Downstream Migration Facilities and Turbine Mortality Evaluation, Atlantic Salmon Smolts at Malay Falls, Nova Scotia

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DOWNSTREAM MIGRATION FACILITIES AND TURBINE MORTALITY EVALUATION, ATLANTIC SALMON SMOLTS AT MALAY FALLS, NOVA SCOTIA

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Fish passage studies were conducted at Malay Falls Hydroelectric Dam, on East River Sheet Harbour, Nova Scotia. Test fish were hatchery-reared Atlantic salmon (*Salmo salar* L.) smolt, equal to or greater than 15 centimetres fork length. Turbine mortality, downstream passage rate, and efficiency of a surface bypass (with and without a forebay deflection system) were evaluated, with smolts being released 100 metres upstream from the bypass. Turbine mortality averaged 10.6±2.3 percent ($\bar{x} \pm S_{\bar{x}}\, t_{0.05}$) and was reduced to 5.1-5.7 percent of the total emmigrant smolt by operation of a surface bypass without a forebay fish deflector.

Bypass efficiencies averaged 45.9 percent (21.7-71.4 percent) without the deflector for the five-day individual tests, and 51.7 percent (32.2-80.9 percent) for the whole recovery period of each test lot.

Provision of a forebay deflector system to guide smolt to the bypass failed to improve bypass efficiency. Mean bypass efficiencies for these tests ranged from 18.1 to 20.4 percent for five-day tests and total recapture periods, respectively.

The majority (86.0-86.4 percent) of test fish recovered were recaptured in the bypass within five days of release in Malay Falls forebay.

Time to median (50 percent) recapture of all test fish at Ruth Falls louvers, 5.8 kilometres downstream, indicated that bypass smolts were one day later arriving than were turbine smolts.

Key words: Atlantic salmon smolt, hydroelectric dam, downstream migration, surface bypass, deflector, bypass efficiency, downstream passage rate, turbine mortality.

RÉSUMÉ

Semple, J.R. 1979. Downstream migration facilities and turbine mortality evaluation, Atlantic salmon smolts at Malay Falls, Nova Scotia. Fish. Mar. Serv. Man. Rep. No. 1541, 22 p.

Des études sur le passage des poissons ont été effectuées au barrage de l'usine hydro-électrique d'East River Sheet Harbour à Malay Falls (Nouvelle-Écosse). Les sujets ayant servi à l'expérience étaient des tacons atlantiques (*Salmo salar* L.) provenant d'un établissement piscicole et ayant une longueur à la fourche d'au moins 15 centimètres. On a évalué la mortalité attribuable aux turbines, la vitesse d'avalaison et l'efficacité d'une passe migratoire aménagée en surface (avec et sans dispositif de déviation du bief d'amont) en lâchant des tacons à 100 mètres en amont de la passe migratoire. L'utilisation de la passe migratoire sans dispositif pour faire dévier le poisson du bief d'amont a réduit la mortalité attribuable aux turbines, qui atteignait en moyenne 10,6 ± 2,3 pour cent, ($X \pm S_{\bar{x}}\, t_{0.05}$), a 5,1-5,7 pour cent de l'ensemble des saumoneaux de descente.

L'efficacité moyenne de la pass migratoire sans dispositif de deflection fut de 45,9 pour cent (21,7-71,4 pour cent) pendant les cinq jours d'essais individuels et de 51,7 pour cent (32,2-80,9 pour cent) pour toute la période de recapture de chaque groupe de sujets d'expérience.

L'aménagement d'un dispositif de deflection du bief d'amont pour orienter les tacons vers la passe migratoire n'a pas augmenté l'efficacité de cette dernière. L'efficacité moyenne de la passe migratoire lors de ces expériences varia respectivement de 18,1 à 20,4 pour cent pour les essais de cinq jours et les périodes totales de recapture.

La majorité (86,0-86,4 pour cent) des sujets d'essai recapturés le furent dans la passe migratoire dans les cinq jours de leur relâchement au bief d'amont de Malay Falls.

Si l'on se fonde sur le délai de recapture de 50 pour cent (médiane) de l'ensemble des sujets d'essai à la passe migratoire de Ruth Falls, 5,8 kilomètres en aval, les tacons ayant emprunté la passe migratoire seraient arrivés un jour plus tard que ceux ayant franchi les turbines.

Mots clés: tacons atlantique, barrage d'une usine hydro-électric, avalaison, la passe migratoire, dispositif de déviation, efficacité de la passe migratoire, vitesse d'avalaison, mortalité attribuable aux turbines.

INTRODUCTION

Although written historical records on the status of Atlantic salmon in East River Sheet Harbour are lacking, older residents of the basin maintain that prior to the late 1920s — before a series of hydro-electric and storage dams was constructed — it was one of the best salmon rivers in Nova Scotia. Runs of salmon to the river then are estimated to have numbered 2,000 fish annually.

Following construction of the dams, the estimated annual salmon runs to the river declined to only 70 fish in 1964; and by 1965, salmon were eliminated from East River above Malay Falls, where 95% of the potential salmon habitat is located (Ducharme 1972*a*).

In 1966, the federal Department of Fisheries undertook a program to restore the salmon run. The program is described in detail by Ducharme (1972*a*). In summary, it endeavoured to rebuild stocks by: (1) transferring mature adult salmon from an adjacent river, (2) stocking supplemental hatchery fish, (3) protecting adults, (4) making the river reaches above the dam accessible to salmon, and (5) reducing turbine mortalities at Ruth Falls (louvers provided) and Malay Falls (skimmer bypass provided).

Despite this concerted effort to restore the run to its estimated present annual potential of 1,090 fish (Ducharme 1972*a*), the greatest number of salmon counted through the fishway at Ruth Falls has been 270, in 1976.

Commercial overexploitation in the estuary (Gray, personal communication)[1] and turbine mortality (immediate and long-term) at the two hydroelectric dams are possible reasons for the low rates of stock recruitment and the delay in attaining the potential, annual river escapement.

This study was undertaken in 1975 to assess the extent of turbine mortality for Atlantic salmon smolts passing the Malay Falls Hydroelectric Dam and to determine the degree of smolt-passage protection afforded by a newly constructed surface bypass, designed to aid fish in circumventing the turbines. It was also desired to know whether deflector screens angled across the forebay would effectively guide smolts to the bypass.

DESCRIPTION OF STUDY AREA AND FACILITIES

East River is located about 113 km (70 mi) northeast of Halifax, Nova Scotia. It drains an area of 648 km² (250 mi²), as it passes through 45 km (28 mi) of heavily forested country and empties into the Atlantic Ocean at the town of Sheet Harbour (Fig. 1). Two hydroelectric dams are located on the main stem of the river, at Ruth Falls and Malay Falls. Water is diverted to each of the hydroelectric stations via power canals. Five other dams upstream from Malay Falls are used for storing or controlling flows for power production.

A vertical-slot fishway with trapping and trucking facilities is provided at Ruth Falls to move Atlantic salmon upstream beyond impassible dams. A louver guidance and bypass system operates in the Ruth Falls power canal to pass downstream migrant smolts around the hydroelectric turbines.

The present study was concentrated immediately upstream from the Malay Falls Hydroelectric Dam (Figs. 1 and 2), with smolt recovery sites located here and at the Ruth Falls louvers.

