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Evaluation of Survival and Behavior of Fish Exposed to an Axial-Flow Hydrokinetic Turbine

Paul T. Jacobson
Sr. Project Manager
Mark Bevelhimer

Recent Developments in Research on the Environmental Effects of MHK Technologies
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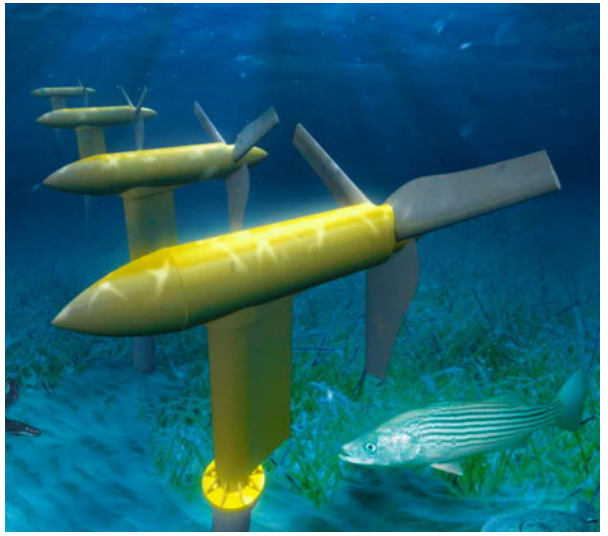
Study Goal and Objectives

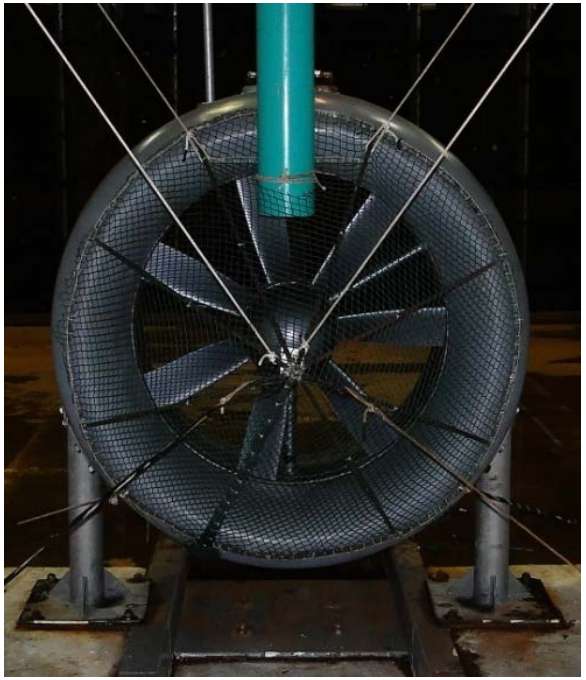
- Goal
  - Provide information and data that can be used to assess the potential impacts of an axial-flow turbine on fish populations
- Objectives
  - Estimate turbine passage survival rates
  - Estimate entrainment and avoidance probabilities



Study Approach and Methods

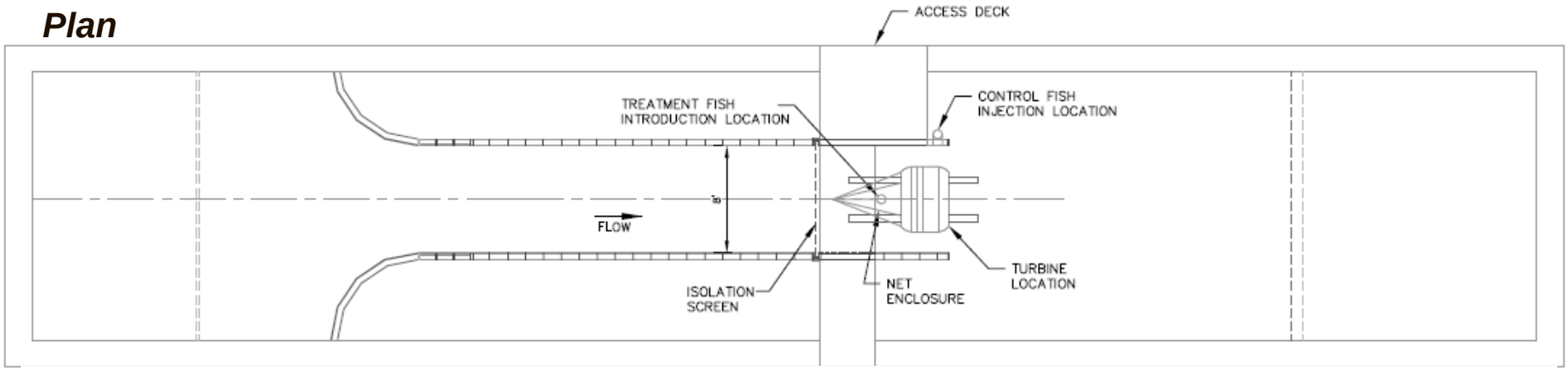
Free Flow Power HK Turbine

Design type:	ducted axial-flow
Number of blades:	7
Diameter (ft):	5
Approach velocities (ft/s):	3.5 – 10.0
Rotational speed (rpm):	45 - 125
Blade thickness (in):	0.6



