Evaluation of a lamprey collector in the Bradford Island makeup water channel, Bonneville Dam, 2003

Fish Ecology Division

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Seattle, Washington

by
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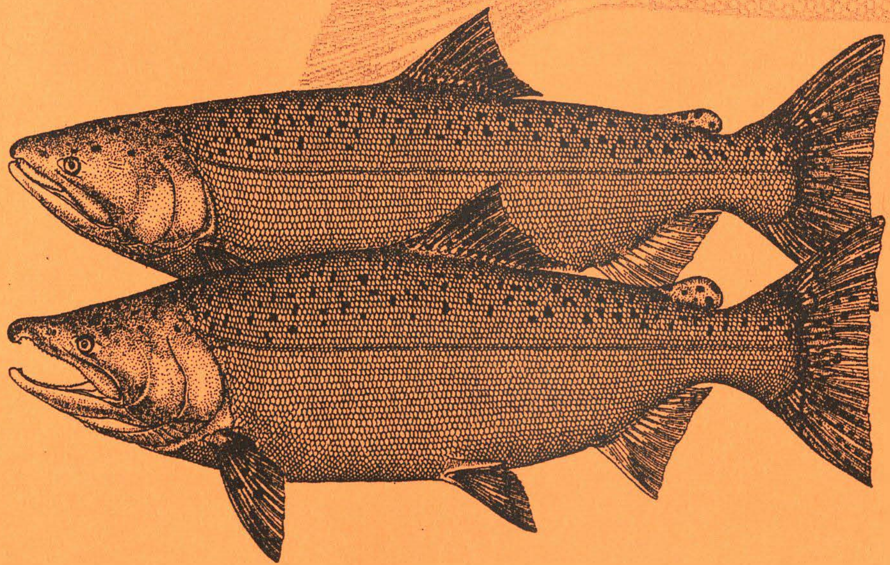

Evaluation of a Lamprey Collector in the Bradford Island Makeup Water Channel, Bonneville Dam, 2003

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Report of research by

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EXECUTIVE SUMMARY

Radiotelemetry studies indicate that upstream migrating, adult Pacific lamprey *Lampetra tridentata* have difficulty negotiating the top of the fishways at Bonneville Dam. Lamprey routinely are delayed and obstructed by the serpentine weirs immediately upstream from the count stations at both the Bradford Island and Washington-shore fishways. Some of these lamprey move into the adjacent makeup water channel (MWC), which offers no ready access to the forebay of Bonneville Dam. The objectives of our research in 2003 were to refine and assess performance of a structure to pass adult lamprey from the MWC to the forebay at Bonneville Dam.

Three collection structures (ramp, tube, and modified tube) were evaluated in both an upstream and a downstream orientation for a total of six treatments. Tests were conducted from 27 May to 12 September 2003 by enumerating lamprey collected in each treatment during both the day and night. In addition, we conducted a mark-recapture study to evaluate the efficiency of each treatment.

During the study period, 5,458 lamprey were collected from the MWC and released into the forebay of Bonneville Dam. Of the 1,089 fish that were marked and released into the MWC, 133 were recaptured, and the median time at large was 6 d. All structures performed better when oriented downstream. Estimated treatment efficiency was highest in the ramp (18%) and second highest in the modified tube (13.5%). This indicated that lamprey were able to use a variety of structures and that modifications to retain lamprey in the collector were effective.

CONTENTS

INTRODUCTION

In 2003, concerns that Pacific lamprey *Lampetra tridentata* abundance is declining resulted in a petition to list this species under the U.S. Endangered Species Act. In addition, tribal representatives throughout the Columbia River drainage have expressed alarm at reductions in lamprey abundance and unprecedented regulation of lamprey fisheries (Kostow 2002). Indigenous peoples from the Pacific coast to the interior Columbia River Basin have harvested adult lamprey for subsistence, religious, and medicinal purposes for many generations (Close et al. 2002). The inability to capture lamprey during key seasons represents the loss of an important cultural resource for tribes both within and outside the Columbia River Basin (Kostow 2002; R. Reed, Karuk Tribal Cultural Biologist, personal communication).

Lamprey must pass four hydropower dams to reach the confluence of the Columbia and Snake Rivers, and up to five additional dams to attain spawning areas in the upper reaches of these rivers. The Columbia River Basin Lamprey Technical Workgroup identified dam passage as one of the most important factors limiting lamprey abundance in the Columbia River drainage (CRBLTW 2005).

Radiotelemetry studies have determined that adult lamprey passage at lower Columbia River dams is poor relative to that of salmonids. For example, less than half of the radio-tagged lamprey that approached Bonneville Dam in 1997-2000 passed successfully upstream (Moser et al. 2002b), whereas passage efficiency for salmonids during this period was typically greater than 90% (Bjornn et al. 2000a,b).

In previous studies, we identified specific obstacles to adult Pacific lamprey passage within the fishways at Bonneville, The Dalles, and John Day Dams using radiotelemetry. Over the past decade an extensive array of fixed-site radio receivers and antennas has been installed on and around these dams to assess adult salmonid passage at discrete areas in each fishway. We used this receiver array to document passage success of radio-tagged lamprey at each area (Moser et al. 2002a).

Lamprey were obstructed or delayed at fishway entrances, collection/transition areas at the bottom of the fishways, and count station areas at the top of the fishways (Moser et al. 2002b). In contrast, lamprey exhibited relatively rapid and successful passage through the pool and weir sections of the fishways, where they were exposed to rapid currents.

At the top of Bonneville Dam fishways, adult Pacific lamprey are routinely delayed and/or obstructed by the serpentine weirs immediately upstream from the count windows at both Bradford Island and Washington-shore fishways (Moser et al. 2002c, 2003, 2005a; Figure 1).

