Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

FINAL REPORT

Evaluation of a Secondary Filtration Technology for Nonnative Fish Exclusion at the Imperial Ponds, Imperial National Wildlife Refuge, Arizona

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

August 2011

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EXECUTIVE SUMMARY

This study evaluated the effectiveness of a gravity sand filter as a secondary filtration technology to a cylindrical wedge-wire screen for use in creating isolated habitat for native desert fishes. As part of their ongoing effort to meet obligations under the terms of the Endangered Species Act (ESA), the Bureau of Reclamation (Reclamation) is the implementing agency of the Lower Colorado River Multi-Species Conservation Program (LCR MSCP). This program is a partnership of Federal and non-Federal stakeholders, created to respond to the need to balance the use of LCR water resources and the conservation of native species and their habitats. The goals of the LCR MSCP are to conserve existing populations and work toward recovery of endangered species, and protect and maintain habitat on the LCR. As part of their effort, the LCR MSCP has been actively restoring or creating protected backwaters along the LCR in support of native fish habitat.

As a part of their ongoing effort, LCR MSCP reconstructed a series of six isolated (disconnected) ponds on the Imperial National Wildlife Refuge to provide habitat for native fishes. Water for these Imperial Ponds is supplied from Martinez Lake by a pump which is equipped with a narrow gap width (0.5 mm) cylindrical wedge-wire screen. In 2009, an evaluation designed to determine the exclusion effectiveness of the screen found that nonnative fish larvae were present in the pump discharge flow over the entire four month sampling period (April - July). The results of this previous study provided the impetus for LCR MSCP to investigate secondary filtration technologies to complement the existing wedge-wire screen system and achieve a goal of 100 percent exclusion. Through an extensive literature review, a gravity sand filter was selected for further testing.

This evaluation was conducted in late April, 2011 when eggs and larvae of nonnative fishes are known to be susceptible to entrainment. To sample water being delivered from Martinez Lake to the Imperial Ponds, the main water supply line was modified to accommodate a large 12-port steel manifold (4,000 gpm capacity), which was constructed over an existing irrigation canal. A high volume (1,000 gpm capacity) portable sand filter containing number-20 silica sand (0.43 mm to 0.50 mm in diameter) was fitted to the manifold so that water delivery from the pump would either pass freely through opened manifold or through the sand filter. All water passed through either conveyance was sampled using 335-micron conical plankton nets. In addition to the entrainment samples, water discharged during the sand filter backwash cycle was collected to determine if eggs and larvae had entered the sand filter. Ichthyoplankton tows and light trap deployments were also used to confirm the presence of nonnative fish near the pump platform outside the screens.

The results of this evaluation indicate that a gravity sand filter was successful in excluding early life-stages of nonnative fish under the conditions tested. Eggs and larvae were collected in nearly every sample collected outside the intake screen (i.e., ichthyoplankton tows), through the primary test manifold (i.e., open entrainment), and from the sand filter backwash; however, no ichthyoplankton were found in the samples collected from the flow discharged from the sand filter. Larvae accounted for the majority of life-stages collected accounting for over 99.5 percent of the catch. The species composition of the larval catch was diverse, but was dominated by three taxonomic families: Centrarchidae, Clupeidae, and Cyprinidae. Length frequency data from larvae collected in the entrainment samples indicated that the sand filter excluded larvae as small as 3.5 mm in length. While this study was not intended to be a comprehensive evaluation of the sand filter technology, the lack of eggs and larvae in the sand filter discharge provides confirmation that a gravity sand filter is a potentially viable technology that can be used as a tool for maintaining isolated habitat for native desert fishes, and further investigation of this technology is warranted.

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1.0 INTRODUCTION

Razorback sucker *(Xyrauchen texanus)* and bonytail (*Gila elegans)* are native fishes of the Lower Colorado River (LCR) and are currently listed as endangered under the terms of the Endangered Species Act (ESA). Their initial declines were attributed to anthropogenic modifications made to the structure and function of the Colorado River through the construction of numerous dams. However, further research indicated that competition and predation by introduced nonnative fishes is also a primary factor contributing to their continued decline (Meffe 1985; Minckley 1991; Clarkston et al. 2005). Because the hydrologic conditions of the Colorado River will likely never resemble the historical conditions these native species thrived under, and extirpating nonnative fishes from the systems is both physically and politically impossible, the U.S. Fish and Wildlife Service, the administrator of the ESA, has advocated the creation of isolated, predator-free backwaters for these endangered species (Minckley et al. 2003).

As the implementing agency for the Lower Colorado River Multi-Species Conservation Program (LCR MSCP; an ESA mitigation program), the Bureau of Reclamation (Reclamation) is responsible for creating or restoring a minimum of 146 hectares (360 acres) of actively managed connected and disconnected backwater habitats dedicated to native fish along the LCR. Backwaters that are isolated or disconnected from the mainstem of the river are considered to be of higher value to bonytail chub and razorback sucker than connected backwaters, and are the preferred type of backwater to create. However, not all backwaters are expected to be managed as disconnected and maintained free of non-native fishes (LCR MSCP 2004). In many of the disconnected backwaters along the LCR a high volume of surface water is required to maintain water quality during the summer months.

