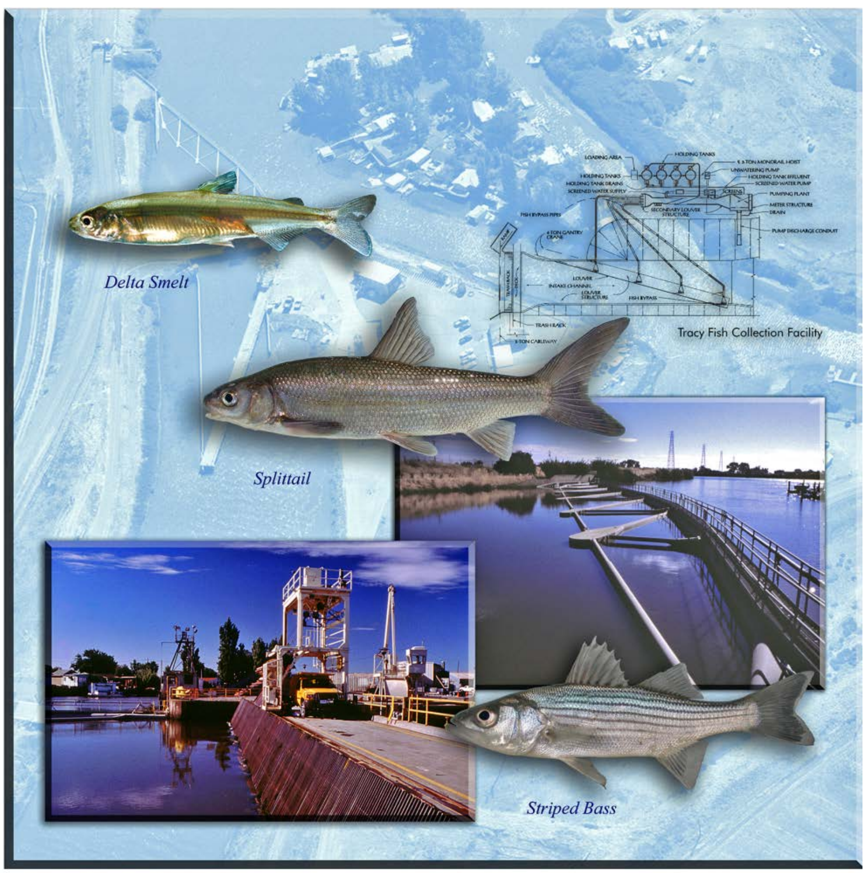
RECLAMATION

Managing Water in the West

Tracy Technical Bulletin 2015-3

White Sturgeon Salvage Efficiency at the Tracy Fish Collection Facility



U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region and
Denver Technical Service Center

May 2015

1. REPORT DATE *(DD-MM-YYYY)*
May 2015

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
White Sturgeon Salvage Efficiency at the Tracy Fish Collection Facility

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Cathy Karp and Brent Bridges

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Bureau of Reclamation, Technical Service Center
Fisheries and Wildlife Resources Group, 86-68290
PO Box 25007, Denver, CO 80225-0007

Bureau of Reclamation,
Tracy Fish Collection Facility
16650 Kelso Road, Byron, CA 94514

8. PERFORMING ORGANIZATION REPORT NUMBER
Tracy Technical Bulletin 2015-3

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Bureau of Reclamation,
Tracy Fish Collection Facility
16650 Kelso Road, Byron, CA 94514

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Available from the National Technical Information Service (NTIS)
Operations Division, 5285 Port Royal Road, Springfield, VA 22161

13. SUPPLEMENTARY NOTE

14. ABSTRACT
The Bureau of Reclamation's Tracy Fish Collection Facility (TFCF) in central California was designed in the mid-1950s to divert, collect, and return salvaged fish to the Sacramento-San Joaquin River Delta from exported flows enroute to the C.W. "Bill" Jones Pumping Plant. Today, millions of fish comprising 50+ species may be drawn into the facility. Juvenile white sturgeon (*Acipenser transmontanus*) louver efficiency was evaluated using release recapture experiments. In 28 trials, secondary and primary channel louver efficiency averaged 93.3 percent and 32.2 percent, respectively. Whole facility efficiency averaged 32.2 percent and was the same as primary channel efficiency. Following application of an underwater noise device in the primary channel, primary channel and whole facility efficiency increased significantly up to 74 percent (Kruskal-Wallis, $P = 0.04$). We attributed this increase to the startle effect of the dry ice device on predatory striped bass (*Morone saxatilis*) feeding behavior. Angling in the primary channel prior to release of the dry ice yielded 5 adult striped bass (mean 657.4 mm fork length), all with experimental white sturgeon in their stomachs. Striped bass were again captured by angling in the primary channel several hours following application of the noise device.

