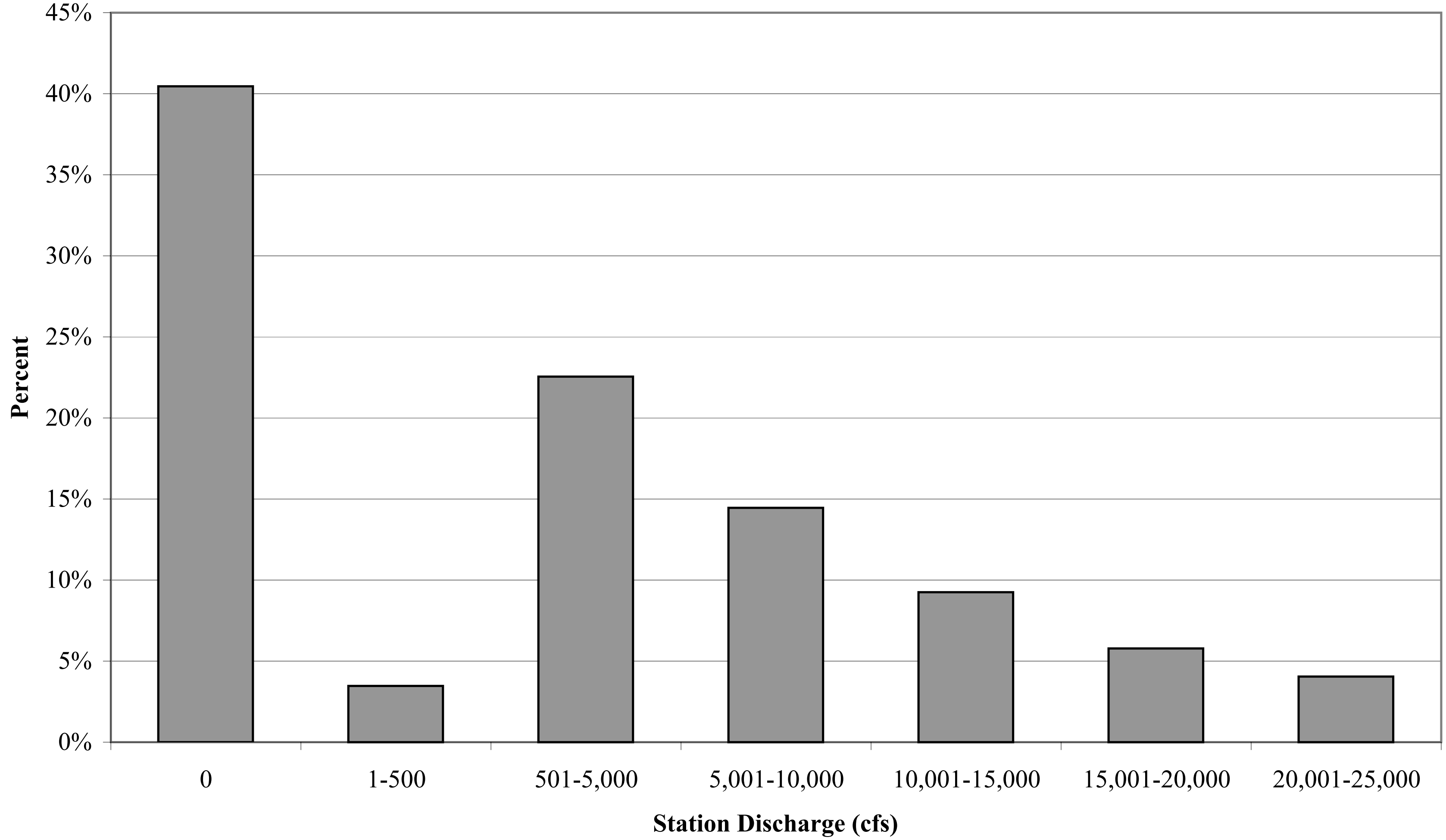

Figure 11

Percent of shad entering the Pinopolis Lock by flow range, spring 2003.

