Intensive Monitoring of Larval/Juvenile Entrainment in the Yakima Subbasin, 2018

[Cover Photo: Dave'y Lumley (left) and Shekinah Saluskin (right) rescuing larval lampreys trapped above the fish screens of Wapato Irrigation Diversion using a backpack electrofisher and a fine-mesh net.]

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Tyler Beals and Ralph Lampman

Confederated Tribes and Bands of the Yakama Nation
Yakama Nation Fisheries Resource Management Program, Pacific Lamprey Project
P.O. Box 151, Toppenish, Washington 98948, USA

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Highlights

- Within Type I (preferred) larval lamprey habitat, an estimated 7,249 lampreys were estimated to be present downstream of the fish screens at Sunnyside Diversion, and 10,880 lampreys upstream of the fish screens at Wapato Diversion immediately after dewatering.
- Within these two diversions, we captured 6,529 lampreys in 11 days of electrofishing efforts, which we estimate to be up to 45% of the total number in wetted Type I habitat and 36% of the grand total estimate (including dry bank collection).
- At Sunnyside Diversion, the maximum incremental dewatering rate was 20.8 cm/hr, which lasted for ~155 minutes. At Wapato Diversion, the maximum incremental dewatering rate was 27.4 cm/hr, which lasted for ~215 minutes.
- Despite similarly high dewatering rates and duration at these two diversions, rate of mortality from desiccation was much lower at Sunnyside Diversion (7%) compared to Wapato Diversion (70%), which may be attributable to the 2-3 hours of delay in rescuing lampreys emerging from the critical high density zones.

Abstract

During the 2018-2019 irrigation dewater season, the Yakama Nation intensively monitored larval/juvenile lamprey entrainment at Sunnyside and Wapato diversions (head gates located at river km 171.4 and 176.2, respectively). The following report is divided into two parts: 1) assessment of lamprey abundance and 2) the effects of dewatering rates on lamprey survival. By using a combination of single pass electrofishing and lamprey collection from dry banks, we estimated that a total of 7,249 lampreys were present in Type I habitat immediately downstream of the fish screens at Sunnyside Diversion. At Wapato Diversion, we estimated the total number of lampreys in Type I habitat immediately upstream of the fish screens to be 10,880. From these two diversions, we captured and rescued 6,529 lampreys from wetted habitat. Within these two diversions, we estimated there were 14,546 lampreys in wetted Type I habitat. Although our estimates are likely a conservative estimate of the total number of lampreys in these locations, our data suggest that we removed approximately 45% of entrained lampreys through the 11 combined days of fish rescue efforts. At Sunnyside Diversion, the maximum incremental dewatering rate was 20.8 cm/hr which lasted for ~155 minutes. At Wapato Diversion, the maximum observed incremental dewatering rate was 27.4 cm/hr and lasted for ~215 minutes. Despite the relatively similar dewatering rates and duration, the rate of mortality was much lower on the first day of dewatering at Sunnyside Diversion (6.8%; 84 of 1,231 lampreys) compared to Wapato Diversion (70.2%; 843 of 1201 lampreys). At Sunnyside Diversion, our staff and volunteers were ready to rescue lampreys from the dry banks immediately after dewatering of the critical high density zones began, whereas at Wapato Diversion, our rescue efforts did not start until 2-3 hours after dewatering in the critical high density zones have already progressed. Therefore, it is imperative that the rescue of lampreys trapped on dewatered banks need to occur in a timely manner (only 2-3 hours of delay in rescue can result in a significantly higher rate of mortality).

Introduction

Pacific Lamprey are an invaluable cultural and ecological resource that are declining in distribution and abundance throughout the Columbia River Basin. One of the myriad of threats Pacific Lamprey (and other lamprey species) face is entrainment within irrigation diversions, which can pose a serious risk to their larval and juvenile life stages as they migrate downstream. The large volumes of fine sediment that collect in many diversions provide ideal, yet misleading, refuge habitat for larval lampreys. Water is drained from these diversions typically in the fall in October/November (or the summer in June/July), and lampreys that have burrowed in the fine sediment during the irrigation season are left to dessicate at many of these facilities unless rescue efforts take place to save them. Many hundreds of irrigation diversions are scattered throughout the Columbia Basin, so it is imperative that simple, adaptive, and innovative techniques to preserve the life of larval/juvenile life stage lampreys are developed, using our best understanding of the lamprey entrainment mechanisms. Effective solutions focusing on both entrainment reduction during the irrigation season and increased efficiency in rescue efforts during the dewatering season are needed.

During the 2018-2019 irrigation dewater season, the Yakama Nation Pacific Lamprey Project (YNPLP) intensively monitored larval and juvenile lamprey entrainment at two large scale irrigation diversions of the Yakima River, Sunnyside Diversion and Wapato Diversion (head gates located at river km 171.4 and 176.2, respectively). Each of these diversions are known to entrain many thousands of larval and juvenile lampreys each year (over 40,000 lampreys estimated to reside in Wapato Diversion alone in 2017). Our surveys at these two diversions pursued four primary objectives: 1) rescue as many trapped lampreys as possible, 2) estimate the number of lampreys that reside in high density zones, and 3) facilitate innovative changes in project operations to manage the dewatering rate at each location, and 4) closely monitor larval and juvenile lamprey responses during the dewatering process. Given those four objectives being our highest priority, this report is divided into two main sections 1) Part I – Assessment of Larval/Juvenile Lamprey Abundance, and 2) Part II – Effects of Dewatering Rates on Larval Lampreys. Both Pacific Lamprey and Western Brook Lamprey enter Sunnyside and Wapato diversions, and both species utilize identical habitat, so our approach to save the most number of Pacific Lamprey will also benefit the secondary species, Western Brook Lamprey.