As a part of their ongoing efforts, the LCR MSCP reconstructed a series of six ponds on the Imperial National Wildlife Refuge (INWR) that now provide approximately 32 hectares (80 acres) of isolated habitat for native fishes (Figure 1). The Imperial Ponds are located between the Colorado River and the inlet channel to Martinez Lake, in a portion of the refuge known as the Intensive Management Area (IMA). Because they are isolated from the main river channel, each pond is supplied with water through a variable speed irrigation pump and a series of conveyance pipes. The pump intake is equipped with a cylindrical T-shaped wedge-wire screen and is located on the inlet channel to Martinez Lake, which supports a high diversity of nonnative fish species.

In 2009, a study was conducted to assess the effectiveness of the cylindrical wedge-wire screen at excluding eggs and larvae of nonnative fishes (McDonald and Karchesky 2010). The results of this previous study found that despite the narrow slot width of the screen (0.5 mm or 500 microns), eggs and larvae of nonnative fishes were found in over 97 percent of the entrainment samples collected from water that had passed through the screen. Given these results, it was recommended that a secondary exclusion technology should be researched to determine if the goal of 100 percent exclusion of nonnative fishes from the Imperial Ponds was feasible and if any technology could prove effective for future applications.

As part of this effort, a literature review was conducted to identify possible fish exclusion technologies that could be incorporated into the existing water management system and serve as a secondary filtration system to achieve complete exclusion of nonnative fishes (Karchesky 2010). The specific criteria established for this secondary filtration system was: 1) the technology must be capable of providing water filtration at a slot size no greater than 100 microns; 2) the technology must be capable of filtering flows of at least 6,000 gallons per minute (gpm) if installed along the main water supply line, or 1,000 gpm if it will be applied to each of the six Imperial Ponds separately; 3) the technology must be robust to harsh environmental conditions and easily maintained; and 4) the technology must be commercially available. Several technologies were identified that met these specific criteria. However, a gravity sand filter was selected for continued evaluation and onsite testing in 2011. This report provides a detailed description of the methods used to evaluate this selected technology, and whether it was effective at removing all life-stages of nonnative fishes from water supplied from Martinez Lake.

2.0 OVERVIEW OF GRAVITY SAND FILTER

The principle of sand media filtration is relatively straightforward. Source water is pressurized and introduced into the top of a tank containing media (e.g., silica sand and gravel) (Figure 2). A diffusion plate at the top of the tank serves to reduce water velocity and distribute the water evenly across the top of the media bed. The depth of the media bed can vary depending on the capacity of the filter, but typically ranges in depth from 600 to 900 mm (24 to 36 inches) for most large capacity units. Contaminants in the water are captured in the media bed and filtered water passes into the discharge manifold at the bottom of the tank.

Captured contaminants are removed from the media bed by a process called “backwashing.” This operation is accomplished by reversing water flow through the filter so that it is directed from the bottom of the tank, up through the sand, flushing the previously trapped debris out through the waste line (Figure 2). The duration between backwashes is dependent on the capacity of the tank and water quality. A backwash water flow rate capable of expanding the media bed 20 to 50 percent is usually adequate to obtain complete cleaning of the substrate (Lorenz 1979).

The size of filter media required is dependent upon the desired filtration capability. In general, the largest interstitial opening in a filter media can be estimated as 15 percent of the average media diameter (Lorenz 1979). For instance, a sand media with an average grain size of 1.0 mm will have a maximum interstitial opening of about 0.15 mm (150 microns). In practice however, a filter should be able to remove through filtration any particle whose diameter is greater than approximately 5 percent of the media size (Lorenz 1979). Conventional sizes of sand filter media for treating water for domestic and agricultural purposes range from 0.35 to 1.3 mm.

3.0 METHODS

3.1 Field Testing

To evaluate the effectiveness of the gravity sand filter at excluding eggs and larvae of nonnative fishes, our sampling methodologies were similar to those used in 2009 (McDonald and Karchesky 2010). Field sampling in 2011 was scheduled over a two-day period in the spring when early life-stages of many nonnative fishes were previously recorded in the Martinez Lake inlet canal (BioWest 2008; McDonald and Karchesky 2010).

3.1.1 Entrainment Sampling

A large steel manifold, previously constructed by Reclamation for entrainment testing in 2009 (McDonald and Karchesky 2010), was used to sample water delivered from the screened irrigation pump. This test manifold was approximately 7.6 meters (25 feet) in length and contained a total of 12 sampling ports evenly spaced along the bottom of the manifold pipe and positioned directly over an irrigation canal (Figure 3). Each port measured 100 mm (4 inches) in diameter and approximately 0.5 meters (20 inches) in length, and had an estimated flow capacity of approximately 333 gpm (total manifold capacity is approximately 4,000 gpm).

The existing manifold was retrofitted to allow installation of a portable gravity sand filter with a flow capacity of approximately 1,000 gpm (Figure 4). The trailer mounted sand filter was positioned near the manifold, and included four separate 250 gpm media tanks containing number-20 silica sand (0.43 mm to 0.50 mm in size). The depth of the silica sand in each tank was approximately 600 mm (24 inches) and was supported on a 150-mm (6-inch) layer of graded 25-mm (1-inch) gravel. To deliver water to the portable sand filter, 4 of the 12 sampling ports along the bottom of the primary test manifold were connected to a series of 100-mm (4-inch) cam-lock fittings and flex hoses; the remaining eight ports remained unmodified and water was allowed to pass freely into the irrigation canal (Figure 4). Discharge from each flex hose was connected to the 200-mm (8-inch) diameter intake of the sand filter. After passing through the portable sand filter, water was discharged into a second, smaller test manifold. This secondary test manifold was independent from the larger primary manifold, contained five ports for sampling the sand filter discharge, and was also positioned over the irrigation canal.

