Response of Pacific lamprey ammocoetes and macropthalmia to several physical and behavioral guidance devices

Progress Report of Science and Technology Program Proposal 0035

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Introduction

Pacific lamprey *Entosphenus tridentatus* populations in the Columbia River basin have declined substantially in recent years and although the species is not listed under the Endangered Species Act, it is the subject of much research by federal, state and tribal agencies. Pacific lamprey are culturally important to Native Americans; they were historically a source of food and medicine and even today figure prominently in Native American culture. The substantial decline of Pacific lamprey populations has diminished to some extent the cultural practices of some Native American tribes. Pacific lamprey also provide numerous ecologically important benefits to aquatic ecosystems, such as a food source for juvenile salmon, birds and mammals, and returning adults historically were a source of marine-derived nutrients that helped sustain aquatic, riparian and terrestrial ecosystems (Beamish 1980, Lewis 2009). Adult Pacific lamprey also provided an alternative food source for California sea lions in the lower Columbia River, thereby reducing predation on returning adult salmon and steelhead.

Irrigation and other water diversion projects are commonplace in the numerous tributaries of the Columbia River basin. The Bureau of Reclamation as well as other federal and state agencies and local irrigation districts own and operate water diversion projects in Columbia Basin tributaries. Historically Pacific lamprey adults spawned and juveniles reared in these fresh water tributaries. There is the potential that during high flow events, juvenile Pacific lamprey rearing in the fine sediments of these tributaries could be dislodged from the substrate and entrained into irrigation and other diversions and lost to the population. Because of the substantially reduced population of Pacific lamprey in the Columbia Basin tributaries where Reclamation operates water diversion projects, it was deemed necessary and important to investigate methods to reduce or eliminate entrainment of juvenile Pacific lamprey into canals and keep them in the river and in suitable rearing habitat. Juvenile Pacific lamprey that were guided away from water diversions would be spared from entrainment into an irrigation canal. They would have an opportunity to seek out lower water velocity areas downstream and resume their filter feeding rearing strategy.

A short description of the early life history of Pacific lamprey is relevant here, since it sets the stage for this research project. The early life history stage of the Pacific lamprey is somewhat complex. After hatching in the spring, the young Pacific lamprey ammocoetes drift downstream to suitable rearing habitats such as backwater areas and pools that generally have low water velocity (Streif 2009) and a silty sandy substrate into which the ammocoetes burrow and feed by filtering diatoms and other small organic material (Simpson and Wallace 1978). During high flow events that disturb or disrupt the substrate, the juvenile lamprey can be displaced downstream. When water velocity decreases and conditions become favorable, they again burrow into the substrate and resume filter feeding. In basins where water is diverted for irrigation or other uses, juvenile Pacific lamprey that are passively moving in the higher flow could be diverted into the canal, and if not returned to the river through a juvenile fish bypass system, but instead get passed the fish screens and settle out in the lower velocity conditions in the canal, they could become lost to the population when the irrigation diversion ceases operation for the season and the canal is dewatered.

After rearing in fresh water habitats for from four to seven years, the juvenile Pacific lamprey undergo a physiological transformation and prepare to migrate downstream in the springtime as macropthalmia. These actively migrating macropthalmia may also be entrained in diverted flows into irrigation canals. The size of the Pacific lamprey at this life stage is generally large enough that they would likely be bypassed back to the river through the juvenile fish bypass system.

The focus of this research project was to evaluate some potential physical and behavioral guidance devices that could potentially reduce the diversion of juvenile Pacific lamprey into canals. We tested a wedge wire screen and woven wire screen. The wedge wire screen met NOAA Fisheries criteria for fry. Woven wire was 4.5-12, or 5/32-inch opening. This size of woven wire screen is commonly used on rotating drum fish screens at juvenile fish bypass systems in the Yakima Basin. We also tested an air bubble curtain similar to that tested in 2009, and a low voltage high intensity light bar array. Lastly we tested a combination of the air bubble curtain and the low voltage high intensity light bar array at night. High intensity lights have been used in some situations to guide fish away from a structure or back to the river (Liter and Maiolie 2002; Königson et al. 2002; Stark and Maiolie 2004; Simmons et al. 2006).

Methods

Test flume—A flume for testing physical and behavioral guidance devices with juvenile Pacific lamprey was constructed by personnel from the Umatilla Field Office, Hemiston, Oregon. The flume is 16-ft-long, 2-ft-wide and 18-inches-deep to provide an operating water depth of about 12 inches and is constructed of 3/4-inch marine-grade plywood (Figure 1). The 2-ft-long head box was formed by three ¼-inch perforated plates installed in slots 12 inches, 18 inches, and 24 inches from the upstream end of the flume that served to diffuse the flow. Three 3-inch-diameter fish introduction tubes on the downstream-most plate were located at the right side, center and left side, centered 5-inches above the bottom of the flume. The right and left tubes were centered 5 inches from each side. Eight feet downstream from the third diffuser plate, the main 2-ft-wide channel was divided into two narrower 1-ft-wide channels with a splitter wall. Grooves were cut into the floor of the flume at the splitter wall at 90, 45 and 30 degrees to serve as anchor points to

