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PROTECTION, PRESERVATION AND EXTENSION OF
THE SOCKEYE AND PINK SALMON FISHERIES
IN THE FRASER RIVER SYSTEM

BULLETIN XXIII

THE 1983 EARLY RUN FRASER AND THOMPSON RIVER PINK SALMON; MORPHOLOGY, ENERGETICS AND FISH HEALTH

I.V. WILLIAMS, J.R. BRETT
G.R. BELL, G.S. TRAXLER, J. BAGSHAW
J.R. McBRIDE, U.H.M. FAGERLUND, H.M. DYE,
J.P. SUMPTER, E.M. DONALDSON
E. BILINSKI, H. TSUYUKI, M.D. PETERS,
E.M. CHOROMANSKI, J.H.Y. CHENG AND W.L. COLERIDGE

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PREFACE

This study was designed to gain as much information on the Fraser and Thompson River pink salmon as possible because of potential impact from railway construction. The objective was to select those biological parameters which would build a baseline of information which could then be used in conjunction with the extensive database for sockeye to assist in the assessment of potential and real impacts on the migration path and spawning areas of pink salmon.

Highly specialized expertise working together was required to produce this report. I.V. Williams and J.R. Brett coordinated this project. G.R. Bell and G.S. Traxler were responsible for the infectious disease survey. J.R. McBride, U.H.M. Fagerlund, H.M. Dye, J.P. Sumpter, J. Bagshaw and E.M. Donaldson collaborated to produce the histopathological and endocrinological assessment. E. Bilinski, H. Tsuyuki, M.D. Peters, E.M. Choromanski, J.Y.H. Cheng and W.L. Coleridge collaborated on the changes in body composition and energy expenditures. J.R. Brett collaborated with C. Millecken, under DFO contract to produce the metabolic rate data, and with D. Furnell, also under DFO contract, to produce the computer model. I.V. Williams produced the critical swimming speed data.

Funding for this project was provided by the Canadian Department of Fisheries and Oceans.

ABSTRACT

This study was designed to examine selected biological parameters in order to build a baseline of information for the Thompson and Fraser River pink salmon. Selected aspects of fish health, energetics and population assessments are reported for the 1983 Thompson and Fraser River pink salmon population. The population was the second largest on record and the fish were the smallest, averaging 1.86 kg. The peak abundance of migrating fish was seven to ten days later than average. Endocrinological assessment of the reproductive hormones and vitellogenin suggested the pink salmon entered the Fraser River in an advanced stage of maturity and were ready to spawn upon arrival at the spawning grounds. An infectious disease survey indicated the presence of four major fish pathogens, *Dermocystidium, VEN, Ceratomyxa shasta and Aeromonas salmonicida.* Cortisol analysis indicated that pink salmon negotiating points of difficult passage are stressed.

The energetics study indicated that the pink salmon metabolic rates are significantly higher than sockeye indicating pinks have a 30% higher energy expenditure at the same swimming speed. Energy expenditure from Ft. Langley to the spawning grounds at Ashcroft averaged 0.99 kcal/kg/km for males and 0.82 kcal/kg/km for females. Utilization of fat provided over 70% of the energy required for migration. Critical swimming speed tests indicated the fish captured from the upriver sites (Thompson Canyon, Ashcroft and Seton) had significantly higher Ucrit at 3.1 L/s compared to 2.25 L/s for the fish captured from the lower river sites (Ft. Langley and Yale).

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1983 PINK SALMON STUDY

INTRODUCTION

The Canadian National Railway is constructing a second track on the mainline to Vancouver. The railway parallels the Thompson and Fraser Rivers which provide salmon migration routes and spawning grounds for some species (Fig. 1). There is the potential for serious impact on salmon utilizing the Fraser and Thompson Rivers. Pink salmon are considered to be the weakest of the salmon in the Thompson and Fraser systems (Brett, 1982). While there is a good scientific data base for sockeye salmon (Brett and Glass, 1973; Foerster, 1968; Gilhousen, 1980; Williams et al, 1977) there is a paucity of information on pink salmon energetics Literature reviews by Beamish (1978) and Lister (1981) indicate very few observations on pink salmon swimming capacity. Therefore the International Pacific Salmon Fisheries Commission and the Canada Department of Fisheries and Oceans cooperated in an extensive research program on pink salmon designed to answer some of the biological concerns associated with the effects of alterations to the migration routes and spawning grounds.

The project involved the I.P.S.F.C and the Pacific Biological Station, the Vancouver Technological Station, and the West Vancouver Laboratory of the Department of Fisheries and Oceans for Canada.

Over and above the Commission's regular spawning ground assessments, there were basically two major areas of pink salmon biology that were examined during the 1983 season The first was the energetics of pink salmon performance which included determinations of the metabolic rates, proximate analysis, and critical swimming speed of pinks sampled at various locations during migration and spawning The second area was fish health which included examinations of pinks for pathogens and indicators of stress during migration and spawning.

METHODS

CAPTURE SITES:

Pink Salmon were sampled from five river locations: two on the Fraser River, two on the Thompson River and one on Seton Creek, a Fraser tributary upstream of the Thompson-Fraser confluence. Fort Langley, approximately 36 river miles above the Fraser River mouth, was selected as the Lower Fraser sample site. Pinks were also sampled from the Fraser at Yale, the start of the Fraser Canyon. One Thompson River sample site was located in the Thompson Canyon, close to the town of Lytton. This is a site of difficult passage. The other site was on the pink salmon spawning area, just upstream of Ashcroft. Seton pinks were sampled from the tailrace of the Seton Hydroelectric Power Generating Station, close to the Seton Creek spawning channels where the critical swimming speed test apparatus was located (Fig. 2).

CAPTURE AND TRANSPORT:

Pinks were captured in the lower Fraser with a large beach seine operated from a commercial gill-net boat. A relatively small beach seine was used at Yale and Ashcroft;

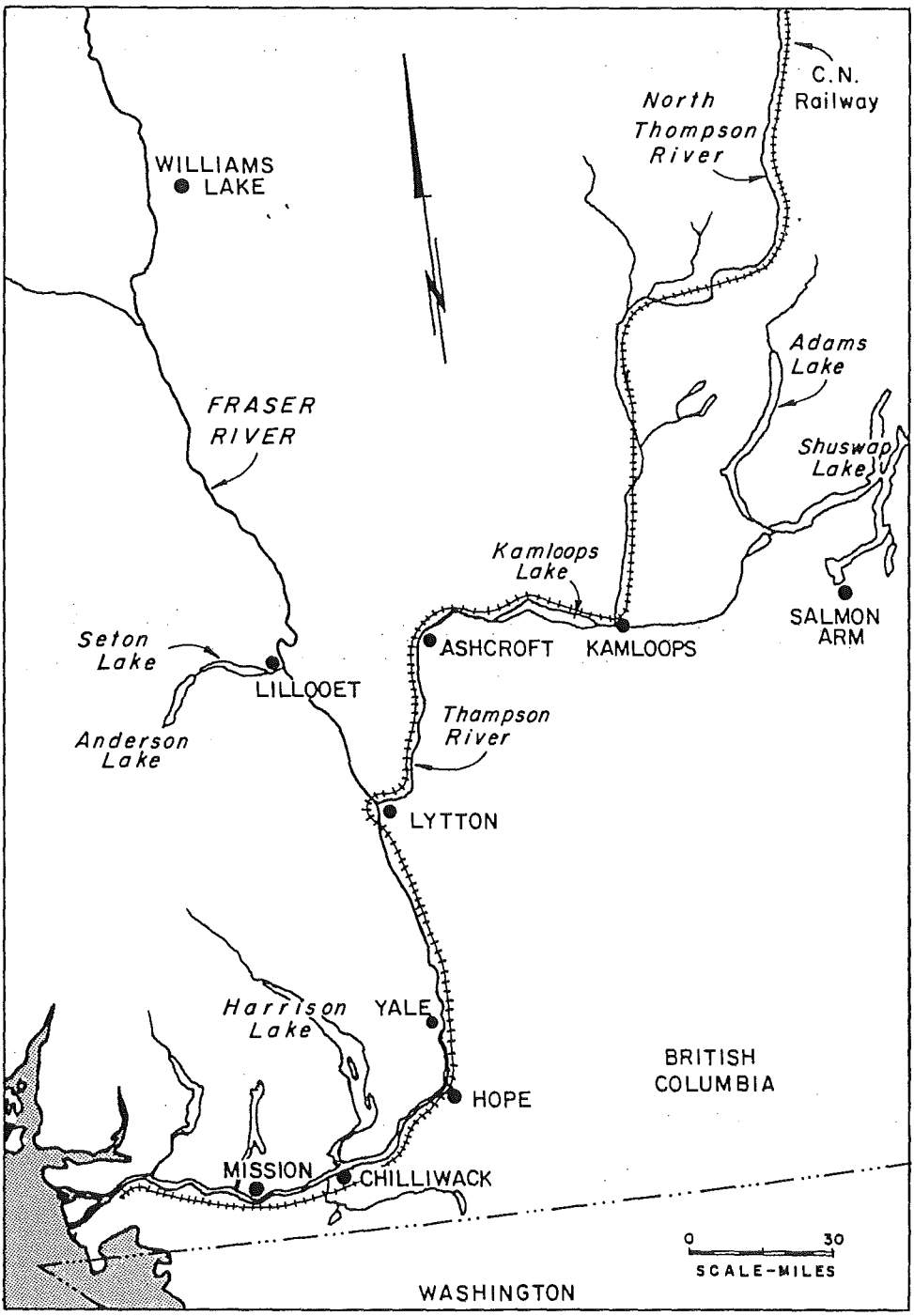

FIGURE 1—Map showing route used by CN Railway.

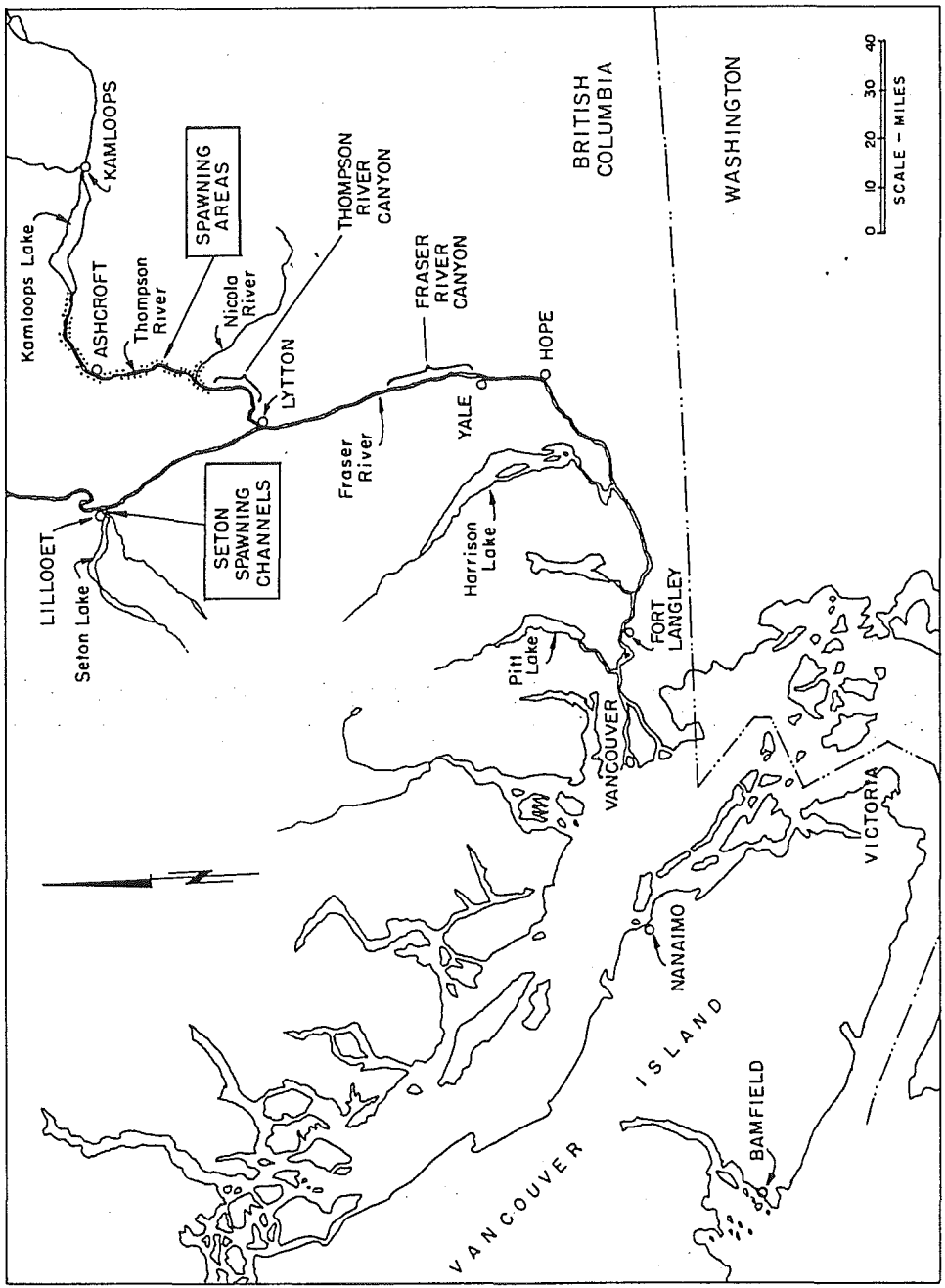

FIGURE 2—Map showing capture sites for 1983 pink salmon study.

dip nets were used in the Thompson Canyon. Pinks were captured using a brail operation at the Seton tailrace.

Pinks were transported alive to Bamfield B.C. for metabolic rate determinations and to Seton Creek near Lillooet B.C. for critical swimming speed tests. Three transportation boxes, each capable of holding a cubic meter of water, were fixed to the deck of a flat-bed truck. Fifteen to twenty pink salmon were loaded in each box, and ice was used to control temperature. Oxygen was bubbled through the water using air stones attached to the oxygen cylinders. Fish were in transit from approximately two hours to a maximum of ten hours, depending on the capture and delivery locations. Pink salmon used in the critical swimming speed tests were placed in large holding pens in the upper pink salmon spawning channel at Seton Creek, and held 24 hours prior to testing. Pinks used for metabolic rate determinations were held for a minimum of 16 hours prior to testing.

