

The Effect of Flow Control on Freshwater Survival of Chum, Coho and Chinook Salmon in the Big Qualicum River

by

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Abstract

An environmental control project has been undertaken on a British Columbia coastal stream by the Department of Fisheries of Canada to increase the production of native chum, coho and chinook salmon populations. The works which have been constructed provide for stabilization of winter flows, increase in the minimum summer flow, and a degree of temperature control during summer and early fall. The freshwater survival rate of each species during a four-year period of natural flow conditions is compared with that resulting from the first two years of controlled flow. Chum salmon egg-to-fry survival ranged from 5 to 17 percent under natural conditions and was inversely related to the peak daily discharge during the incubation period. Survival rates in the two years of flow control were 25.2 percent and 24.5 percent respectively. The magnitude of the coho fry emigration near the river mouth was also related to winter discharge stability. Coho spawning populations of similar size, but affected by differing incubation conditions, produced fry emigrations amounting to 0.3 percent (natural flow) and 4.3 percent (controlled flow) of their respective egg potentials. Little variation occurred in coho smolt output over a five year period. Chinook salmon survival ranged from as low as 0.2 percent under natural conditions to 19.8 percent in one year of controlled flow. The largest production of chinook emigrants was accompanied by a substantial change in quality toward smaller size and earlier migration timing.

Introduction

The Big Qualicum River is being developed by the Department of Fisheries of Canada for the purpose of increasing the production of indigenous stocks of chum (*Oncorhynchus keta*), coho (*O. kisutch*) and chinook salmon (*O. tshawytscha*) through environmental control. The initial stage of the project, which is now completed, has included the construction of works to permit both complete regulation of the river discharge and a degree of water temperature control during the summer and early fall. The secondary stage, which has yet to be initiated, will consist of expansion and improvement of the existing spawning grounds.

Fluctuating discharge has been recognized as the major environmental factor involved in the large year to year variations in embryonic survival of Pacific salmon in coastal streams (Neave, 1953; Royce, 1954). It has been shown that egg-to-fry survival rates can be increased substantially by stabilization of river discharge (Wickett, 1952; Gangmark and Bakkala, 1960) and it has also been indicated that the increased survival can be carried through to the adult stage (MacKinnon, Edgeworth and McLaren, 1961). This knowledge provided the biological basis for the Big Qualicum

project. Under the controlled flow regime now in effect on the Big Qualicum River winter flows have been stabilized and the minimum summer discharge level has been raised. In addition to providing stable spawning area for all species the controlled flow regime is expected to increase the stream rearing capacity for coho salmon.

Feasibility studies were initiated in 1957. It was evident during these studies that extreme flooding had, in some years, caused extensive loss of chum salmon spawn and reduced the amount of suitable spawning area through scouring (Wickett, 1959). Construction of the flow control stage of the project commenced in 1960 and was completed in 1964. By November, 1963 flow control had begun and during the following two winters discharge was maintained within a much more stable range than would have occurred under natural conditions.

A study to determine the effects of flow control on the freshwater production of salmon in the Big Qualicum River was started in September, 1959, to provide four years of information on survival rates prior to control. This paper describes the survival rates of chum, coho and chinook salmon relative to stream discharges during the pre-control period and compares them with the results obtained in the first two years of controlled flow. A brief description of the stream and the project is also presented. The project and the basis for its implementation have been described in detail by Clay and Fahlman (1962).

General Description

The Big Qualicum River is located on the east coast of Vancouver Island, British Columbia, approximately 39 miles north of the city of Nanaimo (Figure 1). The headwaters of the system, situated at elevations of up to 4000 feet above sea level, drain through steep glacially-eroded valleys into Horne Lake, which is three square miles in area and 180 feet at maximum depth. In the first one-half mile downstream of the lake the river drops 190 feet through a series of four falls. Between the base of the falls and the river mouth at the Strait of Georgia there is approximately 6.5 miles of river accessible to salmon. Hunt's Creek, the only major tributary between the lake and the sea, enters four miles downstream of the lake.

The drainage area of the Big Qualicum River totals 58 square miles, of which 42.5 square miles are tributary to Horne Lake. On the basis of 13 years of record the mean annual discharge at the river mouth is 286 cubic feet per second. The maximum and minimum discharges recorded have been 7080 cfs and 14 cfs respectively. Approximately 85 per cent of the system's annual runoff comes from Horne Lake, but the portion of the daily runoff contributed below the lake is highly variable, due mainly to flash freshets from Hunt's Creek. The mean annual discharge of Hunt's Creek is in the order of 20 cfs and its maximum discharge approximates 2500 cfs.

The average rate of fall of the Big Qualicum River between the lower falls and the sea is six feet per thousand feet. The total stream bed area is 275,000 square yards and the average width is approximately 70 feet. Wetted area at discharges of 33 cfs and 230 cfs is 186,000 square yards and 260,000 square yards. The riffle portion of

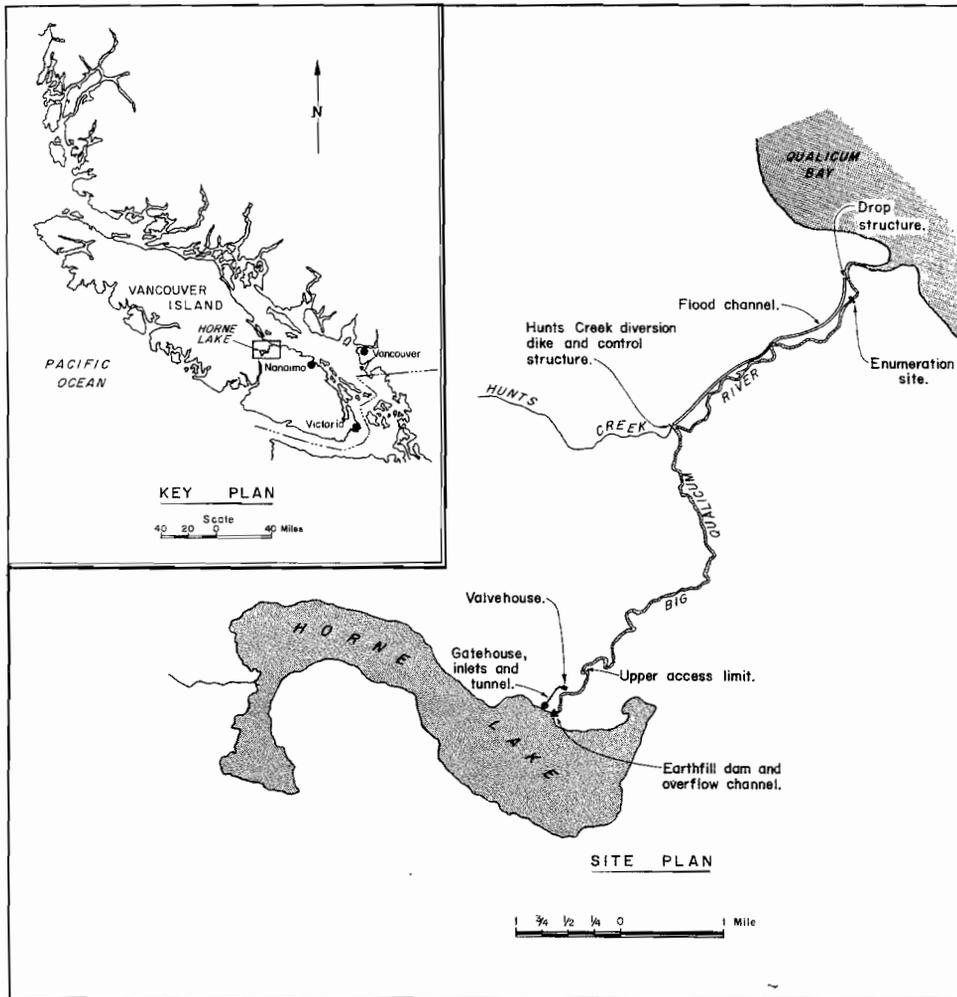


FIGURE 1. Map showing the location of the watershed in southwestern British Columbia and important features of the project.