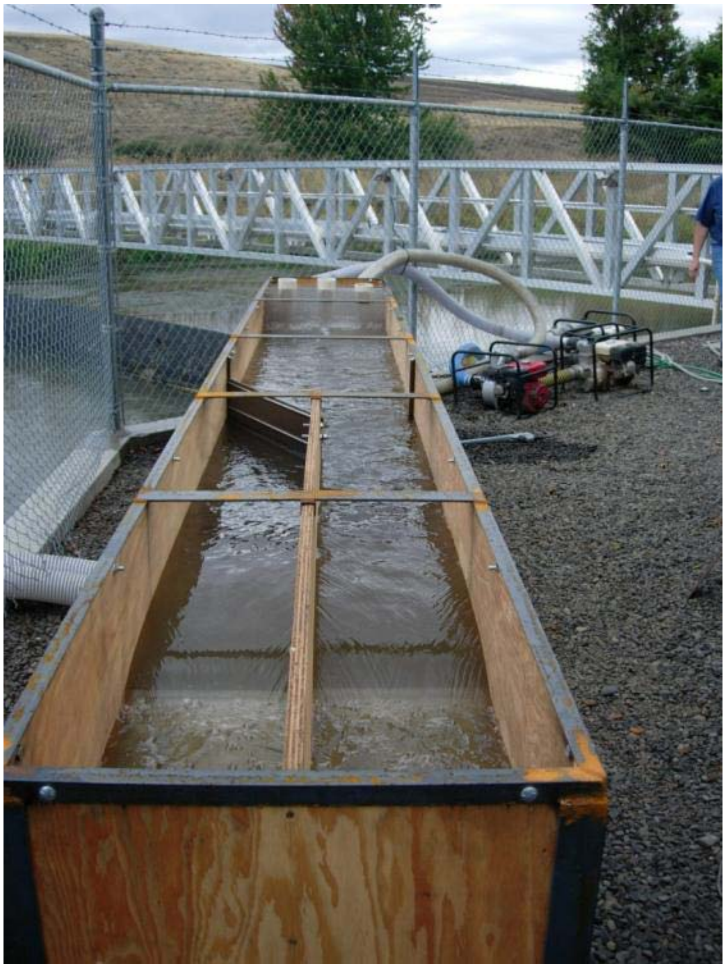

Figure 1. Test flume viewed from downstream to upstream, showing 3-inch pumps in the distance, and the wedge wire screen in place at the mouth of the right downstream channel.

accommodate a variety of physical or behavioral guidance devices. The flume design allowed a physical or behavioral guidance device to be placed in front of either channel to evaluate its potential to guide fish away from a simulated irrigation or other diversion and to remain in the river. Two feet downstream in each 1-ft-wide left and right channel was a ramp to control water level in the flume. At the end of each 7-inch-high ramp was a wedge wire screen "fish slide" that sloped down into a fish trap for collecting test fish (Figure 2).

Water from McKay Creek was pumped to the flume using three 3-inch-diameter trash pumps. Water entered the first chamber of the head box through 3-inch-diameter pipes (Figure 3). The three ¼-inch perforated plates provided a more uniform flow in the flume. Two 4-inch and one 3-inch drain pipes in the sump adjacent to the fish traps allowed water to flow back into McKay Creek.

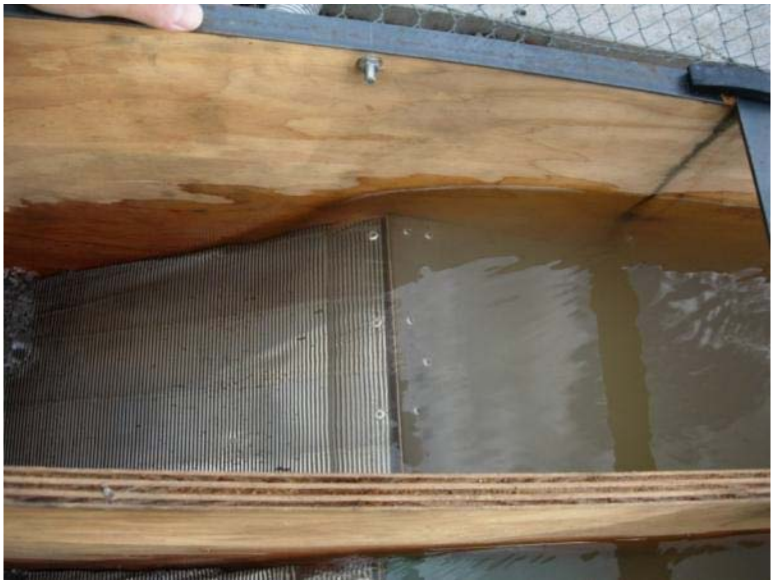

Figure 2. Right channel ramp and fish slide into the fish trap of the test flume.

Figure 3. Photograph of the three ¼-inch porous diffuser plates, water inflow pipes from the three pumps and the right, center, and left fish introduction tubes in the test flume.

Water velocity—Water velocity in the flume was measured with a Swoffer model 2100 flow meter at two flow rates. Velocity was measured on the right side, center, and left side of the flume 2 inches below the surface and 2 inches above the bottom at two transects 1.75 and 6.5 feet downstream from the porous diffuser, at the mouth of each downstream channel, and at the top of the ramp at the junction with the fish slide into the fish trap.

Pacific lamprey ammocoetes—About 500 Pacific lamprey ammocoetes and 50 macropthalmia were provided on the first day of testing by biologists from the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) (Figure 4). These fish were held in three 100-quart coolers that contained about 3 inches of Quickrete Play Sand to provide a substrate for the burrowing fish. Water from McKay Creek was pumped into each holding tank at a rate of about 4 L/min. Fish were not fed for the few days they were held and required for testing, but some organic material was likely present in the water pumped from McKay Creek and the ammocoetes may have utilized this material as a food source. A small air pump provided aeration.