Pink Salmon used for proximate analysis were transported on ice to the Vancouver Technological Station where they were immediately vacuum packed and quick frozen, while the pinks used for stress and health checks were sampled at the capture sites.

FISH HEALTH:

Infectious Disease Survey

Thirty fish were sampled at each of the six sites A thirty fish sample was required to ensure a 95% probability of detecting one or more infected individuals in a population size of $\geq$ 100,000, with an assumed prevalence of infection of 10% (Manual of Compliance, Fish Health Protection Regulations, Ottawa, 1977).

Fish were examined grossly externally and internally and all abnormalities were noted and investigated. Blood was taken from the caudal vessels and haematocrits (packed red blood cell volume) and blood smears prepared. Smears were stained with "Diff-Quik" (Dade Diagnostics Inc.) to detect the cytoplasmic inclusion bodies characteristic of Viral Erythrocytic Necrosis (VEN). Gills, brain and internal organs were taken for histopathology, and kidney tissue was cultured aseptically on Tryptic Soy Agar (TSA) particularly for *Aeromonas salmonicida* (the causative agent of furunculosis) and on KDM, and KDMS an experimental selective medium, for *Renibacterium salmoniarium* (the causative agent of bacterial kidney disease, BKD). Smears were made from scrapings of the lower intestine and stained with 1% methylene blue to detect the protozoan pathogen *Ceratomyxa shasta*. Digests of the brain were examined under the microscope for another protozoan, *Myxobolus neurobius,* not considered to be of pathogenic significance but potentially useful as a stock-identifying "tag".

Details of the particular methods used may be found in the "Manual of Compliance", (Fisheries and Marine Service, 1977).

Histophysiology and Endocrinology

Immediately after the fish were netted they were anaesthetized in 2 phenoxyethanol (0.5 ml/L). Blood samples were removed from the caudal blood vessels of 10 males and 10 females. To reduce the effect of the catching procedure on cortisol values, care was taken to minimize the length of time between catching and sample removal. By utilizing four or more sample takers it was possible to obtain the majority of blood samples within eight minutes from the time the fish were close enough to the shore to be caught by hand. There was no indication that sequence of sampling affected cortisol concentrations.

Blood samples were immediately centrifuged to obtain plasma. A subsample was centrifuged separately for haematocrit determination. Plasma was transported to the laboratory on dry ice and subsequently stored at -37 deg. C. Cortisol analyses were performed in duplicate on 10 ul aliquots of plasma using a radioimmunoassay kit (Gamma Coat-I125, Clinical Assays, Cambridge, Massachusetts).

Immediately following the collection of a blood sample, fork-length and eye socket-hypural-plate length as well as total body weight were recorded. The gonads were then removed and weighed separately. Lastly, for histological assessment, appropriate samples of the alimentary tract, interrenal, liver, gill, kidney, skin, gonad and pituitary gland were excised from each fish and placed in Bouin-Hollande-Sublimate fixative Methods employed for decalcification, embedding, sectioning and staining have been described (McBride and van Overbeeke, 1971).

The radioimmunoassay techniques used in the present study have previously been described for gonadotropin (Van Der Kraak et al, 1983) and the three steroids 17ß-estradiol, testosterone and 17∝-hydroxy-20ß-dihydroprogesterone (17 20 P) (Van Der Kraak et al, 1984). The preparation and radioimmunoassay of plasma samples for 11-ketotestosterone were identical to those for 17 20 P, except for the antiserum and label used. Rabbit anti-11-ketotesterone serum was provided by Dr. T.G. Owen (Helix Biotech Ltd., Richmond, B.C.). This antiserum shows similar cross reactivity to that of Fostier et al, (1982). Radiolabeled 11-keto [1,2(n)-3H] testosterone was obtained from Amersham (Oakville, Ontario).

Statistical analyses of endocrinological and histophysiological data were carried out with ANOVAs followed by Tukey's multiple range tests applied to each sex separately. Values in figures and tables carrying a common superscript are not significantly different at $p = 0.05$.

ENERGETICS:

Critical Swimming Speed

Critical swimming speed (Ucrit) is approximately the maximum speed a fish can maintain for one hour. The free swimming maximum sustained speed, the maximum speed a fish can maintain indefinitely, is approximately 75% of the Ucrit swimming speed (Brett, 1982). In order to increase our sample size with the available time constraints only the Ucrit speed was determined in this study. Pinks from five locations were tested at Seton Creek. Upon arrival the fish were placed in one of three holding pens each measuring approximately 3 m by 8 m and held a minimum of 24 h.

Swimming Test Apparatus

The test apparatus, in the form of parallel tunnels, was installed in the upper end of the upper spawning channel at Seton Creek (Cooper 1977), near Lillooet B.C. A small dam (flow control weir) was constructed across the top of the channel just downstream of the water intake. This provided the head required to produce tunnel velocities in the tunnel in excess of 1.5 m/s.

Eight tunnels, each 30 cm inside diameter, were inserted through the bottom of the dam. Each tunnel was 11 m long with a 1.8 m clear plastic (acrylic) section installed 6 m from the top end of the tunnel. A fixed screen of vertical aluminum plates was placed just upstream of the acrylic section, and a removable screen which was charged with electric-

ity during swimming speed testing was installed at the lower end of the acrylic section. A butterfly valve was installed at the upper end of the tunnel, close to the dam, and another was installed at the downstream end of the tunnel (Fig. 3). The velocities were controlled by use of a combination of these valves and adjusting stop logs in the flow control weir.

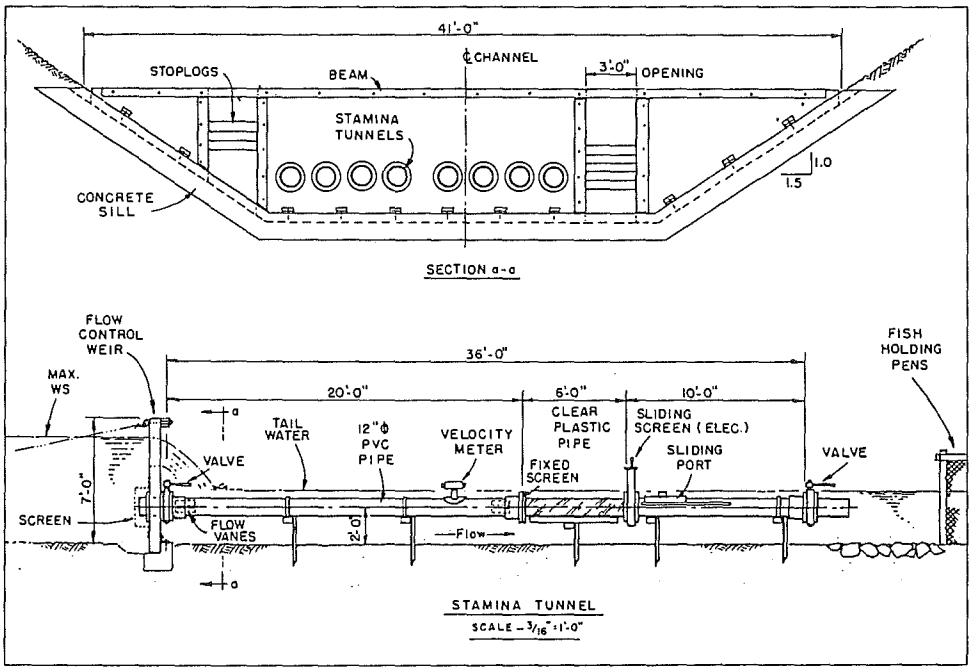

FIGURE 3—Diagram of critical swimming test apparatus installed in the Upper Seton spawning channel.

Velocities were measured with Gurley-Price flow meters installed in each tunnel approximately one meter upstream from the clear acrylic pipe. In addition, a probe meter (Monitek Flo-Probe Magmeter) was installed 60 cm upstream of the Gurley meter in tunnel eight only. Velocities were determined in the cross-sectional area of the tunnels (Fig. 4) and the meter was installed so that the velocity 5-6 cm from the tunnel wall was measured. This was somewhat lower (8%) than maximum velocity at the higher velocities (Fig. 4). The individual Price meters were calibrated with the probe meter.

Fish were loaded through a port located approximately 45 cm downstream of the lower screen. Wooden partitions had to be constructed between tunnels because behavioural interactions, caused by visual contact between fish, interfered with the tests.

Experimental Techniques

Critical swimming speed (Ucrit) tests were conducted 24 h/day. Fish selected from each group at random were carried and loaded into the tunnels using waterproof vinyl bags in the form of a folding stretcher. The fish were allowed to acclimate for one hour at 15 cm/s. While many investigators allow greater than 12 h acclimation, this has been shown to be unecessary for young coho as Glova and McInerny (1977) were unable to show any significant difference between 1 and 12 h acclimations.

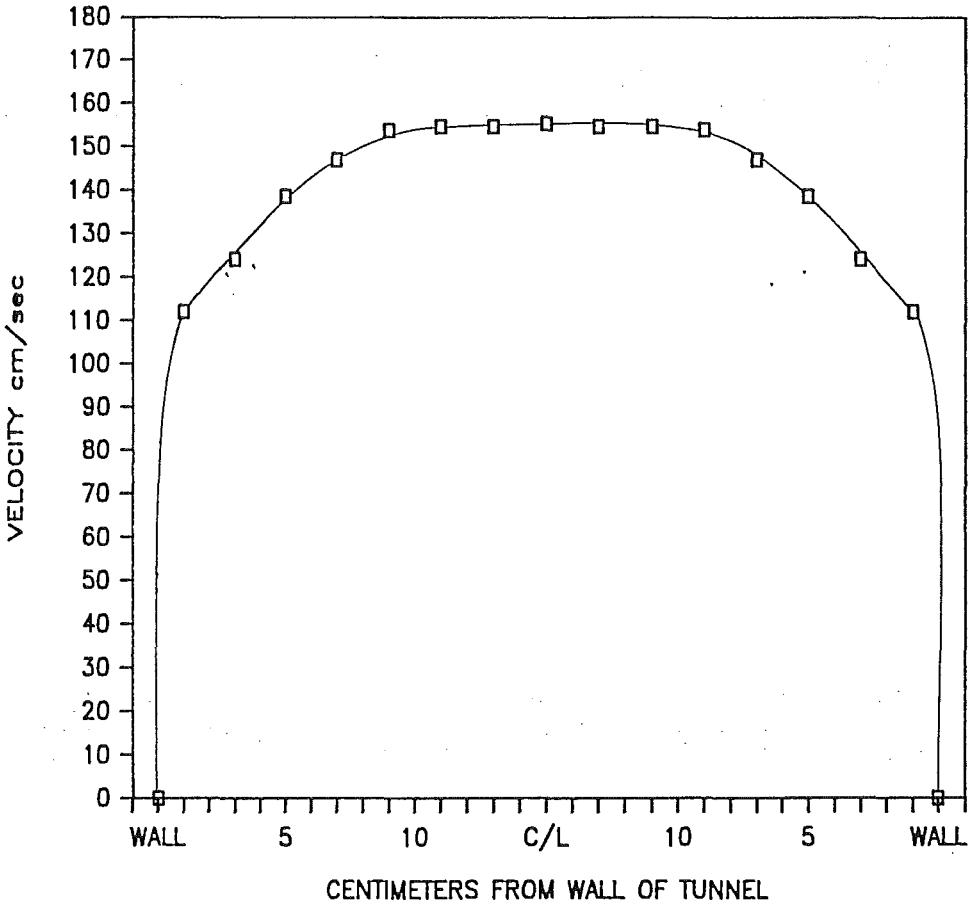

FIGURE 4—Water velocity profile in the test tunnels at 150 cm/s.

Stepwise increases in velocity lasting 30 min were used to determine the critical swimming speed. Tests were started at 30 cm/s and the velocities were increased approximately 10 to 15 cm/s/30 min step until the fish were impinged on the screen. At this time the fish were considered exhausted. A few tests were run with steps of 60 min duration/step to allow comparison with previous data (Brett 1982). Water temperatures were recorded for each test.

Velocities in all tunnels were adjusted simultaneously. Tail beat frequencies were recorded for each fish during each step. The time to exhaustion was recorded. The exhausted fish were then removed, killed and tagged for identification. The maturity of each female pink was classified as gravid (tight egg skeins), spawning (loose eggs from 10%-90%), and spawned out (0-10% eggs). Males were more difficult to classify. However, an attempt was made to differentiate between the stages of maturity. Males which did not leak milt easily were classified as gravid, while those that did were classified as spawning males. Physical measurements taken on each fish included total-, fork- and standard-lengths. The fish were weighed intact and their gonads were removed and

weighed. A piece of female gonad was preserved in 10% formalin. Fecundities, egg size and dry egg weights were determined for gravid females, while egg size and egg weights were determined for spawning females. Each fish was examined for any obvious signs of physical abnormality.

The maximum depth and width of each fish was measured and the maximum cross sectional area was recorded by cutting the fish vertically at the largest cross-section and stamping an impression on blank paper. The cross sectional area was later measured with a planimeter.

Swimming Speed

The swimming speed of fish tested in tunnels is subject to various influences due to the restricted space in the tunnel. The most significant factors are horizontal buoyancy, solid blocking and propeller corrections. The horizontal buoyancy adds to drag. The propeller correction is opposite in effect, approximately cancelling the horizontal buoyancy effect (Webb, 1975). For this study it was felt that solid blocking (the effect of increased velocity around any solid body in a tunnel) was the only significant factor requiring correction.

