EFFECT OF FISHWAY SLOPE ON PERFORMANCE AND BIOCHEMISTRY OF SALMONIDS[1]

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ABSTRACT

The effect of fishway slope on the performance and biochemical state of salmonids was studied in two experimental "endless" fishways with slopes of 1 on 8 and 1 on 16. A locking device in each fishway permitted recycling of fish so that pool-and-overfall fishways of any height could be simulated. Ascents were generally confined to a rise of 104 feet, but a number of fish were permitted to ascend over several hundred feet and one fish was allowed to ascend over 6,000 feet. Principal species tested were chinook salmon (*Oncorhynchus tshawytscha*), sockeye (Columbia River blueback) salmon (*O. nerka*), and steelhead trout (*Salmo gairdneri*).

Comparisons of individual passage times, patterns of movement, and biochemical phenomena associated with muscular activity showed no evidence of fatigue of the fish in either fishway when proper hydraulic conditions existed. Data indicated that ascent of a properly designed pool-and-overfall fishway is only a moderate exercise for salmonids and that the rate of ascent will not decline in the upper end of a long fishway. Hydraulic conditions were shown to control rate of ascent and pattern of movement through fishways. Differences in rate of movement and in blood lactate levels were measured between species.

The effects of size, sex, maturity, and disease on performance and biochemical state of fish were also examined. Significant relationships were found only for length of male chinook and performance (larger fish were slower), and sex and blood lactate level for chinook (female chinook had higher blood lactate levels).

The slope of a pool-type fishway is a major factor in determining the cost of its construction. A fishway that rises 1 foot for every 8 feet of length (1-on-8 slope) needs to be only one-half as long as a fishway that rises 1 foot for every 16 feet of length (1-on-16 slope) to gain the same elevation. On the Columbia River the present standard slope for major fishways is 1 on 16, (e.g., Bonneville Dam, The Dalles Dam and Rocky Reach Dam). An earlier dam, Rock Island Dam, was built with fishways with a 1-on-10 slope, and one dam, McNary Dam, has fishways with a slope of 1 on 20. There are many dams yet to be built on the Columbia River and its tributaries, and significant reduction in fishway costs would be possible if satisfactory fishways could be designed with slopes steeper than the present 1 on 16.

To determine the feasibility of steeper fishway slopes the effect of fishway slope on the rate of passage of chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), and steelhead trout (*Salmo gairdneri*) was studied at the research project at Bonneville Dam during 1956 and 1957. This was done by comparing the passage times of the salmonids through short experimental fishways with slopes of 1 on 8 and 1 on 16. Both fishways were of the pool-and-overfall type without submerged orifices, and both achieved a total gain in elevation of 6 feet. The results of these experi-

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ments (Gauley, 1960, p. 11) were quite favorable. For all three species of fish the rate of passage through a 1-on-8-slope fishway having 1-foot overfalls between pools was as fast or faster than the rate of passage through the conventional 1-on-16-slope fishway. This was true whether the tests were made with individual fish or with groups of fish. However, because the tests in 1956 and 1957 were made with only short segments of fishways, the question still remained whether the steeper slopes were suitable for longer fishways. The possibility that the steeper slope might dangerously fatigue fish in a long fishway had to be investigated.

A study of the effect of fishway slope on fish performance in long fishways was begun at the Fisheries-Engineering Research Laboratory during the 1958 season. Two specially designed "endless" fishways with slopes of 1 on 8 and 1 on 16 were utilized. These endless fishways were experimental pool-and-overfall fishways constructed so that each made a complete circuit, with the highest pool connected to the lowest pool by means of a lock. When a fish had ascended to the top of one of these fishways it was then rapidly locked to the lowest pool to ascend again. Fishways of any desired length could thus be simulated. Knowledge of the effect of fishway slope on fish passage was sought through a comparison of the performance and behavior of the fish in the two endless fishways and through a study of the related biochemical phenomena associated with fatigue.

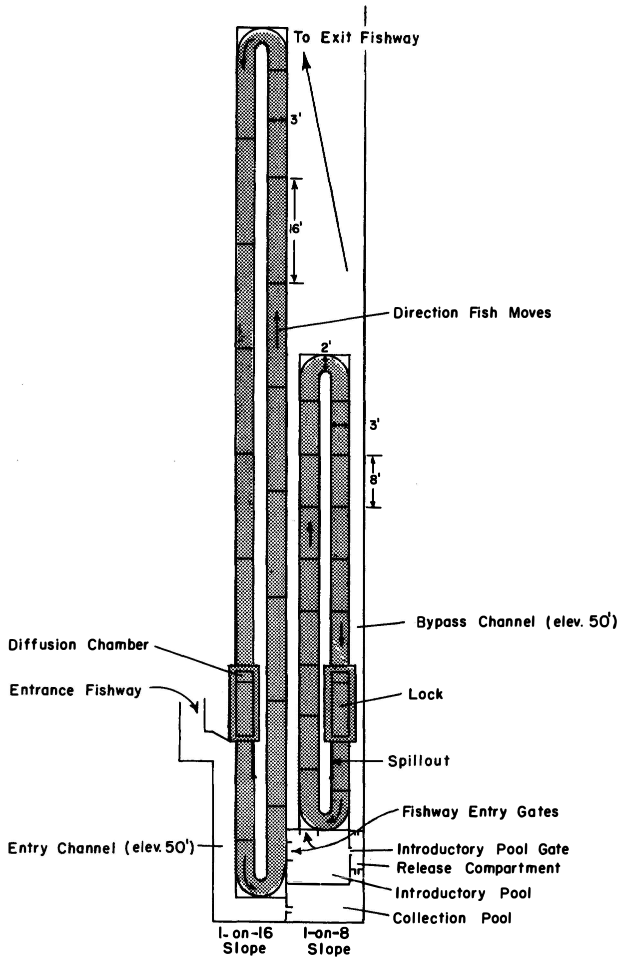

FIGURE 1.—Plan view of the 1-on-16-slope and 1-on-8-slope endless fishways with auxiliary approach channels and pools.

DESCRIPTION AND OPERATION OF ENDLESS FISHWAYS

INITIAL DESIGN

Features of the 1-on-16 and 1-on-8-slope endless fishways and essential auxiliary channels and pools (entrance channel, collection pool, release compartment, introductory pool and exit by-pass) are shown in plan view in figure 1. An enlarged view of the 1-on-8-slope unit showing pool elevations in feet above mean sea level appears in figure 2. All subsequent reference to the various pools will be made by numbers indicating their surface elevation in feet above mean sea level. The same pool elevations apply to the 1-on-16-slope unit. Perspective views of the two fishways are presented in figures 3, 4, 5, and 6.

Each fishway was comprised of 16 pools including 2 turn pools and a locking pool. There was a 1-foot rise between pools and a total rise of 16 feet in the complete circuit. With the exception of the lock and turn pools, the average water depth in each pool was approximately 6.8 feet. Pools were 3 feet wide and either 8 or 16 feet long, depending on the slope of the respective fishway. A 3-foot freeboard prevailed throughout each fishway. Weir crests were 3 feet long and 2 inches wide and were painted white on the square crest to aid in the observation of fish. All other interior surfaces were painted camouflage brown. There were no orifices in the weirs, but a single, 2-inch drain hole was provided in the base of each weir to permit draining during unwatering. A steel flap plate covered each hole when the fishway was operative.

All principal structures were of wood with the exception of the exterior steel supports on the lock

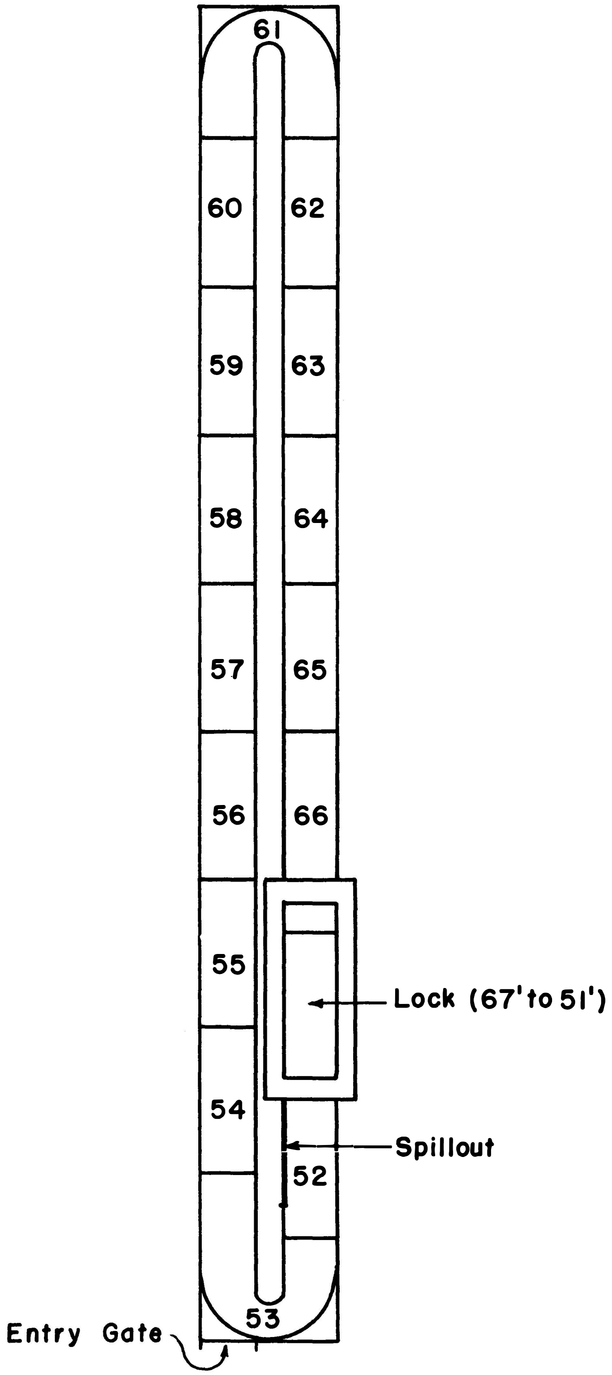

FIGURE 2.—Plan view of 1-on-8-slope fishway showing pool elevations in height above mean sea level.

and certain gates in the two fishways. A cross-sectional view of a typical series of pools in the 1-on-8-slope unit, showing the box-type construction with level floor, is presented in figure 7.

Dimensions of the turn pools (53 and 61) were in keeping with the established slope in each fishway, i.e., the inside longitudinal footage totaled 8 feet in the 1-on-8-slope fishway and 16 feet in the 1-on-16-slope fishway. While pool depth was approximately 6.8 feet, passage area available to the fish was limited to the upper 2 feet of the pool by a horizontal grill. The corners of the pool were coved, and the pool width at the 90° point of the turn was reduced from 3 to 2 feet (figs. 1 and 8).

The lock pool (elevation 67′ to 51′) in each fishway was 8 feet long, 3 feet wide, and 23 feet deep when filled and 7 feet deep when drained. At the lower discharge level (elevation 51′), the lock functioned as a typical pool. A picketed barrier was installed on the crest of the downstream weir of the lock (elevation 50′) to prevent fish from drifting back into the drain area. Ideally, to be consistent with the slope design, the lock in the 1-on-16-slope fishway would have been 16 feet long. Since space limitations and structural considerations posed barriers to the construction of a 16-foot unit, the lock in the 1-on-16 fishway was built identical to that in the 1-on-8-slope unit.

To encourage the fish to pass from the lock pool after the water had been discharged from elevation 67′ to 51′, a horizontal grill was placed in the pool, limiting the depth available to fish to 2 feet. This alteration served to expedite the movement of fish from the lock into the next upstream pool (52).

Operational features of the endless fishway units may be conveniently described by visualizing the passage of a fish into and through the various sections of the laboratory and through an endless fishway. Steps involved in this passage are as follows:

(1) Fish were diverted from the Washington-shore fishway into the entrance fishway (fig. 1) without handling, a unique feature of the research. The fish then ascended the entrance fishway to the entry channel and moved on into the collection pool. This pool was 5 feet by 12 feet by 6 feet with the surface elevation at 50′.

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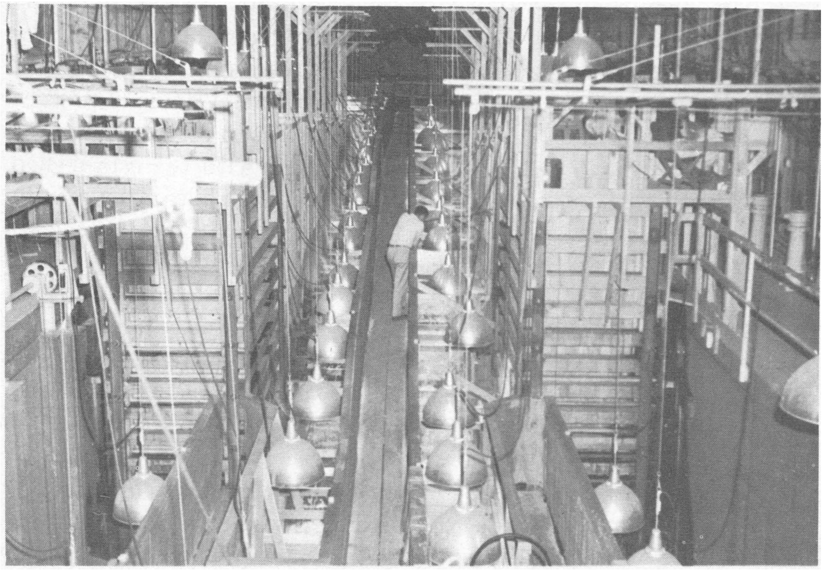

FIGURE 3.—Looking upstream at the 1-on-16 (left) and 1-on-8-slope (right) endless fishways. The locking units in each fishway appear in the left and right foreground.

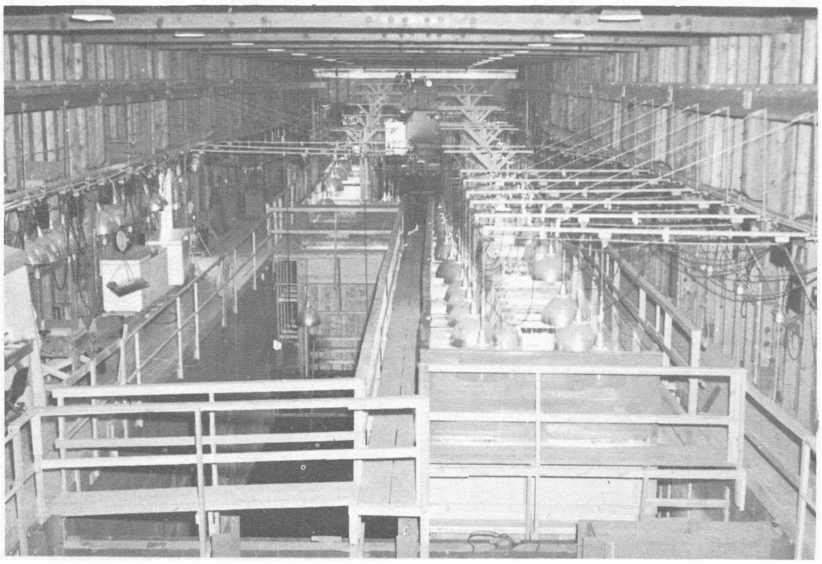

FIGURE 4.—View from the upper turn pool showing respective lengths of the 1-on-16 (right) and 1-on-8-slope (left) fishways. Each fishway rises 16 feet.

(2) From the collection pool a single fish was permitted to pass through an 8-inch-wide gate and enter the release compartment where it was diverted into the introductory pool through an adjoining gate. Water flow from the bypass channel provided the necessary attraction for the movement into the release compartment.

(3) As the fish entered the introductory pool, a wooden drop gate was lowered at the juncture of the release compartment and the introductory pool. This isolated the fish in a quiet pool, which was 6 feet wide, 9 feet long, and 2 feet deep. The water level at this point remained at elevation 50′.

FIGURE 5.—Looking upstream from pool 53 in the 1-on-8-slope endless fishway.