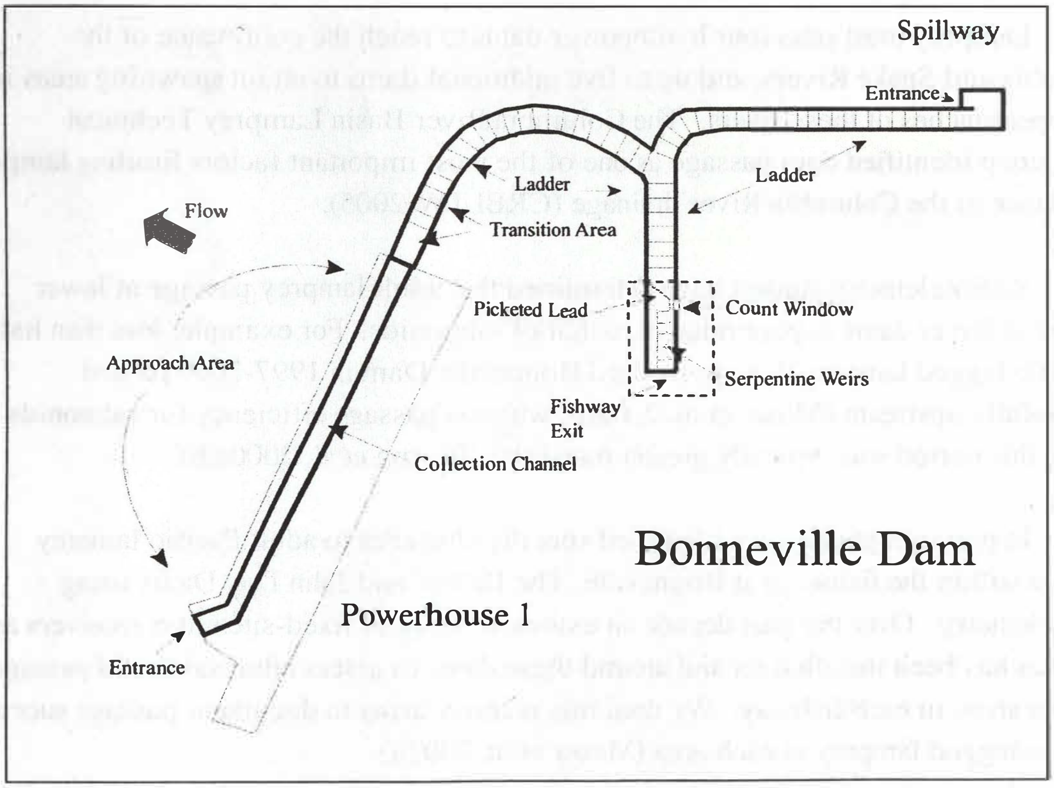

Figure 1. Schematic drawing of the Bradford Island fishway system at Bonneville Dam. The top of the fishway is indicated in the dashed box.

Lamprey delayed at the top of the fish ladder can move into the adjacent makeup water channel (MWC) through connecting diffuser gratings. They also can enter the MWC by passing through the picketed lead at the downstream end of the MWC (Figure 1). There is no ready access to the forebay of Bonneville Dam from the MWC. Radiotelemetry indicated that lamprey reside in the MWC for 4 d on average and then typically fall back downstream.

In 2002, we designed, built, and tested two bypass structures to collect lamprey from the Bradford Island MWC: a closed tube and an open ramp structure (Moser et al. 2005a). These structures could subsequently be extended to allow lamprey passage directly from the MWC into the forebay of Bonneville Dam. Initial testing of the lamprey bypass structures indicated that they held promise for collecting lamprey from the Bradford Island MWC. In preliminary testing, a total of 346 lamprey were collected in the trap box at the top of each structure.

We estimated efficiency of each device from counts made at the Bradford Island count station. Approximately 14% of the lamprey present during the closed tube testing and 18% of the lamprey present during the open ramp testing were collected in the trap box. A mark-recapture study conducted in 2002 to provide an independent measure of efficiency resulted in only two recaptures and was therefore not useful for computing efficiency (Moser et al. 2005a). We speculated that the release methods in 2002 caused most of the marked lamprey to leave the study area. Therefore, in 2003 we installed a volitional release box so that marked animals could acclimate to their surroundings during release (Figure 2).

The objective of our work in 2003 was to further refine both the design of and methods to assess performance of lamprey-specific collectors in the Bradford Island MWC. This included making structural changes to the collector and improving the mark-recapture experiment.

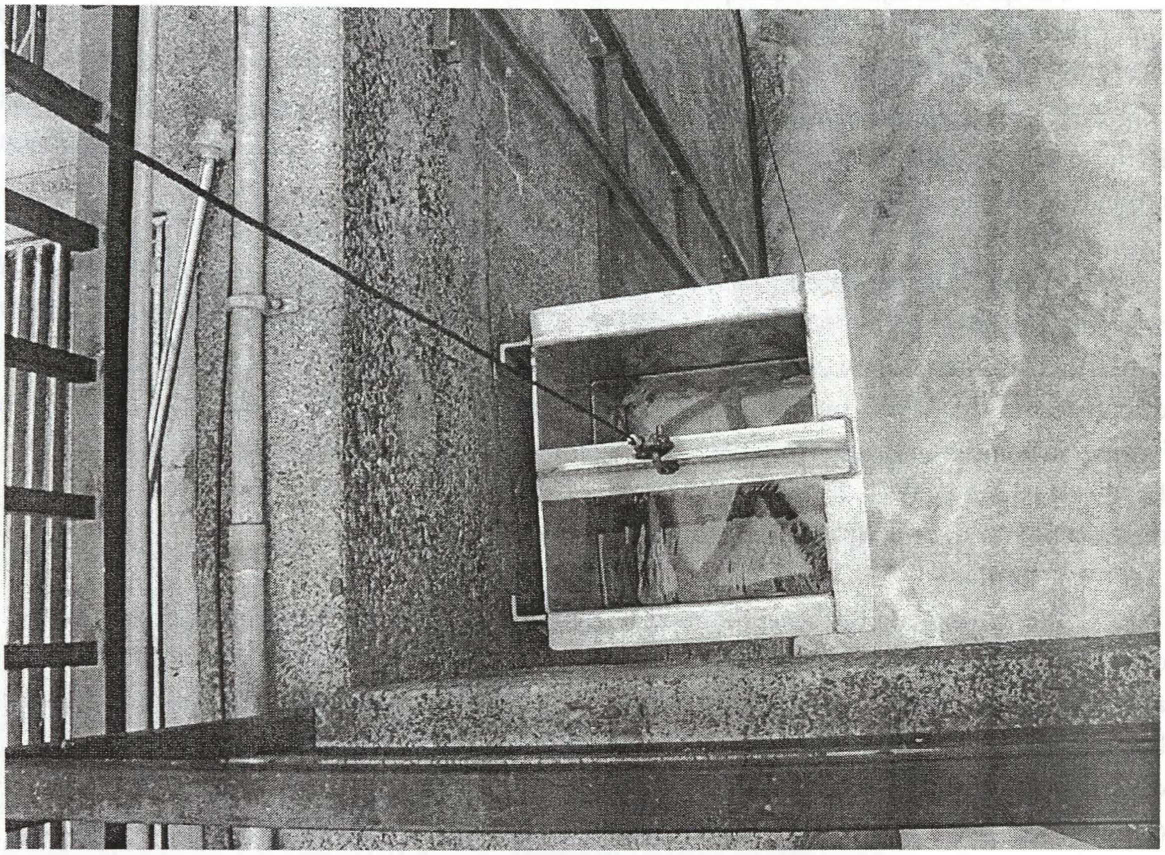

Figure 2. Marked lamprey were lowered into the MWC in 2003 using an open, volitional release box.

METHODS

Structures Tested

In 2002, the bypass structures were deployed on the west wall at the upstream end of the Bradford Island MWC. Guides were put in place during winter dewatering and were attached so that the entrance to the bypass structures could be positioned either 8 or 15 m downstream from the Tainter gate, which is at the upstream end of the MWC (i.e., the entire bypass device could be oriented either in the same direction as flow or in the opposite direction). The same guides were used in 2003 (Figure 3).