Study Approach and Methods: Test Facility

Plan



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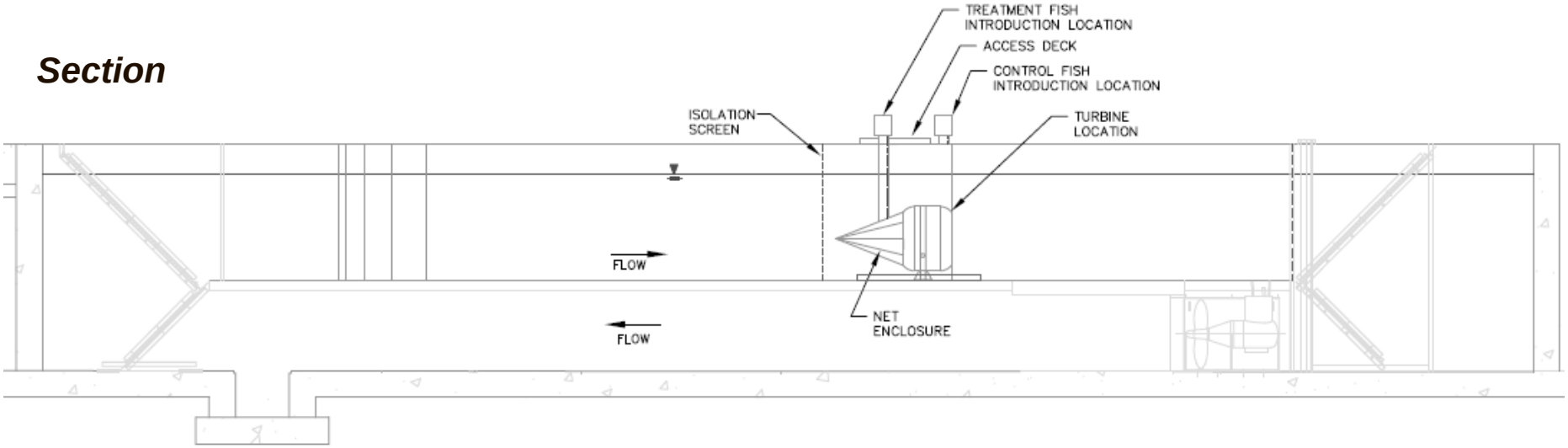


