DIEL MOVEMENT AND VERTICAL DISTRIBUTION OF JUVENILE ANADROMOUS FISH IN TURBINE INTAKES

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ABSTRACT

The behavior of fingerling salmonids was measured in turbine intakes of The Dalles and McNary Dams on the Columbia River to aid in developing methods for reducing fish mortality in Kaplan turbines. At The Dalles Dam, diel movement and vertical distribution were sampled at both ends and at the middle of the section of the powerhouse that housed turbines 1 through 12. At McNary Dam, vertical distribution was sampled in intake 12–C, located near the middle of the River channel.

Comparisons of day-night occurrence at The Dalles Dam showed that most chinook salmon (*Oncorhynchus tshawytscha*), steelhead trout (*Salmo gairdneri*), and ammocoetes of the Pacific lamprey (*Lampetra tridentata*) were caught at night (7 p.m. to 7 a.m.). Vertical distribution studies at McNary and The Dalles Dams included catches of sockeye salmon (*O. nerka*) in addition to the above species. Salmonids were taken at all depths, but most were in the upper 30 percent of water in the intakes (within 4.6 m. of the ceiling). Ammocoetes at The Dalles Dam (no data for McNary Dam) were concentrated near the center and bottom of the intakes; very few were near the ceiling.

To increase survival of fish by manipulating turbine loads during a 24-hour operational period appears feasible. During darkness when fish movements through turbines increase and power demands decrease, the reduction in turbine loads improves the flexibility for adjusting turbine loads to increase fish survival.

The concentration of fingerling salmonids near intake ceilings probably causes most of the fish to pass the turbine runner at or near the hub; therefore, methods for eliminating lethal factors at the runner should be applied first at the hub. In addition, use of deflection and bypass techniques near intake ceilings would be advantageous because the concentration of fish is greatest there.

The behavior of fingerling salmonids in turbine intakes, including their time of passage and distribution in the water mass, can profoundly influence development of efficient and economical methods for reducing fish mortality in turbines. The need for fish protection at dams is becoming particularly acute in the Columbia Basin because the progeny of upriver stocks of salmonids soon will be forced to pass through the turbines of 8 to 10 dams to reach the sea.

At present, normal spring flows are divided about equally between spillways and turbines; numbers of young fish migrating downstream presumably pass through the spillways and the turbines in proportion to the water passed by each. Studies at McNary and Big Cliff Dams under normal operating conditions (wicket gates opened 75–80 percent) have shown that mortality of young salmon in Kaplan turbines is about 11 percent, whereas mortality in the spillway is comparatively light—2 percent (State of Washington Department of Fisheries;[1] Schoeneman, Pressey, and Junge, 1961). Similar mortality is assumed to occur at other dams with comparable turbine designs and operational features.

Unless solutions are found, the total mortality will increase in the future. When the Corps of Engineers' Projects are completed, almost all water in the Columbia Basin's flow regime eventually will pass through turbines, eliminating the relatively safe passageway now provided by water

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[1] State of Washington Department of Fisheries. Research relating to mortality of downstream migrant salmon passing McNary and Big Cliff Dams. Progr. Rep. Fish. Eng. Res. Program, 1960, N. Pac. Div., U.S. Army Corps Eng., pp. 122–126.

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flowing over the spillways. Because of the imminent danger to future runs, the Bureau of Commercial Fisheries has a research program under way to develop methods for protecting fingerlings as they pass through turbines.

From the outset of this program, knowledge of the behavior of fish immediately upstream of turbines was required. Information on diel movement was essential for obtaining more precise measures of total mortality and for estimating the feasibility of different methods for protecting fish. Research at Big Cliff Dam by the State of Washington Department of Fisheries (footnote 1) showed that mortality at two turbine loads (40 versus 80 percent wicket gate openings) differed significantly. Because turbine loads fluctuate daily, it was obvious that mortalities also might vary daily. The estimation of average daily mortality required knowledge of (1) mortality for a wide range of turbine loads, (2) daily fluctuations of turbine loads, and (3) daily variation of fish movement through turbines. If the relation of these three factors were better understood, perhaps mortality could be minimized by manipulation of turbine loads when most of the migrants are passing downstream at damsites.

Another facet of fish behavior, important to the development of protective methods, is the route used by most of the fish. Studies of models showed that flows through turbine intakes and associated scroll cases of dams such as McNary were well ordered; e.g., flows near intake ceilings pass by the top of the wicket gates, and flows near intake floors pass by the bottom of the wicket gates. Because the turbine blades lie only a few meters farther downstream, it is probable that distribution of flows at the blades corresponds with distribution of flows at the wicket gates; i.e., flows from the top of the wicket gates pass the blades at the hub, and flows from the bottom of the wicket gates pass the blades at their tips.[2] Thus, the distribution of fish at the turbine blades might be deduced with some degree of accuracy from the distribution of fish in the intakes. When fish distribution is known, meth-

[2] Personal communication, Johnson, G. Dugan, Allis-Chalmers Manufacturing Co., York, Pa.