We designed, built, and tested two different bypass prototypes in 2002 (Figure 4). The first featured a closed rectangular tube (15.2-cm high × 20.3-cm wide) of schedule-40 aluminum that extended from the bottom of the MWC to the trap box (an elevation of 3.2 m) at a slope of 1.4:1.0. The entire bypass was 6.6 m in length, which included a 0.7-m wide collector that rested on the bottom of the MWC (Figure 5). Ambient Columbia River water was supplied to the trap box via a 10.2-cm diameter flexible corrugated pipe from two, 3-hp submersible pumps. Flow into the trap box was regulated to maintain a 3-cm depth in the rectangular tube.

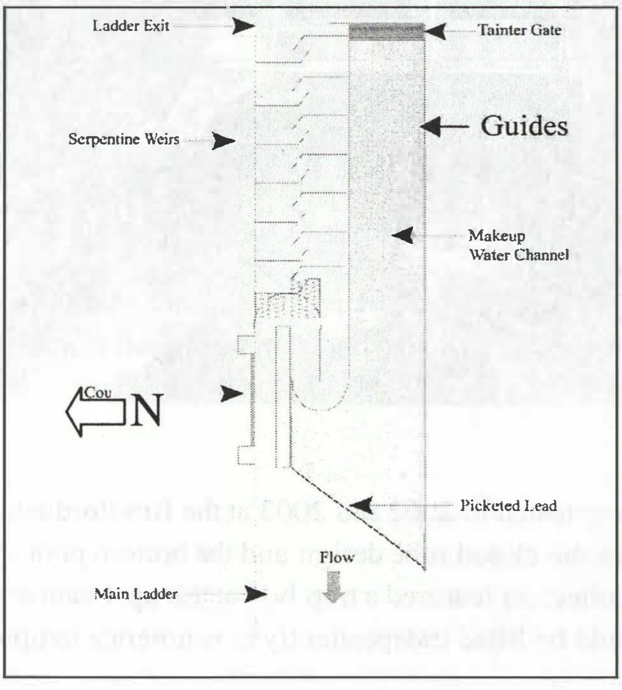

Figure 3. Detail of the top of the Bradford Island fishway.

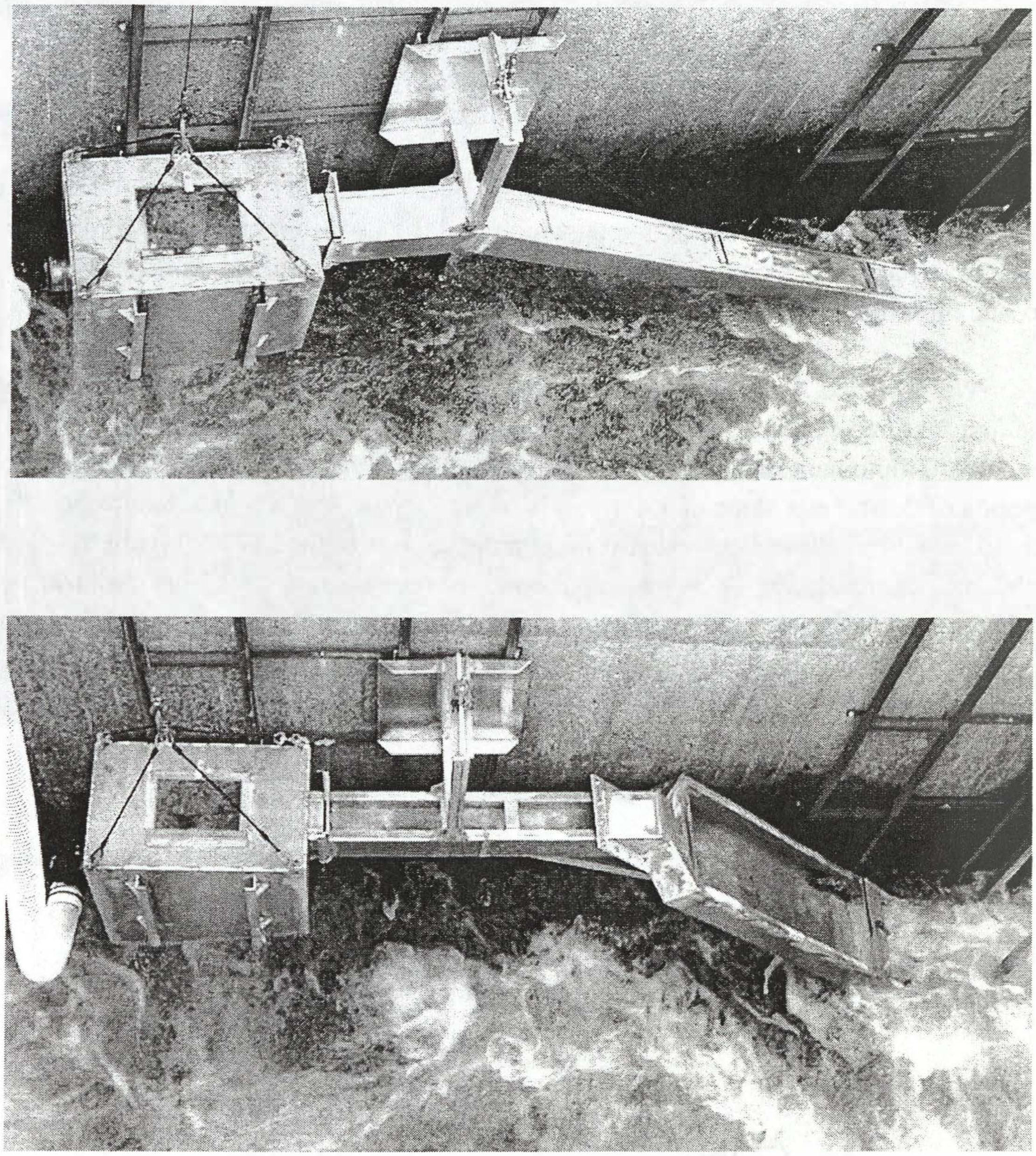

Figure 4. Bypass collectors tested in 2002 and 2003 at the Bradford Island MWC. The top photo shows the closed tube design and the bottom photo the open ramp design. Both collectors featured a trap box at the upstream end (left side of photos) that could be lifted independently to enumerate lamprey.