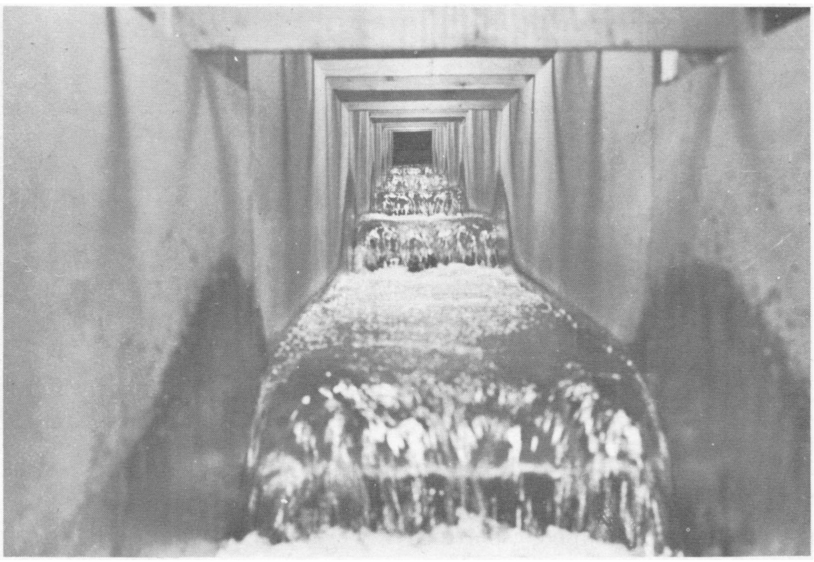

FIGURE 6.—The 1-on-16-slope endless fishway viewed from pool 53.

(4) Passage of the fish from the introductory pool to one of the endless fishway units was facilitated by raising a fishway entry gate joining pool 53 with the introductory pool. This permitted the water in the fishway to spill into the introductory pool, filling it to approximately elevation 52.5′. At this level, excess water passed through a grill on the downstream rim of the introductory pool and spilled into the collection pool. The fish was now in a position to swim from the introductory pool (fig. 9) into the fishway.

(5) Immediately after the fish passed into pool

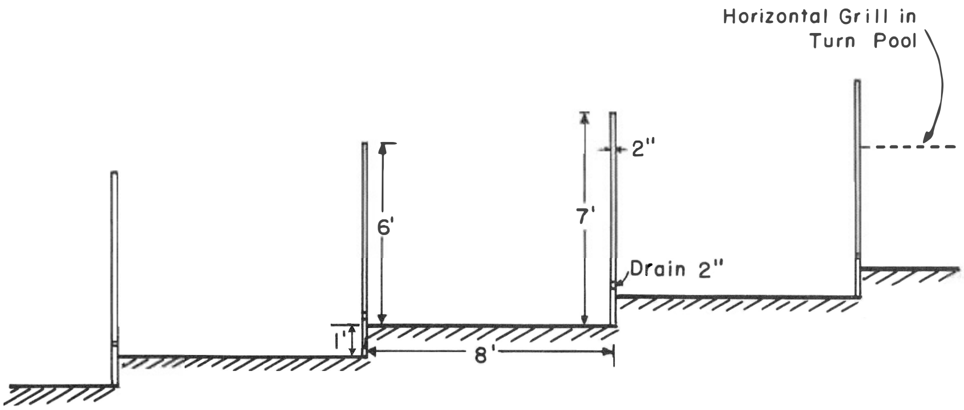

FIGURE 7.—Sectional view of 1-on-8-slope fishway. Note level floors.

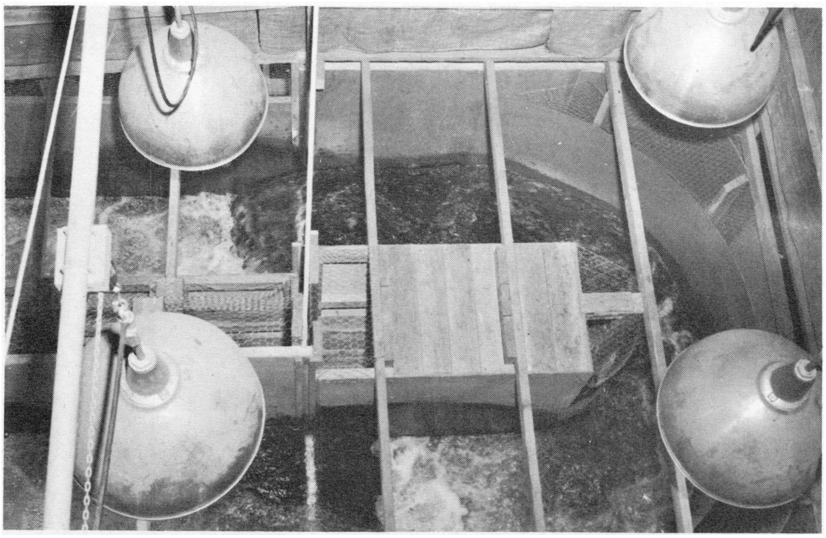
FIGURE 8.—Upper turn pool in the 1-on-8-slope fishway.

53, the fishway entry gate was dropped, isolating the fish in the now closed circuit of the endless fishway.

(6) From pool 53 (see fig. 2 for pool elevations) the fish ascended the straightaway section through pools 54–60 and then around the upper turn pool (61) and again up a straightaway section to pool 66. At this point the fish was ready to enter the lock (fig. 10). Dimensions of the diffusion chamber were 3 feet by 3 feet by 7 feet. A 16-inch pipe with grill openings on the under side entered the base of the chamber and provided a constant water supply for the fishway. Diffusion baffles were placed above the pipe and a finger grill submerged approximately 6 inches beneath the water surface, prevented the fish from sounding into the chamber as it passed from pool 66 into the lock.

(7) After the fish passed over the diffusion chamber grill, the drop gate (A, fig. 10) was lowered to separate the lock pool from the diffusion area. A motor-driven winch, connected to a steel cable (B, fig. 10), raised a steel flap gate at the base of the drain area directly beneath the diffusion chamber. This permitted drainage of the lock to elevation 51′. Discharge of lock water was

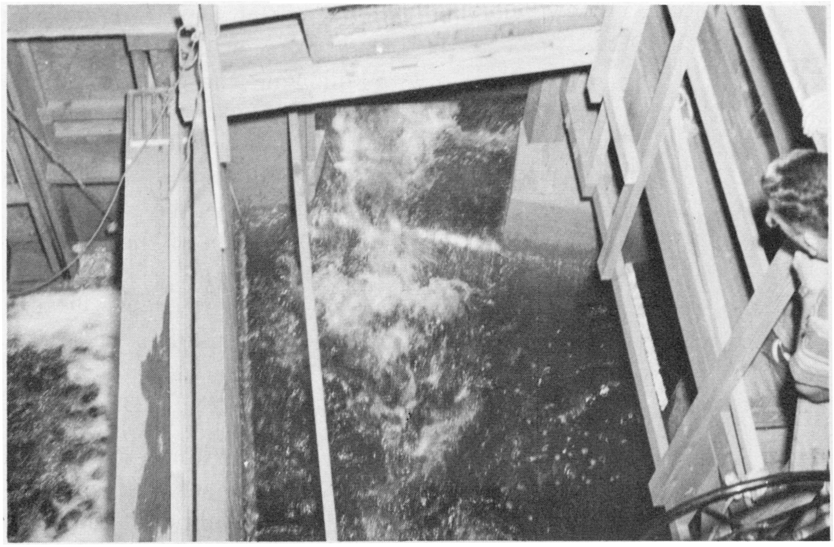

FIGURE 9.—Introductory pool with water level at elevation 52.5′. Entry gate to the 1-on-16 slope fishway is open (upper center) to permit entry of fish into pool 53.

normally accomplished in about 30 to 40 seconds. Figure 11 shows drop gate (A) in down position, isolating the diffusion chamber and the remainder of the fishway from the lock which has been drawn down.

(8) Figure 12 presents a view of the lock after discharge of water from elevation 67′ to 51′. The vertical gate (C) has been raised, and water from pool 52 may be seen spilling into the lock. (Previous to the opening of the pre-vertical gate (C), all water in the fishway spilled out a screened overflow in pool 52.) The fish was now in position to move from the lock into pool 52.

(9) When the fish had passed through pool 52 and the lower turn pool (53) the vertical gate (C) was lowered and the lock drainage gate closed. This readied the lock for filling as the fish began another circuit of the fishway. Filling the lock (fig. 13) required about 1 minute. As the water level in the lock approached elevation 67′, the 16-inch supply valve was gradually closed. At this level the drop gate (A) (figs. 10 and 11) was raised, and the lock was now ready to receive the fish when it once again ascended to this level.

LIGHTING AND HYDRAULICS

A constant light supply approximating an average intensity of 800 foot-candles at the water surface prevailed during all experiments. This was provided by a battery of 1,000-watt fluorescent mercury-vapor lamps placed at 6-foot intervals throughout the course of each fishway. The distance from the lamp reflectors to the water surface was 6 feet.

Water supply for operation of the fishway units came from the forebay of Bonneville Dam, which fluctuated from elevation 82.5′ to 72.5′ during these experiments. This provided a minimum operating head of 5.5 feet (water level of lock and diffusion chamber when filled was approximately at elevation 67′). Water for the bypass channel (fig. 1) came from the Washington-shore fishway which was joined with the laboratory by an exit fishway.

Head on the weirs (measured 4 feet upstream of the weir crest) was controlled by adjusting the valve supplying water to the diffusion chamber. This head was set at 0.8 foot, the approximate upper limit at which a plunging flow (strong directional flow reaches bottom of pool) could be maintained under the prevailing nonorifice condition. Total discharge in each fishway was approximately 7.2 cubic feet per second (c.f.s.).

Flows into the lock pool were changed from the established plunging condition to a streaming motion (strong directional flow along surface of pool) by raising the lip of the lock spillout slightly above elevation 50′. This was done to increase the sur-

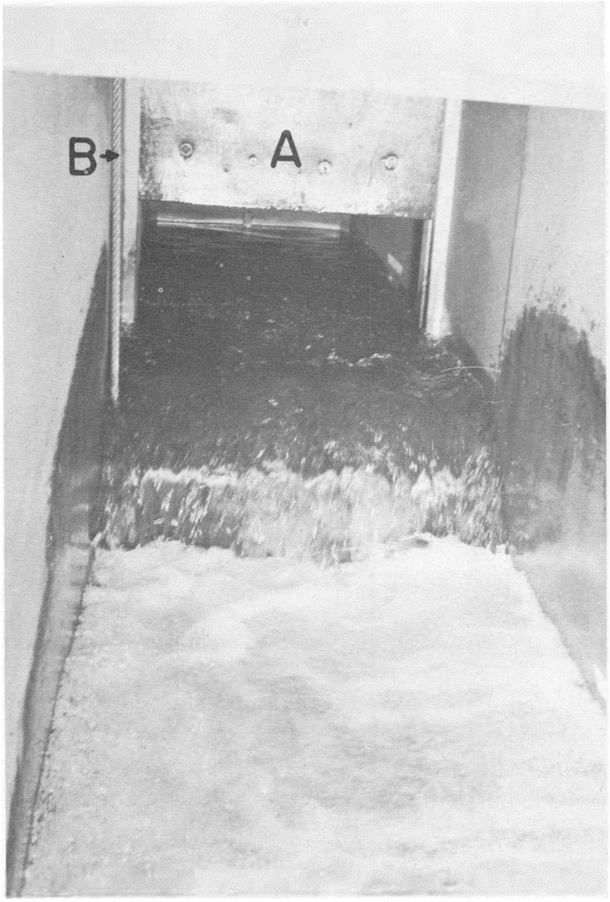

FIGURE 10.—Looking upstream from pool 66 over diffusion chamber and into lock. As fish enters lock, the drop gate (A) is lowered to isolate fish in lock. A motor-driven winch connected to the cable (B) raises a gate at base of lock, discharging water to elevation 51′.

face velocity and encourage the exit of fish from this pool.

SUBSEQUENT DESIGN MODIFICATIONS

During the 1958 experiments, several physical changes were incorporated in the fishways for the purpose of creating special hydraulic conditions designed to facilitate the passage of fish. The turn pools (53 and 61) in both fishways that had previously been grilled to limit fish passage to the 2-foot surface layer were further modified by installing a floor over the grill and placing 6-inch-high baffles on the floor at approximately 4-foot intervals across the width of the pool. These changes created a turbulent, rapidly flowing water pattern which served to prevent the fish from using the turn pools as resting areas.

Following the above modifications, the 1-on-8-slope fishway was altered further by installing baffles on the weir crests (fig. 14). The three types of baffle placements were employed during tests conducted in September 1958.

A comparison of the various fishway conditions applicable to the 1958 tests is given in table 1. Subsequent reference in the text will refer to these conditions by number and slope.

PROCEDURE

The comparison of the two fishway slopes was to be based on an analysis of (a) the performance of individual salmonids in the respective fishways and (b) certain biochemical characteristics of the fish after exercise in the ascent of a fishway. Per-

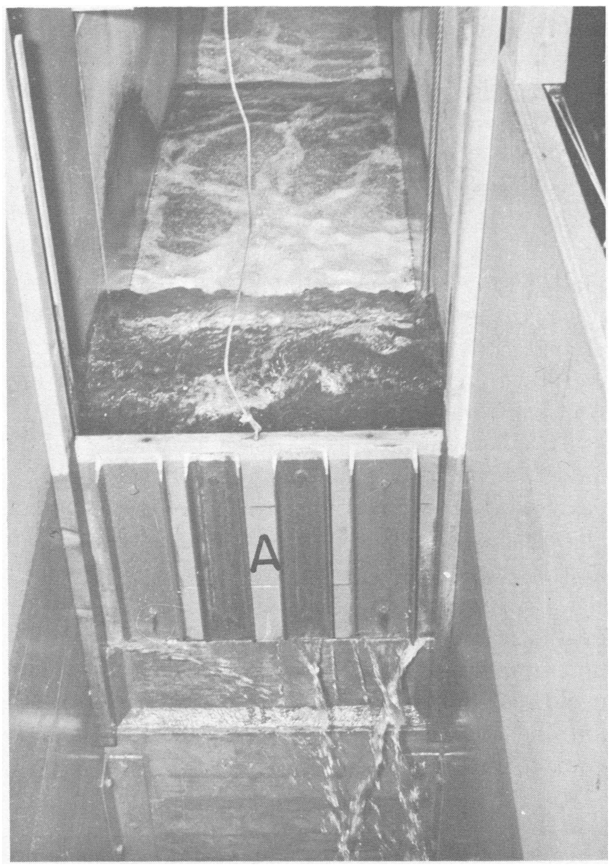

FIGURE 11.—Drop gate (A) in down position separating diffusion chamber from lock (foreground). Water in lock (foreground) has been discharged to elevation 51′.

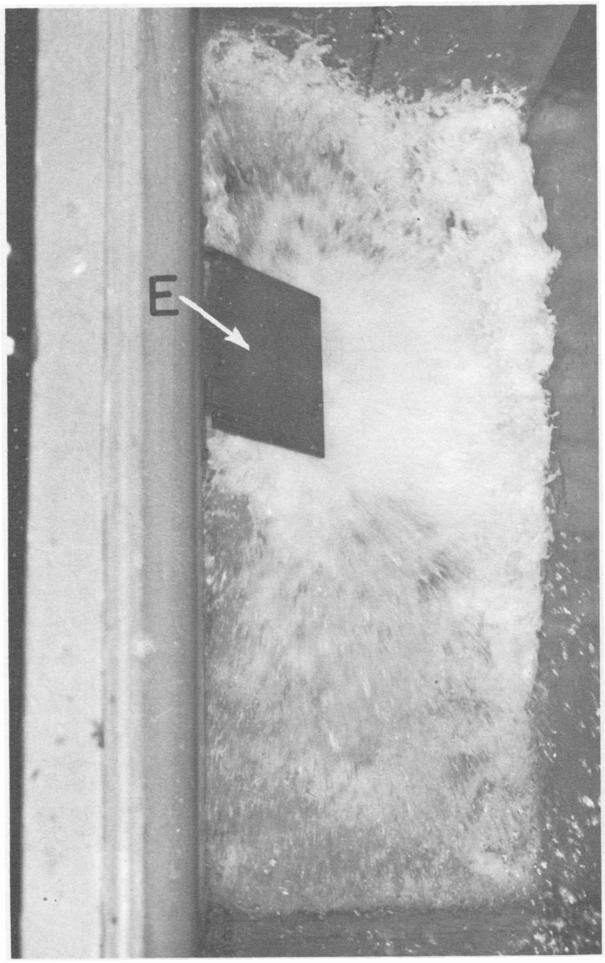

FIGURE 12.—Looking down into lock. Vertical gate (C) has been raised to permit exit of fish from lock into pool 52. Water passes from lock through grill (D) and out drain gate opening behind grill.