total stream area increases from an estimated 33 percent at 33 cfs to 63 percent at 230 cfs, while over the same discharge range, the pool portion decreases from 59 percent to 14 percent.

Reasonably precise estimates of the spawning area available have been difficult to obtain under natural flow conditions. Observations of chum salmon spawner distribution indicate that approximately 20 percent of the stream area is utilized at discharges of 200–250 cfs, and some additional area becomes available at higher and lower discharges as a result of changes in velocity and depth. Discharges in excess of 250 cfs increase wetted area only slightly but accompanying velocity increases are sufficient to restrict chum salmon spawning to marginal areas. Under natural conditions discharge during spawning can be highly variable and because

of the importance of velocity to the spawning distribution pattern it has not been possible to assess the actual area which has been available to a specific spawning population.

The Big Qualicum River is a major contributor of chum salmon to an important net fishery in Johnstone Strait, adjacent to the northeast coast of Vancouver Island. Tagging studies conducted on chinook and coho salmon have indicated that these species could be expected to contribute to a coastwide troll fishery, to net fisheries in both Johnstone and Juan de Fuca Straits, and to a sport fishery in the Strait of Georgia. Visual estimates of salmon escapements to the Big Qualicum River indicated the following ranges occurred in spawning population size during the period 1950 to 1958: 200–2000 chinook, 2000–5000 coho and 10,000–100,000 chum salmon.

Steelhead trout (*Salmo gairdneri*) and coastal cutthroat trout (*Salmo clarki clarki*) populations are native to the system, but as yet their magnitude is unknown. Other species known to be present are the aleutian sculpin (*Cottus aleuticus*), the prickly sculpin (*Cottus asper*), the threespine stickleback (*Gasterosteus aculeatus*) and the Pacific lamprey (*Entosphenus tridentatus*). Kokanee (*Oncorhynchus nerka*) and resident coastal cutthroat and rainbow trout are present in Horne Lake.

Description of the Project

The Big Qualicum River watershed has several features which make it an ideal situation for virtually complete flow control. The major portion of the discharge in the lower river originates from one source, Horne Lake, which is physically suited for use as a storage reservoir. Also of primary importance is the presence of only one significant tributary between Horne Lake and the river mouth and the fact that it was feasible to divert the flood discharges of this tributary from the Big Qualicum River.

Flow control from Horne Lake

Excess inflows during the late fall and winter are impounded in Horne Lake and released gradually during the following summer and early fall when inflow is comparatively low. A total fluctuation in the lake surface level of approximately 80 feet is necessary to achieve the required storage capacity (142,000 acre-feet). A drawdown of up to sixty feet below the natural surface elevation is accomplished by means of a vertical concrete gate shaft, 98 feet deep, which has three separate gate-controlled intakes with bottom elevations at 17.5 feet, 38 feet and 82 feet below the natural lake surface (Figures 2 and 3). Flood control storage above the former lake level is provided by a dam in the natural lake outlet. Although the lake surface can be lowered to elevation 335 during periods of extreme drought, the normal operating range will be between elevations 355 and 385.

Through the use of the three intake levels it is possible to take advantage of thermal stratification in the lake during the summer and fall and thereby provide a degree of temperature control in the river by mixing water drawn from different depths. Water drawn into the gate shaft passes through a tunnel, approximately 1700 feet long, before being discharged into the natural river bed below the base of the second falls. The rate of discharge from the tunnel is controlled precisely by means of

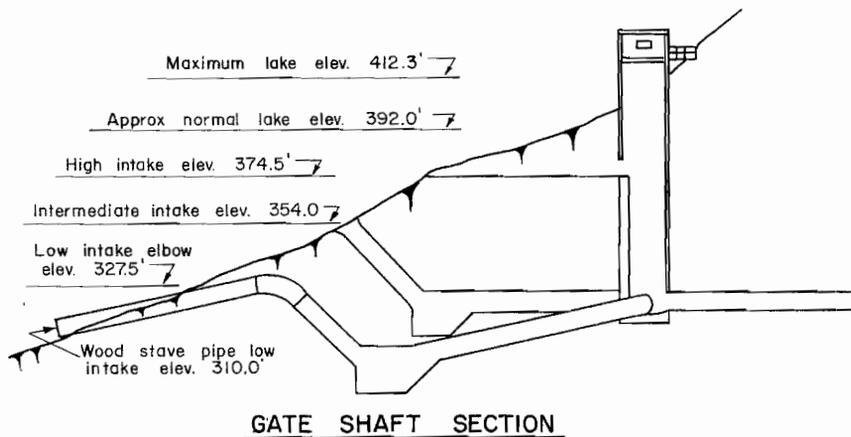
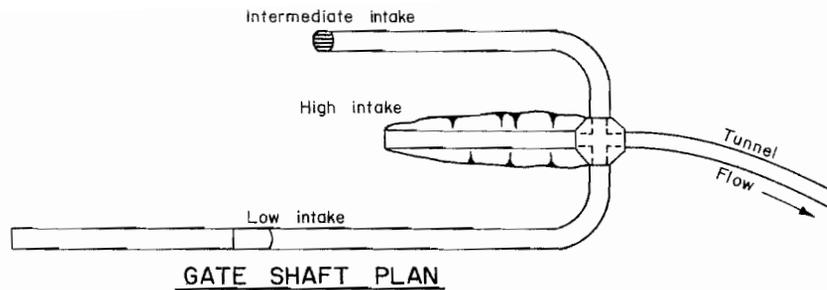


FIGURE 2. Diagram of the gate shaft intake system located near the natural outlet of Horne Lake.

two valves located at the downstream end (Figure 4). Maximum capacity of the valves is 1000 cfs.

The schedule of flow releases to the river and the relation to the various life stages of each species is shown in Figure 5. The discharge range maintained during any one period in a given year will be much narrower than the overall ranges shown in the figure. The controlled range of discharge can be compared with that occurring under natural conditions by reference to Table 1 in the Appendix.