Study Approach and Methods: Test Facility

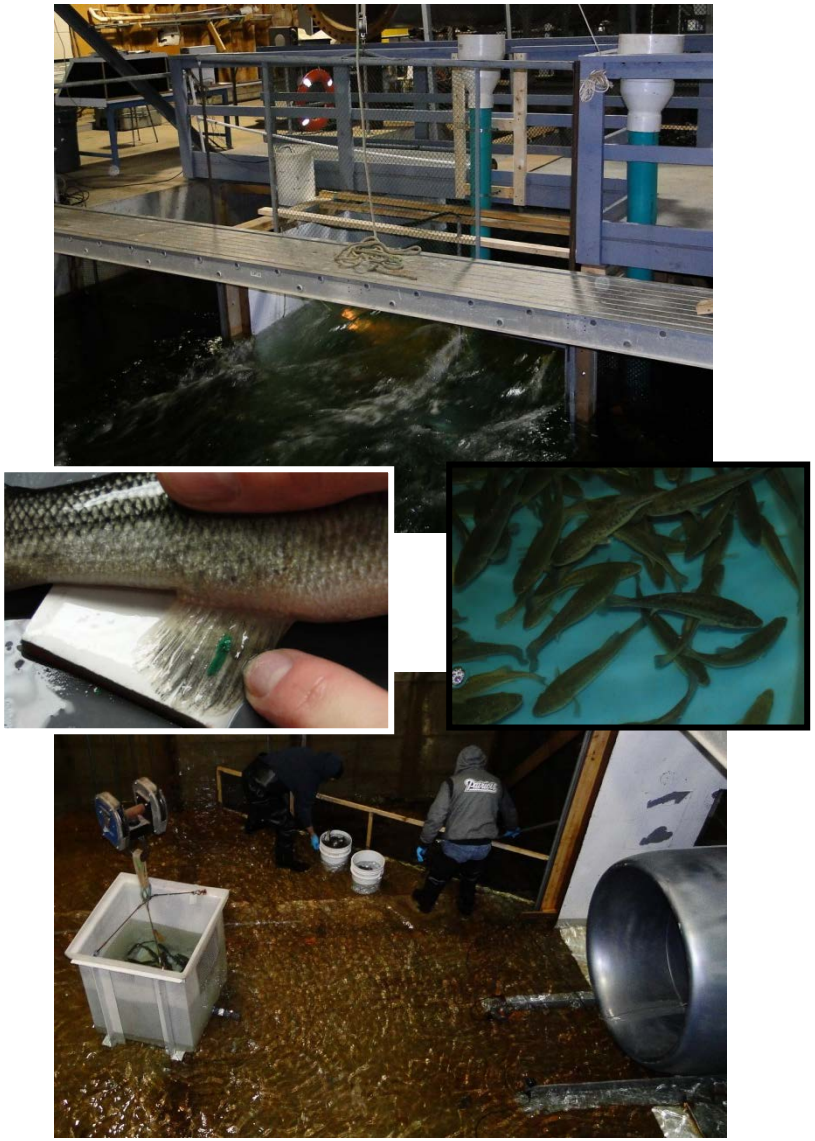
Study Approach and Methods: Survival Evaluation

Study Design for Paired Release-Recapture Survival Tests

Velocities:	4.9 and 6.3 ft/s
Rotational speeds:	64 and 84 rpm
Species:	rainbow trout hybrid striped bass white sturgeon
Target lengths (mm):	125 mm 250 mm (rainbow trout only)
Replicates:	5 (rainbow trout) 3 (sturgeon and bass)
Fish/Rep (T and C):	100 (rainbow trout) 50 (bass) 25 (sturgeon)

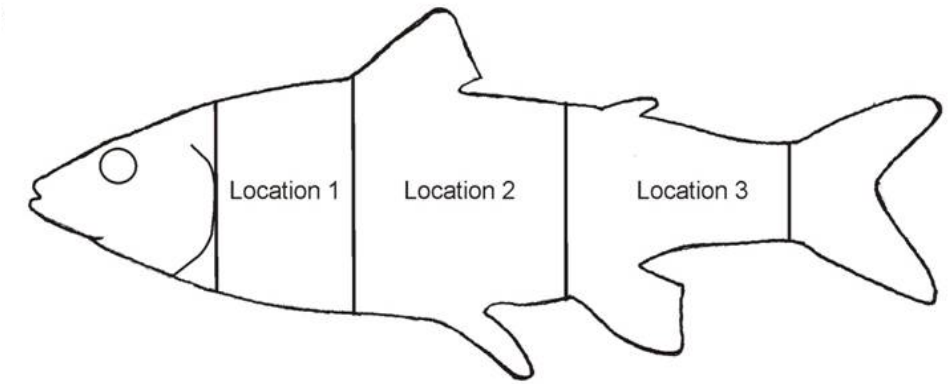
Study Approach and Methods: Survival Evaluation

- Test and control groups uniquely marked
- Released treatment fish followed immediately by control fish
- Test duration about 5 to 10 minutes
- Fish recovered live were held for 48 hr to assess latent mortality
- All fish examined for external injuries and scale loss
- Calculated immediate (1 hr) and total (1 hr + 48 hr) turbine survival rates
- Adjusted treatment injury and scale loss rates using control data to account for effects of handling/testing



Study Approach and Methods: Scale Loss Assessment

- Used methods similar to those described by Basham et al. (1982) and Neitzel et al. (1985) that were developed for scale loss evaluations of juvenile salmonids in the Pacific Northwest.
- Percent scale loss (<3%, 3-20%, 20-40%, and >40%) was recorded for each of three locations along the length of the body.
- Fish that had >20% scale loss in two or more body locations were classified as descaled.



