Intensive Monitoring of Larval/Juvenile Lamprey Entrainment in Irrigation Canals within the Yakima Basin, 2020

(Cover Photo: A larval lamprey emerging from its burrow and slithering over a recently dewatered bank in Sunnyside Canal [Wapato, WA] downstream of the fish screens on October 20, 2020)

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Highlights

- We estimated that a total of 7,026 lampreys were present downstream of the fish screens in the Sunnyside Canal and 8,172 lampreys were present upstream of the fish screens in the Wapato Canal.
- Within these two high density zones, we captured a total of 6,084 lampreys in 19 days of rescue efforts, which we estimate to be up to 34% of the lampreys residing in these areas.
- Overall, the mortality rates for lampreys we encountered on sediment surfaces were 14.1% (of 546 lampreys) in the Sunnyside Canal and 22.7% (of 300 lampreys) in the Wapato Canal. The relatively high mortality rate was partially due to long-term holding in mesh laundry baskets on site at these two facilities.

Abstract

During the 2020-2021 irrigation dewatering season, the Yakama Nation Pacific Lamprey Project intensively monitored larval/juvenile lamprey entrainment in the Sunnyside and Wapato canals (intake structures located on the Yakima River at river km 171.4 and 176.2, respectively). This report is divided into two parts: 1) assessment of larval/juvenile lamprey abundance and 2) effects of dewatering rates on larval lampreys. In Part I, we used a combination of single pass electrofishing and lamprey collection from dry banks to estimate the number of lampreys within high density zones of each canal. We estimated that at least 7,026 and 8,172 lampreys were present in the Sunnyside Canal (immediately downstream of the fish screens) and the Wapato Canal (immediately upstream of the fish screens), respectively. Within these two locations, we captured a total of 6,084 lampreys in 19 days of rescue efforts (5,238 from electrofishing and 846 from dry banks), which we estimate to be up to 34% of the total numbers of lampreys that resided in these high density zones. In Part II, we examined dewatering rates at each facility and its effect on larval lamprey stranding and survival. In the Sunnyside Canal, the maximum dewatering rate on 29 October 2020 (the day when the majority of fine sediment became exposed using large water pumps) was 21.8 cm/h which lasted for ~120 min, with an average dewatering rate of 16.1 cm/h (57 cm drop over the 6.7-h period when the pumps were removing the vast majority of the water). In the Wapato Canal, the maximum dewatering rate on 16 October 2020 (the day the headgate was closed) was 25.7 cm/h which lasted for ~65 min, with an average dewatering rate of 9.3 cm/h (over the 6.0 h monitoring period after the headgate was closed). Lampreys were rescued from dry banks immediately after dewatering utilizing two methods; 1) hand collection of exposed lampreys from sediment surfaces, and 2) electrofishing on top of moist sediment to expose concealed lampreys. Mortality of lampreys trapped on dry banks (both methods combined) was generally high (14.1% of 546 lampreys in the Sunnyside Canal and 22.7% of 300 lampreys in the Wapato Canal), partially due to long-term holding in mesh laundry baskets on site at these two facilities. The majority of dewatering at both locations occurred during the day time, allowing our crew to easily see and collect exposed lampreys.

Introduction

The Pacific Lamprey (*Entosphenus tridentatus*) is an invaluable cultural and ecological resource that has shown declines in both distribution and abundance throughout the Columbia River Basin (CRB) (Kostow 2002). One of the myriad of threats Pacific Lamprey as well as other endemic lamprey species face within the CRB is entrainment within irrigation canals, which poses a sizeable risk to downstream migrating larval and juvenile life stages. The Yakama Nation Pacific Lamprey Project (YNPLP) has been surveying and salvaging larval and juvenile lampreys in irrigation canals within the Yakima Subbasin since 2011. Starting in the 2014 irrigation dewatering season, the YNPLP began intensively monitoring larval and juvenile lamprey entrainment in two large-scale irrigation canals of the Yakima River: the Sunnyside and Wapato canals (intake structures located at river km 171.4 and 176.2, diverting 1,500 and 1,800 cfs of water, respectively). Surveys conducted in the fall after dewatering in these two canals demonstrated that thousands of lampreys are found entrained downstream of the fish screens each year (Lampman et al. 2014 and 2015). Sunnyside and Wapato diversions have consistently carried the largest number of entrained lampreys by far within the Yakima Subbasin and the estimated number was 11,664 and 7,423, respectively, based on a mark-recapture study in 2014 (Beals & Lampman 2015). In a high abundance year, over 40,000 lampreys were estimated to reside in the Wapato Canal alone in 2017 (Lampman and Beals 2019).

The Sunnyside and Wapato canals each have a row of 15 large, woven wire mesh (3.18-mm mesh size) drum screens. Both facilities also have a long (>300 m) canal channel in between its headgate structure and fish screens. These canals, however, have widely contrasting locations where fine sediment and lamprey are distributed relative to the fish screens (Lampman and Beals 2019). At the Sunnyside Canal, the largest volumes of fine sediment and highest densities of lampreys are found immediately downstream of the fish screens. Conversely, at the Wapato Canal, the largest volumes of fine sediment and highest densities of lampreys are found immediately upstream of the fish screens. These two canals also draw down water levels slightly differently in the fall after irrigation shutdown. At the Sunnyside Canal, two large industrial water pumps are used to pump the water level down to a wadeable level (due to various degrees of leakage in the headgate structure each year and contribution from subsurface flows). At the Wapato Canal, when the headgate is closed, water is drained more efficiently through the bypass and other channels within the irrigation canal downstream of the fish screens and pumps are typically not needed. The contrasting fine sediment and lamprey distribution and distinct dewatering operations provide a unique and pronounced opportunity to understand contrasting mechanisms of lamprey entrainment occurring at a large scale within the field. The two canals also provide an opportunity to test and develop innovative strategies to mitigate lamprey mortality during irrigation shutdown, allowing us to observe the results first hand in situ.

The large volumes of fine sediment that collect in these canals provide ideal, yet potentially misleading, habitat for larval lampreys. Water is typically drained in the fall in October/November (or the summer in June/July for some tributary canals), and numerous lampreys burrowed in the fine sediment may be left to desiccate at many of these facilities unless rescue efforts take place to save them. Irrigation canals accessible to anadromous fishes are prevalent throughout the CRB, 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.

In addition to Pacific Lamprey, *Lampetra* spp. (resident Western Brook Lamprey [*Lampetra richardsoni*] and anadromous Western River Lamprey [*Lampetra ayresii*]) are present in the Yakima Subbasin (Lampman 2014). Western Brook Lamprey and Western River Lamprey can only be distinguished in their juvenile and adult life stage (i.e. identical morphological features as larvae; Lampman 2018). Each species utilizes nearly identical fine sediment habitat during their larval and early transformer life stages, so our efforts to rescue Pacific Lamprey also results in the rescue of many *Lampetra* spp. as well. To date, no eyed juvenile Western River Lamprey have been positively identified during irrigation canal surveys or stream habitat electrofishing surveys, although they have been captured at Chandler Juvenile Fish Monitoring Facility almost every year (Beals and Lampman 2020).

As in past years, our surveys during the 2020–2021 irrigation dewatering season within these two canals had four primary objectives: 1) rescue as many trapped lampreys as feasible, 2) estimate the number of lampreys residing in the high density zones, 3) closely monitor larval and juvenile lamprey responses during the dewatering process, and 4) facilitate innovative changes in project operations to optimize the dewatering rates and rescue efficiencies at each facility. This report is divided into two main sections, summarizing our rescue efforts at the Sunnyside and Wapato canals to highlight the key results stemming from the aforementioned four objectives: 1) Part I – Assessment of Larval/Juvenile Lamprey Abundance, and 2) Part II – Effects of Dewatering rates on Larval Lampreys.