TABLE 1.—*Physical features of 1-on-8 and 1-on-16 slope endless fishways* [1]

Fishway		Weirs		Calculated flow	Turn pool conditions
Condition	Slope	Length	Modifications		
		Inches		*c.f.s.*	
1	1-on-8	36.0		7.2	With rest areas.
1	1-on-16	36.0		7.2	Do.
2	1-on-8	36.0		7.2	Turbulent.
2	1-on-16	36.0		7.2	Do.
2A	1-on-8	17.0	Center notch—type A.	3.9	Do.
2B	1-on-8	26.5	In-line baffles—type B.	5.3	Do.
2C	1-on-8	26.5	Alternating baffles—type C.	5.3	Do.

[1] Fishway pools were 8 and 16 feet long respectively, 3 feet wide and 6.8 feet deep. Head on weirs was 0.8 foot and height of overfall 1 foot.

formance was measured in terms of time and ability to ascend the two fishway and the biochemical characteristics measured were the levels of lactate of whole blood, inorganic phosphate of blood plasma, lactate of the muscle tissue, and inorganic phosphate of the muscle tissue.

FISH COLLECTION

Fish utilized for experimental purposes in the endless fishways were diverted from the Washington-shore fishway each day and allowed to ascend to the collection pool (fig. 1). The time required to collect a sufficient number of fish generally was not more than several hours. In the early part of the season, the collection period commenced at about 2:00 p.m. and by 4:00 p.m., 6 to 20 fish

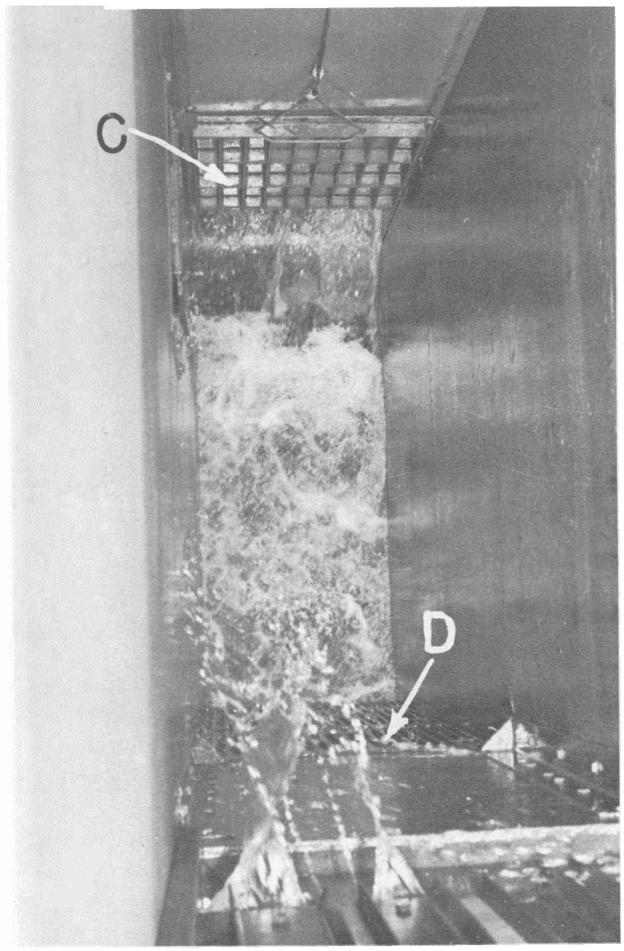

FIGURE 13.—Filling lock. Flap plate (E) returns to "down" position when level reaches elevation 67′ and supply valve is closed.

would be present in the collection pool. The pool entrance was then closed, and covers were placed over the pool to keep the fish quiet during the hold over period which extended to the following morning. Thus, each fish present in the pool was held from 14 to 20 hours depending on the time it entered the pool and the time it subsequently left the pool to enter the experimental area on the following day. The assumption was then made that this procedure placed each fish in a relatively equal state of rest prior to its release into one of the endless fishways. Figures 15 and 16 present views of the collection pool when fish were entering and when the pool was covered during the hold over period.

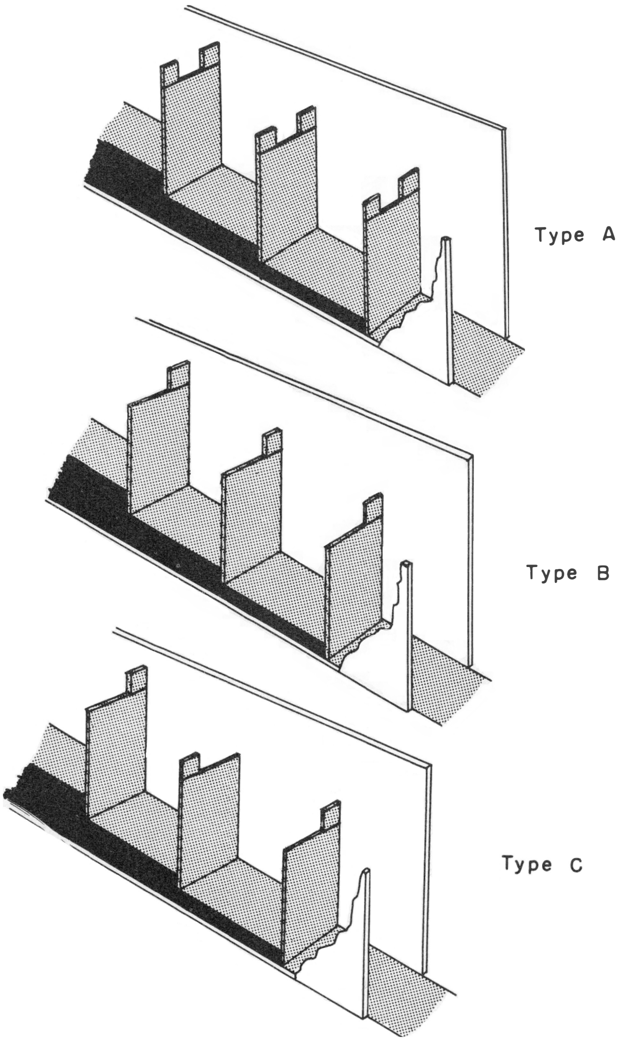

FIGURE 14.—Baffle placements showing notched, in-line, and alternate arrangements on weirs of 1-on-8-slope fishway.

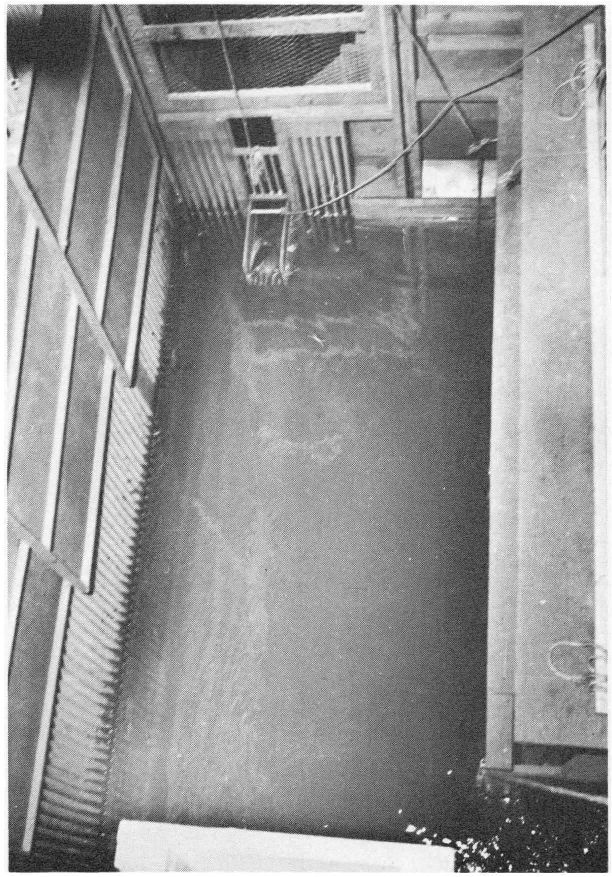

FIGURE 15.—Collection pool open for fish. Note finger fyke at entry gate (upper center).

All fish remaining in the collection pool at 2:00 p.m. each day were released into the bypass channel (fig. 1) where they passed through the laboratory and out into the Washington-shore fishway. A brail on the floor of the collection pool was raised to ensure the exit of all remaining fish previous to the entry of a new group for use in the succeeding day's experiments.

During the latter part of the season this procedure was modified by reducing the time the fish were held in the collection pool to periods not exceeding 6 hours and not less than 1 hour. The change in technique was made to save time. This was done after a comparison of blood lactate levels of fish held overnight with those of fish held for only a few hours indicated no difference in the physical states of the fish.

RELEASE AND TIMING

For each test, an individual fish from the collection pool was permitted to enter the release

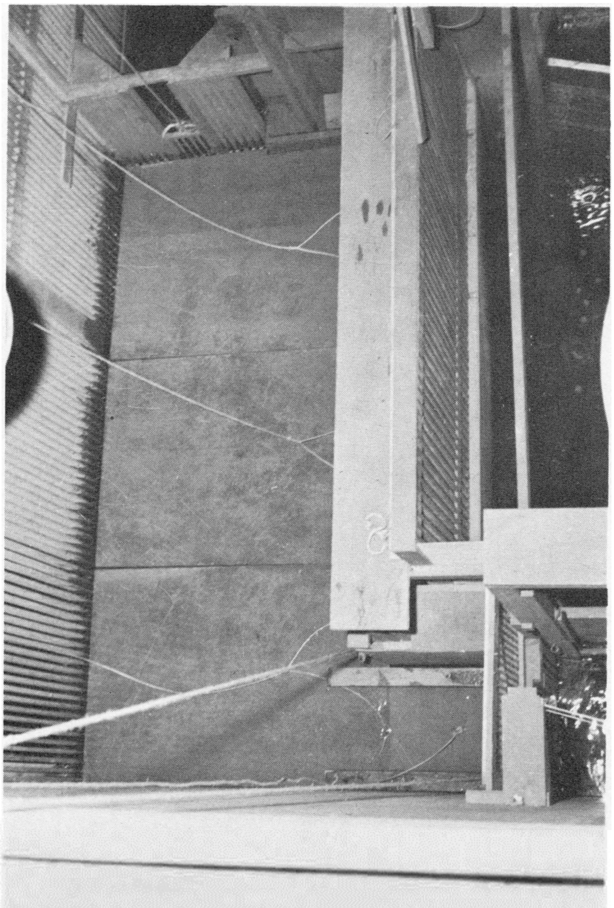

FIGURE 16.—The fish collection pool with covers in place during hold over period.

compartment where it was observed briefly to determine species and physical condition. Fish bearing visible evidence of serious injuries, such as deep cuts or large abrasions, were rejected. There was no selection on the basis of size. The fish was then allowed to enter the introductory pool.

A fish swimming from the introductory pool into the fishway was the signal to start a test. The ascent was timed by a pair of observers who moved along with the fish as it proceeded up the fishway. A button switch was located on a handrail above each weir in the fishway, and as the fish passed from pool to pool, an observer pressed the button for the respective weir. This signal was in turn transmitted to an operations recorder that noted on a continuously revolving time tape the exact time of fish passage over each weir. Another attendant stood by to operate the lock and transfer the chronological record of ascent from the tape to an operations sheet.

When the fish entered the lock, the two observers promptly descended a walkway to the base of the lock and recorded the fish's movement as it entered pool 52 following discharge of lock water from elevation 67′ to 51′.

PERFORMANCE

Two types of performance tests were conducted during the June and July chinook and sockeye salmon migrations. One test consisted of permitting a fish to ascend through 104 pools (6½ circuits of the endless fishway) at which point the fish was immediately removed from the fishway and samples of blood and muscle tissue taken for biochemical analysis. The 104-pool ascent was an arbitrary choice but nevertheless in keeping with a simulated passage over a typical Columbia River dam. The foregoing tests were conducted on Sunday, Wednesday, Thursday, and Saturday of each week, and performance was measured in terms of minutes required to pass through 104 pools. On the remaining days—Monday, Tuesday, and Friday—a "prolonged ascent" test was carried on. These trials were designed to examine performance trends and biochemistry of fish subjected to a long ascent of generally more than 200 feet. As the latter tests often required lengthy periods of observation, they were normally discontinued after (a) approximately 13 hours or (b) after a fish had spent 60 minutes in a single pool.

Individuals removed from the fishway immediately following a specified ascent were called "terminated" fish as contrasted to "volitional" fish, which were those that stopped of their own volition for 60 minutes in a single pool and were then removed. Thus, the former can be considered as having been in an actively ascending state and the latter in a resting state at the time of their removal. All fish removed immediately after ascending 104 pools are, therefore, classified as terminated, while those removed after ascending in excess of 104 pools may be classed as terminated or volitional, depending on the circumstances of their removal. Occasionally, due to the time limitations or operational difficulties, a test was terminated before a 104-pool ascent was completed. There were also a number of instances in which fish came to a volitional stop before reaching 104 pools.

A special category—volitional-terminated—was later assigned to a limited group of summer chinook exhibiting what appeared to be obvious signs of stress or fatigue. These fish generally displayed a pattern of extremely rapid ascent followed by a drift or fallback movement which usually carried them completely down the fishway to the lowermost pool. At this point, the fish became impinged against the spillout grill in the lock, or if the lock was closed, it would appear against the spillout screen in pool 52. When this occurred the fish was removed from the fishway for immediate sampling of blood and tissue for biochemical analysis.

Performance trials conducted during August and September were confined solely to comparisons of the time required to make 104-pool ascents in the 1-on-8 and 1-on-16-slope fishways.

BIOCHEMISTRY

Immediately following the completion of a performance test, the fishway water supply was shut off and the fish was netted from the fishway and immobilized by a sharp blow on the head. In successive steps, and as rapidly as possible, 5 cc. of blood and several muscle-tissue cores were extracted (figs. 17 and 18) from the fish. Muscle cores were always taken from the area directly between the dorsal fin and the lateral line at a right angle to the left side of the fish. A heart puncture, made with a hypodermic syringe inserted through the body wall, served to extract the blood. Similar samples were taken each day from a control fish netted from the collection pool. Records were kept of the time required from the moment the fish was netted from the fishway until (1) the blood was extracted and (2) the tissue was weighed and placed in cold, 5-percent trichloroacetic acid.

After the blood and tissue samples were extracted, they were processed and placed in individual polyethylene containers and stored in a deep freeze for subsequent biochemical determinations. The length and sex of each fish were recorded, and the gonads were weighed for the purpose of determining sexual maturity. Lactate levels of the blood and muscle were determined by the method of Barker and Summerson as described in Hawk, Oser, and Summerson (1954, p. 622–624). King's modification of the Fiske and Subbarow method (King, 1932) was used to determine level of inorganic phosphate in the blood plasma and muscle tissue.

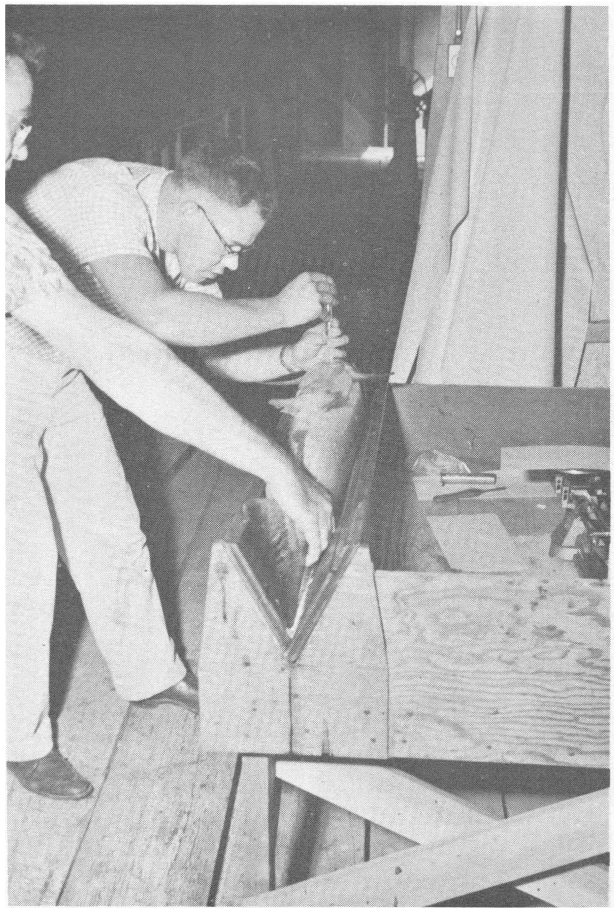

FIGURE 17.—Extracting blood from heart of a chinook salmon.

In addition to the foregoing, extracts of liver tissue and muscle tissue were also obtained for glycogen analysis, and a limited number of muscle tissue samples were taken for fat analysis. Glycogens were determined by the method of Montgomery (1957). Scales were also taken from many of the fish for subsequent age analysis. Special examinations for disease were made during August and September.