At Malay Falls, water is diverted to the powerhouse via a 200-m-long x 22-m-wide canal. A U-shaped, fibreglas-flume bypass, to replace an existing deteriorated structure, was installed in 1974 near the face of the powerhouse (Fig. 2) to assist in safely passing salmon smolts around the turbines. This was considered necessary because spilling at the storage (diversion) dam is normally of short duration, $\lesssim$10 days (Fig. 3), and out of phase with peak smolt migration which normally occurs from May 22 to 25 (Ducharme 1972*a*). Spilling occurs only when plant capacity (36.2 m³/sec) at Malay Falls is exceeded (Fig. 3). A total of 117 m³/sec discharge can be accommodated by adjustable gates (17 m³/sec) and a rollway.

High, normal and low headpond and tailwater levels are shown (Fig. 4). Smolts must sound to a depth of between 0.61 m and 1.83 m (2 and 6 ft) to enter the turbine intakes.

The maximum power production per generating unit is 1,200 kw, and the blades of the Francis turbines rotate at 225 rpm at normal rated head.

The adjustable flow control gate at the entrance to the fish bypass is designed to operate within 0.55 m of headpond fluctuation.

METHODS

Twelve lots, each of approximately 500 hatchery-reared smolts (2-yr olds and $\gtrsim$15 cm length), were released near the head of the power canal — about 100 m upstream from Malay Falls powerhouse and fish bypass (Fig. 2) — over the period May 26-June 12, 1975. All fish were adipose fin-clipped and carried numbered Carlin tags attached through the musculature, just anterior to the dorsal fin.

A fish trap was installed in the stilling pool at the entrance to the fish

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[1]Gray, R.W. Biologist, Freshwater and Anadromous Division, Resource Branch, Fisheries and Marine Service, Department of Fisheries and Oceans, Halifax, Nova Scotia.

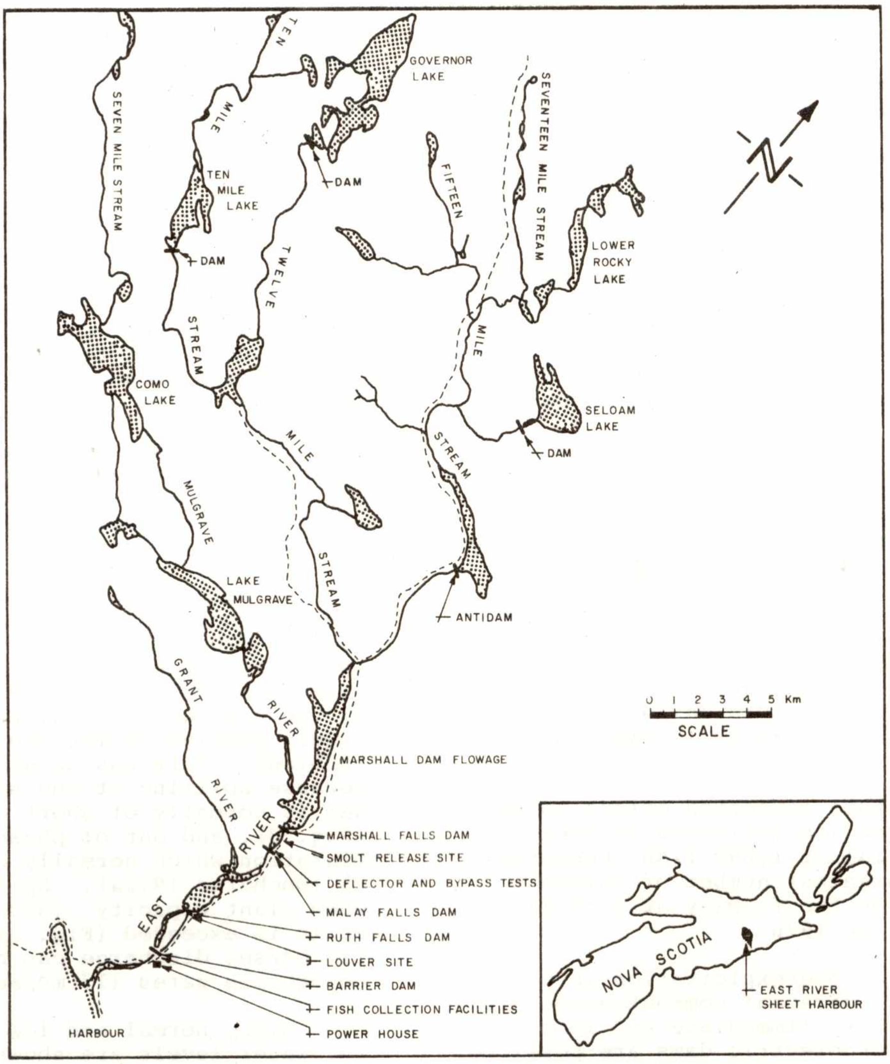

FIG. 1. East River Sheet Harbour, showing its geographic position and various site developments and work locations.

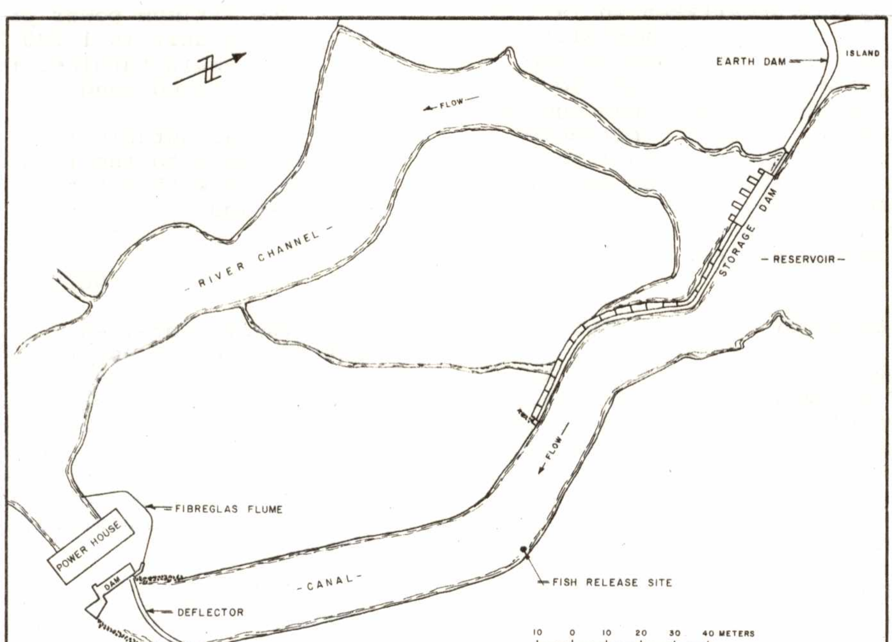

FIG. 2. Site plan of Malay Falls Hydroelectric Dam, East River Sheet Harbour, Nova Scotia.