Hunt's Creek Diversion

Freshets from Hunt's Creek, which could cause damage to spawning area in the lower Big Qualicum River, are isolated from the regulated flows by means of a diversion dam and an open-cut flood channel (Figures 6 and 7). The flood channel follows the north side of the valley for 2.5 miles before joining the river immediately above tidewater. Adult salmon are excluded from the flood channel by a drop structure at its downstream end. A discharge of up to 50 cfs, passed through a culvert in the diversion dam, provides natural access to upper Hunt's Creek for coho salmon and steelhead trout.



FIGURE 3. *The gate shaft on Horne Lake. The lake is shown at approximately 30 feet of drawdown. The dam in the natural lake outlet is in the far right of the photograph.*

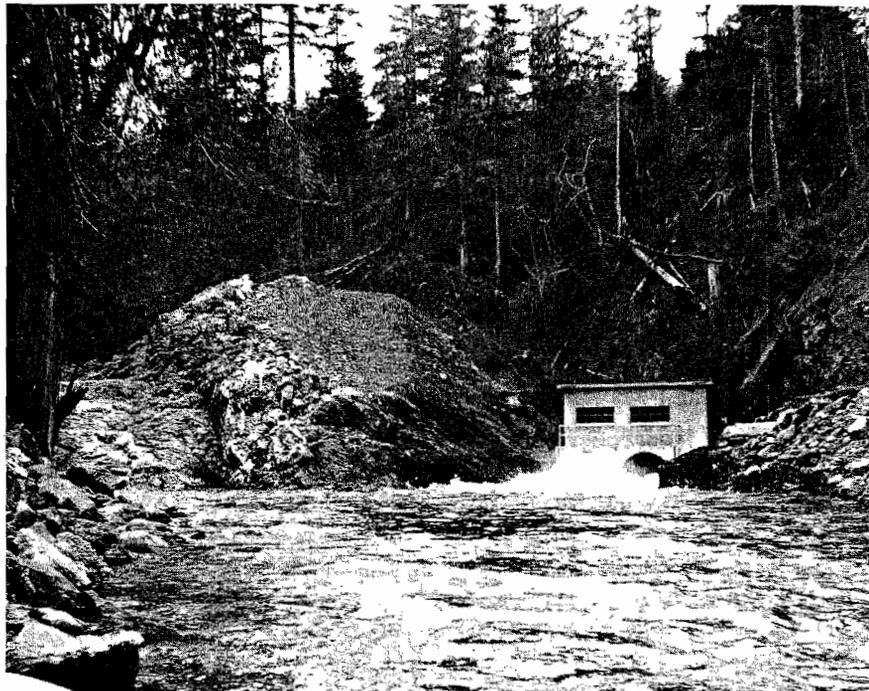


FIGURE 4. *The valvehouse and former river channel at the second falls below Horne Lake.*

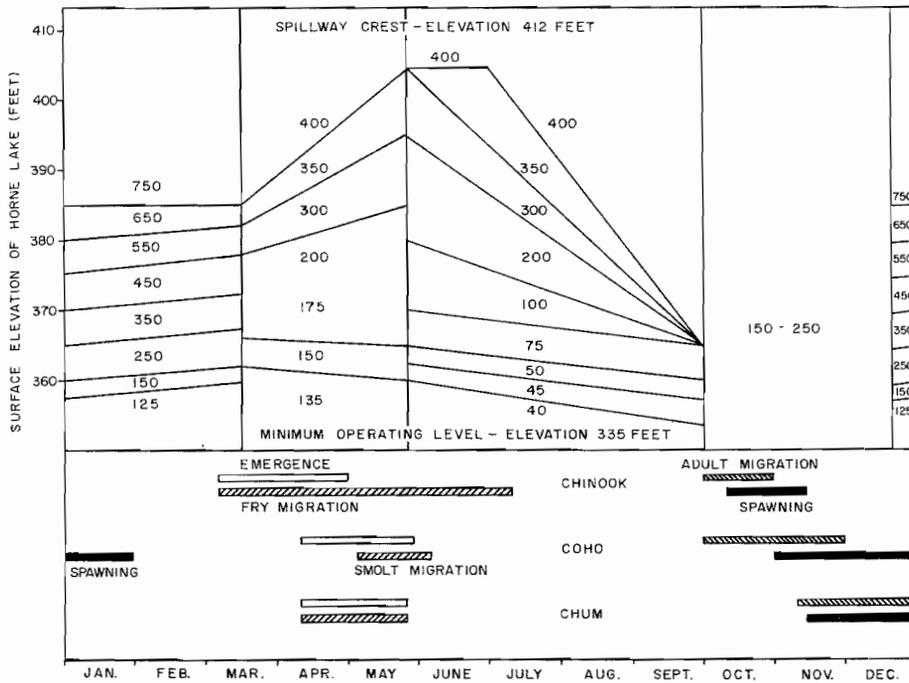


FIGURE 5. Controlled flow schedule of the Big Qualicum River and its relation to the life stages of each species of salmon. The discharge (cfs) released from the valves is dependent within each period on the surface elevation of Horne Lake.



FIGURE 6. The Hunt's Creek flood channel and dike following the north side of the valley.



FIGURE 7. *Diversion dam at the upstream end of the flood channel. The dam and an intake works for passing flow into the original channel of Hunt's Creek are shown in the left of the photograph.*

Methods

Since 1959 adult salmon have been enumerated at a fence located 2300 feet upstream of mean tidal influence (Figures 1 and 8). Although operational problems have been encountered for short periods in some years it has generally been possible to obtain complete counts. The fence was inoperative during the chum salmon migration twice in 1959 and once in 1960. In each of these cases the rate of migration reached a peak during rising discharge, and by the time the fence was removed it had declined to a low level. For this reason chum salmon counts in those years are regarded as reasonably accurate. High discharge over an extended period in 1963 made it impractical to obtain a complete count of the coho escapement.

In order to estimate the egg depositions of chinook and chum salmon, measurements have been obtained of sex and length composition and the degree of egg retention. Length-fecundity relationships have been used with the size data to estimate the mean fecundity. Summaries of the data used are given in Tables 2 and 3 of the Appendix. Chum salmon measurements were obtained both from carcasses recovered on the spawning grounds and from those which drifted against the fence. In determining the overall sex composition the male-to-female ratio at the fence has been used to correct for any excessive drift of males from upstream recovery areas. In three of the five years for which data are given measures of chinook sex and

size composition were obtained from fish trapped at the fence rather than from dead recovered on the spawning grounds. Because an insufficient number of fecundity measures were obtained from Big Qualicum chinook salmon it has been necessary to use fecundity data which has been collected in studies of fall chinook in the Stamp River, located on the west coast of Vancouver Island.

Downstream migrants have been trapped on a 24-hour basis from early March to mid-July in an operation which, with the exception of 1960, has been essentially the same in all years. The traps consist of expanded metal-type screen troughs one foot wide by twelve feet long, with attached liveboxes (Figure 9.) They are spaced at approximately eight-foot intervals across the stream and allow sampling of vertical sections from the water surface to the stream bed comprising 13.5 percent of the stream width.