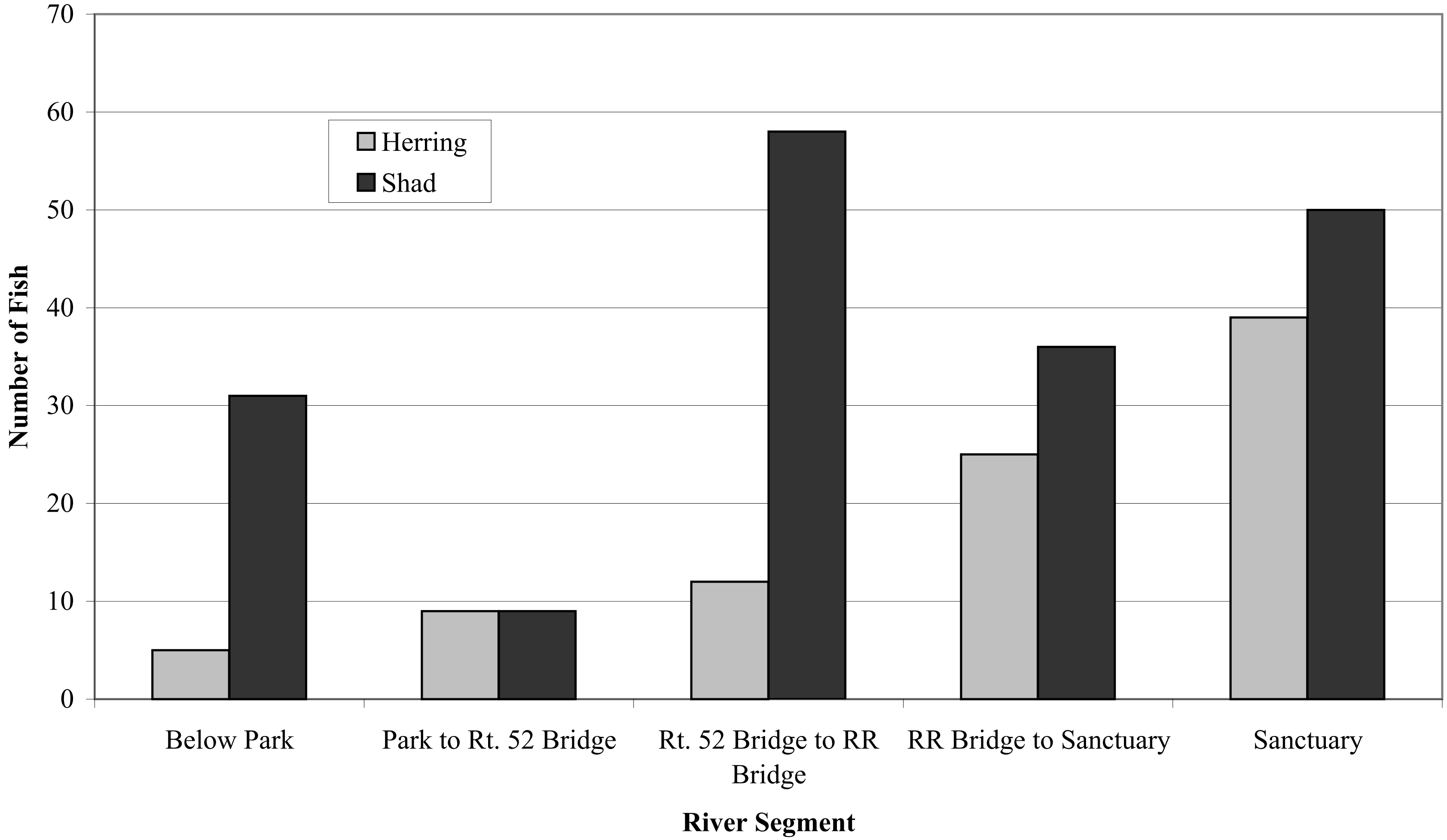

Figure 12

Location of manually tracked shad and herring, by river segment, spring 2003.