Methods

Part I – Assessment of Larval/Juvenile Lamprey Abundance

The Sunnyside and Wapato canals were intensively surveyed for larval/juvenile lampreys during the 2020 dewatering season in October and November, 2020 (Fig. 1 and 2). Surveys in these two canals were focused on the areas that have been known to collect large volumes of fine sediment and, consequently, large numbers of lampreys. In the Sunnyside Canal, surveys were focused immediately downstream of the fish screens, extending downstream to the I-82 Highway Bridge. In the Wapato Canal, surveys were focused upstream of the fish screens, extending 50 m upstream of the trashrack structure. Surveys were conducted as close as possible to the initial dewatering date to limit the additional loss of lampreys from desiccation and/or predation. Both canals required multiple days of dewatering to access optimal lamprey habitat. Both canals were visited daily during the dewatering operation to collect stranded lampreys as additional sediment became exposed.

The high density zones in the Sunnyside and Wapato canals were each spatially divided into sections (prior to dewatering). This was important because of the substantial variation in lamprey densities depending on the location within the canal. In the Sunnyside Canal, the high density 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). In the Wapato Canal, the high density zone upstream of the fish screens was divided into three sections, U1-U3 ("U" stands for "Upstream", numbered in order from downstream to upstream; Fig. 2).

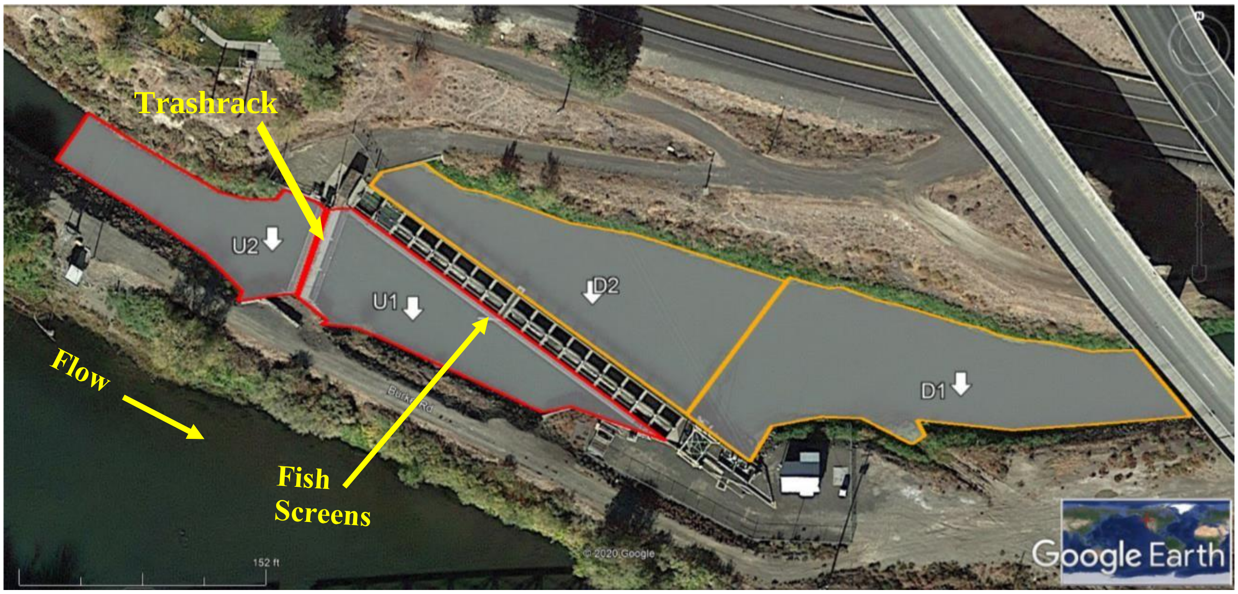


Figure 1. Delineated sections in the Sunnyside Canal (Yakima River, river km 171.4). Surveys focused on sections D1 (from the most downstream fish screen to the I-82 Southbound Bridge) and D2 (immediately downstream of the fish screens) shown with orange outlines. Sections upstream of the fish screens (U1 and U2) shown with red outlines were not included in the abundance estimates for the Sunnyside Canal.

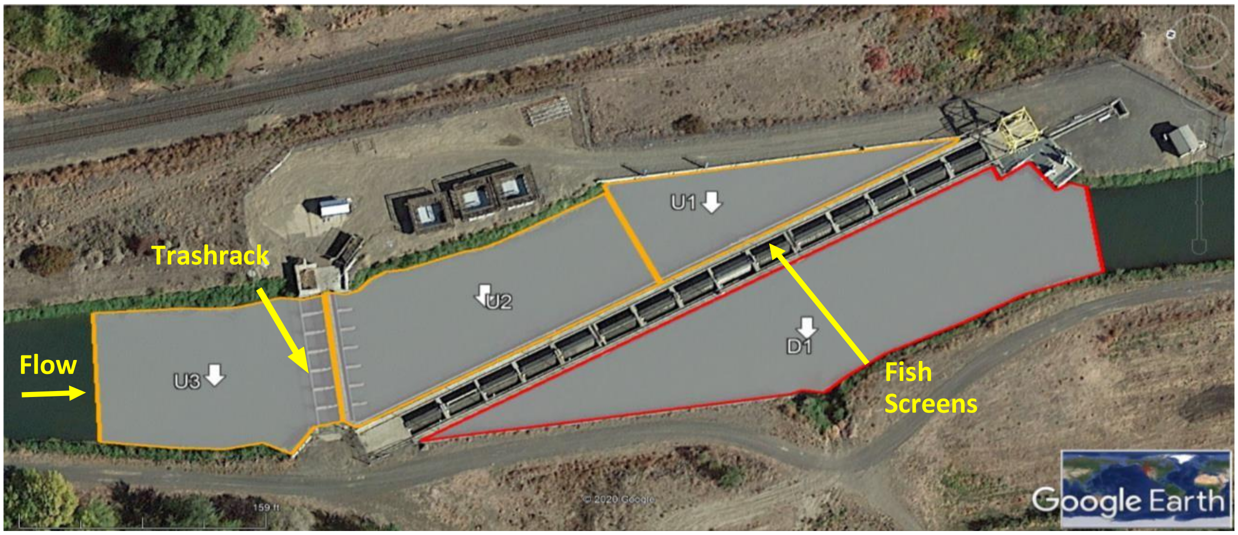


Figure 2. Delineated sections in the Wapato Canal (Yakima River, river km 171.4). Surveys focused on sections U1 (immediately upstream of the fish screens to the end of the north concrete wall), U2 (from the upstream end of U1 up to the trashrack), and U3 (from the trashrack to 50 m upstream) shown with orange outlines. The section downstream of the fish screens (D1) shown with red outlines was not included in the abundance estimates for the Wapato Canal.

Survey & Rescue Techniques

Larval lamprey habitat is classified into three categories (Slade et al. 2003): preferred habitat (Type I), acceptable habitat (Type II), and unacceptable habitat (Type III) (Fig.3). Type I habitat consists of fine sediment (sand, silt, clay), organic matter / detritus, or a combination of both, and lacks coarse substrate (e.g., gravel, cobble, boulder, bedrock). Type II habitat is shifting coarse sand or other fine substrate mixed with coarse substrate. Type III habitat consists of only coarse substrate with no fine sediment. Our surveys focused primarily on Type I habitat and secondarily on Type II habitat. No surveys were conducted in Type III habitat.

ABP-2 backpack electrofishers (ETS Electrofishing Systems LLC., Madison, WI), specifically designed for sampling larval lampreys were used to remove and rescue larval/juvenile lampreys from wetted sediments or newly dewatered drying banks. The ABP-2 features two output modes for lamprey capture: a slow 'tickle' pulse of 3 Hertz (pulses/sec) to induce larval emergence from the substrate and a fast pulse of 30 Hertz to temporarily stun and aid the capture of emerged larvae (Slade et al. 2003). Our surveys also applied other standard larval lamprey survey protocols, including 125 volts, 25% duty cycle and 3:1 burst pulse train. To compensate for reduced conductivity, voltage was increased to 150-200 volts when water temperatures were less than 10°C.

