Effects of Turbine Operations and a Prototype Rotating Vertical Barrier Screen on Fish Condition at McNary Dam, 2006

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EXECUTIVE SUMMARY

This study was initiated to evaluate the condition of juvenile salmonids during passage through the fish bypass and collection system at McNary Dam, with an emphasis on identifying guidance structures and turbine operations that may adversely affect fish condition. Earlier studies at the dam indicated that juvenile salmonid survival may not have differed while passing through turbines over a range of discharges. However, the more turbulent conditions associated with higher discharges, together with debris accumulations on contemporary vertical barrier screens, may require structural modifications to protect collected fish during their time in the gatewells. A prototype rotating vertical barrier screen was installed in gatewell 4A to address these issues. Also, tests at McNary Dam in 2004 indicated that an increase in descaling during higher turbine discharges may not have been solely related to gatewell conditions.

Additional research during the 2005 juvenile salmon migration used PIT-tagged smolts released just downstream from the trashrack in front of turbine unit 4A and also within the gatewell of turbine unit 4A. Results from this study again indicated somewhat higher rates of descaling when turbines were operated at higher loads, but we were unable to isolate the cause.

During the 2006 smolt migration, we utilized an additional orifice trap in gatewell 5A and monitored fish condition in this gatewell for run-of-the-river juveniles. The test design called for both 80- and 62-MW turbine loads for turbine unit 4 and a 62-MW load for turbine unit 5. Additionally, both the rotating vertical barrier screen and a flow control device were used in gatewell 4A, while a standard vertical barrier screen was used in gatewell 5A. We collected descaling data twice each hour, 24 h/d, 6 d/week in both orifice traps throughout the spring and summer juvenile migrations.

During the spring portion of the study, results with the flow control device were inconclusive because the device was constructed improperly and did not mitigate flow. Even so, descaling for all species did increase somewhat with the 80 MW load tests in turbine unit 4. Results for subyearling Chinook salmon during the summer, with the flow control device working properly, indicated that there was no statistically significant difference in descaling between the two flow conditions, with the 80 and 62 MW units producing 2.8 and 2.5% descaling rates, respectively. However, mortality was significantly higher in the 80 MW unit.

Passage through the orifice traps installed at McNary Dam generally showed an increase just after dark, and the descaling percentage also generally appeared to increase during hours of darkness. Descaling rates on all species collected from the orifice traps when the turbine units were operated at 62 MW (standard turbine generation) were quite similar to those observed in the juvenile bypass facility daily collection.

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INTRODUCTION

The objective of this study was to evaluate the condition of juvenile salmonids during passage through the gatewells of turbines operated at high discharge levels and equipped with prototype rotating VBSs and flow control devices at McNary Dam. The need for this work was specified in Appendix G of the 2004 National Marine Fisheries Service Biological Opinion (NMFS 2004) under *McNary Dam Fish Condition Evaluations*. The study was also specified by the U.S. Army Corps of Engineers in its Anadromous Fish Evaluation Program. The study also addresses Question 3 of the Ten Key Questions for Salmon Recovery in the NMFS Salmon Research Plan (NMFS 2002).

Survival of juvenile salmonids that pass through turbines of hydroelectric projects on the Columbia River has long been lower than desired. While passage through other routes, such as spillways and bypass systems, typically results in higher survivals for juvenile salmonids, improving turbine survival can offer great benefits, especially in low flow years such as 2001. The operation of turbines at higher discharge rates at McNary Dam may require modifying bypass system components to minimize any potential impact to juvenile salmonids exposed to the more turbulent gatewell conditions associated with higher turbine discharge rates. We address this question by evaluating gatewell environments to identify components which may have a detrimental effect on fish condition at higher turbine discharge rates.

Results from studies conducted at McNary Dam in 2004 and 2005 suggested that descaling and injury rates were somewhat higher for collected smolts when turbines were operated at higher discharge levels (Absolon et al. 2005). It was not evident where the descaling problem occurred; however, turbulence related to the higher flows within the gatewells was a probable cause.

