Performance of Arctic Grayling in a Twenty Foot Section of Model "A" Alaska Steeppass Fish Ladder

Final Report to the
Army Corps of Engineers
Alaska Division

By

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Introduction

The construction of a flood control dam on the Chena River near Fairbanks necessitated that fish passage be provided for king salmon, *Oncorhynchus tshawytscha*; chum salmon, *O. keta* and Arctic grayling, *Thymallus arcticus*. The use of fish ladders by salmon is well known but no information is available on the use of fish ladders by grayling.

In May 1976 an inter agency meeting was held at the Alaska District Corps of Engineers offices in Anchorage to discuss proposed testing of Arctic grayling in a fish passage facility. Poplar Grove Creek, a tributary of the Gulkana River near Gakona Junction, was selected as the test site because a correlative study of grayling swimming ability was recently completed at the site (MacPhee and Watts, 1976) making available much information and some physical facilities. Corps of Engineers personnel designed and installed the additional apparatus needed for the present study based on functional design as provided by National Marine Fisheries Service.

As a result of this meeting, it was determined that National Marine Fisheries Service would conduct the hydraulic studies relative to the project and would provide an outline of hydraulic criteria for evaluation of an Alaska Steeppass Fish Ladder (Ziemer, 1962).

On June 16, 1976, a memorandum of understanding was signed between National Marine Fisheries Service and the Corps of Engineers which delineated the basic hydraulic testing and evaluation. As part of this project, preliminary hydraulic tests of the fish ladder were planned to determine velocities (as resultant from varying slopes and water quantities) that we felt were consistent with the known swimming capabilities of all year classes of grayling.

In August 1976, an on-site inspection of the project site resulted in a decision to conduct the preliminary hydraulic tests at a location other than the project site. This was due to insufficient flow in Poplar Grove Creek to test the fish ladder. Arrangements were then made to utilize a 27' section of fish ladder located at Bonneville Dam and also utilize the Bonnevile hydraulics laboratory to conduct the tests. These tests were necessary because information from prior testing of this type of fish ladder by Ziemer (1962) had not shown velocities we felt were compatible with grayling swimming ability. The tests with flatter slopes than tested by Ziemer were conducted September 7-10, 1976, at Bonneville Hydraulics Laboratory. Results of these tests indicated that velocities within the swimming capabilities of grayling were possible with the Alaska Steeppass Fish ladder. The results of the tests performed were submitted by the laboratory as a standard report with copies to participating agencies (Smith, Disposition form NPOEN-TE-L, 4 Oct. 76). With the hydraulic/velocity questions resolved, a decision was then made to test the prototype fishway at Poplar Grove Creek during the grayling spring migration period in 1977.

Shortly after the decision was made to conduct the prototype tests, the Corps of Engineers by prior arrangement installed the head box, tail box and performed other necessary work to insure the operational functions. The Corps of Engineers also designed and installed the barrier screens to guide the fish to the facility.

It was agreed in prior meetings of the Chena Inter-Agency Technical Committee that the Alaska Department of Fish and Game would, if possible, conduct the biological tests while National Marine Fisheries Service conducted the hydraulic portion of the tests. On March 10, 1977 the Alaska Department of Fish and Game and the Corps of Engineers entered into a Contract (No. DAC-W85-77-C-0018) for the biolgical testing and reporting.

The primary objective of the study was to determine whether or not Arctic grayling would accept and use an Alaska Steeppass Model "A" Fish Ladder. Further objectives included finding an optimal slope and discharge for passage of all migrating grayling. Other species of fish encountered were to be included in the tests as time permitted.

Methods and Materials

Moving from upstream to down, the upper end of the test facility consisted of a concrete dam with wooden stop logs and expanded metal trash rack followed by a gated inlet culvert, a 6' x 12' head box screened at the upper end and including an energy dissipator to break the flow of incoming water, a 20' section of Alaska Steeppass Fish Ladder, a 6' x 12' tail box with counting periscope at the lower end and a brail for removing fish, and a double screen steel fish weir (Fig. 1 and 2).

The initial sample design called for three 8 hour test periods during each 24 hours (0300-1100, 1100-1900, and 1900-0300). Beginning with test 21 only two tests were run each day and the times were adjusted to divide the natural activity period of the grayling about equally between the two test periods (0900-1500 and 1600-2200). During each test period the ladder was in operation for at least 6 hours. During the last 30 minutes of ladder operation, the tail box entrance was closed, thus ensuring that every fish involved in a test had at least 30 minutes to negotiate the fish ladder. The final 2 hours of each period was for drain down, counting and measuring the fish in head and tail boxes, and setting the ladder slope in preparation for the next test.

The tests were conducted so that all fish approached the ladder without being handled. They were guided into the tail box by the weir and were free to proceed on up the ladder to the head box without being disturbed. A negative aspect of this design was that fish entering the tail box early in the 6 hour test period had a longer exposure to the ladder than those entering later. In an attempt to alleviate this problem an alternate design was tried where the fish were seined below the weir and placed in the tail box all at once and then given 6 hours to negotiate the ladder. Two tests (21 and 22) were run this way, both included about half the daily activity period. The success rates for grayling in these two tests were extremely poor (17% and 49%) compared to the mean for all other tests (82%) so this design was abandoned in favor of the open entrance procedure. Test 23 also gave poor results, presumably because fish affected by the previous days seining were still in the area. The results of tests 21, 22 and 23 were excluded from all further analysis.

The success rate of each species and maturity group was determined for each test by draining the head box and ladder after each test, removing the fish and taking data on species, fork length, maturity, and if mature, the sex. Fish that failed to go through the ladder during the test were removed from the tail box by a large brail operated numerous times while fish were driven out of corners. The tail box was considered empty when the brail came up empty three consecutive times. All fish whether successful or failing, were released in a quiet side pool of the creek about 100' above the dam.