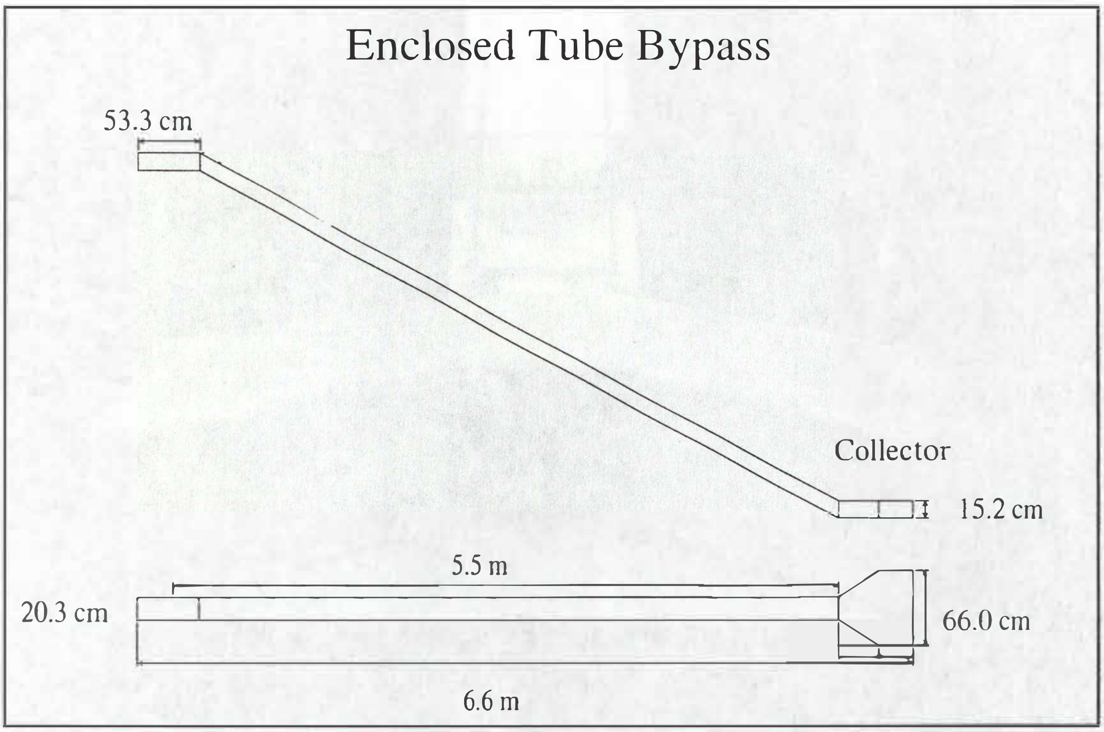

Figure 5. Dimensions of the closed tube bypass design (side view above and top view below) tested at the Bradford Island MWC in 2002 and 2003.

In 2003, we modified the base of the closed-tube collector to better retain lamprey after their initial entry. Video imagery from above the collector in 2002 indicated that lamprey readily entered the collector, but that they easily exited this open collector design. In 2003, we enclosed the top and sides of the collector in an effort to better retain lamprey (Figure 6).

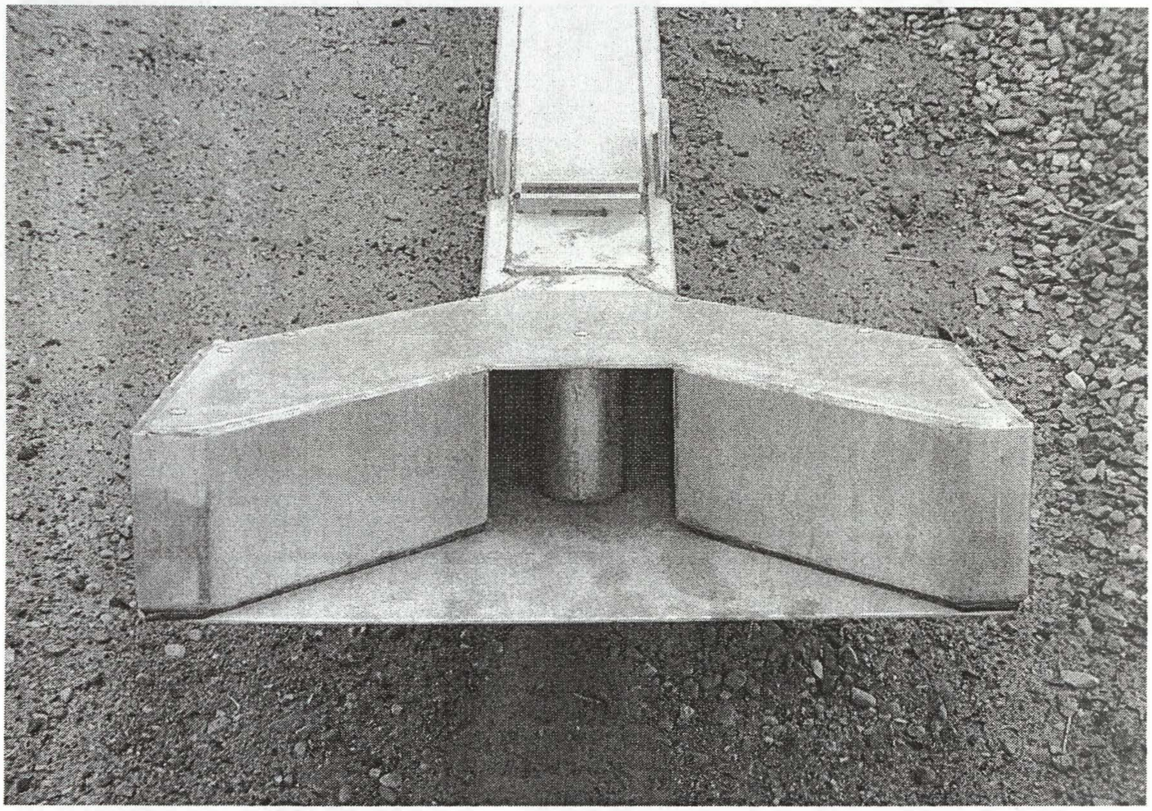

Figure 6. Photo of the entrance to the closed tube collector after it was modified in 2003. Note that the top and sides have been enclosed so that lamprey enter through a narrower opening.

The second design incorporated an open ramp that extended from the bottom of the MWC to the level of the trap box (3.2-m elevation). Lamprey could enter the ramp at any depth in the water column. A heavy rubber flange was used to create a seal against the wall and floor of the MWC and to help guide lamprey onto the ramp (Figure 7). After ascending the 4.4-m long ramp (at a slope of 1:1), lamprey entered a 1.2-m long horizontal rectangular chute (15.2-cm high × 20.3-cm wide) that emptied into the trap box (Figure 4). As with the tube design, ambient Columbia River water was supplied to the trap box via a 10.2-cm diameter flexible corrugated pipe from two, 3-hp submersible pumps. Flow into the trap box was regulated to maintain a 3-cm depth on the ramp.