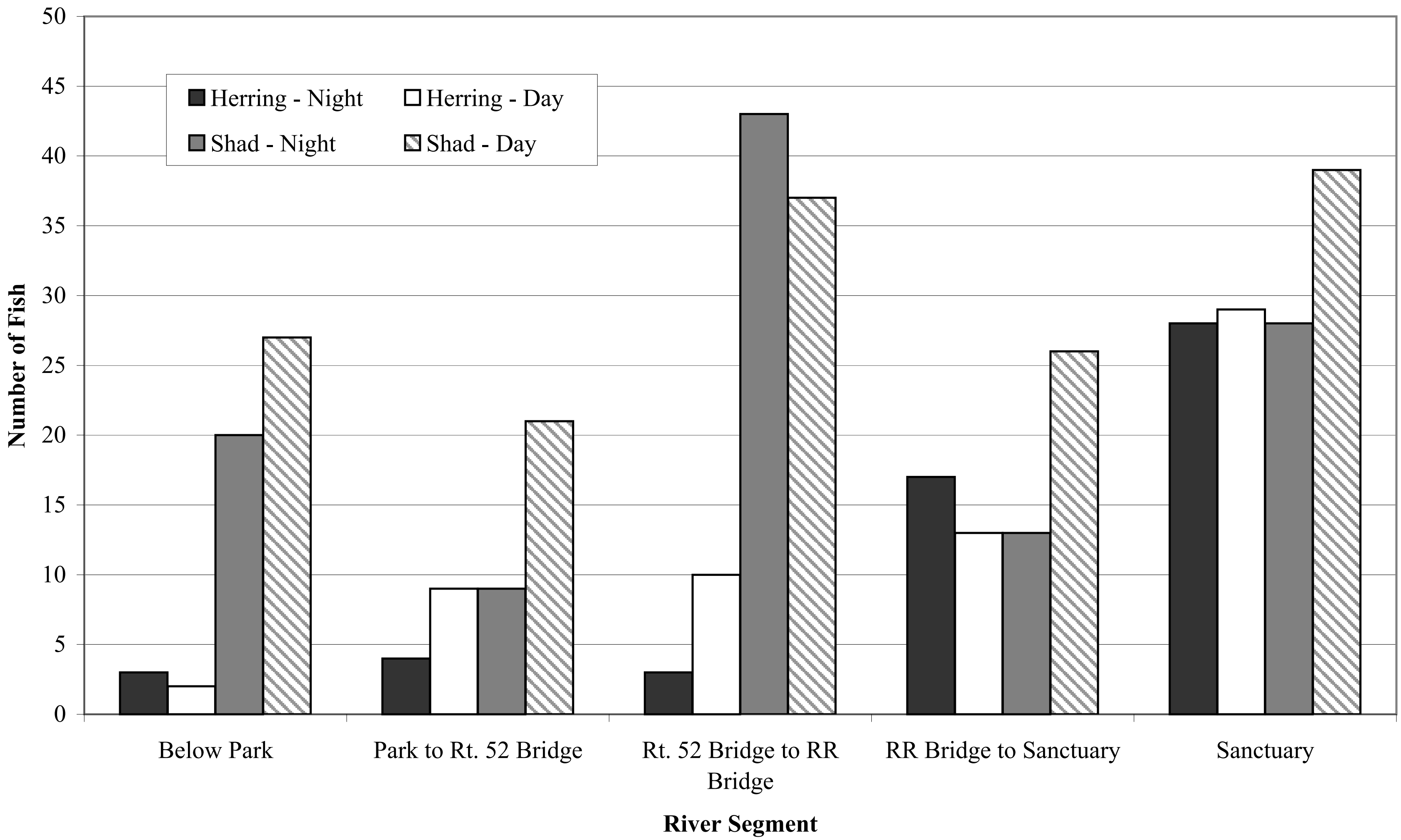

Figure 13

Location of manually tracked shad and herring during daylight (0631-1830h) and nighttime (1831-0630h) hours, spring 2003.

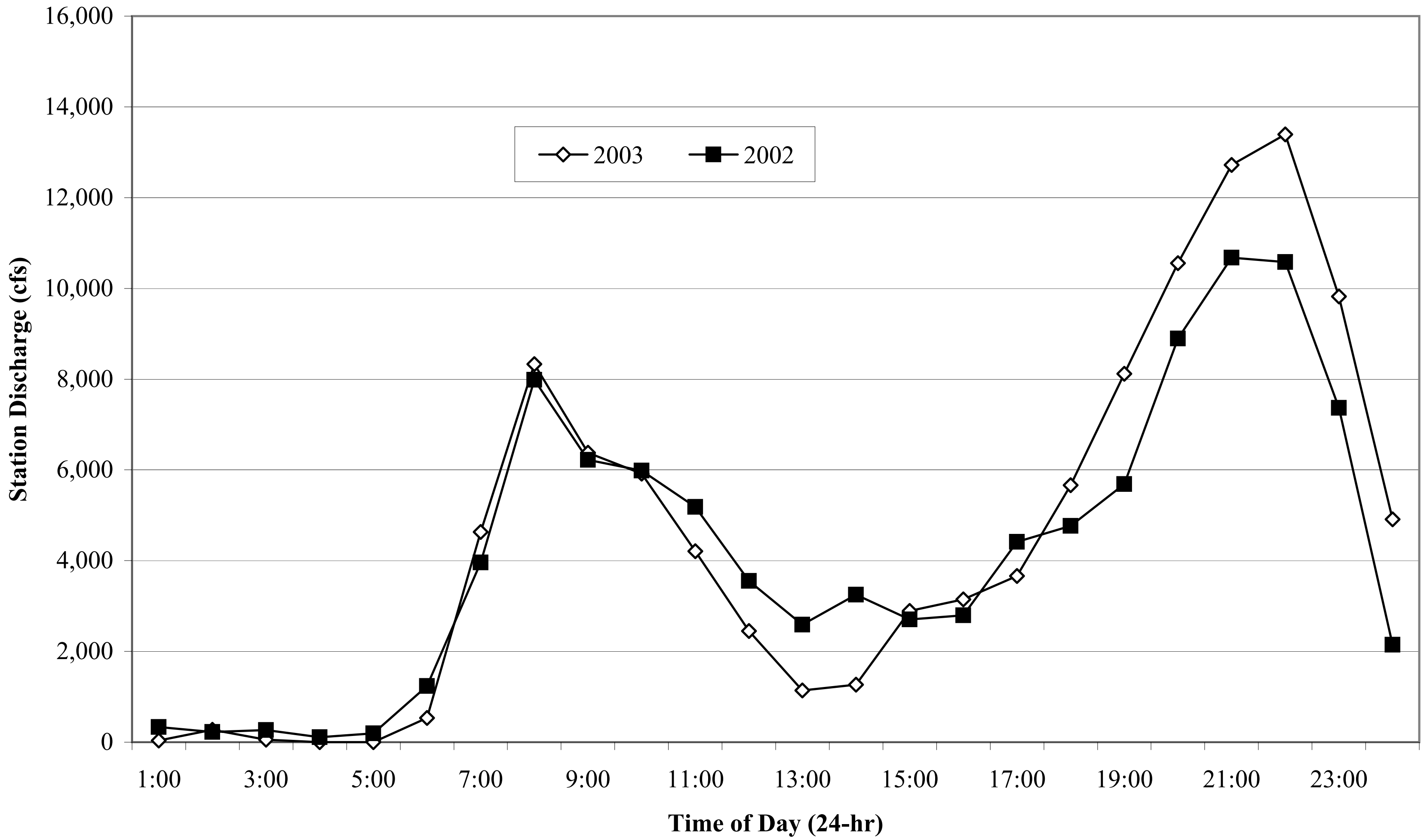

Figure 14

Average daily discharge from the Jefferies Hydroelectric Station during periods of study, spring 2002 and 2003.