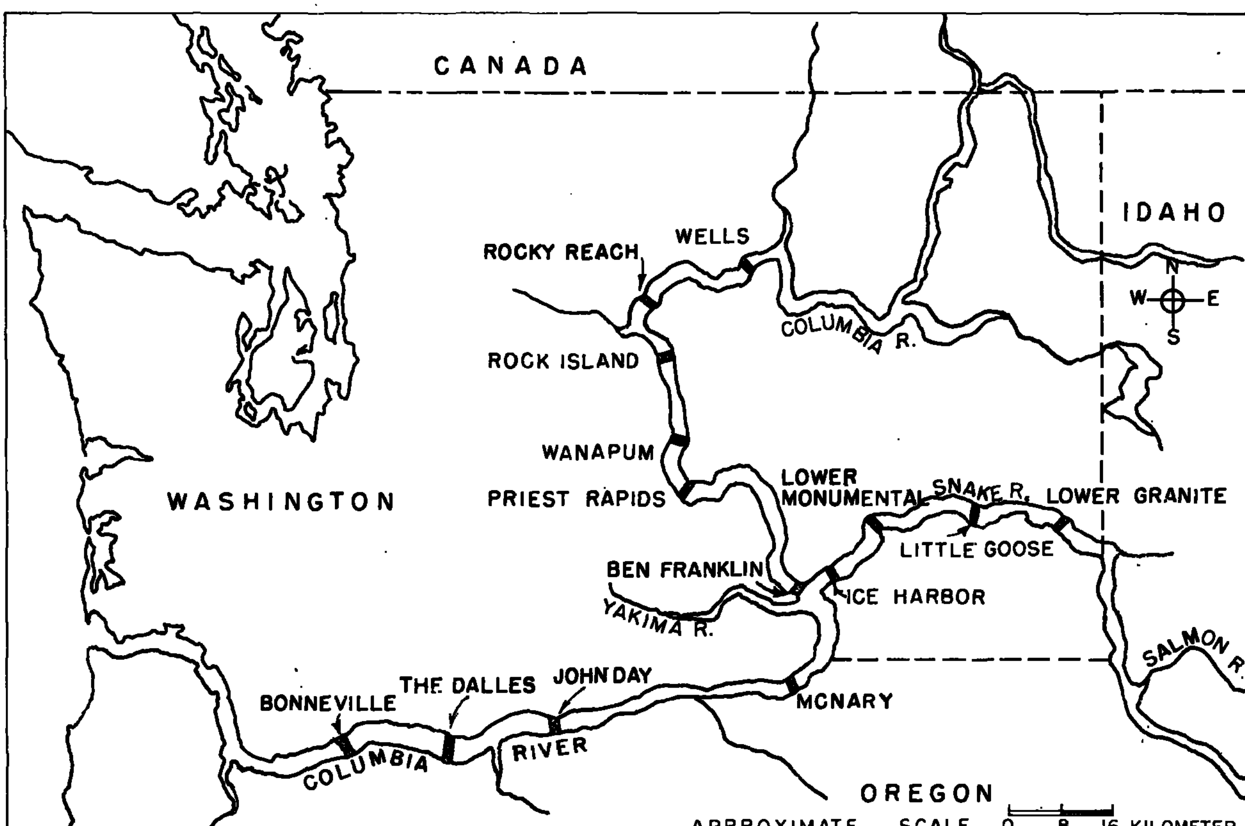

FIGURE 1.—Location of present and future low-head dams on main stem, Columbia and Snake Rivers.

ods for eliminating lethal agents at the turbine blades can be applied at the specific area through which most of the fish pass. Knowledge of the extent of fish concentrations also can aid in determining the feasibility of guiding them into safe bypasses.

Information is available on diel movement and distribution of fingerling salmonids at several points in the river system. Mains and Smith [3] studied timing and distribution of fingerling movement in river channels; Gauley, Anas, and Schlotterbeck (1958) investigated diel movement in special bypasses at Bonneville Dam. Because the physical environment in these studies differed markedly from that in turbines and associated water passages, the data could not be applied to turbine areas with complete confidence. Additional studies accordingly were proposed.

This paper reports on experiments at two dams on the Columbia River to acquire data on timing and distribution of fingerling salmonids entering turbine intakes. In 1960, diel movement and vertical distribution of fingerling salmonids were investigated at The Dalles Dam; data on lamprey ammocoetes also were obtained. In 1961, the vertical distribution of fingerlings was studied at McNary Dam.

RESEARCH AREAS

The Dalles and McNary Dams, operated by the U.S. Army Corps of Engineers, are hydroelectric projects on the Columbia River (fig. 1) with maximum heads of 27.0 and 27.5 m., respectively. Designs and dimensions of low-head dams on the Columbia River are similar, but the powerhouses are located parallel (The Dalles) or at a right angle (McNary) to the course of the River (fig. 2).

At the times of these experiments, in 1960 and 1961, The Dalles Dam had 12 operative turbines and McNary had 14. Turbines of both Dams are equipped with three intakes—A, B, and C. Each intake has a gatewell, or vertical shaft, which extends from an opening in the ceiling of the intake to the forebay deck. Figure 3 is a cross section of an intake at The Dalles Dam, showing the gatewell and other features. The turbines and turbine intakes of McNary Dam have a similar design.

[3] Mains, J. E., and J. M. Smith. Determination of normal stream distribution, size, time and current preferences of downstream migrating salmon and steelhead trout in the Columbia and Snake Rivers. Progr. Rep. Fish. Eng. Res. Program, 1956. North Pacific Division, U.S. Army Corps of Engineers, pp. 14–26.