All water that passed through either the primary test manifold, or through the portable sand filter and the smaller secondary test manifold, was sampled using 335-micron conical plankton nets equipped with reinforced cod-ends and plastic collection bottles. Nets were positioned beneath each port of either the primary or secondary test manifolds to ensure that all water was sampled. In addition to sampling all of the discharge pipes, a net was also positioned to sample debris from the sand filter during the backwash process. Nets were not interchanged between sampling locations to ensure that no cross contamination occurred.

All samples were collected while the screened irrigation pump operated at a volume of approximately 6,300 gpm or 70% maximum capacity (i.e., normal operating conditions). In order to not exceed the maximum flow capacity of the primary test manifold, only 4,000 gpm was diverted to the manifold while the remainder of the flow (approximately 2,300 gpm) was diverted to the Imperial Ponds. This configuration ensured that the entrainment samples were collected using similar through-slot screen velocities as those encountered during normal pump operations. Flow entering the primary test manifold was calculated during each sample using an impeller-type in-line flow meter installed in the pipe that delivered water to the manifold. Using a similar flow meter installed on the discharge pipe of the sand filter, the instantaneous and totalized flows passing through each unit was derived for each sample.

A total of eight separate sampling trials were scheduled over the two-day sampling period. During each trial, samples were collected from the open ports of the primary test manifold and from the discharge of the sand filter passing through the secondary test manifold. Samples from each location were processed separately for each trial. On alternating trials, the backwash system was operated and the discharge collected. All trials were conducted during daylight hours. For each trial, the pump was operated for one hour before being shut down and the contents of the nets processed. At the completion of each trial, the nets were removed from each manifold and rinsed using a hand operated garden sprayer so that all the materials in the nets were washed into the collection bottles. The nets were rinsed from the outside and the sprayers filled with potable water to insure that no biological materials were introduced into the samples during net cleaning. After all the material was rinsed into the collection bottles, the bottles were removed from the plankton net and the contents were decanted into a standard stainless steel sieve with a mesh size of 300-microns. Samples were preserved using a 6.0 percent formalin solution.

Water temperature, Secchi depth, pH, and dissolved oxygen (DO) were collected during entrainment sampling. Water temperature and DO were measured using an YSI Incorporated Model 85 reader, and taken three times daily: at the beginning, mid-point, and end of each sampling day. Water pH was recorded using an Aqua-Chem test kit (Recreational Water Products, Lawrenceville, Georgia) at the beginning and end of each sampling period. Secchi depth was taken using a standard Secchi disc at noon during each sampling day. All water quality parameters were taken on the pump platform or from the discharge from the primary sampling manifold.

3.1.2 Ichthyoplankton Tows

Using a boat equipped with bow-mounted plankton net, a series of ichthyoplankton tows were conducted to confirm the presence of the eggs and larvae in the water column adjacent to the intake screen during the study period. The plankton net was identical to those used to sample the manifold discharge except for a flow-through collection cup affixed to the cod-end portion of the net. The boat towing the plankton-net assembly was operated slowly at a speed of approximately 0.3 m/sec to minimize wake disturbance.

A total of four separate ichthyoplankton tows were scheduled over the two-day sampling period. Samples were collected by maneuvering the boat and net in the canal immediately outside of the intake screen in a manner similar to the 2009 evaluation (McDonald and Karchesky 2010). A transect line of approximately 30 meters (100 feet) was established so that the same approximate distance was traveled during each sample. Two different depths were sampled: the first at the surface and the second at a depth of 1.8 meters (6 feet). Each depth was sampled by completing three revolutions of each transect. Samples collected at each depth were combined for data analysis and reporting.

3.1.3 Light Trap

In addition to the ichthyoplankton tows, larval fish abundance was also monitored using a single light trap. The light trap had a quatrefoil design and was illuminated using a 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. The light trap was deployed on two separate nights during the sampling period.

3.2 Laboratory Analysis

Upon completion of field sampling, all samples were shipped to the Normandeau biological laboratory for analysis. Procedures used for processing these samples were similar to those employed during the 2009 evaluation (McDonald and Karchesky 2010). Before processing, each sample was rinsed through a 335-micron sieve to remove the formalin solution. Water was then added back to the sample to yield a fluid mixture for sorting. All eggs and larvae were removed and preserved in separate vials of 6 percent 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 percent formalin solution and placed in long-term storage.

3.3 Data Analysis

The success of the secondary filtration system was based on a binary selection criterion, in which the presence or absence of eggs and/or larvae in the discharge of the sand filter determined whether it was a viable technology for use at the Imperial Ponds.