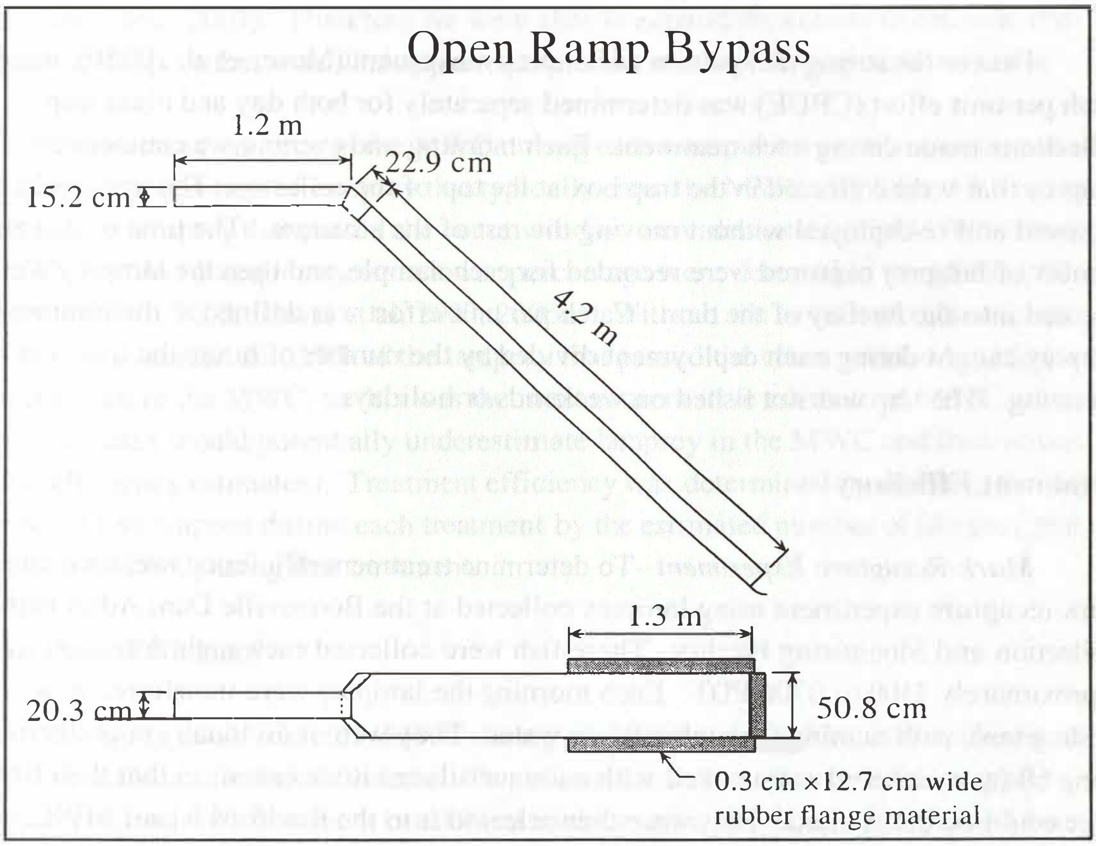

Figure 7. Dimensions of the open ramp bypass design (side view above and top view below) that was tested at the Bradford Island MWC in 2002 and 2003.

Data Collection and Analysis

We tested three structures in two orientations for a total of six treatments. The structures tested were: 1) the original closed tube (tube), 2) the closed tube with the modified collector (modified tube), and 3) the open ramp (ramp). For each treatment testing was conducted for approximately 2 weeks with the collector oriented either at the downstream or upstream end of the MWC. In the following 2 weeks, testing was conducted using the same structure deployed in the opposite orientation. The initial orientation of the collector (i.e., upstream or downstream) was randomly chosen for each test.

Catch Per Unit Effort

Due to the strong diel pattern of lamprey movement (Moser et al. 2005b), mean catch per unit effort (CPUE) was determined separately for both day and night trap collections made during each treatment. Each morning and evening we enumerated lamprey that were collected in the trap box at the top of the collector. The trap could be retrieved and re-deployed without moving the rest of the structure. The time of day and number of lamprey captured were recorded for each sample, and then the lamprey were released into the forebay of the dam. Catch per unit effort was defined as the number of lamprey caught during each deployment divided by the number of hours the trap was operating. The trap was not fished on weekends or holidays.

Treatment Efficiency

Mark-Recapture Experiment--To determine treatment efficiency, we conducted a mark-recapture experiment using lamprey collected at the Bonneville Dam Adult Fish Collection and Monitoring Facility. These fish were collected each night from approximately 2100 to 0700 PDT. Each morning the lamprey were transferred to a holding tank with running Columbia River water. They were individually anaesthetized using 60-ppm clove oil and marked with a unique silver nitrate brand, so that their time at large could be determined. They were then released into the Bradford Island MWC. To help lamprey acclimate upon release, they were lowered into the MWC in an open aluminum release box (Figure 2). Lamprey could volitionally leave the release box at any time after it was submerged.

On each day we recorded the number of marked lamprey caught in the trap box at the top of the collector and the individual brand of each fish. We added up the daily numbers of marked lamprey captured in the trap box during each treatment to determine the number of marked fish collected during that treatment.

Treatment efficiency was computed by dividing the number of marked lamprey that we captured during each treatment by the number of marked lamprey that we estimated were in the MWC during that treatment. Our estimate of the number of marked fish in the MWC was based on the median time at large of all marked fish (x). The time at large for each recaptured lamprey was known because on each release day the lamprey received a unique brand. We assumed that the number of marked fish in the MWC at time t was equal to the accumulated releases made during the period from t-x to t.

Visual counts--We were able to independently estimate treatment efficiency using the visual counts taken at the Bradford Island count window in 2003. In previous studies, 33% of the radio-tagged lamprey that passed the Bradford Island count window would have been counted (the remainder passed during the night when counts were not made, Moser and Close 2003). Therefore we were able to expand the counts to estimate the number of lamprey that would have passed the count window during each treatment.

Numbers of lamprey in the MWC during each treatment were then estimated based on the percentage of lamprey that typically enter the MWC. In 2000, 17% of the radio-tagged lamprey that passed the count window were detected in the MWC (Moser et al. 2002c). In subsequent years a lower percentage were detected in the MWC (8% in 2001 and 6% in 2002; Moser et al. 2003, 2005a). Without the benefit of radiotelemetry in 2003, we assumed that 17% of the lamprey that passed the count window would have been detected in the MWC, as this was the most conservative estimate of MWC use (i.e., lower estimates would potentially underestimate lamprey in the MWC and thus inflate bypass efficiency estimates). Treatment efficiency was determined by dividing the total number of fish trapped during each treatment by the estimated number of lamprey that were in the MWC during that treatment.

Mean Daily Efficiency

Lamprey could leave the MWC during each treatment and not all lamprey entered the collectors near the time of release. To account for this, we estimated mean daily efficiency during each treatment in addition to the treatment efficiency. We used the actual time-at-large distribution from the mark-recapture study to simulate the number of marked lamprey that were in the MWC on each day. We assigned a time at large for each fish in the simulation by randomly drawing from the actual distribution. We averaged results from each of 100 simulations to obtain an estimate of the number of marked lamprey in the MWC on each day. We then divided the number recaptured on each day into this value to obtain a daily efficiency estimate.

RESULTS

The three bypass structures were tested from 27 May to 12 September 2003 (Table 1). During the tests a total of 5,458 lamprey were captured in the bypass trap box. These fish were released into the forebay of Powerhouse 1 immediately after capture and enumeration. The maximum number of lamprey in a single collection was 269 on 13 June. On that night lamprey completely filled the trap box and no additional fish would have been able to enter.

Table 1. The dates of testing for each bypass structure treatment in 2003. The number of lamprey captured in the bypass trap box during each test and the number of marked lamprey that were released in the MWC during each test are also given.

