Evaluation of the Cylindrical Wedge-Wire Screen System at the Imperial National Wildlife Refuge, Arizona 2009
Lower Colorado River Multi-Species Conservation Program
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Ducks Unlimited
Lower Colorado River RC&D Area, Inc.
The Nature Conservancy
Lower Colorado River
Multi-Species Conservation Program

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EXECUTIVE SUMMARY

As part of their ongoing effort to meet obligations under the terms of the ESA to protect endangered fish and wildlife species, the United States Bureau of Reclamation (Reclamation) has partnered with three western states, California, Arizona, and Nevada to form and implement the Lower Colorado River Multi-Species Conservation Program (LCR MSCP). The LCR MSCP is a long-term, multi-agency effort to conserve existing populations and work toward recovery of endangered species, and protect and maintain habitat on the Lower Colorado River (LCR). The LCR MSCP is required to restore or create protected backwaters along the LCR in support of native fish. As a part of this effort, Reclamation reconstructed a series of six ponds on the Imperial National Wildlife Refuge (INWR) to provide habitat for native fish fauna. Water for these Imperial Ponds is supplied by a pump which is equipped with a wedge-wire screen system designed to prevent the entrainment of nonnative fish species.

To determine whether nonnative fishes were being entrained through the screen system, an evaluation was conducted during spring and early summer of 2009. This evaluation was designed to sample water being delivered from the screened pump system to the Imperial Ponds during periods when early life-stages of nonnative fishes were present and susceptible to entrainment. To sample water being delivered from the pump, the main waterline was modified to accommodate a large manifold, which was constructed over an existing irrigation canal near the pump platform. The sampling manifold was constructed of a 0.46 meter (18-inch) pipe that had a series of 12 sampling ports each 0.1 meter (4 inches) in diameter. Each sampling port was equipped with 335-micron plankton net. Sampling events were conducted in April, May, June, and July. Samples were replicated during each sampling event over a three-day period. Approximately one-hour long entrainment samples were taken in the AM and PM hours during daylight, night and crepuscular periods. In conjunction with the entrainment samples, ichthyoplankton tows were conducted to determine the presence of nonnative fish eggs and larvae in the vicinity of the pump and screen system.

Results of this study indicated that the larvae of nonnative fishes are passing through the screen system; larval fish were collected in over 97% of the entrainment samples taken across all sampling months. Larvae accounted for the majority of the organisms collected accounting for over 99.5% of the catch. Composition of the larval catch was dominated by three taxonomic families: Centrarchidae, Clupeidae, and Cyprinidae. Centrarchids were captured in all sampling months, and accounted for 22% of the entrainment sample in April, 63% in May, 88% in June, and 99% in July. Cyprinidae larvae were the most abundant in entrainment samples collected in April when they comprised 48% of the catch, but comprised less than 1% in samples collected during the subsequent months. Clupeids were found predominately in April (18%) and May (14%), but similar to Cyprinids accounted for less than 1% in June and July. Length frequency data showed that significantly (P < 0.05) smaller larvae were captured in the entrainment samples when compared to larvae collected outside the screen for all three taxonomic families indicating that the screens are excluding larger individuals of nonnative species. Further analysis found no correlation between light intensity (time of day) and the abundance of larvae being entrained.
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1.0 INTRODUCTION

Razorback sucker *Xyrauchen texanus* and bonytail chub *Gila elegans* are native fishes of the lower Colorado River and are currently listed as endangered under the terms of the Endangered Species Act (ESA). Their initial declines were attributed to anthropogenic changes to habitat and river conditions related to construction of dams on the Colorado River. However, research suggests that the introduction of nonnative fishes may be a major factor leading to the decline of these species due to competition and predation (Minckley and Deacon 1968; Minckley 1983).

As owners and operators of hydroelectric projects on the Colorado River, the United States Bureau of Reclamation (Reclamation) has responsibilities under the terms of the ESA. As a part of their efforts to meet these responsibilities, Reclamation has partnered with three western states, California, Arizona, and Nevada to form and implement The Lower Colorado River Multi-Species Conservation Program (LCR MSCP). The LCR MSCP is a partnership of Federal and non-Federal stakeholders responding to the need to balance the use of Lower Colorado River (LCR) water resources and the conservation of native species and their habitats in compliance with the ESA. This is a long-term plan to conserve at least 26 species along the LCR from Lake Mead to the Southerly International Boundary with Mexico through implementation of a Habitat Conservation Plan (HCP).