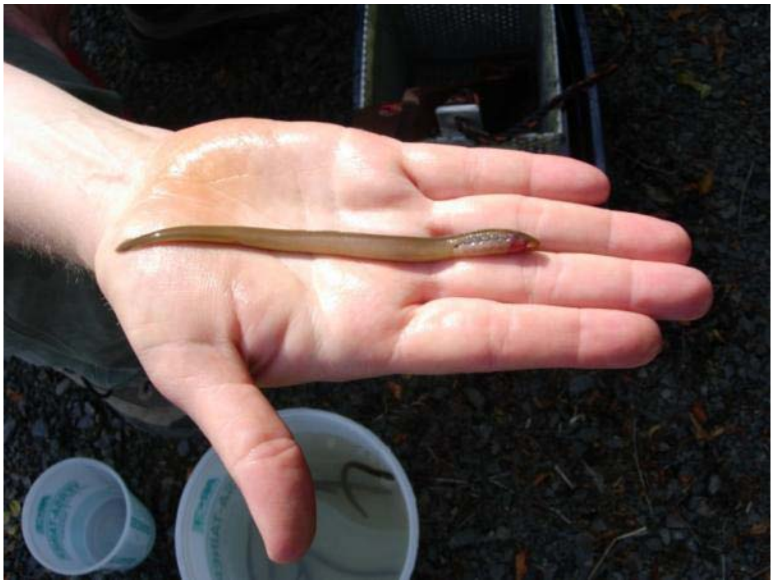

Figure 4. A Pacific lamprey ammocoete.

Distribution of Pacific lamprey ammocoetes with no guidance device in place—Ten Pacific lamprey ammocoetes were released through the right, center and left fish introduction tubes at high flow to assess their distribution and recovery in the fish traps downstream.

Wedge wire and woven wire screens—Ten tests of both the stainless steel wedge wire and woven wire screens were conducted with 10 Pacific lamprey ammocoetes. The wedge wire screen met NOAA Fisheries criteria for fry, that is, 0.093 inch wire width and slot width between bars of 0.069 inch (Figure 5). It was mounted vertically and positioned 30° to the flow. Woven wire was 4.5-12, or about 1/8-inch opening (Figure 6). This size of woven wire screen is commonly used on rotating drum fish screens at fish bypass systems in the Yakima Basin. Five tests were conducted with the screen in front of the right downstream channel and five with the screen in front of the left downstream channel. The initial intent of randomly assigning each screen to either right or left position in front of the right or left channel for each of the ten tests was determined to be logistically impractical due to the amount of time necessary to manipulate the screen and reseal it after each changeover.

Figure 5. Wedge wire screen used in the test flume.

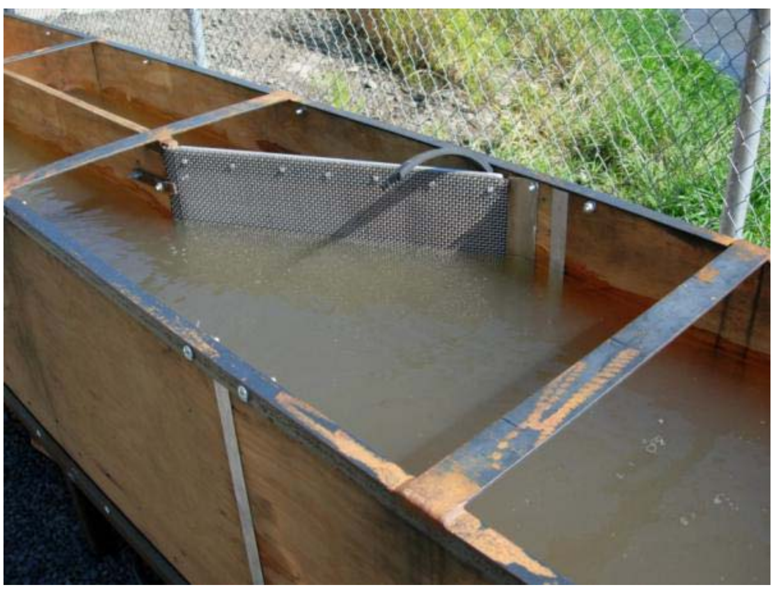

Figure 6. Woven wire screen in position in the test flume in front of the right channel at 30 degrees to the flow.

Test fish were introduced upstream into the flume through the fish introduction tube that corresponded to the side where the wedge wire or woven wire screen was positioned. The tests were conducted with the three pumps pumping at maximum capacity, which resulted in a velocity of about 0.85 fps. Two additional tests were conducted with Pacific lamprey macropthalmia with the wedge wire screen positioned in front of the left downstream channel. After fish were introduced into the upstream end of the flume through the fish introduction tubes, they were counted as they passed over the fish slide into the fish trap. When all test fish were accounted for or after five minutes, the pumps were turned off and fish were carefully netted from the fish traps. Because of the high velocity over the fish slide into the fish traps and the location where the fish came down the fish slide, some were occasionally not observed and counted, so the actual count of fish recovered in the fish trap was higher than the visual count. Fish recovered from each trap were held separately, lightly anesthetized with about 80 mg/L of tricaine methanesulfonate (MS-222) and measured for total length.

Air bubble curtain—The air bubble curtain was generated using a Whitewater model TL66 diaphragm air pump (Aquatic Eco-Systems, Inc., Apopka, FL) and a 25-inch length of 1-inch OD, ½-inch ID porous tubing positioned in the 30° groove and secured to the bottom of the flume with three small clamps. The air pump had a maximum output of 2.9 cfm. Clear plastic tubing connected the air pump to the porous tubing. The bubble generator was positioned in front of the right channel in the same 30° slot used to seat the wedge wire and woven wire screens (Figure 7). Several series of tests were conducted. The first two tests were conducted with Pacific lamprey ammocoetes, and the next three with Pacific lamprey macropthalmia. The first test was conducted with the high flow of 0.85 fps. It appeared that the high flow pulled or dragged the upper portion of the air bubble curtain downstream into the channel. The second test was conducted at a lower flow using only the center 3-inch-diameter pump, with a flow of about 0.61 fps. Tests 3 through 5 with Pacific lamprey macropthalmia were conducted at high flow.