Three slopes and three discharge levels were selected for testing prior to the study, making nine sets of test conditions. One further condition was added by testing the maximum ladder capacity at 15% slope (4.5 cfs). These conditions were selected based on hydraulic tests of the Alaska Steeppass Fish Ladder at the Bonneville Hydraulics Laboratory. The hydraulic tests provided a means of determining the average water velocity for the conditions of slope and discharge tested (Table 1). The ten combinations were tested on a random basis to avoid systematic error.

The facility was altered after test 16 by placing "V" traps at the head of the fish ladder and at the entrance to the tail box. During test 32 a sandbag dam was begun below the tail box and weir to raise the tail box water level. This dam was added to during test 33 and 48. There was no apparent effect of these alterations.

All measurements with the exceptions of fish length and temperature were made using the English system. Because the Sport Fish Division (Alaska Department of Fish and Game) has standardized the metric system for fish and temperature measurements that practice is continued in this report.

Results and Discussion

Grayling Population and Migration Parameters

The basic natural history of the Poplar Grove Creek grayling population is adequately covered by MacPhee and Watts (1976) and will not be repeated here except where specifically applicable. One important variance with the MacPhee and Watt's results was made in the upper limit of fork length for yearling grayling. A sample of 25 fish between 100-160 mm was aged by the scale method. All fish over 130 mm were found to be 2 year olds, thus the upper length limit of yearlings was set at 130 mm, not 160 mm as set by MacPhee and Watts. MacPhee and Watts, reported relatively few fish between 130-160 mm fork length in their study; however, so few yearlings (218) returned this year that the 141 fish between 130-160 mm would affect results substantially.

In this study maturity was determined directly by applying pressure to the abdomen and noting the presence or absence of sex products. The separation of adult and juvenile grayling as used here is accordingly an actual determination, not a length separation. Because of the nearly ripe condition of the migrating adults it is felt that most mature fish were detected. The maturity data revealed that 50% of Poplar Grove Creek grayling were mature at 245 mm and that 100% were mature at 275 mm fork length. Also mature fish of a given size group were found to migrate earlier in the run than their immature counterparts (Table 2).

The timing, magnitude, size and sex makeup of the grayling migration on which the fish ladder tests were carried out is shown in Fig. 3. The run was similar to the runs of 1973, 1974, and 1975 as recorded by MacPhee and Watts (1976). The first grayling was dipped from the tail box on May 5 (water temperature 0.5°C) and the first testable numbers arrived May 9 (water temperature 2°C). The adult grayling migration peaked on May 13 and was essentially over by May 20 (Fig. 3). The juveniles peaked May 14 but continued to run in useable numbers through May 27. Yearling grayling returned in relatively small numbers between May 18 and 30, peaking on May 26.

The 218 yearlings (85-130 mm) in this year's run yielded only 9 tests involving 10 or more fish. This small return was thought to be the result of Poplar Grove Creek being dry except for a few deep holes during most of August 1976. Fred Williams* reports seeing large numbers of yearlings trapped in these holes during this time. A direct comparison of numbers of yearlings with MacPhee and Watts data is not possible because they included the grayling from 130-160 mm with the yearlings. The only comparison that can be made then, is to add the 141 grayling in the 130-160 mm group to this year's data, thus indicating a return of 359 yearlings. This is far below the 1,088 MacPhee and Watts recorded in 1974 but similar to the 386 in 1975. In 1973 MacPhee and Watts captured only about 210 yearlings in May but passed a total of 694 by July 20, 1973. This year's run then may have been more typical than the 1974 run of over 1,000 fish under 160 mm.

The discharge in Poplar Grove Creek reached 156 cfs (4.2M^3/sec) on May 7 then dropped steadily to 32.5 cfs (.92M^3/sec) by May 30 (Fig. 3). The maximum water temperature began rising above 0°C on May 4, reached 0.5°C

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*Alaska Department of Fish and Game, Regional Management Biologist when the first grayling was taken, 2°C when testing began, 8°C when the first yearlings arrived and 12°C by May 30. On only 2 days, May 17 and 20, did the maximum water temperature drop below the previous day's maximums. On May 17 there was a slight rise in the number of adult grayling, a sharp drop in the numbers of juvenile grayling and the first and largest peak in the longnose sucker, *Catostomus catostomus*, run. On May 20 the numbers of juvenile grayling again dropped sharply, but remained at the lower level thereafter, and a sharp internode in the sucker run occurred. Whether these run levels are actually correlated with water temperatures is not known at this time.

The run of longnose suckers began May 13 and was still underway, though at a low level, on May 30 (Fig. 3). The 4,923 suckers came in four peaks, on May 17, 21, 25 and 27. Though size and maturity data were not taken on suckers, it was noted that most of the fish were mature and only near the end of the run did small, immature suckers, including some very small individuals (<150 mm), begin to move upstream.

The 154 rainbow trout, *Salmo gairdneri*, juveniles taken during the study were probably following the grayling and suckers to forage on eggs.

Diel Activity

MacPhee and Watts (1976) concluded that grayling actively moved upstream between 1500 and 2100 hrs but their data consisted of observations of fish jumping at the dam on only one day. The periscope at the entrance to the tail box in the present study provided an excellent means of refining the former observations. The periscope data were also used to adjust the time during which tests were run and was helpful in interpreting results of this study. Figure 4 shows the mean number of grayling entering the tail box during each one hour period that counts were conducted. The May 26-30 means are for the whole period indicated, as counts were only made at the end of the period. Migratory activity began picking up about 1000 hours, peaked from 1600 to 1800 hours and ended about 2200 hours during the entire run. Between May 26 and 30, when the run consisted primarily of yearlings and small juveniles, there was proportionately more activity in the early morning hours, and some tests were obtained with more than 10 grayling in a single size group.

Effects of Slope and Discharge

The overall success rate of all size and maturity groups of grayling and all suckers and rainbow trout are listed in Table 3. In general all groups showed a success rate of 80% or better except the yearling grayling, which had an overall success rate of 33%..