As the implementing agency of the LCR MSCP, Reclamation is required to restore or create backwaters along the LCR. As part of this effort, Reclamation is investigating a variety of methodologies for protecting restored or creating new isolated backwater habitats. One of the technologies that has been applied to date is the use of wedge-wire screens to exclude nonnative fish. Wedge-wire screens are commonly used to reduce entrainment of fish eggs and larvae at pump-storage facilities (Snyder 1975; Prince and Mengel 1980) nuclear power plants, (Merriman and Thorpe 1976; Kelso and Leslie 1979) and other cooling water intakes and hydroelectric facilities (EPRI 2006). The initial application of wedge-wire technology to exclude the eggs and larvae of nonnative fishes for a protected backwater was undertaken at Beal Lake, a restored backwater of the LCR (Normandeau 2006; Normandeau 2007).

Beal Lake is a 225-acre backwater located in Arizona on the Havasu National Wildlife Refuge. Restoration activities performed at Beal Lake included substantial dredging of the previously shallow backwater and the installation of a semi-permeable rock structure across the inlet canal to prevent all life-stages of nonnative fishes from entering the lake. This rock structure, however, did not allow sufficient flow to compensate for evaporation rates during the summer. Therefore, to supplement the flow of water into Beal Lake while preventing the passage of nonnative fishes, three 0.46 meter (18-inch) diameter pipes, each with cylindrical wedge-wire screens attached on either end, were installed in the rock structure. The purpose of the screens was to supplement flow into Beal Lake while preventing the passage of nonnative fishes. Hydraulic testing indicated that the screen system was capable of passing sufficient flow to maintain consistent water levels in Beal Lake during the peak evaporation periods (Normandeau 2006). Further testing on the effectiveness of the screen system at excluding eggs and larvae of nonnative fish indicated that only the small eggs and larvae (< 1 mm in diameter or width) were capable of passing through the 0.6-mm slot width of the screens; passage of larger eggs (>1 mm diameter) and larvae (> 10 mm in length) were found to be inhibited (Normandeau 2007).

The relative success of the screens installed at Beal Lake prompted Reclamation to install a similar type of screen to the pump system delivering water to the recently reconstructed Imperial Ponds, located on the
Imperial National Wildlife Refuge (INWR). Unlike the screens at Beal Lake, which were installed for passive water flow, the wedge-wire screen installed for use at the Imperial Ponds was attached to a variable speed irrigation pump. Differences in screen configuration and through slot velocities necessitated an in-situ investigation of the screen system installed at the Imperial Ponds. The specific objectives of this investigation were to: 1) evaluate the fish exclusion efficiency of the cylindrical wedge-wire screen installed on the INWR; and 2) if eggs and larvae were documented passing through the screen, to quantify their species composition and size structure.

2.0 STUDY AREA

The INWR is located on the LCR approximately 48 river kilometers (Rkm) north of the city of Yuma, Arizona (United States Bureau of Reclamation 2001). In 2006, Reclamation began reconstructing a series of six ponds on the INWR that now provide approximately 80 acres of diverse habitat for native fish and wildlife species (Figure 1). The Imperial Ponds are located between the Colorado River and the inlet canal to Martinez Lake, in a portion of the refuge known as the Intensive Management Area (IMA). This area consists of fields, marshes, and ponds that are managed for waterfowl, marsh birds, native fish, riparian obligate bird species, and other wildlife.

![Figure 1. Aerial image of the Intensive Management Area and Imperial Ponds on the Imperial National Wildlife Refuge, Arizona.](image-url)
To provide water to the Imperial Ponds, Reclamation installed a variable speed irrigation pump equipped with a cylindrical T-shaped wedge-wire screen and airburst cleaning system (Figures 2 and 3). The pump is strictly dedicated to supplying water to the renovated ponds with water from the Martinez Lake inlet canal. Although the pump is capable of up to 8,000 gallons per minute (gpm), the operating protocols of the system dictate that the pump be operated at a discharge rate of approximately 6,000 gpm. This allows delivery of approximately 1,000 gpm to each of the six ponds. A single wedge-wire screen measuring approximately 5.2 meters (17 feet) in length by 1.7 meters (5.5 feet) in diameter was installed on the intake of the variable speed pump (Figure 3). The screen has a slot width of 0.5 mm (0.02 inch). The pump discharges into a 0.41 meter (16 inch) diameter steel pipe which then transitions to a 0.61 meter (24 inch) pipe before being diverted into a series of smaller 0.3 meter (12 inch) diameter supply lines dedicated to each pond. An in-line valve installed along each of the smaller supply lines is used to control flow into individual ponds.