Juvenile salmon population estimates are based on mark and recapture tests which have involved the release of marked migrants 100–200 yards upstream from the fence. Chum salmon fry have been marked by immersion in Neutral Red dye and temporary fin marks have been used on coho salmon smolts and large late-migrating chinook salmon fry. A summary of the results is given in Appendix Table 4. The estimated yearly percentages of the chum salmon fry emigration taken by the gear have also been applied for estimating the numbers of newly-emerged coho and chinook fry emigrants. The relatively low percentage recapture of coho smolts and

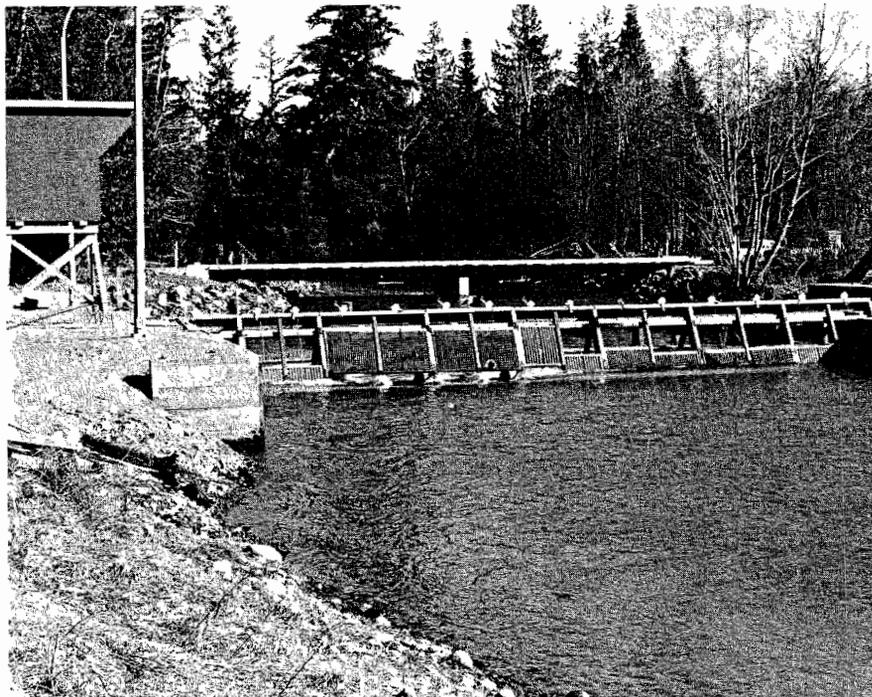


FIGURE 8. *View of the counting fence from upstream during adult enumeration. Salmon are counted as they pass over a white background by an observer stationed in the tower on the left bank.*

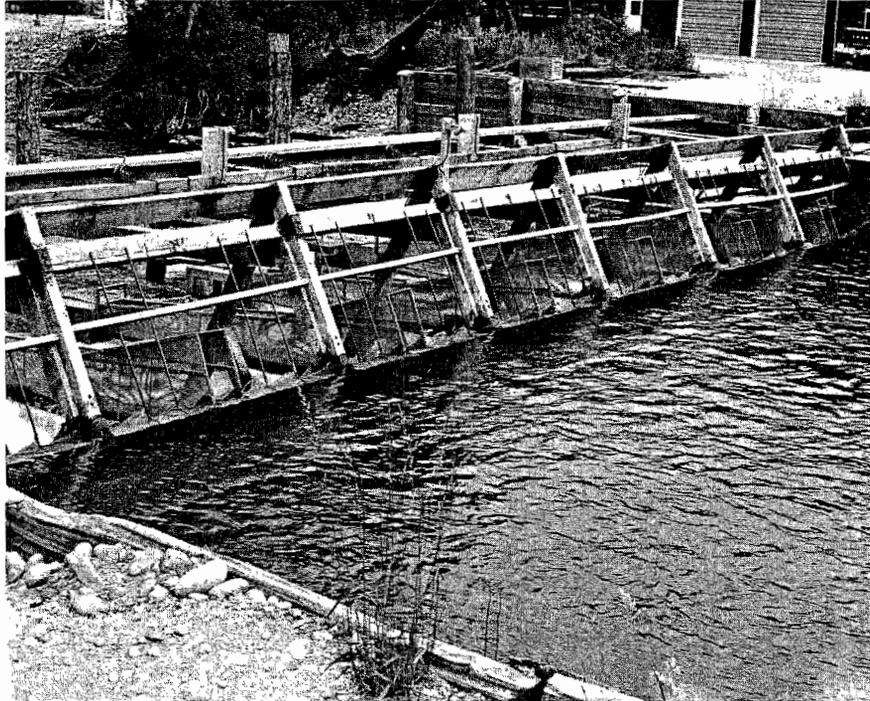


FIGURE 9. Fence site during downstream migrant enumeration. The river flow passes over a board, anchored to the stream bottom, and drops approximately one foot into the traps.

late-migrating chinook fry (Appendix Table 4) as compared to the portion of the stream width sampled probably indicates considerable avoidance of the trapping gear.

There were no mark and recapture tests conducted with the 1960 and 1961 brood late-migrating chinook fry. The general range of magnitude of these populations has been estimated by using the total range of gear efficiency which may have applied. The lower limit of each range was determined by the gear efficiency estimate for chum salmon fry, while the upper limit was based on the assumption that the degree to which late-migrating chinook fry avoided the gear was of the same magnitude as that measured with coho smolts in 1961.

The daily discharge and temperature of the Big Qualicum River has been recorded throughout the study period by means of continuous temperature recorders near the river mouth and at the Horne Lake outlet and a staff-gauge hydrometric station near the river mouth. The mean and extreme discharges in each month of the study are shown in Appendix Table 1.

Results and Discussion

1. CHUM SALMON

The freshwater survival rate of chum salmon over a four-year period of natural conditions averaged 11.2 percent. By comparison, survival rates of approximately

25 percent were achieved in the two years of flow control (Table I). Survival rates calculated from the apparent actual egg deposition (i.e. potential egg deposition minus egg retention) to eliminate mortality occurring prior to deposition are compared in Table II to the discharge extremes in each incubation period. An inverse relation between survival rate and the magnitude of the peak discharge is clearly demonstrated in Figure 10, but no relation between survival rate and the minimum discharge is apparent. It is possible that the effects of low discharges were masked by those of extreme freshets.

Table I.
Chum Salmon Fence Counts, Egg Retention and Total Freshwater Survival,
Big Qualicum River, 1959-64.

Brood Year	Adult Count	Percent Egg Retention	Potential Egg Deposition (Millions)	Fry Output (Millions)	Percent Survival
1959.....	83,500	24.5	128.9	17.7	13.7
1960.....	47,491	5.0	73.7	3.7	5.0
1961.....	10,421	4.4	20.1	3.4	17.0
1962.....	34,465	5.5	54.3	4.9	9.1
1963.....	27,897	2.7	52.4	13.2	25.2
1964.....	24,410	2.8	39.8	9.8	24.5

Egg retention constituted a major loss only in 1959, the year of the largest spawning population. Under conditions of artificial manipulation an increase in spawning density has been demonstrated to raise the level of egg retention (Hanavan and Skud, 1954; Semko, 1954; Mathisen, 1962). However, under natural stream conditions significant egg retention levels are not normal even when seasonal spawning densities of pink and chum salmon are relatively high (Hunter, 1959; McNeil, 1964). The extent of competition appears to be related to instantaneous density, or the distribution of spawning effort in space and time, rather than the overall seasonal spawning density.