4.0 RESULTS

4.1 Overview

Field sampling occurred on 19 and 20 April, 2011. During this two-day sampling period, a total of 26 samples were collected from five different locations (Table 1). Average water temperature varied slightly between sampling days ranging from 20.5^{o} C to 21.7^{o} C (Table 2). Measurements of DO and pH also varied slightly with readings ranging from 65.9 percent to 78.6 percent saturation, and 7.6 to 7.8, respectively. Water clarity remained consistent during both days with a Secchi depth of 1.8 meters.

4.2 Taxonomic Composition

No ichthyoplankton were found in the sand filter discharge, although eggs and larvae were identified in samples collected from all other locations. In all, 430 larvae and eggs of nonnative fish were collected, and belonged exclusively to three primary taxonomic families: Centrarchidae, Cyprinidae, and Clupeidae (Table 3). Larvae accounted for the vast majority of the life-stages collected accounting for over 99.7 percent of the catch; only one egg was collected. No native or endangered fish species were captured during the entrainment sampling.

Percent composition of the three taxonomic families was similar between the open entrainment and sand filter backwash samples. Centrarchids accounted for approximately 80 percent of the fish sampled through each of these water conveyances, with the remainder of the samples consisting mainly of clupeids (Figure 5). Clupeids and cyprinids accounted for the majority of the fish collected in larval tows and represented 50 and 42 percent of the samples, respectively; Centrarchids accounted for less than 10 percent of the fauna sampled from the ichthyoplankton tows.

While it was not possible to identify all larvae to species, in some instances it was possible to identify fish to the genus level. Centrarchids found in the both entrainment samples and ichthyoplankton tows were entirely *Lepomis spp.* Clupeids were identified as either threadfin shad (*Dorosoma petenense)* or gizzard shad *(D. cepedianum*), and cyprinids were exclusively identified as common carp *(Cyprinus carpio*).

A total of 15 nonnative fish larvae were collected in the light trap samples (Table 3). All except one of these fish were identified as centrarchids, specifically largemouth bass (*Micropterus salmoides).* One cyprinid (a common carp) was also collected in the light trap.

4.3 Size Distribution

The size distribution of larvae collected from the entrainment samples were consistent with those collected from the ichthyoplankton tows taken adjacent to the intake screen ranging from about 4.0 to 6.5 mm for all species (Figure 6). Largemouth bass larvae collected in the light trap (n = 13) were larger, ranging from approximately 15 to 20 mm.

5.0 DISCUSSION

The results of this evaluation indicate that a gravity sand filter is a potentially viable technology for meeting the LCR MSCP's goal of 100 percent exclusion of nonnative fishes from water delivered to the Imperial Ponds from Martinez Lake. While eggs and larvae were collected in nearly every sample collected outside the intake screen (i.e., ichthyoplankton tows), through the primary test manifold (i.e., open entrainment), and from the sand filter backwash, none were found in the samples collected from the flow discharged from the sand filter. The lack of eggs and larvae in the sand filter discharge provides confirmation that further investigation of a sand filter as a secondary filtration system is warranted.

This study was designed to provide initial information regarding the feasibility of the sand filter technology, and whether it could be use as a secondary filtration system to meet the LCR MSCP's exclusion goals. Based on the results of the previous evaluation that tested the exclusion effectiveness of the cylindrical wedge-wire screen (McDonald and Karchesky 2010), eggs and larvae were found in the water delivered to the Imperial Ponds throughout the late-spring and early-summer (April – July), with the greatest species diversity occurring in April. By scheduling this initial evaluation in April, our intent was to operate the sand filter under conditions where species richness was known to be high. The outcome of this preliminary evaluation could then be used to guide future management decisions on whether more exhaustive testing of this or other similar technologies was warranted, or whether an exclusion system for eggs and larvae was even feasible.

The sampling design of this study was similar to that implemented in 2009, although some modifications were made based on information gained from the previous evaluation. For instance, during this study entrainment samples were collected only during daylight hours rather than over a series of distinct time periods that corresponded with ambient light intensity. This simplified sampling strategy was utilized because during the 2009 evaluation, no significant difference was found between the relative abundance of eggs and larvae entrained and ambient light conditions (e.g., day versus night) (McDonald and Karchesky 2010). Another slight difference was that the ichthyoplankton tows were only performed in the water column adjacent to the intake screen and did not include littoral, or shoreline, transects. This reduction in effort was based on the observation that no significant difference in species composition was detected between these sampling locations, and hence the open water tows were deemed sufficient to describe the ichthyoplankton community outside the intake screen.

The composition of ichthyoplankton observed during this evaluation was consistent with that observed during the more exhaustive evaluation in 2009 for the month of April (McDonald and Karchesky 2010). Similar to this previous evaluation, larvae accounted for the vast majority (99.7 percent) of the early life-stages collected. The virtual absence of eggs collected in all samples suggests that the density of eggs in the water column near the intake screen is low during this time of year. Also similar to the 2009 evaluation was that the larval fish assemblage was dominated by species from three taxonomic families. These included Centrarchidae consisting largely of *Lepomis spp.*, Cyprinidae represented exclusively by common carp, and Clupeidae, identified as either threadfin shad or gizzard shad. The dominance of these species has also been described in other larval fish surveys conducted in the other areas of the LCR (Burke 1990; Kretschmann and Leslie 2006). The presence of these species during this evaluation indicates that we were successful in testing the sand filter during a period when species richness was high.