15. SUBJECT TERMS
juvenile white sturgeon, louver efficiency, Tracy Fish Collection Facility

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**a. THIS PAGE**		22	Donald E. Portz, Ph.D.
					19b. TELEPHONE NUMBER *(Include area code)* 303-445-2220

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Tracy Fish Facility Studies
California

White Sturgeon Salvage Efficiency at the Tracy Fish Collection Facility

Tracy Technical Bulletin 2015-3

by

Cathy Karp[1] and Brent Bridges[2]

[1] U.S. Department of the Interior
Bureau of Reclamation
Fisheries and Wildlife Resources Group, 86-68290
PO Box 25007
Denver, CO 80225-0007

[2] U.S. Department of the Interior
Bureau of Reclamation
Tracy Fish Collection Facility; TO-411
16650 Kelso Road
Byron, CA 94514-1909

U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region and
Denver Technical Service Center

May 2015

MISSION STATEMENTS

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

TRACY FISH FACILITY IMPROVEMENT PROGRAM

J. Carl Dealy, Manager

TRACY SERIES EDITOR

Donald E. Portz, Ph.D.
U.S. Department of the Interior – Bureau of Reclamation
Technical Service Center
Fisheries and Wildlife Resources Group, 86-68290
PO Box 25007
Denver, CO 80225-0007

COVER

Fish photography by René Reyes, Tracy Fish Collection Facility, Tracy, California.
Design by Doug Craft.

DISCLAIMER

TABLE OF CONTENTS

Tables

Figures

Appendices

EXECUTIVE SUMMARY

The U.S. Department of the Interior, Bureau of Reclamation Tracy Fish Collection Facility (TFCF) in central California was designed in the mid-1950s to divert, collect, and return salvaged fish to the Sacramento-San Joaquin River Delta from exported flows enroute to the C.W. "Bill" Jones Pumping Plant (JPP). The TFCF is situated at the head of the canal leading to the JPP, and up until the summer of 2014, used two louver bypass channels to divert entrained fish. Louvers are a type of behavioral fish barrier and as such, are more or less efficient for different species and life history stages. TFCF fish diversion efficiency was considered high in the early decades of operation due in part to short-term pumping and low numbers of small fish in the entrained flows. However, year-round pumping at the JPP began in the 1960's following completion of San Luis Reservoir, and today, millions of fish comprising more than 50 species may be drawn into the fish facility. Juvenile white sturgeon (*Acipenser transmontanus*) louver efficiency was evaluated using release-recapture experiments. In 28 trials, secondary channel and primary channel louver efficiency averaged 93.3 percent and 32.2 percent, respectively. Whole facility efficiency was identical to primary channel efficiency. Following application of an underwater noise device in the primary channel, primary channel and whole facility efficiency of four trials increased significantly up to 74.0 percent (Kruskal-Wallis, $P = 0.04$). We attributed this to the temporary disruption of striped bass (*Morone saxatilis*) feeding. Angling in the primary channel prior to release of the dry ice yielded five adult striped bass (mean= 657.4 mm fork length) with experimental white sturgeon in their stomachs. Striped bass were again captured by angling several hours following dry ice release.

INTRODUCTION

Reclamation's Tracy Fish Collection Facility (TFCF), located in the southern Sacramento-San Joaquin Delta (Delta) was designed to divert juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and striped bass (*Morone saxatilis*) from Delta Mendota Canal (DMC) flows, thereby preventing entrainment loss to the downstream C.W. "Bill" Jones Pumping Plant (JPP; Bates and Vinsonhaler 1957, Bates *et al*. 1960). These facilities were built in the 1950s to export water off the Old River channel of the San Joaquin River in central California for irrigation, municipal, and industrial uses, while diverting and salvaging entrained fish.