RESULTS

PERFORMANCE

Comparisons of the performance of chinook salmon, sockeye salmon, and steelhead trout with respect to slope consider (1) the passage

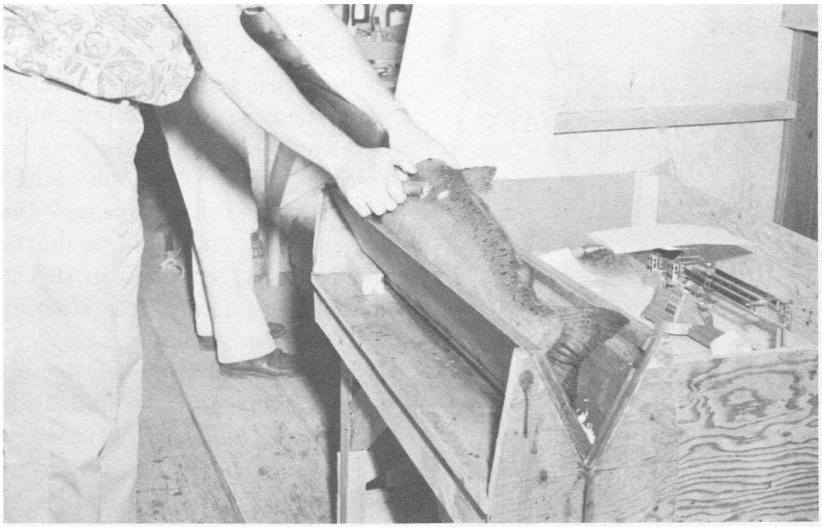

FIGURE 18.—Removing muscle core from side of chinook salmon.

time in minutes required to ascend a specified number of pools, (2) the pattern of movement or the "work-rest" relation, and (3) the willingness to ascend the respective fishways, the latter arbitrarily established as the percentage of fish negotiating 100 pools without stopping for 1 hour in a single pool. In addition, the work level at which fatigue might become apparent was examined by comparing mean rates of ascent at various levels of ascent in the fishway.

Examination of each of the foregoing aspects of performance will be treated in accordance with the prevailing fishway conditions as given in table 1; namely, (1) turn pools with rest areas, (2) turn pools turbulent, and (3) restricted weirs (1-on-8-slope).

Turn pools with rest areas (condition 1)

On June 9, 1958, tests in the endless fishways with rest conditions provided in the turns began with the passage of a limited number of chinook salmon. These were followed by sockeye salmon which continued in sufficient abundance for test purposes until July 20. A comparison of individual passage times of chinook and sockeye salmon through the 104-pool ascent level is given in table 2.

Chinook salmon ascending the 1-on-8-slope fishway required approximately 2.7 minutes per pool, while the mean rate in the 1-on-16-slope fishway was 2.0 minutes per pool. With the limited sample size, the difference in mean passage time for the 104-pool ascent is not statistically significant (table A–1). Because of the small sample size, however, there is a high risk of error in concluding that no true difference exists in the mean rates. A subsequent analysis comparing mean time per circuit (16 pools) showed a consistent (significant) difference between the time taken by chinooks ascending each of 6 circuits in

TABLE 2.—*Time in minutes to ascend 104 pools in endless fishways having slopes of 1 on 8 and 1 on 16 with turn pools providing rest areas (condition 1): Chinook salmon—June 9–20, sockeye salmon—June 21 to July 20, 1958*

Fish number	Chinook salmon		Sockeye salmon	
	1-on-8 slope	1-on-16 slope	1-on-8 slope	1-on-16 slope
1	321	148	167	162
2	430	198	155	155
3	152	237	149	180
4	251	171	177	184
5	207	334	192	217
6	362	308	198	129
7	273	329	204	123
8	----	135	167	126
9	----	----	130	173
10	----	----	144	303
11	----	----	144	254
12	----	----	167	94
13	----	----	197	127
14	----	----	198	213
15	----	----	169	173
16	----	----	179	187
17	----	----	176	158
18	----	----	179	180
19	----	----	151	182
20	----	----	150	138
21	----	----	175	132
22	----	----	134	214
23	----	----	151	139
Mean	285	232	168	175

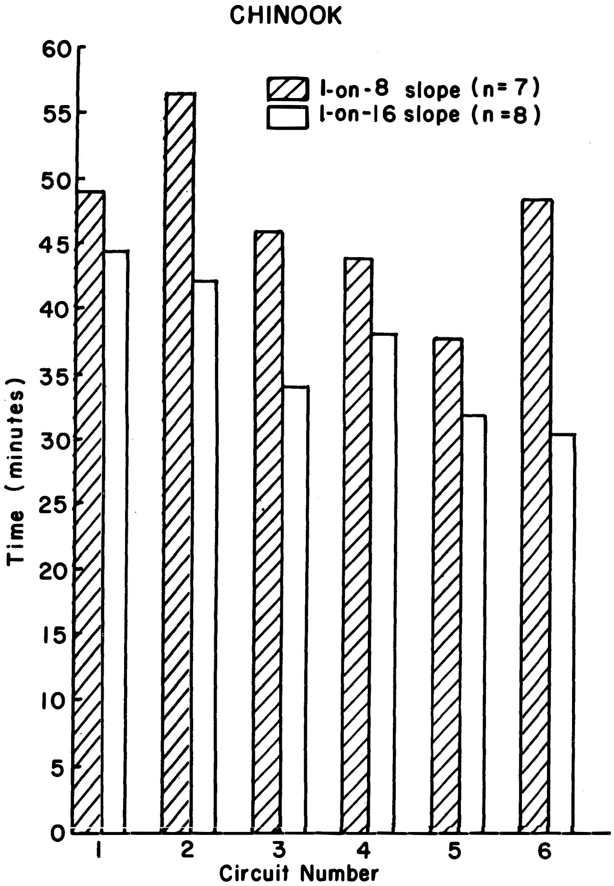

FIGURE 19.—Mean passage time per circuit (16 pools) taken by chinook salmon negotiating endless fishways having slopes of 1 on 8 and 1 on 16. June 9–21, 1958.

the two fishways. The average time per circuit in the 1-on-8-slope fishway was 44.1 minutes as compared to 36.4 minutes in the 1-on-16-slope fishway, or an average of 21 percent longer time in the 1-on-8 unit. (Comparative times per circuit are given in figure 19.)

Mean rates of ascent for sockeye over the 104-pool ascent level were virtually equal, being 1.6 minutes and 1.7 minutes per pool, respectively, in the 1-on-8- and 1-on-16-slope fishways.

The foregoing trials revealed a rather pronounced work-rest pattern of ascent, particularly in the fishway having a slope of 1 on 8. A somewhat similar but less exaggerated pattern of ascent was evidenced in the 1-on-16-slope fishway.

Because of the manner in which the endless fishways were constructed, every eighth pool was a turn pool. These turn pools created hydraulic conditions which were considerably different from those occurring in pools in the straightaway sections of the fishway. When the rates of ascent in both fishways were examined on the basis of time spent in each individual pool, the data indicate that the turn pools apparently were preferred resting areas. Chinook salmon ascending the 1-on-8-slope fishway passed through most of the straightaway pools in a matter of seconds and then usually remained in the turn pools for more than 15 minutes before starting to ascend again. In the 1-on-16-slope fishway, chinook spent an average of approximately 1 minute per pool in the straightaway sections and about 3 to 5 minutes in the turn polls (fig. 20).

Locking the fish appeared to cause relatively little delay in both fishways. The average time from the moment the fish crossed the upper weir until it actually left the lock was less than two minutes. The time spent in the pool following the lock was, however, greater than in straightaway pools. This may have been due to the change in hydraulic conditions encountered after leaving the lock.

A work-rest pattern of ascent similar to that of the chinook was evidenced by sockeye salmon ascending the endless fishways (fig. 21). In the 1-on-8-slope fishway, the average time per pool in the straightaway sections was about 23 seconds as compared to approximately 11 minutes per pool in each of the two turns. Sockeye ascending the fishway with a slope of 1 on 16 spent an average of 54 seconds in each of the straightaway pools and approximately 5 minutes in each turn pool.

The willingness to ascend the two fishway slopes appeared to be about equal when respective performances by chinook and sockeye were considered. Figure 22 gives the percentage of fish ascending 100 pools without stopping for 1 hour in an individual pool. Seven of 13 chinook in the 1-on-8 fishway and 8 of 12 in the 1-on-16 fishway completed the 100-pool ascent without prolonged stops in individual pools. Successful completions of the 100-pool ascent by sockeye were 25 out of 29, and 24 out of 31, respectively, in the 1-on-8 and 1-on-16-slope fishways. With the small number of fish in the samples, differences in the respective percentages completing the 100-pool ascent by species are not statistically significant.

To examine the possibility that ascending the experimental fishways might be fatiguing to fish, and that fatigue might be reflected in lowered per-

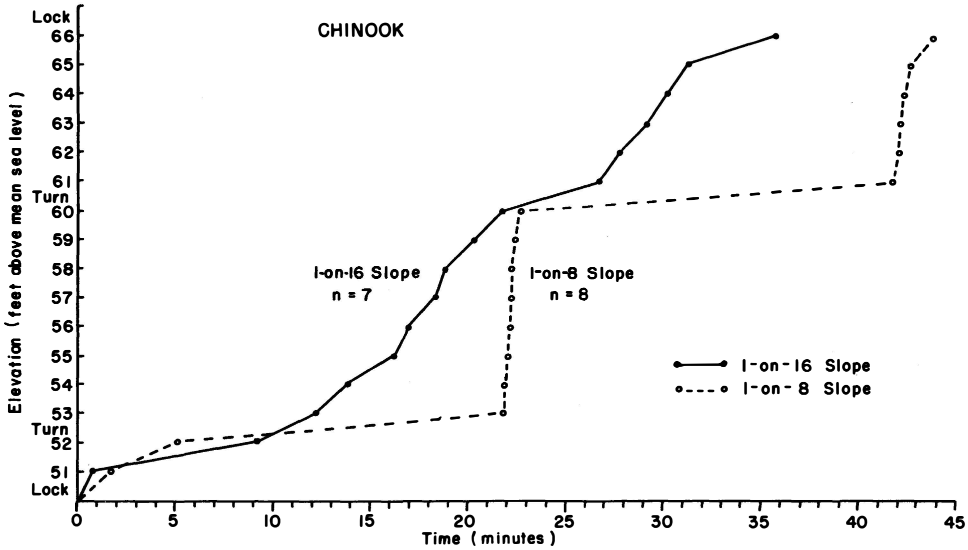

Figure 20.—Ascent pattern of chinook salmon in endless fishways having slopes of 1 on 8 and 1 on 16. Based on mean pool times of fish completing 6 or more circuits. June 9–21, 1958.

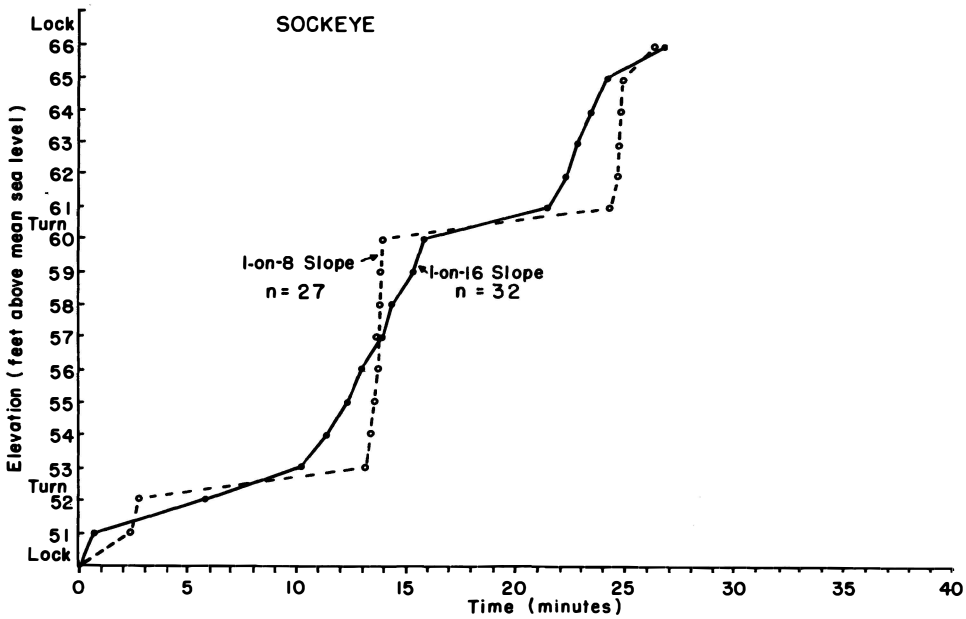

Figure 21.—Ascent pattern of sockeye salmon in endless fishways having slopes of 1 on 8 and 1 on 16. Based on mean pool times of fish completing six or more circuits. June 21 to July 20, 1958.

formance as the total work accomplished increased, the mean times per circuit for the first six circuits were plotted. These are given in figure 19 for chinook and in figure 23 for sockeye. Inspection of these graphs shows no evidence of a declining rate of movement in either fishway following successive ascent of each 16-pool circuit.

In the search for a work level at which fatigue might become apparent in the performance of the fish, a number of fish were permitted to ascend

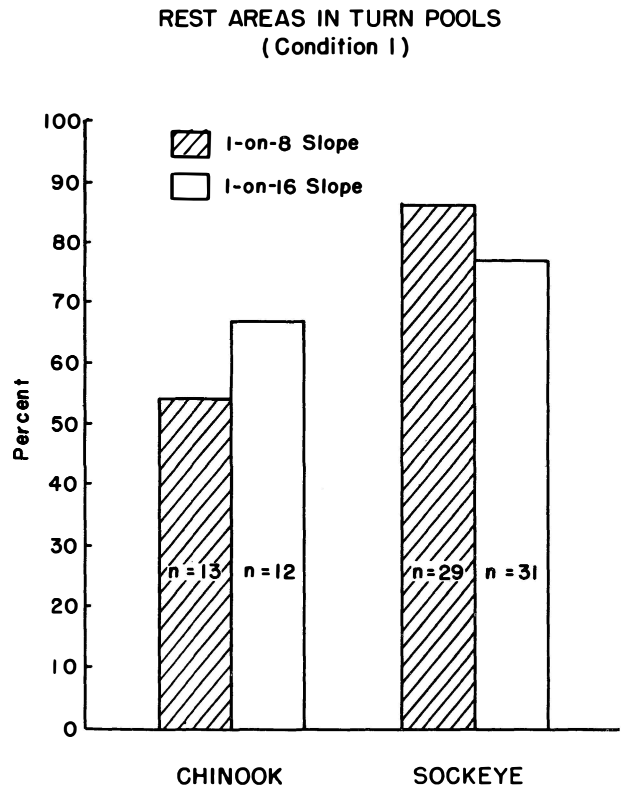

FIGURE 22.—Percentage of chinook and sockeye salmon ascending 100 pools in 1-on-8 slope and 1-on-16 slope endless fishways without stopping for 1 hour. Fishway condition 1 (rest areas in turns).

beyond the 104-pool ascent level in both fishways. Portions of the performance record of the fish that was permitted to ascend the greatest number of pools are shown in figure 24. This sockeye ascended the 1-on-8-slope fishway for 5½ days without stopping, and in that time it passed through 6,648 pools. There was no evidence of fatigue indicated by impaired performance until the fish had ascended more than 5,000 feet. The performance of this fish is discussed in greater detail by Collins, Gauley, and Elling (1962).

Perhaps the most significant finding to come from these extended ascent tests was the fact that salmonids are capable of ascending fishways of considerable height and do so without apparent physical stress.

Turn pools turbulent (condition 2)

While the preceding trials indicated that both chinook and sockeye salmon appeared to make satisfactory ascents in both the 1-on-8-slope fishway and the 1-on-16-slope fishway, the exaggerated work-rest pattern of ascent in the 1-on-8 slope posed a serious question.

Ideally, a pool-type fishway should function so that each pool provides a suitable resting area. This is important as it permits fish to distribute themselves throughout the fishway and does not overtax the physical capacities of even the less vigorous swimmers. If, however, only a small percentage of all pools in a fishway provide resting areas, we may then expect the fish to concentrate in these pools, eventually leading to the possibility of serious overcrowding. Also, if the rest pools are spaced at lengthy intervals, some fish may never complete their ascent because of their inability to pass from one rest area to another.