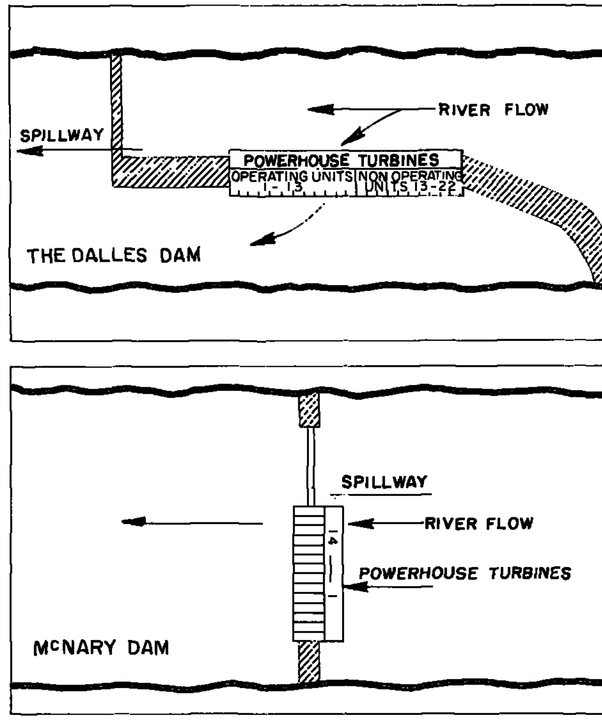

FIGURE 2.—Comparison of The Dalles and McNary Dams. The orientation of the powerhouse of The Dalles Dam, nearly parallel to the course of the River, causes water to turn nearly 90° to pass through turbines. The powerhouse of McNary Dam is oriented at right angles to the course of the River.

DESIGN AND OPERATION OF SAMPLING APPARATUS

A special intake frame supporting six fyke nets (fig. 4) was used to capture fingerlings passing through turbine intakes at The Dalles and McNary Dams. The fyke nets were installed one above the other in the frame. When the frame was installed in the intake, the nets extended from the ceiling of the intake to within 1 m. of the floor and strained the center flows of the intake. Nearly one-third of the flow of a single intake (one-ninth of the flow of a single turbine) was strained by the six nets, discounting slightly reduced flows through the nets owing to head loss caused by the webbing.

The frame was lowered through the intake gatewell (fig. 3) with a gantry crane operated by personnel of the U.S. Army Corps of Engineers. After the frame was installed, the turbine discharge was set. Normal fluctuations in total head on the turbine produced minor changes in turbine discharge during each test. Water velocities without the nets

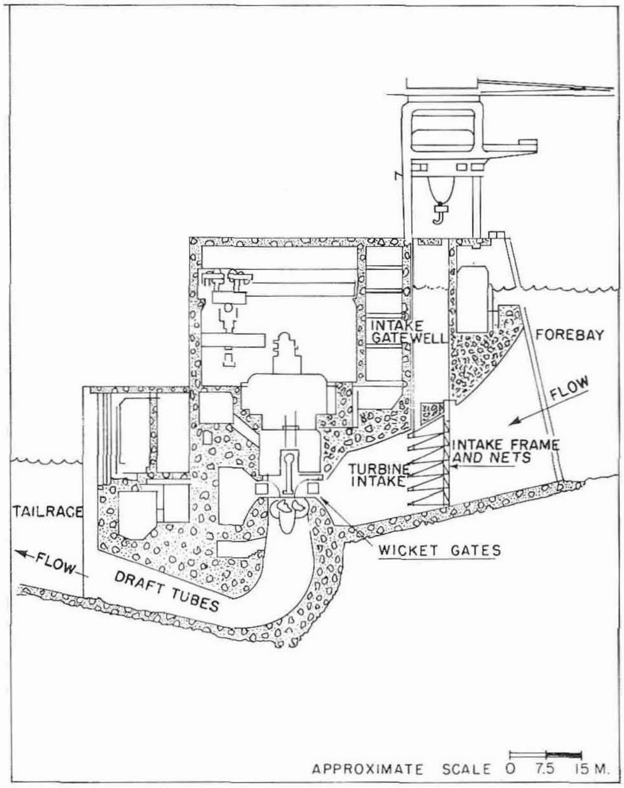

FIGURE 3.—Cross section of a main unit (turbine and associated water passages) at The Dalles Dam with intake frame in fishing position.

in place were almost the same throughout the zone strained by the nets, except for the normal boundary layer associated with the intake ceiling.[4] Therefore, all nets strained about the same amount of water.

The uppermost net was placed on the frame so the top edge of the net mouth was aligned with the intake ceiling. The frame used at The Dalles Dam was equipped with a stationary fish-tight screen extending from the top edge of the net mouth to the upstream side of the frame to provide a partial block of the opening to the gatewell (fig. 5). At McNary Dam, the frame was equipped with a hinged screen as well as a stationary screen (fig. 5). Together, the screens formed a fish-tight barrier that blocked the entire opening to the gatewell upstream from the top net.

The nets at both Dams were 1.97 m. wide by 2.13 m. high at the mouth and were 5.79 m. long, including the cod end. Fyke nets at The Dalles Dam incorporated 12.7 mm. stretched mesh nylon webbing in the forward half of the body and 9.5 mm. stretched mesh nylon in the back half. At The Dalles, the smaller mesh tended to plug up with fine vegetable debris; the difficulty was alleviated at McNary Dam by constructing fyke nets entirely of 12.7 mm. stretched mesh. Cod ends of the nets at both Dams were of 3.2 mm. nylon bobbinet.

Procedure was the same at both Dams. Before the frame was lowered to fishing position, each net was folded and tied to the frame with string that could be broken easily by flows in the turbine intake. Flows were stopped before the frame was lowered or raised to prevent capture of fish while the nets were moving up or down. At the end of each fishing period, the intake frame was hauled to deck level, and the contents of each net were emptied into separate containers for sorting and counting.