3.0 METHODS AND MATERIALS

3.1 Sample Timing

This evaluation was scheduled to coincide with periods when early life-stages of many nonnative fishes are known to be present in Martinez Lake (BioWest 2008). Sampling events were conducted during four discrete time periods beginning in April and continuing through July (Table 1). Each sampling event consisted of a three-day sampling period. Each day was further divided into six distinct time periods that corresponded with ambient light intensity during AM and PM hours.

Figure 2. Installation of wedge-wire screen on the pump platform on the Martinez Lake inlet canal, 2008.
3.2 Field Testing

3.2.1 Entrainment Sampling

To evaluate whether entrainment of nonnative fishes was occurring, water delivered from the screened irrigation pump was sampled by modifying the main supply line from the pump. This modification involved adding a 0.25 meter (10 inch) diameter pipe to redirect flow from the main supply line to a newly constructed irrigation canal. For sampling purposes, the water pumped from Martinez Lake was discharged through a large steel manifold, specifically constructed for this study, which was installed at the end of the pipe and directly over the irrigation canal (Figure 4). The manifold contained a total of 12 sampling ports evenly spaced along the bottom of the manifold pipe. Each port was 0.1 meter (4 inches) in diameter and approximately 0.46 meters in length. Flow through each port was sampled using a 335-micron conical plankton net with a reinforced cod-end collection bottle (Sea-Gear Corp., Melbourne, FL). Nets were positioned beneath each port to ensure that all discharged water was sampled (Figure 5).

To allow for better system operation and increased flow capacity, pressure in the sampling manifold needed to be reduced. Pressure reduction in the manifold was achieved by increasing the diameter of the 0.25 meter delivery pipe to 0.36 meters (14 inches) in the transition from the valve to the manifold, and then increasing the pipe diameter again to accommodate the outer 0.46 meter (18 inch) pipe of the manifold itself. The manifold was approximately 7.6 meter (25 feet) in length and had a maximum flow capacity of approximately 4,000 gpm (Figure 4).

Table 1. Schedule and times for the 72 entrainment samples collected at the Imperial Ponds, 2009. Samples were collected over a one-hour period beginning at the start time.

<table>
<thead>
<tr>
<th>Date sampled</th>
<th>Sunrise</th>
<th>Sunset</th>
<th>AM Sample Start Time</th>
<th>PM Sample Start Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
<td>PM</td>
<td>Dark</td>
<td>Crep</td>
</tr>
<tr>
<td>4/21/2009</td>
<td>6:01</td>
<td>19:12</td>
<td>4:07</td>
<td>6:10</td>
</tr>
</tbody>
</table>
Figure 3. Operation of the airburst cleaning system at the newly installed pump and wedge-wire screen located on the Martinez Lake inlet canal.

Figure 4. The large steel manifold with 12 evenly spaced sampling ports and attached plankton nets used for entrainment sampling.
During each distinct sampling period, entrainment samples were collected while the screened irrigation pump operated at a volume of approximately 6,300 gpm (70% capacity). This volume was achieved by allowing approximately 2,000 gpm to continue to flow into the ponds and not be redirected through the manifold. The remainder of the flow (approximately 4,000 gpm) was directed to the sampling manifold. This pump operation scenario was developed to ensure that the entrainment samples were collected at screen slot velocities which were similar to those encountered during normal pump operations. Flow through the manifold was calculated during each sample using an impeller-type in-line flow meter installed in the pipe that delivered water to the manifold.

For each sampling period, the pump was allowed to operate for one hour before being shut down and the contents of the nets processed. When water ceased to flow though the manifold, the nets were carefully removed and rinsed so that all the materials in the nets were washed into the collection bottles using a hand operated garden sprayer. The nets were rinsed from the outside to insure that no biological materials were introduced into the samples. Once all the material was rinsed into the collection bottles, the bottles were removed and the contents were decanted into a standard stainless steel sieve with mesh size of 300-microns. The contents of all 12 nets from each sampling event were combined and transferred into a single pint collection jar and preserved using a 6.0% formalin solution.

![Water discharging from an individual manifold port into a plankton net during entrainment sampling.](image)

**Figure 5.** Water discharging from an individual manifold port into a plankton net during entrainment sampling.
Water temperature, secchi depth, and dissolved oxygen (DO) were collected during entrainment sampling. Water temperature and DO were measured using an YSI Incorporated Model 85 reader. Secchi depth was taken on the pump platform using a standard Secchi disc during daylight samples.