Correction for the solid blocking effect created by the cross sectional volume displacement was determined by the formula,

$$Vf = Vt(1 + Es)$$

where, Vf = corrected velocity
Vt = test velocity
$Es = \gamma \lambda (Ao/At) + e1.5$

where, $\gamma = 0.8$
$\lambda = 0.7$ length/thickness
Ao = maximum cross section area of fish
At = tunnel cross section area

These formulae are explained by Bell and Terhune, 1970. Corrected tunnel velocities were then converted to fish lengths/per second (L/s) to allow comparisons of different size fish within a relatively small size range.

The critical swimming speed (Ucrit) was calculated from the corrected velocities by the formula,

$$Ucrit = V1 + (TVF/TV1 \times VF - V1)$$

where, $V1$ = velocity prior to fatigue
VF = velocity at fatigue
TVF = time at VF
$TV1$ = time at V1

The Ucrit was then standardized to 15°C for comparison with other salmonid data. This was done by using the formulae developed from the data of Brett and Glass (1973), (Furnell and Brett, 1983) where,

$$\text{Log Ucrit} = At + B \log Lt$$

where, $At = 0.8695 + 0.01707\,T$
Lt = total length
T = degrees C.

The assumption was made that temperature changes would affect pinks in a similar way to sockeye. The B constant was then calculated for each fish by,

$$B = \text{Log Ucrit} - (0.8695 + 0.01707\,T)/\text{Log Lt}$$

The Log Ucrit 15°C was then calculated,

$$\text{Log Ucrit } 15°C = Ba + 1.12556 \times \text{Log Lt}$$

and,

$$\text{Ucrit } 15°C = 10\text{^Log Ucrit } 15°C$$

Tail beat frequencies were used to compare the corrected velocities obtained in this test to those obtained in previous tests by Brett (1982).

Student's t test was used to test for differences between sample means (Simpson et al, 1960). Regression analysis was taken from Biometry (Sokal and Rohlf, 1969).

PROXIMATE COMPOSITION:

Analytical Determinations

All samples were thoroughly homogenized before conducting the analytical determinations. The frozen body (excluding gonads) was cut into pieces with an electric butcher saw and converted into a homogeneous paste using the Hobart Food Cutter (Model 84185D) provided with a chopping and grinding device. The gonads were partially thawed and homogenized in the Sorvall Omnimixer. Samples of each fish were analyzed individually. The water, ash and total nitrogen were determined by AOAC (1980) methods and the fat by the Bligh and Dyer (1959) method. For the conversion of total nitrogen to protein, the factor of 5.5 was used for the testis (Magnusson and Whitaker, 1952) and the factor of 6.25 for all the other tissues.

To calculate the caloric values, 1 g of fat has been taken as equal to 8.66 kilocalories (kcal), and 1 g of protein as equal to 5.65 kcal (Brett and Groves, 1979). For the statistical comparison of results, the Student's t-test was used.

METABOLIC RATES:

Pink salmon were transported from the Fraser River to Bamfield Marine Station in two groups. They were held in a circular tank (1.9 m diameter × 1.2 m depth) with water circulation to encourage the fish to swim continuously. The fresh water was aerated vigorously. Fish were not fed during the holding period. Temperature in the holding tank remained at 14 to 14.5°C throughout the test period.

A description of the tunnel respirometer and the method of operation is presented in Brett, 1964, 1965a, and the use of the large tunnel respirometer is described in Brett, 1973; Brett and Glass, 1973. The internal diameter of the fish-holding chamber in the respirometer is 18 cm, length 94 cm. Tunnel velocities were calibrated at the start of this series of experiments using an OTT meter.

The experimental procedure was as follows: a fish was netted early in the evening, lightly anaesthetised in a bath containing 100 ppm MS-222 neutralized to pH 7, and transferred to the respirometer. It was allowed to recover and acclimate overnight with adequate water flow and a low applied velocity of up to 0.5 body lengths per second (l/s), at which speed the fish did not have to exert itself to maintain position.

The next morning the "resting" oxygen consumption was measured by Winkler titration of water samples taken before and after a defined period during which the respirometer was "closed" so that no fresh water was introduced. A standard, stepwise,

sequential increase in velocity at one hour intervals was imposed until a state of exhaustion was reached (Brett, 1964, 1967). Oxygen consumption by the fish was measured over a defined time period of each step (respirometer closed) and fresh water was introduced during the remainder of each step (respirometer open). The maximum 60 minute sustained speed (critical velocity = Ucrit) was determined.

It was found necessary to modify the procedure previously used (incremental increases of 0.5 l/s, starting at 1 l/s, with 45 minute sample times and 15 minute flushes) because of the size and limited swimming ability of the pink salmon. Initially, this velocity regime was used (Group I, fish #1 to 7), then modified to increase the number of incremental steps in velocity so as to provide more data for each fish. Thus, measurements were started at 0.5 l/s and increases of 0.25 l/s were applied for a large number (8 to 26) of the fish.

Because of the large size of the fish relative to the volume of the respirometer, the sample time had to be shortened in order to prevent hypoxic stress and to emulate more closely conditions in the wild. Pure oxygen was bubbled into the header tank of the respirometer for 10 to 15 minutes at the end of the flush period to raise the oxygen content of the respirometer water to near saturation (8 to 9 ppm). Sampling times were adjusted, depending on the velocity, to prevent oxygen levels falling below 5 to 6 ppm and, in general, oxygen levels were maintained above 7 ppm at the end of each sampling period. Twenty minutes were found to be a suitable time period in most cases.

The temperature in the respirometer was maintained at 15°C ± 0.5°C throughout the experiment by operation of a refrigerated flow through a cooling jacket, balanced against a heater controlled by a YSI temperature controller.

The Winkler method of oxygen determination followed the procedures used at the Pacific Biological Station, Nanaimo. Samples for Winkler titration were taken at the beginning of each velocity step after flushing with fresh water (oxygenated in some cases), and after a defined time into each velocity step, usually 20 minutes, by allowing a 300 ml BOD bottle to fill to overflowing 1.5 times. The oxygen consumption rate of the fish at each velocity was calculated from the difference in titration values before and after a sample period at each velocity.

A further modification to the method was made with some fish to increase the amount of data obtained. When a fish collapsed from exhaustion (critical velocity), the fish was allowed to rest at a lower velocity for an hour and some of the measurements at lower velocities were repeated to compare values. These repeated values were generally quite close to the initial values obtained at those velocities.

The adult pink salmon occupied a substantial area of the cross section of the respirometer tunnel, so the true speed relative to applied flow rate was estimated by recording tail beat frequency at the various velocities for many of the fish. It has been shown that a direct relation exists between tail beat frequency and speed for all but the lowest velocities (Bainbridge, 1958), and this has been confirmed and examined specifically for pink salmon (Brett, 1982). However, not all fish were checked in this way, and at high velocities beats were too rapid to count.

Fish were sacrificed at the end of the swimming regime, and various length measurements, total weight and gonad weight were ascertained, and the state of maturity was noted. Cross sectional area was calculated as width multiplied by depth at the maximum girth of the fish.

RESULTS

1983 PINK SALMON POPULATION:

The estimated total return of 15.2 million Fraser River pink salmon in 1983 was the second largest run on record (IPSFC, 1984). They were also the smallest pink salmon on record, with an average landed weight of 1.86 kg. In addition, the run was approximately 7 to 10 days later than normal. The early run pinks began entering the Fraser River in early September and the peak of spawning for Fraser River fish occurred between October 7-14, similar to 1981 but several days later than the October 4-11 peak of spawning in 1979. The Thompson fish were tagged at the Thompson Canyon between September 28 and October 15. Peak of spawning occurred between October 7 and 18, several days later than 1981 (October 5-16) and 1979 (October 4-17). Dead recovery on the Thompson spawning ground began October 7 and concluded November 1 with peak dead recovery on October 19.

There was an estimated 4.632 million total escapement to the spawning grounds in the Fraser River watershed. The early run escapement, which includes the Fraser and Thompson pinks, totalled 4.373 million with almost 76% of the spawners on the main Fraser spawning grounds. This compares with a mean (1975-1981) of 41.9% of the total early run spawning in the main Fraser. The proportion of early run pinks spawning in the Thompson and Seton systems in 1983 was significantly reduced compared with 1979 and 1981, and the greatest reduction occurred in the Thompson River watershed. The Thompson escapement declined from an average 36.2% of the early run to 11.7% of the early run in 1983, a reduction of 68% while Seton, at 10.3% in 1983, dropped by 44% (Table 1) (Fig. 5).

Table 1. Summary of the Early Run Fraser River pink escapement, 1975 to 1983 (numbers in thousands).

	Year					% Distribution	
Area	1975	1977	1979	1981	1983	Mean 75-81	1983
Main Fraser	315	775	1522	2252	3308	41.9	75.6
Thompson River	480	973	885	1163	512	36.2	11.7
Seton	253	390	594	563	449	18.4	10.3
Misc. Streams	38	64	154	119	104	3.5	2.4
Total	1086	2202	3155	4097	4373	100.0	100.0

MIGRATION SPEED:

The migration speed of the 1983 Thompson pinks was calculated from the recapture of pinks tagged at Fort Langley and recovered at the Thompson Canyon tagging site and the Thompson River spawning grounds.

These data indicate an average migration time of 9.5 days for males to migrate from Fort Langley to Thompson Canyon, a distance of approximately 220 km. The females took an average of 10.5 days to travel the same distance. This is a migration rate of 23 km/day for males and 21 km/day for females. The average number of days to death was 23.1 for males, 23.9 for females and 23.5 for both (Fig. 6). This is based on the assumption that there is a 3 day lag from death to recovery of dead fish (Killick, 1980). This compares to an average of 9 days travel time to Thompson Canyon and 23.9 days to death for the 1979 Thompson River pink salmon (Table 2).

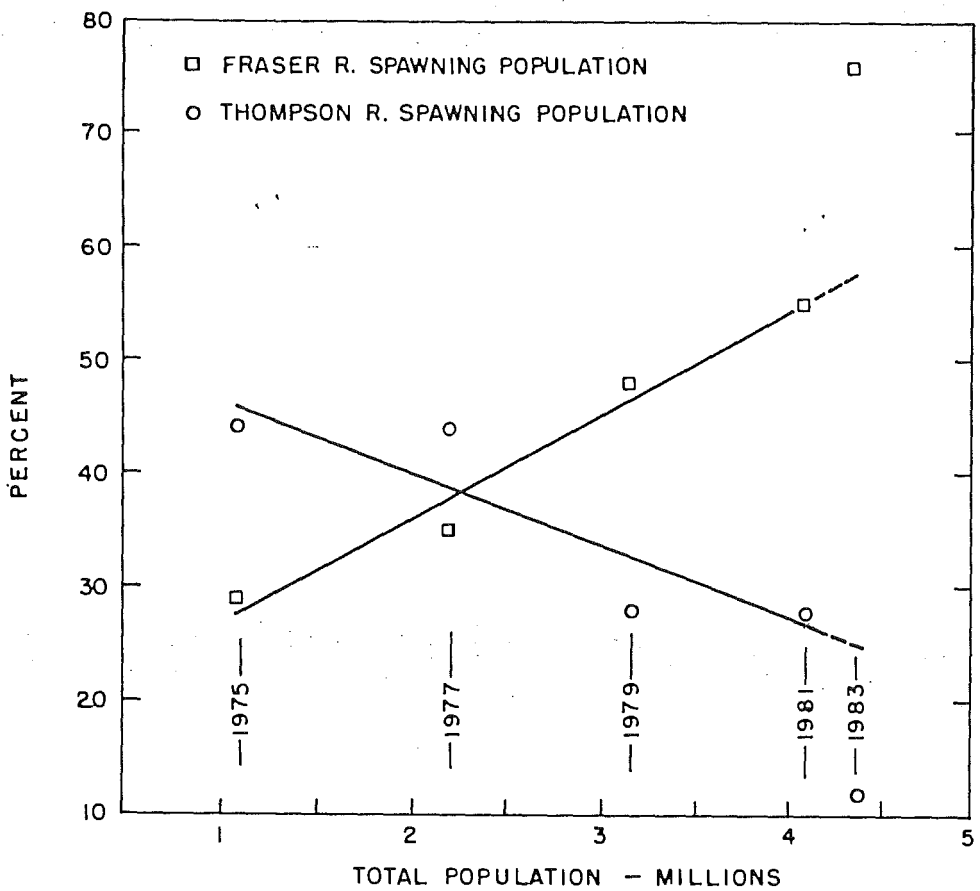

FIGURE 5—Percent of the total early pink population spawning in the Thompson and Fraser Rivers versus total number of spawners.

Table 2. Estimated Migration Times for Thompson River Pinks, males and females combined.

Year	No. of Days from Ft. Langley to: Thompson Canyon	Ashcroft	Death	Spawning Ground Life Span
1957	12	14	25.5	11.5
1979	9	11	23.9	12.9
1983	10	12	23.5	11.5

FISH CAPTURE:

There was a total of 338 male and 482 female pink salmon captured from six locations in 1983. Fish captured from Johnstone Strait were only used for chemical composition tests. Fish captured from the remaining five locations were used for swimming performance tests, metabolism study, chemical composition, fish disease survey and endocrine assessment (Table 3).

River temperatures during the sampling period varied from a high of 15.6°C maximum, on September 11, date of first fish captured at Fort Langley, to a low of 11.4°C minimum, on October 14, date of last fish captured (Fig. 7).