Surveys were conducted with a crew of two to four people: one electrofisher operator and one to three netters. Lampreys stranded on top of recently dewatered sediments were collected by hand and/or hand nets. Recently dewatered (dry) banks were also electrofished using the same settings for underwater electrofishing to encourage concealed lampreys to emerge (hereafter termed “dry shocking”); lampreys collected from dry shocking were counted separately from those collected by hand. For abundance estimation in wetted habitat, we used single pass electrofishing due to its efficiency in covering an expansive area (Slade et al. 2003; Silva et al. 2014 and 2016; Reid and Goodman 2015). Sites were surveyed at a rate of approximately 1 m^2 per 60 s (of slow pulse time).

Within each section, single pass electrofishing surveys were performed in plots (10-30 m^2 area in size). The goal was to cover at least 5% of the Type I habitat to ensure the subsamples sufficiently represent the overall area. Surveys were conducted in three unique survey locations (when present): 1) the main water body, 2) along the bank of the main water body (the “bank” is defined as the area $\leq$ 2 m from the water’s bank), or 3) within isolated pools. These unique survey locations (“bank” of main water body, “main” water body, and “isolated pool”) are referred to as “habitat categories” and were identified to best categorize the variable densities within each section. The specific location of each plot (within each section/habitat category) was randomly selected by the electrofishing team, covering well distributed (and visually representative) subsamples of Type I and Type II habitat within each of the delineated sections. The goal of the single pass electrofishing survey is to efficiently cover representative areas that adequately cover the highly variable densities that were present within each section/habitat category based on visual inspection of the overall area.

For each surveyed plot, records of habitat category, survey (electrofishing) time, area surveyed (m^2 area), and total numbers of electrofished lampreys (captured and missed) were recorded separately by habitat type (Type I and Type II habitat). Because we were not incorporating capture numbers from multiple passes, we also counted the number of “missed” lampreys (those that were observed emerging from the substrate but were not captured by our nets) from our single pass surveys. Survey visibility was also recorded in 10% increments (described as the percent of the water column that was sufficiently visible during the survey). The number of missed lampreys was only recorded by the electrofishing person, to limit double counting with the person(s) netting. Captured lampreys were immediately placed into flow-through mesh baskets (Fig. 4) until their enumeration, identification, and/or release. Rescued (live) lampreys were returned to the river/stream, downstream of the respective canal headgate. In some cases, lampreys were transported to a safe location further downstream, depending on the distribution of habitat and/or nearby canal facilities (i.e. lack of larval lamprey habitat or close proximity to another canal intake).

Within each canal, captured lampreys were numerated from each section. Then, after counting, all lampreys were grouped by collection location (upstream and downstream) and collection source (wetted habitat or dry banks). Lampreys captured from each source were measured and identified at least once, generally on the first day of survey. A minimum of 30 lampreys were measured for total length (to the nearest 1 mm) from each source. The 30 measured lampreys excluded young-of-year (YOY) lampreys due to their sometimes high abundance and distinct narrow size range (estimated to be $\leq$ 27 mm, $\leq$ 30 mm, $\leq$ 36 mm and $\leq$ 38 mm in July, August, October and November, respectively based on YNPLP unpublished data). In some cases, the number of captured lampreys from a given source was high (> 250). In this case, we removed a representative subsample of approximately 100 lampreys (excluding YOY larvae) to help in the visual determination of which 30 lampreys should be measured as part of the representative subsample.

In addition to the 30 subsample, a minimum of ten YOY larvae, when present, were measured for total length: the longest, shortest, and eight intermediate-length individuals. Metamorphosed lampreys (with eyes) that were not included in the 30 subsample were tallied by each genus/species, and up to 10 were measured for total length. In addition to the total length measurements, a minimum of 30 lampreys were identified (if of identifiable length, i.e. ≥ 50 mm) from the high density zones as either Pacific Lamprey or *Lampetra* spp. If there were less than 30 lampreys of identifiable length within the subsampled lampreys collected from the high density zones, additional lampreys outside of the subsample (from the same collection location) were identified to reach the identification minimum threshold number goal. Species identification was only limited to live lampreys as identification of decomposing lampreys collected from dry banks tended to be challenging. Lampreys were measured for total length using a photarium (Wild Fish Conservancy, Duvall, WA) without anesthetics. Photariums were also useful in observing tail characteristics for identification. Genetic samples (fin clips) were collected from each canal from Pacific Lamprey and, in some cases, *Lampetra* spp. and lampreys too small to identify (< 50 mm total length).

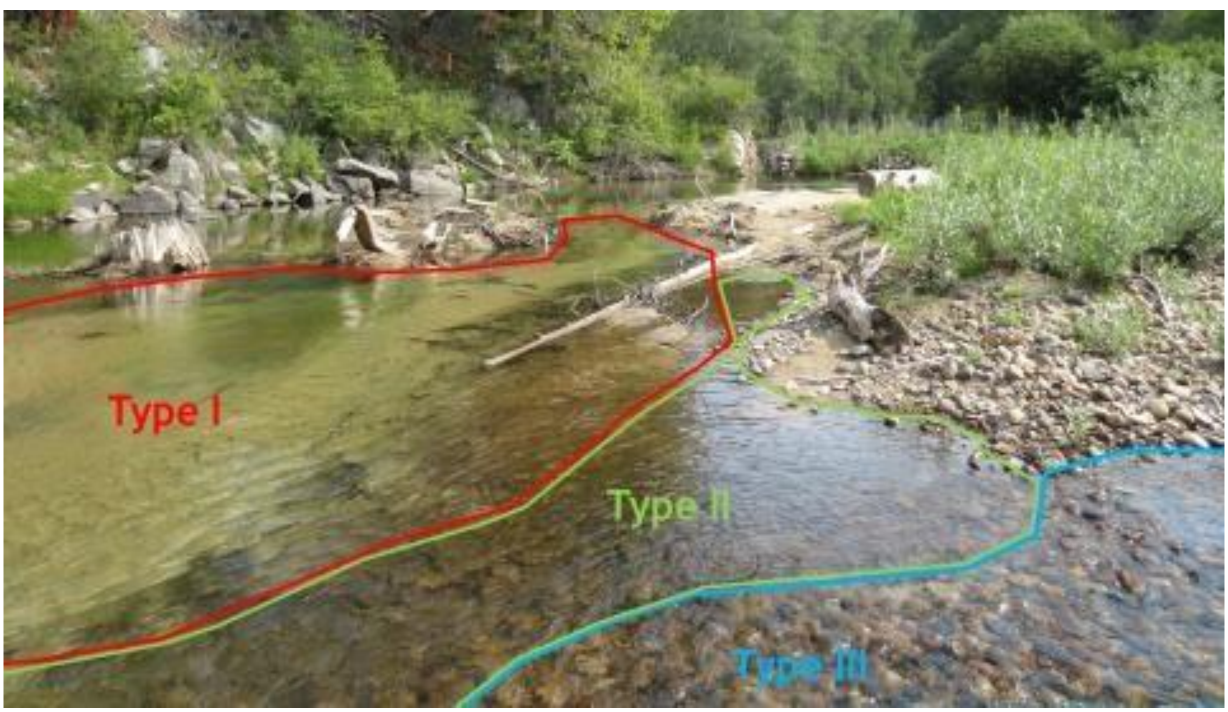


Figure 3. An example of Type I, II, and III habitats used by larval/juvenile lampreys in a stream.

Figure 4. A 21-gallon mesh laundry basket (Fyllen brand) with a ~750 micron-mesh that was used to hold captured lampreys prior to release. The baskets were purchased from IKEA and can be found at the following link: https://www.ikea.com/us/en/p/fyllen-laundry-basket-white20408017/.