Since the sampling manifold could not accommodate the flow capacity of the water supply system (~ 6,000 gpm), small particles with buoyancy characteristics similar to that of eggs and larvae were used as tracers to validate the assumption that organisms entrained through the wedge-wire screen would be collected in the manifold and not pass exclusively into the Imperial Ponds. The particles were released directly at the entrance of the pump during every sampling event. A portion of the particles were then collected in the sampling nets after passing through the manifold. The particles were small multicolored spheres of sodium polyacrylate measuring approximately 1.5 to 2 mm in diameter (Figure 6). When allowed to soak in water, the particles increase in size by approximately 3 fold, which permitted the particles to pass through the pipe at a size similar to eggs and larvae, but once they were collected at the end of each entrainment sampling interval, they were larger and easy to enumerate. Five hundred particles were released at the entrance of the pipe at the beginning of each entrainment sample. Additional sampling was also conducted using 100% of the flow directed through the entrainment manifold. Due to limitations of the manifold, this flow rate was reduced to approximately 4,000 gpm, so that 100% of the flow would be passing through the manifold. This was done to ensure the manifold and net system were effective in capturing particles when they were present.

![Image of particles](image)

**Figure 6.** Artificial particles released directly into water supply pipe to assess the collection effectiveness of the manifold.
3.2.2 Ichthyoplankton Tows

A series of ichthyoplankton tows were conducted to determine whether eggs and larvae of nonnative fishes were present in the water column and shoreline areas adjacent to the intake screen during the entrainment sampling. During each 1-hour sampling period, a boat equipped with bow-mounted plankton net was used to sample two distinct habitats near the intake screen: open water and shoreline. The plankton net was identical to those used to sample the manifold discharge except that the cod-end collection bottle was perforated with 335 micron netting to allow water to pass through the collection bottle as it was being towed. The volume of water sampled during each tow was recorded using a Sea Gear model MF-315 flow meter that was mounted in the mouth of the net. The boat towing the plankton-net assembly was operated slowly at a speed of approximately 0.3 m/sec.

Open water tows were performed by maneuvering the boat and net in the canal immediately outside of the intake screen (Figure 7). A transect line of approximately 30 meters (100 feet) was established so that the same approximate distance was traveled during each sample. Two series of net tows were conducted at two different depths: the first at the surface and the second at a depth of 1.8 meters (6 feet) to ensure that the portion of the water column immediately adjacent to the intake screen was sampled. Each depth was sampled by completing three revolutions of each transect. Replicates collected at each depth were combined for data analysis and reporting.

Shoreline tows were conducted at one of two shoreline transects located immediately upstream and downstream of the intake screen. Each shoreline transect was approximately 90 meters (300 feet) in length. Two shoreline transects were established because of concern that passing through the shallow water with the boat would increase water turbidity and would be difficult to sample on a frequent basis. To minimize this potential problem, the order in which transects were sampled was alternated. Each transect was sampled by completing one complete pass with the plankton net.

3.2.3 Light Trapping

In addition to the ichthyoplankton tows, larval fish abundance was also monitored during each sampling event using a light trap (Figure 8). The light trap had a quatrefoil design and was illuminated using 12-hour chemical light stick. The trap was suspended from the pump platform immediately above the intake screen just before dark and then retrieved the following morning. Larval fish captured in the trap were rinsed into a 0.5 liter collection jar, and preserved using a 6% formalin solution. The light trap was set for three consecutive nights during each sampling event.

3.3 Laboratory Analysis

Following each monthly sampling period, all samples were shipped via overnight courier to the Normandeau biological laboratory for analysis. When the samples arrived, laboratory personnel used specific inventory sheets to develop a sample log in order to ensure quality assurance/quality control. The sample log contained information regarding the project number, collection date, station/replicate, sample control number, and a column for the date and time and initials of the individual who performed each procedural step that each sample underwent.
Figure 7. A bow mounted ichthyoplankton net being tow adjacent to the pump platform and wedge-wire screen.

Figure 8. Light trap used to collect larval fish near the pump platform.
Prior to evaluation, each sample was rinsed through a 335-micron sieve to remove the formalin solution. The sample was then placed under a ventilation hood and enough water was added to yield a fluid mixture. The samples were sorted, and all eggs and larvae were removed and preserved in separate vials of 6% buffered formalin solution for later identification.