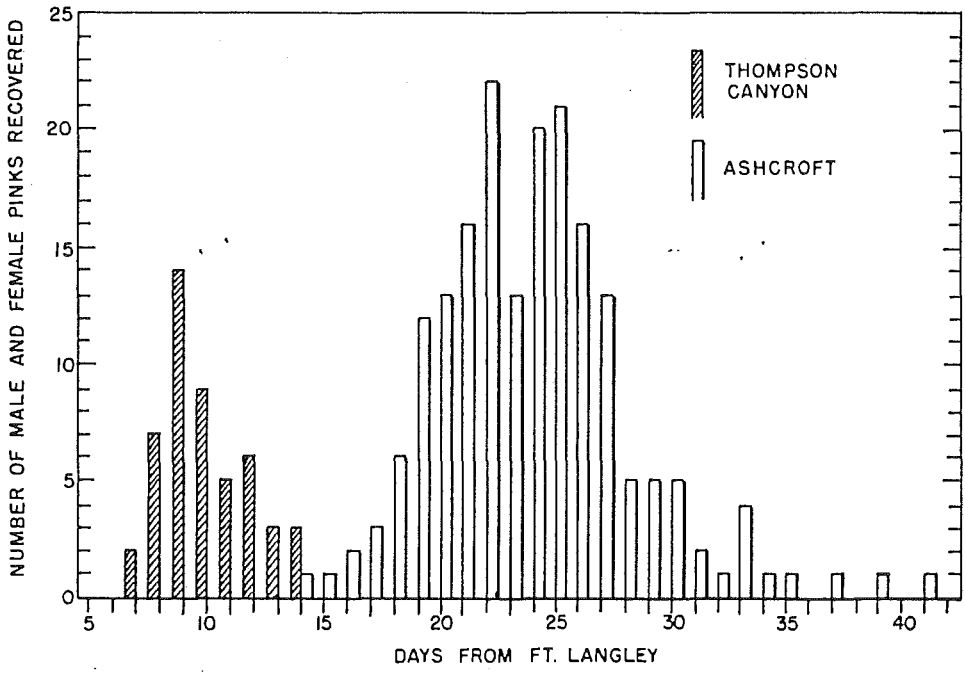

FIGURE 6—Number of fish tagged at Fort Langley and recaptured at Thompson Canyon and recovered dead at Ashcroft.

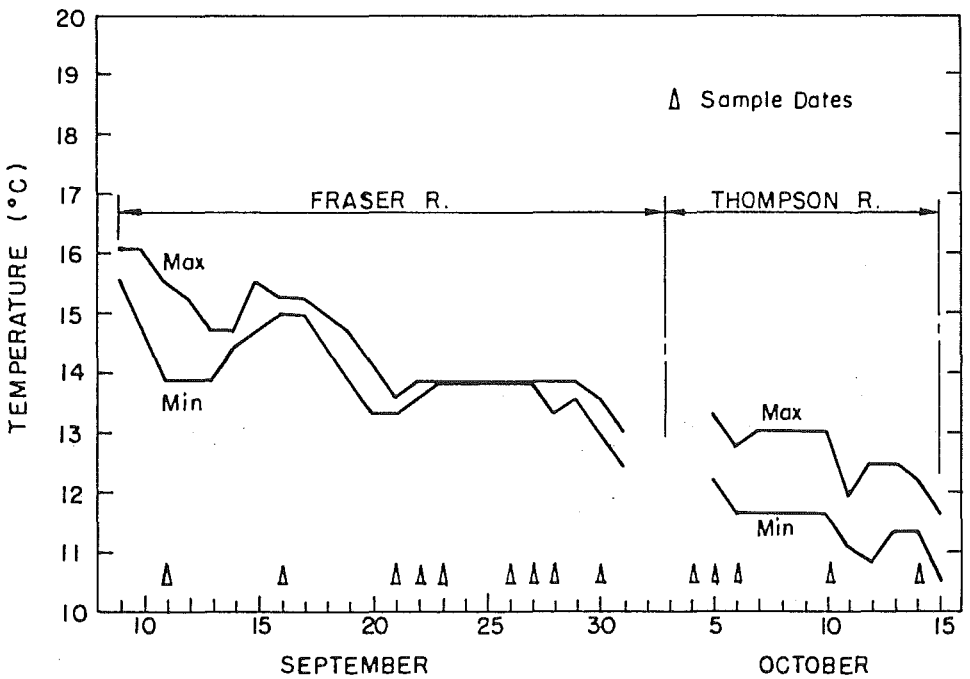

FIGURE 7—The maximum and minimum daily temperatures of the Fraser and Thompson Rivers during the fish capture period.

Table 3. Summary of number and location of pinks captured for the 1983 pink salmon study.

		Number Sampled									
		Swimming Performance		Metabolism Study		Chemical Composition		Fish Health		*Endocrine Assessment	
Date	Location	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Sep 6	Johnstone St.					15	14				
Sep 11	Ft. Langley	21	24	1	9						
16	Ft. Langley	16	23								
21	Ft. Langley					14	15				
22	Ft. Langley							13	17	10	10
23	Ft. Langley	28	21								
Oct 13	Ft. Langley			6	7						
Sep 26	Yale	17	31								
27	Yale					15	15	10	20	10	10
28	Yale	25	25								
Sep 30	Thompson Canyon	24	28			14	15	11	19	10	10
Oct 4	Seton (Lillooet)							11	19	10	10
5	Seton (Lillooet)	5	6								
10	Seton (Lillooet)	31	29								
14	Seton Spawning Ch. - spawned out							4	26		
Oct 5	Ashcroft	4	28			14	15	13	17	10	10
5	Ashcroft - spawned out					8	15				
6	Ashcroft	18	44								
	Total	189	259	7	16	80	89	62	118		

* - samples taken from pinks used in fish health survey

PHYSICAL CHARACTERISTICS:

Pink salmon lengths are reported as standard lengths. These may be converted to fork and total length with the following regressions developed for each sex from the 1983 data:

Males: Total length (cm) = 5.4518 + 1.0324 * standard length ($p<.001$)
n = 180 Fork length (cm) = 2.4850 + 1.0535 * standard length ($p<.001$)

Females: Total length (cm) = 10.2010 + 0.9195 * standard length ($p<.001$)
n = 266 Fork length (cm) = 6.0497 + 0.9788 * standard length ($p<.001$)

Male pink salmon sampled from all five locations averaged 1853 g weight and 49.3 cm standard length, with an average gonad weight of 87 g. The mean gonadosomatic index (G.S.I.) for males was 4.70. The mean weights and lengths for the five locations varied from a high of 1918 g and 49.9 cm at Thompson Canyon to a low of 1674 g and 47.6 cm at Ashcroft. The mean gonad weight varied from 91.7 g at Yale to 80.2 g at Thompson Canyon. The G.S.I index varied from 5.24 to 4.17 (Table 4).

The female pinks were categorized into gravid (tight egg skeins), spawning (loose eggs) and spawned (few eggs remaining). For the purposes of physical measurements the spawning and spawned fish were combined.

The gravid females averaged 46.8 cm standard length and 1596 g weight, with a mean gonad weight of 249 g. The fecundities averaged 1434 eggs and ranged from a low of 690 to a high of 2254. The dry egg weights for gravid females averaged .065 g and ranged from a low of .030 g to a high of .084 g (Table 5).

Table 4. Length and weight of male pinks sampled in 1983 (Standard Deviation in brackets).

Location	No.	Standard Length (cm)	Weight (g)		
			Total	Gonad	G.S.I.
Ft. Langley	60	50.0 (4.1)	1911 (533)	87 (33.5)	4.58 (1.18)
Yale	42	48.9 (3.9)	1806 (486)	92 (24.3)	5.24 (1.28)
Thompson Canyon	24	49.9 (2.9)	1918 (352)	80 (24.4)	4.17 (1.04)
Ashcroft	23	47.6 (3.2)	1674 (362)	87 (37.2)	5.03 (1.99)
Lillooet	33	49.4 (3.6)	1887 (495)	86 (31.1)	4.25 (1.13)
All Males	182	49.3 (3.8)	1853 (481)	87 (30.6)	4.70 (1.36)

Table 5. Summary of Physical Measurements of Gravid Female Pink Salmon Sampled in 1983 (Standard Deviation in brackets).

Location	No.	Standard Length (cm)	Weight (g)		G.S.I.	Dry Egg Wt.	Fecundity
			Total	Gonad			
Ft. Langley	58	46.7 (2.2)	1560 (308)	232 (60.7)	14.6 (2.4)	.063 (.010)	1418 (295)
Yale	54	47.0 (2.8)	1630 (277)	257 (59.9)	15.7 (2.3)	.067 (.011)	1422 (259)
Thompson Canyon	10	47.7 (1.8)	1633 (188)	270 (27.0)	16.6 (1.1)	.068 (.008)	1497 (144)
Ashcroft	18	46.2 (2.2)	1598 (225)	260 (60.5)	16.1 (2.9)	.062 (.012)	1378 (412)
Lillooet	4	45.7 (1.9)	1518 (219)	267 (18.8)	16.5 (.47)	.058 (.011)	1474 (177)
All Gravid Females	144	46.8 (2.4)	1596 (276)	249 (56.9)	15.4 (2.3)	.065 (.010)	1434 (282)

The spawning females sampled with a mean length of 46.0 cm and a mean weight of 1484 g, were slightly smaller than the gravid females, however, there was a greater range of size. These fish ranged from 26.5 cm and 945 g to 54.7 cm and 2505 g. The mean dry egg weight of spawning fish at 67.3 mg was very slightly larger than that of gravid pinks. The range went from 38.3 mg to 81.2 mg (Table 6).

Even though there is a statistically significant relationship between standard weight and dry egg weight in spawning pinks ($r = .3194$, $n = 94$, $p < .005$), there is too much variability to use this as an indicator of state of maturity (Fig. 8).

The mean G.S.I. index for gravid females generally increased as they migrated to the spawning grounds. The G.S.I. was lowest at Fort Langley at 14.56 and increased to 15.70 at Yale, 16.57 at Thompson Canyon, 16.07 at Ashcroft and 16.52 at Seton Creek (Fig. 9). The greatest extremes in values of G.S.I. index occurred at Yale with a range of 6.76 to 19.18. The pink GSI values were slightly higher than similar data for Horsefly sockeye.

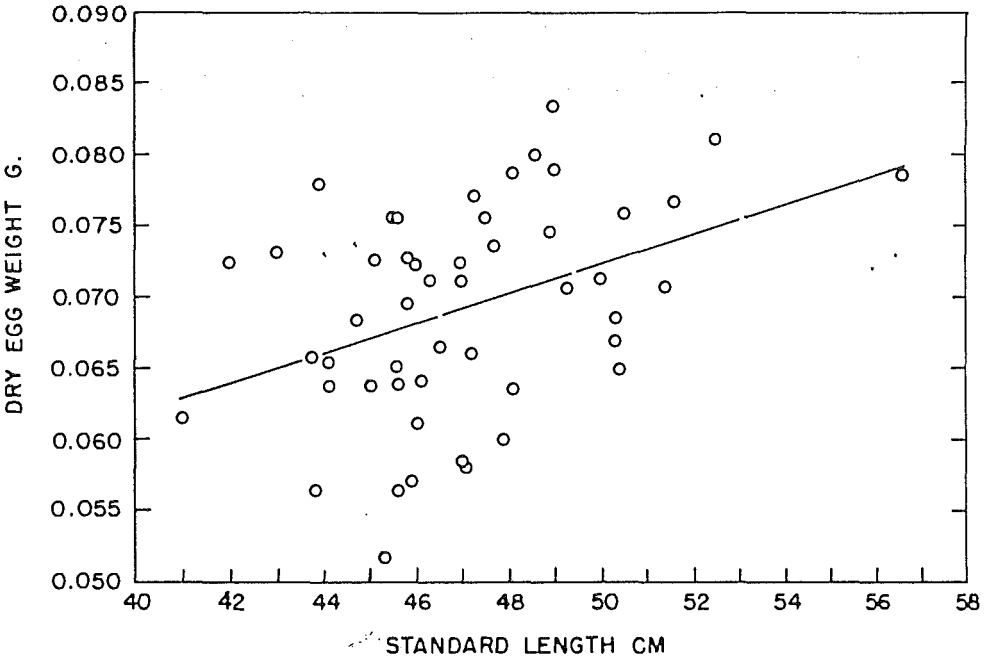

FIGURE 8—Relationship between total weight and dry egg weight for female spawning pinks.

Table 6. Length and weight of spawning female pinks sampled in 1983 (Standard Deviation in brackets).

Location	Number	Length (cm)	Weight (g)	Dry Egg Wt (g)
Thompson Canyon	17	46.0 (1.6)	1416 (204)	0.069 (0.006)
Ashcroft	45	46.0 (2.6)	1451 (212)	0.067 (0.009)
Lillooet	25	45.8 (4.8)	1575 (323)	0.065 (0.009)
Total	87	46.0 (3.0)	1484 (254)	0.067 (0.009)

The mean lengths of the pink salmon tagged at Fort Langley and Thompson Canyon in 1983 are very similar to the lengths of pinks sampled for experimental purposes (Table 7). The difference in length between all males and gravid experimental females compared with tagged fish ranged from 0.1 cm for males and females at Fort Langley to 0.7 cm for females at Thompson Canyon.

FISH HEALTH:

Infectious Disease Survey

There were four pathogenic organisims detected in the pink salmon examined during this study. These were *Dermocystidium* (a pathogen of uncertain classification), the virus VEN (Viral Erythrocytic Necrosis), the protozoan pathogen *Ceratomyxa shasta,* and the bacterium Aeromonas *salmonicida*.

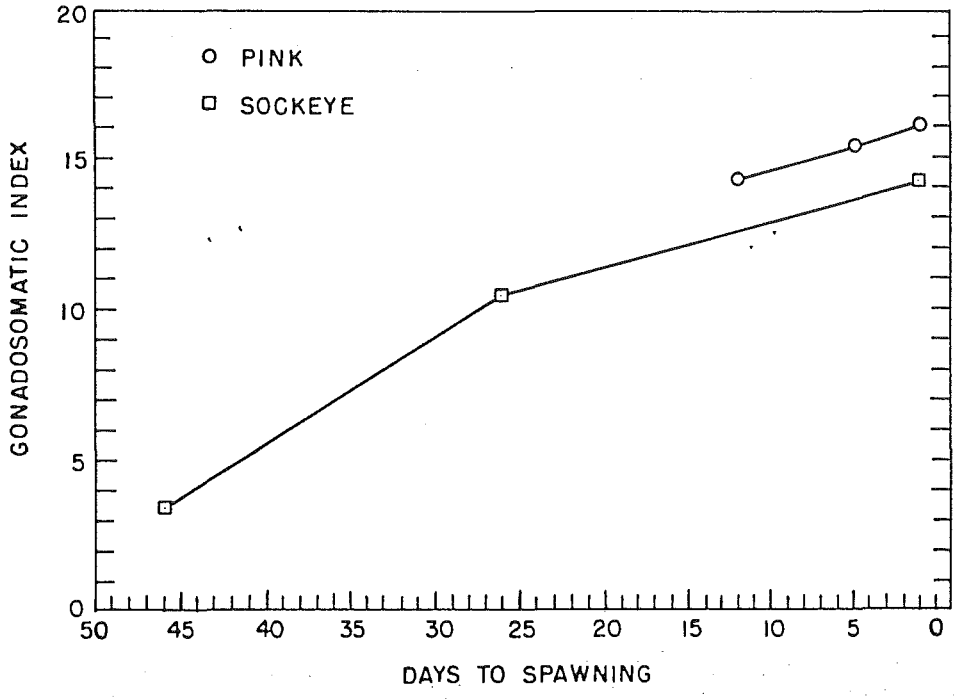

FIGURE 9—A comparison of 1983 female pink and sockeye salmon gonadosomatic index versus time of spawning.