Estimating the Number of Entrained Lampreys

The number of missed lampreys was added to the number of captured lampreys to get an observed total for each plot. Then, we calculated an estimated number of lampreys from electrofishing, which is the number of observed lampreys adjusted based on the survey visibility. To calculate this adjusted number, the number of missed lampreys was adjusted based on the survey area visibility (see Lampman and Beals 2019). When the survey area visibility was less than 100%, the total number of missed lampreys was adjusted (increased) based on the percent visibility to account for the number of lampreys that emerged but likely remained invisible to our surveyors while electrofishing due to visibility limitations. For this calculation, the number of missed lampreys was divided by the estimated percent visibility (i.e., if 50% of the water volume was clearly visible, the number of missed lampreys was doubled). From this, an estimated lamprey density (#/m^2) was calculated for each individual plot by dividing the estimated number of lampreys from electrofishing (the adjusted observed total based on survey visibility) by the surveyed area (m^2).

The polygon feature on Google Earth Pro was used to calculate the overall surface area (m^2) of each delineated section in the high density zones at Sunnyside and Wapato canals. On site prior to our estimation survey, we visually estimated the percent of surface area in each section covered by water (i.e. "wetted" area). Then, based on a visual inspection of the sediment distribution throughout the high density zones, we estimated the percent of each habitat type (Type I, II and III) within the wetted areas. The YNPLP uses a minimum size threshold of 0.5 m^2 to avoid over splitting of habitat. If multiple small Type I habitat patches (< 0.5 m^2) are embedded inside Type III habitat, this overall area was classified as Type II habitat. The overall area of each habitat category surveyed within each section (“bank”, “main” and “isolated pool”) was visually estimated.

The attained plot densities were grouped by habitat category. The resulting density for each habitat category was then extrapolated over the respective wetted area. The density was applied to similar habitat category areas, even if they were not directly surveyed (i.e. isolated pool densities from a surveyed area were applied to other isolated pools that were not surveyed). If Type II habitat was not surveyed on the same day as Type I, we estimated larval density in Type II habitat by multiplying Type I habitat density by 0.1 (10%) based on Great Lakes sea lamprey research (Slade et al. 2003) and Yakama Nation field survey data (T. Beals, YNPLP, unpublished data). The extrapolated totals for Type I and Type II habitat for each habitat category (i.e. bank, open water, or isolated pool) and section (“U” sections at Wapato Canal and “D” sections at Sunnyside Canal) were summed together to attain the estimated number of lampreys from electrofishing surveys. The total number of lampreys removed from dry banks and electrofishing efforts prior to the representative survey were added to this number to attain the estimated minimum total number for each canal. The term “removed” is used here instead of “rescued” due to the fact that a small number of lampreys were collected as mortalities and not all were returned back to the river alive. The term “minimum” is used here because these estimates are based on single pass electrofishing surveys, which does not account for electrofishing inefficiencies. Maximum estimated percentages of lampreys removed from the high density zones were calculated by dividing the total number removed from each canal (via electrofishing and bank collection) by our minimum abundance estimate. This is considered a “maximum” rate due to our lack of consideration for electrofishing efficiency in this study; past studies have demonstrated that lamprey specific electrofishing efficiency can range from 13-82% and is highly variable depending on lamprey body sizes and density as well as environmental conditions (Steeves et al. 2003; Christie and Goddard 2003; Silva et al. 2014; Harris et al. 2016).

Part II – Effects of Dewatering Rates on Larval Lampreys

The YNPLP closely coordinated with the Bureau of Reclamation (the Reclamation) staff regarding the scheduled pump operations at the Sunnyside Canal. Two industrial water pumps, one large (12-inch diameter) and one small (8-inch diameter), were used to drop the water level in the Sunnyside Canal due to subsurface flow and variable levels of leakage in the headworks annually. The dewatering plan was to perform all pump operations during the daytime to allow for rescue of stranded lampreys during normal work hours to mitigate desiccation and predation as much as possible. The final stages of dewatering was conducted over a two-day period.

The YNPLP also closely collaborated with the Wapato Irrigation Project (WIP) prior to the irrigation shut-off date at the Wapato Canal to design a dewatering schedule that minimizes larval lamprey desiccation and mortality. The headgates were closed in stages (rather than all at once) and a weir approximately 6 km downstream (referred to as “Drop 1”) was operated in a way to store water and minimize rapid draining of the screen area, effectively slowing the overall rate of dewatering. On the first "critical" dewatering day for each canal (when the low gradient, high density larval habitat first became dewatered), the U.S. Geological Survey (USGS) and U.S. Fish and Wildlife Service (USFWS) staff were also present on site conducting an enclosure study. Their staff also provided assistance in monitoring the water level fluctuation during this period, which is summarized in this report.

Water levels in both canals were monitored closely. Water depths were recorded periodically as water levels dropped using the water height gauges established at each canal. When water levels dropped below the lowest value on the established gauge, we continued to measure water depth using a tape measure secured in place at a location near the fish screens with sufficient water depth. Because the critical dewatering rate occurred below the lowest level on the gauges, having this additional water depth measurement point was critical. We estimated "critical" instantaneous dewatering rates, which occurred on the day when the majority of larval lamprey habitat was exposed (generally this was the last day of dewatering). The dewatering rates were calculated based on the decrease in water surface level (in cm) and the elapsed time. The start and end time of the maximum dewatering rate was chosen from a series of incremental measurements taken throughout the dewatering period, and it includes the time period when the overall water drop and sediment exposure was most significant (over a minimum of a 1-h period).

Using the same collection methodology as described in Part I, we collected emerged lampreys from the dry (and drying) banks. Using these data, we calculated the percent mortality of lampreys collected on the surface of dry banks by dividing the number of total mortalities observed on sediment surfaces (primarily from dry banks, but also included a small number found under water) by the total number of lampreys removed from the dry sediment. When encountered, mortalities from the wetted environment were also included in this estimation due to our assumption that these lampreys likely died from desiccation first followed by inundation due to fluctuations in water levels at these facilities. Finally, we estimated annual lamprey stranding rates within the high density zones in both canals by dividing the total number of lampreys removed from dry banks by the total number of lampreys removed from the canal by all salvage methods.

Results

Part I: Assessment of Larval/Juvenile Abundance

Sunnyside Canal

At the Sunnyside Canal, approximately 23% of the high density zone downstream of the fish screens was wetted at the time of our single pass electrofishing surveys, resulting in approximately 566 m^2 and 178 m^2 of wetted Type I and Type II habitat, respectively (Table 1). In Type I habitat, our single pass survey covered an estimated area of 38 m^2, or 5.6% of the Type I area (surpassing our 5% minimum). We estimated that at least 6,377 lampreys were present in wetted Type I and

Type II habitat immediately downstream of the fish screens based on representative single pass electrofishing surveys on 29 October 2020 (Table 2). Given that 649 lampreys were previously removed from the high density zone (546 from dry banks and 103 from wetted habitat), the estimated minimum total number is 7,026. On the final day of dewatering (29 October 2020), single pass electrofishing was prioritized in section D2 (immediately downstream of the fish screens) due to its relatively higher density compared to section D1 (canal area) and this continued for the following three weeks. A total of 3,532 lampreys were collected (via dry bank and electrofishing efforts), which suggests that YNPLP and partners were successful in removing/rescuing up to 50% of the minimum total number we estimated.

Table 1. Estimated wetted area by habitat type within each delineated section upstream of the fish screens in the Sunnyside Canal. *Rep. Survey Date* is the date when a representative single pass electrofishing survey was conducted within the respective section. *# of Days Post Drawdown* is the number of days after October 28, 2020, the day when the headgate was closed.