After these five tests, the bubble generator was repositioned 6 inches further upstream in an attempt to reduce the bubble curtain from being dragged into the channel by the flow. This required installation of an additional plywood floor to provide a recessed anchor point for the porous tubing air bubble generator, since there was no groove in the floor of the flume at this location. The plywood insert had a tapered upstream edge to maintain a smooth flow pattern in the flume. After two tests the bubble generator and plywood insert was repositioned an additional 6 inches upstream for a total upstream change of 12 inches (Figure 8). With the high flow, three additional tests were conducted. We then reduced the flow and conducted five tests with 10 ammocoetes each released through the right side fish introduction tube with the air bubble curtain in front of the right downstream channel.

Low voltage high intensity light bars—Low voltage high intensity light bars were provided by Ovivo USA, LLC, Salt Lake city, Utah, courtesy of Mr. Kaveh Someah. The light units and their power supply had been used in some fish guidance tests by Reclamation’s Fisheries and Wildlife Research Group at the TSC in Denver, Colorado. Each light unit was 20-1/4 inch (51.4 cm) in overall length, 1-1/2-inch (3.8 cm) in diameter with brass end caps about 1-15/16 (4.92 cm) inch in diameter and 2 inch (5.08 cm) long, each having 360 fps. The lights have a 3-prong connector that extended out from the end of the tube about 1-5/8 inch (4.13 cm). The effective light unit was about 16-1/4 inch (41.3 cm) long. Two light units were mounted side by side and suspended just below the water surface at about a 45° angle to the flow upstream of the right channel (Figure 9). Five tests with 10 ammocoetes each were conducted with high flow during the daytime. Five additional tests were conducted at night.

Figure 7. Air bubble curtain in front of the right channel of the test flume.

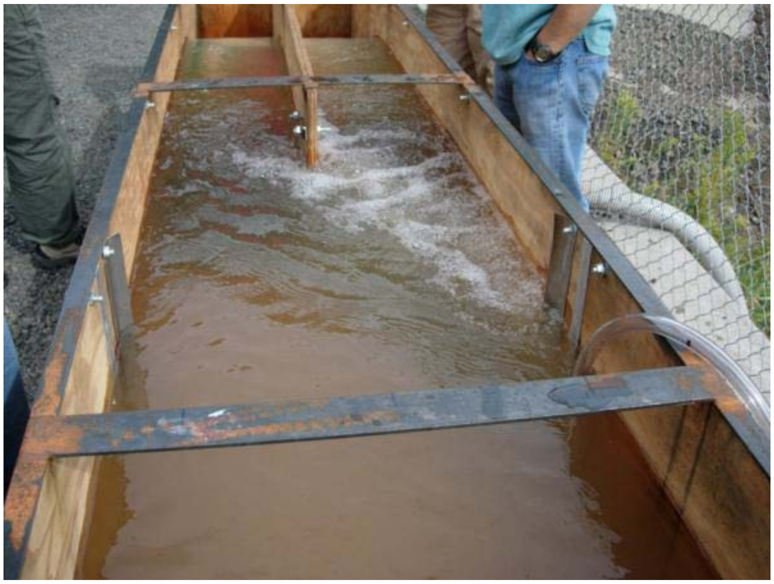

Figure 8. Air bubble curtain repositioned 12 inches upstream.

Low voltage high intensity light bar array combined with the air bubble curtain—These two potential behavioral guidance devices were combined to assess whether when combined they might provide better guidance than either device itself. These tests were conducted at night under the high flow conditions. Since the bubble curtain had been relocated 12 inches upstream in the flume, we suspended the light array upstream over the bubble curtain and conducted five tests with the guidance devices in this configuration positioned in front of the right channel (Figure 10).

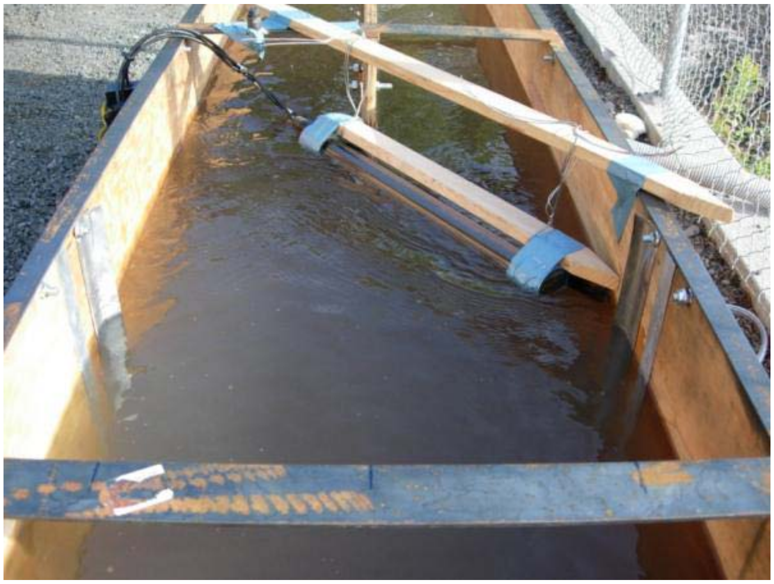

Figure 9. Low voltage high intensity light array positioned in front of the right channel in the test flume.