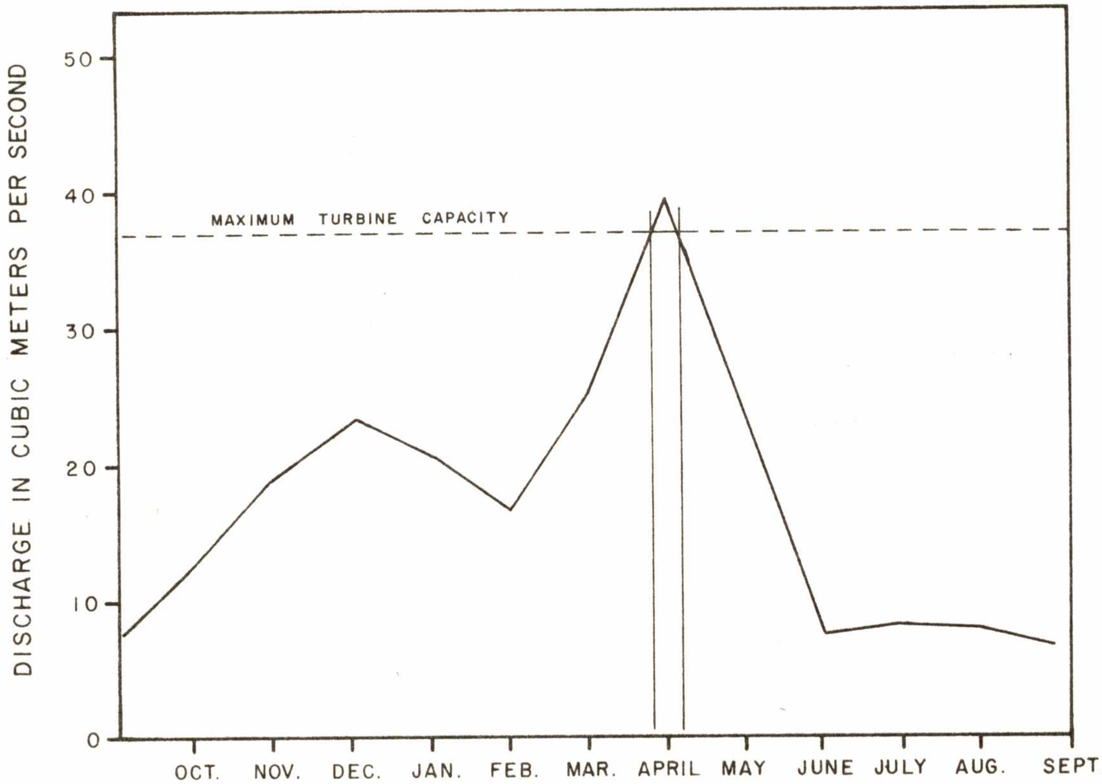

FIG. 3. Mean monthly river discharge below Malay Falls Hydroelectric Dam, showing turbine flow capacity and period of spillway discharge.

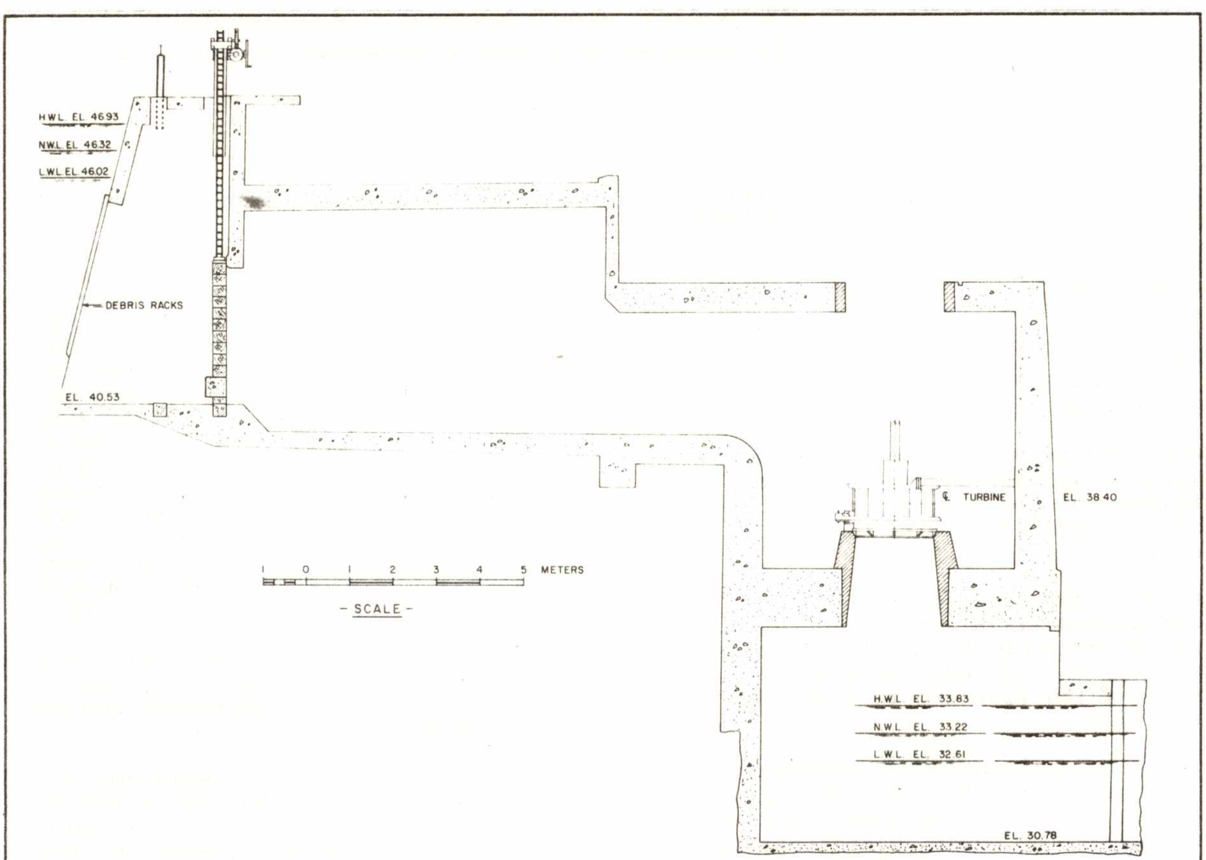

FIG. 4. Transverse section through Malay Falls Hydroelectric Dam on center line of Unit No. 1, showing forebay and tailrace water levels.

bypass flume, and all tagged hatchery smolts passing through the facility were counted and tag numbers were recorded. A similar procedure was executed at the Ruth Falls louver site.

To estimate the extent of mortality for smolts that passed through the turbines at Malay Falls, it was necessary to first compute the numbers of turbine fish which reached Ruth Falls and then compare this figure with the numbers of smolts passing through the turbines (Table 1).

Since the tag numbers of each test smolt using the bypass were recorded, it was possible by omission to determine the numbers of smolts of each test group using the turbines. To estimate the numbers of turbine fish reaching Ruth Falls, the guiding efficiency of the Ruth Falls louvers had to be determined. Only bypass smolts were used in this calculation, since it was expected that there would be little, if any, mortality of smolts employing this route, in their short migration to Ruth Falls.

TABLE 1. Estimated turbine mortalities for Atlantic salmon smolts passing Malay Falls Hydroelectric Dam, East River Sheet Harbour, Nova Scotia, 1975.

Test no.	Smolts released (A)	Smolts recaptured in bypass (B)	Smolts passing bypass [1] (C)	Smolts through turbines (D=A-B)	Smolts from 'C' recaptured at Ruth Falls (E)	Ruth Falls louver efficiency (%) ($F=\frac{E}{C}\cdot 100$)	Smolts from 'D' captured at Ruth Falls (G)	Total smolts from 'D' reaching Ruth Falls ($H=\frac{100}{F}\cdot G$)	Turbine mortality (%) at Malay Falls ($M=\frac{D-H}{D}\cdot 100$)
1	498	161	161	337	115	71.4	214	300	11.0
2	497	160	160	337	104	65.0	198	305	9.5
3	467	169	169	298	112	66.3	159	240	19.5
4	500	128	128	372	67	52.3	193	369	0.8
5	496	147	147	349	85	57.8	200	346	0.9
6	498	161	161	337	71	44.1	142	322	4.4
7	495	35	35	460	18	51.4	154	300	34.8
8	486	28	28	458	12	42.9	169	394	14.0
9	495	109	109	386	59	54.1	155	287	25.6
10	495	276	271	219	189	69.7	130	187	14.6
11	497	363	345	134	218	63.2	95	150[2]	-
12	492	398	316	94	154	48.8	41	84	10.6
Total	5,916	2,135	2,030	3,781	1,204	59.3	1,850	3,284	10.6±2.3[3]

[1]These figures are adjusted for mortality in the bypass.