Table II.
Chum Salmon Survival from Actual Egg Deposition to Fry Migration in Relation to
Discharge Extremes during Incubation, Big Qualicum River, 1959-64.

Brood Year	Percent Survival	Discharge Range (cfs)	
		Daily Maximum	Daily Minimum
1959.....	18.2	1360	99
1960.....	5.3	3200	156
1961.....	17.8	1260	108
1962.....	9.6	2000	59
1963.....	25.9	800	280
1964.....	25.2	393	150

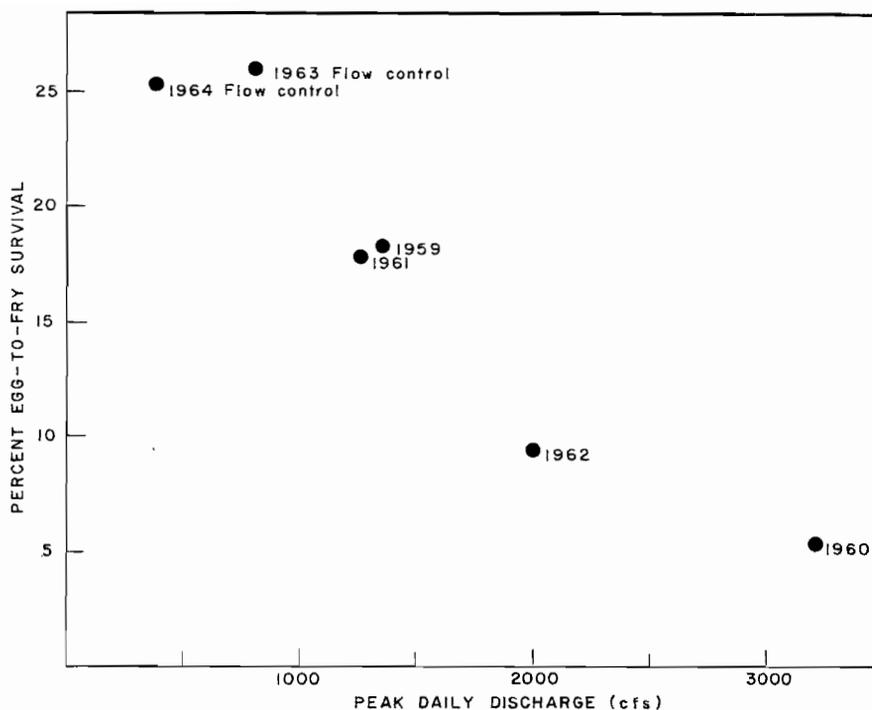


FIGURE 10. *Chum salmon egg-to-fry survival in relation to peak discharge during the incubation period. Survival rates are calculated from potential egg deposition corrected for egg retention.*

Tagging studies have shown that Big Qualicum chum salmon characteristically delay at the mouth of the river and enter as mature fish within three to four days of spawning. In 1959 migration into the river was unusually constricted, in that 38,000 fish or 46 percent of the season total moved through the fence on two days, November 19 and 20. This migration occurred on rapidly rising discharge after a period of extremely low discharge. Comparison of the upstream distribution of spawners in 1959 with that of the relatively small population in 1961 (Figure 11) shows that the large population spread no more extensively over the available area. There was no indication of a response to population pressure, as would be expected from observations elsewhere (Hunter, 1959; Merrell, 1962). The constricted migration pattern and lack of upstream distribution in 1959 may reflect excessive delay of mature chum salmon at the river mouth. Also, during the peak of spawning in late November discharges of 500 to 800 cfs prevailed, confining much of the spawning to the stream margins and thereby reducing the amount of available spawning area. It is likely that two environmental factors, low discharge prior to stream entry and high discharge during peak spawning, in the presence of a large population combined to promote excessive competition for spawning area.

Over the range in adult population size observed to date flow stability appears to have been the major factor inducing variability in the freshwater survival rate of chum salmon. With the exception of the high egg retention recorded in 1959 there

has been no evidence of mortality which is either positively or negatively related to adult population size through such factors as superimposition, operating in a density-dependent manner (McNeil, 1964), or predation on emergent fry, which Hunter (1959) has demonstrated to be inversely density-dependent in a coastal stream situation. This observation is supported by the peak discharge-survival relationship and the fact that comparable high survival rates have been recorded with both the largest and smallest spawning populations.

2. COHO SALMON

Fry Emigration

During the April-May emergence period and to a lesser extent in June, newly-emerged fry migrate seaward past the fence site. Comparable migrations of coho fry have been reported in several other coastal streams (Chapman, 1962). In five years of study the magnitude of this emigration, shown in Table III, has closely reflected the stability of winter flows. Relatively large emigrations have resulted from the two broods subjected to flow control (1963 and 1964), whereas the two smallest emigrations resulted from broods encountering the highest peak discharges during incubation (1960 and 1962). Adult populations of similar size, but affected by differing incubation conditions, have produced greatly different numbers of emigrants. The numbers of emigrants produced by the 1962 and 1964 broods amounted to 0.3 percent and 4.3 percent respectively, of potential egg deposition.

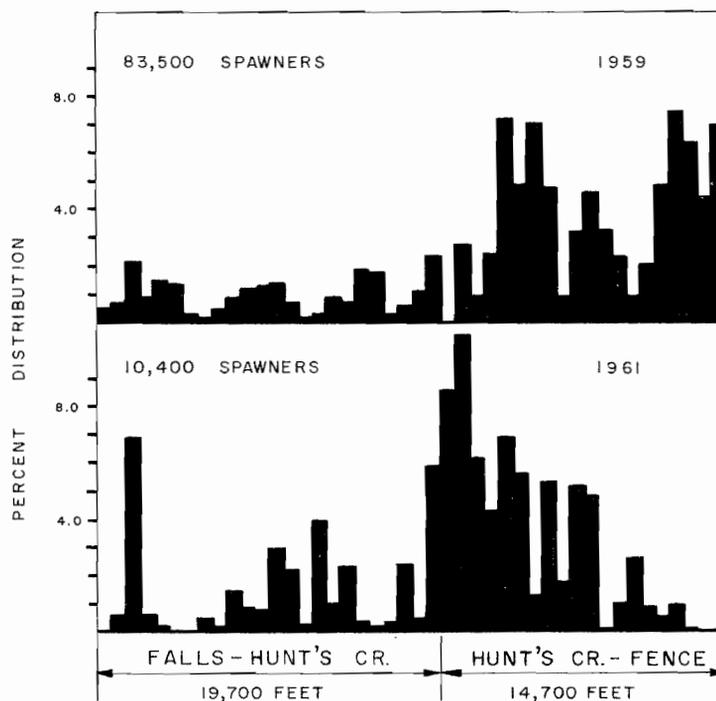


FIGURE 11. Live count distribution of chum salmon at peak of spawning, 1959 and 1961. Counts were made by stream sections approximately 800 feet long from the upper limit of access to the counting fence near the river mouth.