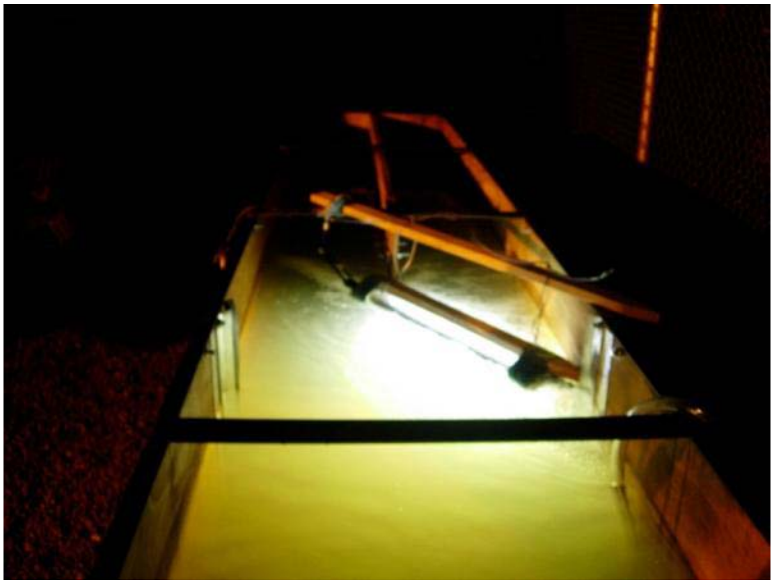

Figure 10. Low voltage high intensity light bar array and air bubble curtain in use in the test flume at night.

Results

Water velocity in the test flume—With the three 3-inch-diameter pumps operating at maximum capacity, and with a water depth of about 12.75 inches in the flume, average water velocity 2-inches below the surface at transect A 1.75 ft below the third diffuser plate was 0.853 fps, while at 2-inches above the bottom flow averaged 0.75 fps. At transect B, 6.5 ft from the diffuser plate, flow averaged 0.79 fps at surface and 0.70 fps at the bottom. Surface flow in the right channel at the splitter wall was 0.80 fps and 0.83 fps in the left channel, while flow at the bottom was 0.78 fps on the right and 0.72 fps on the left. At the top of the ramp with the transition to the fish slide into the fish trap the flow in the right channel was 2.08 fps and 2.14 fps in the left channel.

At the low flow with only the center pump operating, water velocity 2-inches below the surface at transect A 1.75 ft below the third diffuser plate averaged 0.61 fps, while at 2-inches above the bottom flow averaged 0.49 fps. At transect B, 6.5 ft from the diffuser plate, flow averaged 0.64 fps at surface and 0.59 fps at the bottom. Surface flow in the right channel at the splitter wall was 0.63 fps and 0.66 fps in the left channel, while flow at the bottom was 0.58 fps on the right and 0.59 fps on the left. At the top of the ramp with the transition to the fish slide into the fish trap the flow was 1.80 fps on the right side and 1.86 fps on the left side.

Distribution of Pacific lamprey ammocoetes with no guidance device in place—Ten Pacific lamprey ammocoetes each were released through the right, center and left fish introduction tubes. Of the 10 released through the right tube, four were recovered in the right channel fish trap and six in the left channel fish trap. Of the 10 ammocoetes released through the center tube, five each were recovered in the right and left channel fish traps, and of the 10 ammocoetes released through the left tube, two were recovered in the right channel fish trap and eight were recovered in the left channel fish trap.

Wedge wire screen—Wedge wire screen of the dimensions noted above appeared to guide Pacific lamprey ammocoetes and macropthalmia, as indicated by the number of Pacific lamprey recovered in the opposite channel fish trap (Table 1). All Pacific lamprey ammocoetes that were accounted for were recovered in the opposite channel fish trap. In seven of 10 tests, we recovered all 10 of the fish introduced upstream of the screen in the opposite channel fish trap. On three occasions one or two fish were not recovered in the fish trap; two were unaccounted for and in one test two fish were observed in the channel opposite the screen but they did not go over the ramp into the fish trap. They were the smallest of the 10 ammocoetes introduced and were recovered when the flow in the flume was shut off. Average length for those fish recovered in the left channel fish trap when the screen was located in front of the right channel was 121.5 mm, ranging from 108.6 mm to 127.7 mm. For fish recovered in the right channel fish trap when the screen was located in front of the left channel, fish length averaged 117.2 mm, ranging from 78 mm to 141 mm.

For the two tests conducted with Pacific lamprey macropthalmia with the wedge wire screen positioned in front of the left channel, all fish were recovered in the right channel fish trap. Average length of the 20 fish recovered was126.4 mm, ranging from 113 mm to 140 mm.

Woven wire screen—Ten tests were conducted using 4.5-12 woven wire screen, five tests run with the woven wire screen positioned in front of the left channel and five with the screen positioned in front of the right channel. With the screen in front of the left channel, most Pacific

Table 1. Number of Pacific lamprey ammocoetes and macropthalmia recovered in downstream fish traps when they were released into the flume upstream of wedge-wire screen at high flow on 21 September 2010.						
Screen location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right side	1	10 ammocoetes		10		
	2	10		10		
	3	10		10		
	4	10		10		
	5	10		10		
Left side	6	10	10			
	7	10	10			
	8	10	10			
	9	10	10			
	10	10	10			
	11	10 macrop-thalmia	10			
	12	10 macro	10			

lamprey ammocoetes were recovered in the right channel fish trap, and with the screen in front of the right channel, most juveniles were recovered in the left channel fish trap.