The overall size distribution of larvae observed in this study was also consistent with the 2009 results (McDonald and Karchesky 2010); larvae ranged in size from about 3.5 to 20 mm regardless of species. While the small sample sizes precluded a robust statistical comparison, the various size distributions of larval species collected in the entrainment samples were similar with those collected from the ichthyoplankton tows outside the intake structure. This similarity in size was inconsistent with the results of the previous evaluation, which found only the smaller individuals were entrained and that larvae greater than 10 mm in length were physically excluded by the wedge-wire screen (McDonald and Karchesky 2010). However, all larvae collected during this study in the entrainment samples and from the ichthyoplankton tow were less than 10 mm in length. While the reason for this is not entirely clear, the largest larvae observed during this study were collected using the light trap (15-20 mm in length), although these larger individuals (mainly largemouth bass) were not observed in the entrainment samples. This provides further support to the 10-mm maximum size threshold previously established for physical exclusion of larvae by the wedge-wire screen installed at the Imperial Ponds.

The presence of larvae in the samples collected from the sand filter backwash confirms the presence of these organisms entering the secondary filter, but not passing. Larval fish as small as 3.5 mm were identified in the backwash samples[1], a length commonly characterized as a minimum size for larvae of even the smallest nonnative fish species identified in the LCR (Tin 1982; Wallus et al. 1990). The exclusion of these small life-stages is not entirely surprising considering that the effective filtration size of number-20 silica sand is estimated to be approximately 20 microns. More importantly perhaps, these results also indicate that the backwash rate was sufficient to wash these organisms out and larvae did not penetrate the interstitial spaces of the media bed while it was expanded to remove trapped solids. In an early review of the sand filter technology's ability to removing fish eggs and larvae, Lorenz (1979) warned that due to their motility, larval fish may be able to penetrate the void space of the expanded media bed if backwash flows were too low.

In summary, this study was not intended to be a comprehensive evaluation of the sand filter technology. It was designed to provide initial information regarding the feasibility of this technology to exclude early life-stages of fishes, and whether it could be used as a tool to deliver water free from nonnative fishes to disconnected backwaters. The lack of eggs and larvae successfully passing through the sand filter is encouraging and does provide initial confirmation that this may be a viable technology for use in creating isolated habitat for native fishes. However, further investigation regarding the functionality of this technology over a longer temporal scale, as well as the benefit to the program, should be considered and weighed against other options before any decisions are made to move forward with full installation of sand filters at the Imperial Ponds.

[1] Head capsule measurements (the horizontal distance between the flared opercles) were not taken because accurate measurements are difficult to obtain. Functionally, head capsule widths have been reported to range from 8 to 12 percent of body length (Weisberg et al. 1987; Hanson 1981).

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TABLES

Table 1. Schedule and times of eight entrainment samples (collected from the primary and secondary manifolds during each event, and from the sand filter backwash on allternating events), four ichthyoplankton tows, and two light trap deployments. (Asterisks indicate those samples where the sand filter backwash was operated and contents collected).

	Interval	Date	Sample Duration	
			Start Time	End Time
Entrainment				
	1	19-Apr	09:11	10:08
	2*	19-Apr	10:40	11:45
	3	19-Apr	12:55	13:55
	4*	19-Apr	14:23	15:29
	5	20-Apr	07:36	08:35
	6*	20-Apr	08:57	10:11
	7	20-Apr	10:30	11:32
	8*	20-Apr	11:53	13:08
Icthyoplankton Tows				
	1	19-Apr	13:07	13:25
	2	19-Apr	14:30	14:48
	3	20-Apr	07:48	08:06
	4	20-Apr	09:12	09:34
Larval Trap				
	1	18-Apr /19-Apr	16:30	09:00
	2	19-Apr /20-Apr	15:58	07:50

Table 2. Summary of water chemistry measurements collected durng the two-day sampling period.

Date	Water Temperature (C) Min	Water Temperature (C) Mean	Water Temperature (C) Max	Dissolved Oxygen (%) Min	Dissolved Oxygen (%) Mean	Dissolved Oxygen (%) Max	pH	Secchi Depth (m)
4/19/2011	20.5	21.1	21.7	70.9	75.1	78.6	7.6	1.8
4/20/2011	20.6	21.1	21.7	65.9	69.6	74.7	7.8	1.8

Table 3. Taxonomic composition of eggs and larvae collected from the primary sampling manifold (Open Ent.), the sand filter backwash (SF-BW), the sand filter discharge (SF-DIS), ichthyoplankton tows (IP-TOW), and light trap (LT).