Further, it is known that debris accumulates on the face of the vertical barrier screens (VBS), which can lead to higher descaling and injury rates to fish. Large amounts of windswept debris (tumbleweeds in this case) accumulated on the trashracks at McNary Dam during the spring juvenile migration in 2005. Higher turbine intake flows drew this debris onto the trashracks, where it accumulated until becoming sufficiently water-logged to sink to the lower ends of the trashracks. With time, this type of debris can partially block complete sections of the trashrack from the surface to the river bottom. As this occurs, descaling estimates for migrating juvenile salmonid can be very high (in excess of 20%).

Ongoing evaluations to monitor the condition of juvenile salmonids during higher turbine discharges at McNary Dam present a difficult question. McNary Dam is in the midst of a modernization program, but the existing turbines are not capable of generating the flow conditions that can be created by the new turbines. The maximum outflow of our test turbines is 80 MW (roughly 12,000 cfs of flow), while the new turbines will be capable of producing a much higher flow of roughly 110 MW (roughly 18,000 cfs of flow). Hence, we are currently unable to test the maximum range of flows that will be available when the new turbines are in place.

This uncertainty about future flow conditions is combined with a continually changing river environment (i.e., variability in water temperature and debris loads and types), as well as rates of descaling that vary for different juvenile salmon species. These conditions dictate that more robust data sets will be necessary if we are to continue the use of descaling and injury measurements as the primary methodology to evaluate the effects of various juvenile salmonid passage conditions at dams.

During the 2006 study, we attempted to improve our descaling and injury data sets by increasing the sample rate so that our point estimates would reflect more complete daily samples. We collected run-of-the-river smolts twice each hour, 24 h per day, 6 days per week during the spring and summer juvenile salmonid migrations. Samples were taken at 30-minute intervals, with a goal of 10-30 fish sampled for each period. This sampling regime gave a descaling point estimate for each 24-h period of operation for the different species examined.

METHODS

We collected descaling/injury data on run-of-the-river smolts (yearling and subyearling Chinook, coho, and sockeye salmon and steelhead) that were captured in orifice traps at McNary Dam. Descaling criteria of the Standard Fish Transport Oversight Team were used (Ceballos et al. 1993), wherein a fish that was missing at least 20% of the scales on at least one side considered descaled. Data on any obvious external injuries were also collected.

The two orifice traps were attached to the A gatewells (south orifices) in turbine units 4 and 5. Data were collected during both spring and summer juvenile migrations (April-July). The test gatewells were equipped with a prototype rotating VBS in turbine unit 4 and a standard VBS in turbine unit 5. Both turbines were equipped with extended-length bar screens as guidance devices. Turbine unit 4 was also equipped with an outlet flow control device installed in the A gatewell. When deployed, the flow control device restricted flow in the outlet area on the downstream side of the VBS. This restriction, in effect, allows the gatewell flow (turbulence) in a turbine operating at 80 MW to remain similar to flow in a turbine operating at 62 MW. Turbine unit 5 was the control unit and was operated at 62 MW throughout the study.

Using three different test configurations in turbine unit 4 (62 MW, 80 MW with the flow control device, and 80 MW without the flow control device) and working 6 days per week, we set up our test schedule in randomized 2-day blocks. The basic test scenario was to operate each turbine configuration continuously for 48 h, with each replicate beginning and ending at 0600 PDT. On test days when the load in turbine unit 4 changed from 80 MW to 62 MW, we did not begin our hourly sampling until 1000. (During this period we also opened the north orifice in gatewell 4A.) Both of these procedures were followed so that any fish that had entered the gatewell during the high flow regime could exit prior to our beginning the descaling sample for the lower flow test. Approximate numbers of fish required for each sample were set at 10-30 smolts.

RESULTS AND DISCUSSION

Descaling sampling began on April 12 and ended on July 19. During that period, we collected and examined a total of 32,566 subyearling Chinook salmon, 21,429 yearling Chinook salmon, 8,480 steelhead, 1,596 coho, and 5,063 sockeye salmon. The majority of subyearling Chinook salmon were examined during the summer migration, while the other species were examined primarily during the spring.