Study Approach and Methods: Turbine Passage Survival Estimation

Maximum Likelihood Estimation (MLE) model developed for paired release-recapture survival experiments (Burnham et al. 1987; Skalski 1999):

Control Survival: $S_C = \frac{c}{N_C}$

Turbine Survival: $S_T = \frac{tN_C}{N_T c}$

Variance: $Var(S_T) = S_T^{\,2} \left[\frac{1 - S_C S_T}{N_T S_C S_T} + \frac{(1 - S_C)}{N_C S_C} \right]$

Model Assumptions:

- All treatment fish have the same probability of survival
- All control fish have the same probability of survival
- Survival probabilities from the point of the control release to recapture are the same for control and treatment fish
- Survival from the point of control release to recapture is conditionally independent of turbine survival

Study Approach and Methods: Turbine Passage Injury and Descaling

Turbine passage adjusted injury rate $= 1 - [\ T_U / C_U\ ]$

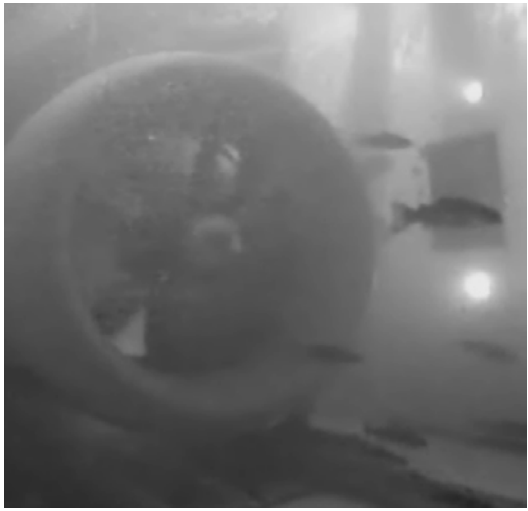
Where T_U and C_U are the proportion of treatment and control fish classified as uninjured.

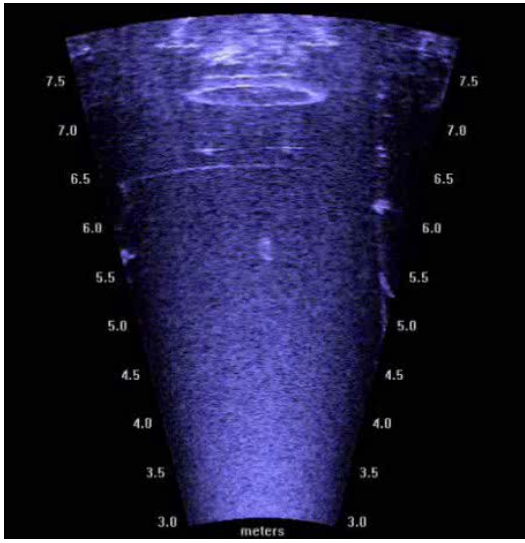
Turbine passage adjusted descaling rate $= 1 - [\ T_{ND} / C_{ND}\ ]$

Where T_{ND} and C_{ND} are the proportion of treatment and control fish classified as not descaled.

Study Approach and Methods: Behavioral Tests

- Same species, size groups, and approach velocities.
- 3 trials for each set of test conditions (species, size, velocity).
- 100 fish released per trial for RBT, 50 for HSB, and 25 for WST.
- Conducted tests with a lighted (daytime condition) and darkened (nighttime condition) flume.
- Daytime light condition evaluated at velocities of 3.5, 5.0., and 6.5 ft/s; dark condition tested at a velocity of 3.5 ft/s only.
- Underwater video used observe fish for lighted trials; DIDSON acoustic camera used for dark trials; both were used for daytime trials with the 3.5 ft/s approach velocity.
- Used video from downstream camera, which recorded fish exiting turbine, to estimate the number of fish entrained during each trial.
- Estimated avoidance rates (i.e., proportion of fish passing downstream without being entrained through turbine).





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Study Approach and Methods: Behavioral Tests

Adjustment of DIDSON Nighttime Entrainment Counts

- Underwater video counts considered reliable and accurate
- Ratio of DIDSON counts to underwater video counts calculated for multiple **daylight** trials at 3.5 ft/s by size class (rainbow trout only) and species
- DIDSON counts from **nighttime** trials were multiplied by the **daylight** detection ratio

Results: Survival Testing – Rainbow Trout

Summary of Fish Release, Recovery, and Survival Data

Size Group	Approach Velocity (ft/s)	Mean FL and SD (mm)	Number of Trials	Test Group	Total Released	Treatment Fish in Upstream Containment Net at Test End	Total Recovered Live	Turbine-passed Fish Recovered Live (1 hr)[1]	Immediate Mortalities (1 hr)[2]	Delayed Mortalities (48 hr)[3]
small	5.0	172 (12.8)	5	T	500	95	490	404	0	0
				C	500	--	501	--	0	0
				NM	--	--	--	--	--	--
	6.5	168 (15.5)	5	T	494	14	491	477	3	3
				C	492	--	477	--	1	0
				NM	--	--	13	--	0	0
large	5.0	271 (21.6)	5	T	502	107	496	392	0	0
				C	509	--	471	--	0	0
				NM	--	--	41	--	0	0
	6.5	246 (16.5)	5	T	501	11	486	478	11	1
				C	502	--	501	--	0	0
				NM	--	--	2	--	0	0