	Open Ent.		SF-BW		SF-DIS		IP-TOW		LT	
	No.	%	No.	%	No.	%	No.	%	No.	%
Centrarchidae										
Largemouth bass	0	0	0	0	0	0	0	0	14	93.3
Lepomis spp.	263	83.5	64	72.7	0	0	1	8.3	0	0
Egg	0	0	1	1.1	0	0	0	0	0	0
Subtotal	263	83.5	65	73.9	0	0	1	8.3	14	93.3
Clupeidae										
Dorosoma spp.	47	14.9	23	26.1	0	0	6	50.0	1	6.7
Subtotal	47	14.9	23	26.1	0	0	6	50.0	1	6.7
Cyprinidae										
Carp	5	1.6	0	0	0	0	5	41.7	0	0
Subtotal	5	1.6	0	0	0	0	5	41.7	0	0
Total	315		88		0		12		15	

FIGURES

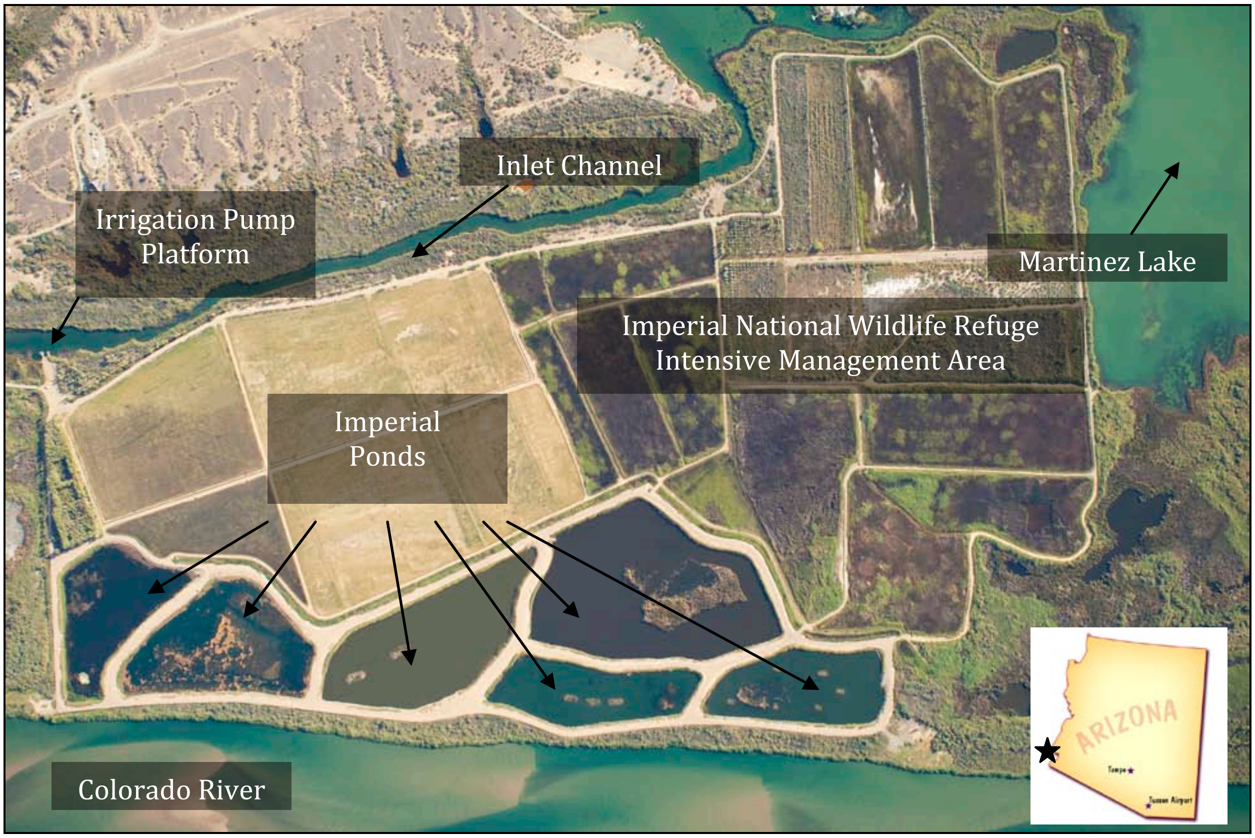

Figure 1. Aerial image of the Intensive Management Area (IMA) and Imperial Ponds on the Imperial National Wildlife Refuge, Arizona.

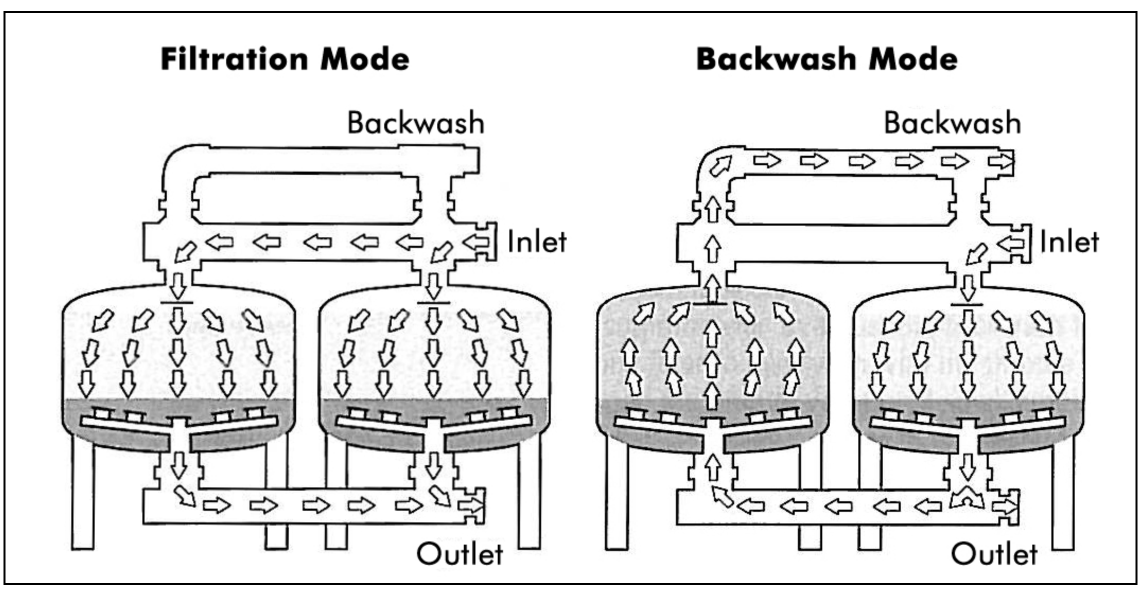

Figure 2. Filtration and backwash principles of a gravity sand filter.