The success rates of male, female, juvenile and yearling grayling by average water velocity in the fish ladder is shown in Fig. 5. The solid line (fitted by inspection) represents the best fit among all points regardless of slope or discharge. Adult grayling show improved success rates at high average water velocity, indicating a positive attraction response at higher velocities. Juvenile grayling did equally well at all velocities tested, while yearlings showed the best success at about 2 fps with total failure at 2.64 fps.

The independent effect of slope and discharge on male, female, juvenile and yearling grayling as indicated by the mean success rate of all tests run at each condition is given in Table 4. A graphic presentation (Fig. 6) shows the spread of points obtained from all tests. For adult males and females success increased from 87% to 98% as slope increased from 7.5% to 15% (the steepest slope tested). Juvenile success rate increased from 84% to 92% for the same slopes. Yearlings showed an increase in success rates from 34% to 44% in going from 7.5% to 11.25% slope, but success dropped sharply to 13% at 15% slope. Increasing slope apparently has an attractive affect on adult and juvenile grayling and also on yearlings up to the point that water velocities prevent their passage.

The independent effect of discharge (Table 4) also shows a positive correlation with success rate for adult and juvenile grayling and also for yearlings up to about 3 cfs, above which success of yearlings decreased. Again, grayling appear to be attracted by the greater water velocity produced by higher discharge up to the point that the velocity approaches the limits of their swimming ability.

The experimentally controlled variables of slope and discharge produced only two detectable effects on the success rate of grayling in the Alaska Steeppass Fish Ladder: (1) Above 11.25% slope and 2.9 cfs, yearling grayling were inhibited in their passage; (2) Increased water velocity at sublimiting levels increases success rate, presumably through improved attraction. For adults and juveniles the maximum water velocity (2.6 fps) tested produced the best results, but for yearlings 2 fps was the maximum water velocity that produced improved attraction without inhibiting success.

In considering the success rates of yearling grayling one must consider the motivation of these fish to ascend the stream. One should consider the unavoidable question of: what percent of a group of yearlings might be expected to surmount a natural barrier such as a log jam in a 6 hour period? Yearlings were often observed moving about in front of the periscope for 15 to 20 minutes before progressing into the tail box. It may be that 40% success in 6 hours is a near optimum level for this maturity group.

The Effects of Some Uncontrolled Variables

The randomization of controlled variables among tests, as described under methods, should have minimized the effects of experimental design, environmental, and any other uncontrolled variables on the final results. The effect of some of these uncontrolled variables can be studied independently, however, producing information useful in future test designs.

One design condition suspected of affecting success rate in the current study was the time of day a particular test was run. (The test schedule and its relation to the grayling's activity period was discussed earlier.) Figure 7 shows that adult grayling did better in evening tests (1600-2300 hours) after the first 6 days than in midday tests. After the twelfth day of the run, tests with ten adult fish occurred only in the evening. Juvenile grayling generally did better in midday tests (0100-1700 hours and 0900-1500 hours), though not markedly so. The general drop in success rate shown in Fig. 7 during the second or third three day period is not readily explainable. The generally improved success rate toward the end of the run for the adults and juveniles may be due to their improved swimming ability as a result of high water temperatures (MacPhee and Watts, 1976) or may be due to improvements made in the test facility such as "V" traps at the tail box entrance and head of ladder.

Another uncontrolled variable suspected of affecting the results was the water level in the tail box. This level affected the water velocity in the lower 10' of the 20' fish ladder, lowering the velocity if the water level was too high or raising it if too low. The hydraulically proper height depended on the discharge of the ladder and was not determined in this study. The depth of water in the tail box was measured at the beginning of each test and this measurement was related to success rate of juvenile grayling at each slope and discharge in Fig. 8. The analysis was done for juvenile grayling only because more data were available. The one consistent feature of the curves is their drop as the tail box water level increases to near the high level for the particular discharge. This is probably best explained as a reduction in attraction velocity due to flooding of the lower ladder. Or conversely, low tail box water levels caused an increase in velocity in the lower 10' of the ladder resulting in better attraction and also making the ascent of the fish ladder progressively easier as the fish approaches mid ladder. There is also evidence that low tail box levels at particular discharge levels for 7.5% and 11.25% slope result in lower success rates for juvenile grayling. This would indicate there is an optimum submergence of the lower ladder for a given slope and discharge.

Conclusions

The 20' (6.1 m) Model "A" Alaska Steeppass Fish Ladder of standard design was fully accepted by the migrating grayling of Poplar Grove Creek. Adult grayling achieved the best success rates (near 100%) at 15% slope and 4.5 cfs discharge which was the most difficult condition tested, producing an average velocity in the ladder of 2.6 fps. Juvenile grayling (130 mm - maturity) also did best (92% success) at the highest slope and discharges tested. Yearling grayling (85-130 mm), however, reached their best success rate of 44% at 11.25% slope and 2.9 cfs discharge. They were severely inhibited at 15% slope and the higher discharges at that slope. Any ladder installation intended to pass all grayling would be limited to the conditions that limit yearlings.

The fact that success rate of fish in the ladder increases as velocity increases until a velocity is reached that approaches the limits of swimming ability for a given size group indicates that attraction is an important factor in getting grayling to ascend the ladder.

The submergence of the lower end of the ladder is also critical in producing optimum use of the ladder. This would probably be about 15.5" for the ladder set at 11.25% slope and a discharge of 2.9 cfs.

Acknowledgements

Special appreciation goes to Jerry Hallberg, Bret Luick and Chris Young for their able assistance throughout the field operation. Fred Williams and Butch Potterville provided appreciated equipment and logistics help. John LaSalle stuck with cleaning screens while several others came and went. Bill Crane, who designed and installed the apparatus, deserves credit for a job well done. Thanks to Eugene Roguski for editing the manuscript and Don Borchert for the graphics.

Literature Cited

MacPhee, C. and F. Watts. 1976. Swimming performance of Arctic grayling in highway culverts. Bulletin No. 13, College of Forestry, Wildlife and Range Science. University of Idaho, Moscow, Idaho. 41p.