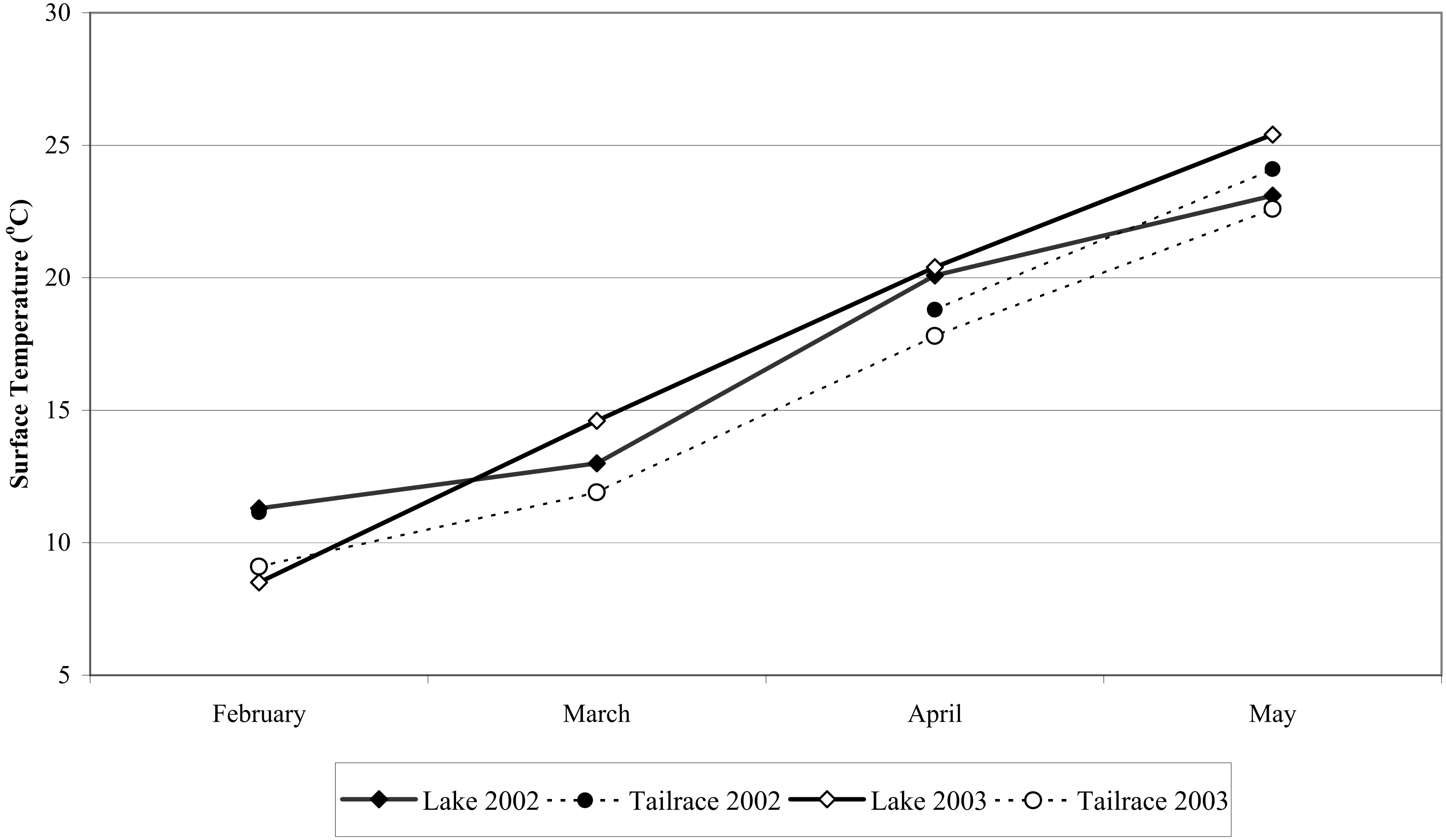

Figure 15

Surface water temperature (°C) in Lake Moultrie near the dam and in the Cooper River tailrace during spring 2002 and 2003.