FIGURE 4.—Intake frame being lowered through gatewell into a turbine intake at McNary Dam. Frame supports fyke nets used to measure diel movement and vertical distribution of fingerling salmonids approaching Kaplan turbines.

[4] Unpublished data furnished by U.S. Army Corps of Engineers, North Pacific Division, Water Control Branch, 921 SW. Washington, Portland, Oreg. 97205.

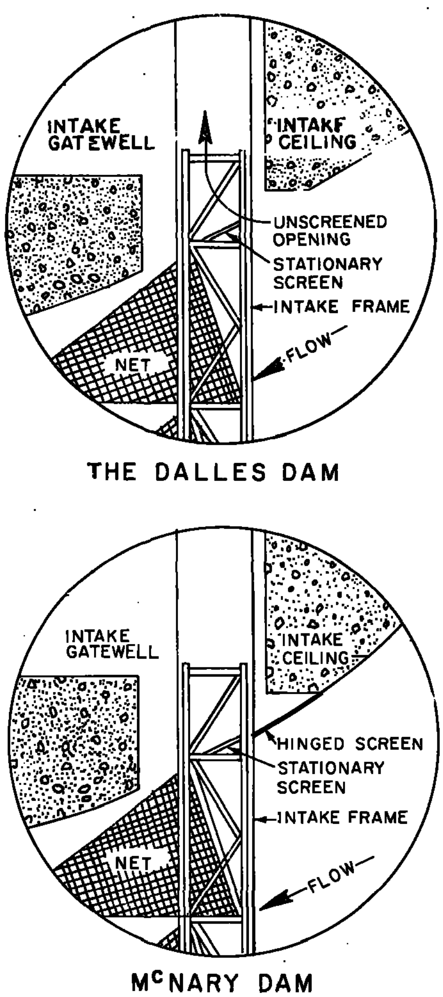

FIGURE 5.—Upper portions of intake frame in fishing position at The Dalles Dam and McNary Dam. Note hinged screen used at McNary Dam to ensure that fish near the ceiling of the intake did not escape the top net by swimming up into the gatewell.

DESIGN OF EXPERIMENTS

Experiments at The Dalles Dam measured (1) diel movement and (2) vertical distribution of fingerling salmonids in the turbine intakes. An additional experiment provided information on the vertical distribution of fingerlings at McNary Dam.

THE DALLES DAM EXPERIMENTS

In both experiments at The Dalles Dam, the fyke nets were fished in the center intake (B) of turbines at both ends and at the middle of the part of the powerhouse that contained operating turbines. Turbines 1 to 10 operated continuously; turbines 11 and 12 operated intermittently; turbines 13 through 22 had not been installed. At the beginning of each fishing period, the turbine was set to discharge about 310 c.m.s. (cubic meters per second), producing a water velocity of about 1.2 m.p.s. (meters per second) in the zone strained by the nets (measured without the nets in place). The gatewell involved during a test was uncovered for the entire test period.

The salmonids were classified into two major size groups. Fish in the smaller group (under 80 mm. fork length) were termed O-group, or first year of life. Periodic examinations indicated this group was composed almost exclusively of juvenile chinook salmon (*Oncorhynchus tshawytscha*). Fish 80 mm. and longer were classed as I-group (second year of life or more) and identified by species. Catches of I-group salmonids during the experiment on diel movement included chinook salmon and steelhead trout (*Salmo gairdneri*). Ammocoetes of the Pacific lamprey (*Lampetra tridentata*) also were caught. Catches made during the study of vertical distribution included I-group sockeye salmon (*O. nerka*) in addition to the species mentioned above.

The first experiment (April 7–27, 1960) consisted of 18 tests to study diel movement of juvenile salmonids in turbine intakes. Each test was composed of one day- and one night-fishing period in the same intake within a single 24-hour period. Day fishing averaged 10¼ hours within the 12-hour period, 7 a.m. to 7 p.m. Night fishing averaged 10¼ hours within the 12-hour period, 7 p.m. to 7 a.m. Tests in each area of the powerhouse were made at 2- to 6-day intervals, conditions permitting. Five tests were made at unit 1, seven at unit 5, and six at units 10 and 11 (fig. 2).

In the second experiment (April 28 to May 12, 1960), 14 tests were made to sample the vertical distribution of fingerling salmonids. Each test was composed of a single fishing period, averaging 16 hours within the 17-hour period from 3:30 p.m. to 8:30 a.m.[5] Tests were made in each of three areas of the powerhouse; five in unit 1, six in units 5 and 6, and three in units 10 and 12. Tests in a single area were spaced at least 3 days apart.

[5] This fishing period was chosen to allow personnel of the U.S. Army Corps of Engineers to install and remove the intake frame without seriously disrupting their normal work schedule.

McNARY DAM EXPERIMENT

One set of 10 tests was completed at McNary Dam (April 24 to May 26, 1961) to determine the vertical distribution of juvenile salmonids. Each test covered a single 8-hour fishing period, beginning at 7 p.m. and ending at 5 a.m. Tests were run only in intake C of unit 12, which is near the center of the River channel. At the beginning of each test, the turbine discharge was set at 354 c.m.s., producing a water velocity of about 1 m.p.s. in the zone strained by the nets, as measured without the nets in place (footnote 4). Tests were run in pairs (2 consecutive days) with 6 nights between each pair. The gatewell was uncovered for the duration of the experiment.

The O-group salmonids were scarce; only I-group chinook and sockeye salmon and I-group steelhead trout were taken in sufficient numbers for analysis. Some ammocoetes were caught, but the data are not included here.