Ziemer, G. 1962. Steeppass fishway development. Alaska Department of Fish and Game Informational Leaflet No. 12. Subport Building, Juneau, Alaska.

Table 1. The conditions of slope and discharge tested at Poplar Grove Creek and the computed average water velocity at each condition.

Slope	Discharge cfs	Average Velocity
7.5%	1.74	1.43
	2.88	1.82
	3.51	2.06
11.25%	1.74	1.78
	2.88	2.05
	3.51	2.17
15%	1.74	2.01
	2.88	2.26
	3.51	2.35
	4.47	2.64

Table 2. Fork length at maturity of Arctic grayling from Poplar Grove Creek taken before and during (Tests 1-16) and after (Tests 17-30) the run peak, May, 1977.

Fork Length Group (mm)	Tests 1-16			Tests 17-30		
	Total Fish	No. Mature	% Mature	Total Fish	No. Mature	% Mature
<200	49	0	0	303		0
200	5	0	0	11		0
205	4	1	25	14		0
210	6	0	0	16		0
215	7	0	0	24		0
220	8	1	12	14	0	0
225	19	4	21	28	1	4
230	49	15	31	48	10	21
235	61	31	51	66	19	29
240	99	50	50	77	28	36
245	119	72	60	82	48	58
250	150	103	69	107	65	61
255	160	116	72	79	58	73
260	133	119	89	70	61	87
265	90	79	88	43	34	79
270	83	75	90	38	37	97
275	56	56	100	24	24	100
>275	290	290	100	102	102	100
Totals	1,388			1,146		

Table 3. Success rates of all fish that entered the Steeppass Fish Ladder testing facility, May, 1977.

Fish Group	No. of Individuals	Success Rate (%)
Male grayling	867	88
Female grayling	813	87
Juvenile grayling (130-160 mm)	141	79
Juvenile grayling (160 mm to maturity)	1,483	84
Yearling grayling	218	33
All grayling	3,522	82
Suckers	4,932	86
Rainbow trout	154	82

Table 4. The independent effect of Alaska Steeppass Fish Ladder slope and discharge on success rate of Arctic grayling, Poplar Grove, May, 1977.

Slope Effect

	Males		Females		Juveniles		Yearlings	
Slope	No. of Tests	Mean Success Rate	No. of Tests	Mean Success Rate	No. of Tests	Mean Success Rate	No. of Tests	Mean Success Rate
7.5%	6	87%	7	87%	12	84%	2	34%
11.5%	5	89%	6	87%	14	90%	4	44%
15%	10	98%	11	98%	17	92%	3	13%

Discharge Effect

	Males		Females		Juveniles		Yearlings	
Discharge ft^3/s	No. of Tests	Mean Success Rate	No. of Tests	Mean Success Rate	No. of Tests	Mean Success Rate	No. of Tests	Mean Success Rate
1.7	6	90%	6	87%	11	86%	1	28%
2.9	6	95%	7	93%	14	86%	3	38%
3.5	6	90%	8	94%	13	87%	4	35%
4.5	3	100%	2	100%	5	94%	1	0%

Figure 1. View of Alaska Steeppass Fish Ladder test site on Poplar Grove Creek looking downstream. Note the trash rack above the dam in right center of photograph and the gated inlet to the head box at the extreme left corner.

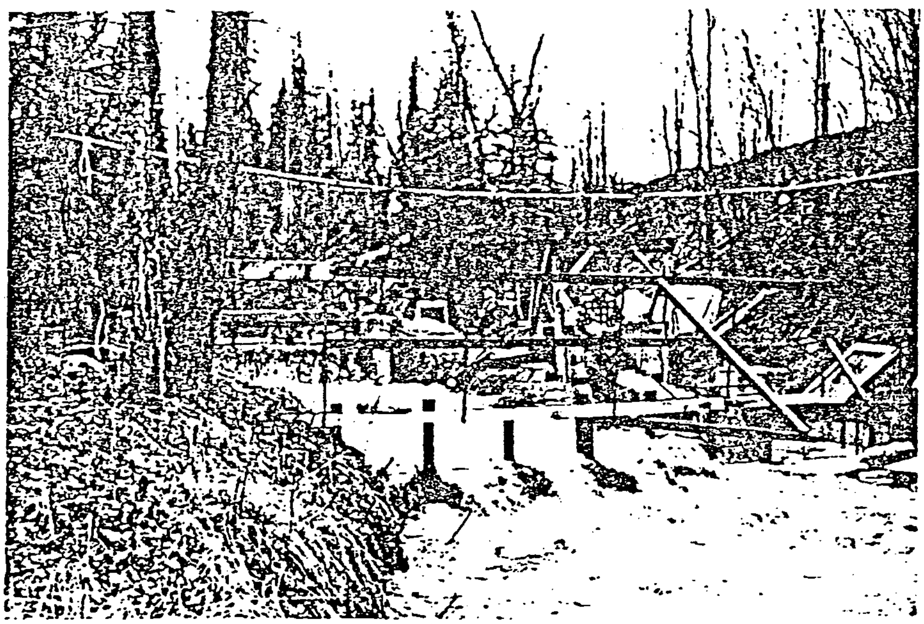

Figure 2. A view looking upstream at the Alaska Steeppass Fish Ladder test site on Poplar Grove Creek showing the weir (foreground) with screens removed except at right end, the tail box entrance at extreme right end of weir, and the fish ladder (behind knees of man in checked shirt).