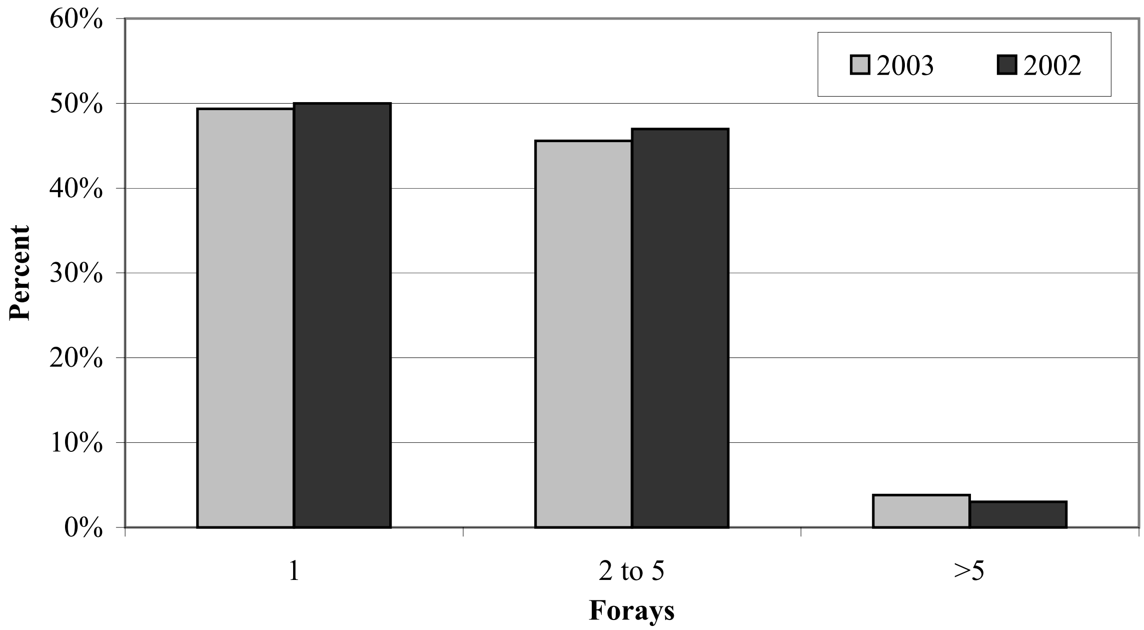

Figure 16

Comparison of the percent of forays shad made to the Jefferies tailrace during spring 2002 and 2003.

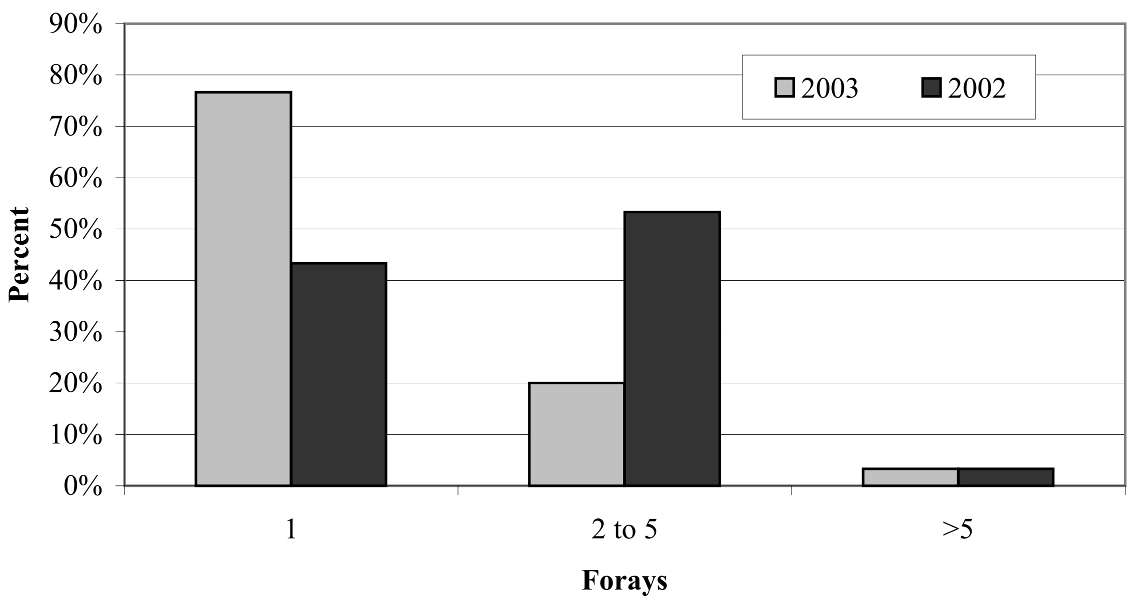

Figure 17

Comparison of the percent of forays herring made to the Jefferies tailrace during spring 2002 and 2003.