Section	Section Description	Rep. Survey Date	# of Days Post Drawdown	Overall Section Area (m^2)	% Overall Section Wetted	Total Wetted Area (m^2)	% of Wetted is Type I	% of Wetted is Type II	% of Wetted is Type III	Wetted Area Type I (m^2)	Wetted Area Type II (m^2)	Wetted Area Type III (m^2)
D1	Canal	29-Oct-2020	1	1778	10%	178	30%	50%	20%	53	89	36
D2	Screens	29-Oct-2020	1	1416	40%	566	80%	15%	5%	453	85	28
Summary		**-**		**3194**	**23%**	**744**	**68%**	**23%**	**9%**	**506**	**174**	**64**

Table 2. Estimated numbers of lampreys in Type I and Type II habitat downstream of the fish screens in the Sunnyside Canal. *Rep. Survey Date* is the date when a representative single pass electrofishing survey was conducted within the respective section. *# of Days Post Drawdown* is the number of days after 28 October 2020, the day when the headgate was closed. *# Previously Removed From Dry Banks* is the number of lampreys removed from dry banks by hand and dry bank electrofishing prior to the representative survey. *# Previously Removed From Wetted Habitat* is the number of lampreys removed by electrofishing in wetted habitat prior to the representative survey. *Total # Removed (All Efforts)* is the total number of lampreys removed from all rescue efforts prior and post the representative survey. The Type II habitat density is estimated as 10% of the section Type I density because no surveys were directly conducted in the Type II habitat.

Section	Section Description	Rep. Survey Date	# of Days Post Drawdown	Habitat Category	Habitat Type	Estimated Total Habitat Area (m^2)	Survey Area (m^2)	# Captured	Capture Density (#/m^2)	Estimated Densiy (#/m^2)	# Estimated From E-Fishing
D1	Canal	29-Oct-2020	1	Bank	Type I	53	8.0	71	9.6	9.7	518
				Bank/Main	Type II	89	5.5	21	4.5	4.6	411
D2	Screens	29-Oct-2020	1	Bank	Type I	453	24.0	252	11.5	11.8	5348
				Main	Type II	85	0.0	-	-	1.2	100
# Estimated from Electrofishing											**6377**
# Previously Removed From Dry Banks											**546**
# Previously Removed From Wetted Habitat											**103**
Estimated Minimum Total #											**7026**
Total # Removed (All Efforts)											**3532**
Maximum % Removed (Total # Removed [All Efforts] / Estimated Minimum Total #)											**50%**

Wapato Canal

In the Wapato Canal, approximately 85% of the high density zone upstream of the fish screens was wetted at the time of our single pass electrofishing surveys, resulting in approximately 979 m^2 and 1,818 m^2 of wetted Type I and Type II habitat, respectively (Table 3). In Type I habitat, our single pass survey covered an estimated area of 70 m^2, or 7.2% of the Type I area (surpassing our 5% minimum). We estimated that at least 7,615 lampreys were present in wetted Type I and Type II habitat immediately upstream of the fish screens based on representative single pass electrofishing surveys on 17 October 2020 and 19 October 2020 (Table 4). Given that 557 lampreys were previously removed from the high density zone (300 from dry banks and 257 from wetted habitat), the estimated minimum total number is 8,172. On 16 October 2020, representative single pass electrofishing was conducted over the next few days in sections U1, U2 and U3. A total of 2,552 lampreys were collected (via dry bank and electrofishing efforts), which suggests that YNPLP and partners were successful in removing/rescuing up to 31% of the minimum total number we estimated.

Table 3. Estimated wetted area by habitat type within each delineated section upstream of the fish screens in the Wapato Canal. *Rep. Survey Date* is the date when a representative single pass electrofishing survey was conducted within the respective section. *# of Days Post Drawdown* is the number of days after October 16, 2020, the day when the headgate was sealed shut.

Section	Section Description	Rep. Survey Date	# of Days Post Drawdown	Overall Section Area (m^2)	% Overall Section Wetted	Total Wetted Area (m^2)	% of Wetted is Type I	% of Wetted is Type II	% of Wetted is Type III	Wetted Area Type I (m^2)	Wetted Area Type II (m^2)	Wetted Area Type III (m^2)
U1	Screens	17-Oct-2020	1	827	100%	827	95%	0%	5%	786	0	41
U2	Screens	17-Oct-2020	1	1593	90%	1434	10%	75%	15%	143	1075	215
U3	Canal	19-Oct-2020	3	1414	70%	990	5%	75%	20%	49	742	198
Summary			**-**	**3834**	**85%**	**3251**	**30%**	**56%**	**14%**	**979**	**1818**	**454**

Table 2. Estimated numbers of lampreys in Type I and Type II habitat upstream of the fish screens in the Wapato Canal. *Rep. Survey Date* is the date when a representative single pass electrofishing survey was conducted within the respective section. *# of Days Post Drawdown* is the number of days after 16 October 2020, the day when the headgate was closed. *# Previously Removed From Dry Banks* is the number of lampreys removed from dry banks by hand and dry bank electrofishing prior to the representative survey. *# Previously Removed From Wetted Habitat* is the number of lampreys removed by electrofishing in wetted habitat prior to the representative survey. *Total # Removed (All Efforts)* is the total number of lampreys removed from all rescue efforts prior and post the representative survey. The Type II habitat density is estimated as 10% of the section Type I density because no surveys were directly conducted in the Type II habitat.

Section	Section Description	Rep. Survey Date	# of Days Post Drawdown	Habitat Category	Habitat Type	Estimated Total Habitat Area (m^2)	Survey Area (m^2)	# Captured	Capture Density (#/m^2)	Estimated Density (#/m^2)	# Estimated From E-Fishing
U1	Screens	17-Oct-2020	1	Main	Type I	786	36.0	81	2.3	2.4	1850
U2	Screens	17-Oct-2020	1	Bank	Type I	80	7.5	76	14.5	16.3	1307
				Main	Type I	63	5.0	27	6.8	7.7	485
				Main	Type II	1075	21.0	26	1.4	1.4	1559
U3	Canal	19-Oct-2020	3	Bank	Type I	50	21.0	14	0.7	0.7	495
				Main	Type II	742	8.0	200	35.7	38.4	1920
# Estimated from Electrofishing											7615
# Previously Removed From Dry Banks											300
# Previously Removed From Wetted Habitat											257
Estimated Minimum Total #											8172
Total # Removed (All Efforts)											2552
Maximum % Removed (Total # Removed [All Efforts] / Estimated Minimum Total #)											31%

Part II – Effects of Dewatering Rates on Larval Lampreys

Sunnyside Canal

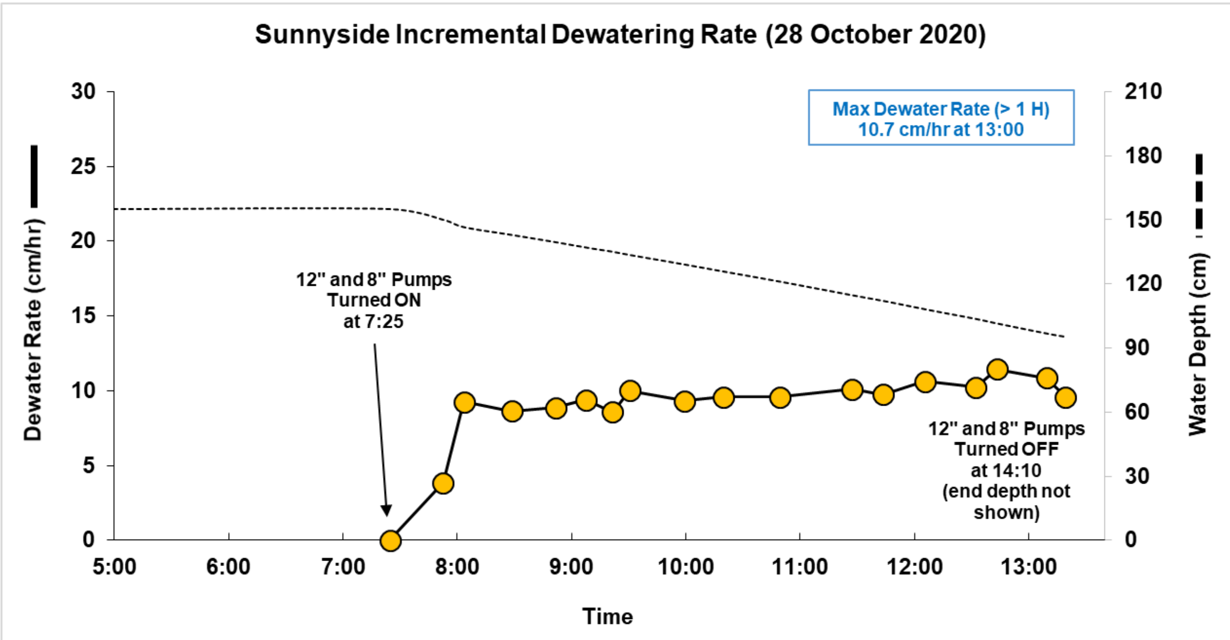
At the Sunnyside Canal, we evaluated dewatering rates immediately downstream of the fish screens (in the area with the highest density of lampreys). We closely coordinated with the Reclamation and agreed upon a schedule in which all pump dewatering operations would be performed during the day time hours. At the facility, two industrial water pumps (12-inch diameter and 8-inch diameter pumps) were available for operation. Pump operation first began on 27 October 2020. By the end of the day on 27 October, the sediment along the water's bank started to become exposed.