Part I – Assessment of Larval/Juvenile Lamprey Abundance

Methods

Overview of Sunnyside and Wapato Diversions

Sunnyside and Wapato diversions were intensively surveyed for larval lampreys during the 2018-2019 dewatering period (October, 2018 to March, 2019). Surveys at these two diversions were

focused in zones that are known to collect large volumes of fine sediment, and consequently large numbers of lampreys. At Sunnyside Diversion, surveys were focused immediately downstream of the fish screens, extending downstream to the I-82 Highway Bridge (~115 m zone in length). Total distance between the headgate and trashrack is 325 m. At Wapato Diversion, surveys were focused upstream of the fish screens, extending 50 m upstream of the trashrack, which encompasses the majority of lamprey habitat at this facility (~122 m zone in length). Total distance between the headgate and the trashrack is 780 m.

Survey (Rescue) Techniques

An AbP-2 Backpack Electrofisher (ETS Electrofishing Systems LLC., Madison, WI) was used to remove larval lampreys from wetted sediments or newly dewatered drying banks. Our surveys used standard larval lamprey survey protocols (slow tickle pulse of 3 pulses/sec and fast stunning pulse of 30 pulses/sec, 25% duty cycle, 3:1 burst pulse train, 125 volts). The water temperatures during the duration of our surveys were consistently less than 10°C, so the voltage was increased to 150-200 volts to compensate for the reduced conductivity. Surveys were focused on Type I habitat, which is preferred by larval lampreys and consists of fine sediment (sand, silt and clay) and/or detritus (fine and coarse organic matter). Type II habitat was opportunistically surveyed, and is less preferred by larval lampreys, consisting of a mix of fine and course sediment. Captured lampreys were immediately placed into flow through mesh baskets until counting, identification, and release took place. Stranded lampreys on dry (recently dewatered) sediments were collected by hand and placed into separate mesh baskets.

Estimating the Number of Entrained Lampreys

Sunnyside and Wapato diversions were spatially divided into sections (prior to dewatering) to ensure our electrofishing efforts would cover representative density areas within each section. This was important because of the considerably high variation in densities depending on the location within the diversion. At Sunnyside Diversion, the zone downstream of the fish screens was divided into two sections, D1 and D2 (“D” stands for “Downstream,” numbered in order from downstream to upstream; Fig. 1). At Wapato Diversion, the zone upstream of the fish screens was divided into six sections, U1-U6 (“U” stands for “Upstream”, numbered in order from downstream to upstream; Fig. 2).

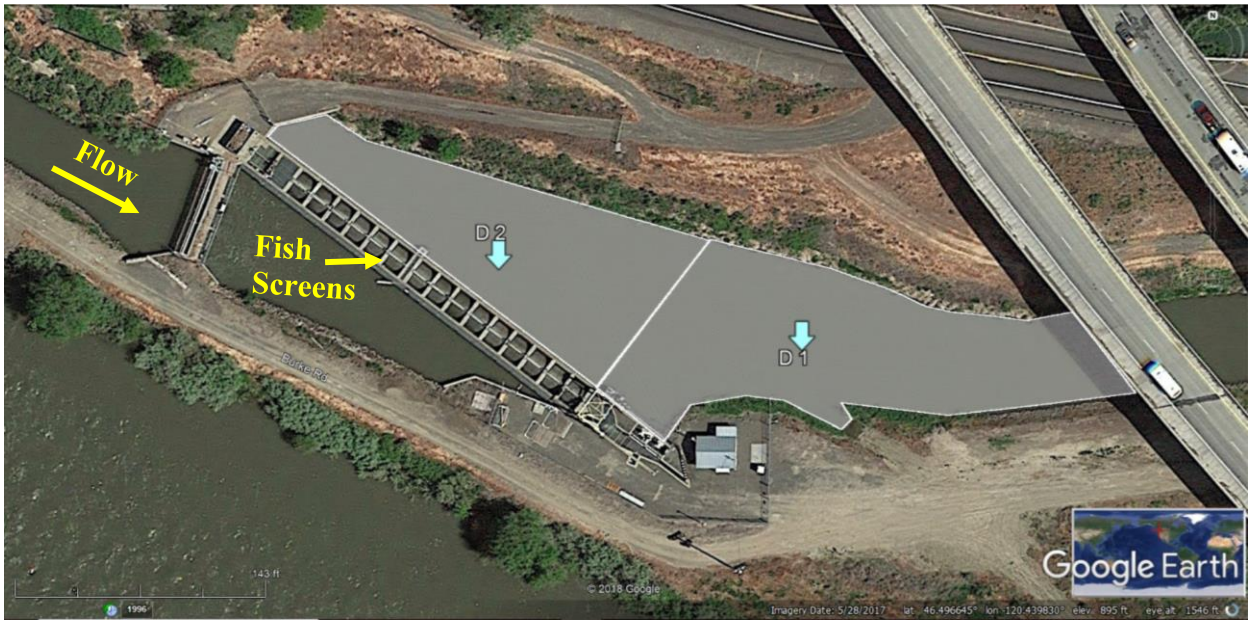

Figure 1. Delineated sections of the zone downstream of the fish screens at Sunnyside Diversion (light grey polygons and blue arrows). Section D2 is located immediately downstream of the fish screens, and Section D1 is located downstream of section D2, extending downstream to the I-82 Highway Bridge. Water flow is moving from left to right.