In the first test, nine juveniles were recovered in the right channel fish trap and one in the left channel fish trap (Table 2). In the second test of the series, nine fish were recovered in the right channel fish trap and one juvenile moved up through the diffuser plate into the head box where it was recovered, and in test 3, eight ammocoetes were recovered in the right channel fish trap with an additional juvenile found in the slot in the floor of the flume. One fish was unaccounted for. We determined that the woven wire screen was not completely seated in the slot, and it was reseated about an additional 1/4 inch and resealed. In test 4 and 5, all Pacific lamprey ammocoetes released through the left side fish introduction tube were recovered in the right channel fish trap, and in test 5, an additional ammocoete was recovered, possibly one of the unaccounted for fish from test 3 that might have gone through the diffuser plate into the head box where it was not observed. All Pacific lamprey ammocoetes released were accounted for in these two tests. For the 46 fish recovered in the right channel fish trap when the woven wire screen was positioned in front of the left channel, fish length averaged 118.7 mm, ranging from 62 mm to 140 mm.

Tests 6 through 10 were conducted with the woven wire screen in front of the right channel, with Pacific lamprey ammocoetes released through the right side fish introduction tube. Fish were

Table 2. Number of Pacific lamprey ammocoetes and macropthalmia recovered in downstream fish traps when they were released into the flume upstream of woven-wire screen at high flow on 22 September 2010.						
Screen location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Left	1	10 ammocoetes	9	1		
	2	10	9		1 H	
	3	10	8			2
	4	10	10			
	5	10	10			
Right	6	10		9	1 H	
	7	10		9		1
	8	10		10		
	9	10		9		1
	10	10		10		
Note: The "H" under salvaged in tests 2 and 6 indicate that one ammocoetes each was recovered upstream in the head box.						

recovered in the left channel fish trap. One fish in test 6 worked its way up through the head box diffuser plate and was recovered there, and one fish each in tests 7 and 9 were unaccounted for. For fish 47 recovered in the left channel fish trap when the screen was located in front of the right channel, fish length averaged 118.0 mm, ranging from 66 mm to 147 mm.

Air bubble curtain—The air bubble curtain did not appear to guide Pacific lamprey ammocoetes away from the channel with the bubble curtain (Table 3). In the two initial tests with ammocoetes, one at high flow and the second at low flow, six ammocoetes each were recovered after each test in the right channel fish trap downstream from the channel with the air bubble curtain, with four and two recovered in the left channel fish trap in tests 1 and 2, respectively. Two ammocoetes were recovered in the flume after flow was shut off in test 2. At the lower flow, it took somewhat longer for the fish to move downstream and some fish appeared to hold in lower velocity areas in the corners of the flume. We therefore resumed testing with higher flows. Average length of the 12 fish recovered in the right channel fish trap when the bubble curtain was positioned in front of the right channel was 110.8 mm, ranging from 74 to 137 mm, while the average length for the 6 fish recovered in the left trap was 110.7 mm, ranging from 52 to 135 mm.

In three tests with 10 Pacific lamprey macropthalmia each, with the air bubble curtain positioned upstream of the right channel, at the high flow, seven fish were recovered in the left channel fish trap while three were recovered in the right channel fish trap downstream from the bubble

Table 3. Number of Pacific lamprey ammocoetes and macropthalmia recovered in downstream fish traps when they were released into the flume upstream of air bubble curtain at high flow on 22 September 2010.						
Bubble curtain location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right-High	1	10 ammocoetes	6	4		
Low	2	10	6	2	2	
High	3	10 macrop-thalmia	3	7		
	4	10	3	7		
	5	10	9	1		

curtain in the first two tests. It appeared that the air bubble curtain might be somewhat effective in guiding macropthalmia. However, in the third test, nine Pacific lamprey macropthalmia were recovered in the right channel fish trap downstream from the air bubble curtain, and only one was recovered in the left channel fish trap (Table 3). At that point we exhausted the supply of macropthalmia. Average length of the 15 fish recovered in the right channel fish trap was 128.5 mm, ranging from 122 to 137 mm, while the average length for the 15 fish recovered in the left channel fish trap was 129.7 mm, ranging from 117 to 140 mm.

Air bubble curtain repositioned upstream in the flume—In the first test with the air bubble curtain repositioned 6 inches upstream in front of the right channel, five Pacific lamprey ammocoetes were recovered in the right channel fish trap, three recovered in the left channel fish trap, and one recovered in the flume after the test (Table 4). One ammocoete moved up into the head box through the porous diffuser plate. In the second test, results were similar, but two ammocoetes were unaccounted for. Average length of the 10 fish recovered in the right channel fish trap was 118.7 mm, ranging from 88 to 139 mm, while the average length for the six fish recovered in the left channel fish trap was 113.5 mm, ranging from 79 to 134 mm.

When the bubble generator was repositioned another six inches upstream on the right side for a total of 12 inches from the entrance to the right side channel, two-thirds of the ammocoetes (20 of 30) were recovered in the right channel fish trap downstream from the bubble curtain, while 26.7 percent (8 of 30) were recovered in the left channel fish trap. One ammocoete moved up into the head box and one was unaccounted for. Average length of the 20 fish recovered in the right channel fish trap was 129.6 mm, ranging from 90 to 141 mm, while the average length for the eight fish recovered in the left channel fish trap was 126.1 mm, ranging from 100 to 140 mm.