The critical dewatering occurred on 28 October 2020 and 29 October 2020, exposing the majority (> 70%) of the fine sediment. On 28 October 2020, the pumps were operated between 7:25 and 14:10 and USGS and USFWS staff were on site working on a lamprey enclosure study. A measurement tape was placed into the canal to monitor the changing water levels. The maximum dewatering rate (> 1 h) was measured at 10.7 cm/h towards the end of this time period (Fig. 5).

Throughout the day, with both pumps running, the dewatering rate ranged from 9.0-11.5 cm/h. The average dewatering rate for the entire 327 min (5.5 h) period was 9.7 cm/h. During the night of 28 October 2019, the water level had risen 12 cm due to the continual leak in the headgate.

On the second day, 29 October 2020, the water level was brought down to its lowest level. Both pumps were turned on in the morning at 5:37. With both pumps running, the maximum dewatering rate (> 1 h) was 21.8 cm/h, at its peak by 7:58. There were no measurements recorded between 5:37 and 7:58, so it is difficult to know how high the maximum dewatering rate became within this over 2-h period. The 12-inch pump began 'sucking air' around 7:30 and shut off automatically (on its own) by 8:00. Afterwards, with only the 8-inch pump running, the dewatering rate averaged around 5 cm/h. The overall average dewatering rate for the day was 8.2 cm/h (62 cm water drop over the 453-min [7.5-h] period). However, between 9:10 and 1:00, the water level only dropped 4 cm. A total of 546 lampreys were collected from dry banks (215 on 28 October 2020 and 331 on 29 October 2020). Overall, the mortality rate of lampreys found on sediment surfaces was 14.1% (n=77). Of those collected from dry banks, 509 lampreys were collected from the surface of dry banks by hand and 37 lampreys were collected from dry banks via electrofishing (i.e., dry shocking).

On 29 October 2020, a sprinkler system was deployed immediately downstream of the fish screens to keep the ground moist for newly exposed lampreys (Fig. 6). The sprinkler was not deployed on 28 October 2020 because the majority of exposed sediment was in the area of the USGS study (which could have been impacted by this spraying water). Other exposed banks at this time were rocky (lacking larval lamprey habitat) or steep and deep, making it challenging to install the sprinkler system. The stranding rate of lampreys (the number of lampreys removed from the sediment surfaces [n=546] divided by the overall number removed [n=3,600]) was 15.1%; this value includes lampreys removed via dry shocking. If those collected via dry shocking were excluded from the stranding rate of lampreys, the percentage decreases to 14.3%.



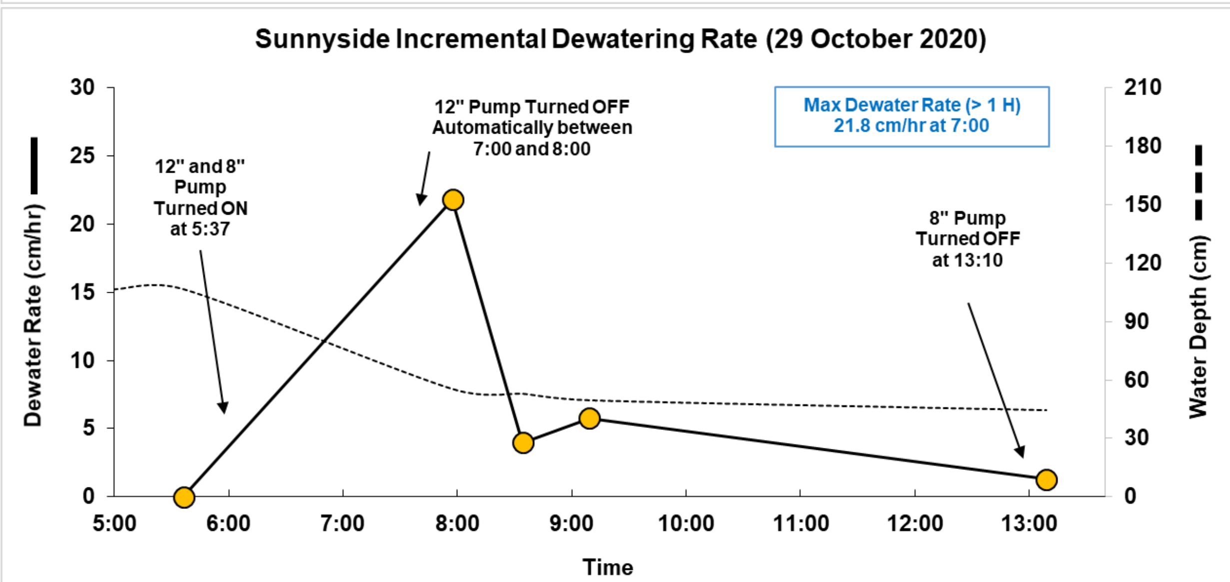


Figure 5. Water depths and associated incremental dewatering rates measured at the Sunnyside Canal on October 28, 2020 (top graph) and October 29, 2020 (bottom graph). Key operation events/notes regarding the 8-inch and 12-inch industrial water pumps are also displayed.

Figure 6. Overview of the PVC sprinkler system deployed downstream of the fish screens in the Sunnyside Canal in October, 2019, immediately after dewatering. Although ice accumulation (yellow arrow) was visible on the sprinkler shaft just below the spray nozzle, it did not prevent the sprinkler from operating properly. The same system was deployed in 2020 as well.

Wapato Canal

For the Wapato Canal, we closely coordinated with the WIP and agreed upon a schedule in which the headgate would be closed in stages to slowly reduce the flow discharge entering the canal. It was planned that the canal would be reduced from 720 cfs to approximately 420 cfs on 13 October 2020 (in thee 100 cfs increments), from 420 cfs to 100-120 cfs on 14 October 2019 (in three ~100 cfs increments; water gauge at 930.9 ft and water height below screens was > 7 ft at 120 cfs), and from 100-120 cfs to 50 cfs at 5:00 on 15 October 2020 (water height below screens was at 7 ft at 7:50). Overall, all adjustments were made within an estimated 12-h period (morning, afternoon and evening) over each of the three days. On and after 15 October 2020, we were allowed to provide recommendations regarding if and when the headgate should be completely shut, based on the resulting changing water levels, drying of Type I habitat, and stranding rates of lampreys.