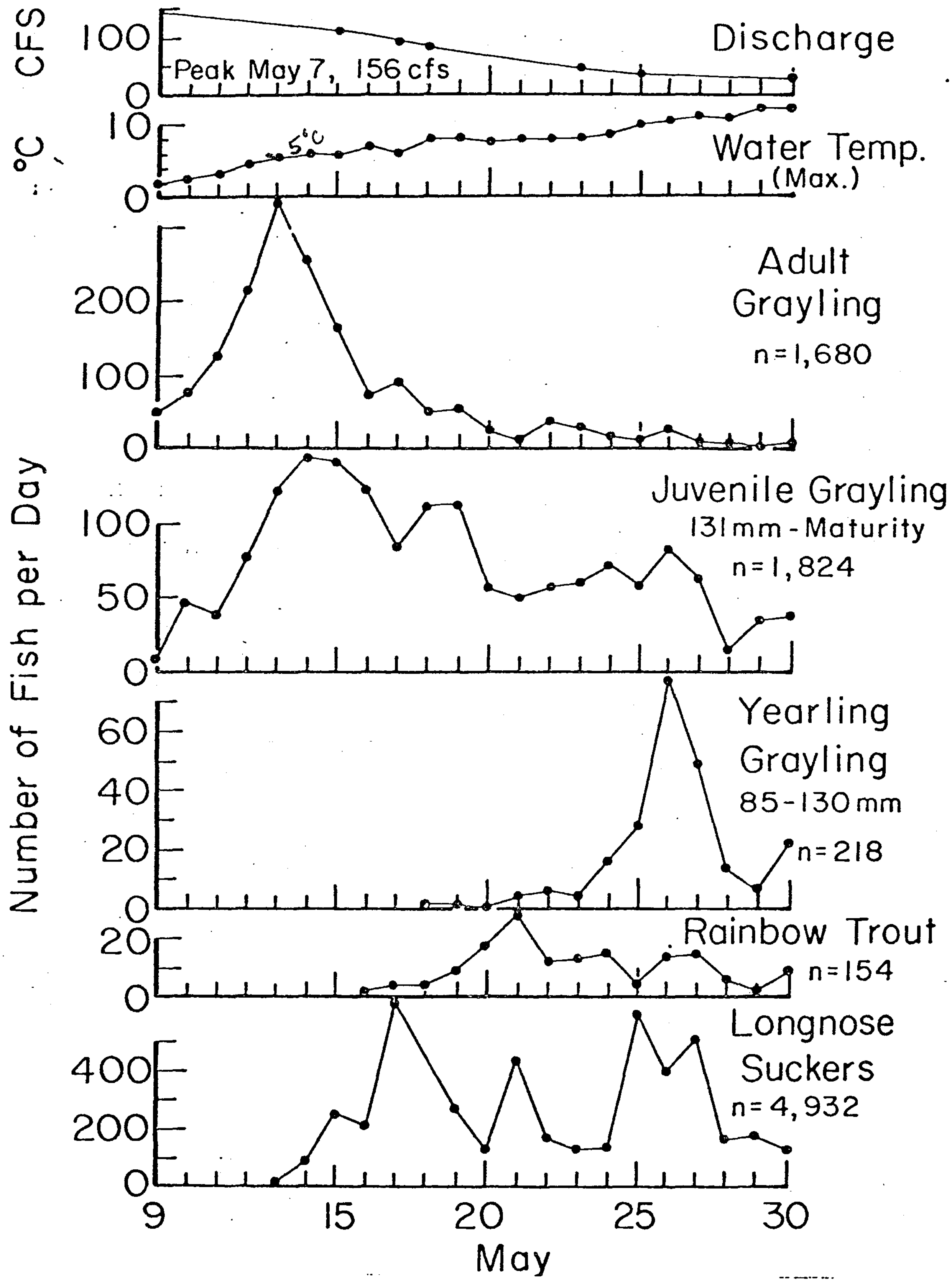

Figure 3. Stream discharge, maximum water temperature, and daily totals of fish moving up Poplar Grove Creek, May, 1977.