The TFCF is situated at the head of the DMC and up until summer 2014, used two louver-bypass systems to intercept and guide entrained fish (Figure 1). Fish and exported flows enter the facility beneath a surface debris collector (trash boom), through a trash rack with 5.1 cm (2.0 in) wide spacing, and into the 25.6 m (84 ft) wide, 6 m (20 ft) deep primary louver channel. The primary channel louver wall is 97.5 m (320 ft) long with four 22.9 m (75 ft) sections terminating in bypass entrances (15.2 cm [6 in] width). Once inside a bypass, fish move into 0.9 m (36 in) diameter underground pipes to the 2.4 m (8 ft) wide, 4.9 m (16 ft) deep secondary channel where, up until summer of 2014, they encountered a double louver wall (9.3m long [30.2 ft]). Here, fish and diverted aquatic material enter a common bypass (15.2 cm [6 in]) to one of four holding tanks. Salvaged fish are regularly removed and released back to the Delta, downstream of the influence of the JPP pumps. Both the primary and secondary channel louver walls are angled 15^{o} to the flow and contain evenly spaced vertical slats (2.54 cm [1 in]) angled 90^{o} to the flow. Both the trash rack and the louver walls become clogged with aquatic debris and are cleaned frequently.

Louver systems act as a behavioral barrier in that fish sense the turbulence created by the vertical slats, and move along the louver wall until they enter a bypass (Hallock *et al*. 1968, EPRI 1986). The effectiveness of louvers at excluding fish depends on many factors including fish species, life history stage, swimming ability, hydraulic conditions, and debris load. Regulatory criteria were established for the TFCF to define appropriate channel, louver wall, and bypass velocities (California State Water Resources Control Board 1978, NMFS 2004, USFWS 2004). These include maintaining bypass ratios (BR) > 1, and maintaining secondary channel velocities between 0.9–1.1 m/s (3–3.5 ft/s) November through mid-May and < 0.76 m/s (2.5 ft/s) mid-May through October. Primary channel velocity is determined by the number of JPP pumps in operation and tide stage and thus, there are no legal requirements for maintaining a certain velocity.