Orifice Trap Evaluation

Prior to beginning our replicated test scenario, we examined run-of-the-river smolts collected from the orifice traps installed in turbine units 4 and 5 to ensure that neither trap was causing injury or descaling. During the period 12-20 April, we examined over 1,500 yearling Chinook with minimal descaling of 1.4% and 0.9% in each respective orifice trap and saw no other injuries in turbine units 4 and 5, respectively.

Throughout the juvenile migration in spring, we also periodically marked and released yearling Chinook. Fish were released into the test gatewells (4A and 5A) when both units were operated at the 62 MW load. Fish used for these releases were not previously descaled and were marked with a partial caudal clip, which is easily identifiable and does not affect the fish. Fish were released on the surface of each gatewell and recovered during our normal sampling periods. Although the recovery rate for these fish was lower than desired, we recaptured and examined over 200 in each trap and again found minimal descaling and no differences in fish condition between the traps.

Descaling data collected in both spring and summer during the juvenile migrations when both turbine units were operated at 62 MW, are shown in Appendix Table 1. The data indicated that although the differences in descaling between traps in turbine intakes 4A and 5A were statistically significant, the percentages of descaled fish were very low throughout the field season. For the two respective traps, descaling rates were 3.5 and 2.1% for subyearling Chinook, 4.3 and 3.4% for yearling Chinook, and 1.4 and 2.2% for steelhead. Descaling was virtually identical for sockeye salmon sampled from the 4A and 5A traps, respectively, at 6.3 and 6.2%. Numbers of coho were insufficient for analysis, but average descaling data for coho was low and similar in each orifice trap at 1.1 and 2.6% for the 4A and 5A traps, respectively. Descaling estimates from our orifice traps were also similar to those observed from the daily descaling samples taken at the juvenile collection facility at McNary Dam.

Spring Juvenile Migration

The study was plagued by a major problem during the spring juvenile migration: a portion of the outlet flow control device was omitted when it was initially installed. Therefore, when the flow control was deployed, there was essentially no restriction in the outlet area. This problem was not discovered until late spring. The U.S. Army Corps of Engineers modified and reinstalled the device for testing during the summer juvenile migration.

Not surprisingly, results from the spring migration for tests using the improperly installed flow control device indicated that descaling for bypassed fish increased when a turbine was operated at 80 MW. Overall data comparing the turbine operated at 80 MW to the one operated at 62 MW during spring showed higher descaling rates for all salmonid species passing through gatewells during the higher discharge rate. Overall descaling rates for the respective turbine operations were 4.9 and 2.5% for yearling Chinook, 3.0 and 2.0% for steelhead, and 9.9 and 4.8% sockeye.

In addition to the increase in descaling at the higher turbine discharge, we also noted a fairly substantial mortality during some of the 80 MW tests, especially for sockeye smolts. During several tests in mid May, the mortality rate for sampled sockeye smolts was greater than 10%. Whether this or a similar mortality would have occurred if a standard VBS had been used during the 80MW operation is unknown. One of the unique characteristics of the rotating VBS is that it brings any impinged fish close to the surface. There the fish can be dislodged from the screen and can then pass through the orifice. A standard VBS may also impinge fish, but those that may eventually pass through the orifice would likely be in various stages of decomposition, and therefore not easily identifiable. We need to be aware of the possibility for a potential increase in mortality that is not readily recognizable and ensure that high turbine flow conditions are closely monitored at McNary Dam. We again caution that the flow control device was not properly installed when the spring tests above were conducted. Therefore, results should be interpreted accordingly.

Summer Juvenile Migration

Results for subyearling Chinook salmon examined during the summer migration and with a properly constructed flow control device installed indicated that there was no statistically significant difference in descaling between the two turbine discharge rates (Table 1). Descaling was very minimal for both low and high turbine operations at 2.5% for the 62 MW load and 2.8% for the 80 MW load with the flow control device operating properly.