The foregoing considerations led us to examine the built-in pacing pattern which in effect was the result of the particular design of the endless fishways. The question to be answered was: Will fish ascending the endless fishways be able to pace themselves if the rest areas are eliminated from the turns? To accomplish this end, the turn pools

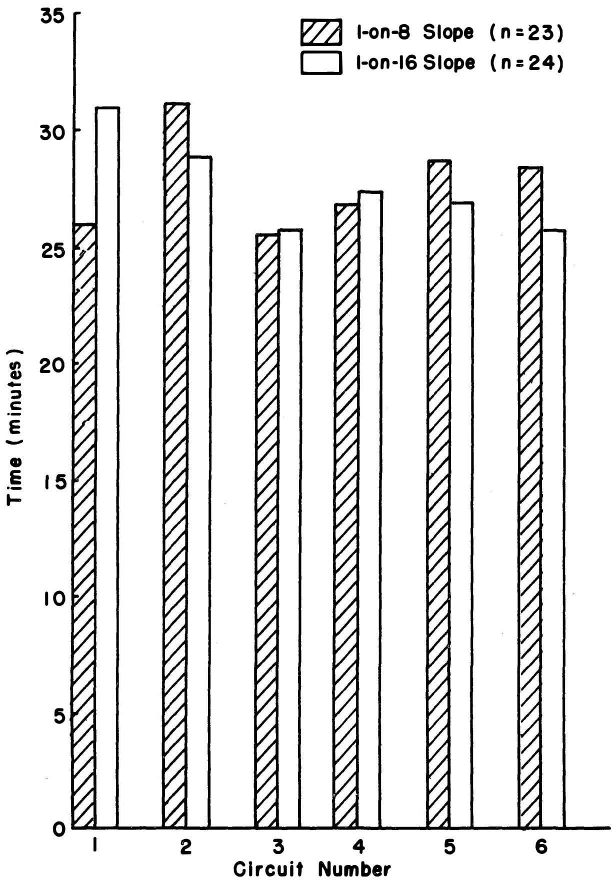

FIGURE 23.—Mean passage time per circuit (16 pools) taken by sockeye salmon negotiating endless fishways having slopes of 1 on 8 and 1 on 16. June 21 to July 20, 1958.

were made so turbulent that they no longer provided satisfactory resting areas.

Passage of fish through the endless fishways having turbulent turn pools began on July 24 and continued until September 7. During this period, river temperatures ranged from 68° to 74° Fahrenheit. Chinook salmon and steelhead trout were the principal species tested in this period. A few sockeye and silver salmon (*O. kisutch*) were also passed during this time.

Table 3 presents the passage times of chinook and steelhead ascending the endless fishways with turbulent turn pools (condition 2). Both chinook and steelhead made significantly slower ascents in the 1-on-8-slope fishway than did their counterparts in the 1-on-16-slope unit (table A–1).

Most apparent in the foregoing tests was the obvious difficulty chinook salmon displayed in their ascent of the 1-on-8-slope fishway. Only 43 percent of all chinook entering the 1-on-8-slope fishway completed the 100-pool ascent without stopping in some pool for an hour (fig. 25).

Steelhead trout fared much better than chinook in the 1-on-8 fishway and were able to negotiate the 100-pool ascent without stopping in approximately the same proportion as those ascending the 1-on-16 fishway (fig. 25).

The difficulty encountered by chinook in the 1-on-8-slope could be traced to their inability to pace themselves when the rest areas were eliminated from the turns. Their pattern of ascent

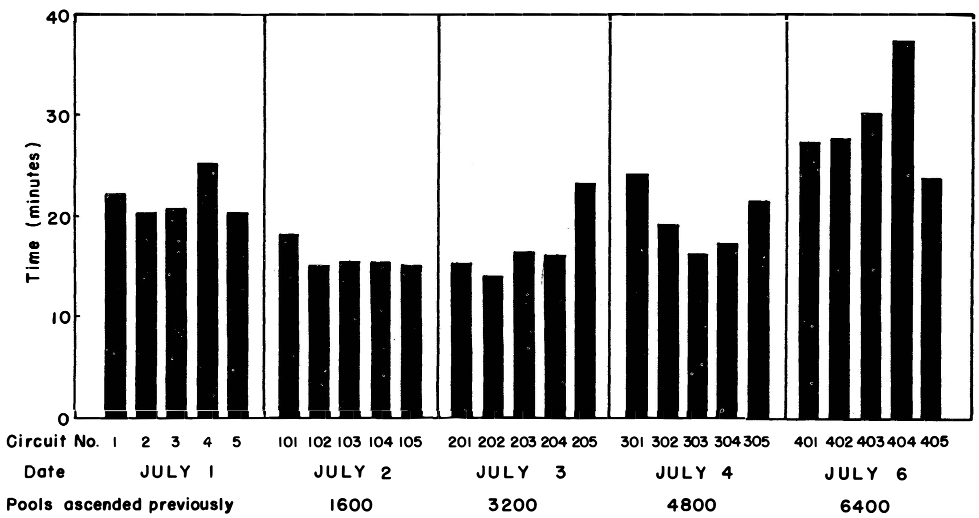

FIGURE 24.—Performance of an individual sockeye salmon in endless fishway with 1-on-8 slope. July 1–6, 1958.

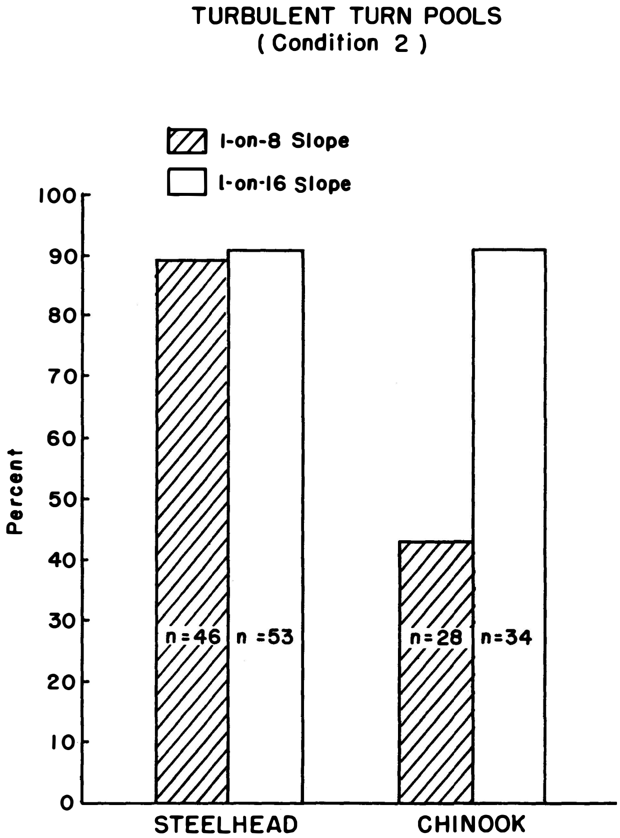

FIGURE 25.—Percentage of chinook salmon and steelhead trout ascending 100 pools in 1-on-8-slope and 1-on-16-slope endless fishways without stopping for 1 hour. Fishway condition 2 (turbulent turns).

was again similar to that evidenced in the earlier trials (fig. 19) with the exception that the rest was usually taken in a straightaway pool after a very rapid ascent through a number of preceding pools. However, in several instances chinook salmon were observed to prolong a swift ascent for approximately 16 to 20 pools. At this point they appeared to be in a state of exhaustion and on occasion were actually swept back down the fishway, seemingly lacking the strength to maintain equilibrium within a pool. Subsequent examination of the biochemical state of these fish confirmed the observation that they were experiencing physical stress.

In contrast to chinook, steelhead did not experience the same difficulty in pacing their movements through the 1-on-8 fishway. A comparison of mean ascent times by individual pools in the two fishways is given in figure 26. While steelhead required more time to ascend the 1-on-8 slope, the work-rest pattern was not greatly divergent from that evidenced in the 1-on-16 slope.

Restricted Weirs (1-on-8 Slope) vs. Condition 2 (1-on-16 Slope)

Because of the apparent inability of a large percentage of the chinook to pace themselves successfully in the 1-on-8-slope fishway when resting areas had been removed from the turn pools, an attempt was made to pace the fish by altering the hydraulics in all pools of the fishway. This was done by restricting the water flows over the weirs by means of baffles. The reduction in the total volume of water entering each pool resulted in considerably reduced turbulence and also created a definite lateral component in the pool flow pattern. The three methods used to

TABLE 3.—*Time in minutes to ascend 104 pools in endless fishways having slopes of 1 on 8 and 1 on 16 with turbulent turn pools (condition 2)*

[Chinook salmon—July 24 to September 7; steelhead trout—July 24 to September 2, 1958]

Fish number	Chinook		Steelhead	
	1-on-8 slope	1-on-16 slope	1-on-8 slope	1-on-16 slope
1	275	197	182	169
2	227	261	213	139
3	178	107	243	212
4	208	111	306	161
5	220	122	250	245
6	303	285	178	193
7	300	307	247	247
8	232	157	236	286
9	190	159	154	133
10	374	129	251	100
11	244	249	221	97
12	314	115	174	171
13	-----	169	271	109
14	-----	121	170	131
15	-----	111	182	145
16	-----	183	165	166
17	-----	198	244	206
18	-----	165	252	116
19	-----	241	148	116
20	-----	166	144	105
21	-----	202	202	118
22	-----	171	181	136
23	-----	205	378	166
24	-----	200	139	149
25	-----	153	205	145
26	-----	264	196	180
27	-----	187	331	123
28	-----	207	187	139
29	-----	-----	236	111
30	-----	-----	363	106
31	-----	-----	163	127
32	-----	-----	293	135
33	-----	-----	140	258
34	-----	-----	280	105
35	-----	-----	219	177
36	-----	-----	266	190
37	-----	-----	208	174
38	-----	-----	-----	119
39	-----	-----	-----	143
40	-----	-----	-----	131
41	-----	-----	-----	149
42	-----	-----	-----	175
43	-----	-----	-----	123
44	-----	-----	-----	146
45	-----	-----	-----	131
46	-----	-----	-----	212
Mean	255	184	222	155

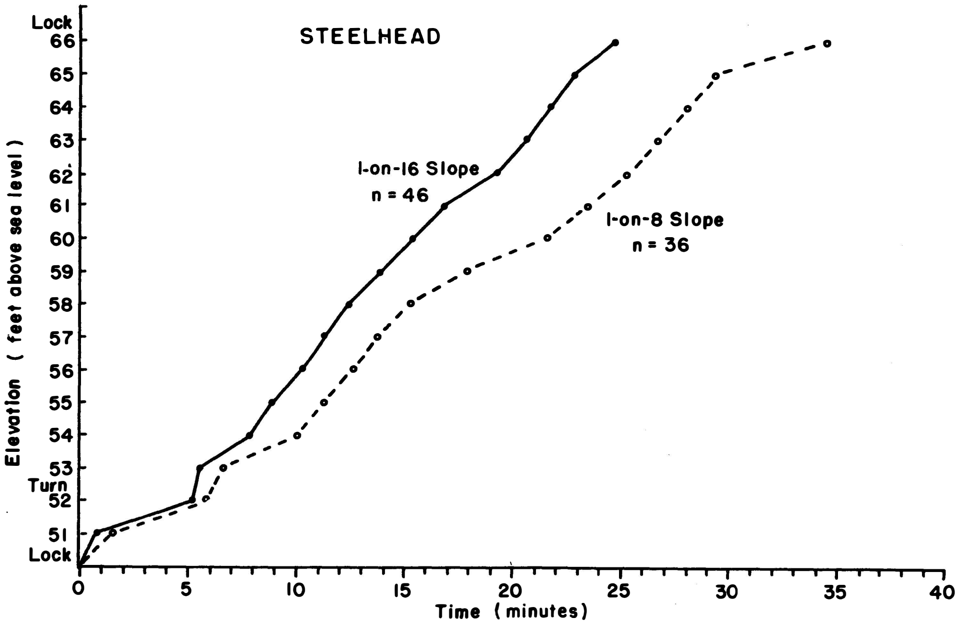

FIGURE 26.—Ascent pattern of steelhead trout in endless fishways having slopes of 1 on 8 and 1 on 16. Based on mean pool times of fish completing 6 or more circuits. Condition 2 (turbulent turn pools).

restrict flows are shown in figure 14. These baffle arrangements were applied only to the 1-on-8 fishway. Condition 2 (table 1) continued to prevail in the 1-on-16 fishway during these tests.

On September 10 and 11, several exploratory trials utilizing condition 2A (center-notched weir fig. 14) revealed an improved work-rest pattern in the 1-on-8 fishway. The rate of ascent and willingness to ascend, however, did not compare favorably with that shown in the 1-on-16 fishway. Rather than continue further experiments with this design, we made a series of tests during the remainder of September employing the other baffle arrangements, in-line baffles B and alternating baffles C (fig. 14).

A comparison of chinook salmon passage times in the two fishways for the period September 12–29 is given in table 3. While the mean ascent time of chinook in the 1-on-8-slope fishway with in-line baffles (condition 2B) was significantly slower (table A–1) than that in the 1-on-16-slope fishway, the final trials employing alternating baffles (condition 2C) in the 1-on-8-slope fishway show no difference in the time of ascent in the two fishways.

The patterns of movement resulting in the foregoing tests are shown in figures 27 and 28. Notably, chinook salmon paced their movements in the 1-on-8-slope fishway as well as they did in

TABLE 4.—*Chinook salmon passage time in minutes to ascend 104 pools in endless fishways with slopes of 1 on 8 and 1 on 16*

[Weir baffles in-line (condition 2B) and alternating (condition 2C) in the 1-on-8 fishway. Turbulent turn pools (condition 2) in the 1-on-16 fishway.]

Fish number	September 12–23		September 24–29	
	1-on-8 slope condition 2B	1-on-16 slope condition 2	1-on-8 slope condition 2C	1-on-16 slope condition 2
1	382	193	183	182
2	339	190	108	258
3	233	223	112	91
4	134	134	133	153
5	211	210	138	178
6	178	132	165	182
7	272	147	165	123
8	314	182	175	140
9	157	146	178	135
10	317	138		
11	209	236		
12	125	206		
13	251	111		
14	188	106		
15	159	264		
16	179	166		
17	139	201		
18	153	103		
19	191	172		
20	113	127		
21	243	188		
22	173	131		
23	167	169		
24	224	153		
25	179	136		
26	203	184		
27		122		
28		177		
29		136		
30		128		
31		176		
Mean	209	164	151	160

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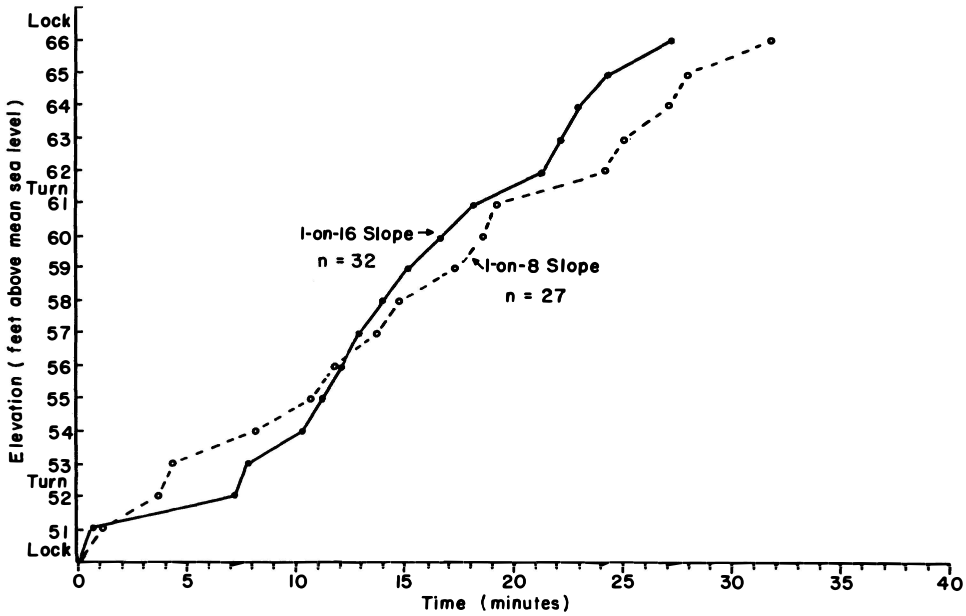

FIGURE 27.—Ascent pattern of chinook salmon in endless fishways having slopes of 1 on 8 (condition 2B, in-line baffles) and 1 on 16 (condition 2). Pool times derived from mean of 6 trips. September 12–23, 1958.