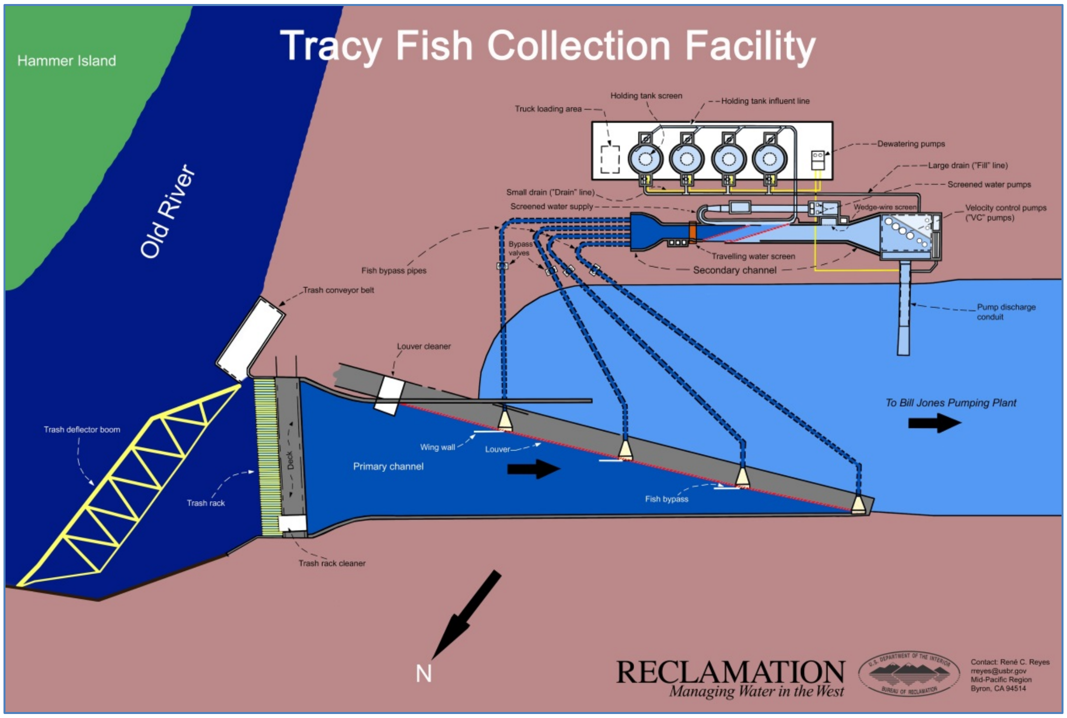


Figure 1.—Schematic of the Tracy Fish Collection Facility, Byron, California.

In the 1950s, pumping mostly occurred in the summer months and the TFCF was considered highly efficient at diverting fish from the entrained flow (Bates and Vinsonhaler 1957, Bates *et al*. 1960). Today however, both the JPP and the TFCF operate year-round, salvaging over 50 fish species under varying aquatic debris and fish entrainment conditions, and the TFCF is no longer as efficient (Karp *et al*. 1995, Bowen *et al*. 1998, Bowen *et al*. 2004, TFCF, unpublished data). The objective of this study was to determine facility efficiency for juvenile white sturgeon (*Acipenser transmontanus*; Figure 2) as a surrogate for green sturgeon (*A. medirostris*) as they are similar (NMFS 2010) and it was difficult to obtain hatchery green sturgeon.

Juvenile white and green sturgeon are infrequent at the TFCF, but may occur in the facility salvage year-round (salvage records maintained by the California Department of Fish and Game: ftp.delta.dfg.ca.gov/salvage). Both are native to the Sacramento-San Joaquin river system, but only the southern Distinct Population Segment (sDPS) green sturgeon is protected under the Endangered Species Act (NMFS 2006). Recently, National Marine Fisheries Service (NMFS) completed a Biological Opinion stating that TFCF operations are likely to jeopardize the continued existence of the sDPS green sturgeon and that at least 75 percent of the entrained green sturgeon be successfully returned to the Delta (NMFS 2009).

Figure 2.—Juvenile white sturgeon (*Acipenser transmontanus)*. Note pink mark on caudal fin.

METHODOLOGY

Release-recovery experiments were used to estimate louver efficiency for juvenile white sturgeon at the TFCF. Thirty-two replicates were performed in January and November 2009. For each replicate, a uniquely marked group of 100 fish was released downstream of the trash rack in the primary channel and an additional 40 uniquely marked fish were released at the upstream end of the secondary channel; Figure 2). For most trials, a group of 10 uniquely marked white sturgeon were released into the holding tank to determine efficiency of the fish recovery process at that time. Prior to the last four trials in November, an underwater noise device (i.e., dry ice in capped 2-L plastic bottles, about 2 kg) was released into the primary channel to determine whether an underwater loud noise would temporarily disrupt feeding of the fish predators (*e.g.*, striped bass) and thus, allow more experimental fish to be recovered in the holding tanks. Sturgeon were obtained from the Stolt Sea Farm, Sacramento, California, held in 750-L (198-gallon) flow-through tanks in a mix of ozone purified well (18–19^{o}C) and Delta waters, and fed Silver Cup salmon feed. Two weeks prior to testing, the sturgeon were acclimated, at rates not exceeding 1°C/d, to test temperatures by gradually exposing test fish to a greater proportion of ozonated Delta water.

One week prior to experiments, fish were anaesthetized using 150-ppm tricaine methanesulfonate (MS-222), measured (fork length [FL], mm) and marked with fluorescent microbeads (New West Technology, Santa Rosa, California) on anal, dorsal, or caudal fins (note pink mark on caudal fin, Figure 2). Fish were sized with a 2.54 cm grader to insure that all experimental fish were narrow enough to potentially fit through the louvers. Any striped bass recovered from the holding tank during the study period were examined for consumption of experimental fish. We also angled for 30 minutes in the primary channel following each week of experiments to determine if resident striped bass were consuming experimental fish (striped bass entrained into the primary channel may take up residency for months, Wu et al. in prep, Karp et al. in prep). Prior to each set of releases, the secondary channel was drained and flushed and both primary and secondary channel louvers were cleaned.