In tests 6 through 10, with the air bubble curtain 12 inches upstream from the right channel mouth, with reduced flow, 26 ammocoetes were recovered in the left channel fish trap, while 20

Table 4. Number of Pacific lamprey ammocoetes recovered in downstream fish traps when they were released into the flume upstream of bubble curtain at high and low flows on 23 September 2010, with the bubble curtain repositioned 6 and 12 inches upstream from the mouth of the channel.						
Bubble curtain location	Test No.	No. released	Number recovered			
Right			Right trap	Left trap	Salvaged	Missing
6 inches upstream	1	10 ammocoetes	5	3	2	
	2	10	5	3		2
12 inches upstream	3	10	5	4	1	
	4	10	7	2		1
	5	10	8	2		
Low flow	6	10	5	4		1
	7	10	5	4	1	
	8	10	2	8		
	9	10	4	6		
	10	10	4	4	2	

ammocoetes were recovered in the right channel fish trap downstream from the bubble curtain. Three ammocoetes were recovered in the flume after the tests were terminated and the flow was shut down, and one ammocoete was unaccounted for.

Average length of the 20 fish recovered in the right channel fish trap for these five tests was 119.3 mm, ranging from 78 to 142 mm, while the average length for the 26 fish recovered in the left channel fish trap was 109.4 mm, ranging from 77 to 131 mm.

Low voltage high intensity light bar array—In five daytime tests with the low voltage high intensity light units, 27 Pacific lamprey ammocoetes were recovered in the right channel fish trap below the light array, 20 were recovered in the left channel fish trap, one was recovered after the flow was shut off, and two were unaccounted for (Table 5). Average length of the 27 fish recovered in the right channel fish trap was 121.9 mm, ranging from 84 to 139 mm, while the average length for the 20 fish recovered in the left channel fish trap was 123.3 mm, ranging from 112 to 132 mm.

During five additional nighttime tests, the results were nearly reversed, with 20 ammocoetes recovered in the right channel fish trap downstream from the light array, 28 recovered in the left channel fish trap, and two recovered after flow was shut down (Table 6). Average length of the 20 fish recovered in the right channel fish trap was 118.1 mm, ranging from 69 to 140 mm, while

Table 5. Number of Pacific lamprey ammocoetes recovered in downstream fish traps when they were released into the flume upstream of high intensity lights at high flow during the daytime on 23 September 2010.						
Light array location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right	1	10	5	4	1	
	2	10	6	4		
	3	10	6	4		
	4	10	7	3		
	5	10	3	5		2

Table 6. Number of Pacific lamprey ammocoetes recovered in downstream fish traps when they were released into the flume upstream of high intensity lights at high flow during the nighttime on 23 September 2010.						
Light array location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right	1	10	4	5	1	
	2	10	5	4	1	
	3	10	4	6		
	4	10	3	7		
	5	10	4	6		

the average length of the 28 fish recovered in the left channel fish trap was 124.1 mm, ranging from 106 to 151 mm.

Low voltage high intensity light bar array combined with air bubble curtain—In a series of five nighttime tests that combined both the low voltage high intensity light array and the air bubble curtain in front of the right channel, 23 ammocoetes were recovered in the right channel fish trap downstream from the light bar array-bubble curtain, while 25 were recovered in the left channel fish trap, and two recovered after flow in the flume was shut down (Table 7). Average length of the 23 fish recovered in the right channel fish trap was 121.1 mm, ranging from 87 to 141 mm, while the average length for the 25 fish recovered in the left channel fish trap was 121.1 mm, ranging from 84 to 140 mm.

Table 7. Number of Pacific lamprey ammocoetes recovered in downstream fish traps when they were released into the flume upstream of high intensity lights and the bubble curtain at high flow during the nighttime on 23 September 2010.						
Light array location	Test No.	No. released	Number recovered			
			Right trap	Left trap	Salvaged	Missing
Right	1	10	7	3		
	2	10	4	6		
	3	10	5	4	1	
	4	10	5	5		
	5	10	2	7	1	

Discussion

Wedge wire screen—Wedge wire screen meeting NOAA Fisheries criteria for fry successfully guided Pacific lamprey ammocoetes. In the 10 tests, all ammocoetes were recovered in the opposite channel fish trap. In two tests with 10 Pacific lamprey macropthalmia each, they also were recovered in the opposite channel fish trap. Four ammocoetes were unaccounted for; juvenile Pacific lamprey appear to be particularly adept at finding small gaps in the flume to either escape the fish traps and return back to the river in the outflow, or simply hiding in small gaps and crevasses. These tests indicate that Pacific lamprey ammocoetes can be guided successfully with wedge wire screen meeting NOAA Fisheries criteria for fry, oriented vertically at a 30 degree angle to the flow. If wedge wire screen were to be selected for installation at water diversions to reduce or eliminate juvenile Pacific lamprey entrainment, the actual location and size and operation of the screen would have to be considered carefully to avoid the screen becoming plugged with debris.

Woven wire screen—Most (93 of 100) of the Pacific lamprey ammocoetes were guided by the woven wire screen at the high flow of about 0.85 fps. In the initial tests, the fish recovered from the left channel fish trap when the screen was positioned in front of the left channel may have passed through a small gap at the bottom of the screen that resulted from the screen inadvertently not being completely seated in the slot. After the screen was reseated and the gap sealed, all juveniles were recovered in the opposite channel fish trap, indicating that this screen type successfully guided the fish. Two juvenile Pacific lamprey worked their way up through the ¼-inch openings of the porous diffuser perforated plate and entered the head box, where they were recovered. Two ammocoetes were not recovered and their fate is unknown. Pacific lamprey ammocoetes appear to be quite adept at getting through small gaps and crevasses and either escape back to the river in the outflow or simply hide along the edge of screens or any protrusion in the channel.