[1] The number of turbine-passed fish recovered live was calculated by subtracting the number of treatment fish that remained upstream of the turbine (until the flow and turbine were shut off) from the total number recovered live downstream of the turbine.

[2] All treatment fish recovered dead downstream of the turbine at the end of a trial were assumed to be turbine-passed fish.

[3] All treatment mortalities that occurred during the 48-hour post test holding periods were assumed to be turbine-passed fish.

Study Results:
Survival Testing – Hybrid Striped Bass

Summary of Fish Release, Recovery, and Survival Data

Approach Velocity (ft/s)	Mean FL and SD (mm)	Number of Trials	Test Group	Total Released	Treatment Fish in Upstream Containment Net at Test End	Total Recovered Live	Turbine-passed Fish Recovered Live (1 hr)[1]	Immediate Mortalities (1 hr)[2]	Delayed Mortalities (48 hr)[3]
5.0	131 (30.1)	3	T	149	1	146	145	3	12
			C	148	--	148	--	0	2
6.5	118 (25.7)	3	T	150	0	146	146	0	6
			C	152	--	151	--	1	6

[1] The number of turbine-passed fish recovered live was calculated by subtracting the number of treatment fish that remained upstream of the turbine (until the flow and turbine were shut off) from the total number recovered live downstream of the turbine.

[2] All treatment fish recovered dead downstream of the turbine at the end of a trial were assumed to be turbine-passed fish.

[3] All treatment mortalities that occurred during the 48-hour post test holding periods were assumed to be turbine-passed fish.

Results: Survival Testing – White Sturgeon

Summary of Fish Release, Recovery, and Survival Data

Approach Velocity (ft/s)	Mean FL and SD (mm)	Number of Trials	Test Group	Total Released	Treatment Fish in Upstream Containment Net at Test End	Total Recovered Live	Turbine-passed Fish Recovered Live (1 hr)[1]	Immediate Mortalities (1 hr)[2]	Delayed Mortalities (48 hr)[3]
5.0	123 (14.7)	3	T	75	3	72	69	0	1
			C	75	--	74	--	0	2
			NM	--	--	4	--	0	0
6.5	126 (14.6)	3	T	74	0	74	74	0	0
			C	76	--	76	--	0	0

[1] The number of turbine-passed fish recovered live was calculated by subtracting the number of treatment fish that remained upstream of the turbine (until the flow and turbine were shut off) from the total number recovered live downstream of the turbine.

[2] All treatment fish recovered dead downstream of the turbine at the end of a trial were assumed to be turbine-passed fish.

[3] All treatment mortalities that occurred during the 48-hour post test holding periods were assumed to be turbine-passed fish.

Results: Injury Rates

Species	Size Group	Approach Velocity (ft/s)	Total Number Assessed		Uninjured (%)		Bruising (%)		Eye Injury (%)		Laceration (%)	
			T	C	T	C	T	C	T	C	T	C
RBT	small	5.0	490	501	81.8	90.8	9.0	1.2	0.6	0.0	0.0	0.0
		6.5	489	477	78.9	89.7	17.8	6.1	0.6	0.2	0.2	0.0
	large	5.0	496	471	64.3	76.2	13.5	3.0	0.8	1.3	0.4	0.4
		6.5	497	501	64.0	87.8	22.1	3.8	0.8	0.2	0.0	0.0
HSB	small	5.0	149	148	73.8	86.5	29.5	14.9	0.0	0.0	0.7	0.0
		6.5	146	152	78.8	65.8	24.7	50.0	0.0	0.7	0.0	0.0
WST	small	5.0	72	74	88.9	93.2	11.1	6.8	0.0	0.0	0.0	0.0
		6.5	74	76	86.5	82.9	8.1	2.6	0.0	0.0	0.0	0.0

Results: Descaling Rates

Species	Size Group	Approach Velocity (ft/s)	Treatment		Control	
			Number Recovered	% Classified as Descaled	Number Recovered	% Classified as Descaled
RBT	small	5.0	490	28.4	501	30.1
		6.5	489	27.6	477	27.5
	large	5.0	496	26.6	471	18.9
		6.5	497	28.4	501	7.8
HSB	small	5.0	149	14.8	148	16.9
		6.5	146	28.1	152	34.2