A sieve net (2.69 m [8.8 ft] high, 2.5 m [8.2 ft] wide and 7.62 m [25 ft] long, with 2 mm [0.8 in] mesh) located behind the secondary channel louvers was used to collect fish that passed through the secondary channel louvers. Experimental fish were recovered from the sieve net and holding tank at 1 h (November trials) and 2 h (January trials) intervals following fish releases, and experimental fish recovered. We did not release fish in front of the sieve net to evaluate our effectiveness at recovering fish from this area of the secondary channel.

Channel discharge, velocities, and depths were recorded with TFCF meters. Bypass ratios (BR, the ratio of bypass entrance velocity to channel velocity) were calculated as:

- Primary channel bypass ratio = primary channel bypass discharge/combined bypass width/primary channel depth/primary channel velocity.

- Secondary channel bypass ratio = secondary channel bypass discharge/secondary channel depth/bypass width/secondary channel velocity.

Data Analysis

Louver efficiencies were calculated from the following formulas (fish recovery from the holding tanks was assumed 100 percent for all experiments based on 100 percent recovery of fish in 24 control groups; we assumed sieve net recoveries were 100% of all fish that passed through the secondary louvers):

- Secondary channel louver efficiency = # fish collected in the holding tank / (# fish collected in the holding tank + # fish collected in the sieve net) for secondary channel releases only (the numerator are fish successfully diverted by the secondary channel louvers, the denominator is the sum of fish that participated in the experiment).

- Primary channel louver efficiency = (# fish collected in the holding tank and sieve net after 1 or 2 h)/# fish released downstream of the trash rack (the numerator are those fish successfully diverted by the primary channel louvers, the denominator is the total number of fish released into the primary channel). Primary channel louver efficiency cannot be tested directly because of logistic constraints with netting downstream of the primary louvers.

- Whole facility louver efficiency = # fish collected in the holding tank after 1 or 2 h / # fish released downstream of the trash rack

The number of experimental fish that could not be accounted for 1 - 2 h following release was determined by subtracting total recoveries from the # released. Louver efficiency and # of unaccounted for experimental fish were not normally distributed and Kruskal-Wallis One-Way Analysis of Variance (Statistix 8, Analytical Software) was used to determine if the dry ice release had an effect on louver efficiency.

RESULTS AND DISCUSSION

Average size of test fish was smaller (193.8 mm FL, range: 105 to 265 mm) than that seen in the wild salvage (229 mm FL, range: 50 to 400 mm, from TFCF salvage records between July 2006 and June 2011). However, we rejected larger fish whose width's exceeded the 2.54 cm (1 in) slot opening of the louver walls.

Experiments were conducted with 2–4 JPP pumps in operation (Table 1). Secondary channel velocities averaged 0.9 m/s (2.9 ft/s) and ranged from 0.6 to 1.0 m/s (2.0 to 3.2 ft/s). Primary channel velocities averaged 0.5 m/s (1.7 ft/s) and ranged from 0.3 to 0.7 m/s (1.1 to 2.2 ft/s). Primary channel velocities were positively correlated with the number of JPP pumps in operation ($r = 0.8$). Primary and secondary channel bypass ratios were always > 1.

Table 1.—Summary channel velocities and bypass ratios for juvenile white sturgeon louver efficiency experiments, 2009, Tracy Fish Collection Facility, Byron, California

# trials	# Jones Pumping Plant Pumps	Mean Primary Channel Velocity (m/s, ft/s)	Mean Secondary Channel Velocity (m/s, ft/s)	Primary Channel Bypass Ratio	Secondary Channel Bypass Ratio
2	2	0.4, 1.2	0.9, 3.1	3.1	1.6
12	3	0.5, 1.6	0.8, 2.6	2.0	2.0
18[1]	4	0.6, 1.9	0.9, 3.1	2.0	1.3

[1] Last four trials conducted after dry ice was released into the primary channel.

Under normal facility operations, secondary channel louver efficiency averaged 93.3 percent (28 trials, 30.6 to 100 percent) and primary channel louver efficiency averaged 32.2 percent (28 trials, 0 to 68.0 percent; Table 2). Whole facility efficiency was identical to primary channel efficiency as no fish released at the trash rack were recovered in the secondary channel sieve net. Thus, both primary channel and whole facility estimates were determined from fish recovered in the holding tank. Primary channel and facility efficiency were higher in the January experiments (53.1 percent) than November (11.4 percent).