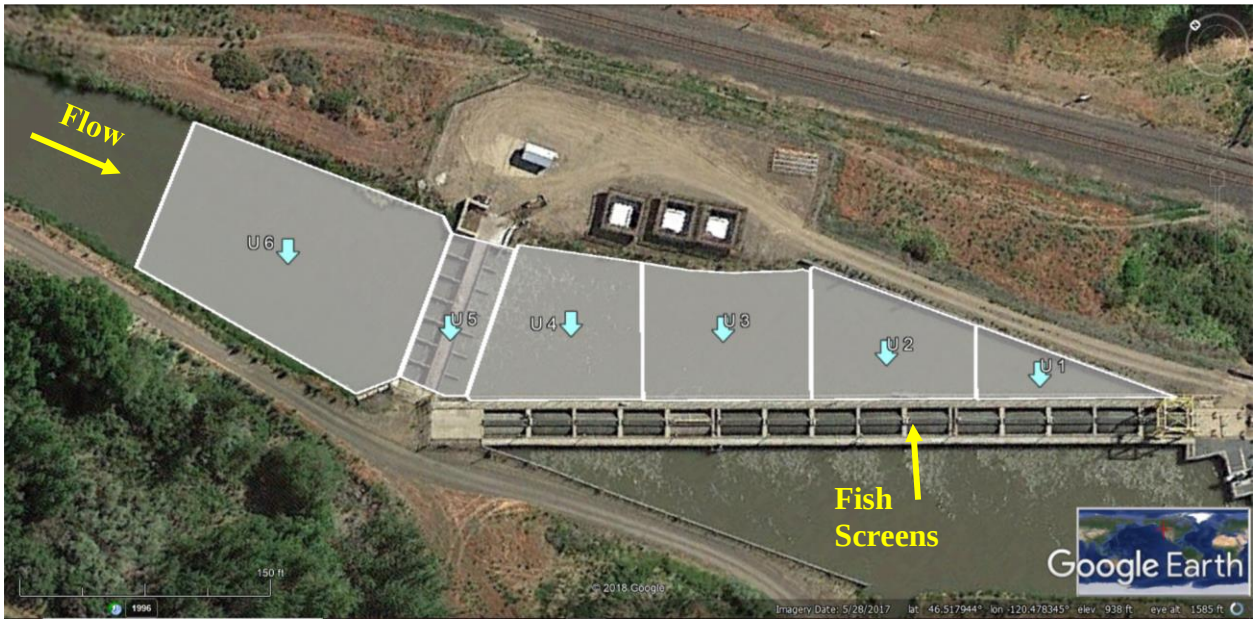

Figure 2. Delineated sections of the zone upstream of the fish screens at Wapato Diversion (light grey polygons and blue arrows). Sections U1, U2, U3, and U4 divide the zone immediately upstream of fish screens. Section U5 surrounds the trashrack, and U6 is located in the upstream canal, reaching 50 m upstream of the trash racks (total upstream canal length is 780 m). Water flow is moving from left to right.

We calculated the number of lampreys residing in Type I habitat in the high density zones within Sunnyside and Wapato diversions. The polygon feature on Google Earth Pro was used to calculate the overall area (m^2) of each section within the overall zones. The percentage of each larval lamprey habitat type (Type I, II and III) was visually estimated for each section, and the overall area of each habitat type was calculated. The percent of Type I habitat that was wet at the time of our first pass survey was also estimated and used to obtain the total area of wetted Type I habitat in each section.

Single pass electrofishing surveys were performed in plots (5 to 28 m^2 in size), and covered representative areas of Type I (preferred) larval lamprey habitat within each of the delineated sections. The size of the plot was dependent on the wetted habitat area within each section (an effort was made to cover at least 5% of the overall area whenever possible). Plot surveys were conducted in the main water body, along the edge of the main water body (the edge is defined as the area within 2 m from the water's edge), or within isolated pools. These unique survey locations ("edge" of main water body, "main" water body and "isolated pool") are referred to as "habitat categories," and were identified to represent the variable densities within each area. Within the wetted area of each section, the proportion of each habitat category (main, edge, or isolated pool) was also calculated. After the initial surveys were conducted to estimate the total larval abundance, the electrofishing focused on the lamprey rescue in the highest density areas.

Studies have shown that the capture efficiency of single pass larval lamprey electrofishing is approximately 50% (captured lamprey numbers only account for approximately 50% of the total lampreys present). To ensure that our abundance estimation accounts for all lampreys present, we adjusted the number of captured lampreys to account for this inefficiency (referred to as "Adjusted Total" in the results section). During the single pass surveys within each habitat category (per section) we tallied both the captured and missed larvae to determine the total number of observed lampreys from electrofishing. In the results section, the "total number observed" refers to the sum of the captured and missed lampreys. If the number of captured lampreys was more than half of the lampreys observed, we doubled the number of captured lampreys for the calculation of final "Adjusted Total" numbers to ensure that our abundance estimate would account for the 50% electrofishing inefficiency. However, if the number of captured lampreys was equal to, or less than half of the observed total, the recorded observed number was used instead for the adjusted total; in those specific instances, the number observed was indeed higher than the 50% electrofishing efficiency adjustment and better represented the numbers of lampreys present. The first pass density was then calculated by dividing the survey area by the adjusted total [referred to as "Electrofishing (E-Fish) Density" in the results section].

Resulting first pass lamprey densities for each habitat category were extrapolated over their respective wetted area. The resulting totals were then summed by category to get the total number of estimated lampreys from electrofishing surveys for each section. The estimated number of lampreys for each section were then tallied together to get the total number of lampreys in Type I habitat (for each diversion). The total number of lampreys removed from dry banks and

electrofishing prior to the first pass estimation surveys in each section were added to the estimated total, to arrive at a final estimated number of lampreys at each diversion. Because we did not include any estimate from lampreys residing in Type II habitat during our electrofishing surveys, our estimate is likely a conservative estimate.

For each diversion, we also calculated the total number of lampreys captured each day (from high density zones) through electrofishing, and present the daily catch per unit effort (CPUE). The daily CPUE is a division of the daily total number captured by the daily total electrofishing time. The electrofishing density for each day is also shown (calculated from all daily survey data within the high density zones). Both Type I and II habitat were included in these rescue surveys, although large preference was given to high density areas, focusing on Type I habitat. In the end, we calculated the percentage of lampreys that were removed from electrofishing (based on our abundance estimate).