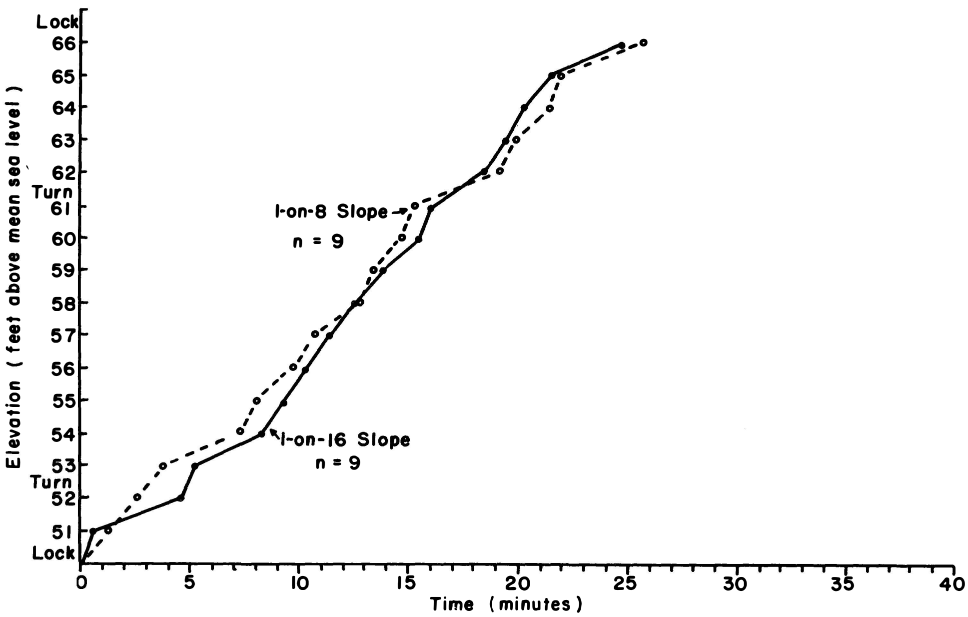

FIGURE 28.— Ascent pattern of chinook salmon in endless fishways having slopes of 1 on 8 (condition 2C, alternate baffles) and 1 on 16 (condition 2). Pool times derived from mean of 6 trips. September 24 to 29, 1958.

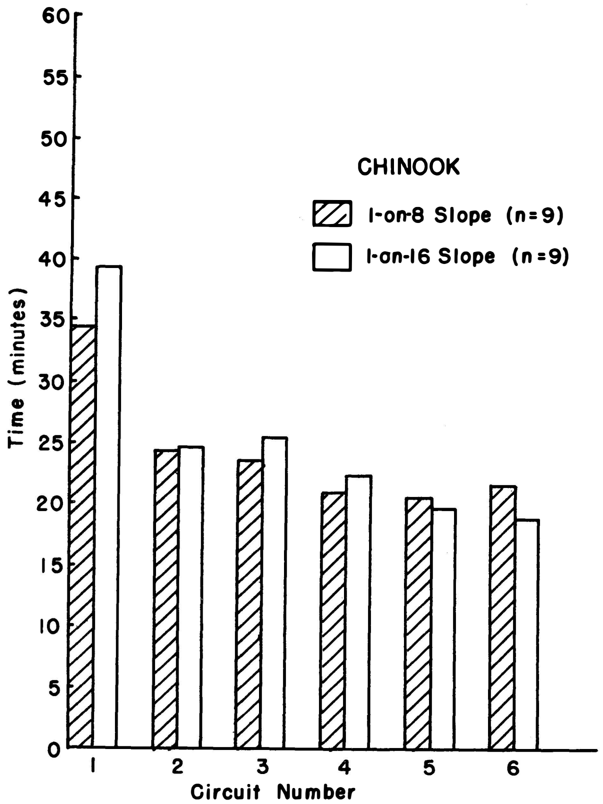

FIGURE 29.—Mean passage time per circuit taken by chinook salmon negotiating endless fishways having slopes of 1 on 8 (condition 2C, alternate baffles) and 1 on 16 (condition 2). September 24–29, 1958.

the 1-on-16-slope fishway. Evidence of the exaggerated work-rest pattern was completely lacking in both fishways.

Another encouraging aspect of the performance in the 1-on-8 fishway was that all chinook tested when conditions 2B and 2C prevailed completed the 100-pool ascent without stopping in an individual pool for 1 hour. In the same period, 93 percent of all chinook entering the 1-on-16 fishway passed the 100-pool ascent level without stopping.

Comparisons of the mean passage time per circuit for first 6 circuits show no evidence that chinook salmon were tiring after successive trips in either fishway (fig. 29). By inspection the first circuit appears to have required the longest time, and thereafter the time per circuit was about the same.

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In further search for evidence that one fishway might be more fatiguing than another, lactate and inorganic phosphate levels were measured in the blood and muscle of the experimental fish. The basis for study of these chemical compounds is well documented in biochemical literature. Black (1958a) has prepared an excellent summary on the subject of chemical correlates associated with muscular activity and recovery from fatigue in fishes. The four correlates selected for study in this experiment have all been shown to increase in level following muscular activity. The degree of muscular activity, i.e., minimal, moderate, and maximal, has been somewhat more difficult to assess because of the lack of recognizable standards. In this study, we reasoned that if the ascent of one fishway were to require more effort than that in another, the difference would be reflected in the chemistry of the fish. In addition, a comparison between the chemistry of exercised and unexercised fish (controls) was expected to provide some insight on the degree of muscular activity that may be necessary in the ascent of fishways.

In this study, the unexercised controls may be considered to represent a minimal state of activity. It should be pointed out, however, that these fish were by no means quiescent since they were free to swim about in the collection pool prior to their removal. To prepare a control fish for chemical extractions, it was necessary to net and then lift the fish approximately 14 feet to floor level in the laboratory. While this was accomplished as rapidly and efficiently as possible, some struggling did occur before the fish could be immobilized. The combination of these circumstances conceivably may have produced somewhat higher chemical values than would normally be expected in unexercised fish.

The majority of fish removed from the fishway while actively ascending (terminated treatments) were expected to be representative of an intermediate stage of muscular activity in the broad range between minimal and maximal activity. Again, the circumstances of fish removal from the fishway may have had some effect on the chemical values. Since most of the terminated treatments were taken from the shallow, upper turn pool, netting and immobilization of these fish were accomplished quite rapidly and generally with a minimum of struggling.

Fish stopping for 1 hour in an individual pool (volitional treatments) were of particular interest in this study inasmuch as the chemistry of these fish would be expected to yield certain information on the degree to which fish might recover from their exertions in the ascent of a fishway. Removal of these fish was not always accomplished as easily as was the case with the terminated treatments. If a fish stopped at a point other than in the turns or the lock, it was necessary to net the fish from a pool which was 6 feet deep. This was readily accomplished if the fish surfaced when the fishway water supply was shut off, but if the fish remained in the depths of the pool, it was occasionally necessary to chase the fish some time before capture.

Capture and removal of the volitional-terminated treatments were achieved with little or no struggling as these fish were incapable of vigorous evasive action, probably due to exhaustion resulting from a rapid and improperly paced ascent. As will be pointed out later in the text, the chemistry of these fish suggests they may have been subjected to a period of maximal activity.

The following analysis of the biochemical determinations is made in accordance with the prevailing fishway conditions as was done under the section on performance. As may be seen in the subsequent tables, lactate of whole blood appears to have been the most sensitive of the four chemical measurements obtained.

Turn pools with rest areas (condition 1)

Summaries of the biochemical measurements on chinook and sockeye salmon ascending the 1-on-8 and 1-on-16-slope fishways when condition 1 prevailed appear in tables 5 and 6. Inspection of tables 5 and 6 indicates that levels of blood lactate in exercised fish terminated while still actively moving and regardless of the height ascended were approximately equal in both fishways. Blood lactates of terminated treatments were significantly higher than the unexercised controls (table 7). With the exception of a few fish having special case histories, none of the blood lactates from exercised fish exceeded 100 mg. percent. Levels of whole blood lactate in terminated treatments of exercised sockeye were significantly higher than similarly treated chinook salmon (1-on-8 slope, $t=3.757$, d.f. 26, $P<.01$; 1-on-16 slope, $t=2.516$, d.f. 25, $.02>P>.01$).

The blood lactate level of fish that stopped for an hour on their own volition (at a variety of ascent levels) did not differ significantly from that of the unexercised control fish (table 7). This suggests that the fish were able to rest in either fishway slope, and that they had recovered from exercise within an hour.

Levels of muscle lactate and inorganic phosphate of the blood plasma and muscle tissue indicate the possibility that similar patterns may exist for these measurements. However, the sample sizes are so small and the variation between individuals so great that only gross differences are detectable with any degree of confidence.

TABLE 5.—*Biochemistry of chinook salmon ascending 1-on-8- and 1-on-16-slope endless fishways with 36-inch weirs and turn pools providing rest areas (condition 1)*

[Mean values in mg. percent, June 9–21, 1958 [1]]

Substance	1-on-8 slope				1-on-16 slope				Controls	
	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Unexercised
Lactate of whole blood	7	39.1	6	29.3	8	38.4	4	23.1	11	24.3
Lactate of muscle tissue	7	318	6	293	8	334	4	347	11	306
Inorganic PO_4 of blood plasma	7	11.6	6	10.3	8	10.7	4	11.4	11	12.2
Inorganic PO_4 of muscle tissue	7	183	6	163	8	179	4	173	11	172

[1] Mean daily water temperature during test period: 63° F. (17.2° C.).

TABLE 6.—*Biochemistry of sockeye salmon ascending 1-on-8- and 1-on-16-slope endless fishways with 36-inch weirs and turn pools providing rest areas (condition 1)*

[Mean values in mg percent, June 21–July 20, 1958 [1]]

Substance	1-on-8 slope				1-on-16 slope				Controls	
	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Unexercised
Lactate of whole blood	21	63.5	9	25.0	19	57.9	11	28.5	19	21.8
Lactate of muscle tissue	20	370	10	261	18	387	12	332	18	298
Inorganic PO_4 of blood plasma	21	14.0	10	10.4	17	13.3	11	12.9	18	11.8
Inorganic PO_4 of muscle tissue	21	151	10	152	19	139	12	147	18	137

[1] Mean daily water temperature during test period: 67° F. (19.4° C.).

TABLE 7.—*Tests of significance between mean blood lactate levels (mg. percent) in exercised and unexercised chinook and sockeye salmon in endless fishways with slopes of 1-on-8 and 1-on-16 (condition 1)*

Fishway slope	Species	Exercised				Unexercised		Degrees of freedom	Value of t
		Number of fish	Terminated	Number of fish	Volitional	Number of fish	Control		
1-on-8	Chinook	7	39.1			11	24.3	16	2.60*
	Chinook			6	29.3	11	24.3	15	.94 N.S.
	Sockeye	21	63.5			19	21.8	38	10.43**
	Sockeye			9	25.0	19	21.8	26	.36 N.S.
1-on-16	Chinook	8	38.4			11	24.3	17	2.33*
	Chinook			4	23.1	11	24.3	13	.18 N.S.
	Sockeye	19	57.9			19	21.8	30	7.06**
	Sockeye			11	28.5	19	21.8	28	1.33 N.S.

*Significant at 0.05 level.
**Significant at 0.01 level.
N.S. Not significant.

Turn Pools Turbulent (Condition 2)

Chinook salmon and steelhead trout were the principal species tested during the period of July 24 to September 7 when the turbulent turn pools (condition 2) were employed in the endless fishways.

Note is made of the abnormally high river temperatures prevailing during this time. At Bonneville, records [3] show these ranged from 68°–74° Fahrenheit (20°–23.3° C.). The mean August temperature (71.7° F.) was the highest on record since construction of the dam. During the 20-year period 1938 to 1957, mean August water temperatures ranged from 63° to 69.7° F., with a 20-year mean of 67.5° F.

Summary data covering the biochemistry of chinook and steelhead ascending the endless fishways when condition 2 prevailed are presented, respectively, in tables 8 and 9. A few sockeye were also tested in the fishways during the above period, but the limited data from these tests were not considered in this analysis.

Examination of tables 8 and 9 reveals several points of interest with respect to the levels of lactate of whole blood. Mean blood lactate levels of both chinook and steelhead, terminated while actively ascending the fishways, appear to be somewhat higher in the 1-on-8 slope than in the 1-on-16 slope. These differences, however, were not significant: chinook—t=1.735, d.f. 41, $.09<P<.10$; steelhead—t=1.213, d.f. 56, $.2<P<.3$. Blood lactates of the terminated fish were significantly higher than those of the control fish (table 10) as they were in the earlier trials under condition 1. Again, a similar but not always consistent trend was evidenced by the lactate of muscle and inorganic phosphate of blood plasma and muscle tissue.

By inspection, mean blood lactates of volitional treatments (fish that had exercised and stopped for 1 hour in a fishway pool) of both chinook and steelhead are considerably higher than those of the control treatments; however, because of the small sample sizes involved and the unequal variance between samples, the differences in lactate level generally were not significant (table 10). In the case of chinook salmon ascending the 1-on-8-slope fishway, the blood lactate of volitional treatments was significantly higher than that of the controls. This represents a clear departure from the trend evidenced in the earlier trials under condition 1 when volitional treatments yielded blood lactate levels quite comparable to those of the controls. It may also be noted that the blood lactate levels for exercised chinook salmon (terminated and volitional) in both fishways were higher under condition 2 than in condition 1 (tables 5 and 8), but the differences were statistically significant only for volitional treatments in the 1-on-8-slope fishway.

Whether or not the comparatively high blood lactate levels under condition 2 are linked in some way with the prevailing high water temperatures during this period is a matter of speculation. Examination of the work pattern of the volitional fish in both fishways shows the pattern was generally that of rapid ascent followed by the 1-hour stop. Presumably the fish had not fully recovered from the vigorous exercise which preceded the volitional stop. Additional studies will be necessary to determine the relationship between water temperature and blood lactate levels in exercising fish.

[3] Daily operation reports, U.S. Army Corps of Engineers, Bonneville Dam.

TABLE 8.—*Biochemistry of chinook salmon ascending 1-on-8 and 1-on-16-slope endless fishways with 36-inch weirs and turbulent turn pools (condition 2)*

[Mean values in mg. percent, July 24–September 7, 1958 [1]]

Substance	1-on-8 slope				1-on-16 slope				Controls	
	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Unexercised
Lactate of whole blood	12	51.6	12	89.1	31	42.0	3	81.5	13	26.0
Lactate of muscle tissue	12	329	12	324	31	315	3	376	13	295
Inorganic PO_4 of blood plasma	6	9.0	9	12.8	19	8.8	3	14.2	8	9.9
Inorganic PO_4 of muscle tissue	11	163	12	170	31	164	3	164	13	159

[1] Mean daily water temperature during test period: 71° F. (21.7° C.).

TABLE 9.—*Biochemistry of steelhead trout ascending 1-on-8 and 1-on-16-slope endless fishways with 36-inch weirs and turbulent turn pools (condition 2)*

[Mean values in mg. percent, July 24–September 2, 1958 [1]]

Substance	1-on-8 slope				1-on-16 slope				Controls	
	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Unexercised
Lactate of whole blood	42	42.4	5	57.1	47	34.5	5	46.5	29	21.6
Lactate of muscle tissue	45	350	5	401	49	371	6	391	30	326
Inorganic PO_4 of blood plasma	42	10.4	5	11.0	44	10.2	5	11.9	29	9.1
Inorganic PO_4 of muscle tissue	45	167	5	162	47	165	6	171	30	164

[1] Mean daily water temperature during test period: 72° F. (22.2° C.).

TABLE 10.—*Tests of significance between mean levels of blood lactate (mg. percent) in exercised and unexercised chinook and steelhead ascending 1-on-8 and 1-on-16-slopes endless fishway (condition 2)*

Fishway slope	Species	Exercised				Unexercised		Degrees of freedom	Value of t
		Number of fish	Terminated	Number of fish	Volitional	Number of fish	Control		
1-on-8	Chinook	12	51.6			13	26.0	18	3.96**
	Chinook			12	89.1	13	26.0	13	5.34**
	Steelhead	42	42.4			29	21.6	55	5.36**
	Steelhead			5	57.1	29	21.6	4	1.30 N.S.
1-on-16	Chinook	31	42.0			13	26.0	42	3.48**
	Chinook			3	81.5	13	26.0	2	2.33 N.S.
	Steelhead	47	34.5			29	21.6	75	4.821**
	Steelhead			5	46.5	29	21.6	4	1.52 N.S.