[2]This would have resulted in a negative value for 'M' and was therefore not included in the estimation of mean turbine mortality.

[3]Individual mortality estimates were changed to arcsin $\sqrt{\%}$ to normalize data, and the average was then determined. The ± value represents the 95% confidence limit for the mean or $\bar{x} \pm S_{\bar{x}}\, t_{.05}$.

To estimate mean turbine mortality, individual percent mortalities were normalized by transformation to arcsin $\sqrt{\%}$. Ninety-five percent confidence limits of the mean were estimated according to Alder and Roessler (1964), by computing the standard error of the mean and multiplying it by the student "t" value for 95% confidence. The confidence interval for the mean then becomes $\bar{x} \pm S_{\bar{x}} t_{0.05}$.

Tagged smolts recaptured at the Malay Falls bypass trap were used to estimate the efficiency of the bypass under control (no deflector) and test (with deflector) conditions.

The smolt deflector described by Semple and McLeod (1976) was angled across the forebay of the dam to the bypass entrance (Fig. 2). It was operated at 45° to the approaching flow and to a maximum depth of 2.44 m.

Daily total kilowatt-hour production for the hydroelectric station and hourly water temperatures were recorded. During the period 0800-1700 hours, water passing over the control gate to the bypass was maintained at a depth of 24 cm, or a flow rate of 0.337 m^3/sec. This reduced the natural variation in flow at the site to a minimum, and permitted a better reflection of bypass efficiency under different power-production regimes.

The relationship between bypass efficiency and the magnitude of power production (average, total, daily, kwh production) was tested over the period in which 50% of the total test-lot smolts were recovered. This reduced the effect of delayed migration from the release site on subsequent results. Plots of the data without the deflector (controls) and with the deflector suggested separate regression analysis, requiring, in the case of control tests, the transformation of kilowatt-hour production to its logarithmic value. The regression statistics were computed according to Alder and Roessler (1964).

The relationship between rate of power production and turbine mortality was examined by a similar regression and correlation analysis.

One hundred and fifty wild smolts were tagged and released on May 26 in the Ruth Falls power canal to determine if their behavior (recapture rate), when confronted by a guidance device such as louvers, was the same as that of hatchery fish released at Malay Falls during May 26-28. A chi-square analysis was performed to test the null hypothesis.

RESULTS AND DISCUSSION

TURBINE MORTALITY

Turbine mortality of smolts at Malay Falls ranged from 0.8% to 34.8%, averaging 10.6±2.3% for eleven test groups (Table 1). This average is comparable to the mean mortality of 13% reported by Ducharme (1972*b*) for a previous investigation at this site. It would appear, however, through cross-reference to Fig. 5 and Fig. 8, that turbine mortalities for test fish are least when wild smolts are passing Malay Falls in greatest numbers and are greatest when they are not. This would suggest that turbine mortality of wild smolts at Malay Falls is even less than the 10.6% figure just cited.

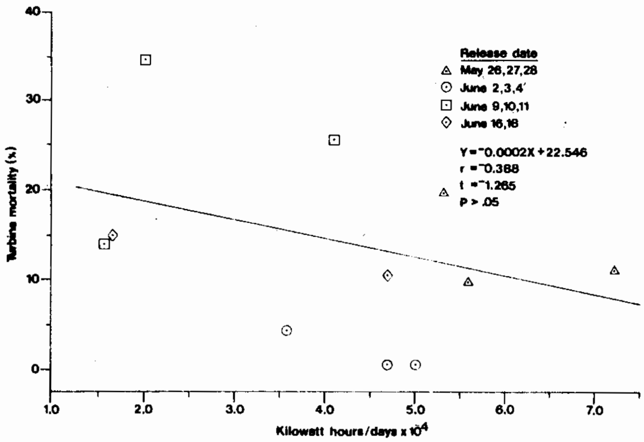

FIG. 5. Relationship between rate of power production and percent turbine mortality for Atlantic salmon smolts at Malay Falls Hydroelectric Dam, East River Sheet Harbour, Nova Scotia.

No significant relationship was evident between power production and turbine mortality ($r=-0.388$, $P>0.05$) (Fig. 5). As headpond elevation at this station is maintained at a nearly constant level, average total kwh/day is a good reflection of relative, mean, daily turbine discharge, which increases as power production increases. The lack of correlation between power production and turbine mortality therefore indicates that increased turbine flow does not result in increased mortality. This was not expected, because it was thought that increased turbine flow would result in greater numbers of smolts being drawn through the turbines, and therefore result in higher mortality.

Chi-square analysis revealed that turbine mortality was not the same for all release periods ($\chi^2=252.27$, $P<0.001$), and a G-test (Sokal and Rohlf 1969) showed that the turbine mortality rate was associated with the time of smolt release ($G=296.06$, $P<0.001$).

Late May and late June turbine mortality rates were similar ($\chi^2=3.84$, $P>0.05$). On these occasions, water temperatures and rates of power production (Fig. 5) were near the extreme high and low values encountered during the field program. These results would suggest that factors other than temperature and rate of power production are responsible for the seasonal differences in turbine mortality that were found.

As Farmer et al. (1978) point out, there are seasonal differences in the biochemical and physical condition of smolts prior to, during, and following their migration to salt water. In studies on hatchery smolts, they found that migratory urge was associated with low condition factor (K) and decreasing lipid level (potential energy reserve). This would appear to operate against the maintenance of high survival during the seaward descent of smolts. Other factors, such as cavitation, percent wicket-gate opening and plant sigma (elevation of turbine runner in relation to tailwater) – though not considered in the present study – may have also influenced the outcome of the tests (Bell et al. 1967, Lucas 1962, and Cramer and Oligher 1964).

Fish mortalities in Francis turbines operated under different heads are compared (Table 2). Results indicate that at operating heads >43.3 m, average turbine mortality can range from 27.0% to 41.9% for the limited number of stations and species considered, whereas, at stations with lower operating heads (12.2 m-43.3 m), such as Malay Falls, turbine mortality can range from 0% to 10.6%.

The greater size of fish used at Malay Falls may account for the slightly higher mortality experienced at this station than in other hydro-electric plants with low operating heads (≤43.3 m). Fish size has been shown by Hannover (1957) and reported by Bell et al. (1967) to be a factor affecting the magnitude of turbine mortality or injury to fish. In general, larger fish experience a greater incidence of injury and mortality than do smaller individuals.

To consider only fish size, turbine type and operating head in relation to turbine mortality, is to oversimplify a very complex relationship with other factors which may have a greater effect. Cramer and Oligher (1964) have found, for instance, that the characteristics of a Francis runner which will provide maximum fish survival are relatively low runner speed, relatively deep setting of turbines, and maximum clearance between the turbine blades and between the ends of the runner blades and edges of the wickett gates.