RELIABILITY OF CATCH DATA

Three major factors could have affected the reliability of the catch data: (1) different fishing efficiency of the fyke nets between day- and night-fishing periods, (2) capture of fish as the nets were drawn up through the water in the gatewells, and (3) avoidance of the top net at The Dalles Dam by fish that entered the gatewell before reaching the net.

Efficiency of the fyke nets could have varied if fish were able to see the nets better during the day than during the night. Recent experiments in the Snake River below Brownlee Dam indicated this possibility. Sims (unpublished)[6] found that "scoop traps" were three times more efficient in capturing marked fish at night than during the day. Because vertical distribution of the fish was constant, he suggested that lessened visibility may have been responsible for the higher trap efficiencies at night. Illumination within the turbine intakes was not measured during tests reported here, but Secchi disc readings ranged from 0.43 to 0.85 m. at The Dalles Dam. In addition, the fyke nets were located within the turbine intake (about 15 m. downstream from the mouth) under more than 20 m. of water (vertical distance through the water in the gatewell). The turbidity and the location of the nets indicated that illumination was probably not much higher during the day than during the night. It seems unlikely that fish were able to see the nets well during either day or night.

Recognizing that fish might be caught as the nets were drawn up through static water in the gatewells, I examined the physical condition of the fish to determine where they were caught. Prior experience had proven that fish would be dead and extensively descaled when caught by nets in water velocities equal to those in the turbine intakes. I reasoned that because water in the gatewell was not flowing, fish from nets raised slowly through the gatewell would be alive and suffer no more harm than would be caused by a dip net. Few live fish were taken during the experiment; when present, they were excluded from the catch data.

The catches made in the top net at The Dalles Dam may not have been indicative of the actual number of fish in that area because some may have escaped by swimming into the gatewell through the unscreened opening upstream from the net. Modifications of the intake frame precluded avoidance of the top net at McNary Dam.

Available information concerning the three points discussed in this section leads me to believe that the catch data depict reliably the general behavior of fish in turbine intakes. Experimental equipment and procedures that can circumvent these potential sources of error are nevertheless desirable for future experiments.

DIEL MOVEMENT

Data on diel movement of migrating juvenile salmonids in turbine intakes (intake B of units 1, 5, 10, and 11) at The Dalles Dam are presented in table 1. Occurrence by age groups and species is presented graphically in figure 6.

The following conclusions seem to be warranted:

1. Day and night passage for all age groups and species did not differ significantly among intakes sampled (at both ends and the middle of the row of operating turbines).

2. Although all age groups and species were more abundant at night than during the day, only the I-group salmonids were significantly more plentiful.

3. Of the I-group chinook salmon and I-group steelhead trout, 94 and 85 percent, respectively,

[6] Sims, Carl W. Escapement of juvenile salmonids from Brownlee Reservoir. Fish-Passage Research Program, Bureau of Commercial Fisheries, Seattle, Wash. Manuscript in preparation.

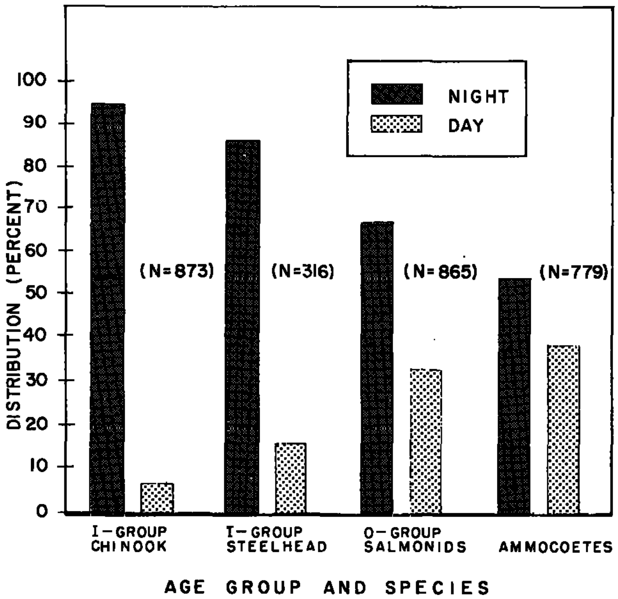

FIGURE 6.—Comparison of day (7 a.m. to 7 p.m.) and night (7 p.m. to 7 a.m.) catches of juvenile anadromous fish in turbine intakes of The Dalles Dam. Results of 18 tests, April 7–27, 1960.

TABLE 1.—*Diel movement of fingerling salmonids and lamprey ammocoetes in turbine intakes of unit 1 (downstream end), unit 5 (center), and units 10 and 11 (upstream end of powerhouse) at The Dalles Dam*

[Results of 18 tests, April 7–27, 1960]

Age groups and species	Catch by powerhouse area [1]								
	Downstream end			Middle			Upstream end		
	Night	Day	Total	Night	Day	Total	Night	Day	Total
	Percent	*Percent*	*Number*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Number*
I-group chinook salmon	94.4	5.6	358	94.2	5.8	189	93.9	6.1	326
I-group steelhead trout	89.8	10.2	118	82.7	17.3	127	81.7	18.3	71
O-group salmonids	61.2	38.8	201	62.5	37.5	248	71.7	28.3	416
Ammocoetes	63.5	36.5	315	51.1	48.9	282	75.8	24.2	182

[1] See figure 2 for location.

were caught at night. Of the O-group salmonids and ammocoetes, 67 and 62 percent, respectively, were caught at night.