All eggs and larvae were identified to the lowest practical taxonomic level using dissecting microscopes. Identification was based on Auer (1982). Eggs and larvae were separated into taxonomic groups and enumerated. When possible, larval fish were identified to species (larval fish past the family level is often difficult as many species’ early life stages are nearly identical). A subsample of up to 20 larvae from each group was measured for length to the nearest 0.1 mm. Upon completion of identification and measurement, eggs and larvae were returned to the 6% formalin solution and placed in long-term storage.

3.4 Data Analysis

The percent composition of each taxonomic group of eggs and larvae collected during each monthly sampling event was compared between entrainment samples and ichthyoplankton tows using a Chi-Square test of homogeneity (Conover 1999). This was used to determine whether the taxonomic composition of eggs and larvae present outside of the screen was similar to the entrainment samples.

To determine whether the size distribution of eggs and larvae collected in the entrainment samples were similar to those collected outside of the screen, differences in size distributions were evaluated between collection locations. Length frequency histograms were constructed (1 mm intervals) from entrainment and ichthyoplankton tow data, and compared using Kolmogorov-Smirnov test (Kiefer 1959). Length data were combined across all sampling months.

To determine whether relative abundance of eggs and larvae entrained through the screen system was influenced by photoperiod, catch-per-unit-effort (CPUE) was used as an index of abundance for eggs and larvae entrained through the manifold during each light intensity period and by monthly sampling event. CPUE was calculated for each species as the number of eggs and larvae collected per 10,000 gallons of water sampled. Multivariate analysis of variance (MANOVA) was used to determine temporal effects in CPUE data by species. If overall significance was determined, individual species analysis of variance (ANOVA) tests were conducted. If significant differences were found, a least significant difference test (Fisher’s LSD, P < 0.05) was used to determine pairwise differences among sampling events.

4.0 RESULTS

4.1 Overview

A total of four monthly sampling events occurred in spring and early summer 2009, resulting in a total of 72 entrainment samples and 216 ichthyoplankton tows (Table 1). Average water temperature varied among sampling events ranging from 21.6° C in April to 30.1° C in July (Table 2). Water clarity increased throughout the sampling period with average secchi depths ranging from approximately 1.3 meters in April to 2.1 meters in July. Dissolved oxygen levels varied slightly during sampling events with monthly average readings ranging from 62% in July to 71% in May.

In all, 9,841 eggs and larvae of nonnative fish were collected in all of the samples taken (Table 3). Eggs and larvae were found in 97% of all the entrainment samples and 72% of all the ichthyoplankton tows taken. Larvae accounted for the vast majority of the life-stages collected accounting for over 99.5% of the catch;
only 38 eggs were collected throughout the entire study period. No native or endangered fish species were captured during the entrainment sampling.

A total of 13 light trap samples were taken. Three samples were taken each month except May, when four light trap samples were collected. Of the light trap samples collected, 11 (85%) contained larvae of nonnative fishes; a total of 136 nonnative fish larvae were collected in the light trap samples.

Recapture rates of artificial particles during the regular entrainment samples remained consistent across all sampling months and was 29% in April, 29% in May, 29% in June, and 32% in July. Average recapture rates of artificial particles during the 4K samples were also consistent, but were considerably higher than those collected during the entrainment samples. Recapture rates of artificial particles with 100% of the flow passing through the manifold were 98% in April, 99% in May, 97% in June, and 93% in July.

Table 2. Average water temperature, secchi depth and dissolved oxygen percentage recorded during each monthly sampling event, 2009

<table>
<thead>
<tr>
<th></th>
<th>Water Temperature (C)</th>
<th>Secchi Depth (m)</th>
<th>Dissolved Oxygen %</th>
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<tbody>
<tr>
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<td></td>
<td></td>
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<tr>
<td>Min</td>
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<td>0.9</td>
<td>57.6</td>
</tr>
<tr>
<td>Max</td>
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<tr>
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<tr>
<td><strong>May</strong></td>
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<tr>
<td>Min</td>
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<tr>
<td>Mean</td>
<td>30.1</td>
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</tbody>
</table>
### Table 3: Taxonomic composition of eggs and larvae collected from entrainment (ENT), open water (OW), and light trap (LT) samples.

<table>
<thead>
<tr>
<th>Month</th>
<th>ENT</th>
<th>OW</th>
<th>LT</th>
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<tbody>
<tr>
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<td></td>
<td></td>
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Data are presented as monthly number and percentage of eggs and larvae collected by sampling method.
Three taxonomic families accounted for nearly 90% of all eggs and larvae collected and were therefore the focus of the analysis (Table 3). These families included Centrarchidae, Cyprinidae, and Clupeidae. The majority of the remaining eggs and larvae (11%) could not be identified and were classified as unknown.