Results Summary:
Turbine Passage Survival, Injury, and Descaling

Species	Mean Fork Length (mm)	Approach Velocity (ft/s)	Total Survival ± 95% CI (%)	Adjusted Injury (%)	Adjusted Descaled (%)
RBT	172	5.0	100.0 ± 0.0	9.9	0.0
	168	6.5	98.7 ± 1.1	12.0	0.1
	271	5.0	100.0 ± 0.0	15.6	9.5
	246	6.5	97.5 ± 1.4	27.1	22.3
HSB	131	5.0	91.1 ± 5.2	14.6	0.0
	118	6.5	100.5 ± 4.9	0.0	0.0
WST	123	5.0	101.3 ± 4.8	4.7	--
	126	6.5	100.0 ± 0.0	0.0	--

Results Summary: Behavioral Testing

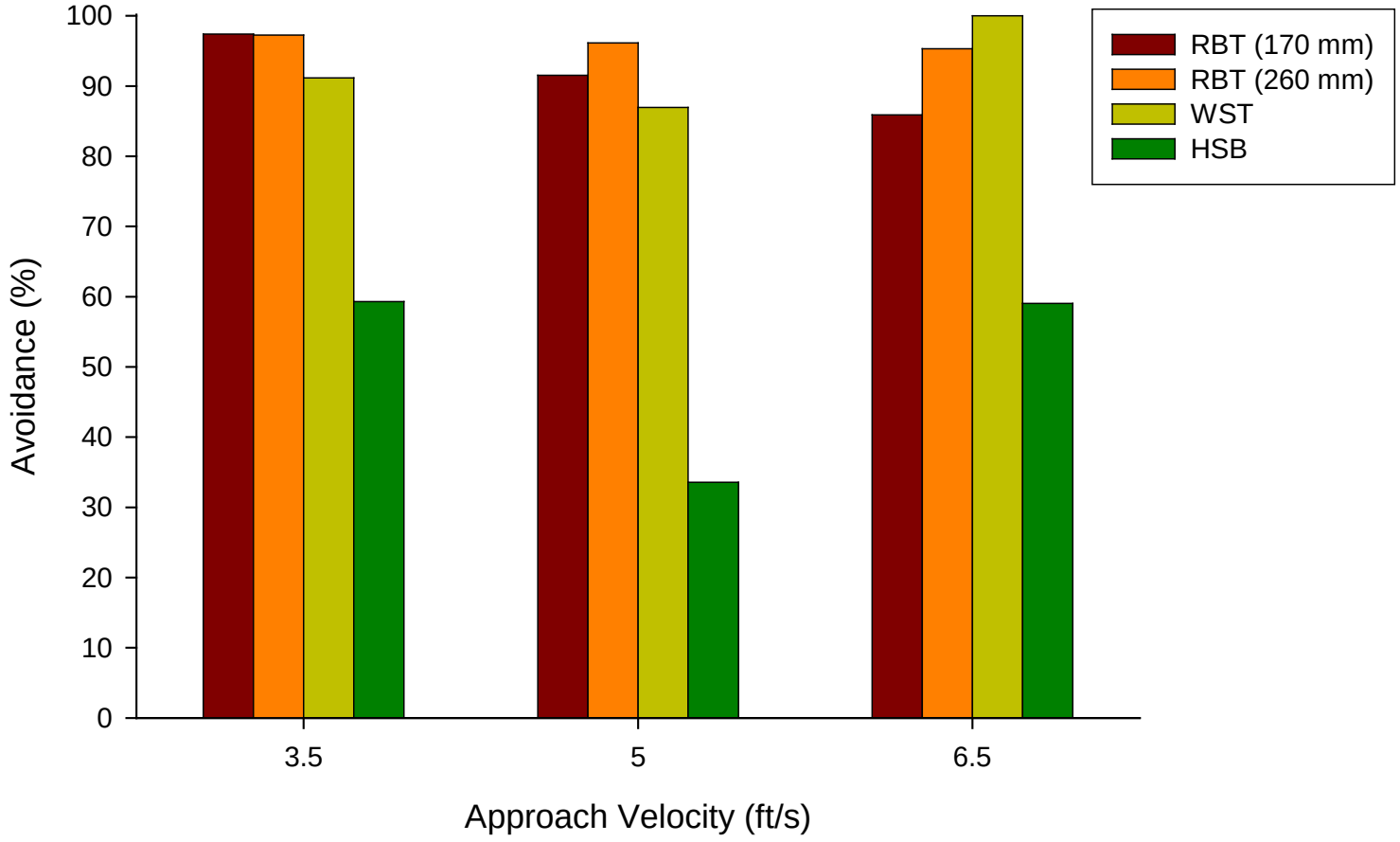
Species	Size Group	Approach Velocity (ft/s)	Light Condition	Trials	Total Number Released	Number Recovered Downstream	Number Recovered Upstream	Number Recovered Dead	Total Number Recovered
RBT	small	3.5	day	3	150	116	34	1	150
			night	3	150	144	6	0	150
		5.0	day	3	150	142	8	0	150
		6.5	day	3	150	149	1	2	150
	large	3.5	day	3	300	147	153	0	300
			night	3	300	285	15	0	300
		5.0	day	3	300	207	93	0	300
		6.5	light	3	300	299	1	1	300
HSB	small	3.5	day	3	150	145	4	17	149
			night	3	150	149	1	7	150
		5.0	day	3	150	143	4	10	147
		6.5	day	3	150	149	0	52	149
WST	small	3.5	day	3	69	68	1	0	69
			night	3	69	69	0	0	69
		5.0	day	3	69	69	0	0	69
		6.5	day	3	69	68	1	0	69