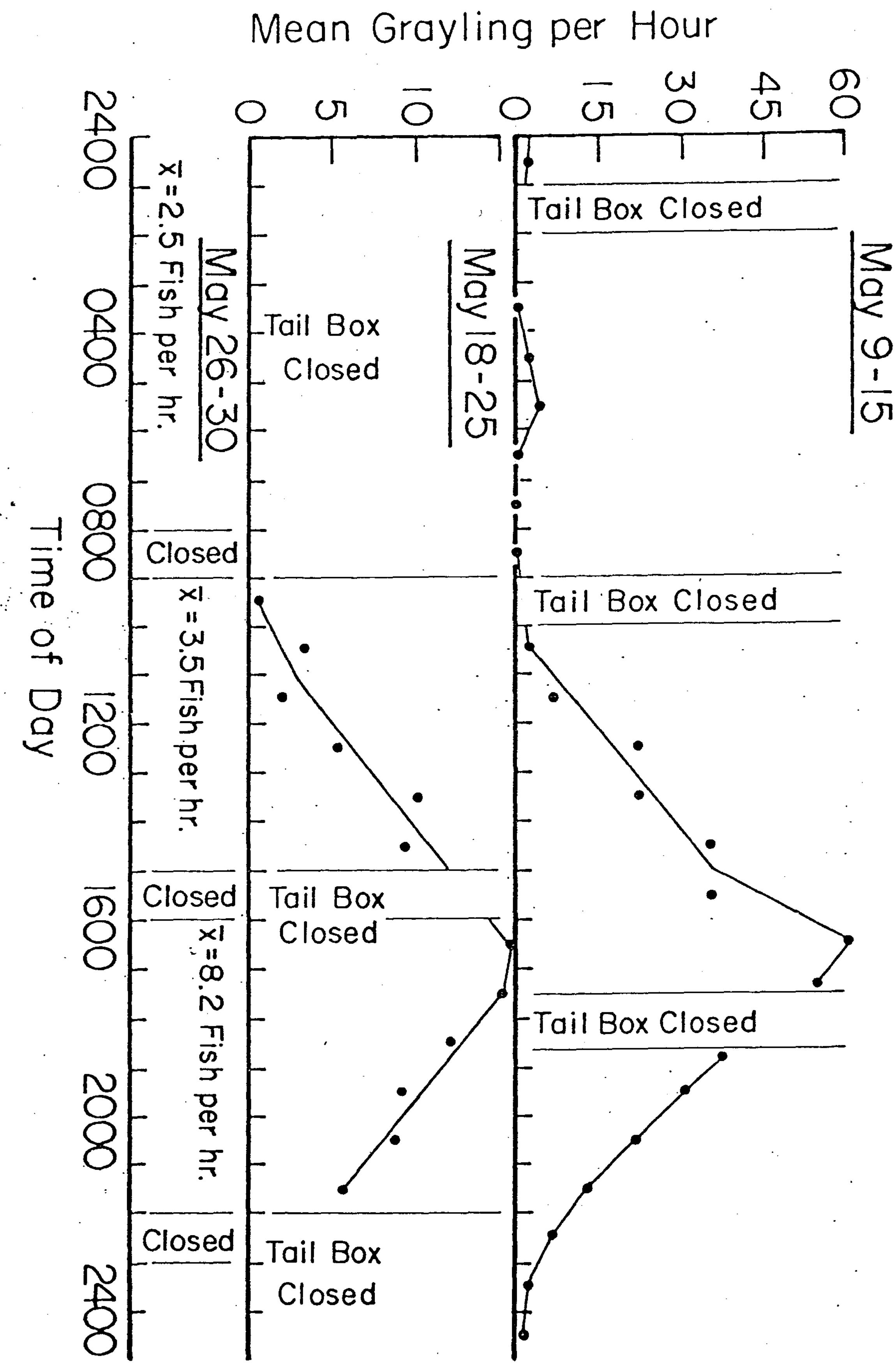

Figure 4. Diel activity period of upstream migrant grayling as determined by periscope counts at the tail box entrance (May 26-30) in relation to test periods at Popular Grove Creek, 1977.

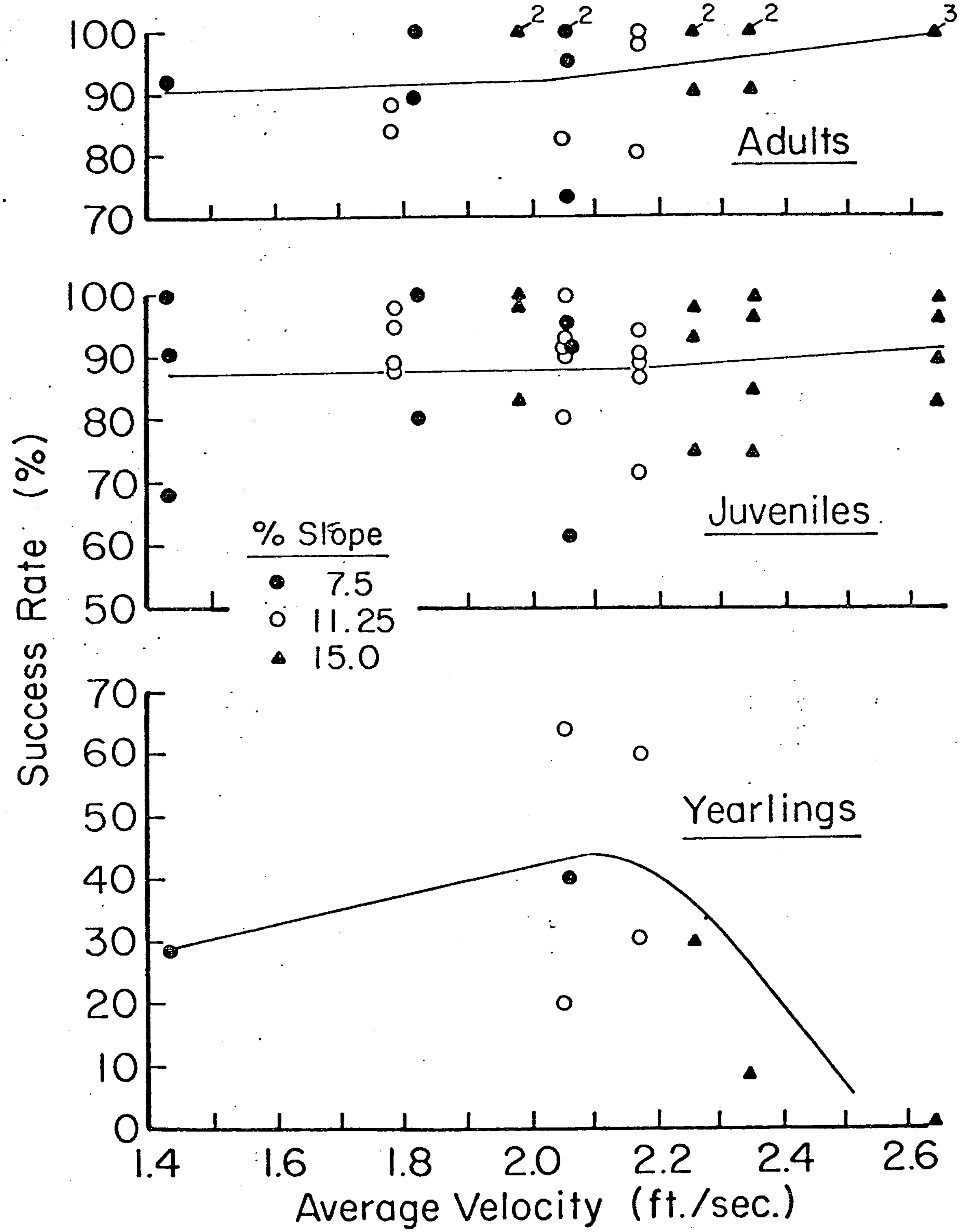

Figure 5. The success rate of three maturity groups of Arctic grayling in a 20' section of Alaska Steeppass Fish Ladder in relation to average calculated water velocity produced by the ten conditions of slope and discharge tested at Poplar Grove Creek, May, 1977.