Table 2.—Summary louver efficiency and unrecovered experimental fish for juvenile white sturgeon louver efficiency experiments, 2009, Tracy Fish Collection Facility, Tracy, California

	# Trials	Primary Channel Louver Efficiency[1] (mean/range, percent)	Secondary Channel Louver Efficiency[2] (mean/range, percent)	Whole Facility Efficiency[3] (mean/range, percent)	Unrecovered Experimental Fish-Primary Channel (mean/range, percent)	Unrecovered Experimental Fish-Secondary Channel (mean/range, percent)
Typical Facility Conditions	28	32.2 (0.0-68.0)	93.3 (30.6-100.0)	32.2 (0.0-68.0)	67.8 (32.0-100.0)	6.0 (0-27.5)
After CO_2 release	4	59.5 (43.0-74.0)	98.1 (92.5-100.0)	59.5 (43.0-74.0)	40.5 (26.0-57.0)	3.1 (0-7.5)

[1] Efficiency = (fish recovered in holding tank and sieve net)/fish released at the trash rack.
[2] Efficiency = fish recovered in the holding tank/(fish recovered in the holding tank and sieve net), for fish released into the secondary channel only.
[3] Efficiency = fish recovered in holding tank/fish released at the trash rack.

Following the dry ice release in the primary channel in November, primary channel and whole facility efficiency increased significantly (Kruskal-Wallis, P = 0.04), but not secondary channel efficiency (Kruskal-Wallis, P = 0.84; Table 2). Similarly, number of unrecovered experimental fish decreased significantly in the primary channel (Kruskal-Wallis, P = 0.04) but not secondary channel (Kruskal-Wallis, P = 0.52). We presume the increase in primary channel/facility efficiency following use of the underwater noise device was due to the disruption of feeding by the resident striped bass. No striped bass were collected in the holding tank or in angling efforts in the primary channel during the 2 hours following dry ice application. However, they were captured by angling in the primary channel several hours later.

The number of unrecovered experimental fish was high in the primary channel compared to the secondary channel (Table 2). Angling in the primary channel for 30 min following experiment completion during both January and November experiments (prior to dry ice release) resulted in the capture of five adult striped bass (619 to 695 mm FL), all with experimental juvenile sturgeon in their stomachs (Figure 3). Thus, we presume that many of our missing experimental fish were consumed by striped bass in the primary channel.

Figure 3.—A single striped bass captured by angling in the primary channel with five experimental white sturgeon removed from its stomach.

CONCLUSIONS

Our secondary channel louver efficiency estimate of 93.3 percent was high, and slightly higher than previously reported for juvenile sturgeon based on their analysis of paired sieve net and holding tank collections (80 percent, Bowen *et al.* 1998). However, our primary channel and whole facility estimates were low, presumably due to the high number of fish (>67 percent average) that were not recovered during the 1-2 h following release. These experimental fish either swam upstream out of the facility, remained within the primary louver channel and bypasses, passed through the louvers and lost to the salvage process, or were lost to predation.

Observations in laboratory flume studies reveal that juvenile sturgeon may "rest" or remain in position on the bottom (Kynard and Horgan 2001, Fangue 2012). This holding behavior together with the benthic nature of juvenile sturgeon suggests that some of our missing experimental fish may have settled on the channel floor for the brief period of our study.

Juvenile sturgeon appeared vulnerable to predation, particularly in November, as evidenced by capture of adult striped bass with experimental fish in their stomachs. This was further supported by the observed increased louver efficiency following release of the underwater noise device into the primary channel. Carbon dioxide is a known fish anesthetic (Summerfelt and Smith 1990) and in the form of dry ice, has recently been found to be effective at the TFCF at moving striped bass through the bypass system/secondary channel (Wu and Bridges 2014). Rather than acting as an anesthetic, we presume the underwater noise device startled the striped bass residing in the primary channel enough to disrupt their usual predatory feeding behavior.