Results

Sunnyside Diversion

At Sunnyside Diversion, we estimate a total of 5,196 larval lampreys were present in wetted Type I habitat downstream of the fish screens based on single pass electrofishing surveys on November 8 and 9, 2018 (Table 3). However, only an estimated 7% of the Type I habitat in this area was wetted and accessible for electrofishing (189 m^2; Table 2). A total of 1601 larval lampreys were removed from the dry banks during and immediately after dewatering. Electrofishing surveys were conducted as the water level was dropping on November 7, 2018. In total, we estimate that 7,249 lampreys were present downstream of the fish screens at Sunnyside Diversion in Type I habitat (Table 3). In total, we captured a total of 2,176 larval lampreys from electrofishing (Table 4), which accounts for 41.9% of the lampreys we estimated to reside in wetted Type I habitat. The number of captured lampreys from electrofishing was highest on the last day (651), and the CPUE was higher on the last day (13.6 #/min) compared to the first day (9.4 #/min).

Table 1. Estimated area of Type I (preferred), Type II (acceptable) and Type III (unusable) larval lamprey habitat for each delineated section downstream of the fish screens at Sunnyside Diversion.

Section #	Section Description	Overall Section Area (m2)	% of Section Type I	% of Section Type II	% of Section Type III	Area of Type I (m2)	Area of Type II (m2)	Area of Type III (m2)
D1	Canal	1992	70%	10%	20%	1394	199	398
D2	Screens	1489	80%	10%	10%	1191	149	149
Total	**-**	**3481**	**74%**	**10%**	**16%**	**2586**	**348**	**547**

Table 2. Estimated area of wetted Type I (preferred) habitat for each delineated section downstream of the fish screens at Sunnyside Diversion. "First Pass Survey Date" is the date when a first pass electrofishing survey was conducted within the respective section. "Days Post Water Drawdown" is the number of days after November 7, 2018, the day when the pumps dropped the water to its lowest level.

Section #	Section Description	First Pass Survey Date	Days Post Water Drawdown	Overall Section Area (m2)	% Type I Wet	% Type I Dry	Wetted Type I Area (m2)	Dry Type I Area (m2)
D1	Canal	11/9/2018	2	1992	5%	95%	70	1325
D2	Screens	11/8/2018	1	1489	10%	90%	119	1072
Total	**All**		**-**	**3481**	**7%**	**93%**	**189**	**2397**

Table 3. Total estimated number of lampreys in Type I habitat downstream of the fish screens at Sunnyside Diversion. The estimated number of lampreys for each section, and habitat category, are shown. The blue bold font at the bottom of the table indicates the total estimated number. "First Pass Survey Date" is the date when a first pass electrofishing survey was conducted within the respective section. "Total # Recovered from Dry Banks" is the total number of exposed lampreys removed from dry banks. The "Total Previous # Recovered from Electrofishing" is the number of lampreys opportunistically removed by electrofishing before a first pass in each section was completed.

Section	Type I Habitat Category	First Pass Survey Date	Area of Wetted Type I (m2)	Survey Area (m2) Type I	Total # Captured	Total # Observed	# Adjusted Total	E-Fish Density (#/m2)	Estimated # (E-Fish)
D1	Edge/Main	11/9/2018	70	10	14	14	28	2.8	195
D1	Isolated Pool	11/9/2018	15	12	268	368	536	44.7	670
D2	Edge/Main	11/8/2018	119	28	509	739	1018	36.4	4331
Estimated Total (E-Fish)									**5196**
Total # Recovered from Dry Banks									**1601**
Total Previous # Recovered from Electrofishing									**452**
Total Estimated # in Type I Habitat									**7249**

Table 4. Daily lamprey capture details from electrofishing surveys downstream of the fish screens at Sunnyside Diversion (cumulative for all surveyed sections and habitat types). The "Cumml. # of Days Post Water Drawdown" is the number of days after November 7, 2018, the day when the pumps dropped the water to its lowest level. "% of Observed Captured" shows the percent captured within the observed number.

Survey Date	# of Days Between Surveys	Cummul. # of Days Post Water Drawdown	Shock Time (min)	Shock Area (m2)	# Captured	# Observed	% of Observed Captured	# Adjusted Total	Cumml. # Removed (E-Fish)	Daily CPUE (#/min)	Daily E-Fish Density (#/m2)
11/6/2018	-	-	0.0	0	-	-	-	-	-	-	-
11/7/2018	1	0	42.5	40	400	500	80%	800	400	9.4	20.3
11/8/2018	1	1	28.4	29	561	826	68%	1122	961	19.8	38.7
11/9/2018	1	2	35.8	37	600	800	75%	1200	1561	16.8	32.4
11/13/2018	4	6	45.2	47	615	677	91%	1230	2176	13.6	26.2
Total		**-**	**151.9**	**153**	**2176**	**2803**	**78%**	**4352**	**2176**	**14.3**	**28.5**

Wapato Diversion

At Wapato Diversion, we estimate that a total of 9,350 larval lampreys were present in wetted Type I habitat downstream of the fish screens based on single pass electrofishing surveys on October 18 and 19, 2018 (Table 7). An estimated 43% of the Type I habitat was wet and available for electrofishing (696 m^2; Table 2), compared to only 7% at Sunnyside Diversion. A total of 1,531 larval lampreys were removed from the dry banks. The lampreys removed from the dewatered banks were combined with our electrofishing total to estimate the total number of lampreys. In total, we estimated that 10,880 lampreys were present upstream of the fish screens at Wapato Diversion in Type I habitat (Table 3). We captured a total of 4,353 larval lampreys from electrofishing (Table 8), which accounts for 46.6% of the lampreys we estimated to reside in wetted Type I habitat (similar to Sunnyside Diversion at 41.9%). Daily electrofishing surveys that contribute to the overall wet captured number includes some Type II habitat survey, although the majority of all surveys focused on Type I habitat. On each day, our survey efforts focus on the highest density areas, so we expect to see a decrease in CPUE from the first to the last survey date. The CPUE showed a small decrease from the first survey date (11.9 #/min) to the last survey date (9.3 #/min). The small decrease in CPUE between the first and last survey dates suggest that a significant number of lampreys still remained in Wapato Diversion after our last survey date.