The bypass gates and Drop 1 (6 km downstream) were scheduled to be kept closed until the final dewatering and could be adjusted on an as-needed basis. The dewatering operation took place as scheduled. On 15 and 16 October 2020, USGS and USFWS staff was on site performing a dewatering/enclosure study upstream of the fish screens, so we closely coordinated with them to ensure all of our needs could be adequately met including the USGS study as well as the rescue operations. On the morning of 15 October 2020, approximately 90-95% of the overall area was wetted, with some dewatered Type I habitat along the bank of the canal upstream of the fish screens (indicating that 50 cfs was enough flow to keep the majority of the lamprey habitat wetted). Drop 1 water gage level was initially at 8.94 ft (at 7:30) and decreased at 0.15-0.20 ft/h rate when shut. Then at 9:38, Drop 1 gates #1 and #2 were opened by 1.75 ft to allow ~250 cfs through the bypass gates), which resulted in approximately 0.50-0.70 ft/h drop rate at the Drop 1 water gage. At 11:17, an additional 30 cfs from the M-80 weir were released, but higher dewatering rate at Drop 1 was not observed as a result of this. At 12:22, Drop 1 gate bypass flow was reduced to 1.0 cfs at both gates to allow 140 cfs through the bypass gates (which resulted in 0.35~0.40 ft/h drop rate), and they were gradually reduced overtime and closed completely at 13:30 to ensure no water loss overnight (water level at Drop 1 was 6.05 ft at the end of the day at 16:00). The fish screen bypass was also closed at 14:00 by the Reclamation staff and the water level by the fish screens remained the same till the following morning (water gauge was at 927.5 ft). Drop 1 water gage the next morning at 8:55 was 5.00 ft (indicating a 1.05 ft drop overnight and 0.06 ft/h drop overall).

The headgate was closed on the morning of 16 October 2020 at 8:55. At the same time, Drop 1 was opened to spill 100-150 cfs (an opening of 0.5 ft.). These actions immediately resulted in a dewatering rate of 25.7 cm/h by the fish screens, although this quickly diminished to 8 cm/h by 10:00 (Fig. 7). At 10:05, the two Drop 1 gates were opened by 1.40 ft initially and were then opened to 1.75 ft to spill 250 cfs, resulting in a 0.4 to 1.5 ft/h drop rate; at the same time, 25 cfs was also released from the M-80 weir. This increased the dewatering rate by the fish screens slightly (to 16 cm/h), and eventually stabilized and maintained a similar dewatering rate, ranging from 11-13 cm/h. At 12:05, we opened the bypass gate to drain the water from the upstream area to its lowest level. Finally, between 13:30 and 14:00, both Drop 1 and M-80 bypass gates were closed for the day (final gage height at Drop 1 was 2.42 ft at 13:30). A combination of these actions resulted in a dewatering rate of 12 cm/h for approximately 1 h initially, until diminishing to a rate of 1.9 cm/h by 15:00.

Throughout this day, the maximum dewatering rate (> 1 h) was 15.1 cm/h and started between 9:00 and 9:15 immediately after closing the headgate. The average dewatering rate throughout the day after the headgate was closed was 9.3 cm/h (water drop of 55 cm over a 360-min [6.0-h] period). A total of 300 lampreys were collected from dry banks on 16 October 2020. Overall, the mortality rate of lampreys found on sediment surfaces was 22.7% (n = 68). Of those collected from dry banks, 254 lampreys were collected from the surface of dry banks by hand and 46 lampreys were collected from dry banks via electrofishing (i.e. dry shocking). On 16 October 2020, a sprinkler system was deployed in the Wapato Canal immediately upstream of the fish screens to keep the ground moist for newly exposed lampreys (Fig. 8). The stranding rate of lampreys (the number of lampreys removed from the sediment surfaces [n = 300] divided by the overall number removed [n = 2,551]) was 11.8%; this value includes lampreys removed via dry shocking. If those collected via dry shocking were excluded from the stranding rate of lampreys, the percentage decreases to 10.0%.

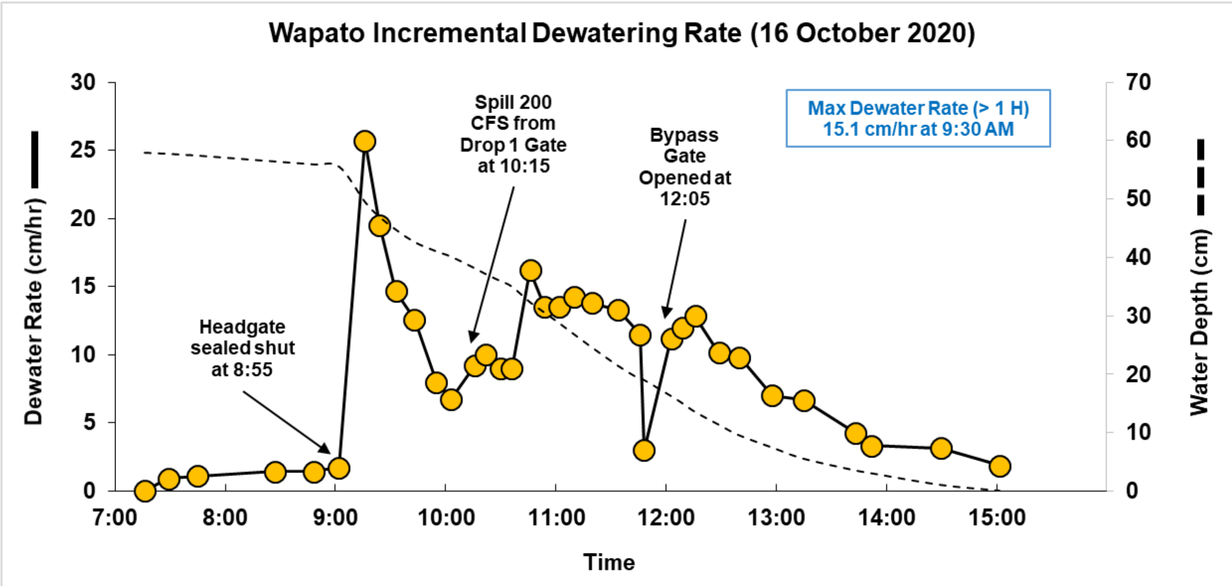


Figure 7. Water depths (primary y-axis) and associated incremental dewatering rates (secondary y-axis) measured in the Wapato Canal on 16 October 2020 (top graph). Key operation events/notes are also displayed.

Figure 8. Overview of the PVC sprinkler system deployed upstream of the fish screens in the Wapato Canal in October 2019 immediately after dewatering. The sprinkler spray was directed towards the wetted area in anticipation that the water level would drop overnight, exposing additional sediment and lampreys. The same system was deployed in 2020 as well.

Discussion

Part I – Assessment of Larval/Juvenile Lamprey Abundance

In 2020, the minimum number of lampreys present was estimated to be 7,026 downstream of the fish screens in the Sunnyside Canal and 8,172 upstream of the fish screens in the Wapato Canal (upstream of the fish screens). Since 2014, the YNPLP has been estimating the number of lampreys within these high density zones. In the Wapato Canal, 8,172 is just below the eight-year average of 10,128, and in the Sunnyside Canal, 7,026 is slightly lower than the eight-year average of 10,618. In 2020, the estimated percent removed of the estimated total (based on our single pass electrofishing estimate) was 50% and 31% in the Sunnyside and Wapato canals, respectively. This estimated percentage removed was slightly higher than the eight-year average for the Sunnyside Canal (44%), but lower than the eight-year average for the Wapato Canal (43%). The lower percentage removed in the Wapato Canal could potentially be due to the relatively large area of Type II habitat that was present at this site. Our efforts are typically not focused on Type II habitat because density is generally much lower compared to Type I habitat. However, when an expansive area of Type II habitat is available, cumulatively the number of lampreys in these areas may make up a considerable portion of the overall number.

Due to the lack of correction related to electrofishing efficiency (i.e. probability of lamprey emergence from electrofishing) that are applied to our calculation of estimates, we consider these estimates to be "minimal estimates" and surmise that the actual numbers present at these facilities are likely to be considerably greater. For example, a mark-recapture study in the Wapato Canal in 2014 using VIE tags suggested that the observed and captured numbers from electrofishing only represented 45% and 22%, respectively, of the overall numbers present (Beals and Lampman 2015; Lampman and Beals 2019).