BYPASS EFFICIENCY

Bypass efficiencies for control tests without deflectors ranged from 21.7% to 71.4% for the five-day test periods and from 32.2% to 80.9% for the whole recovery period. Test conditions were not constant during the latter period. The mean bypass efficiencies for both periods were 45.9% and 51.7%, respectively (Table 3).

TABLE 2. Comparison of fish mortalities in Francis turbines at different operating heads and different mean lengths of fish.[1]

Location	Head (m)	Species	Mean length (cm)	Turbine mortality (%)	References
Malay Falls (East River)	12.2	Atlantic salmon	>15.0	10.6±2.3	Present study
Elwha (Elwha River)	31.7	Chinook salmon	7.0	0	Schoeneman & Junge 1954
Ruskin (Stave River)	39.6	Sockeye salmon	8.6	10.5	Hamilton & Andrew 1954*a*
Seton (Seton Creek)	43.3	Sockeye salmon	8.6	9.2	Andrew & Geen 1958
Glines Dam (Elwha River)	59.2	Coho salmon	10.8	30.0	Schoeneman & Junge 1954
		Chinook salmon	7.0	33.0	
Baker Dam (Baker River)	76.2	Sockeye salmon	9.7	34.0	Hamilton & Andrew 1954*b*
		Coho salmon	9.8	28.0	
Puntledge (Puntledge River)	106.8	Steelhead trout	7.6-16.5	41.9	Can. Dept. Fish 1958
		Rainbow trout	5.1- 8.9	27.5	
		Rainbow trout	3.8- 5.8	28.8	
		Native salmon	3.0- 5.3	32.6	
Shasta Dam (Sacramento River)					
No. 1 test	125.0	Chinook, steelhead & rainbow (in both tests)	7.6	27.0	Anonymous 1962
No. 2 test	131.8		22.9	31.0	

[1]Adapted principally from Can. Dept. Env. and Intern. Pac. Salm. Fish. Comm. 1971 and Lucas 1962.

TABLE 3. Fish bypass efficiency and recovery rates of tagged, hatchery-reared Atlantic salmon smolts under different test conditions at Malay Falls Hydroelectric Dam, East River Sheet Harbour.

	Smolt releases		Bypass efficiency: 5-day test period		Bypass efficiency: Whole recovery period[2]		Total recoveries taken in 5-day test period (%)	Test condition
Test No.	Date	No.	No.	%[1]	No.	%[1]		
1	May 26	498	108	21.7	161	32.3	67.1	No deflector (controls)
2	27	497	137	27.6	160	32.2	85.6	
3	28	467	137	29.3	169	36.2	81.1	
4	Jun 2	500	115	23.0	128	25.6	89.8	Deflector
5	3	496	125	25.2	147	29.6	85.0	
6	4	498	144	28.9	161	32.3	89.4	
7	9	495	30	6.1	35	7.1	85.7	
8	10	486	19	3.9	28	5.8	67.9	
9	11	495	107	21.6	109	22.0	98.2	
10	Jun 16	495	269	54.3	276	55.8	98.9	No deflector (controls)
11	17	497	355	71.4	363	73.0	97.8	
12	18	492	350	71.1	398	80.9	87.9	
Mean				45.9		51.7	86.4	No deflector
Mean				18.1		20.4	86.0	Deflector

[1]Percentages based on total fish released.
[2]Test conditions during the remainder of the recovery period are not homogeneous.

Control (no deflector) groups tested in late May and late June had dissimilar recovery rates in the bypass (χ^2=462.75, P<0.001). Similarly, with the deflectors in operation, early June and mid-June test groups were recovered in significantly different proportions (χ^2=115.31, P<0.001). This would suggest that bypass efficiency is not only affected by operation of the deflectors but also by other conditions, which change with time and alter the behavior and migratory disposition of smolts.

At Ruth Falls louvers, tagged hatchery and wild smolts were recovered at the same rate (χ^2=0.949, P>0.05) (Table 4). Hence, both groups probably behave similarly, when confronted by a guidance device such as the floating-screen deflector system used at Malay Falls.

With the deflector in operation, bypass efficiencies for the five-day test periods ranged from 3.9% to 29.9% and averaged 18.1%. Considering the whole recovery period, bypass efficiencies ranged from 5.8% to 32.3% and averaged 20.4% (Table 3).

It is believed that the deflector reduced bypass efficiency because water pressure caused the screens to bend vertically and horizontally inwards towards the dam. At Tusket River, Nova Scotia, where a similar deflector arrangement was tested, bypass efficiencies were lower when the deflection angle relative to the current direction was large (90°). Semple and McLeod (1976) concluded that if the deflection angle is too high, smolts will sound under the screens and become more susceptible to turbine entrainment. A more rigid supporting frame might have prevented distortion from the intended deflection angle (45°) and resulted in improved bypass efficiency. The Tusket River experiments gave a mean bypass efficiency (5-day) of 72.1% when the deflector angle was maintained at 45° to the approaching flow and the screens were operated to a depth of 2.44 m.

TABLE 4. Chi-square test to determine if tagged hatchery and wild Atlantic salmon smolts are taken at the same rate, at Ruth Falls louvers, East River Sheet Harbour, Nova Scotia.

Groups	Categories	Observed frequencies (O)	Expected frequencies (E)	O-E	(O-E)²	$\frac{(O-E)^2}{E}$
Wild smolts	Recovered tags	107	103.8	3.2	10.24	0.099
	Unrecovered tags	43	46.2	-3.2	10.24	0.222
Hatchery smolts	Recovered tags	331	339.1	-8.1	65.61	0.193
	Unrecovered tags	159	150.9	8.1	65.61	0.435
$\chi^2=\Sigma\left[\frac{(O-E)^2}{E}\right]$						0.949

In the case of control tests without deflectors at Malay Falls, a negative correlation (r=-0.767, P>0.1) was found between bypass efficiency and power production. The line of best fit and the equation from which it was derived are given in Fig. 6. As power production or relative turbine flow increased, bypass efficiency decreased. The degree of correlation, however, was not significant (P>0.1).

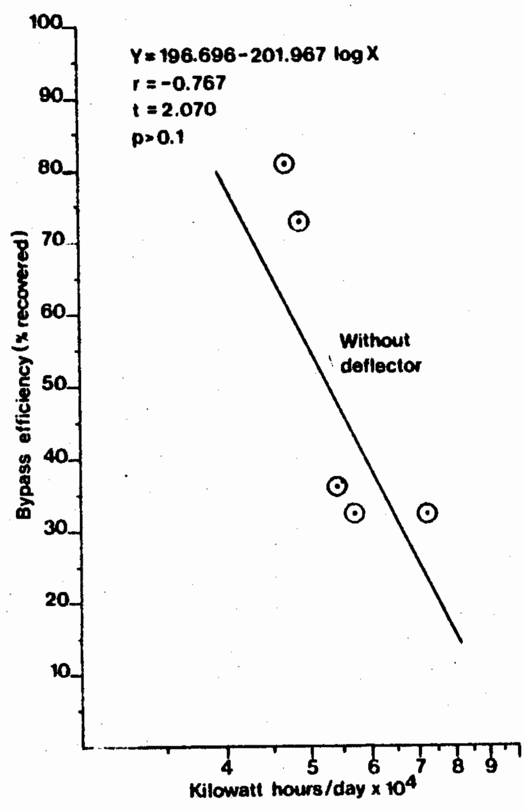

FIG. 6 (right). Relationship between bypass efficiency and rate of power production for Atlantic salmon smolts at Malay Falls Hydroelectric Dam, East River Sheet Harbour, Nova Scotia, without deflectors.