Table 1. Descaling results for subyearling Chinook captured in the 4A orifice trap, comparing the 62 MW flow and the 80 MW flow with the flow control device during summer.

Date	Flow Control	RVBS	MW	Test	Fish (n)	Descaling (%)	Mortality (%)	Descaling Mortality (%)
15 June	No	Yes	62	Control	425	3.8	0.0	3.8
23 June	No	Yes	62	Control	536	2.8	0.0	2.8
24 June	No	Yes	62	Control	634	0.6	0.8	1.4
28 June	No	Yes	62	Control	684	2.5	0.3	2.8
29 June	No	Yes	62	Control	411	2.2	0.2	2.4
30 June	No	Yes	62	Control	720	3.1	1.0	4.1
1 July	No	Yes	62	Control	729	2.5	1.9	4.4
16 June	Yes	Yes	80	Test	615	3.3	3.4	6.7
17 June	Yes	Yes	80	Test	624	3.8	3.3	7.1
19 June	Yes	Yes	80	Test	707	3.8	1.6	5.4
20 June	Yes	Yes	80	Test	644	2.8	2.1	4.9
21 June	Yes	Yes	80	Test	362	0.6	1.3	1.9
22 June	Yes	Yes	80	Test	588	2.4	1.8	4.2
26 June	Yes	Yes	80	Test	582	3.4	0.5	3.9
27 June	Yes	Yes	80	Test	648	2.0	0.9	2.9
Mean				Control	591.25	2.5	0.6	3.1
SE						0.4	0.3	0.4
Mean				Test	596.25	2.8	1.9	4.6
SE						0.4	0.4	0.6
t (2 sample)						0.49	2.79	2.04
df						13	13	13
P						0.632	0.015	0.062

Table 1 also shows that, similar to sockeye smolts, the 80 MW flow resulted in a significant increase in mortality for collected subyearling Chinook, although not as severely as for sockeye. The increase in mortality for collected fish of these two species at the higher turbine discharge is a concern at McNary Dam.

Diel Passage and Descaling

During the 2006 field season, the orifice traps in turbine units 4 and 5 collected smolts for more than 25 days during both the spring and summer juvenile migrations. By sampling during each hour of operation, we compiled a large amount of hourly passage data. Not all of the sampling periods were of the same duration; however, since we knew the number of minutes for each sample, we could then estimate hourly passage for each orifice. Figures 1 and 2 show diel passage of the two orifice traps for both spring and summer migrants during the 62 MW operation. All species showed an increase in passage just after dark and, at times, the increase was quite substantial. Hourly passage was similar when turbine unit 4 was operated at the 80 MW flow level.

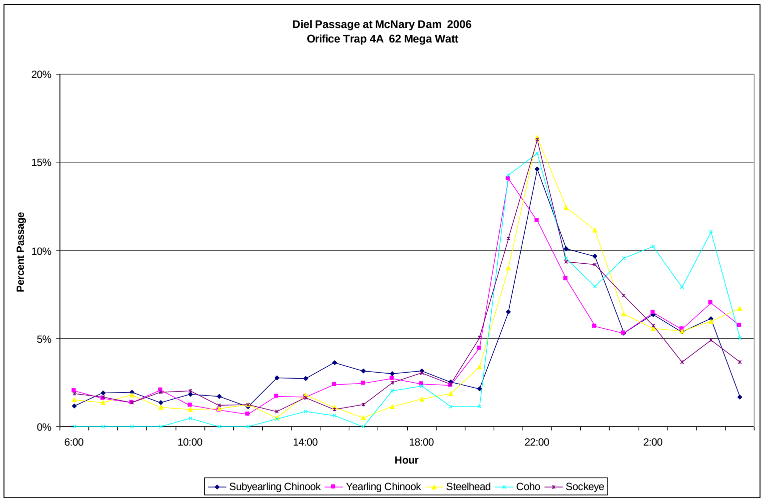

Figure 1. Diel passage of juvenile salmonids in orifice trap 4A at a 62 MW load.