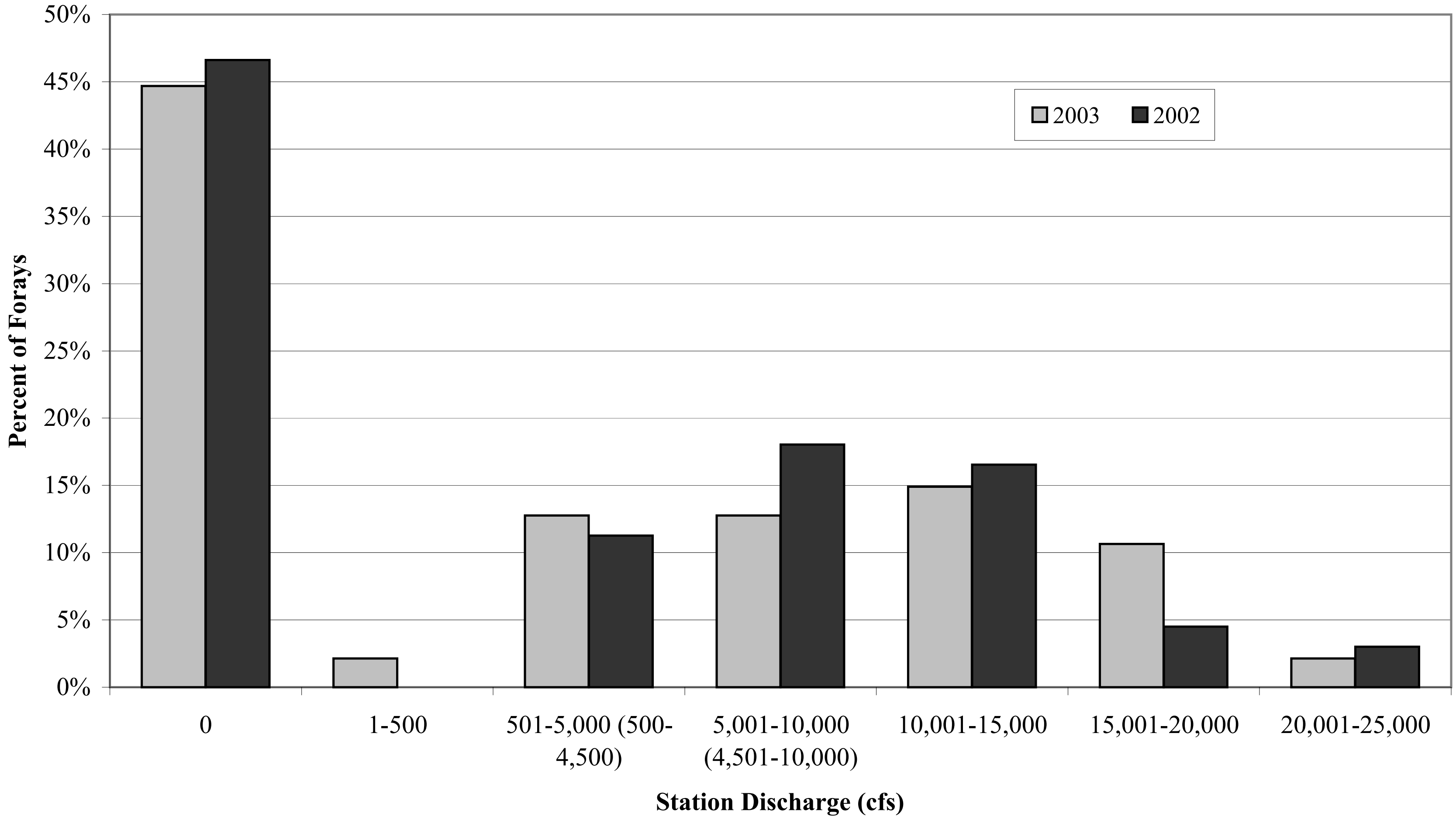

Figure 18

Percent of forays herring made to the tailrace by flow category during the course of each study, spring 2002 and 2003. Six flow categories were used in 2002 and seven in 2003, resulting in three non-congruent categories. Flow categories in parentheses are for 2002.