Percent composition of the three taxonomic families varied significantly among monthly sampling events (P < 0.001) and between collection methods (P < 0.001). In April, Cyprinids and Clupeids accounted for the majority of the larvae sampled in both entrainment and ichthyoplankton tows, whereas in May, June and July, Centrarchids generally dominated the catch (Figure 9). Larvae that could not be identified accounted for a higher percentage of the taxonomic composition in entrainment samples compared to samples collected outside the screen.

While it was not possible to identify all larvae to species, in some instances it was possible to identify fish to the genus level. Many of the Centrarchids captured were identified as *Lepomis spp.*, which were found in both ichthyoplankton tows and the entrainment samples. Other Centrarchids were identified to species such as largemouth *Micropterus salmoides* and smallmouth bass *M. dolomieu*, but these species were only found in ichthyoplankton and light trap samples; none of these species were identified in the entrainment sampling (Table 3). Clupeids that were identified consisted predominately of threadfin shad *Dorosoma petenense* and gizzard shad *D. cepedianum*, and Cyprinids that were identified to species consisted exclusively of common carp *Cyprinus carpio*.
A limited number of individuals from a variety of taxonomic families were also collected in the entrainment and ichthyoplankton tows, and combined into the category “Other” (Table 3). These included representatives of family Poeciliidea and Ictaluridea. None of these species were captured consistently or in great numbers.

Over 80% of the larvae collected using the light trap (n=113) were collected in April (Table 3). The taxonomic composition of larvae collected in the light trap was inconsistent with the entrainment samples and the ichthyoplankton tows. Centrarchids were the predominant family captured in the light trap making up 88% of the total catch (n=136). The primary species captured in the light trap was largemouth bass which composed 94% of Centrarchid larvae sampled while *Lepomis spp.* accounted for the remaining 6%. Comparatively few Cyprinids (n=9) and Clupeids (n=2) were collected in the light trap.

### 4.3 Size Distribution

The size distribution of larvae differed significantly (P < 0.05) between those collected in entrainment samples and those collected in the ichthyoplankton tows for all three primary taxonomic groups; larvae collected in the entrainment samples were on average smaller than those collected in the ichthyoplankton tows.

The size distribution of Centrarchid larvae that were entrained through the screen system ranged from 3.2 mm to 7.5 mm with an average length of 4.6 mm (Figure 10). In contrast, Centrarchid larvae collected outside of the screen using ichthyoplankton tows ranged from 3.3 mm to over 20 mm and averaged 5.5 mm in length.

Clupeids captured in the entrainment samples ranged in length from 2.4 mm to 10.0 mm and averaged 4.5 mm (Figure 11). In contrast, Clupeids captured outside of the screens using ichthyoplankton tows ranged in length from 2.8 mm to over 21 mm and averaged 5.3 mm in length.

Length of Cyprinids captured in the entrainment samples ranged from 3.8 to 9.3 mm and averaged 5.5 mm while those captured outside of the screens ranged from 3.2 mm to over 21 mm and averaged 6.6 mm (Figure 12).

Larvae that were collected in the light trap were typically larger than larvae collected in the entrainment samples and from the ichthyoplankton tows. Centrarchids collected in the light trap ranged in length from 11.3 mm to 61.0 mm and averaged 19.6 mm. Only 2 Clupeids were captured in the light trap samples but these fish were the largest Clupeids sampled measuring 28.0 mm and 42.0 mm. Cyprinids captured in the light trap ranged from 5.6 mm to 11.3 mm and averaged 7.5 mm.

### 4.4 Influence of Photoperiod on Entrainment

CPUE was calculated for Centrarchids, Clupeids, and Cyprinids as they were the only family groups collected in sufficient numbers to support analysis. Results of the MANOVA using CPUE as the response variable revealed a significant difference (α = 0.05) among sampling months (Wilk’s Criterion = 0.417, P < 0.001; Figure 13), but not among periods of different light intensity (Wilk’s Criterion = 0.839, P = 0.245; Figure 14). Furthermore, the two-way interaction between months and sampling periods was not significant (Wilk’s Criterion = 0.694, P = 0.574), indicating that light intensity did not influence CPUE of the entrainment samples regardless of sampling event.
Figure 10. Length frequency distribution of Centrarchidae larvae collected during entrainment sampling and ichthyoplankton tows.
Figure 11. Length frequency distribution of Clupeidae larvae collected during entrainment sampling and ichthyoplankton tows.
Figure 12. Length frequency distribution of Cyprinidae larvae collected during entrainment sampling and ichthyoplankton tows.
Figure 13. Comparison of catch per unit effort of the three primary taxonomic groups by month for entrainment samples. The y-axis represents the number of larvae per 10,000 gallons of water. (Note the different scales for the y-axis among individual graphs).
Figure 14. Comparison of catch per unit effort of the three primary taxonomic groups by sampling period for entrainment samples. The y-axis represents the number of larvae per 10,000 gallons of water. (Note the different scales for the y-axis among individual graphs).
5.0 DISCUSSION