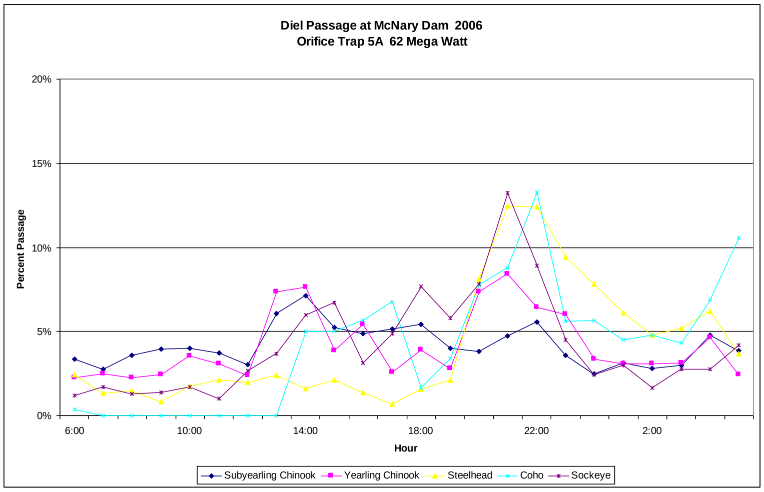

Figure 2. Diel passage of juvenile salmonids in orifice trap 5A at 62 MW load.

As an adjunct to the diel passage data, we also observed an increase in descaling for most of the study configurations for fish that were sampled after dark. Table 2 shows the descaling data for only the 62 MW turbine operation from both orifice traps. These data were collected throughout the field season, and although the actual descaling percentages for subyearling Chinook were quite low, there appeared to be fairly consistent increases in descaling for subyearling and yearling Chinook as well as for sockeye when the fish were sampled at night. The lone outlier was steelhead, which is not surprising since these smolts are larger and much stronger swimmers and their descaling rates are nearly always lower than for the other species.

Whether or not the higher descaling rates at night are typical during each juvenile migration is unknown. This study is the first we have conducted that has systematically taken descaling samples throughout each 24-hour day. We plan to continue this work during the 2007 juvenile migration; it will be useful to see if the diel pattern in descaling observed this year repeats itself.

Table 2. Diel descaling for smolts collected from orifice traps in gatewells 4A and 5A when turbine operation was at the standard McNary loading of 62 MW in 2006. Daylight sampling times were from 0400-2000 PDT and nighttime from 2030 to 0330.

	Descaling (%)				
Sampling Period	Subyearling	Yearling	Steelhead	Sockeye	Orifice Trap
Day	2.2	1.8	1.4	4.2	4A
Night	3.6	6.7	1.1	7.8	
Total Fish	5,116	2,344	886	940	
Day	1.4	1.8	2.1	4.4	5A
Night	2.2	4.9	1.9	9.1	
Total Fish	7,199	2,670	1,328	1,055	

CONCLUSIONS

1. Descaling for nearly all salmonid species increased to some degree when the turbine was operated at an 80MW load during the spring juvenile migration. However, the outlet flow control device designed to mitigate turbulence at the higher turbine load was not functioning properly when these tests were conducted.

2. For subyearling Chinook, use of a properly constructed flow control device during the summer resulted in no significant increase in descaling at the 80 MW load compared to the 62 MW load.

3. Passage through the orifice traps installed at McNary Dam generally showed an increase just after dark, and the descaling percentage also generally appeared to increase during hours of darkness.

4. Descaling rates on all species collected from the orifice traps when the turbine units were operated at 62 MW (standard turbine generation) were quite similar to those observed in the juvenile bypass facility's daily collection.

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APPENDIX

Appendix Table 1. Individual test descaling percentages and overall statistical values for orifice traps in gatewell slots 4A and 5A in the McNary Dam turbine units operating at 62 MW for all tests.