Table 5. Estimated area of Type I (preferred), Type II (acceptable) and Type III (unacceptable) larval lamprey habitat for each delineated section upstream of the fish screens at Wapato Diversion.

Section #	Section Description	Overall Section Area (m2)	% of Section Type I	% of Section Type II	% of Section Type III	Area of Type I (m2)	Area of Type II (m2)	Area of Type III (m2)
U1	Screens	249	100%	0%	0%	249	0	0
U2	Screens	569	95%	5%	0%	541	28	0
U3	Screens	730	60%	40%	0%	438	292	0
U4	Screens	740	30%	70%	0%	222	518	0
U5	Trashrack	350	0%	60%	40%	0	210	140
U6	Canal (50 m)	1672	10%	80%	10%	167	1338	167
Total	**-**	**4310**	**38%**	**55%**	**7%**	**1617**	**2386**	**307**

Table 6. Estimated area of wetted Type I (preferred) habitat for each delineated section upstream of the fish screens at Wapato Diversion. "First Pass Survey Date" is the date when a first pass electrofishing survey was conducted within the respective section.

Section #	Section Description	First Pass Survey Date	Days Post Headgate Closure	Overall Section Area (m2)	% Type I Wet	% Type I Dry	Wetted Type I Area (m2)	Dry Type I Area (m2)
U1	Screens	10/19/2018	2	249	95%	5%	237	12
U2	Screens	10/18/2018	1	569	40%	60%	216	324
U3	Screens	10/18/2018	1	730	25%	75%	110	329
U4	Screens	10/18/2018	1	740	30%	70%	67	155
U5	Trashrack	-	-	350	100%	0%	0	0
U6	Canal (50 m)	10/18/2018	1	1672	40%	60%	67	100
Total	**All**		**-**	**4310**	**43%**	**57%**	**696**	**921**

Table 7. Total estimated number of lampreys in Type I habitat upstream of the fish screens at Wapato Diversion. The estimated number of lampreys for each section, and habitat category, are shown. The blue bold font at the bottom of the table indicates the total estimated number of lampreys. "First Pass Survey Date" is the date when a first pass electrofishing survey was conducted within the respective section. "Total # Recovered from Dry Banks" is the total number of exposed lampreys removed from dry banks.

Section	Type I Habitat Category	First Pass Survey Date	Area of Wetted Type I (m2)	Survey Area (m2) Type I	Total # Captured	Total # Observed	# Adjusted Total	E-Fish Density (#/m2)	Estimated # (E-Fish)
U1	Edge/Main	10/19/2018	237	10	5	6	10	1.0	237
U2	Edge	10/18/2018	126	11	109	129	218	19.8	2505
U2	Main	10/18/2018	90	10	35	45	70	7.0	629
U3	Edge	10/18/2018	36	25	327	654	654	26.2	952
U3	Main	10/18/2018	73	10	99	199	199	19.9	1455
U4	Edge	10/18/2018	17	15	228	456	456	30.4	511
U4	Main	10/18/2018	50	9	128	213	256	28.4	1417
U5	-	-	0	-	-	-	-	-	-
U6	Edge/Man	10/18/2018	67	10	123	230	246	24.6	1645
Estimated Total (E-Fish)									**9350**
Total # Recovered from Dry Banks									**1531**
Total Estimated # in Type I Habitat									**10880**

Table 8. Daily lamprey capture details from electrofishing surveys upstream of the fish screens at Wapato Diversion (cumulative for all surveyed sections and habitat types). The "Cumml. # of Days Post Dewatering" is the number of days after the headgate was closed on October 17, 2018. *On October 25, 2018, survey data was incomplete, so daily CPUE and electrofishing density was not calculated. "% of Captured (Observed)" shows the percent captured within the observed number.

Survey Date	# of Days Post Previous Survey	Cummul. # of Days Post Dewatering	Shock Time (min)	Survey Area (m2)	# Captured	# Observed	% of Captured (Observed)	# Adjusted Total	% of Captured (Adjusted Total)	Cumml. # Removed (E-Fish)	Daily CPUE (#/min)	E-Fish Density (#/m2)
10/18/2018	0	1	101.4	100	1208	2385	51%	2558	47%	1208	11.9	25.6
10/19/2018	1	2	141.6	175	1198	1484	81%	2396	50%	2406	8.5	13.7
10/22/2018	3	5	117.6	161	805	1196	67%	1597	50%	3211	6.8	9.9
10/24/2018	2	7	43.1	43	450	580	78%	900	50%	3661	10.4	20.9
10/25/2018*	1	8	39.6	39	531	681	78%	1062	50%	4192	-	-
11/16/2018	22	30	17.3	17	161	230	70%	322	50%	4353	9.3	18.9
Total		**-**	**460.5**	**535**	**4353**	**6556**	**66%**	**8835**	**49%**	**4353**	**9.5**	**16.5**

Discussion

Our daily electrofishing efforts (after the first pass estimation surveys) focused on the areas with the highest density of lampreys to ensure the greatest number of rescued fish. As a result, although the majority of surveys focused on Type I habitat, the overall captured number includes some lampreys from Type II habitat. The density of lampreys from Type II habitat is typically around 10% of the density from adjacent Type I habitat from our past surveys.

The number of captured lampreys, and the daily CPUE, was expected to decrease from the first to the last survey date. However, in the case of Sunnyside Diversion, the number of captured lampreys was actually highest on the last day (651), and the CPUE was higher on the last day (13.6 #/min) compared to the first day (9.4 #/min). At Wapato Diversion, the CPUE showed a small decrease from the first survey date (11.9 #/min) to the last survey date (9.3 #/min). The lack of major reduction in CPUE (as well as density) between the first and last survey dates suggest that a significant number of lampreys still remained in both Sunnyside and Wapato diversions after our last survey dates.