Table 7. Mean length of pink salmon tagged in 1983 (Standard Deviation in brackets).

	Males		Females	
Location	No.	Standard Length	No.	Standard Length
Ft. Langley	1341	49.9 (4.2)	1141	46.6 (2.8)
Thompson Canyon	605	50.3 (4.0)	778	47.0 (2.7)

VEN is caused by a group of viruses tentatively assigned to the Iridoviridae and is known to affect naturally or experimentally a number of species of marine and anadromous fishes, and possibly also some terrestrial ectothermic vertebrates (MacMillan et al, 1980). The most obvious gross sign of disease is severe or chronic anemia but the appearance, using light microscopy, of 0.8-4.0 um diameter amorphous, pink or magenta colored inclusion bodies (usually one per cell) in the cytoplasm of Giemsa-stained erythrocytes is considered pathognomonic (Evelyn and Traxler, 1978). Affected salmon, which can have hematocrits of <5% instead of the usual 30-40%, may succumb to environmental stressors such as low p02, or to bacterial infections (Evelyn and Traxler, 1978; MacMillan et al, 1980).

Ceratomyxosis, the disease caused by *C. shasta*, is a severe illness affecting many cultured and wild salmonids in certain Pacific watersheds (Johnson et al, 1979). Of the Pacific salmon species, coho (*O. kisutch*), chinook (*O. tshawytscha*), chum (*O. keta*), and sockeye (*O. nerka*) are known to be susceptible to this disease. The prevalence of *C. shasta* among adult chinook, coho, steelhead (*S. gairdneri*), and cutthroat trout (*S. clarki*) at various sites on the Fraser River was recently reported (McDonald, 1983). No pink salmon were examined in that study.

Aeromonas salmonicida, the causative agent of furunculosis, is a world wide pathogen affecting both fresh and salt water fish including all species of Pacific salmon (Wood, 1974).

Dermocystidium infections of the gills have been known to cause high prespawning losses of chinook salmon; this is also possible for pink salmon (Pauley, 1967; Allen et al, 1968).

The only pathogen detected at Fort Langley was *Dermocystidium*. This occurred in the gills of 15 of 30 fish examined histologically, in densities of 1 to 14 per section. These organisims were detected at every location at similar rates and densities of infection (Table 8).

Table 8. Rate and intensity of *Dermocystidium* infections in the 1983 Fraser pink salmon (N = 30).

		Dermocystidium Prevalence			
			*Intensity of Infection		
Site	Date 1983	No. Positive	Light (%)	Moderate (%)	Heavy (%)
Ft. Langley	Sep 22	15	43	7	0
Yale	Sep 21	16	40	10	3
Thompson Canyon	Sep 30	15	47	3	0
Lillooet	Oct 4	17	37	17	3
Ashcroft	Oct 5	16	43	10	0
Seton Spawning	Oct 14	20	57	3	7

* - Level of infection estimated by counting the number of *Dermocystidium* cysts in each filament:
Low - <3 cysts per filament
Moderate - 3-10 cysts per filament
Heavy - 10 cysts per filament

The first sign of the virus VEN occurred at Yale, where it was detected in 4 of 30 fish examined. The frequency of detection increased to 40% or 12 of 30 fish examined at Thompson Canyon. The fish examined at the Ashcroft spawning grounds had a 30% detection rate. The virus was detected in 50% of the fish examined at the Lillooet location, while 23% of the pinks examined at the Seton spawning channel were positive for VEN (Table 9). In a separate sample, seventeen of 38 pinks examined after completing the swimming tests at the Seton channel were positive for VEN.

Aeromonas and *Ceratomyxa* were only detected in spawned-out pinks taken from the Seton spawning channel on Oct. 14, 1983. *Aeromonas* was detected in 5 fish and *Ceratomyxa* was detected in 6 of the 30 fish examined (Table 9).

Table 9. Hematocrit values, and the prevalence of *A. salmonicida* (the causative agent of furunculosis), VEN, and *C. shasta* (the causative agent of ceratomyxosis) in adult pink salmon at various dates and sites on the Fraser River (Sample size = 30).

		Percent Occurrence		
Site	PCV Hematocrit	*A. salmonicida*	VEN	*C.shasta*
Ft. Langley	42.8	0*	0	0
Yale	37.0	0	13	0
Thompson Canyon	35.4	0	40	0
Lillooet	37.2	0	50	0
Ashcroft	37.4	0	30	0
Seton Spawn. Chan.(spent)	61.0	17	23	20

* - Statistically, the prevalence in the population would be <10% rather than 0.

Haematocrits

Haematocrit values did not differ between sexes (Table 10). When sexes were combined, values in fish from Fort Langley were significantly higher than those in fish from other locations. The latter fish, however, had similar haematocrits. The same results were obtained when females were analyzed separately, but values for males so analyzed did not vary significantly between locations.

Table 10. Haematocrit values (means ± SE) of adult pink salmon migrants. Numbers of fish are shown in brackets.

	Males	Females
Fort Langley	42.3 ± 2.0 (12)	43.8 ± 1.3c* (9)
Yale	39.5 ± 1.5 (11)	37.3 ± 1.0ab (9)
Thompson Canyon	36.7 ± 4.6 (6)	34.5 ± 2.2a (8)
Ashcroft, arrival	37.9 ± 1.6 (10)	37.1 + 0.8ab (9)
Ashcroft, spent	36.1 ± 1.0 (9)	37.7 ± 1.0ab (10)
Seton Creek	37.0 ± 1.0 (10)	37.4 ± 1.1b (10)

* - For details regarding statistical analyses refer to Methods

Histology and Endocrinology:

Gonads

As indicated by the gonadosomatic index, (Tables 4, 5) both the testes and ovaries were in a relatively advanced state of maturity in the samples collected at Fort Langley. The germ cells of the testes consisted mainly of spermatids and spermatozoa. Also, the ova diameters showed little change between Fort Langley and the time of arrival on the spawning ground.

Stomach

The structure of the stomach from fish sampled at Fort Langley was not unlike that of actively feeding fish. Villi were discernible while the epithelial cells lining the mucosa were columnar in shape. Gastric glands were numerous and their cytoplasm was well

granulated. Both the longitudinal and circular muscle layers of the stomachs were well developed. Food remnants, however, were not noted in the stomach lumens of any of the fish examined.

A general atrophy of the stomach was evident in fish sampled at Yale. Not only were the villi visibly reduced in number, but also many epithelial cells of the lining were cuboidal in shape. Similarly, there was a clear diminution in cytoplasmic granulation of the gastric glands. A few fish showed a modest thinning of the muscle layers. A significant poliferation of large, well granulated cells of the stratum granulosum had occurred.

Further deterioration, although not marked, was evident in those fish that had fully matured sexually (Ashcroft, B.C.). Most conspicuous was the atrophy of the muscle layers, involving some loss of fibrils from the muscle fiber.

Kidney

Degenerative changes in this organ involved essentially sclerosis of the glomeruli and a marked thickening of Bowman's capsule. These alterations were well established in the fish examined from the first site and showed little, if any, further change with sexual maturity. Degeneration of the tubules was noted only occasionally and then only in fully mature fish. Of interest was the presence of presumptive spores (unknown history) located generally in Bowman's space. The latter were not detected in any of the fish from Fort Langley, but they were noted in a few fish from each of the subsequent sites.

Skin

In adult sexually immature salmon, the epidermis, the outer portion of the skin, consists of an inner germinal layer covered by a layer of stratified squamous epithelium three to sex cells in depth. The total thickness of the epidermis for adults fresh from the sea is generally in the range of 35-70 um. Sexual maturation is known to induce a marked increase in the thickness of the epidermis with the greatest increase occurring in the males.

The depth (um) of the epidermis for the pink salmon collected at Fort Langley was 176.5 ± 24.3 and 135.6 ± 20.7 (mean $\pm$ SD) for males and females, respectively. The fully mature fish sampled at Ashcroft showed no appreciable change to these values. Most if not all of the increase in thickness of the epidermis attributable to sexual development had occurred in the pink salmon by the time of their arrival at Fort Langley.

Liver

The structure of this organ underwent the transitional changes generally associated with sexual maturation in salmonids. At Fort Langley the structure appeared normal and the hepatocytes had a fine, evenly distributed granular cytoplasm. Lipid droplets, usually related to the very early stages of sexual development, were noted in only two of 20 fish examined. Reflecting their role in vitellogenesis, the hepatocytes of the females were visibly hypertrophied.

Degenerative alterations were first detected in the livers of fish collected at Yale. In the females, the hypertrophied state of the cells remained, but small focal areas of degenerating and/or necrotic tissue were noted in five of 10 fish assessed. The changes consisted primarily of cells showing pyknotic nuclei with loss of cell boundaries The

males, on the other hand, displayed a general vacuolization of the cytoplasm with focal necrotic areas noted in only one fish.

At Thompson Canyon the most prominent changes had occurred in the females, in which a general shrinkage of the hepatocytes was noted in eight out of 10 fish. Possibly this marked the completion of the role of the liver in vitellogenesis. No obvious increase in the incidence of focal necrotic areas was evident in either sex.

At full sexual maturity of the fish (Ashcroft samples), the general deterioration of this organ was more pronounced. Focal areas of necrotic tissue were observed in the majority of fish of both sexes. Moreover, the areas affected were visibly larger than noted at previous sample sites and often these foci of dead cells lacked any degree of cellular organization. In the remaining tissue the amount of cytoplasm was reduced and often presented a moth-eaten appearance.

Interrenal

Interrenal tissue in salmon consists of clusters of cells dispersed in the anterior kidney, generally in association with the numerous branches of the postcardinal veins. In the fish from Fort Langley the structure of the interrenal cells was consistent with that of a relatively active gland. There was abundant tissue with columns, bordering on the veins, often exceeding 10-15 cells in depth; furthermore the cells contained considerable amounts of evenly distributed fine granular cytoplasm. The nuclei were large (Table 11) and contained a single prominent nucleolus. While mitotic activity was not noted the tissue did appear to be well vascularized. By contrast adult sockeye salmon in the early stages of migration (Horsefly race, Fraser River) have less active interrenals. In the latter, the cells are densely packed, contain little cytoplasm and the nuclei are small with an inconspicuous nucleolus (Williams et al., 1977).

Structural changes in the state of the interrenal were not evident in the pink salmon at Yale. However, in the fish sampled at Thompson Canyon, clear evidence of heightened interrenal activity was noted. The nuclei were hypertrophied (Table 11) and small focal hemorrhages, often in association with necrotic areas were noted in 40-50% of the fish of both sexes. The presence of hemorrhages as well as necrotic tissue may be indicative of tissue exhaustion.

Table 11. Interrenal cell nuclear diameters (um) of adult pink salmon migrants. Values are means ± SE of 25 measurements for each of the fish in a sample. N is number of fish.

	X ± SE	
Collection Site	Males	Females
Fort Langley	6.214 ± 0.008a* N = 7	6.234 ± 0.019a N = 8
Yale	6.224 ± 0.021a N = 8	6.216 ± 0.014a N = 10
Thompson Canyon	6.407 ± 0.021b N = 7	6.448 ± 0.021b N = 10
Ashcroft, arrived	6.411 ± 0.008b N = 4	6.430 ± 0.015b N = 10
Ashcroft, spent	6.396 ± 0.014b N = 10	6.435 ± 0.016b N = 8
Seton Creek	6.425 ± 0.014b N = 9	6.580 ± 0.039c N = 10

* - For details regarding statistical analyses refer to Methods

Examination of pink salmon collected from upstream sites, Ashcroft and Seton Creek, did not indicate any further deterioration in structure. Possibly in the spent fish, at Ashcroft, the prevalence of necrotic tissue was more common, but the change was not pronounced.

Gills

The gill tissue from pink salmon captured at Fort Langley was essentially healthy. Focal hyperplasia of the basal lamellar epithelium was noted in two fish but the affected area composed less than 1% of the total. Five of 20 fish examined at Yale exhibited marked pathological changes. Hyperplasia of the lamellar epithelium occurred in 10 to 25% of the total area sampled. In many instances the proliferation of cells resulted in fusion of adjacent lamellae. There were also two to five aneurysms per section in these fish (Fig. 10). All plates in Fig. 10 show gill tissue (H.&E., × 40) collected from adult migrant pink salmon sampled at Yale, B.C.

Plate 1 - Normal gill structure showing typical delicate lamellae.
Plate 2 - Hyperplasia of lamellar epithelium (−>); also note presence of an aneurysm (A).
Plate 3 - Extensive lamellar hyperplasia, note hemorrhage (−>).
Plate 4 - Cyst (*Dermocystidium*) of unknown origin (C) as well as lamellar hyperplasia.

The pathological changes were very similar in fish sampled from the remaining sites, however, the frequency increased. These changes were seen in 10 of 20 fish sampled at Thompson Canyon and 11 of 20 fish sampled at Ashcroft and Lillooet.