Results Summary: Behavioral Testing

Species	Size Group	Approach Velocity (ft/s)	Light Condition	% of Fish Recovered Downstream of Turbine	Estimate of Number Entrained	Entrainment Rate (%)	Avoidance Rate (%)
RBT	small	3.5	Day	77.3	3.0	2.6	97.4
			Night	96.0	2.7	1.9	98.1
		5.0	Day	94.7	12.0	8.5	91.5
		6.5	Day	99.3	21.0	14.1	85.9
	large	3.5	Day	49.0	4.0	2.7	97.3
			Night	95.0	5.4	1.9	98.1
		5.0	Day	69.0	8.0	3.9	96.1
		6.5	Day	99.7	14.0	4.7	95.3
HSB	small	3.5	Day	97.3	59.0	40.7	59.3
			Night	97.3	51.6	34.6	64.6
		5.0	Day	97.3	95.0	66.4	33.6
		6.5	Day	100.0	61.0	40.9	59.1
WST	small	3.5	Day	98.6	6.0	8.8	91.2
			Night	100.0	8.8	12.7	87.3
		5.0	Day	100.0	9.0	13.0	87.0
		6.5	Day	98.6	0.0	0.0	100.0

Results: Behavioral Testing

"Daytime" Light Condition



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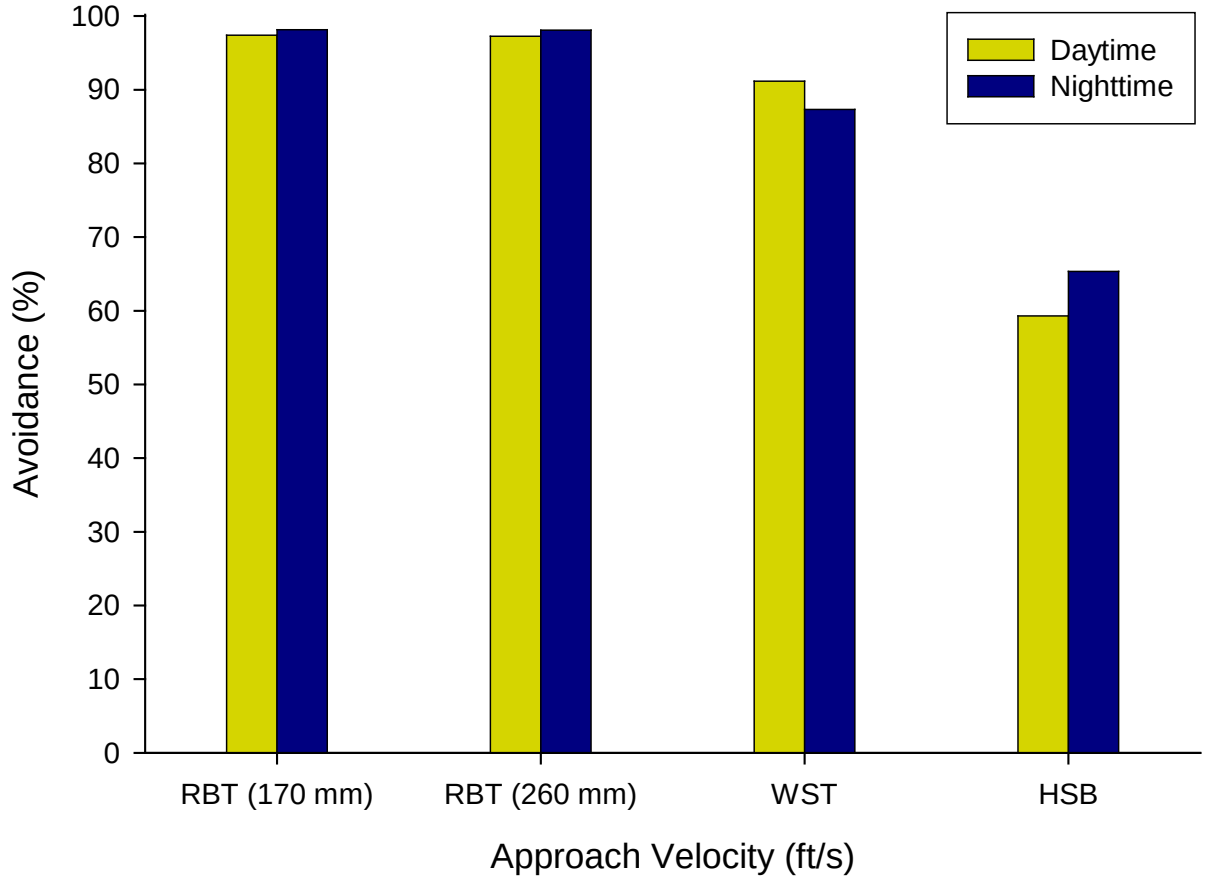
Results: Behavioral Testing