Figure 3. The large steel manifold with 12 evenly spaced sampling ports and attached plankton nets. Photograph taken durng the 2009 evaluation (McDonald and Karchesky 2010).

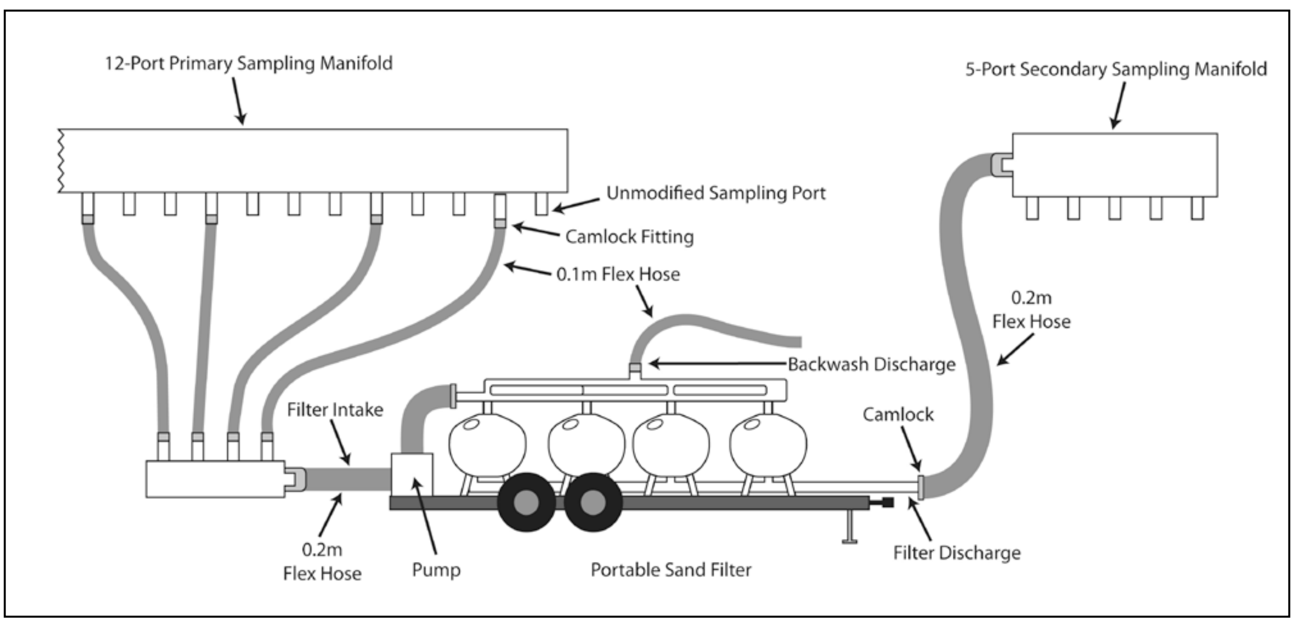

Figure 4. Design layout of sampling apparatus connecting the 12-port sampling manifold to the portable sand filter. Conical plankton nets with cod-end collection bottles were secured to each sampling ports on the primary and secondary manifold.