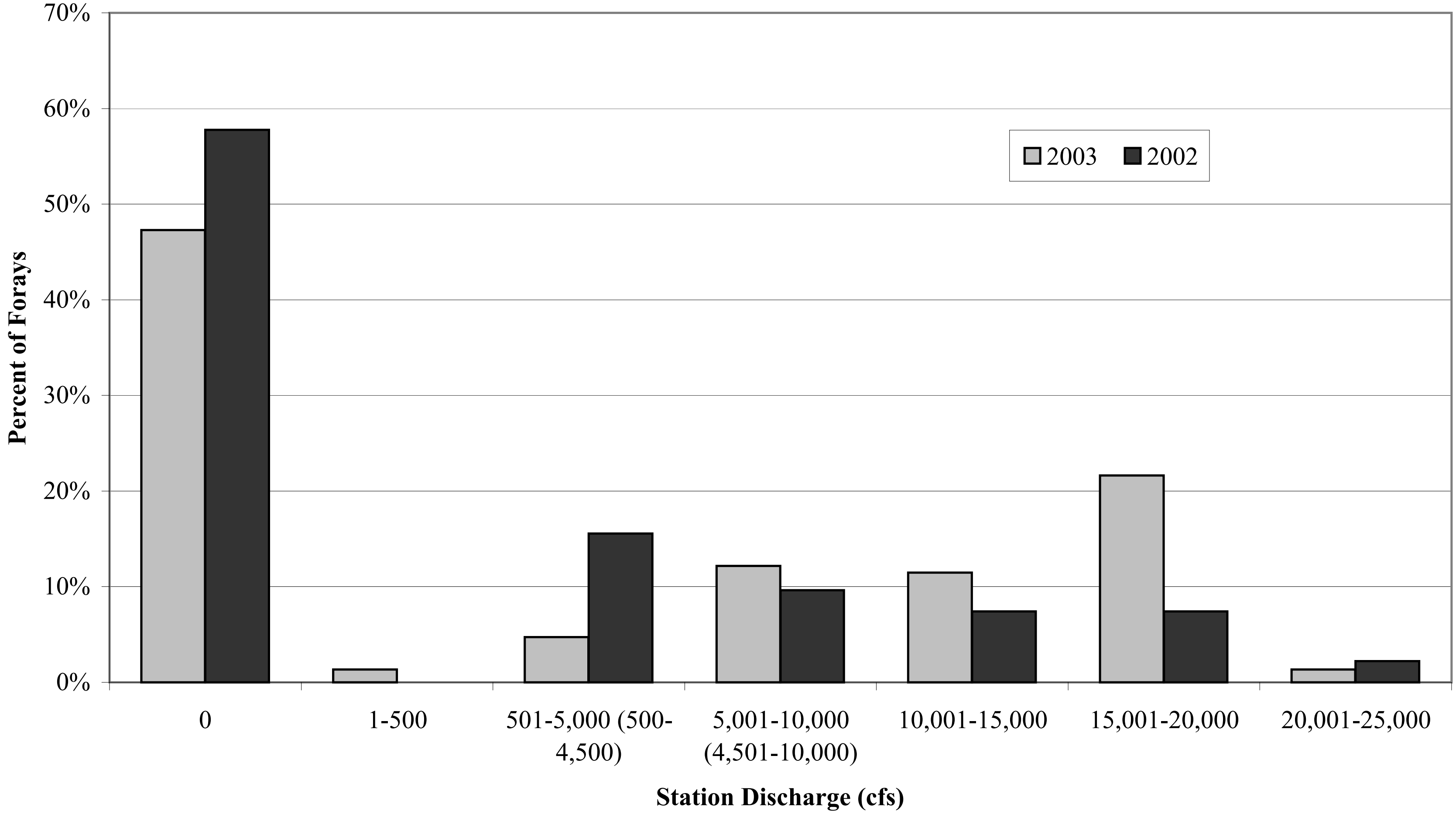

Figure 19

Percent of forays shad made to the tailrace by flow category during the course of each study, spring 2002 and 2003. Six flow categories were used in 2002 and seven in 2003, resulting in three non-congruent categories. Flow categories in parentheses are for 2002.