Pituitary: Gonadotrop Activity

In the initial sample (Fort Langley) large numbers of well granulated gonadotrops were noted in all parts of the pars distalis, with the greatest concentration in the area adjacent to the rostral pars distalis. There were no visible differences between sexes. Based on published data for adult migrant sockeye and coho salmon (Robertson and Wexler, 1962; Van Overbeeke and McBride, 1967) the gonadotrop profile of these pink salmon is consistent with that of fish in a relatively advanced stage of maturity. A progressive increase in total number of gonadotrops was evident, especially in the deeper areas of the proximal pars distalis, in fish collected from each of the subsequent sample sites. At Ashcroft, these cells were the dominant cell-type of the pars distalis. However, in the latter samples, small numbers of gonadotrops showed vacuolar disintegration of the cytoplasm and pyknotic nuclei. Interestingly, while the number and distribution of the gonadotrops was similar in fish from Seton Creek and Ashcroft, the cells in the former did not give any evidence of degeneration.

Plasma Cortisol Concentrations

Cortisol concentrations in adult Pacific salmon increase in response to disturbances in the environment (stressors) (Fagerlund, 1967). Acute stressors cause highly elevated cortisol levels within minutes of application, while chronic stressors may result in gradual increases to moderately higher levels. If adaptation occurs, cortisol concentrations return to pre-stress levels (Schreck, 1981). Increases in cortisol concentrations may also be an indication of physiological changes occurring in the fish, such as those caused by changes

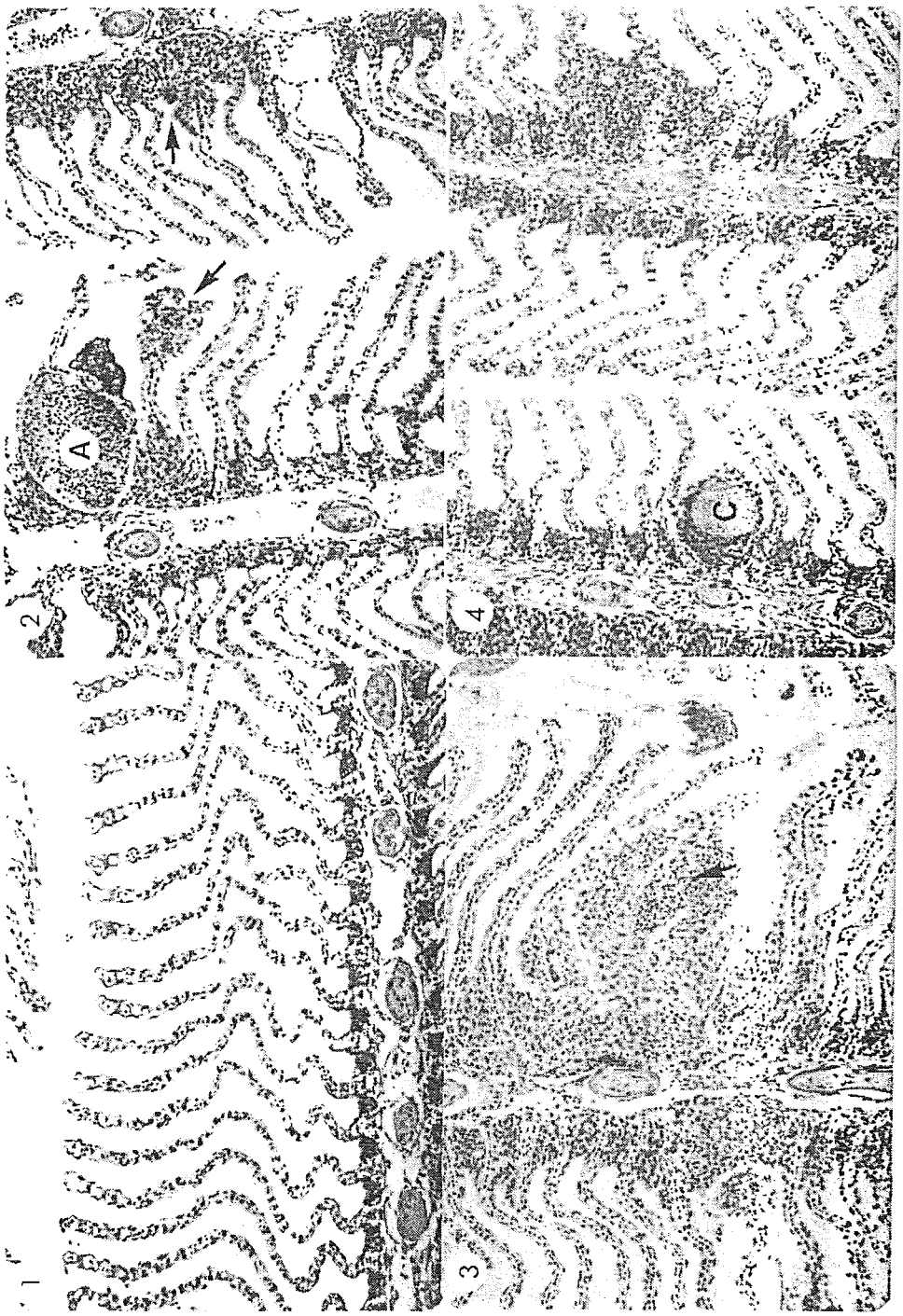

FIGURE 10—Photoplate showing deterioration in gill tissue of pink salmon.

in water salinity, strenuous physical activity, reproductive development and disease conditions. Elevated cortisol levels, if allowed to persist, are harmful and will impair normal body functions.

Plasma cortisol concentrations (mean ± SE of 9-11 fish) in adult pink salmon are shown in Fig. 11. Cortisol levels in fish caught at Fort Langley and Yale were within the range found in unstressed healthy salmon. Concentrations in females were higher than in males, as previously noted in adult sockeye salmon.

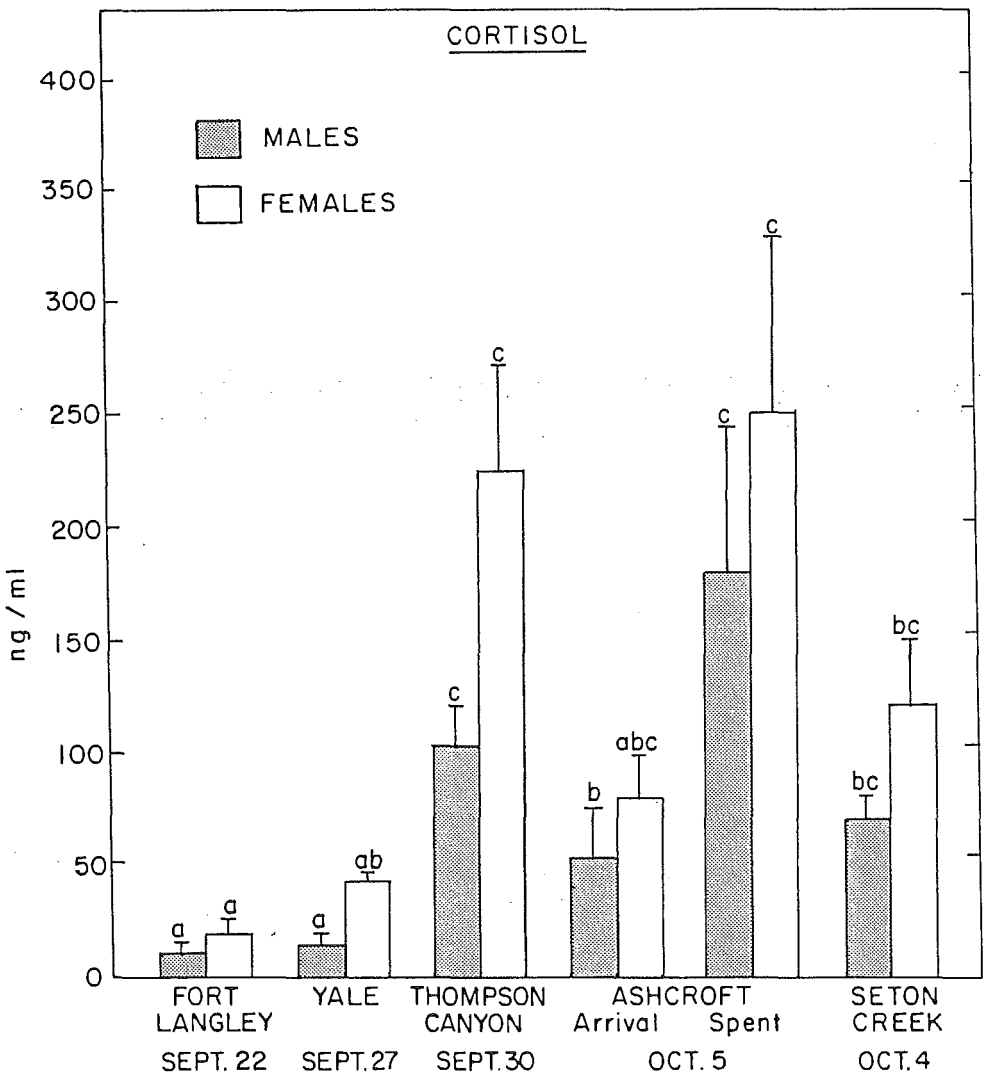

FIGURE 11—Cortisol concentration in the plasma of pink salmon captured at all five locations.

Cortisol concentrations in fish caught by dipnet in the Thompson Canyon were highly elevated and reached levels reminiscent of stressed fish. Similar levels have been measured in adult sockeye caught in the Canyon. The fact that the levels in these fish were higher than in the fish taken later at either Ashcroft (arrival) or Seton Creek support the contention that the cortisol increases in these fish were caused by the physical exertion required to negotiate this particularly turbulent segment of the river.

Cortisol concentrations in unspawned fish at Ashcroft and Seton Creek, although lower than in fish taken in the Thompson Canyon, were substantially higher than those in fish from the lower segments of the Fraser River. The increases noted may be partly caused by swimming activity but may also reflect the rapid deterioration and increasingly pathological condition of the fish. Further pathological deterioration resulted in maximal cortisol concentrations in spawned fish taken at Ashcroft.

When exercised to exhaustion in swim tunnels (Table 12), fish had higher cortisol concentrations than when resting. Concentrations in resting fish before the tests commenced were higher than anticipated. The high basal levels may have been the result of exposure to disturbances or they may have been caused by increases in spawning activity which were observed in the stream enclosure.

In general, the increase in plasma cortisol levels during the spawning migration proceeded in a manner similar to that observed in sockeye salmon. However, the rate of increase in plasma cortisol in pink salmon paralleled the more advanced state of sexual development in this species. At each test site the range of cortisol values was very wide, reflecting the large variation between individuals in sexual development and probably in health.

Table 12. Cortisol concentrations (ng/mL, mean ± SE) in plasma of fish before and after exercise to exhaustion in swim tunnels. "River" samples were obtained from fish caught at Fraser and Thompson Rivers. "Resting" samples were taken from fish resting before exercise in a stream adjacent to the swim tunnels. Numbers of fish in brackets.

Origin of Fish	River	Resting	Exhausted
Lower Fraser River Males			231.6 ± 14.1(5)
Lower Fraser River Females			342.2 ± 41.8(10)
Ashcroft (arrivals) Females	64.9 ± 17.1(9)	234.3 ± 63.3(4)	402.7 ± 62.4(6)

Reproductive Hormones and Vitellogenin

The critical processes involved in the completion of egg and milt development and preparation for the processes of ovulation and spermiation occur in Pacific salmon during the upstream migration. Thus, measurement of reproductive parameters during this migration accurately assesses sexual development and any deviations from the normal process.

Plasma samples, obtained from male and female pink salmon at the five sampling locations, have been analysed by radioimmunoassay (RIA) for the following hormones and yolk precursor: gonadotropin, vitellogenin, 17ß-estradiol, 17∝-hydroxy-20ß-dihydroprogesterone, testosterone, and 11 ketotestosterone. The changes observed in the concentrations of the above proteins and steroids are significant and measurable and

indicate the timing and geographic location of the fish where these specific processes critical to successful spawning occur.

Concentrations of vitellogenin, (a yolk precursor), were high (over 8 mg/ml) in females at Fort Langley and Yale and then dropped sharply between Yale and Thompson Canyon signalling the completion of exogenous yolk production. In spent females at Ashcroft vitellogenin concentrations were extremely low indicating that the vitellogenin had been fully utilized (Fig. 12).

Changes in concentration of 17ß-estradiol (the estrogen which stimulates vitellogenin synthesis in the liver) paralleled the changes in vitellogenin concentration. High concentrations of estradiol observed at Fort Langley and Yale indicate that vitellogenin synthesis was still being stimulated. Between Yale and Thompson Canyon there was a dramatic drop in estradiol concentration which triggered the above noted drop in vitellogenin concentration and terminated vitellogenesis (Fig. 12).

The pattern of change in concentrations of gonadotropin (the pituitary hormone which regulates development of the ovary including ovarian steroidogenesis) were opposite that in estradiol and vitellogenin. Gonadotropin concentrations were relatively low at Fort Langley and Yale and then steadily rose with maximal levels observed in spent females on the spawning grounds at Ashcroft (Fig. 12).

17∝-hydroxy-20ß-dihydroprogesterone is responsible for final maturation of the oocytes prior to ovulation. Concentrations of this hormone were, as expected, very low at Fort Langley and Yale. However, there was a dramatic rise in its concentration between Yale and Thompson Canyon which coincides with the sharp drop in 17ß-estradiol between these locations. The reversal in the levels of these two hormones signifies the switch in follicular steroidogenesis from estrogen to progestogen synthesis. The concentration of 17∝-hydroxy-20ß-dihydroprogesterone peaked in females arriving on the spawning grounds at Ashcroft indicating that the oocytes in these fish were undergoing or had just undergone final maturation i.e., germinal vesicle breakdown, a process which occurs just before ovulation (Fig. 12).

Testosterone is the major androgen in the female salmon, its concentration declined gradually between Fort Langley and the spawning grounds. Concentrations of this hormone in the female salmon were higher than those observed in male salmon at all locations. Its specific role in gonad maturation is not known.