Results reported here agree generally with those of other investigators of day and night movement of fingerlings. In the undammed sections of the Snake and Columbia Rivers, most of the I-group chinook salmon and I-group steelhead trout were captured from 6 p.m. to 6 a.m. (Mains and Smith, footnote 3). In research in special bypasses at Bonneville Dam, Gauley et al. (1958) found significantly more O-group chinook salmon, I-group chinook salmon, and I-group steelhead trout migrating from 6 p.m. to 6 a.m. in 4 out of 5 seasons—1946, 1949, 1950, and 1953. More recently, Monan, McConnell, Pugh, and Smith (unpublished) [7] caught a majority of salmonid fingerlings (mixed species) between 8 p.m. and 6 a.m. in the Snake River.

VERTICAL DISTRIBUTION

Vertical distribution of juvenile anadromous fish migrating through turbine intakes of The Dalles Dam (intake B of units 1, 5, 6, 10, and 12) and of McNary Dam (intake C of unit 12) is presented in tables 2 through 8 and figures 7 and 8.

TABLE 2.—*Vertical distribution of O-group salmonids in turbine intakes of The Dalles Dam. Combined results of 14 tests extending from 3:30 p.m. to 8:30 a.m.*

[Test period, April 28 to May 12, 1960]

Net number (top to bottom)	Depth [1]	Catch by powerhouse area					
		Downstream end		Middle		Upstream end	
	M.	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1	0–2.1	88	30.4	111	31.6	107	24.6
2	2.3–4.4	42	14.5	70	19.9	93	21.4
3	4.6–6.7	41	14.2	49	14.0	76	17.5
4	6.9–9.0	43	14.9	63	18.0	81	18.7
5	9.2–11.3	32	11.1	40	11.4	62	14.3
6	11.4–13.6	43	14.9	18	5.1	15	3.5
Total		289	100.0	351	100.0	434	100.0

[1] From ceiling of intake at gatewell.

TABLE 3.—*Vertical distribution of I-group chinook salmon fingerlings in turbine intakes of The Dalles Dam. Combined results of 14 tests extending from 3:30 p.m. to 8:30 a.m.*

[Test period, April 28 to May 12, 1960]

Net number (top to bottom)	Depth [1]	Catch by powerhouse area					
		Downstream end		Middle		Upstream end	
	M.	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1	0–2.1	321	55.9	211	45.8	51	35.2
2	2.3–4.4	131	22.8	113	24.5	46	31.7
3	4.6–6.7	62	10.8	67	14.5	29	20.0
4	6.9–9.0	25	4.4	36	7.8	13	9.0
5	9.2–11.3	17	3.0	24	5.2	5	3.4
6	11.4–13.6	18	3.1	10	2.2	1	.7
Total		574	100.0	461	100.0	145	100.0

[1] From ceiling of intake at gatewell.

[7] Monan, Gerald E., Robert J. McConnell, John R. Pugh, and Jim R. Smith. Distribution of downstream migrant salmonids and the study of debris in the Snake River above Brownlee Reservoir. Fish-Passage Research Program, Bureau of Commercial Fisheries, Seattle, Wash. Manuscript in preparation.

TABLE 4.—*Vertical distribution of I-group steelhead trout fingerlings in turbine intakes of The Dalles Dam. Combined results of 14 tests extending from 3:30 p.m. to 8:30 a.m.*

[Test period, April 28 to May 12, 1960]

Net number (top to bottom)	Depth [1]	Catch by powerhouse area					
		Downstream end		Middle		Upstream end	
	M.	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1	0- 2.1	66	44.9	87	46.3	9	56.3
2	2.3- 4.4	39	26.6	51	27.1	3	18.7
3	4.6- 6.7	19	12.9	25	13.3	3	18.7
4	6.9- 9.0	9	6.1	18	9.6	0	0
5	9.2-11.3	8	5.4	3	1.6	1	6.3
6	11.4-13.6	6	4.1	4	2.1	0	0
Total		147	100.0	188	100.0	16	100.0

[1] From ceiling of intake at gatewell.

TABLE 5.—*Vertical distribution of I-group sockeye salmon fingerlings in turbine intakes of The Dalles Dam. Combined results of 14 tests extending from 3:30 p.m. to 8:30 a.m.*

[Test period, April 28 to May 12, 1960]

Net number (top to bottom)	Depth [1]	Catch by powerhouse area					
		Downstream end		Middle		Upstream end	
	M.	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1	0- 2.1	70	36.6	52	26.1	17	50.0
2	2.3-.4.4	47	24.6	54	27.2	6	17.6
3	4.6- 6.7	31	16.2	37	18.6	3	8.8
4	6.9- 9.0	20	10.5	33	16.6	4	11.8
5	9.2-11.3	15	7.9	8	4.0	2	5.9
6	11.4-13.6	8	4.2	15	7.5	2	5.9
Total		191	100.0	199	100.0	34	100.0

[1] From ceiling of intake at gatewell.

TABLE 6.—*Vertical distribution of lamprey ammocoetes in turbine intakes of The Dalles Dam. Combined results of 14 tests extending from 3:30 p.m. to 8:30 a.m.*

[Test period, April 28 to May 12, 1960]

Net number (top to bottom)	Depth [1]	Catch by powerhouse area					
		Downstream end		Middle		Upstream end	
	M.	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1	0- 2.1	52	8.0	36	4.9	13	4.4
2	2.3- 4.4	98	15.1	92	12.4	19	6.5
3	4.6- 6.7	128	19.7	142	19.3	41	14.0
4	6.9- 9.0	154	23.7	171	23.2	62	21.2
5	9.2-11.3	167	25.8	204	27.7	89	30.4
6	11.4-13.6	50	7.7	92	12.5	69	23.5
Total		649	100.0	737	100.0	293	100.0

[1] From ceiling of intake at gatewell.