**Significant at the 0.01 level.
N.S. Not significant.

Attention is called to the biochemistry of a special group of chinook salmon that displayed visible evidence of physical stress during their ascent of the 1-on-8-slope fishway. For lack of a more appropriate term, this group was classified "volitional-terminated" and includes only those individuals evidencing an obvious loss of equilibrium, i.e., an inability to maintain position in the fishway following a period of exercise. In all cases, these fish made extremely rapid ascents of a succession of pools (several seconds per pool) at which point they appeared to reach a state of exhaustion and drifted completely down the fishway to the lowermost pool where they became impinged against the spillout screen. Analysis of the biochemistry of these fish appears in table 11. While there are exceptions, notably in the levels of inorganic phosphate of the plasma and muscle tissue, the majority of these measures clearly affirm the observation that the fish were experiencing physical stress. The levels of blood lactate appear to be the most consistent in indicating the state of fatigue. All approached or exceeded 100 mg. percent, which from our experience to date is well above the blood lactate response expected in fish exhibiting a uniform work-rest pattern during ascent of a fishway.

Four of the five fish listed in table 11 were tested during the period of high river temperatures and when condition 2 prevailed in the 1-on-8-slope fishway. The lone entry occurring during the earlier period, when condition 1 applied,

TABLE 11.—*Biochemistry of chinook salmon taken from the 1-on-8-slope endless fishway following evidence of physical stress, 1958*

Fish number	Date	Temperature F.	Temperature C.	Fishway condition	Substance—mg. percent: Lactate of blood	Lactate of muscle	Inorganic PO_4 of plasma	Inorganic PO_4 of muscle
		Degrees	*Degrees*					
1	June 13	62	16.7	1	123.1	347	16.5	163
2	July 25	72	22.2	2	168.2	474	17.4	210
3	July 28	74	23.3	2	120.6	630	22.6	165
4	July 31	73	22.8	2	98.0	245	16.3	153
5	Aug. 18	71	21.7	2	105.4	401	11.9	126
Mean		70	21.3		123.1	419	16.9	161

TABLE 12.—*Biochemistry of chinook salmon ascending 1-on-8 (condition 2B) and 1-on-16-slope (condition 2) endless fishways*

[Mean values in mg. percent, September 12-23, 1958 [1]]

Substance	1-on-8 slope				1-on-16 slope				Controls	
	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Terminated	Number of fish	Volitional	Number of fish	Unexercised
Lactate of whole blood	[2] 20	35.5	0		24	36.5	2	33.0	12	19.7
Lactate of muscle tissue	20	281	0		24	303	2	403	12	315
Inorganic PO_4 of blood plasma	20	10.1	0		17	9.4	2	9.4	12	10.0
Inorganic PO_4 of muscle tissue	18	156	0		24	153	2	161	12	152

[1] Mean daily water temperature during test period: 66° F. (18.9° C.).
[2] Includes 1 fish ascending less than 104 pools.

was a 40-pound 6-ounce male, the largest fish encountered in all of the tests.

Restricted Weirs (1-on-8 Slope) vs. Condition 2 (1-on-16 Slope)

Following structural adjustments designed to reduce turbulence in the 1-on-8-slope fishway, a series of biochemical measurements was obtained from chinook salmon tested during the period of September 12 to 23, inclusive. These were compared with similar measurements from fish ascending the 1-on-16-slope fishway which remained unchanged structurally from the previous period (condition 2, July 24 to September 7). Results of these analyses appear in table 12. With a single exception, all terminated treatments include fish that had completed an ascent of 104 pools. Examination of the blood lactate levels of fish terminated immediately after exercise shows there was no difference in the lactate response of fish ascending either the 1-on-8- or 1-on-16-slope fishways. Blood lactate levels of terminated treatments in the 1-on-16-slope fishway ranged from 16.8 to 62.5 mg. percent while those in the 1-on-8-slope fishway ranged from 20.1 to 48.3 mg. percent. Thus, the installation of weir baffles in the 1-on-8-slope fishway appears to have created hydraulic conditions which were no more fatiguing than those in the 1-on-16-slope fishway.

The blood lactate of terminated treatments in both fishways was significantly higher than that of the controls. A slightly less than twofold increase was indicated.

Levels of muscle lactate and inorganic phosphate of the blood plasma appear to be less sensitive than the whole blood lactate measurements, but in general they indicate comparable work levels for fish ascending either fishway.

Recovery following exercise in fishways

A number of investigators have demonstrated delayed effects due to strenuous exercise that have resulted in mortalities of test fish (von Buddenbrock, 1938; Secondat and Diaz, 1942; Bates and Vinsonhaler, 1957; Black, 1957; Parker and Black, 1959; Parker, Black, and Larkin, 1959). Black (1958b) in summarizing available evidence states that death in fish occurs ½ to 3 hours following severe muscular activity and is the result of a combination of adverse factors as yet not completely described. Parker and Black (1959) found that mortalities among troll-caught chinook salmon in salt water occurred from 1 to 7½ hours following capture and that death was significantly correlated with high blood levels of lactic acid.

To explore the possibility of serious latent or delayed effects due to exercise in the fishways, a number of exercised fish were held overnight in a relatively quiet fishway pool (upper turn pool, elevation 61′). The procedure followed during the holding period was as follows: at the moment the fish entered the 105th pool, screen barriers were placed on the upstream and downstream weirs of the pool. Flows in the fishway were then reduced to approximately .25 c.f.s. and the pool was completely covered with plywood sheets. On the following morning, generally between 12 and 16 hours after the fish had entered the pool, the plywood covers were removed and the fish were carefully netted and immobilized in preparation for the usual biochemical extractions.

Eight chinook salmon in each fishway were held overnight in the foregoing manner, and in each instance no mortality was observed. Analysis of the biochemistry of these fish appears in table 13. In general, it may be seen that the condition of these fish approximated that of the controls for the same period, and on the basis of these limited observations, at least, we consider it very unlikely that delayed mortality would result from the physical exertion needed to ascend a properly designed fishway. This appears to be in keeping with investigations by Parker, et al. (1959), who in working with nonfeeding silver salmon in fresh water, found no mortalities and lower lactate levels than occurred under similar circumstances in sea water.

TABLE 13.—*Biochemistry of chinook salmon held overnight (12–16 hours) after ascending 104 pools in endless fishways with slopes of 1-on-8 and 1-on-16, September 15–23, 1958*

[Mean values in mg. percent]

Substance	1-on-8 slope		1-on-16 slope		Controls	
	Number of fish [1]	Held after exercise	Number of fish [1]	Held after exercise	Number of fish [1]	Unexercised
Lactate of whole blood	7	24.5	8	18.7	9	19.4
Lactate of muscle tissue	7	254	8	277	9	308
Inorganic PO_4 of blood plasma	6	8.4	7	9.4	9	10.1
Inorganic PO_4 of muscle tissue	7	172	8	158	9	154

[1] Eight fish were held overnight in each fishway but certain measurements were not obtained from all fish.

Other factors affecting performance and biochemical state

In the preceding discussions, all comparisons of performance in the two fishways (1-on-16 and 1-on-8 slopes) have been based on the assumption that the individual capacity to perform was randomly distributed among all fish. We have previously noted that individual fish were entered into each fishway with no distinction as to size, sex, or visible physical condition. Only those fish having obvious severe physical injuries were rejected.

Aside from the slope and prevailing hydraulics of the respective fishways, other factors which may have influenced performance and biochemical state are the size, sex, maturity, racial origin, and physical condition (injured or diseased) of the fish. Water temperature and turbidity possibly may also be related to performance and biochemical state, but as a common water source served both fishways, these variables need not be considered in evaluating respective ascents in the two fishways.

In the recent tests, data are available to permit limited analysis of the effects of size, sex, and maturity of the fish on performance and biochemical state. The effect of disease on performance is also considered briefly. Available data were not considered adequate for study of the relationship between performance and biochemical state and racial origin of the fish.

Size and sex.—Table 14 lists sex composition and length frequency distributions of the various species tested during respective trials in each slope. These data show that sex ratios of fish tested in each of the specific conditions in the 1-on-8 and 1-on-16-slope fishways were not always equal, but differences in the average size of fish passed in the two fishways generally were negligible.

An examination of the effect of size and sex on the performance of fish was made by utilizing appropriate data from tests in the 1-on-16-slope fishway for the period July 24 to September 29 when condition 2 prevailed. Steelhead trout and chinook salmon were the principal species present during this period. As several physical changes were made in the 1-on-8-slope fishway during this same period, data from these trials were not considered in this analysis.

In relating size and sex of fish to their performance, the fork length in centimeters was used to denote size, and performance was expressed in terms of the time (minutes) required to ascend 104 pools. Respective relationships for male and female chinook salmon and steelhead trout are shown in figure 30. With the exception of male steelhead trout, all regression lines exhibit a positive correlation, i.e., the larger the fish the longer

TABLE 14.—*Length and sex of salmonids tested in endless fishways, 1958*

Species and slope	Condition	Test periods	Number		Fork length—inches				
			Males	Females	Males		Females		Mean, all fish
					Range	Mean	Range	Mean	
Chinook:									
1 on 8	1	June 9 to July 20	7	7	28.0–42.5	31.7	25.6–34.6	31.2	31.4
1 on 16	1		3	9	24.4–26.6	25.5	32.3–40.0	35.6	33.0
1 on 8	2	July 24 to Sept. 7	16	13	19.1–37.0	28.2	25.2–39.6	34.0	30.8
1 on 16	2		23	11	18.3–39.2	29.2	27.8–37.6	32.6	30.4
1 on 8	2A	Sept. 10 and 11	2	3	29.5–30.7	30.1	32.1–37.2	35.0	33.0
1 on 16	2		2	2	30.1–34.3	32.2	33.1–35.6	34.3	33.3
1 on 8	2B	Sept. 12 to 23	9	18	30.3–34.3	32.4	28.1–36.6	31.7	31.9
1 on 16	2		17	17	26.6–41.7	32.2	29.7–38.2	32.7	32.4
1 on 8	[1] 2C	Sept. 24 to 30	6	2	26.0–32.0	28.7	30.0–32.0	31.0	29.3
1 on 16	[1] 2		2	7	24.0–30.0	27.0	28.0–40.0	32.5	31.3
Sockeye:									
1 on 8	1	June 21 to July 20	14	18	16.7–21.7	20.0	15.7–21.5	20.2	20.1
1 on 16	1		18	13	15.4–21.5	18.3	16.7–21.9	20.4	19.1
1 on 8	2	July 23 to Aug. 7	1	3	16.1	16.1	18.7–21.9	20.2	19.1
1 on 16	2		1	1	21.7	21.7	19.9	19.9	20.8
Steelhead:									
1 on 8	2	July 24 to Sept. 2	19	32	21.1–35.4	25.0	20.5–32.9	25.1	25.1
1 on 16	2		13	41	22.4–30.9	24.5	21.1–33.3	25.7	25.4

[1] Lengths estimated. Sex based on external features (not dissected).

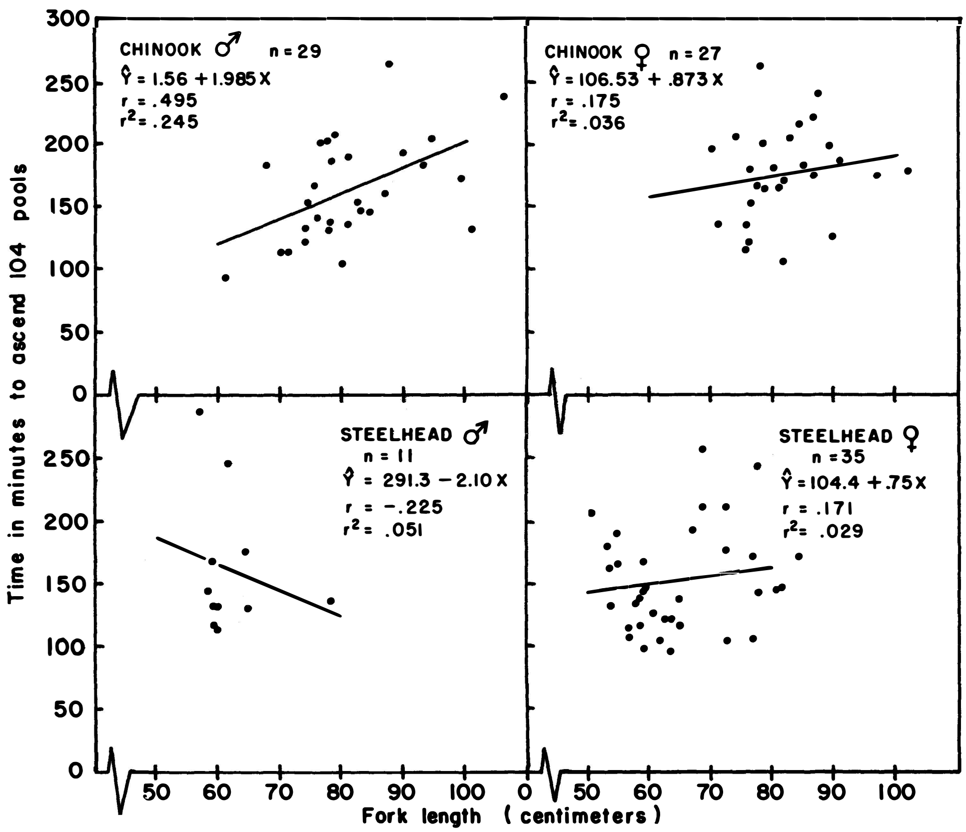

FIGURE 30.—Relationship between performance and fork length of male and female chinook salmon and steelhead trout ascending 104 pools in a 1-on-16-slope endless fishway. Chinook, September 2 to 29; steelhead, July 26 to August 30.

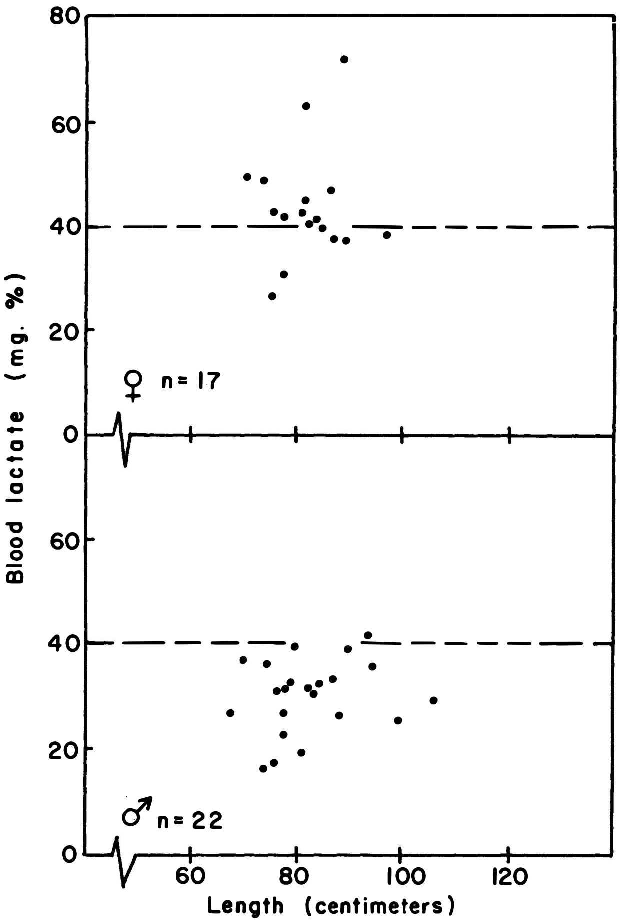

FIGURE 31.—Levels of blood lactate (mg. percent) in exercised chinook salmon according to length and sex.

the ascent time. Only in the case of male chinook salmon, however, was the regression found to be significant. Therefore, on the basis of these data, size of fish influenced performance only in the case of male chinook salmon.

Testing for the difference in the regression lines between sexes for chinook salmon and steelhead, respectively, no significant differences were found. This suggests performance within species occurred independently of sex.

When respective blood lactate levels were plotted against size of the fish tested in the endless fishways, no relation was found. In chinook salmon, however, the lactate level in females was significantly higher than that in the males (fig. 31). Further opportunity for study of this relation (as yet unexplained) will be afforded when results of a subsequent series of tests conducted in 1959 are analyzed. Lactate levels of male and female chinook salmon ascending the two fishways (1-on-8 and 1-on-16) were re-examined separately. However, no differences between fishways were found.

Sexual maturity.—Comparisons of sexual maturity and performance consider only chinook salmon for the period September 2–23. The state of sexual maturity as used herein was the gonad weight expressed as a percentage of body weight. Performance was again measured in terms of the time required to ascend 104 pools. Steelhead were not utilized in this analysis, because gonad development in virtually every specimen was uniformly immature, generally representing less than 1 percent of the body weight. This may be explained by the fact that spawning in this species usually does not take place until late winter or early spring of the following year. On the other hand, chinook salmon passing Bonneville Dam in September are present in varying stages of sexual maturity. Some may commence spawning within several weeks after passing Bonneville while others bound for the more distant upriver tributaries may not begin spawning for several months.