ACKNOWLEDGMENTS

We appreciate the help of Brandon Wu and Rene Reyes (Bureau of Reclamation Tracy Office) for helping with the experiments, and Zak Sutphin, Don Portz, and an anonymous reviewer (Bureau of Reclamation Denver Technical Services Center) for technical bulletin review. We thank Ronald G. Silva, Joel Imai, and the staff at the TFCF for their support. This project was funded by the Bureau of Reclamation Mid-Pacific Region (Sacramento, California) under the Central Valley Project Improvement Act of 1992.

REFERENCES

Bates, D.W. and R. Vinsonhaler. 1957. *Use of louvers for guiding fish*. Transactions of the American Fisheries Society, 86:38–57.

Bates, D.W., O. Logan, and E.A. Pesonen. 1960. *Efficiency evaluation, Tracy Fish Collection Facility, Central Valley Project, California*. U.S. Fish and Wildlife Service. Seattle, Washington.

Bowen, M., S. Siegfried, C. Liston, L. Hess, and C. Karp. 1998. *Fish collections and secondary louver efficiency at the Tracy Fish Collection Facility: October 1993 to September 1993*. U.S. Department of the Interior, Bureau of Reclamation, Denver Technical Service Center and the Mid-Pacific Region.

Bowen, M., B. Bridges, K. Frizell, L. Hess, C. Karp, S. Siegfried, and S. Wynn. 2004. *Empirical and experimental analyses of secondary louver efficiency at the Tracy Fish Collection Facility: March 1996 to November 1997*. Tracy Fish Collection Facility Studies, California. Volume 11. U.S. Department of Interior, Bureau of Reclamation, Mid-Pacific Region and the Technical Service Center.

California State Water Resources Control Board. 1978. *Water Right Decision 1485 – Sacramento-San Joaquin Delta and Suisun Marsh*. Sacramento, California.

Electric Power Research Institute (EPRI). 1986. *Assessment of downstream migrant fish protection technologies for hydroelectric application*. EPRI, Palo Alto, California.

Fangue, N. 2012. *Goofy sturgeon behavior*. Estuary News 21(3):4.

Hallock, R., R. Iselin, and D. Fry, Jr. 1968. *Efficiency tests of the primary louver system, Tracy Fish Screen 1966–67*. Marine Resources Administrative Report No. 67, California Department of Fish and Game.

Heubach, W. and J. E. Skinner. 1978. *1973 Evaluation of the federal Fish Collecting Facility at Tracy, California*. California Department of Fish and Game.

Karp, C.A., L. Hess, and C. Liston. 1995. *Re-evaluation of louver efficiencies for juvenile Chinook salmon and striped bass at the Tracy Fish Collection Facility, Tracy, California, 1993*. Tracy Fish Collection Facility Studies, Volume 3.

Karp, C., B. Wu, and A. Schultz. In prep. Evaluation of Chinook salmon and Central Valley steelhead facility losses at the Tracy Fish Collection Facility. Tracy Fish Collection Facility Studies, California. U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region and the Technical Service Center.

Kynard, B. and M. Horgan. 2001. Guidance of yearling shortnose and pallid sturgeon using vertical bar rack and louver arrays. North American Journal of Fisheries Management 21:561–570.

National Marine Fisheries Service (NMFS). 2004. *Biological Opinion on the Long-term Central Valley Project and State Water Project Operations Criteria and Plan*, NMFS Southwest Regional Office, Long Beach, California.

_____. 2006. Federal Register 71(67):17757–17766, April 07, 2006.

_____. 2009. *Biological Opinion and Conference Opinion of the Proposed Long-term operations of the Central Valley Project and State Water Project*. U.S. Department of Commerce, National Marine Fisheries Service, June 4, 2009.

_____. 2010. Federal Register 75(105):30714–30730. June 2, 2010.

Summerfelt, R. C. and L. S. Smith. 1990. Anesthesia, surgery, and related techniques. Pages 213-272 *in* C. B. Schreck and P. B. Moyle, eds., *Methods for fish biology*. American Fisheries Society, Bethesda, Maryland.

U.S. Fish and Wildlife Service (USFWS). 2004. *Biological Opinion on the Longterm Central Valley Project and State Water Project Operations Criteria and Plan*. Sacramento, California.