TABLE 7.—*Vertical distribution of fingerling salmonids in turbine intakes of The Dalles Dam. Combined results of 14 tests extending from 3:30 p.m. to 8:30 a.m.*

[Test period, April 28 to May 12, 1960]

Net number (top to bottom)	Depth [1]	All species and age groups	
	M.	*Number*	*Percent*
1	0- 2.1	1,190	39.3
2	2.3- 4.4	695	22.9
3	4.6- 6.7	442	14.6
4	6.9- 9.0	345	11.4
5	9.2-11.3	217	7.2
6	11.4-13.6	140	4.6
Total		3,029	100.0

[1] From ceiling of intake at gatewell.

TABLE 8.—*Vertical distribution of fingerling salmonids in turbine intake 12-C at McNary Dam. Combined results of 10 tests extending from 7 p.m. to 5 a.m.*

[Test period, April 24 to May 26, 1961]

Net number (top to bottom)	Depth [1]	Age group and species						Total	
		I-group chinook		I-group steelhead		I-group sockeye			
	M.	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1	0- 2.1	351	56.7	47	54.0	104	33.6	502	49.4
2	2.3- 4.4	140	22.6	17	19.5	89	28.7	246	24.2
3	4.6- 6.7	74	12.0	16	18.4	46	14.8	136	13.4
4	6.9- 9.0	33	5.3	5	5.8	35	11.3	73	7.2
5	9.2-11.3	12	1.9	2	2.3	22	7.1	36	3.5
6	11.4-13.6	9	1.5	0	0	14	4.5	23	2.3
Total		619	100.0	87	100.0	310	100.0	1,016	100.0

[1] From ceiling of intake at gatewell.

Catches at The Dalles Dam showed:

1. Vertical distribution of salmonids did not vary among areas of the powerhouse sampled; therefore, the catch data for all intakes were combined for subsequent analysis.

2. The combined catches of all salmonid species and age groups showed that most were caught in the top two of the six nets.

3. The I-group chinook salmon and I-group steelhead trout were most strongly concentrated in the top two nets—73 and 74 percent, respectively.

4. The O-group chinook salmon and I-group sockeye salmon were less strongly concentrated in the top two nets—48 and 58 percent, respectively.

5. The vertical distribution of ammocoetes was the reverse of that of salmonids; very few were caught in the top two of the six nets. This distribution held for all areas of the powerhouse. The zone of highest concentration at the upstream end

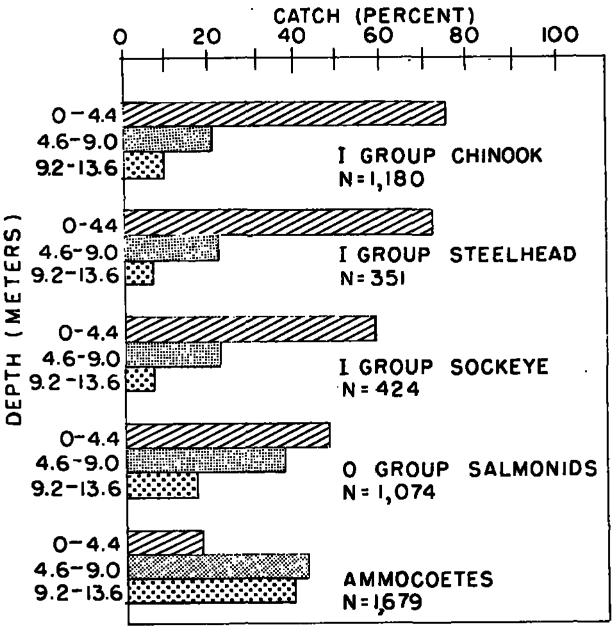

FIGURE 7.—Combined results of 14 tests showing vertical distribution of juvenile anadromous fish in turbine intakes of The Dalles Dam. Each 16-hour test was between 3:30 p.m. and 8:30 a.m. Test period, April 28 to May 12, 1960.

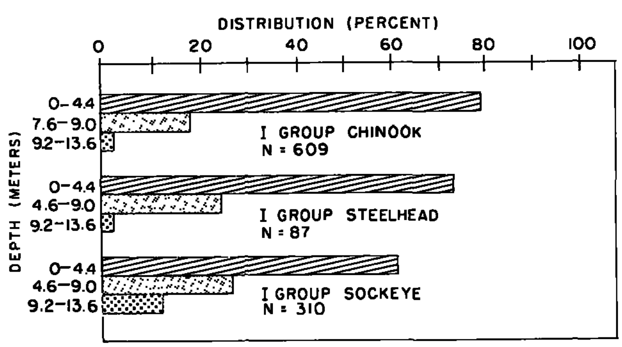

FIGURE 8.—Combined results of 10 tests showing vertical distribution of fingerling salmonids in intake 12–C at McNary Dam. Each 8-hour test was between 7 p.m. and 5 a.m. Test period, April 24 to May 26, 1961.

of the powerhouse occurred in the bottom two of the six nets, whereas the zone of highest concentration was in the two center nets in the center and downstream end of the powerhouse. This difference was statistically significant.

Catches at McNary Dam showed that the vertical distribution of I-group chinook and sockeye salmon and I-group steelhead trout was much the same as the vertical distribution of these age groups and species at The Dalles Dam. The I-group chinook salmon and steelhead trout were most strongly concentrated in the top two nets (79.3 and 73.5 percent, respectively), whereas I-group sockeye salmon were somewhat less concentrated (62.3 percent).