Table III.
Coho Salmon Fry Emigration and corresponding Adult Population Size,
Big Qualicum River Fence, 1960-64.

Brood Year	Adult Count ¹	Fry Emigration
1960.....	2562	17,200
1961.....	2886	63,800
1962.....	4618	32,100
1963.....	1291 ²	420,700
1964.....	5130	535,900

¹Includes jack coho counts, which in 1961, 1962 and 1964 were 600, 395, and 369 respectively.

²Incomplete count.

Chapman (1962) concluded that aggressive behaviour is one factor causing the downstream migration of coho fry and that this aggression and consequent emigration are probably density-regulating mechanisms. He found that downstream migrant fry would cease their migration if introduced to stream areas barren of resident fry. It seems reasonable to conclude that the egg-to-fry survival rate of coho in the Big Qualicum River has been increased by controlled winter flow and that this has produced larger emergent fry populations than those of the preceding three years. It is likely that the increase in emigration is much more than proportionate to the increase in embryonic survival. In the last two years emigrant fry would appear to have comprised a much larger percentage of the emergent population than in the three years prior to flow control. The evidence is strong that the magnitude of emigration has depended to a large extent on the density of emergent fry. Considering Chapman's findings, it is concluded that fry populations in the two years of controlled flow greatly exceeded the initial rearing capacity of the stream.

Smolt Emigration

The majority of juvenile coho salmon reside one year in the Big Qualicum River and Hunt's Creek before migrating to sea, but a small percentage of individuals remain for two years. Analysis of scale samples collected over a five-year period from a total of 371 smolts revealed that 97.3 percent were Age I.

Estimates of coho smolt output have been examined for a relationship with the stream flows recorded in the summer previous to emigration (Table IV). The data includes three years of natural flow conditions, one year in which conditions were altered by construction activities (1961 brood), and one year of flow control (1963 brood). The range in smolt output has been small in the five years of record, suggesting that fluctuations in fry abundance have had little or no effect on smolt abundance.

Several studies have given indirect evidence that coho smolt output is related to the minimum summer discharge level. Neave (1949) demonstrated a positive relationship between the minimum summer discharge in the Cowichan River, Vancouver Island, and the availability of adult coho to the local sport fishery two years later. Over a four-year period at Nile Creek, Vancouver Island, smolt output was found to be positively related to the minimum monthly rainfall during the summer of stream

Table IV.
Coho Salmon Smolt Output in Relation to Low Summer Discharge,
Big Qualicum River, 1959-63.

Brood Year	Adult Count	Estimated Smolt Output	August-September Discharge Near River Mouth (cfs)	
			Mean	Daily Minimum
1959.....	3624	30,600	31.1	25
1960.....	2562	26,000	22.1	14
1961.....	2886	34,300 (28,100) ²	186 ¹	32
1962.....	4618	33,400 (27,900) ²	28.9	25
1963.....	1291 ³	34,700 (30,300) ²	47.6	32

¹Relatively high fluctuating flows due to construction activities.

²Figures in brackets are estimates of the Big Qualicum output, excluding Hunt's Creek contribution.

³Incomplete count.

residence (Wickett, 1951). McKernan et al (1950) showed fluctuations in gillnet catches of adult coho in the Siletz River, Oregon to be significantly correlated with the summer flow level which had occurred two years previously but the same correlation for the Coquille River in Oregon was insignificant. Although the lowest smolt output from the Big Qualicum River was associated with the lowest minimum summer discharge (1960 brood), there has not been a sufficient range of conditions to establish whether any clear relationship exists between discharge and smolt output. Controlled conditions will provide further opportunity to assess this relationship, as minimum discharges will generally exceed by several times those observed to date.

The 1961 and 1962 brood smolt outputs from the Big Qualicum River, exclusive of Hunt's Creek, were approximately 16 per 100 square yards of wetted stream bed at the minimum discharge. This is low in comparison to that reported by Chapman (1964) for three relatively small Oregon streams in which the output over a four-year period averaged approximately 37 smolts per 100 square yards. Smolt biomass produced per unit area in these streams was approximately twice that of the Big Qualicum River.

3. CHINOOK SALMON

Most chinook salmon spawn in the upper two miles of the Big Qualicum River. Hunt's Creek is not utilized for either spawning or rearing. Chinook fry emergence takes place during March and April and emigration is complete by mid-July of the same year. The downstream migration pattern at the fence tends to be bimodal (Figure 12). The position of the modes indicates that fry emigrate either within a short time of their emergence or after six weeks or more of rearing. The size distribution of fry caught at the fence also reflects these two main groups, in that the

majority of individuals measure either between 40 mm and 48 mm fork length (measured live, anaesthetized) or 60 mm and 90 mm. The mean length of late-migrating fry at any given time generally falls between 70 mm and 80 mm. Separation of emigrants into early and late groups, as in Figure 12, is based on samples taken for length measurements at least once weekly over the entire migration period. The size division point is a length of 55 mm.

Table V.
Chinook Salmon Fry Output and Freshwater Survival, Big Qualicum River, 1960-64.

Brood Year	Adult Count	Potential Egg Deposition (Millions)	Estimated Fry Emigration		Percent Survival
			Early	Late	
1960.....	1511	3.54	3,000	3,100— 5,600 ¹	0.17—0.24
1961.....	1087	1.49	29,000	45,800— 75,500 ¹	5.0 — 7.0
1962.....	787	1.95	41,700	39,400	4.2
1963.....	619	1.41	241,000	37,000	19.8
1964.....	697	0.87	35,100	69,400	12.0

¹Range estimate given because actual gear efficiency for late chinook fry was not tested (See Methods)

Freshwater survival rates and the estimated numbers in each group of emigrants are shown in Table V for three years of natural flow conditions and for the two years of flow control. Because a large portion of the fry population tends to reside in the stream for varying periods and is therefore subjected to a degree of natural mortality prior to emigration the survival rates given are lower than the survival to emergence. The 1963 brood would most closely reflect emergent survival because of the predominance of newly-emerged fry in the emigration. This was also the only year in which the number of migrants in the early group could have equalled or exceeded the number remaining in the stream.

The high mortality recorded for the 1960 brood is thought to have resulted from extreme flooding in January, 1961, which also severely affected chum salmon. The survival rate in that year was probably in the order of one percent or less. The low output of both groups of chinook fry from the 1960 brood may indicate not only a small emerging fry population but also a lack of sufficient fry to fully utilize available rearing area. Inadequate fry emergence was not apparent in 1960 brood coho salmon. However, coho spawning is more widely distributed in the watershed and its duration is much greater than that of chinook (i.e. three months as compared to one month). Both of these characteristics tend to ensure adequate numbers of emerging fry under extreme environmental conditions.