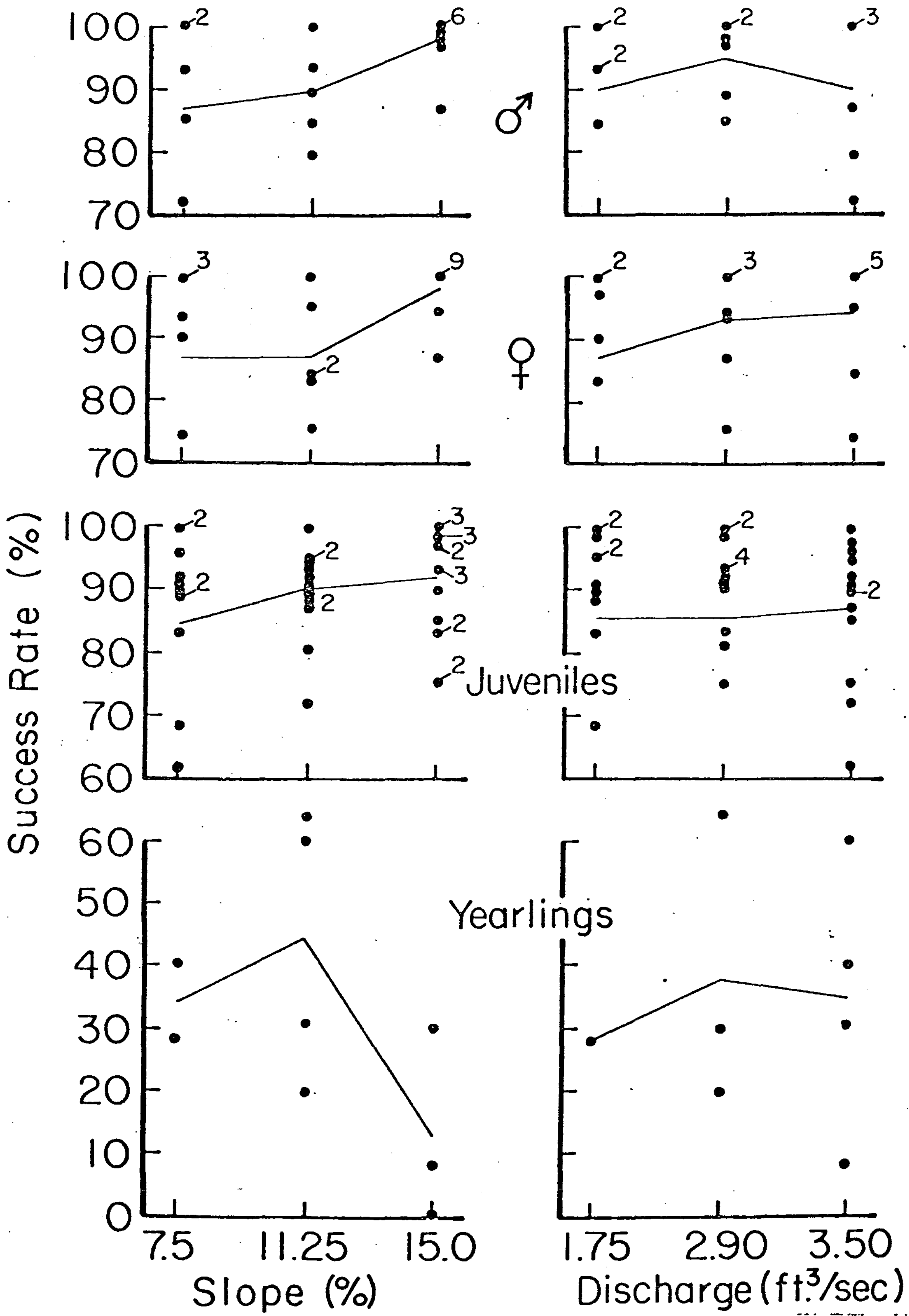

Figure 6. The independent effects of slope and discharge on success rate of Arctic grayling in a 20' section of Alaska Steeppass Fish Ladder as shown by the point spread of individual tests with the means connected.