Part II – Effects of Dewatering Rates on Larval Lampreys

Methods

For Sunnyside Diversion, the YNPLP closely coordinated with the Bureau of Reclamation (BOR) regarding their scheduled pump operations (both a large [12 inch] and small [8 inch] industrial water pumps are needed to drop the water level at Sunnyside due to subsurface flow and variable levels of leak in the headworks annually). The plan was to perform all pump dewatering operations during the day time to allow for easy rescue of the stranded lampreys, and mitigate desiccation and predation as much as possible.

Prior to diversion shut-off at Wapato Diversion, the YNPLP closely collaborated with the Wapato Irrigation Project (WIP) to design a dewatering schedule conducive to limiting larval lamprey mortality. The headgate would be closed in stages (rather than all at once), and a weir several miles downstream (referred to as "Drop 1") would be operated in a way to let water slowly drain from the screening area, effectively slowing the rate of dewatering.

Changing water levels at both diversions were monitored closely in order to estimate the "critical" dewatering rate; the dewatering rate when the largest amount of larval lamrey habitat becomes exposed. While water levels were dropping, water depth was periodically recorded using the diversions' water height gauges. When the water level dropped below the lowest value on the gauge, we measured the water depth using a tape measure secured in place at a consistent location to monitor those changes. The critical dewatering rate occurred below the lowest level on the gauge. Incremental dewatering rates were then calculated from the water level observation time and resulting drop in water levels.

Results

Sunnyside Diversion

At Sunnyside and Wapato diversions, we evaluated the dewatering rate in the areas with the highest densities of lampreys. At Sunnyside Diversion, we closely coordinated with BOR, and agreed upon a schedule where all pump dewatering operations would be performed during the day time. Both the 12" and 8" pumps were available for operation, although the 12" pump was shut off automatically when the water level got too low. Although the water level had to be dropped fairly quickly (within 12 hours) due to next day salmon rescue operations, our crew was able to pick up lampreys as they became exposed, greatly limiting mortality (of what could be seen). Out of 1,231 larval lampreys collected during the day on 11/7/2018, only 6.8% (84) were dead (Table 9 and Figure 3). Most of the dead lampreys were young of year lampreys (< 36 mm). The maximum incremental dewatering rate that was observed was 20.8 cm/hr which lasted for about 49 minutes

(Table 9 and Figure 3). For a 155 minute period from 10:40 to 12:45, the incremental dewatering rate varied between 18.5 and 20.8 cm/hr (with both pumps running).

Table 9. Incremental dewatering rate calculated at Sunnyside Diversion on November 7, 2018 from a measuring tape placed at the bypass pipe immediately downstream of the fish screens. "12" (or 8") Pump Running" highlights whether the 12" or 8" pump was running (an "x" indicates the pump was running). "Cumulative Water Drop" is the total water drop observed. "Incremental Time Change" is the number of minutes between the water height measurement. "Incremental Dewater Rate" is the rate at which the water level dropped between measurements. Bold text highlights the time when the dewatering rate was at its peak.

Water Measurement Time	Water Depth (cm)	Cumulative Water Drop (cm)	Incremental Time Change (min)	Incremental Water Drop (cm)	Incremental Dewatering Rate (cm/hr)	12" Pump Running	8" Pump Running	Pump Comments
7:30	155	0	0	0.0	0.0	X	X	Both Pumps Running
10:10	130	25	160	25.0	9.4	X	X	Both Pumps Running
10:40	**120**	**35**	**30**	**10.0**	**20.0**	**X**	**X**	Both Pumps Running
10:55	**115**	**40**	**15**	**5.0**	**20.0**	**X**	**X**	Both Pumps Running
11:30	**103**	**52**	**35**	**12.0**	**20.6**	**X**	**X**	Both Pumps Running
11:56	**95**	**60**	**26**	**8.0**	**18.5**	**X**	**X**	Both Pumps Running
12:45	**78**	**77**	**49**	**17.0**	**20.8**	**-**	X	12" Pump off at 12:40
13:12	75	80	27	3.0	6.7	-	X	8" Running
13:32	70	85	20	5.0	15.0	-	X	8" Running
13:56	64	91	24	6.0	15.0	-	X	8" Running
14:15	63	92	19	1.0	3.2	-	X	8" Running
15:00	63	92	45	0.0	0.0	-	-	**No** Pumps Running
16:30	63	92	90	0.0	0.0	-	-	**No** Pumps Running