With the deflectors in operation, bypass efficiency was positively correlated ($r=0.852$, $P<0.05$) (Fig. 7) with power production, or relative flow, and increased as flow increased. Since mean forebay velocities increase in proportion to flow, improved bypass efficiency may be due to a more favourable screen approach velocity.

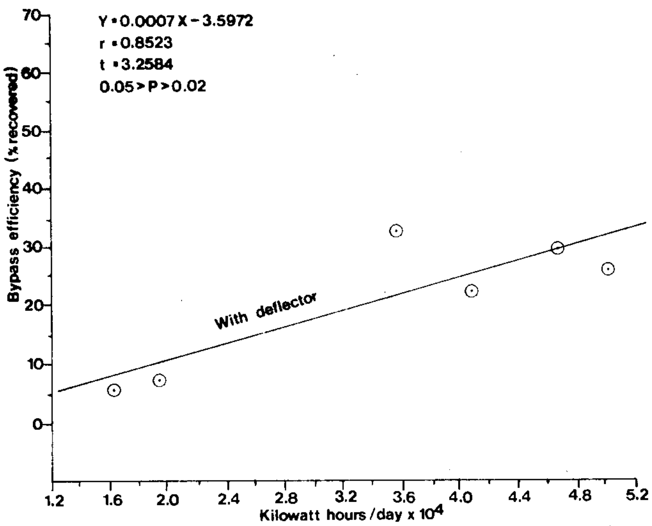

FIG. 7. Relationship between bypass efficiency and rate of power production for Atlantic salmon smolts at Malay Falls Hydroelectric Dam, East River Sheet Harbour, Nova Scotia, with a deflector guidance system.

It was observed that smolts passing under the screens milled around the forebay and moved along the downstream side of the screens. They did not appear to return upstream to take advantage of the bypass. However, when no deflector screen was employed, they continued to search for a surface outlet even if missed in the first instance.

Average turbine mortality at Malay Falls (10.6%) can be reduced by 45.9%-51.7% from that expected without the bypass and deflectors. Mean turbine mortality rate for the whole smolt run can therefore be expected to range from 5.1% to 5.7%, which should yield adequate survival for future salmon recruitment to the river.

The overall mean water velocity along the length and depth of the smolt deflector screens was 0.26 m/sec (Table 5). The greatest velocities (0.28-0.30 m/sec) were found at mid-depth of the screen and in the area of the bypass entrance.

A summary of the main hydraulic features of the fish bypass and flume at Malay Falls is given in Table 6. During the present study, the depth of spill over the control gate at the bypass entrance was maintained at 24 cm. This resulted in a bypass flow of 0.337 m^3/sec, 16 cm deep, with a velocity of 6.1 m/sec. The velocity over the control gate at this flow was 1.34 m/sec and, when related to the average bypass approach velocity of 0.26 m/sec (Table 5), resulted in a bypass velocity acceleration of 515%. Bypass velocity accelerations of 150% for Atlantic salmon smolt (Ducharme 1972*b*) and 140% for sockeye, chinook and coho juvenile (Bates and Vinsonhaler 1957; Ruggles and Ryan 1964) have previously been found to be prerequisites for high bypass guidance efficiency. Other things being equal then, the bypass acceleration observed at Malay Falls is considered more than adequate for effective bypass operation.

TABLE 5. Mean water velocities (m/sec) for a series of six measurements made at equally spaced stations along the length of the smolt deflector screens at Malay Falls Hydroelectric Dam, East River Sheet Harbour.

Depth (m)	Station number[1] 1	2	3	4	5	6	7	8	$\bar{x}$
0.6	0.24	0.23	0.23	0.24	0.28	0.30	0.30	0.29	0.26
1.2	0.25	0.30	0.23	0.27	0.29	0.29	0.30	0.32	0.28
1.8	0.25	0.26	0.24	0.25	0.30	0.30	0.29	0.26	0.27
2.4	0.12	0.21	0.22	0.22	0.26	0.29	0.28	0.31	0.24
$\bar{x}$	0.22	0.25	0.23	0.25	0.28	0.30	0.29	0.30	0.26

[1]Station No. 1 is located on the opposite shore from the bypass entrance.

TABLE 6. Hydraulic data for the fish bypass at Malay Falls Hydroelectric Dam, East River Sheet Harbour.

Water depth (cm): Spill over control gate	Water depth (cm): Average along flume	Average water velocity (m/sec): Over control gate	Average water velocity (m/sec): Throughout flume	Calculated discharge (m^3/sec)
24	16	1.34	6.10	0.337
18	14	1.28	5.70	0.238
12	11	1.22	5.34	0.153

SMOLT MIGRATION

During the course of this study, only the turbines or bypass were available to smolts for continued downstream migration. No spilling at the diversion dam occurred after the investigation commenced.

At Malay Falls, peaks of abundance of wild smolts occurred on May 30, June 3 and June 13. Respective water temperatures on these occasions were 12°, 13° and 14°C. The run showed signs of termination in late June (Fig. 8) when water temperatures were reaching 17°-20°C. Thus, it appears that the timing of the experiments with hatchery smolts conformed with the natural migration period of wild fish.

Peak recovery of hatchery smolts at Ruth Falls usually occurred earlier and was of greater magnitude for turbine smolts