It is difficult (and likely impossible) to remove all of the lampreys from a canal area due to a wide variety of factors including limited salvage time, limited personnel, cooling and freezing water temperatures (as salvage work generally occurs in the late fall and winter months) further limiting electrofishing efficiency and unavoidable (and unseen) mortalities within the fine sediment. In an effort to increase capture efficiency, we utilized the dry bank electrofishing technique (i.e., dry shocking) to remove concealed lampreys immediately after dewatering, especially in the Wapato Canal. We recommend that the dry shocking technique be used regularly after the first dewatering day in high density areas in an effort to limit the number of lampreys that may become stranded.

Part II – Effects of Dewatering Rates on Larval Lampreys

Sunnyside Canal Dewatering Recommendations

At the Sunnyside Canal, the Sunnyside Valley Irrigation District controls the headgate operations. The Reclamation has allowed the YNPLP to operate the industrial water pumps to drop the water level as needed in the fish screen area. This worked well as our team on site could immediately adjust pump operations when the water level reached critical Type I habitat (i.e., larval lamprey high density habitat). This allowed for pump operations to only occur during the day time hours when YNPLP staff were available to pick up emerging lampreys in real time as they emerged from the fine sediment. We recommend that the pumps operate only during the day time when staff are available to pick up emerging lampreys, preferably over a multiple day period. The YNPLP is responsible in providing updates to Reclamation staff and following their guidance, including timely water level adjustments to meet Reclamation fish salvage and maintenance operation needs.

Wapato Canal Dewatering Recommendations

At the Wapato Canal, the WIP controls the headgate operations. The headgate closing in stages (100-300 cfs increments) has worked well for lamprey self-rescue (i.e. larval lampreys' ability to return to the wetted area on their own). The initial dewatering that impacts mainly Type III (coarse substrate) habitat, however, is less critical for lampreys. Once the headgate inflow is lowered to 50-100 cfs, fine sediment starts to become exposed within the high density habitat (reaching a critical water level). We recommend that WIP and YNPLP staff remain in close communication when water levels reach this critical level. We recommend that the water inflow be reduced to 50 cfs the day prior to the headgate closing. Approximately 90-95% of the area was covered, which suggested that 50 cfs was enough flow to keep the sediment wetted in the high density zone. The Drop 1 weir gate (approximately 6 km downstream of the fish screens) should be closed when the canal is brought to 50 cfs, and remain closed until the headgate is closed. Also, a bypass stop log (gate) should be put in place when the canal is cut down to 50 cfs, and left in place until the headgate is closed. By having both Drop 1 closed and the bypass gate in place, we can effectively reduce the risk of drastic water level changes in the high density zone. Once the headgate is closed we can open the Drop 1 gate in stages (0.5 ft increments, 100-150 cfs at a time) to slowly drop the water in the screening area. Once the water level changes are minimal by adjusting Drop 1, we can open the bypass gate by the fish screens to further reduce the water level. These adjustments can be made based on what we see on site during the dewatering process.

General Dewatering Recommendations

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

- Slow rates of dewatering (e.g., < 10 cm/h) are crucial in minimizing both the rates of stranding and overall mortalities (especially important in areas with high densities, such as the Sunnyside and Wapato canals) (Fig. 9).

- Laboratory work by the USGS research 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 burrowed fine sediment (Liedtke et al. 2015). 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 larval lamprey habitat, dewatering rates need to slow down. We recommend a 10 cm/h rate or slower based on previous studies by the YNPLP (Lampman and Beals 2019).
- Lampreys can easily become trapped on dewatered banks as water levels decrease. It is critical to arrive at the dewatered site immediately after (or prior to) the drying of fine sediment (at least within 0-2 hours). When possible, the critical dewatering period (when the majority of fine sediment becomes exposed) should occur during the daytime hours to allow salvage activities. In 2020, we were able to rescue exposed lampreys efficiently as they surfaced on the drying banks in the Sunnyside and Wapato canals (without the need for flashlights and overtime hours), resulting in very high survival rates.
- Upon arrival, rescue crews should utilize "dry shocking" (focusing on potential high density zones at the base of steep banks and shallow areas with Type I fine sediments). Emerging and stranded lampreys that we observe upon arrival at a dewatered site are potentially only a fraction of the lampreys that are trapped within the fine sediment. As a result, douse the wetted banks with buckets of water and electrofish for any concealed lampreys. Our electrofishing surveys in dried sediment, after pouring water to maximize capture, demonstrated that hundreds of larvae can stay in the seemingly dry fine sediment.
- When conducting a lamprey rescue, electrofishing efforts in wetted environment should first focus on isolated pools of water (before they dry up completely) and along the sloped banks of the main water body (lamprey densities tend to be highest in these isolated pools and along the bank of the main water body).
- Installing a sprinkler system to spray water over the dewatered sediment overnight could help prolong the lives of emerged as well as concealed lampreys until rescue crews arrive the following day.

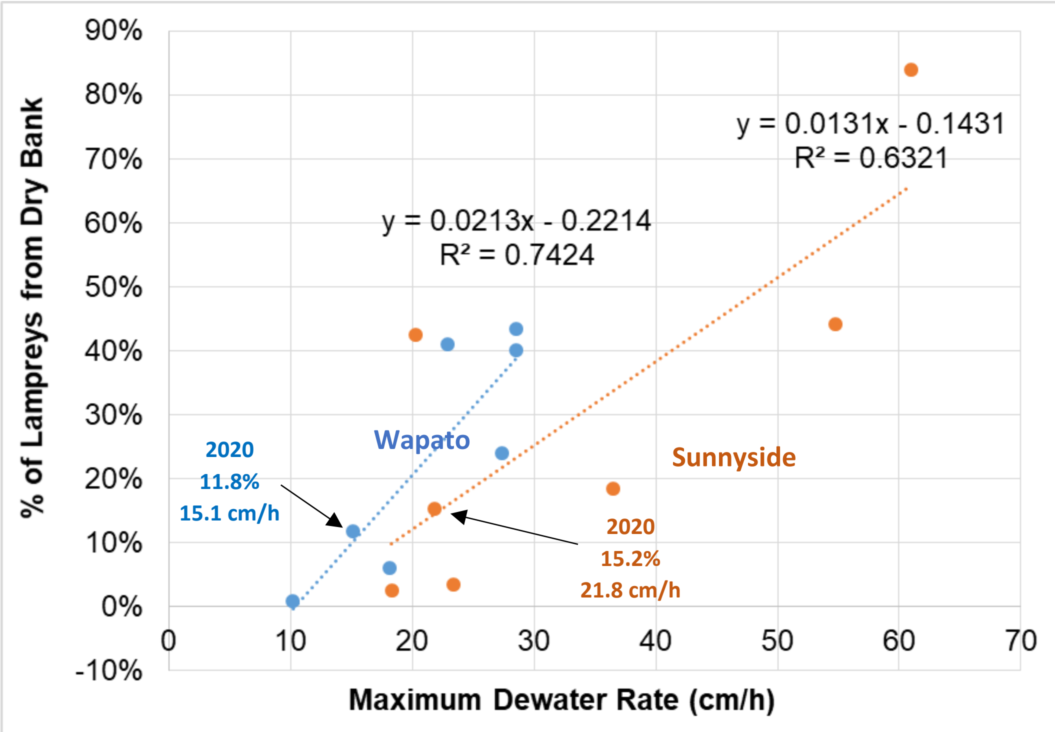


Figure 9. A scatter plot of maximum dewatering rates (> 1 h) during the critical sediment level period and percent of lampreys captured from dry banks annually between 2014 and 2020 in the Sunnyside and Wapato canals. Both 2020 points are labeled with a black arrow. The trend line, associated equation, and r-square values are also shown. All lampreys included in the dry bank collection are a summation of hand collected lampreys from the surface of dry banks as well as those collected from "dry shocking."

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