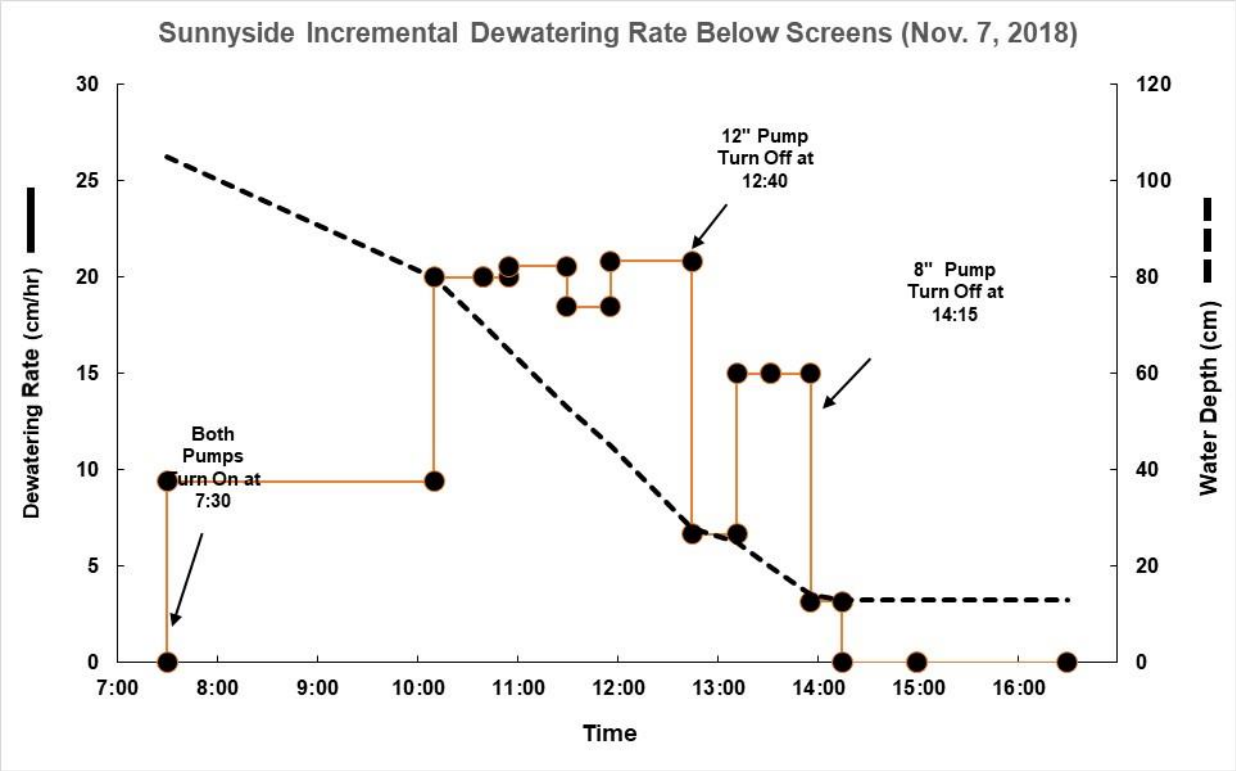

Figure 3. Incremental dewater rate observed at Sunnyside Diversion on November 7, 2018. The majority of Type I habitat dewatering downstream of the screens at Sunnyside Diversion occurred on this date. The operating schedule of each pump is also shown. The water depth was measured near a bypass pipe, located immediately downstream of the fish screens near the center of the screen complex.

Table 10. Summary of daily lamprey capture from dry banks at Sunnyside Diversion downstream of the fish screens. The "Cumml. # of Days Post Water Drawdown" is the number of days after the pumps dropped the water to its lowest level on November 7, 2018.

Survey Date	# of Days Between Surveys	Cummul. # of Days Post Water Drawdown	# Live (Dry Bank)	# Dead (Dry Bank)	# Observed (Live+Dead)	% Dead	Cumml. # Removed (Dry Bank)
11/6/2018	-1	-	76	0	76	0.0%	76
11/7/2018*	1	0	1147	84	1231	6.8%	1307
11/8/2018	1	1	182	36	218	16.5%	1525
11/9/2018	1	2	13	63	76	82.9%	1601
11/13/2018	4	6	0	0	0	-	1601
Total		**-**	**1418**	**183**	**1601**	**11.4%**	**1601**

Wapato Diversion

At Wapato Diversion, we closely coordinated with Wapato Irrigation District, and agreed upon a schedule in which the headgate would be closed in stages, to slowly reduce the flow discharge entering the canal (Table 11). Once the headgate was shut, our goal was to use the Drop 1 Weir

gates (~ 3 miles downstream of the screens) to hold a pool of water upstream of the fish screens (then slowly open the gates and let out water). However, the water level dropped much quicker than expected, despite the efforts made to hold water at the Drop 1 gate. Water drained out of the bypass. In the future, we may place stop logs in the bypass, in conjunction with the Drop 1 weir gate adjustments, to hold water in the screen area longer.

The majority of Type I habitat became exposed on October 17, 2018. In total, 1201 larval lampreys were picked up from the dry banks on October 17, with a high mortality rate of 70.2% (843 dead lampreys). Due to the sprinkler system set up, our staff did not check for larval lampreys in the dry banks until about 15:00; as a result, many lampreys could have desiccated between 11:00 and 13:30 (a 2.5-hour period). Mortality rates were lower the next day (33.9% of 274 lampreys), potentially due to the sprinkler system that was set up overnight, which delivered water sprays to lampreys trapped on the dewatered banks. The maximum observed dewatering rate was 27.4 cm/hr and lasted for about 215 minutes between 5:00 AM and 12:10 AM. The two peaks of dewatering were observed after 100 cfs was cut from the canal at 5:00 AM, and after the final closing of the headgate at 11:00 AM (when the last remaining 100 cfs of flow in the canal was shut). However, our measurements only represent an average dewatering rate; the dewatering rates that we observed from these measurements may not fully represent the true maximum rate of dewatering, which could have contributed considerably to the large number of lampreys stranded on the dry banks at Wapato Diversion.

Table 11. Planned headgate operations at Wapato Diversion through close coordination with the Wapato Irrigation District. "CFS" is the cubic feet per second of water that is entering the canal.

Date	Time	CFS Cuts	Remaining CFS
10/15/2018	12:00 AM	-	720
10/15/2018	3:00 AM	100	620
10/15/2018	5:00 AM	100	520
10/15/2018	7:00 AM	100	420
10/16/2018	3:00 AM	100	320
10/16/2018	5:00 AM	100	220
10/17/2018	5:00 AM	100	120
10/17/2018	11:00 AM	120	0

Table 12. Incremental dewatering rate calculated at Wapato Diversion on October 17, 2018, from a measuring tape secured to an upstream bypass wall immediately upstream of the fish screens. "Incremental Time Change" is the number of minutes between two water height measurement. "Incremental Dewater Rate" is the rate at which the water level dropped over the time between each measurement. Bold text highlights the time when the dewatering rates were at its peak.