Wu, B. J. and B. B. Bridges. 2014. Evaluating the use of carbon dioxide as an alternative predator removal technique to decrease Tracy Fish Collection Facility predator numbers and improve facility operations. Tracy Fish Collection Facility Studies, California. Volume 49. U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region and the Technical Service Center.

Wu, B. J., R.C. Bark, and W. K. Frizell. In prep. The Use of Acoustic Telemetry to Estimate Striped Bass Residence Time and Identify Most Utilized Holding Locations within the Tracy Fish Collection Facility. Tracy Fish Collection Facility Studies, California. U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region and the Technical Service Center.

APPENDIX 1

Data Summary

Experiment	Dry Ice[1]	Jones Pumping Plant pumps	Primary Channel Velocity (ft/s)	Secondary Channel Velocity (ft/s)	Primary Bypass Ratio	Secondary Bypass Ratio	Whole Facility Efficiency (percent)	Primary Channel Efficiency (percent)	Secondary Channel Efficiency (percent)	Unaccounted Fish-Primary Channel (percent)	Unaccounted Fish-Secondary Channel (percent)
1	1	2	1.1	3.1	3.3	1.5	66	66	100	33.3	10
2	1	2	1.2	3	2.8	1.6	36	36	100	64	2.5
3	1	3	1.5	3	2.4	1.7	47	47	-	53	-
4	1	3	1.5	3.1	2.3	1.7	68	68	100	32	0
5	1	3	1.6	3	2.1	1.6	59	59	-	41	-
6	1	3	1.6	3.1	2.1	1.8	61	61	100	39	2.5
7	1	3	1.7	3	2	1.7	47	47	-	53	-
8	1	3	1.8	3	1.9	1.9	66	66	100	34	2.5
9	1	3	1.4	2.2	2	2.2	46	46	-	54	-
10	1	3	1.4	2.1	2	2.1	44	44	100	56	17.5
11	1	3	1.5	2.1	1.8	2.2	56	56	-	44	-
12	1	3	1.5	2.1	1.8	2.2	53	53	97.1	47	15
13	1	3	1.6	2	1.6	2.5	47	47	-	53	-
14	1	3	1.7	2.1	1.7	2.6	47	47	100	53	27.5
15	1	4	2	3	1.9	1.3	10	10	100	90	0
16	1	4	1.8	3.1	2.1	1.4	12	12	100	88	5
17	1	4	1.8	3.1	2.1	1.1	5	5	100	95	0
18	1	4	1.9	3.2	2	1.3	3	3	100	97	2.5
19	1	4	2	3.1	1.9	1.2	1	1	100	99	2.5
20	1	4	2.1	3.1	1.7	1.4	6	6	100	94	0
21	1	4	2.2	3.1	1.8	1.2	4	4	100	96	2.5
22	1	4	2	3.1	2	1.2	0	0	100	100	7.5

Experiment	Dry Ice[1]	Jones Pumping Plant pumps	Primary Channel Velocity (ft/s)	Secondary Channel Velocity (ft/s)	Primary Bypass Ratio	Secondary Bypass Ratio	Whole Facility Efficiency (percent)	Primary Channel Efficiency (percent)	Secondary Channel Efficiency (percent)	Unaccounted Fish-Primary Channel (percent)	Unaccounted Fish-Secondary Channel (percent)
23	1	4	2	3.1	2	1.2	1	1	68.4	99	5
24	1	4	1.8	3.1	2.1	1.3	3	3	30.6	97	10
25	1	4	1.8	3.2	2.2	1.3	30	30	100	70	0
26	1	4	1.8	3.2	2.2	1.3	41	41	100	59	5
27	1	4	1.9	3.1	2.1	1.1	16	16	100	84	0
28	1	4	1.9	3.1	2.1	1.4	27	27	57.1	73	12.5
29	2	4	1.8	3.1	2.2	1.3	43	43	92.5	57	7.5
30	2	4	1.8	3.1	2.1	1.2	57	57	100	43	0
31	2	4	1.7	3.1	2.2	1.2	64	64	100	36	5
32	2	4	1.7	2.9	2.1	1.4	74	74	100	26	0

[1] Dry Ice (solid carbon dioxide): 1= underwater noise device not used, 2= underwater noise device used