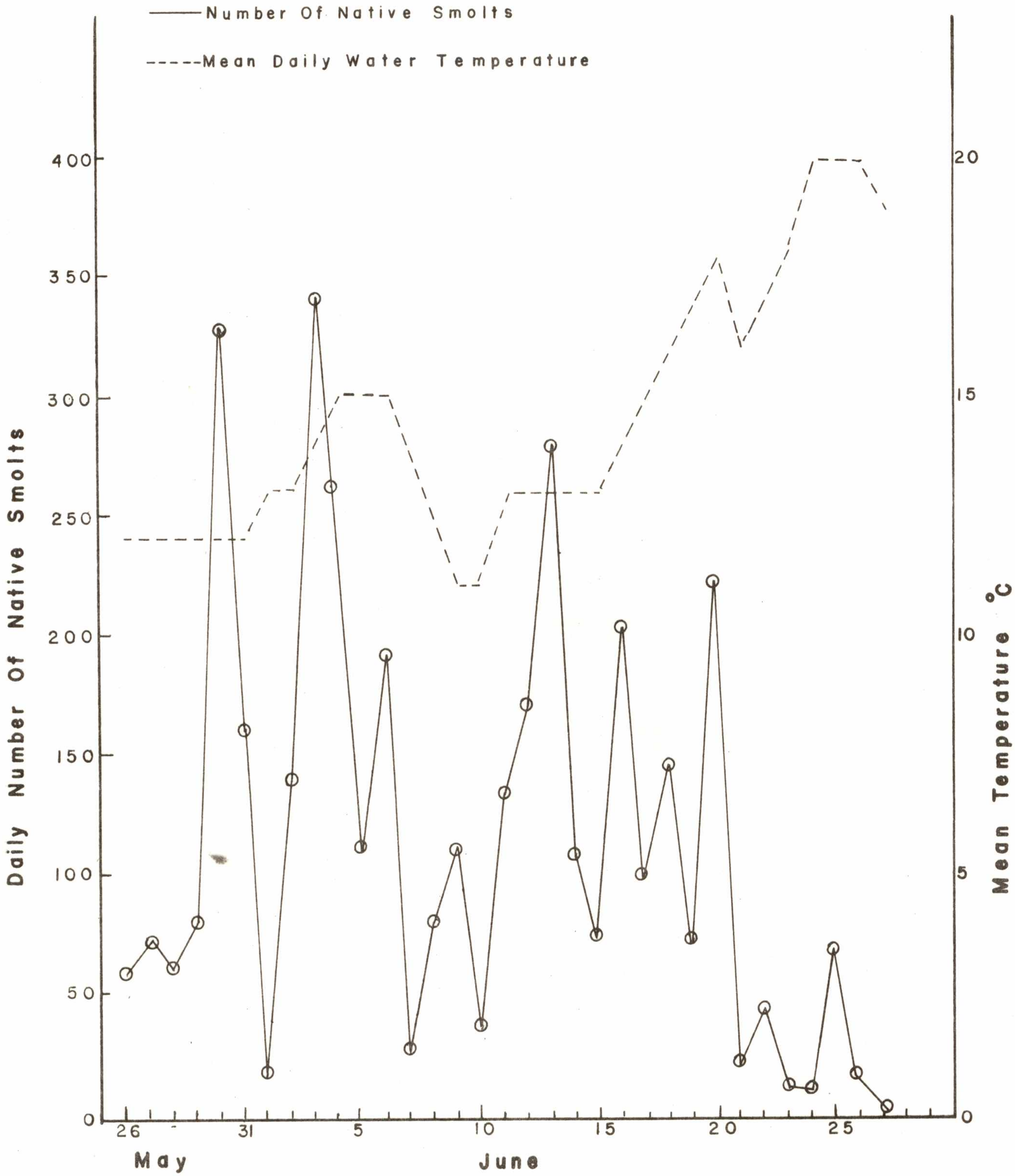

FIG. 8. Seasonal distribution of wild Atlantic salmon smolts and average daily water temperature at Malay Falls, East River Sheet Harbour, Nova Scotia.

than for bypass smolts (Fig. 9, A-E). On the peak days of recovery at Ruth Falls, from 14% to 29% of the total number of recaptures were taken.

Cumulative recapture rates of hatchery smolts at Ruth Falls indicated that turbine smolts generally pass downstream more rapidly than those using the bypass (Fig. 9, F-J), regardless of release date. The median number of smolts recovered at Ruth Falls, from all tests combined, occurred about one day (0.84 days) earlier for turbine smolts than for bypass smolts. A postulate for the faster downstream migration of turbine smolts is that they were

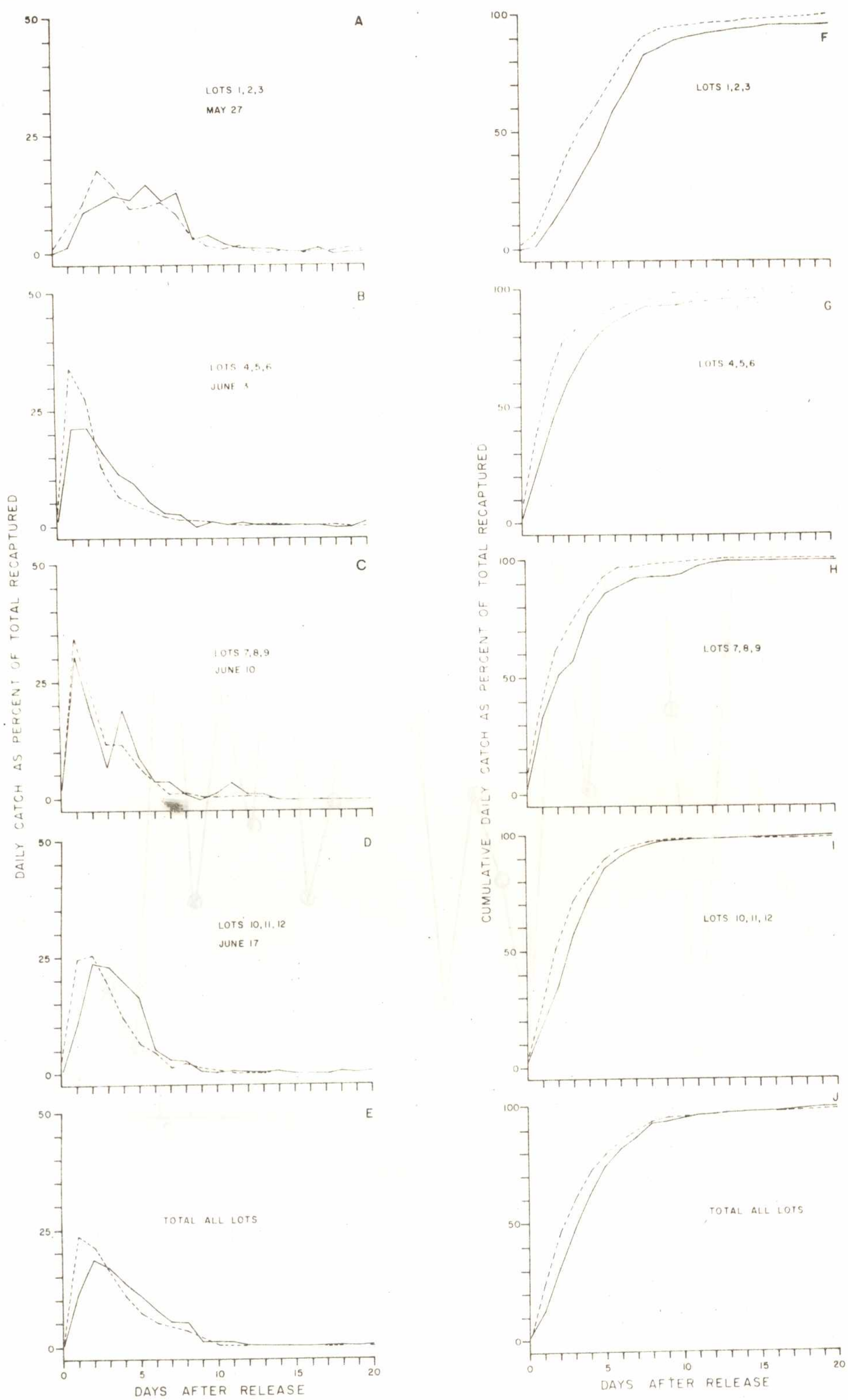

FIG. 9 (A-J). Daily and cumulative rates of passage of turbine and bypass smolts from Malay Falls forebay to Ruth Falls louvers, East River Sheet Harbour, Nova Scotia. (------ turbine fish, ——— bypass fish.)

entrained in the relatively faster turbine flows and moved rather passively with prevailing water currents (Stuart 1964). Flow from the bypass plunges 4.7 m into the tailrace of the dam and loses a great deal of its horizontal velocity component. Raymond (1968) found that the rate of migration of chinook salmon *(Oncorhynchus tshawytscha)* through the flowing and impounded stretches of a river was directly related to river discharge.

Although not great, the faster migration of turbine smolts to Ruth Falls (Fig. 9, F-J) may help to offset turbine mortality by removing the fish more quickly from the influence of predators such as brown trout *(Salmo trutta)* and brook trout *(Salvelinus fontinalis)* and fish-eating birds in the river.