Date	Treatment	Orientation	Lamprey captured	Marked lamprey released in MWC
5/27-6/3	Ramp	Upstream	16	21
6/4–6/18	Ramp	Downstream	1,974	212
6/19-7/2	Tube	Downstream	894	141
7/3-7/16	Tube	Upstream	560	152
7/17-7/30	Modified tube	Upstream	508	183
7/31-8/13	Modified tube	Downstream	668	148
8/14-8/27	Ramp	Downstream	627	148
8/28-9/12	Ramp	Upstream	211	135

Catch Per Unit Effort

CPUE varied with treatment and time of sampling. Mean CPUE was higher during the night than during the day and it was also higher with the downstream orientation of each collector than with the upstream orientation of the same collector (Figure 8). Mean CPUE also differed among bypass structures, with highest mean CPUE (15 lamprey/night) recorded during the ramp testing. However, the number of lamprey available to each device changed during the course of the testing. The number of lamprey counted at the Bradford Island count window (adjacent to the testing area, see Figure 2) varied by over an order of magnitude during the testing period (Figure 9). Therefore, CPUE is biased and should be used with caution when comparing performance of the different structures.

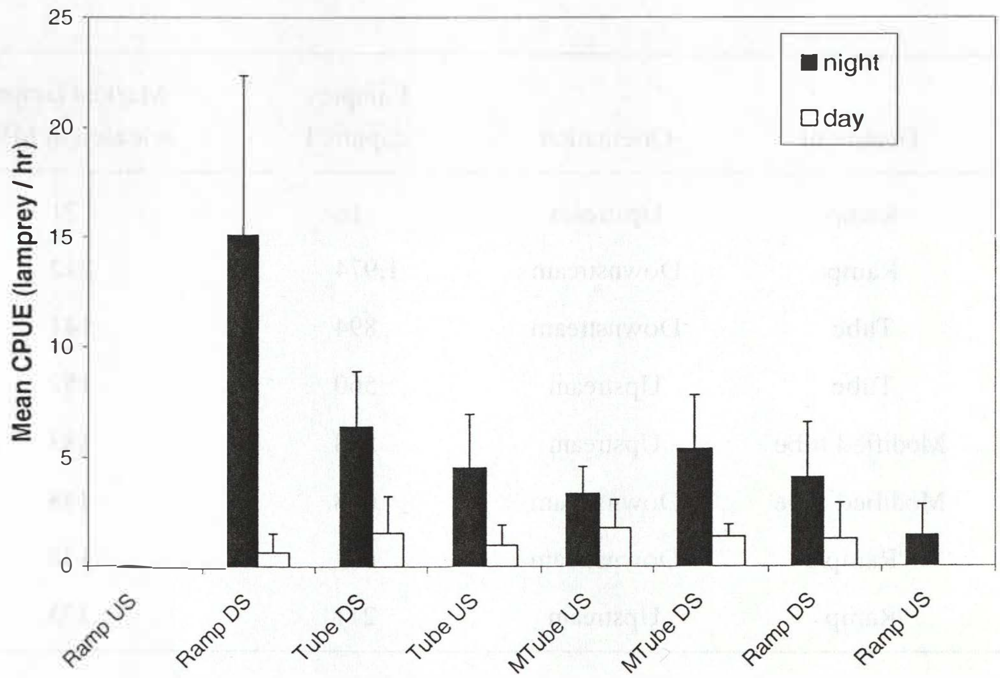

Figure 8. Mean CPUE (lamprey/hour) for each treatment (ramp, tube, modified tube) and orientation (US = upstream, DS = downstream) in day (open bars) and night (solid bars). Error bars are standard deviation.

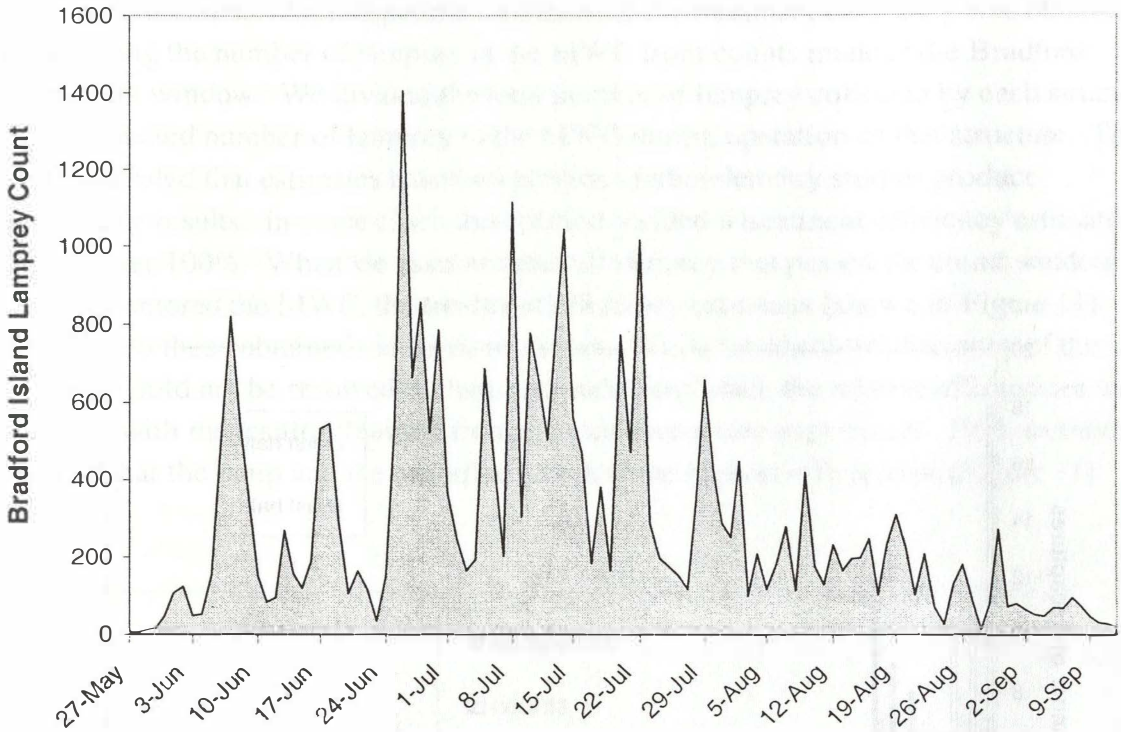

Figure 9. Lamprey counted at the Bradford Island count window during bypass structure testing in 2003.

Treatment Efficiency

Mark recapture experiment--A total of 1,089 marked lamprey were introduced into the MWC during bypass testing. The number released during each treatment varied due to availability of lamprey to mark during that period (Table 1). A total of 133 marked lamprey were recaptured in the bypass trap box. The time that they were at large ranged from 1 to 49 d with a median of 6 d (Figure 10).

Treatment efficiency estimates for each bypass structure were computed by dividing the number of marked lamprey that were caught during each treatment by the number of marked lamprey released into the MWC during that treatment. In addition, the number of marked lamprey released into the MWC during the 6 d prior to the test were added to the denominator to account for marked lamprey from the previous treatment that were holding in the MWC. Efficiency estimates based on the mark-recapture experiment ranged from 2.9% (ramp oriented upstream) to 18.4% (ramp oriented downstream) and efficiency was typically higher when each collector was oriented downstream than when the same collector was oriented upstream (Figure 11).