Measures of the total freshwater mortality of chinook salmon comparable to those made at Big Qualicum have not, to our knowledge, been reported in the literature. Gangmark and Bakkala (1960), compared survival rates of artificially-planted

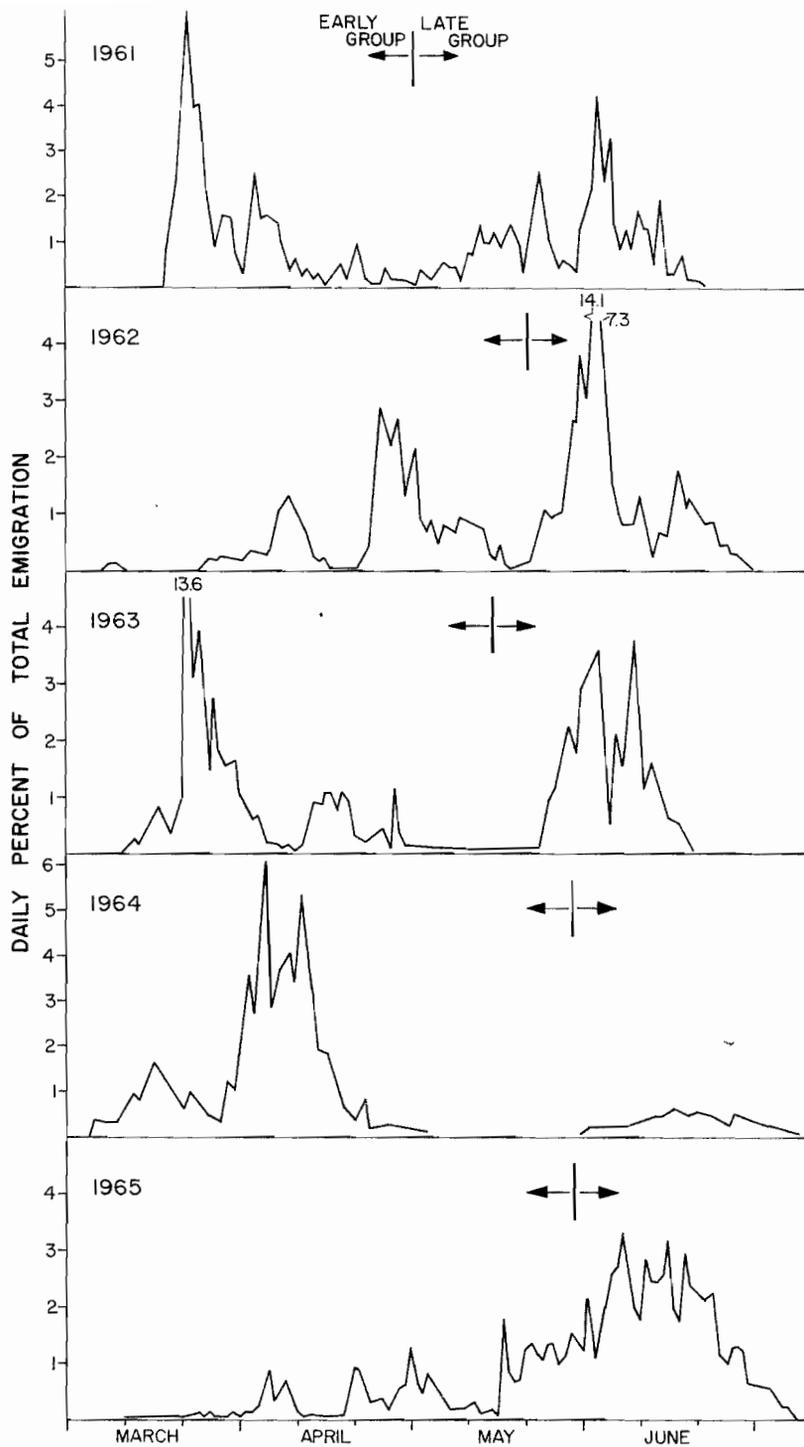


FIGURE 12. Downstream migration timing of chinook salmon fry at the fence site, showing dates of separation into early and late groups.

chinook eggs in stable and unstable stream channels. Survival rate to the advanced alevin stage in a controlled flow situation approximated 60 percent, whereas in the natural stream bed extreme flooding resulted in survival rates as low as 1.7 per cent and zero. At Fall Creek, a tributary of the Sacramento River, the chinook survival rate from deposited egg to fry migrant ranged from 7 to 32 percent over a four-year period, the highest survival occurring in a year of particularly stable flow (Wales and Coots, 1954). As the fry trapping site employed in that study was located within one mile of all spawning and since the majority of migrants were reported to have recently emerged, these survival rates were probably close to the actual rates from egg deposition to fry emergence.

The restricted range over the last four years in late-migrating fry output from the Big Qualicum suggests that there is some consistency in the stream's capacity to rear juvenile chinook to that stage. A large emigration of newly-emerged fry, such as that occurring in the first year of flow control (1963), may reflect an emerging fry population which greatly exceeded the initial rearing capacity of the stream. With a larger adult escapement than those of the last two years and stable winter flows the fry emergence is likely to increase substantially. If the magnitude of the early group is mainly density-dependent, an increase in the emergent fry population would result in a significantly larger early emigration than any observed to date. This would change the overall quality of the fry output toward smaller size and earlier migration timing. There is evidence that the change would result in a lower rate of ocean survival and that early group fry may contribute very little to adult production. A study of the comparative fry-to-adult survival in two groups of marked fall chinook, roughly equivalent in size to the early and late migrating Big Qualicum fry, was undertaken at the Spring Creek hatchery on the Columbia River (Junge and Phinney, 1963). Fry reared for three months prior to release from the hatchery survived at 18 times the rate of fry released unfed. Multiple correlation analysis, relating adult return to Spring Creek over nine broods to the magnitude of the fry and fingerling releases involved, also indicated that variation in returns was completely dependent on the magnitude of fingerling releases and was not influenced by the quantity of fry released.

Summary

1. As part of a continuing program to assess the effect of controlled flow on the chum, coho and chinook salmon production of the Big Qualicum River freshwater survival rates were measured and related to stream flow over a six-year period from 1959 to 1964. The first four years of the study were conducted under natural flow conditions.
2. At the adult population levels encountered, chum salmon egg-to-fry survival rates were inversely related to the maximum daily discharge during each incubation period. The freshwater survival rates in the first two years of controlled flow were 24.5 and 25.2 per cent, as compared to an 11.2 per cent average recorded under natural conditions.
3. The abundance of emerging coho fry, as indicated by the size of the emigration at the fence site, was dependent upon the stability of the winter discharge. The

- total emigration increased from a maximum of 64,000 fry under natural flow conditions to 421,000 and 536,000, respectively, in the two years of flow control.
4. Coho salmon smolt output ranged from 26,000 to 35,000 over a five-year period. No clear relationship between output and the minimum summer discharge is evident. However, the range in discharge levels was small.
 5. The freshwater survival rates of chinook salmon under natural conditions did not exceed 7 per cent, and in the year of most extreme flooding (1960) approximated only 0.2 per cent. Under controlled flow survival rates increased to 19.8 per cent and 12 per cent, but the highest survival rate was accompanied by a substantial change in the quality of the fry output toward smaller size and earlier migration timing.