The relationship between gonad development and the respective performances of male and female chinook salmon is plotted in figure 32. From the figure it is obvious that there was very little agreement between the two variables. The r^2 values indicate that only 1.5 percent of the variation in performance of males and 0.2 percent in the females was associated with variability in gonad development (sexual maturity). The difference between the regressions of males and females was found to be nonsignificant, i.e., there was no difference in performance of males and females with respect to sexual maturity.

Considering the effect of sexual maturity on the biochemical state of the fish tested, blood lactate levels were compared with gonad development and no relationship was found.

Disease.—In the Columbia River a number of highly virulent strains of *Chondrococcus columnaris*, the etiological agent of columnaris disease, have been isolated in adult and young salmon (Rucker, Earp, and Ordal, 1953). These authors further state that strains of this type when tested with young salmon in an experimental hatchery caused mortalities often reaching 100 percent in 12 to 24 hours. Particularly virulent strains appear to be associated with water temperatures in excess

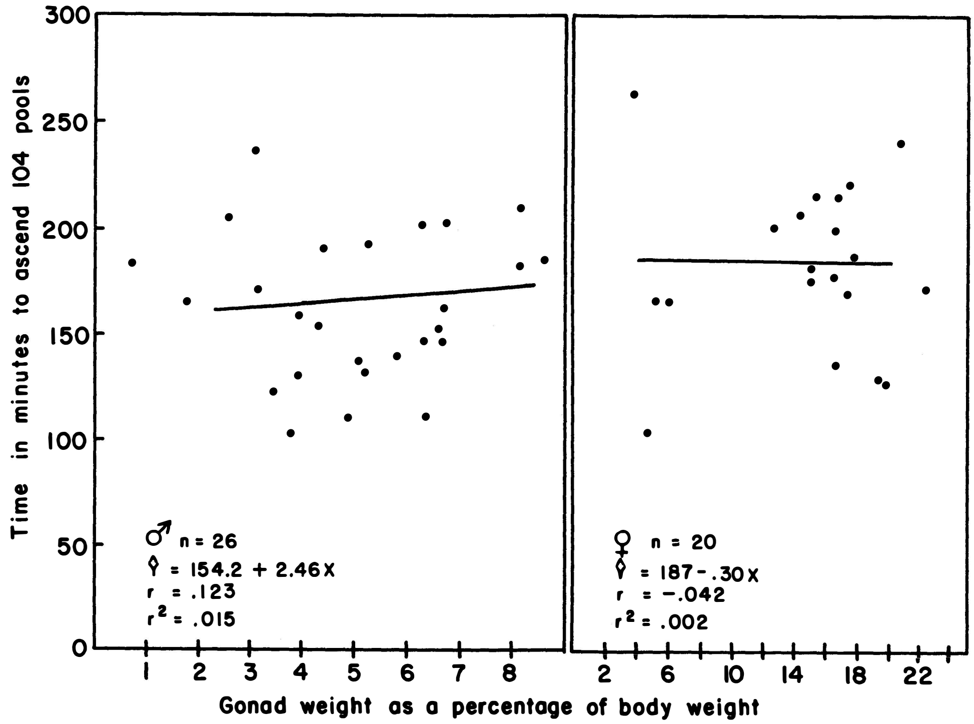

FIGURE 32.—Relationship between performance and sexual maturity. Chinook salmon, September 2–23, 1958.

of 70° F. (Fish and Rucker, 1943; Ordal and Rucker, 1944.)

During our tests from August 6 to September 23, inclusive, 245 salmonids were examined for presence of *C. columnaris*. Minor to severe lesions were found in 30 (12.2 percent) individuals. Water temperatures during this period ranged from 64° to 73° F.

A comparison of the performance of infected and noninfected fish may be made by examining the passage times of fish tested in the 1-on-16-slope fishway, which remained structurally unchanged during the period when examinations for columnaris disease were made. Only steelhead trout and chinook salmon were sufficiently abundant to be considered in this analysis.

A total of 60 chinook, 7 infected and 53 noninfected, ascended 104 pools in the 1-on-16-slope fishway during these examinations. The seven infected fish had minor to severe lesions from which *C. columnaris* was isolated. The mean ascent time for 104 pools among the infected fish was 190 minutes and that of the noninfected group was 170 minutes. This difference in performance was not significant (t=1.06, d.f. 58, P>.2).

Comparison of steelhead performances reveals that 5 infected fish ascended 104 pools in a mean time of 218 minutes while 28 noninfected individuals negotiated the same rise in a mean time of 141 minutes. Passage times for infected fish ranged from 123 to 397 minutes and from 105 to 206 minutes in the noninfected group. Despite the apparent variation in performance of the two groups of steelhead, the difference was not significant (t=1.498, d.f. 4, P>.2). This result possibly may have been influenced by the small sample size of infected fish.

Similar analyses were conducted to determine whether or not the blood lactate level was influenced by columnaris infection. No significant difference between the lactate level of infected and noninfected fish was found for either chinook salmon or steelhead trout. Again, the small sample sizes of infected fish and the degree of individual infection may have been instrumental in affecting the end result of these analyses.

DISCUSSION

One of the most significant aspects of the information gained from the foregoing experiments is the complete lack of evidence for any serious fish fatigue in either test fishway when the proper hydraulic conditions existed. The biochemical measurements on spring chinook and sockeye salmon, admittedly from small numbers of fish with large individual variations, were sensitive enough to detect significant species differences and differences between treatments "terminated" and "volitional," yet were unable to detect a difference between "volitional" fish that had stopped for 1 hour and the unexercised control fish. The implication is that the fish stopped either for reasons other than muscular fatigue or that their fatigue was so slight that they recovered very quickly. The performances of the fish in the fishways appear to bear this out. A review of the performance records of all fish ascending 96 pools or more shows that the fish did not slow down in six complete circuits. As to the sockeye salmon that was permitted to ascend for more than 5 days, there was no indication of fatigue or slowing down for at least 5,000 pools. Most of the evidence seems to point to the conclusion that when suitable hydraulic conditions prevail, the ascent in either of the two fishways is only a moderate exercise for the fish, possibly similar to that of swimming at a cruising speed which can be maintained for long periods of time.

The different patterns of ascent and rates of passage in the 1-on-8-slope fishway illustrate the manner in which hydraulic conditions can influence the pacing of fish movements through a pool-and-overfall fishway. Under condition 1, both chinook and sockeye followed an exaggerated work-and-rest pattern that resulted in the fish spending 70 percent of the time in the turn pools. Under conditions 2A, 2B, and 2C, when the weirs had been restricted to reduce turbulence and introduce lateral eddies in the pools, the fish distributed their time evenly throughout all of the pools. Under condition 2A, the rate of passage in the 1-on-8-slope fishway was much slower than in the 1-on-16-slope fishway even though the pattern of ascent was very similar. Condition 2B produced a rate of passage only slightly slower than that in the 1-on-16 slope (fig. 27), and condition 2C resulted in a rate of passage almost identical (fig. 28) to that in the 1-on-16-slope fishway.

With this clear demonstration of the importance of hydraulic conditions in a fishway, two questions remain to be answered: what is the most desirable rate of ascent, and what are the proper hydraulic conditions to achieve this rate? To either of these questions we have as yet no sure answer. For the purpose of these experiments, we arbitrarily selected as the desired rate the rate of ascent in the 1-on-16-slope fishway now standard on the Columbia River. Further studies will be necessary to determine the range of rates of ascent within which fish will ascend indefinitely without stress or fatigue. How broad this range may be is a matter of great practical interest. There is a strong suggestion in the data (see figs. 21, 27, and 28) that ascending fish may have a tendency to accomplish a definite amount of work per unit time regardless of the pattern of movement or the slope of the fishway. Note how sockeye, with a pronounced run-and-rest pattern of ascent, in the 1-on-8-slope fishway (fig. 21), consistently ascended the 16 pools in the same time as sockeye in the 1-on-16-slope fishway using a very different pattern of ascent.

With a rate of ascent arbitrarily selected, it was possible in these experiments to modify the hydraulic pattern in the 1-on-8-slope fishway by restricting weirs until it produced the desired effect on fish movement. However, the degree to which this solution, satisfactory for an experimental fishway only 3 feet wide and without orifices, will apply to fishways of larger dimensions and different design is a matter of speculation. Clearly, the task of defining "proper hydraulic conditions" is one of the important fishway problems ahead of us.

SUMMARY AND CONCLUSIONS

The effect of fishway slope on fish performance and biochemical state in long fishways was studied with two experimental "endless" fishways constructed so that each made a complete circuit, with the highest pool connected to the lowest pool by means of a lock. Fish that ascended to the top of these fishways were rapidly locked to the bottom pool to begin the ascent again, and in this manner fishways of any desired length were simulated.

The initial experiments were made with turn pools in each fishway that could be used as resting pools. Performances of sockeye showed no significant difference between fishways in rates of movement or in willingness to ascend. For chinooks a slower rate of passage in the 1-on-8 fishway was observed. There was, for both species, a major difference in patterns of movement in the two fishways. A pronounced work-and-rest pattern was observed in the 1-on-8-slope fishway with the fish spending 70 percent of their time in the turn pools while fish in the 1-on-16-slope fishway showed a tendency to distribute their time more evenly in all pools. Examination of biochemical indices of fatigue showed no significant difference between fishways for blood lactate levels of fish actively ascending or for fish that had stopped for 1 hour. Significant species differences in blood lactate levels and in rates of ascent were noted, but in neither the biochemistry of the fish nor in their performance was there any indication of fatigue in either fishway. Most of the experiments were with 104-pool ascents, a few with extended ascents of a few hundred pools, and one sockeye salmon was permitted to ascend more than 6,600 pools before the test was arbitrarily terminated.

A second group of experiments was made with the turn pools in each fishway modified so as to be very turbulent and not suitable as resting areas. Both the chinook and steelhead tested were significantly slower in the 1-on-8-slope fishway under these conditions, and only 43 percent of the chinook salmon in the 1-on-8-slope fishway completed 100-pool ascents compared to 91 percent in the 1-on-16-slope fishway. Steelhead were equally successful in completing 100 pools in both fishways and their well-paced patterns of movement were similar in each. Chinook salmon appeared unable to pace themselves successfully in the 1-on-8-slope fishway, and the lactate levels of the fish swept back showed definite evidence of distress.

A third set of experiments was done with the turn pools still turbulent but with the weirs of the 1-on-8-slope fishway restricted to reduce pool turbulence and to induce lateral eddies in the pool flow pattern. When the weirs were restricted with baffles arranged either in line or in alternating sequence, the chinook tested showed a pattern of movement similar to that in the 1-on-16-slope fishway. All of the chinook entering the 1-on-8-slope fishway under these conditions completed 100 pools compared to 93 percent completing in the 1-on-16-slope fishway. With in-line baffles the rate of movement was slower in the 1-on-8-slope fishway; with alternating baffles on the weirs the rate of movement in the 1-on-8-slope fishway was equal to the rate in the 1-on-16-slope fishway. There were no significant differences between blood lactate levels of fish ascending either fishway.

Assessments were made of the effect of size, sex, maturity, and disease on performance and biochemical state of the fish. Significant relationships were found only for length of male chinook and performance (larger fish were slower), and sex and lactate level for chinook (female chinook had higher lactate levels). No delayed mortalities resulting from exercise were observed in fish held overnight in each fishway. Initial increases in rates of movement of fish in both fishways indicate that fish learn to ascend. This suggests that changes in hydraulic patterns from pool to pool may adversely influence rates of movement. A tendency for the ascending fish to accomplish a definite amount of work per-unit of time regardless of the slope of the fishway or the pattern of movement was also observed.

The major conclusions reached were:

1. A 1-on-8 slope is as suitable for a long pool-and-overfall fishway for salmonids as the standard 1-on-16 slope provided that the proper hydraulic conditions are obtained.

2. The ascent of a properly designed pool-and-overfall fishway of either slope is only a moderate exercise for salmonids.

3. Hydraulic conditions in the pools can control the rate of ascent and the pattern of movement through a fishway.

4. For all practical purposes, the rate of movement of ascending salmonids will not decrease in the upper end of a long pool-and-overfall fishway and so result in crowding or delay.

5. A 1-on-8-slope fishway with a full weir length overfall and conventional depth (6.5′) in the pools does not have hydraulic conditions desirable for a long fishway and is not recommended for the passage of large chinook salmon.

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LITERATURE CITED

Bates, Daniel W., and Russel Vinsonhaler.
1957. Use of louvers for guiding fish. Transactions of the American Fisheries Society, vol. 86, pp. 38–57.

Black, Edgar C.
1957. Alterations in the blood level of lactic acid in certain salmonoid fishes following muscular activity. III. Sockeye salmon, *Oncorhynchus nerka*. Journal of the Fisheries Research Board of Canada, vol. 14, no. 6, pp. 807–814.
1958a. Energy stores and metabolism in relation to muscular activity in fishes. *In:* The Investigation of Fish-Power Problems. H. R. MacMillan Lectures in Fisheries. P. A. Larkin, Editor. University of British Columbia, Vancouver, pp. 51–67.
1958b. Hyperactivity as a lethal factor in fish. Journal of the Fisheries Research Board of Canada, vol. 15, no. 4, pp. 573–586.

Collins, Gerald B., Joseph R. Gauley, and Carl H. Elling.
1962. Ability of salmonids to ascend high fishways. Transactions of the American Fisheries Society, vol. 91, no. 1, January 1962, pp. 1–7.

Fish, Frederick F., and Robert R. Rucker.
1943. Columnaris as a disease of cold-water fishes. Transactions of the American Fisheries Society, vol. 73, pp. 32–36.

Gauley, Joseph R.
1960. Effect of fishway slope on rate of passage of salmonids. U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries 350, 23 pp.

Hawk, Philip B., Bernard Oser, and William H. Summerson.
1954. Practical physiological chemistry. 13th ed. Blakiston, New York, 1,439 pp.

King, Earl Judson.
1932. The colorimetric determination of phosphorus. Biochemical Journal, vol. 26, no. 2, pp. 292–297.

Montgomery, R.
1957. The determination of glycogen. Archives of Biochemistry and Biophysics, vol. 67, no. 2, pp. 378–386.

Ordal, E. J., and Robert R. Rucker.
1944. Pathogenic mycobacteria. Proceedings of the Society for Experimental Biology and Medicine, vol. 56, pp. 15–18.

Parker, Robert R., and Edgar C. Black.
1959. Muscular fatigue and mortality in troll-caught chinook salmon (*Oncorhynchus tshawytscha*). Journal of the Fisheries Research Board of Canada, vol. 16, no. 1, pp. 95–106.

Parker, R. R., E. C. Black, and P. A. Larkin.
1959. Fatigue and mortality in troll-caught Pacific salmon (*Oncorhynchus*). Journal of the Fisheries Research Board of Canada, vol. 16, no. 4, pp. 429–448.

Rucker, Robert R., Brian J. Earp, and Erling J. Ordal.
1954. Infectious diseases of Pacific salmon. Transactions of the American Fisheries Society, 1953 (1954), vol. 83, pp. 297–312.

Secondat, Marcel, and Diego Diaz.
1942. Recherches sur la lactacidémie chez le Poisson d'eau douce. Comtes Rendus Hebdomadaires des Séances de l'Académie des Sciences (Paris), tom 215, pp. 71–73.

von Buddenbrock, W.
1938. Beobachtungen über das Sterben gefangener Seefische und über den Milchsäuregehalt des Fischblutes. Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procès-Verbaux des Réunions, vol. 101, 4 eme Partie, 2nd part, pp. 3–7.

APPENDIX

Table A–1.—*Summary of significance tests between salmonid passage times in fishways with slopes of 1-on-8 and 1-on-16*

Species and slope	Condition	n	Mean passage time in minutes 104 pools	d.f.	t value	Significance
Chinook:						
1 on 8	1	7	285			
1 on 16	1	8	232	13	1.16	N.S.
1 on 8	2	12	255			
1 on 16	2	28	184	38	3.67	(**)
1 on 8	2A	2	282			
1 on 16	2	3	193			
1 on 8	2B	26	209			
1 on 16	2	31	164	38	2.85	(**)
1 on 8	2C	9	151			
1 on 16	2	9	160	16	.49	N.S.
Blueback:						
1 on 8	1	23	168			
1 on 16	1	23	171	44	.36	N.S.
Steelhead:						
1 on 8	2	37	222			
1 on 16	2	46	155	66	5.61	(**)

** Significant at the .01 level.
N.S.—Not significant, $P > .05$.

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