The results of this study found that eggs and larvae of nonnative fish were entrained through the wedge-wire screen system at the Imperial Ponds on INWR. Early life-stages of nonnative fishes (eggs and larvae) were collected in nearly every entrainment sample taken throughout the four-month evaluation period. Larvae accounted for over 99.5% of the early life-stages collected. We suspect that such a small percentage of eggs were collected because there were fewer present in the water column; typically, eggs are deposited in nests or attached to substrate, aquatic plants, or other structure at spawning (Larimore 1957; Swee and McCrnimmon 1966; Wallus et al. 1990).

The larval fish assemblage collected in ichthyoplankton and entrainment samples throughout the study period was dominated by three taxonomic families: Centrarchids; Clupeids; and Cyprinids. The dominance of these groups was consistent with data collected at Headgate Rock Dam between 1987 and 1989 which found that nearly all of the larval fish collected were members of these three taxonomic families (Burke 1990). Similarly, Kretschmann and Leslie (2006) found that over 90% of the larval fish captured in the spring using light traps at Senator Wash Reservoir (located 12 Rkm downstream of the INWR) were from the same three taxonomic families.

While the three prominent taxonomic groups were present in entrainment samples across all months, their contribution to the overall monthly catch varied significantly. These differences in relative abundance were likely attributed to differences in life history and spawning behavior among species. Cyprinids accounted for over 50% of larvae collected in April. This taxonomic group consisted largely of common carp, which have been shown to spawn at temperatures ranging from 15 to 27° C with peak spawning occurring from 18 to 23° C (Swee and McCRimmon 1966; Walberg and Nelson 1966; Heufelder and Fuiman 1982). Larval carp were most abundant in the samples taken in April when water temperatures averaged 21.6° C and presumably just after optimal spawning conditions (Heufelder and Fuiman 1982).

Similar to Cyprinids, Clupeids were present early in the year and were most prevalent in entrainment samples collected in April and May. Clupeids consisted predominately of threadfin and gizzard shad larvae. These species spawn at temperatures ranging from 14 to 27° C with incubation ranging from 106 hrs at 15° C to 36 hours at 27° C (Tin 1982; Wallus et al. 1990). Eggs of both species are adhesive and demersal and newly hatched gizzard shad larvae range in length from 3.0 to 3.5 mm. Water temperatures observed during April, May, and June were within the reported range when shad are known to spawn. The relative abundance of these larvae during the early sampling and scarcity during the July sampling event is likely related to the water temperature and the timing of spawning.

Centrarchids accounted for the highest proportion of larvae collected during this study especially in June and July when they accounted for over 85% of the larvae collected in both the entrainment samples and from the ichthyoplankton tows. All of the Centrarchids captured in the entrainment samples were identified as Lepomis spp. Members of Lepomis spp. often spawn at temperatures ranging from 15° to 32° C (Tin 1982; Mischke and Morris 1997; Ross 2001). Temperatures within this wide range occurred at Martinez Lake throughout the extent of the sampling period. The presence of Lepomis larvae in samples throughout the study period may be an indication that spawning is occurring throughout the spring and early summer, and possibly by multiple species of Lepomis. Tin (1982) provided information regarding the dimensions of eggs and larvae of several species of Lepomis; stating that eggs range in diameter from 0.8 to 1.4 mm and larvae range in length from 2.2 to 3.7 mm immediately after hatching. This
information combined with the results of our entrainment samples and recent observations of warmouth *Lepomis glouosus* in the Imperial Ponds (N. Lenon, USBR Pers. Comm.) suggests that some Centrarchids are likely surviving passage through the screen system.

The condition of larval fish collected from the entrainment samples was not assessed due to sampling limitations. While previous evaluations have found that newly emerged larvae are susceptible to entrainment through wedge-wire screens, this process has been shown to cause severe trauma to their underdeveloped skeleton, musculature and integument, which often results in death (Marcy et al. 1978; Normandeau 2006). It is possible that many of the larvae that were entrained through the screen sustained some type of physical trauma which resulted in mortality. However, because of the large quantity of larvae observed in the entrainment samples it is likely that a portion of them are safely passing into the Imperial Ponds.