Air bubble curtain—The air bubble curtain when positioned in front of the right channel did not appear to guide Pacific lamprey ammocoetes effectively to the opposite channel, as evidenced by the number of fish recovered in the fish trap below the bubble curtain; more (12 of 20 or 60 percent) were captured in the fish trap downstream from the bubble curtain, while 8 of 20 (40 percent) were recovered in the opposite channel fish trap. In three tests with 10 Pacific lamprey macropthalmia each, 15 macropthalmia each were recovered in each fish trap. In the first two of these three tests, it appeared that the macropthalmia were responding to the bubble curtain, with 7 out of 10 fish recovered in the left channel fish trap, but in the third and last test of the series, only one fish was recovered in the left channel fish trap while the other nine fish were recovered in the right channel fish trap downstream from the bubble curtain. Based on the tests conducted here, it does not appear that the bubble curtain is a reliable and effective method to guide Pacific lamprey ammocoetes.

When the bubble curtain was repositioned 6 inches upstream from the mouth of the channel, half of the released ammocoetes were recovered in the right channel fish trap, and 40 percent were recovered in the left channel fish trap, indicating that the bubble curtain did not appear to be a very effective guidance device. When we moved the bubble curtain upstream another 6 inches, about two thirds of the fish were recovered in the right channel fish trap and about 27 percent were recovered in the left channel fish trap. These tests were conducted at the high flow. After we reduced the flow, with the bubble curtain 12 inches upstream from the mouth of the channel, there was slightly better recovery of test fish in the fish trap opposite the bubble curtain and site of release; 52 percent were recovered there and 40 percent were recovered in the right channel fish trap. Six percent of the fish were recovered in the flume after the tests were terminated and one fish was unaccounted for. It appears that with the reduced flow and the bubble curtain positioned upstream from the mouth of the channel there was slightly better guidance of the fish away from the channel. It is possible that Pacific lamprey might respond differently to finer or coarser bubbles. Further testing using different types of porous tubing that produced a finer bubble stream might elicit a different response from the lamprey ammocoetes. Finer bubbles than those generated in these tests might produce a tighter bubble curtain, perhaps affecting guidance. Lower water velocity reduced the drag on the bubbles into the channel, but the ammocoetes moved downstream more slowly in the reduced flow. Although Pacific lamprey ammocoetes are generally sedentary, they are relatively good swimmers for their size. Sutphin (2010) reported that Pacific lamprey ammocoetes from 107 to 150 mm TL had a burst swimming speed ranging from 33.3 to 75 cm/sec (1.09 to 2.46 fps), which may explain why they moved downstream in the flume slower under the low flow condition because they were not overwhelmed by the low flow of 0.61 fps. We observed ammocoetes swimming actively both upstream and downstream in the flume. In a field application of an air bubble curtain, where the diversion generally takes off from the river at an angle, a bubble curtain might be more effective than when the bubble curtain is positioned directly in front of a channel in line with the flow, as it was in the test flume.

Low voltage high intensity light bar array—During daytime tests with the high flow, 54 percent of the ammocoetes were recovered in the right channel fish trap downstream from the low voltage high intensity light bar array, with 40 percent recovered from the left channel fish trap. However, during the five nighttime tests, 56 percent of the ammocoetes were recovered in the left channel fish trap, while 40 percent were recovered in the right channel fish trap. Pacific lamprey juveniles are generally more active at night, and the propensity for greater nighttime movement might affect their response to the high intensity lights. Since Pacific lamprey ammocoetes do not have developed eyes, it is not known why or whether they would respond to light. During the daytime, the high intensity light bar array might not be much different from the full sunlight condition that prevailed during the tests. The light bar array might have been more effective if it had been recessed in the floor of the flume rather than suspended just below the water surface. The light tube was too large to set flush in the floor of the flume as it is currently configured; the light tube itself might have served as a physical guidance device for any Pacific lamprey ammocoetes moving along the bottom of the flume. Little is known about how Pacific lamprey ammocoetes respond to various environmental cues. Additional research is needed to elucidate the response of juvenile lamprey to environmental stimuli since they do not have developed eyes at this life stage. Macropthalmia with developed eys might respond differently to the high intensity light array.

Low voltage high intensity light bar array combined with the air bubble curtain—The combined low voltage high intensity light bar array and the air bubble curtain tested during the nighttime resulted in about equal numbers of Pacific lamprey ammocoetes being guided as not. With two fish recovered in the flume after the tests were terminated, 25 ammocoetes (50 percent) were recovered in the left channel fish trap, with 23 (46 percent) recovered in the right channel fish trap. Under the conditions of these tests, it does not appear that the combination of the light array and the bubble curtain provides any better guidance of Pacific lamprey ammocoetes than the light bar array itself, during nighttime. It would be informative to modify this flume or construct a new flume in which the high intensity light bar and/or air bubble curtain could be recessed and flush with the floor of the flume and conduct several additional tests.

Some additional observations on behavior of Pacific lamprey ammocoetes—Pacific lamprey ammocoetes exhibited some interesting behavior both in the holding tanks and in the test flume. They appeared to be very sensitive to disturbance in the holding tank, such as when they were dislodged out of the substrate and netted for testing in the flume. The holding tanks for the ammocoetes had a substrate of Quickrete Play Sand about 3 inches deep to allow them to burrow. This material was recommended by staff at the Columbia River Research Laboratory, Cook Washington, as a suitable substrate for rearing Pacific lamprey ammocoetes. After the substrate was disturbed and fish collected to introduce into the flume, they relatively quickly burrowed back into the substrate. They generally burrowed head first, often at a shallow angle rather than vertical. Many remained completely buried in the substrate.

Summary

Physical guidance devices such as wedge wire and woven wire screens appear to guide Pacific lamprey ammocoetes and macropthalmia away from a channel, while the air bubble curtain and the low voltage high intensity light bar array as tested here did not provide consistent guidance, at least under the conditions of the field tests.

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