	Subyearling Chinook				Yearling Chinook				Steelhead				Sockeye			
Date	5A	4A	5A	Variance	5A	4A	5A	Variance	5A	4A	5A	Variance	5A	4A	5A	Variance
04/24/06					5.1				1.8							
04/25/06					5.1	3.1	5.1	-0.2	3.1	3.3	3.1	0.2				
04/26/06					2.6				2.2							
04/27/06					5.2				1.4							
04/28/06					3.2				3.6							
04/29/06					2.8				2.2							
05/01/06					5.4				5.0							
05/02/06					2.0				5.3				8.0			
05/03/06					1.4	5.0	1.4	3.6	0.8	0.9	0.8	0.1	7.8	7.1	7.7	-0.5
05/04/06					2.4	1.4	2.4	-1.0	4.7	2.7	4.7	-1.9	5.6	1.5	5.6	-4.1
05/05/06					1.9				3.6				5.6			
05/06/06					1.5				2.4				5.2			
05/08/06					3.6				1.4				2.2			
05/09/06					2.3				0.7				5.9			
05/10/06					2.4				2.4				1.2			
05/11/06					4.2				0.0				2.6			
05/12/06					2.1	5.8	2.1	3.7	1.7	1.6	1.7	0.0	2.6	6.7	2.6	4.1
05/13/06					2.4	3.9	2.4	1.5	0.0	0.0	0.0	0.0	4.8	3.9	4.8	-1.0
05/15/06					4.8	6.0	4.8	1.2	1.2	0.0	1.2	-1.2	3.5	3.7	3.5	0.1

Appendix Table 1. Continued.

	Subyearling Chinook				Yearling Chinook				Steelhead				Sockeye			
Date	5A	4A	5A	Variance	5A	4A	5A	Variance	5A	4A	5A	Variance	5A	4A	5A	Variance
05/16/06					3.3	7.8	3.3	4.5	2.1	1.5	2.1	-0.6	5.1	7.3	5.1	2.2
05/17/06					3.8				2.8				5.6			
05/18/06					4.7				0.0				0.0			
05/22/06	0.0	0.0	0.0	0.0	8.1	1.9	0.1	-6.1	5.0	1.7	0.0	-3.3	8.6	11.5	8.6	2.9
05/23/06	0.0	2.1	0.0	2.1	4.5	4.1	4.5	-0.5	0.9	1.0	0.9	0.1	11.5	8.5	11.5	-3.5
05/24/06	0.0				0.5				2.5				1.6			
05/25/06	2.9				2.4				0.8				6.1			
05/26/06	1.1				0.6				0.8				5.6			
05/27/06	1.2	0.8	1.2	-0.5	0.0	3.8	0.0	3.8	2.5	1.3	2.5	-1.2	6.1	6.7	6.1	0.5
06/05/06	2.6															
06/06/06	3.5															
06/07/06	2.0	1.9	2.0	-0.1												
06/08/06	1.9	5.4	1.9	3.5												
06/09/06	0.3															
06/10/06	2.3															
06/12/06	3.1	4.7	3.1	1.6												
06/13/06	6.9	9.7	6.9	2.8												
06/14/06	3.3															
06/15/06	1.7	3.8	1.7	2.1												

Appendix Table 1. Continued.

	Subyearling Chinook				Yearling Chinook				Steelhead				Sockeye			
Date	5A	4A	5A	Variance	5A	4A	5A	Variance	5A	4A	5A	Variance	5A	4A	5A	Variance
06/16/06	1.4															
06/17/06	0.6															
06/19/06	1.0															
06/20/06	0.8															
06/21/06	1.4															
06/22/06	1.1															
06/23/06	1.0															
06/24/06	1.5															
06/26/06	1.3															
06/27/06	1.1															
06/28/06	1.0															
06/29/06	1.3															
06/30/06	1.4															
07/01/06	1.1															
mean	1.6	3.5	2.1	1.4	3.2	4.3	3.4	0.9	2.1	1.4	2.2	-0.8	5.0	6.3	6.2	0.1
s.e.	0.0	0.4	0.3	0.2	0.1	0.2	0.2	0.3	0.1	0.1	0.2	0.1	0.1	0.3	0.3	0.3
t				7.85				2.61				6.82				0.30
df				7				9				9				8
p-value				0.000				0.028				0.000				0.771