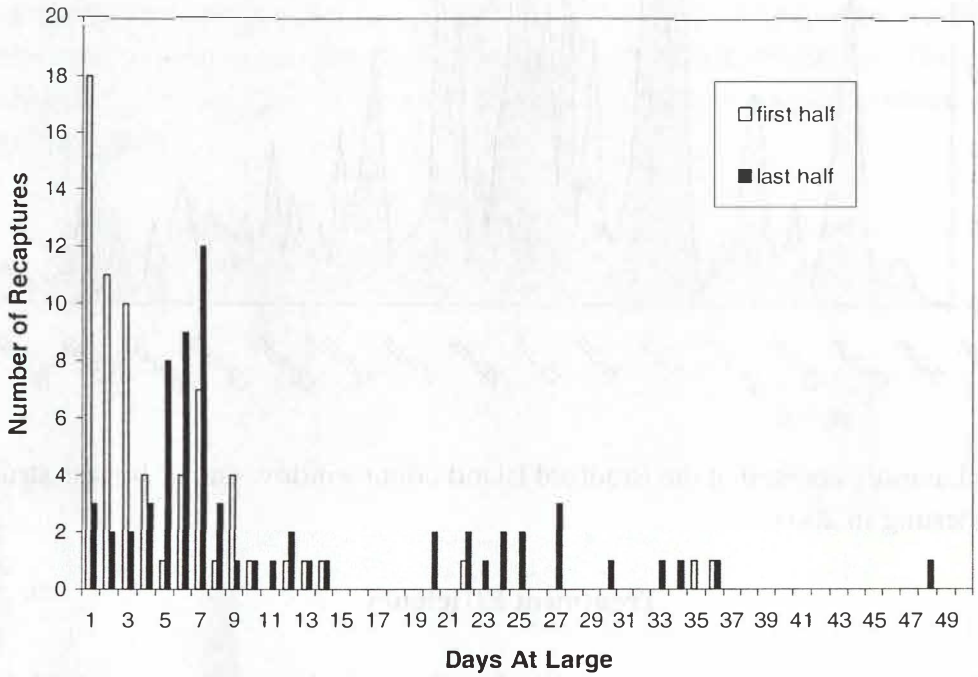

Figure 10. Frequency histogram of the number of days marked lamprey were at large before collection in the bypass trap box in 2003. The open bars represent times at large for fish released during the first half of the study (27 May-11 July) and the solid bars represent times at large for fish released during the last half of the study (July 14-12 September).

Visual counts--An independent measure of the treatment efficiency was obtained by estimating the number of lamprey in the MWC from counts made at the Bradford Island count window. We divided the total number of lamprey collected by each structure by the estimated number of lamprey in the MWC during operation of that structure. The results indicated that estimates based on previous radiotelemetry studies produce questionable results. In some cases this method yielded a treatment efficiency estimate that was over 100%. When we assumed that all lamprey that passed the count window eventually entered the MWC, the treatment efficiency estimates (shown in Figure 11) were close to those obtained via mark-recapture. While the absolute efficiency of the structures could not be resolved without radiotelemetry data, the relative efficiencies were consistent with the results obtained from the mark-recapture experiment. Both methods indicated that the ramp and the modified tube had the highest efficiencies (Figure 11).

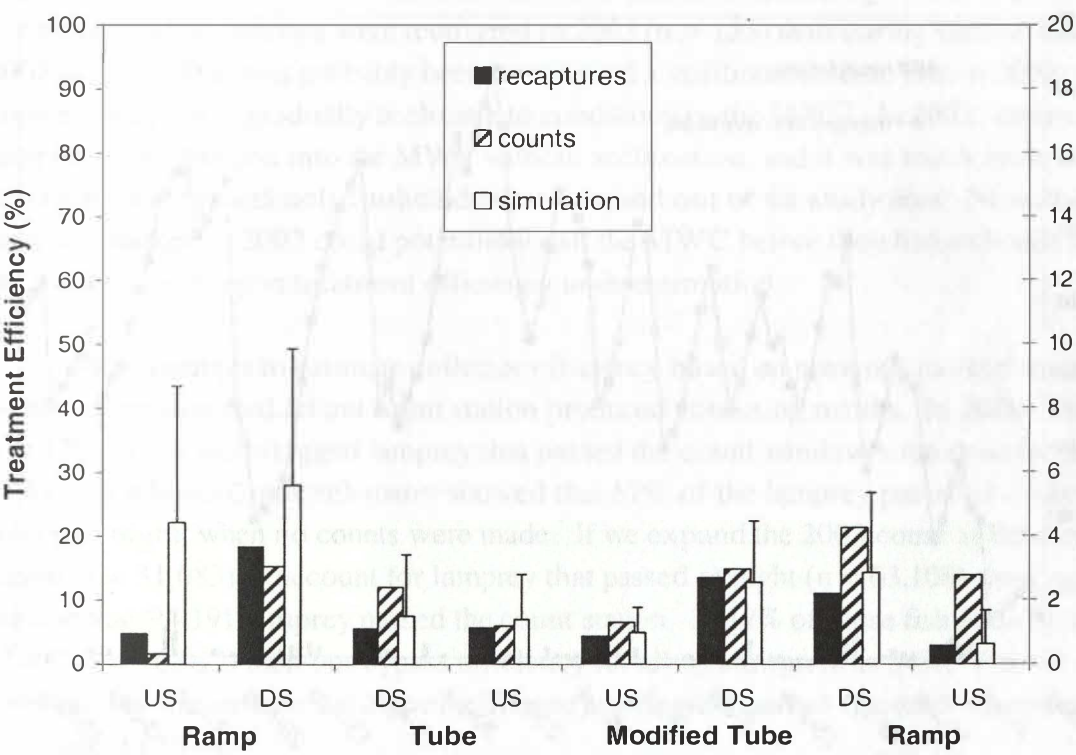

Figure 11. Efficiency estimates in chronological order of testing for each structure (ramp, tube, and modified tube) and orientation (upstream (US) and downstream (DS)). Treatment efficiency estimates were based on both recapture data (solid bars) and counts (hatched bars). Mean daily efficiency estimates (open bars) were based on simulation results (error bars represent standard deviation of these means).

Mean Daily Efficiency

Daily efficiency estimates addressed the question, "Of the fish in the MWC during a given treatment day, how many were collected on that day?" We simulated the number of marked lamprey that were available to each structure on each day. The distribution of times at large for recaptured lamprey was different in the first and last half of the study period. Therefore, we drew from the appropriate distribution when conducting the simulations. There were many days when no marked lamprey were recaptured (Figure 12). Mean daily efficiency estimates were consistently lower than overall treatment efficiency estimates (Figure 11).