Most of the smolts recovered at Ruth Falls were taken within five days of release at Malay Falls (43%-88%), which is 5.8 km upstream (Fig. 9, F-J). With all fish combined, 90% of the total recaptures were made within seven to eight days of release. For this reason and the fact that median passage speed (1.9-2.9 km/day) compared favorably with unimpeded smolt migration (3.8-8.0 km/day - Knight 1975), it is unlikely that the majority of smolts passing dams at Malay Falls and Ruth Falls were seriously delayed in their seaward descent. No residualism in the Malay Falls headpond is therefore anticipated.

SUMMARY AND CONCLUSIONS

Turbine mortality of Atlantic salmon smolts ($\bar{>}$15 cm fork length) at Malay Falls is not great and averages 10.6±2.3% ($\bar{x} \pm S_{\bar{x}} t_{0.05}$). It is in the same order of magnitude as that experienced in Francis turbines at other low-head dams. Although the immediate consequences of smolt passage through Malay Falls turbines are not considered serious, the long-term effect of single and multiple passage through turbines and bypasses at Malay Falls and Ruth Falls deserves consideration.

There was no significant ($P>0.05$) correlation between turbine mortality and rate of power production.

The bypass flume at Malay Falls power station reduces the turbine mortality to a range of 5.1%-5.7%, by providing a safe route around hydroelectric turbines for 45.9%-51.7% of the descending smolts. This is accomplished without smolt deflector screens.

Bypass efficiency was not improved by provision of a forebay deflector system. A more rigid frame would have to be constructed to prevent distortion in the deflector and achieve bypass efficiencies superior to those of the control tests, where no deflectors were employed.

Recapture rates of wild and hatchery smolts at Ruth Falls louvers were similar. It is therefore assumed that wild and hatchery smolts behave similarly when confronted by other guidance devices such as the one used at Malay Falls.

Bypass efficiency and rate of power production were not significantly correlated ($P>0.01$) when deflectors were used. However, a significant correlation ($P<0.05$) between these two variables was obtained when deflectors were not provided.

Approach velocity at the Malay Falls bypass entrance was accelerated 515%. It is therefore considered more than adequate for achieving relatively high smolt passage efficiency in the bypass.

The timing of experiments with hatchery smolts conformed with the timing of the wild smolt migration. Wild smolts peaked in abundance at Malay Falls during the late-May to early-June period, and migration was virtually complete by June 27, when water temperatures were reaching 17°-20°C.

The speed of migration to Ruth Falls is greater for turbine smolts (one day earlier) than for bypass smolts. For this reason, and the fact that the cumulative rate of downstream passage (90% in seven to eight days) is high, turbine mortality may be partly offset through less time exposure of turbine smolts to freshwater predators. Also under these conditions, no residualism is anticipated in the Malay Falls forebay.

The installation of bypass flumes so that bypass smolts become better entrained in the outflow from the turbines might hasten their downstream passage and thereby increase their survival during migration to salt water.

It follows from the above-mentioned observations that provision of an additional bypass outlet would further reduce the magnitude of turbine mortality encountered at Malay Falls power station, but to what extent is uncertain.

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REFERENCES

Alder, H.L. and E.B. Roessler. 1964. Introduction to probability and statistics, 3rd ed. W.H. Freeman and Co., London.

Andrew, F.J. and G.H. Geen. 1958. Sockeye and pink salmon investigations at the Seton Creek hydroelectric installation. Intern. Pac. Salm. Fish. Comm., Prog. Rept. 4, 74 p.

Anonymous. 1962. Fish passage through turbine-tests at Shasta Hydroelectric plant. U.S. Army Engineering District. Walla Walla. Letter Rept. (Unpubl.).

Bates, D.W. and R. Vinsonhaler. 1957. Use of louvers for guiding fish. Trans. Amer. Fish. Soc. 86:38-57.

Bell, M.C., A.C. DeLacy, G.J. Paulik and R.A. Winnor. 1967. A compendium on the success of passage of small fish through turbines. Fish. Eng. Res. Program, U.S. Army, North Pacific Div., Corps of Eng., Portland, Oregon. 268 p.

Can. Dept. Env. and Intern. Pac. Salm. Fish. Comm. 1971. Fisheries problems related to Moran Dam on the Fraser River. Vancouver. 206 p. (unpubl.).

Can. Dept. Fish. 1958. The fisheries problems associated with the power development of the Puntledge River, Vancouver Island, B.C. 40 p.

Cramer, F.K. and R.O. Oligher. 1964. Passing fish through hydraulic turbines. Trans. Amer. Fish. Soc. 93(3):243-259.

Ducharme, L.J.A. 1972*a*. Atlantic salmon *(Salmo salar)* rehabilitation in the East River, Sheet Harbour, Nova Scotia - project description and initial results. Can. Dept. Env., Fish. Serv., Res. Devel. Br., Prog. Rept. No. 4. 31 p.

Ducharme, L.J.A. 1972*b*. An application of louver deflectors for guiding Atlantic salmon *(Salmo salar)* smolts from power turbines. J. Fish. Res. Bd. Canada 29: 1397-1404.

Farmer, G.J., J.A. Ritter and D. Ashfield. 1978. Seawater adaption and parr-smolt transformation of juvenile Atlantic salmon, *Salmo salar*. J. Fish. Res. Bd. Can. 35:93-100.

Hamilton, J.A.R. and F.J. Andrew. 1954*a*. An investigation of the effect of Baker Dam on downstream migrant salmon. Intern. Pac. Salm. Fish. Comm. Bull. 6. 73 p.

Hamilton, J.A.R. and F.J. Andrew. 1954*b*. A study of mortality rates of sockeye salmon fingerlings in a turbine at Ruskin Dam. Intern. Pac. Salm. Fish. Comm. (Unpubl.).

Knight, A.E. 1975. Evaluation of radio telemetry methods for monitoring Atlantic salmon smolt movement. U.S. Dept. Int., Fish and Wildl. Serv., Laconia, New Hampshire. Spec. Rept. 9 p. + illust.

Lucas, K.C. 1962. The mortality of fish passing through hydraulic turbines as related to cavitation and performance characteristics, pressure change, negative pressure and other factors. Proc. I.A.H.R. Symp. on Cavitation and hydraulic machinery. Sendai, Japan. Paper B8:307-335.

Raben, K.von. 1957. Uber turbinen und ihre schädliche wirkung auf fische (Turbines and their destructive effect on fishes). Zeitschrift Fur Fischerei und deren Hilfswissen-schaften Sonderdruck aus Band VI, N.F. (1957), Heft 1-7.

Raymond, H.L. 1968. Migration rates of yearling chinook salmon in relation to flows and impoundments in the Columbia and Snake rivers. Trans. Amer. Fish. Soc. 97(4):356-359.

Ruggles, C.P. and P. Ryan. 1964. An investigation of louvers as a method of guiding juvenile Pacific salmon. Can. Fish. Cult. 33:1-68.

Schoeneman, D.E. and C.D. Junge. 1954. Investigations of mortalities to downstream migrant salmon at two dams on the Elwha River. Wash. Dept. Fish., Res. Bull. 3. 51 p.

Semple, J.R. and C.L. McLeod. 1976. Experiments related to directing Atlantic salmon smolts *(Salmo salar)* around hydroelectric turbines. Can. Dept. Env., Fish. and Mar. Serv., Halifax, N.S. Tech. Rept. No. MAR/T-76-2. 23 p.

Sokal, R.R. and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco. 776 p.

Stuart, T.A. 1964. The leaping behaviour of salmon and trout at falls and obstructions. Dept. Agric. Fish. Scot., Freshw. Salmon. Fish. Res. No. 28. 46 p.