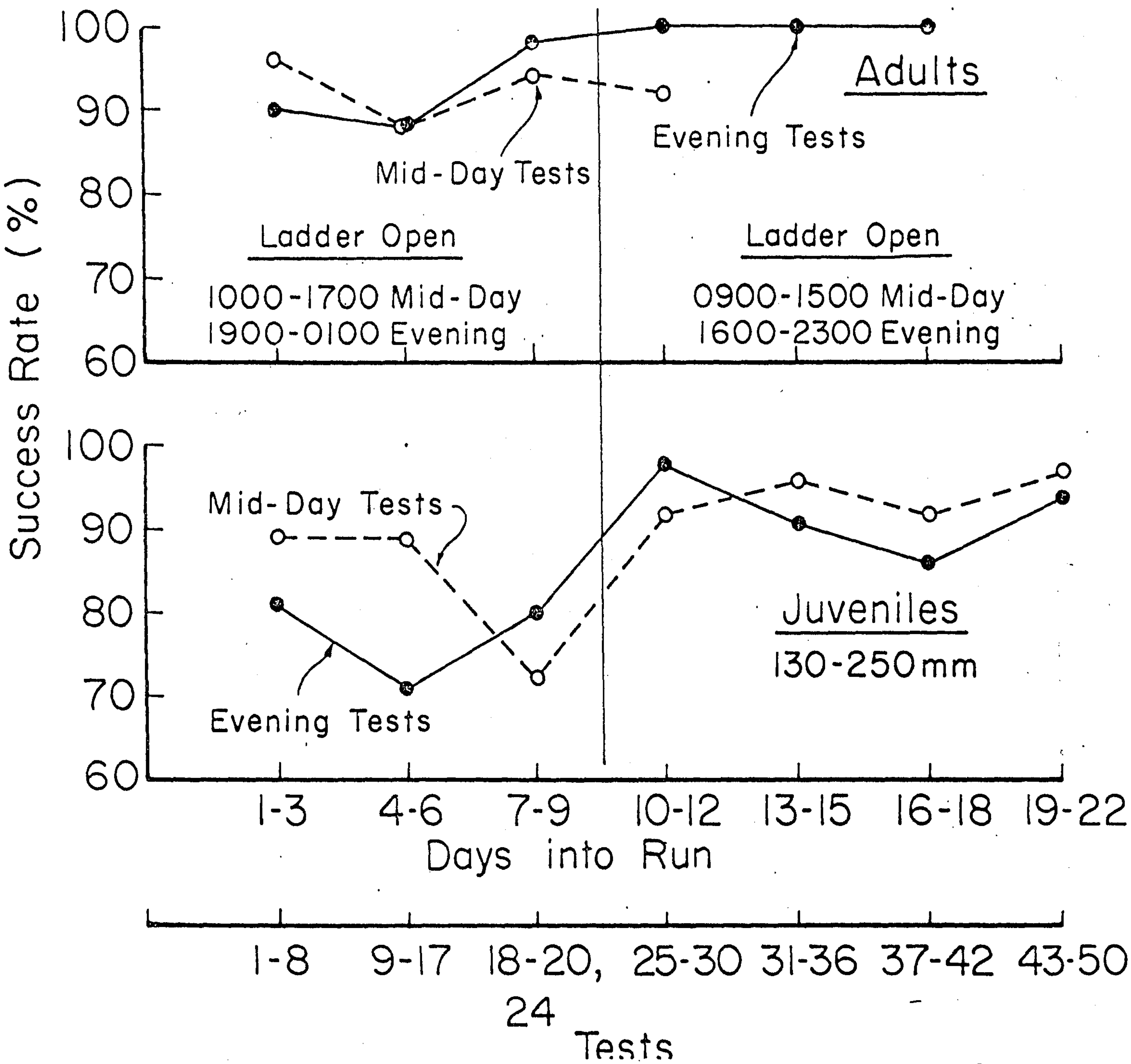

Figure 7. Success rate of adult and juvenile grayling as affected by test time, state of migration and associated water ...

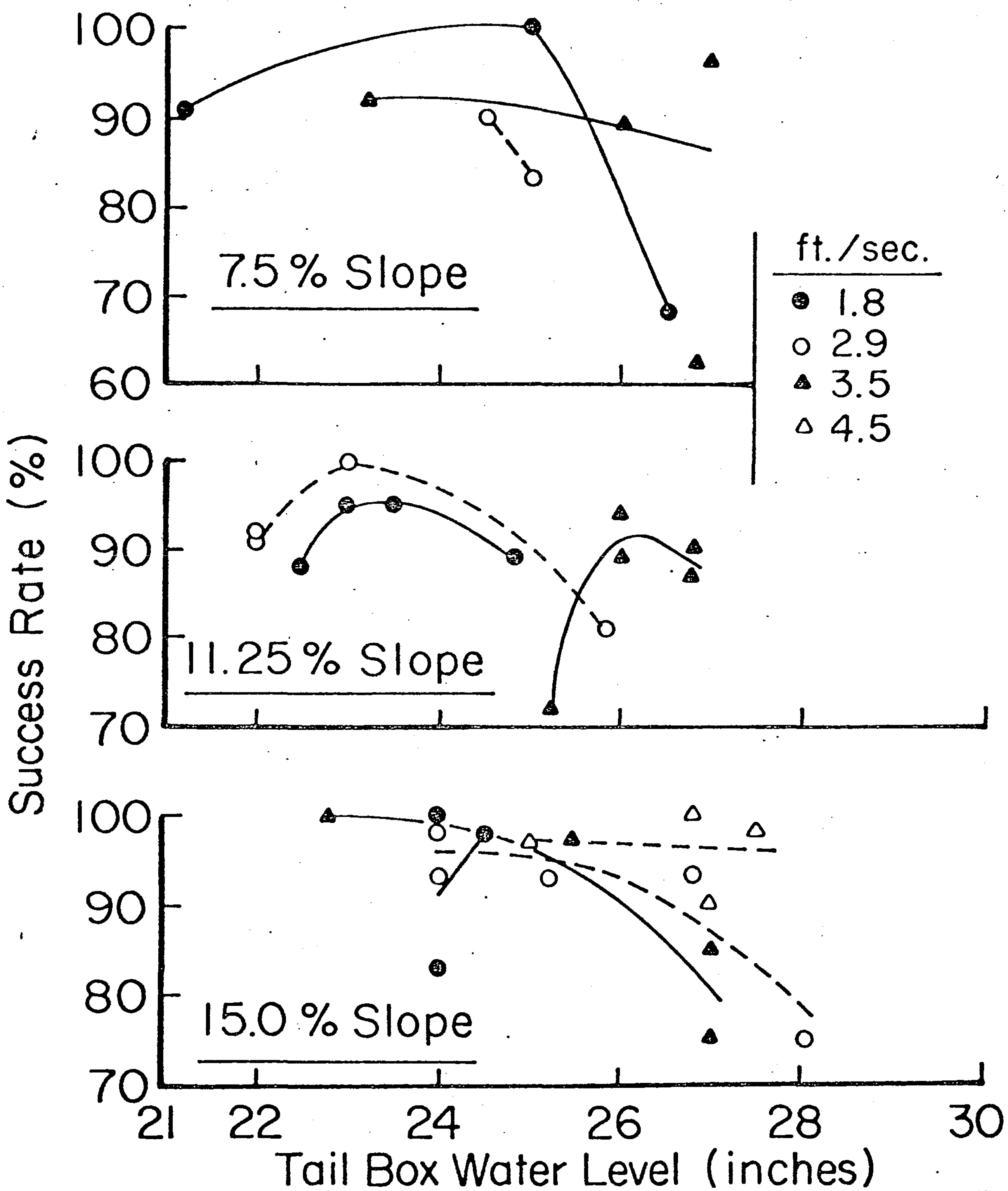

Figure 8. The effect of tail box water level on success rate of juvenile Arctic grayling in an Alaska Steeppass Fish Ladder at Poplar Grove Creek, May, 1977.