The androgen 11-ketotestosterone was present in females at one-tenth of the concentration of testosterone. It showed a gradual decline during the migration. In males this hormone is the major androgen.

The male pink salmon had a somewhat similar pattern of changes in the endocrine components, however, the concentrations were considerably lower.

Vitellogenin was present at extremely low but detectable levels in males throughout the spawning migration (Fig. 13).

17ß-estradiol was present at extremely low concentrations throughout the migration. It's presence is probably responsible for the low levels of vitellogenin observed in male salmon.

As in the females, the hormone gonadotropin was low at first and then rose quickly in concentration between Thompson Canyon and Ashcroft with highest concentrations observed in spent salmon. The maximal concentrations observed were one-third of those observed in the females (Fig. 13).

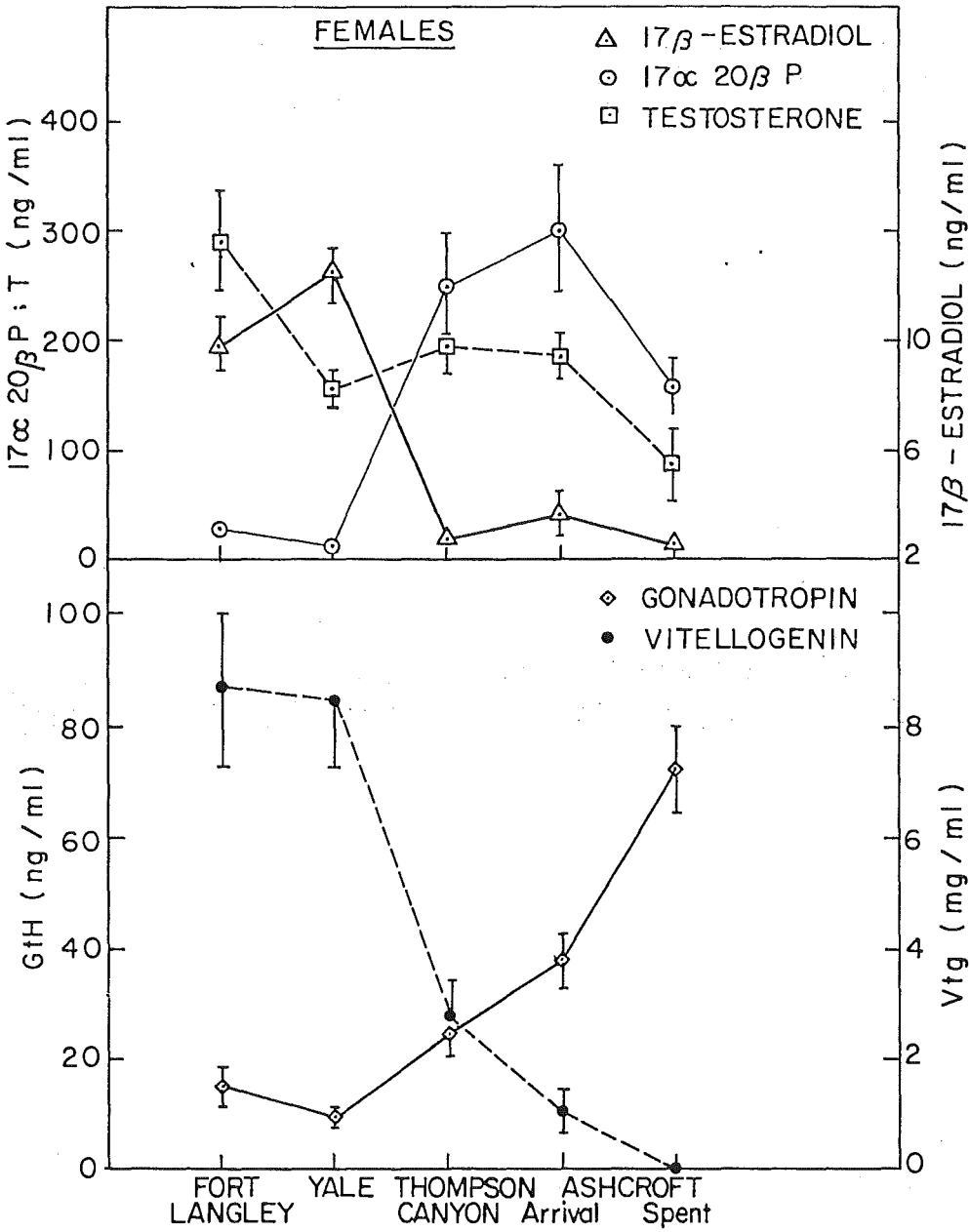

FIGURE 12—Concentrations of 17 -estradiol, 17 -hydroxy-20 -dihydroprogesterone (17 20 P), testosterone, gonadotropin and vitellogenin (mean ± SE) in plasma of female pink salmon.

The hormone 17∝-hydroxy-20ß-dihydroprogesterone, as in the females, increased in concentration dramatically between Thompson Canyon and Ashcroft. Recent studies have indicated that the hormone has an important role in spermiation in male salmonids and the data presented here are consistent with this hypothesis (Fig. 13).

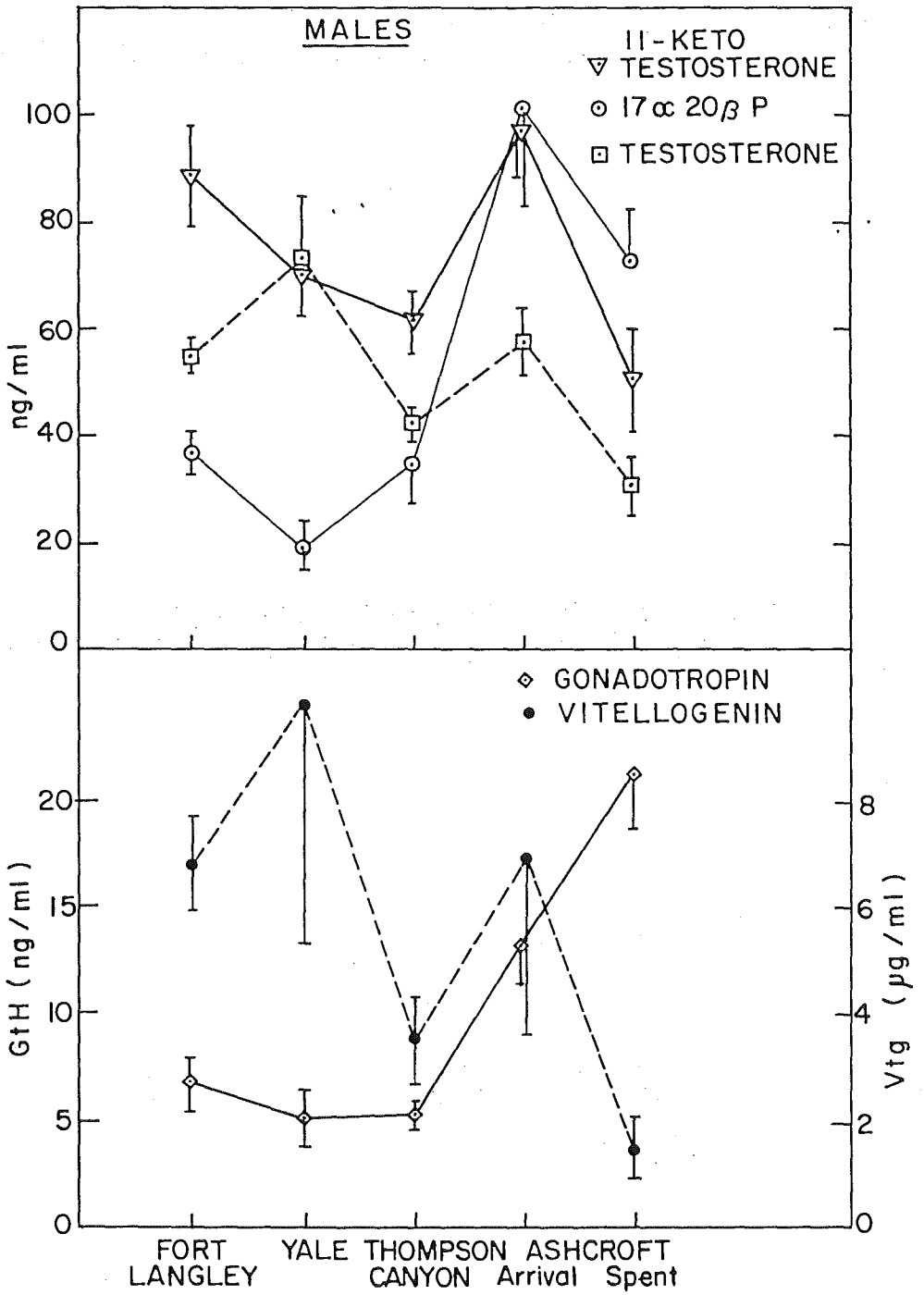

FIGURE 13—Concentration of 11-ketotestosterone, 17 -hydroxy-20 -dihydroprogesterone (17 20 P), testosterone, gonadotropin and vitellogenin (mean ± SE) in plasma of male pink salmon.

Concentrations of the androgen testosterone in general declined during the spawning migration (Fig. 13).

The hormone 11-ketotestosterone (the major androgen in male salmon) was present in high concentration at Fort Langley, declined somewhat through Yale and Thompson Canyon and then rose to a peak on arrival at the Ashcroft spawning grounds (Fig. 13).

The hepatosomatic index (HSI) expresses liver weight as a percentage of body weight. In males there was a slight increase in the index during the migration. In females the liver was much larger in fish sampled at Fort Langley and Yale where estradiol concentration was still high and vitellogenin synthesis was still active. Between Yale and Thompson Canyon there was a drop in HSI in the females compared with that observed in male fish (Fig. 14).

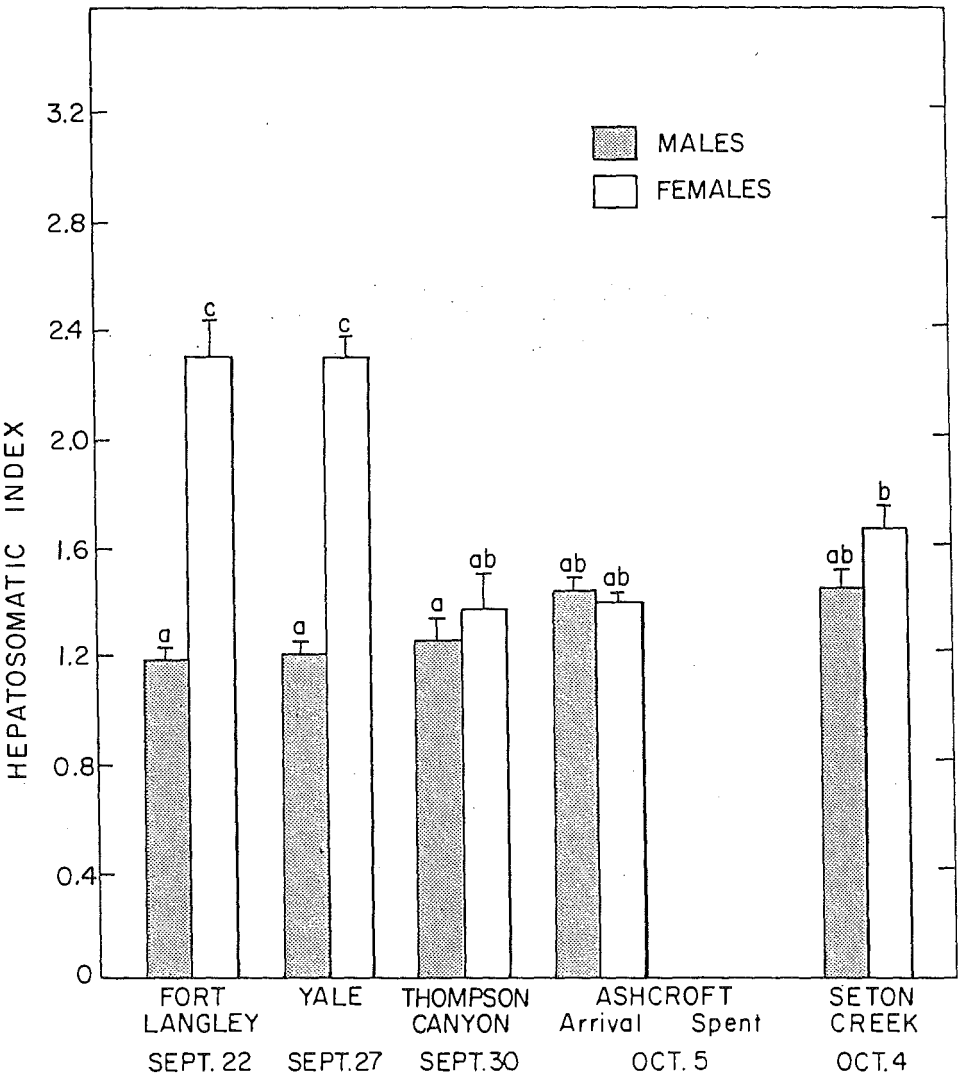

FIGURE 14—Hepatosomatic index.

ENERGETICS:

Critical Swimming Speed

Critical swimming speeds were determined for 189 male and 259 female pink salmon captured over a 30 day period from five locations (Table 3). A significant factor which affects the critical swimming speed of fish tested in tunnels is the solid blocking effect. Therefore, the critical swimming speeds were corrected to compensate for this.