Daytime and Nighttime Light Conditions

Approach velocity = 3.5 ft/s



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Results: Total Passage Survival

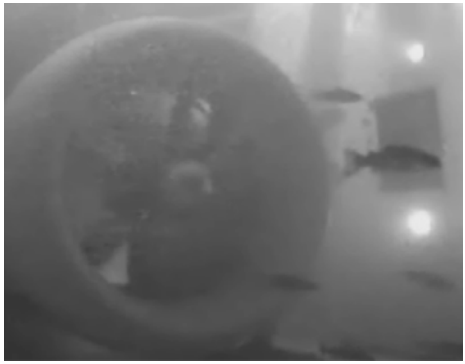
Species	Size Group	Approach Velocity (ft/s)	Entrainment Rate (%)	Avoidance Rate (%)	Turbine Passage Survival (%)	Total Passage Survival (%)
RBT	small	1.5	8.5	91.5	100.0	100.0
		2.0	14.1	85.9	99.0	99.9
RBT	large	1.5	3.9	96.1	100.0	100.0
		2.0	4.7	95.3	97.5	99.9
HSB	small	1.5	66.4	33.6	91.7	94.5
		2.0	40.9	59.1	100.0	100.0
WST	small	1.5	13.0	87.0	100.0	100.0
		2.0	0.0	100.0	100.0	100.0

Results: Free Flow Turbine Survival Testing

Rainbow trout (125 mm) tested at 5 ft/s

Conclusions and Observations

- Treatment fish were reluctant to pass through the turbine during survival tests.
- High survival (97-100%) rates were typically observed for the species, size groups, and operational conditions evaluated.
- Turbine passage injury rates ranged from about 5 to 27% and increased with approach velocity and fish size for rainbow trout.
- Descaling rates associated with turbine passage were typically 0 to 5% depending on species and approach velocity.



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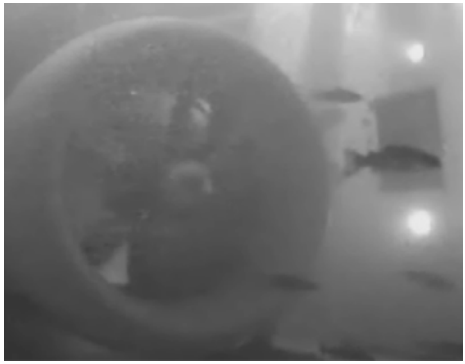
Conclusions and Observations (cont.)

- Behavioral testing indicated active avoidance by trout and hybrid striped bass, and passive avoidance by white sturgeon.
- Turbine avoidance rates were high for trout and sturgeon (> 85%) and moderate for hybrid bass (about 33-65%).
- For each species, there was no apparent difference in avoidance rates estimated for light and dark test conditions.
- With the exception of hybrid bass tested at 5 ft/s, total passage survival rates were essentially 100% for all test conditions.



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