Water Measurement Time	Water Depth (cm)	Cumulative Water Drop (cm)	Incremental Time Change (min)	Incremental Water Drop (cm)	Incremental Dewatering Rate (cm/hr)	Headgate Comments
5:00	223	0	0	0	0.0	Flow Reduce by 100 CFS
7:25	**159**	**64**	**145**	**64**	**26.5**	**-**
11:00	139	84	215	20	5.5	Headgate Closed
12:10	**107**	**116**	**70**	**32**	**27.4**	**-**
12:45	104	119	35	3	5.1	-
14:25	99	124	100	5	3.0	-
16:05	92	131	100	7	4.2	-
16:40	89	134	35	3	5.1	-
18:10	84	139	90	5	3.3	-

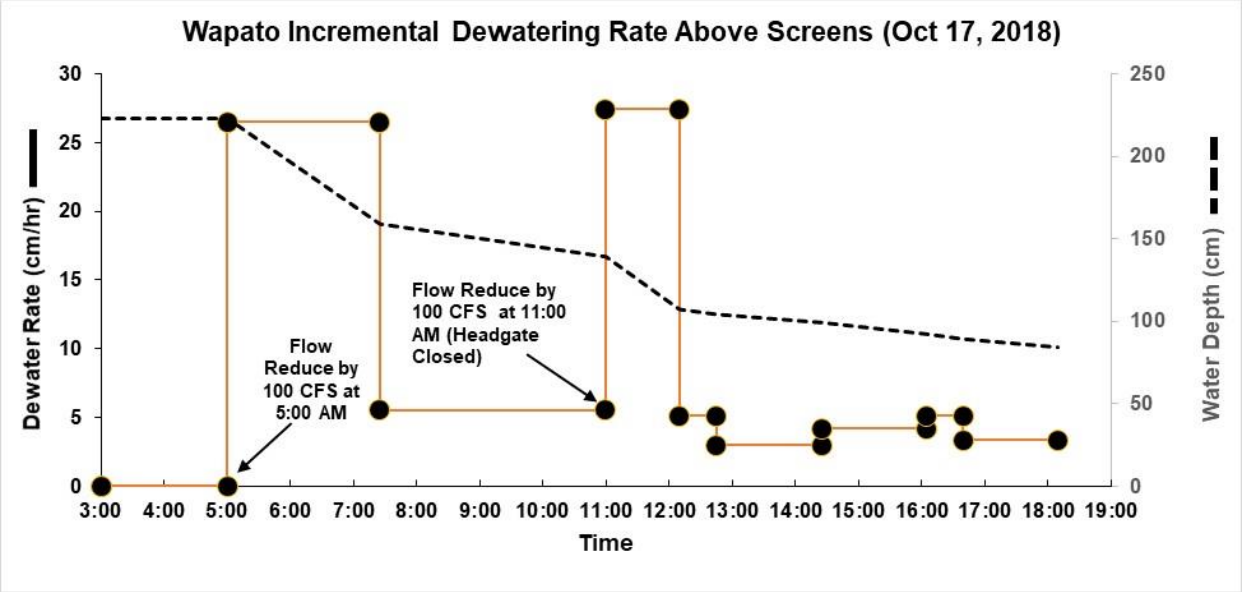

Figure 4. Incremental dewatering rate observed at Wapato Diversion on October 17, 2018. The majority of Type I habitat dewatered downstream of the screens at Sunnyside Diversion occurred on this date. The operating schedule of the head gate (and corresponding flow reduction) is shown. The water depth was measured immediately upstream of the fish screens near the mid-channel bypass wing wall, located near the center of the fish screen complex.

Table 13. Summary of daily lamprey captured from dry banks at Wapato Diversion downstream of the fish screens. The "Cumml. # of Days Post Dewatering" is the number of days after the headgate was closed on October 17, 2018.

Survey Date	# of Days Post Previous Survey	Cummul. # of Days Post Dewatering	# Live (Dry Bank)	# Dead (Dry Bank)	# Observed (Live+Dead)	% Dead	Cumml. # Removed (Dry Bank)
10/17/2018	0	0	358	843	1201	70.2%	1201
10/18/2018	1	1	181	93	274	33.9%	1475
10/19/2018	1	2	8	48	56	85.7%	1531
10/22/2018	3	5	0	0	0	-	1531
10/24/2018	2	7	0	0	0	-	1531
10/25/2018	1	8	0	0	0	-	1531
11/16/2018	22	30	0	0	0	-	1531
Total		**-**	**547**	**984**	**1531**	**64.3%**	**1531**

Discussion

Below are some considerations for lamprey rescue efforts at diversions or streams/rivers that experience dewatering activities:

- Slow rates of dewatering (<10 cm/hr) are crucial to ensure the highest level of survival for larval lampreys (especially important in areas with high densities, such as Sunnyside and Wapato diversions).
- Laboratory work by USGS has shown that larval lampreys do not react to dropping water levels until the surface of the sediment becomes dewatered, which is when they experience the changes in water availability within the burrowed fine sediment. In other words, the dewatering rate can be rapid until water reaches the fine sediment, but as soon as the water level reaches the core of the larval lamprey habitat, the dewatering rate needs to slow down (we recommend a 10 cm/hr rate or slower based on our past data).
- Lampreys can easily become trapped on dewatered banks when the water level drops. It is critical to arrive at the dewatered location soon after the fine sediment becomes dewatered (within 1-2 hours).
- The stranded lampreys that we observe upon arrival to a dewatered site are potentially only a fraction of the lampreys that are trapped within the fine sediment (our electrofishing surveys in dried sediment, after pouring water to make the sampling possible, demonstrated that many larvae can stay in the seemingly dry fine sediment).
- When conducting a lamprey rescue, electrofishing efforts should first focus on isolated pools of water (before the pools dry up) and along the bank of the main water body (lamprey densities tend to be highest in isolated pools and along the bank of the main water body).

- Installing a sprinkler system to spray over the dewatered sediment would keep both exposed and concealed lampreys alive until rescue crews arrive. Upon arrival, rescue crews should douse the wetted banks with buckets of water and electrofish for any concealed larvae (focusing on potential high density areas at the base of steep banks and naturally flat areas with Type I fine sediments).