We found a significant difference in the size distribution between larvae entrained through the screen system and those collected in the ichthyoplankton tows for each primary taxonomic group. In general, the larvae captured in the entrainment samples were smaller than larvae of the same species captured in the ichthyoplankton tows outside of the screens. This suggests that the screen system was excluding larger individuals of the same species. These results are consistent with those reported by Weisberg et al. (1987) who consistently collected smaller larvae of bay anchovy *Anchoa mitchilli* and naked gobie *Gobiosoma bosci* through a 1 mm wedge-wire screen than compared to an open pipe.

In addition, it is likely that size-selective entrainment explains some of the observed differences in the taxonomic composition. For instance, Clupeids accounted for over 50% of the larvae collected in the ichthyoplankton tows in May, but accounted for less than 15% of the larvae collected in the entrainment samples during that same period. In June, a similar pattern was observed with Clupeids that accounted for over 12% of the catch in ichthyoplankton tows but less than 1% of the entrainment samples; indicating that in June Clupeids had reached a size that precluded entrainment. Similarly, Cyprinids accounted for nearly 5% of the larvae collected in ichthyoplankton tows in May but less than 1% of the corresponding entrainment samples.

While size-selective entrainment may explain differences in taxonomic compositions, differences in spawning behavior and early life history likely explains the differences observed in species composition throughout the 4-month period. Centrarchids dominated the catch in both the entrainment and ichthyoplankton tows during June and July. However only *Lepomis spp.* were identified in the entrainment samples; while other Centrarchid species such as largemouth bass, were only collected in the ichthyoplankton tows and in light trap samples outside the screen. Although this could indicate size selection, Tin (1982) reported largemouth bass larvae as small as 2.3 mm upon hatching; a size commonly observed in our entrainment samples. Largemouth bass typically begin spawning at a water temperature near 15° C (Thomas et al. 2007). While the lack of Centrarchid species other than *Lepomis spp.* in the entrainment samples in April may be related to the timing of their spawning and size during the sampling events, it may also be related to behavioral characteristics which may make them less vulnerable to entrainment. For instance, largemouth bass are nest spawners and the early emergent larvae typically remain near the nest for up to several days following hatching. Although no largemouth bass were collected in the entrainment samples, due to the reported size of the newly hatched larvae the possibility that they may be entrained should not be ruled out.
The larvae we captured in the entrainment samples were smaller on average than those captured outside the screens. Weisberg et al. (1987) reported that larvae smaller than 10 mm were still susceptible to being entrained through a wedge-wire screen with a slot width of 1.0 mm and recommended that slot width should be less than 10% of a fish’s length to prevent entrainment. However, this recommendation did not apply to our data. The largest larvae collected during entrainment sampling measured 10 mm, and with a screen slot width of 0.5 mm, this suggests that larvae were passing through a gap that was approximately 5% of their total length. While the reason for this inconsistency is unknown, it does imply that the wedge-wire screen system deployed at the INWR is only effective at completely excluding larvae greater than 10 mm in length.

We failed to find a significant relationship between light intensity and larval entrainment through the screen system. Several authors have discussed positive phototactic behavior in larval fishes, which can often result in diel changes in the vertical distribution of larval fish within the water column (Bulkowski and Meade 1983; Kawamura and Washiyama 1989; Zigler and Dewey 1995). More specifically, during periods of high light intensity (i.e., daylight), larvae abundance is typically highest at the water surface and during periods of low light intensity (i.e., nighttime), larvae are more evenly distributed throughout the water column. Since the screened pump intake is located at approximately 3 m below the water surface, it is conceivable that this behavior could limit larval fish entrainment if the pump were only operated during daylight hours. While our results do not support this potential management practice, our evaluation was conducted over a relatively narrow time frame and there may be other times of the year that this type of practice is beneficial.

Our results are consistent with other studies that have shown while wedge-wire screens are effective at reducing larval fish entrainment, they are not an exclusive barrier (Weisberg et al. 1987; Bestgen et al. 2004; Normandeau 2006). Because of this, exclusive use of wedge-wire screens is not recommended if the management goal is full exclusion of all nonnative species. To meet a goal of 100% exclusion, a secondary screening technology needs to be developed and implemented to completely eliminate entrainment of nonnative fish.

6.0 LITERATURE CITED