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Engineers who have been closely associated with construction of the project and have aided in providing facilities for the assessment programs have been: R. A. Fahlman, senior construction engineer, B. A. Heskin, B. W. Howard, J. P. Parkinson and J. A. Wood. Dr. P. A. Larkin, director, Fisheries Research Board of Canada Biological Station, Nanaimo, B.C., and M. C. Bell, of the University of Washington, provided valuable advice during the planning of the project. I. S. Todd was the project biologist in charge of the assessment study during 1961. The authors are grateful to F. C. Boyd for the use of the chinook salmon fecundity data.

R. A. L. Harvey, senior technician, has worked on the project almost continuously since 1959. His enthusiasm and resourcefulness have been valuable attributes in the collection, tabulation and analysis of biological data.

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Appendix

Table 1.

Mean and extreme monthly discharges near the mouth of the Big Qualicum River, September, 1959 to June, 1965^a.

		1959	1960	1961	1962	1963	1964	1965
January	Max.		1300	3200	1260	1020	800	228
	Mean		258	1040	504	320	710	171
	Min.		99	198	179	70	580	150
February	Max.		1020	1130	260	2000	585	393
	Mean		564	868	203	672	567 ^b	295
	Min.		181	473	120	59	535	181
March	Max.		538	970	252	580	535	393
	Mean		220	472	154	250	330 ^b	265
	Min.		133	272	108	69	310	178
April	Max.		680	379	320	344	310	187
	Mean		437	220	197	255	293 ^b	177
	Min.		318	156	140	152	280	168
May	Max.		306	250	404	229	388	181
	Mean		246	208	196	148	310	173
	Min.		184	152	108	78	280	130
June	Max.		232	154	145	75	278	117
	Mean		154	117	102	53	173	83
	Min.		96	68	57	37	150	77
July	Max.		94	67	63	47	165	
	Mean		61	44	47	42	141	
	Min.		38	28	34	36	70	
August	Max.		37	27	901	40	75	
	Mean		29	20	208	31	49	
	Min.		25	14	33	26	32	
September	Max.		52	37	905	28	99	
	Mean	41	34	25	169	26	46	
	Min.		36	16	32	25	32	
October	Max.		130	409	327	1480	274	
	Mean	71	138	117	160	445	234	
	Min.		43	28	36	32	106	
November	Max.		836	818	422	549	935	291
	Mean	277	426	263	270	716	269	
	Min.		100	160	132	650	231	
December	Max.		1360	834	680	1340	765	281
	Mean	588	476	362	624	594	234	
	Min.		228	213	186	248	168	

^aPublished and unpublished data from the Dept. Northern Affairs and National Resources, Water Resources Branch. Surface water supply of Canada, Pacific Drainage. Water Resources Paper Nos. 128, 131, 136 and 139. Data shown after September, 1962 are unpublished and subject to revision.

^bDischarge as released from the valves; up to 100 cfs higher near the river mouth.

Table 2.

Statistics used to estimate chum salmon egg deposition.
Sample sizes are given in brackets.

Brood Year	Percent Females	Number of Females in Population	Mean Female Length mm ^a	Mean Fecundity ^b	Percent Egg Retention
1959.....	50.7 (3696)	42,335	576 (531)	3050	24.5 (103)
1960.....	50.0 (3334)	23,746	580 (948)	3100	5.0 (411)
1961.....	56.2 (3397)	5,857	607 (443)	3400	4.4 (237)
1962.....	50.4 (10,717)	17,370	582 (531)	3100	5.5 (441)
1963.....	58.5 (2693)	16,320	589 (913)	3200	2.7 (881)
1964.....	49.9 ^c	12,181	594 (647)	3300	2.8 (647)

^aPostorbital—hypural plate length.

^bEstimated from the equation $y = -3400 + 11.23 x$, where y = egg content and x = postorbital - hypural length in mm. Egg counts from 164 females taken over a five-year period.

^cSex identified on fish passing upstream through the fence.

Table 3.

Statistics used to estimate chinook salmon egg deposition.
Sample sizes are given in brackets.

Brood Year	Percent Female	Number of Females in Population	Mean Length cm ^a	Mean Fecundity ^b
1960.....	53.0 ^c (97)	801	73.1 (51)	4450
1961.....	36.0 ^d (136)	391	66.2 (47)	3800
1962.....	60.4 ^c (207)	475	69.5 (125)	4100
1963.....	50.0 ^d (66)	310	74.4 (88)	4550
1964.....	30.4 ^d (84)	212	69.3 (30)	4100

^aPostorbital - hypural plate length.

^bEstimated from the equation $y = -1964 + 87.4 x$, where y = egg content and x = postorbital - hypural length in cm. ($N = 31$).

^cSex ratio taken from spawning ground dead recovery.

^dSex ratio taken from fish trapped at the fence.

Table 4.

Summary of mark and recapture tests of trapping gear efficiency on juvenile migrant salmon.

Species	Migration Year	Number of Tests	Total Number Released	Total Number Recovered	Percent Recovery	
					Mean	Standard Deviation
Chum.....	1960	24	23,980	1782	7.4	1.2
	1961	33	33,269	4054	12.2	2.1
	1962	15	15,000	1692	11.3	1.6
	1963	25	24,871	3056	12.3	1.2
	1964	8	7,799	936	12.0	1.5
	1965	9	9,000	1143	12.7	2.6
Coho Smolt	1961	3	1,368	95	6.9 ^a	3.0
	1963	8	2,524	525	20.8 ^b	7.6
	1964	4	1,711	166	9.7	3.5
	1965	5	1,708	156	9.1	3.2
Late Chinook Fry.....	1963	2	476	100	21.0 ^b	0.5
	1964	6	1,611	121	7.5	3.2
	1965	3	4,008	415	10.4	4.9

^aThe 1961 percent recapture figure was also used to estimate the 1962 smolt emigration and the upper limit of the chinook fry emigration in 1961 and 1962. Similar water velocity situations and arrangements of trapping gear existed at the fence site in both 1961 and 1962.

^bThe stream width at the fence site was reduced during the smolt and late chinook fry emigrations in 1963 to provide higher velocities for trapping and a larger sample of the emigration.

ERRATA

For: The Canadian Fish Culturist, Issue No. 37.

Page 3—Lines 10-13 of the Abstract should read:

Coho spawning populations of similar size, but affected by differing incubation conditions, produced fry emigrations amounting to 0.6 percent (natural flow) and 9.6 percent (controlled flow) of the respective egg potentials.

Page 15—Lines 9-11 of the Fry Emigration section should read:

The numbers of emigrants produced by the 1962 and 1964 broods amounted to 0.6 percent and 9.6 percent respectively, of potential egg deposition.



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