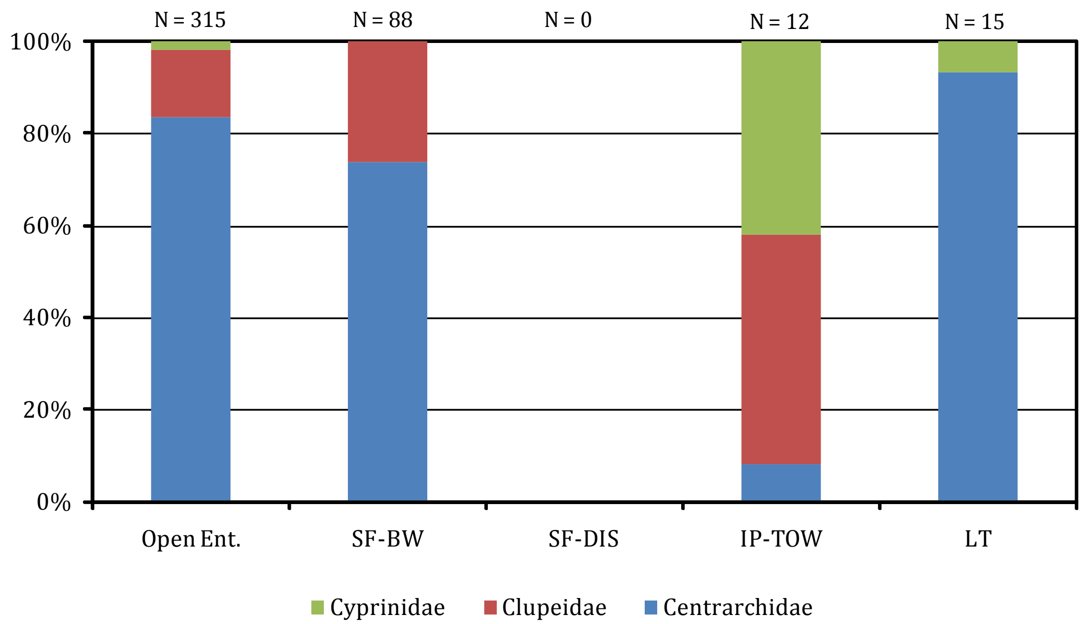

Figure 5. Percent composition of larvae from the three primary taxonomic families collected from the open entrainment discharge (Open Ent.), the sand filter backwash (SF-BW), the sand filter discharge (SF-DIS), ichthyoplankton tows (IP-TOW), and light trap (LT).

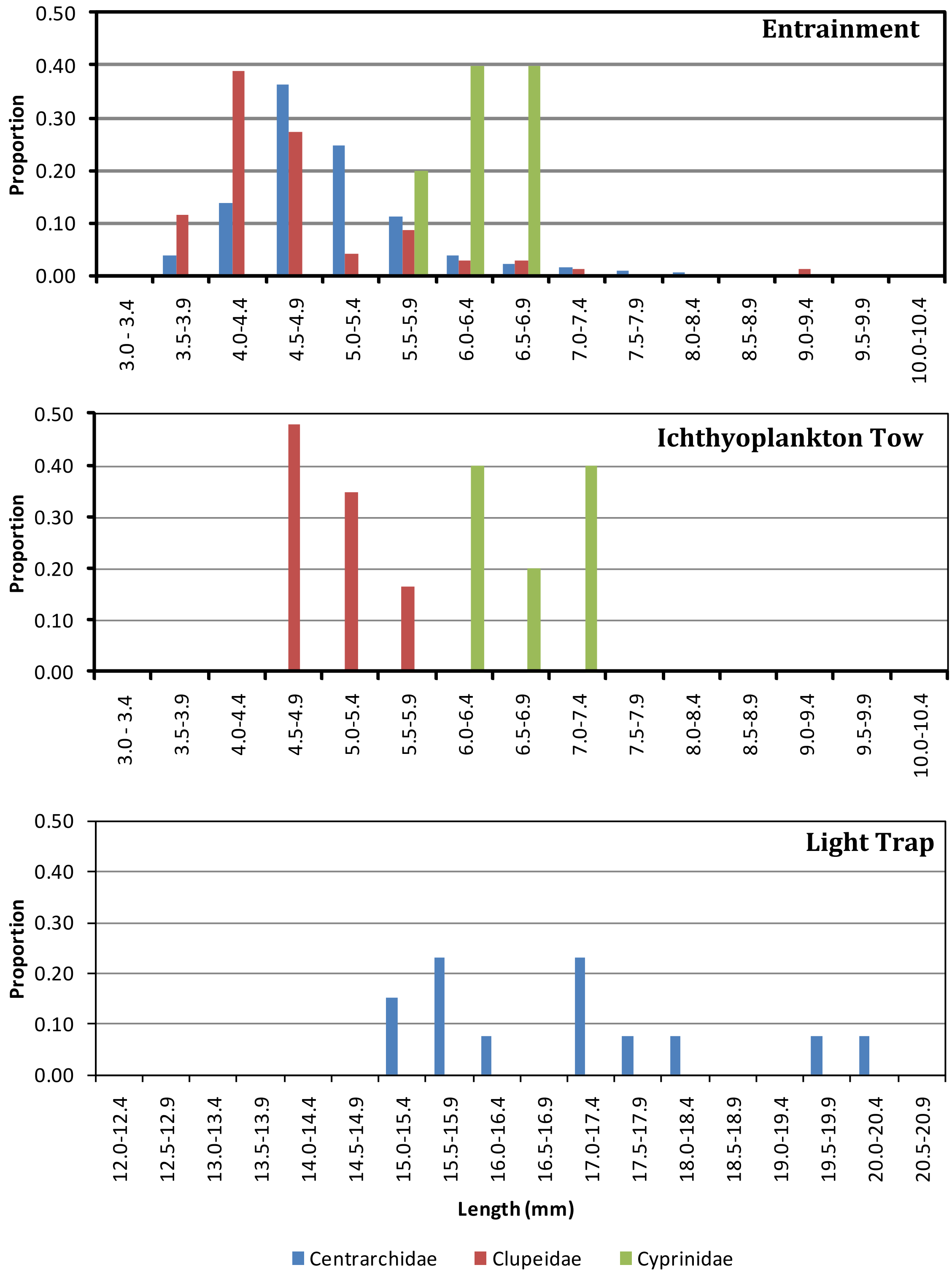

Figure 6. Length frequency distribution of the three primary taxonomic groups collected during the entrainment samples (open entrainment and sand filter backwash combined), ichthyoplankton tows, and light traps samples. (Note the different scales for the x-axis among individual graphs).