IMPLICATIONS OF RESEARCH IN TURBINE INTAKES

Information on diel movement and vertical distribution of fingerling salmonids in turbine intakes applies directly to the problem of developing methods for reducing fingerling mortality in Kaplan turbines. Important implications are discussed below.

DIEL MOVEMENT

According to past research, day and night movement of fish can vary significantly from year to year, presumably because of changes in turbidity and other facets of water quality. Mains and Smith (footnote 3) caught 57 percent of the I-group chinook salmon at night in the Snake River in 1954, whereas in 1955 they caught 78 percent at night. Gauley et al. (1958) caught significantly more O-group chinook salmon and I-group steelhead trout in special bypasses at Bonneville Dam during the night in 4 of 5 seasons; but in 1952, significantly more of these species were caught by day. Data by Gauley et al. (1958) suggested that turbidity may have influenced timing of fish movement. In view of past research, the data on day and night movement reported here should be applied with some reservation because continuing development of the river system may well alter water quality, including turbidity, in the future.

Although data on day and night movement must be considered only partially complete, the results—especially for I-group fingerlings—suggest a fortunate relation between timing of fish passage at dams and the normal schedule of turbine loading. Night movement of fish through turbines favors higher rather than lower average survival. At night the decreased demand for power causes reduced turbine loads. Preliminary information recently obtained at Big Cliff Dam[8] indi-

[8] Oligher, Ray. Fish passage through turbines—tests at Big Cliff hydroelectric plant. U.S. Army Corps of Engineers, North Pacific Division, Walla Walla District, Walla Walla, Wash. Letter report (1965), 14 pp.

cates that survival is highest at highest turbine efficiencies. Peak efficiency is achieved at reduced turbine loads, typically near 70 percent of maximum rated capacity.[9]

Reduced power demand also increases flexibility for adjusting turbine loads to maximize fish survival—shifting of load demand from turbines where fish passage is high to turbines where fish passage is low (between turbines in a given dam and between dams in the same power-grid system). The potential increase in fish survival that might be achieved by using this technique, however, cannot be estimated with accuracy from available data. Among other requirements, timing of fish movement should be determined for shorter periods of time, especially for dawn and dusk. Peaks are expected at dawn and dusk (Mains and Smith, footnote 3; Gauley et al., 1958; Monan et al., footnote 7) and the demand for power fluctuates during these hours of the day.

VERTICAL DISTRIBUTION

Data on vertical distribution have helped define more precisely the direction that future research should take to develop suitable protective methods. Most fingerlings in turbine intakes of both The Dalles Dam and McNary Dam are in flows near the ceiling of the intake. These flows pass the turbine blades at or near the hub (G. D. Johnson, footnote 2). If fish remain in these flows, they also must pass the blades near the hub. Protective methods designed to eliminate or nullify the effects of lethal agents, therefore, should be used first at the hub of the runner. These data also imply that most salmonid fingerlings could be routed into safe bypasses if a guiding system were designed to remove fish only from the upper 4.6 m. of water within turbine intakes.

SUMMARY

1. A frame supporting six fyke nets was used to measure diel movement and vertical distribution of fingerling chinook salmon, sockeye salmon, steelhead trout, and ammocoetes of the Pacific lamprey in turbine intakes at The Dalles Dam (1960) and McNary Dam (1961).

2. The nets were positioned one above the other in the frame and extended from the intake ceiling to within 1 m. of the floor to strain the center third of flows in a single intake (one-ninth of total turbine discharge).

3. Diel movement for all age groups and species did not differ significantly between areas of the powerhouse at The Dalles Dam. Although all age groups and species were more abundant at night (7 p.m. to 7 a.m.) than during the day (7 a.m. to 7 p.m.), only the I-group salmonids were significantly so. The night catches of I-group chinook salmon and I-group steelhead trout were 94 and 85 percent of the total, respectively, whereas the night catches of O-group salmonids and ammocoetes were 67 and 62 percent of the total, respectively.

4. Vertical distribution of salmonids did not vary between areas of the powerhouse sampled at The Dalles Dam. At both Dams, most I-group fingerlings were concentrated in the top two of six nets, or within 4.6 m. of the ceiling of the turbine intakes. At The Dalles and McNary Dams, respectively, the results for I-group chinook salmon were 73 and 79.3 percent; for I-group steelhead trout, 74 and 73.5 percent; and for I-group sockeye salmon, 58 and 62.3 percent. O-group salmonids were less strongly stratified than I-group fingerlings; 48 percent were caught in the top two nets.

5. Vertical distribution of ammocoetes at The Dalles Dam was the reverse of that for salmonids; few were taken in the top two nets.

6. Predominantly night movement of fingerlings through turbines favors higher rather than lower survival because (a) survival is highest at reduced loads near 70 percent of maximum rated capacity and (b) reduction in demand for power at night results in lower turbine loads. Reduced turbine loads also make it possible to shift loads from turbines where fish passage is greatest to those where fish passage is least, thus increasing total fish survival.

7. The concentration of fingerlings near the ceilings of intakes implies that most fish pass through the Kaplan runners at or near the hub. It follows that methods for eliminating the effects of lethal agents at the runner should be applied first at the hub. In addition, use of deflection and bypass techniques near intake ceilings would be advantageous because the concentration of fish is greatest in this region.

[9] Hydraulic plant operator training manual, Part II, U.S. Army Corps of Engineers, North Pacific Division, Portland, Oreg. 22 pp.

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