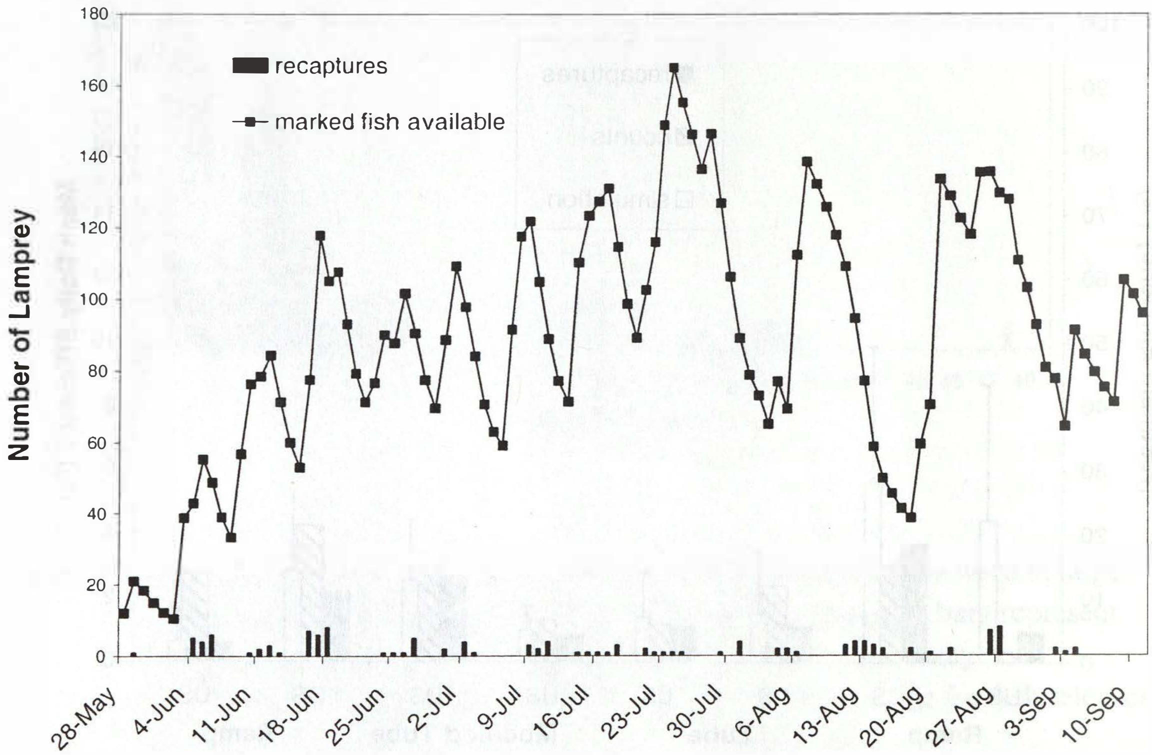

Figure 12. The estimated number of marked lamprey that were in the MWC on each day based on the average of 100 simulations (dots). The bars represent the number of recaptures on each day.

DISCUSSION

The prototype lamprey bypass collectors we tested in 2003 successfully attracted migrating lamprey from the Bradford Island MWC. The 5,458 lamprey we captured in the bypass trap box represented 18% of the Bradford Island lamprey count during the study period (from 23 May to 12 September, 31,083 lamprey were counted) and an estimated 6% of all lamprey that used the Bradford Island fishway. There were several nights when the trap was not fished (weekends and holidays) or when it was completely full. Consequently, more lamprey could have been collected if there were no limit to the trap box size or days of operation.

Mark-recapture methods used to evaluate bypass collector efficiency were improved in 2003, and our results indicated that treatment efficiency was as high as 18%. Far more marked lamprey were recovered in 2003 (n = 133) than during similar tests in 2002 (n = 2). This was probably because we used a volitional release box in 2003, which allowed lamprey to gradually acclimate to conditions in the MWC. In 2002, marked lamprey were dropped into the MWC without acclimation, and it was much more likely that they were immediately flushed downstream and out of the study area. Nevertheless, lamprey marked in 2003 could potentially exit the MWC before they had a chance to use the bypass, resulting in treatment efficiency underestimation.

Our attempts to estimate collector efficiency based on previous radiotelemetry and counts at the Bradford Island count station produced confusing results. In 2000-2002, 6 to 17% of the radio-tagged lamprey that passed the count window were detected in the MWC. In addition, radiotelemetry showed that 67% of the lamprey passed the count station at night, when no counts were made. If we expand the 2003 count at Bradford Island (n = 31,083) to account for lamprey that passed at night (n = 63,108) then we can assume that 94,191 lamprey passed the count station. If 17% of these fish entered the MWC (n = 16,012) then our bypass efficiency for all treatments was 34%. This is considerably higher than the highest efficiency estimate based on the mark-recapture experiment (20%).

Consequently, the absolute efficiency estimates based on count data are suspect. Without the benefit of radiotelemetry in 2003, we do not know what percentage of the lamprey passed the count station without being counted and what percentage of the lamprey that were counted would have entered the MWC. However, the efficiency estimates based on count data did allow for comparisons of relative efficiency among treatments.

Both efficiency estimates and CPUE indicated that the collector was more effective in the downstream orientation than the upstream orientation. The rationale for trying the upstream orientation was that lamprey tend to accumulate near the Tainter gate at the upstream end of the MWC. At night, lamprey can readily be observed as they attempt to find a passage route in this area. However, our efficiency estimates indicated that fewer lamprey used the bypass when it was oriented upstream. This is likely due to the fact that lamprey, and most other fishes, are positively rheotactic (i.e., they swim into the current) and therefore are more likely to encounter the downstream-oriented collectors when moving upstream.

All estimates of efficiency indicated that the ramp and the modified tube collected lamprey best. Apparently, the modification to the tube collector helped to retain lamprey that entered this device. It is interesting that even though the ramp and modified tube collectors featured very different designs and hydraulic characteristics, efficiency estimates were similar for both designs. Perhaps this highlights the fact that lamprey are constantly searching for a relatively benign passage route and that almost any structure that provides a weak attracting flow will collect them eventually.

Both the times at large for marked fish and the daily efficiency estimates provided evidence that marked lamprey did not find and enter the bypass collector for extended periods after release in the MWC (over a week in many cases). Radiotelemetry also suggested that lamprey reside in the MWC for extended periods (Moser et al. 2005a). We noted that time at large was generally longer during the last half of the study period. This may have been a response to handling during the high water temperatures in late July and August. During this time period we noted that lamprey took a longer time to exit the volitional release box. Moreover, Ocker et al. (2001) reported that radio-tagged lamprey appeared to suffer from handling when water temperature exceeded 19.5°C.

There are several reasons that we believe collector efficiency was underestimated in these experiments. Handling may have caused lamprey to fall back and out of the study area. We had numerous reports of branded lamprey sightings at the Bradford Island count station. Clearly these animals left the study area either via the picketed lead or diffuser grating. Also, the limited size of the trap box made it impossible for lamprey to enter the trap on some occasions.

We have some evidence that lamprey that used the bypass eventually made it to the spawning ground, or at least further upstream. Branded lamprey were sighted at count windows at The Dalles and John Day Dams. Two branded lamprey were reported by tribal members fishing for lamprey on the Deschutes River near Shearar's Falls, and one branded lamprey was observed during winter dewatering operations at Rocky Reach Dam in both 2004 and 2005. These observations are further testimony to the benefits of providing passage alternatives for lamprey. However, absolute efficiency estimates of bypass collectors are still needed to determine whether bypass operation results in a substantial improvement in overall lamprey passage at Bonneville Dam.

ACKNOWLEDGMENTS

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