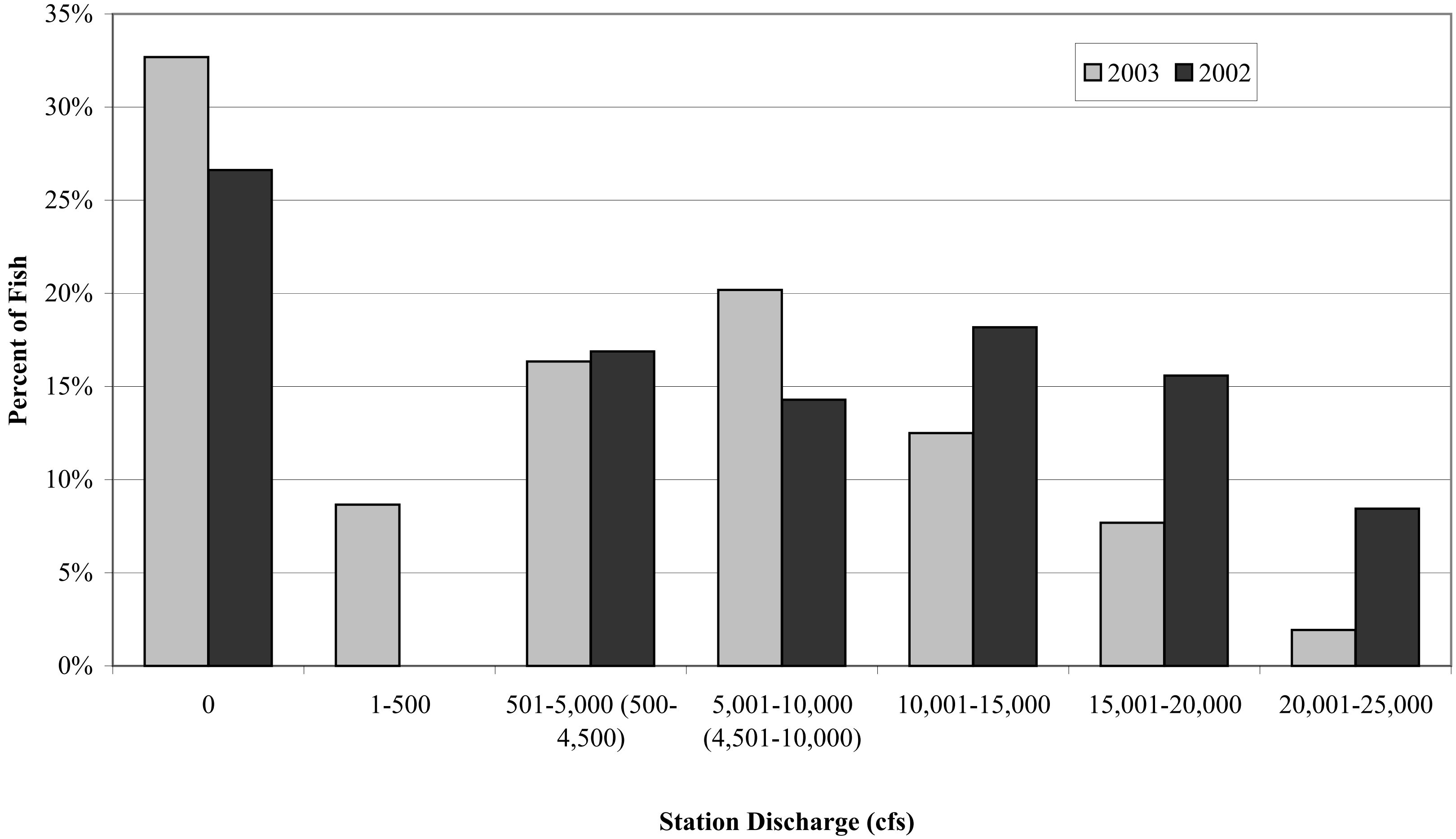

Figure 20

Percent of herring entering the lock by flow category during the course of each study, spring 2002 and 2003. Six flow categories were used in 2002 and seven in 2003, resulting in three non-congruent categories. Flow categories in parentheses are for 2002.

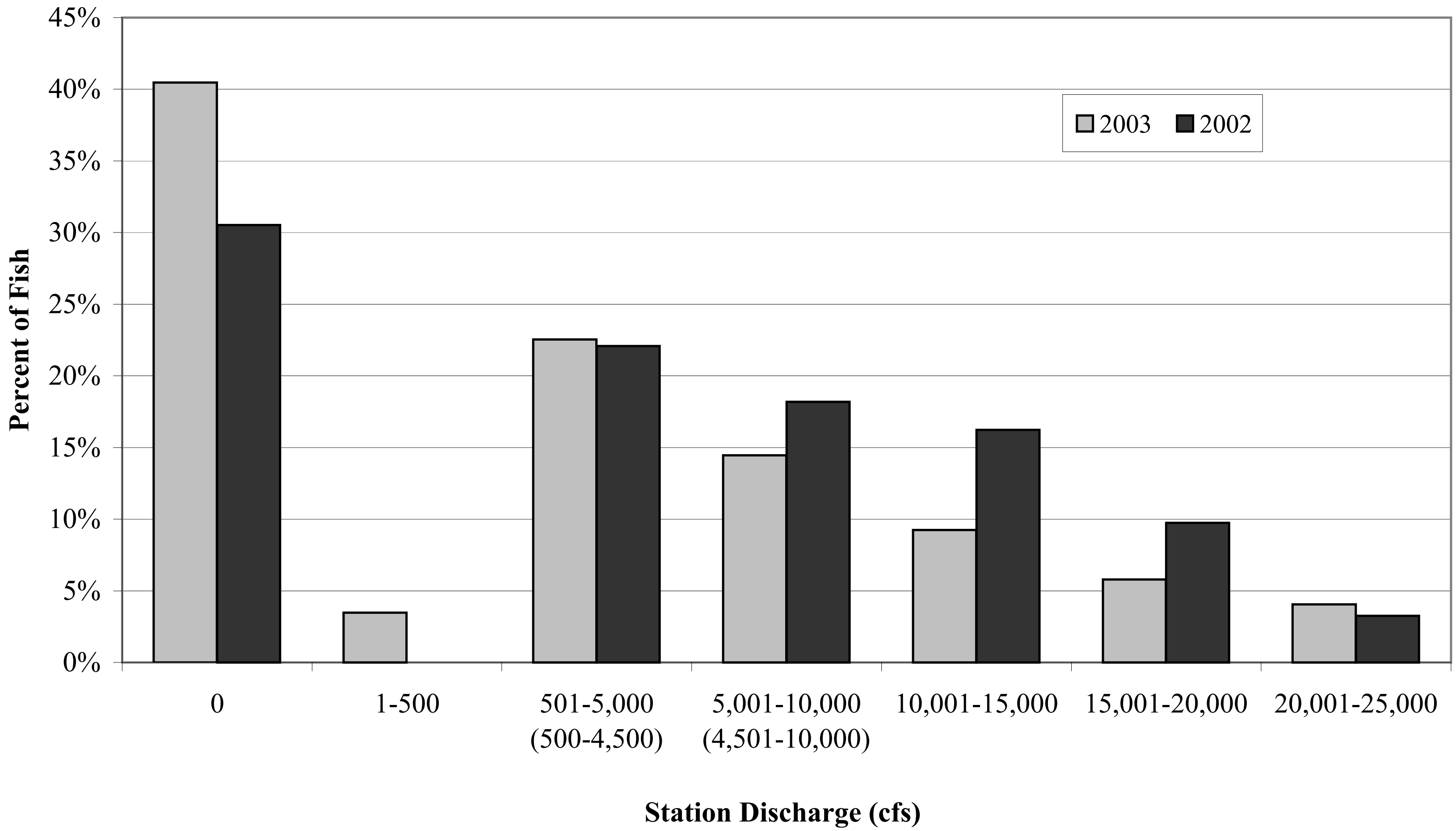

Figure 21

Percent of shad entering the lock by flow category during the course of each study, spring 2002 and 2003. Six flow categories were used in 2002 and seven in 2003, resulting in three non-congruent categories. Flow categories in parentheses are for 2002.