The formula used to correct for solid blocking corrected for different form drag (different cross sectional areas) and also surface drag (shapes of the fish) (Fig. 15). That is, the males with the greater cross sectional area and more pronounced secondary sexual characteristics (i.e., large hump) had similar tail beat frequencies (TBF) as females while swimming at the same relative speed (corrected for solid blocking and expressed as lengths/second) (l/s). Males had a slightly higher TBF at the higher velocities, however, the t test indicated no significant difference between the male (TBFm = 50.65 + 48.16 l/s) and female (TBFf = 50.85 + 46.73 l/s) regressions for tail beats per minute versus corrected velocity (t = 0.000012) (Fig. 16). Therefore, the male and female data were combined. The regression from these data provides a very tight fit of the 99% confidence limits about the line TBF = 50.45 + 47.28 l/s (Fig. 17). This allows a high degree of predictability. The 95% predictability limits for a mean of 10 observations are shown in Fig. 18. This allows a comparison of the 1983 data with data that were collected on the Cheakamus pink salmon in 1963 (Brett 1982). These data indicate that the TBF of the Cheakamus River pinks fall within the 95% predictability limits of the Fraser 1983 tests (Fig. 18).

Water temperature directly affects the swimming performance of fish (Beamish, 1978). The water temperatures, measured at the outlet of the test apparatus varied from a high of 13.6°C at the beginning of the season, to a low of 10.5°C at the end. Most of the tests were conducted within a 2 degree Celcius range from 10.5 to 12.5°C (Fig. 19). While there is no direct evidence of the effect of temperature on pink salmon swimming speed, there is a good data base for sockeye salmon (Brett and Glass, 1973). As temperatures increase the swimming performance of sockeye increases to a maximum at 15°C. Therefore, the critical swimming speeds were corrected to a standardized 15°C.

The data, standardized to 15°C, were examined for differences in Ucrit between 60 min and 30 min duration for increasing velocity steps. The majority of the fish used for the tests with 60 min stepwise velocity increments were captured at Fort Langley with a few from Yale (down river sites). No upriver fish were tested with 60 min increments. The differences between mean Ucrit 60 and mean Ucrit 30 for males and females are not statistically significant (Table 13), however, based on the sockeye data by Brett (1982), they are considered biologically significant.

Regression analysis of the relationship between the corrected swimming speeds expressed as l/s and the cumulative percent fatigued indicate that there is a difference between the 60 min and 30 min steps at levels of fatigue between 10% and 80%. Therefore the 30 min swimming speeds were adjusted to 60 min values by a reduction of approximately 0.2 l/s (Fig. 20).

These adjusted data were then examined for differences (Student's t) between sexes, state of maturity, capture location, capture dates, holding time prior to testing, tests conducted in natural light (day) and artificial light (night) and tunnels used during testing.

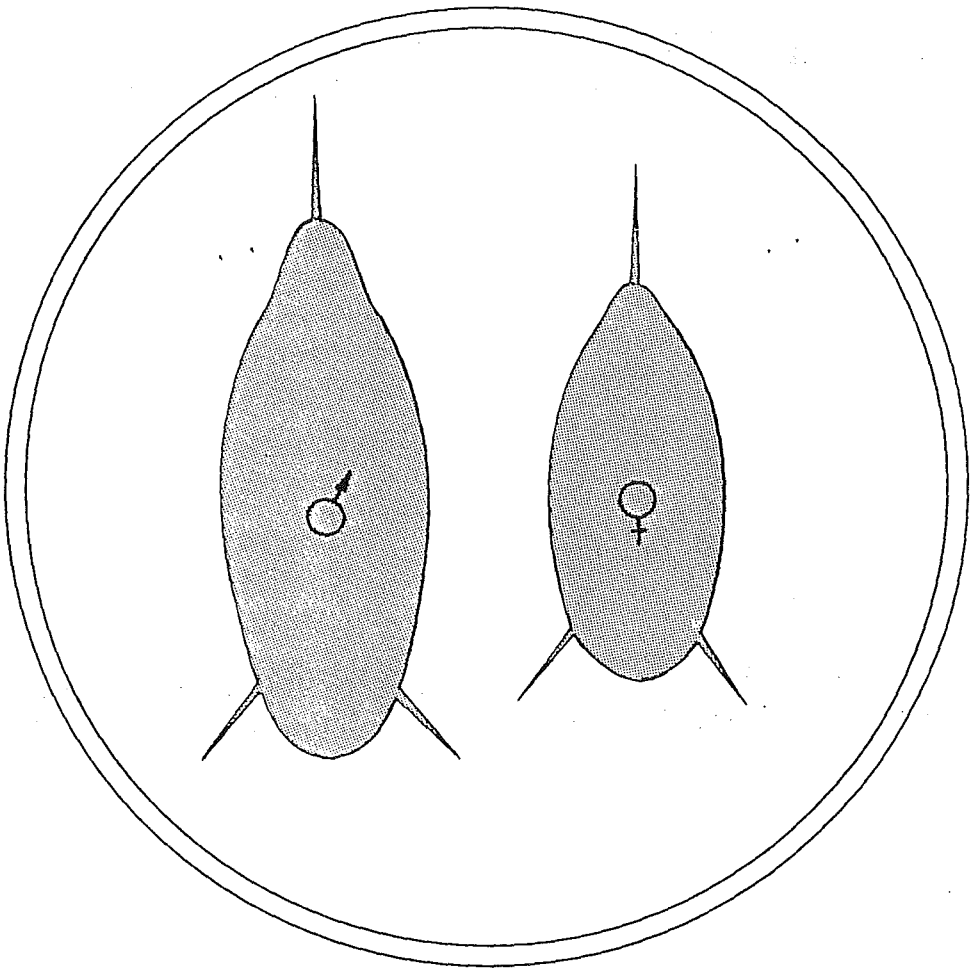

FIGURE 15—Cross-section of swim tunnel and pink salmon showing relative sizes of tunnel, male pink and female pink salmon (only one fish in tunnel during tests).

There was no significant difference found between the Ucrits of gravid fish from Langley and Yale or between the Ucrits of gravid fish from Thompson Canyon, Ashcroft and Seton. There was no significant difference between groups held 1, 2, 3, 4, 5, 10, 11 and 12 days prior to testing within these classifications or between tunnels or between day and night tests. There was no significant difference between any of the groups in the spawning category or between groups in the spawned out category.

Table 13. A comparison of the Ucrits of gravid pinks tested with 60 minute and 30 minute stepwise velocity increments; all fish from Langley and Yale.

Duration of Increment	Male				Female			
		Mean				Mean		
	N	Temp(C)	L/S	S.D.	N	Temp(C)	L/S	S.D.
30 min	78	12.1	2.4	0.75	101	12.1	2.2	0.87
60 min	25	12.4	2.3	0.57	15	12.4	2.2	0.76

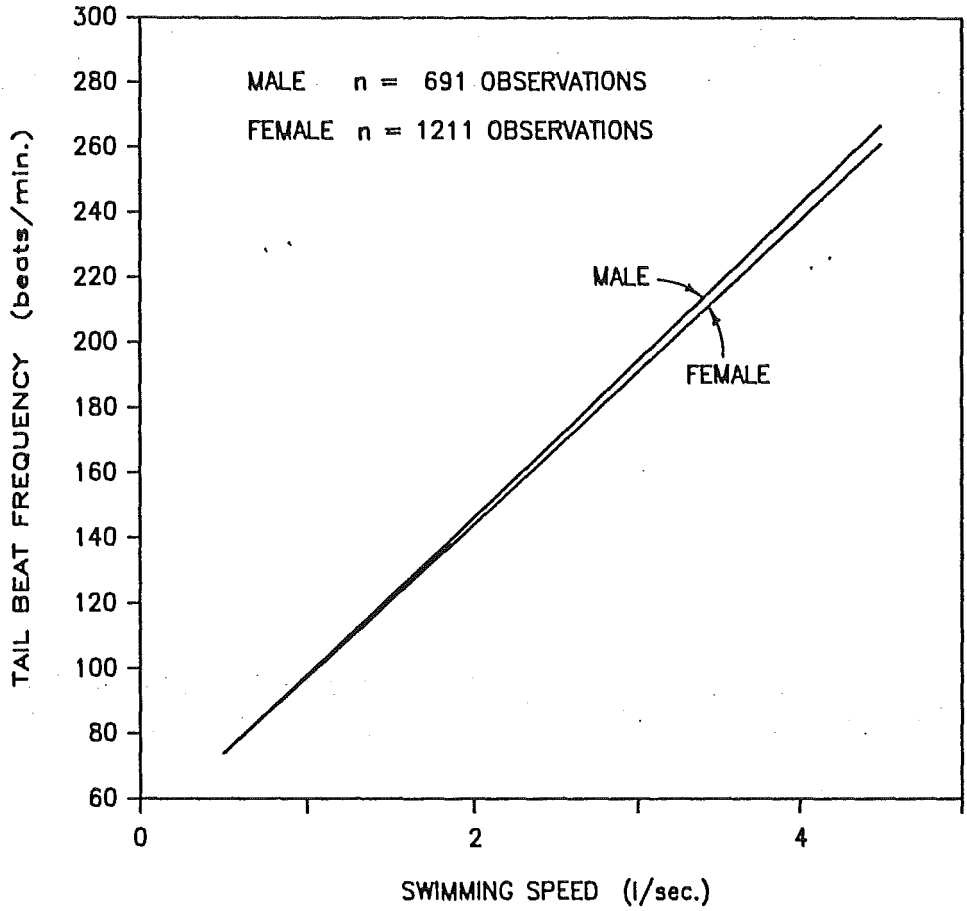

FIGURE 16—A comparison of regressions of male and female tail beat frequencies on swimming speed.

Data analysis of fish captured from the same location on different days indicated no significant differences within their categories with the exception of one group of 6 males captured Sept. 23 at Fort Langley. This group had a significantly higher Ucrit at 2.94 l/s compared to all other Langley males at 2.41 l/s. These were also slightly larger fish at 50.7 cm vs 49.3 cm standard length for all Langley males; however, correlation analysis indicated no relationship between size and corrected swimming speed expressed as lengths per second (l/s). Females captured the same day had a slightly higher Ucrit of 2.29 compared to all other Langley females at 2.23; however, there is no statistically significant difference between these groups. The males captured September 23 could have been an early group of late run pinks as there tends to be some overlap in migration times (Ward, 1959).

There were strong differences between the combined Ucrits of the Langley-Yale (L-Y) groups and the Ucrits of the Thompson Canyon-Ashcroft-Seton (T-A-S) groups. There were also strong differences in the Ucrit of both males and females captured at T-A-S and tested at various stages of maturity. The spawning fish were stronger swimmers than the spawned fish while the gravid fish were significantly stronger than the spawning fish.

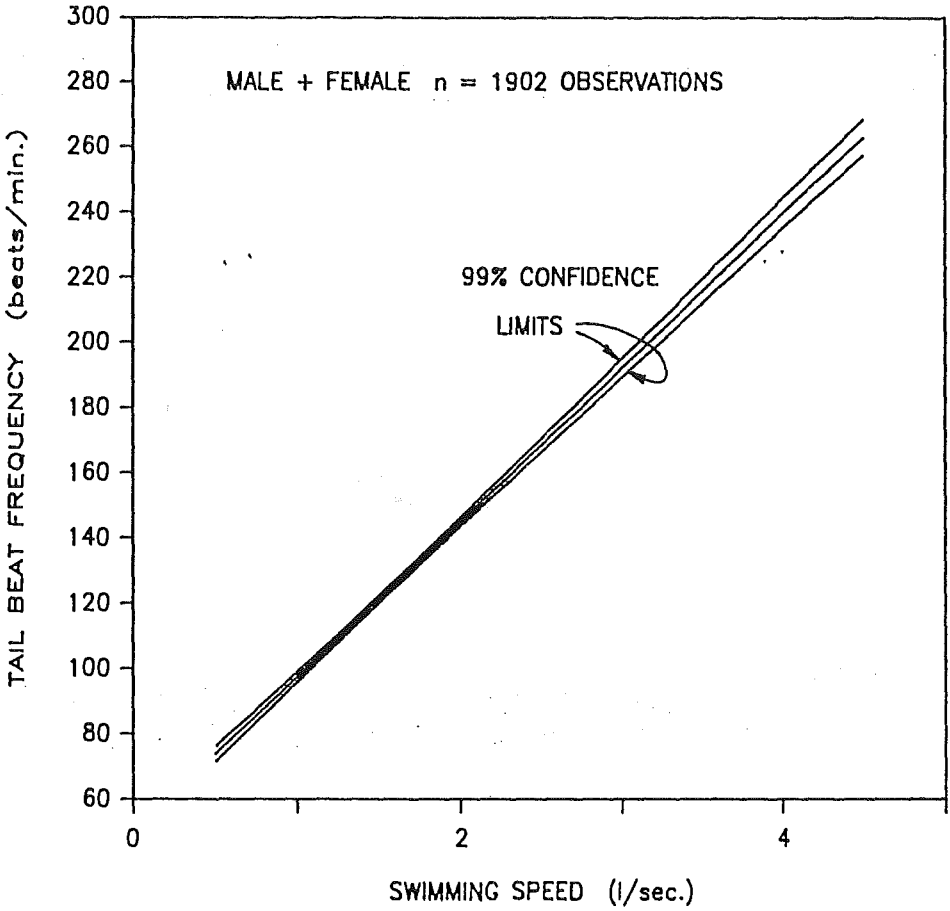

FIGURE 17—Regression of tail beat frequencies on swimming speed showing the 99% confidence limits.

There were also differences between the Ucrits of the males and females in the T-A-S group.

Therefore, the Ucrit 60 min swimming speeds were grouped by sex into gravid, spawning and spawned categories with the Ucrit 60 of gravid fish grouped into a combined Fort Langley and Yale group (L-Y) and a combined Thompson Canyon, Ashcroft, Seton (T-A-S) group.

There were no significant differences in size (weight, length) of males between the different groups or in size of females between groups. The difference between the mean size of the gravid L-Y and T-A-S males was only 0.4 cm and 1 g while the females had differences of only 0.1 cm and 5 g (Table 14).

There were no significant differences between the mean Ucrits of spawning males and females at 2.34 l/s and 2.31 l/s respectively, and the mean Ucrits of the gravid males and females from the L-Y group at 2.34 and 2.15 l/s (Table 15). While the mean Ucrits are not significantly different between the spawning group and the L-Y gravid fish, the relationship between cumulative fatigue and swimming speeds is different. The slope of the regression for the gravid L-Y group is similar to that for the gravid females and males

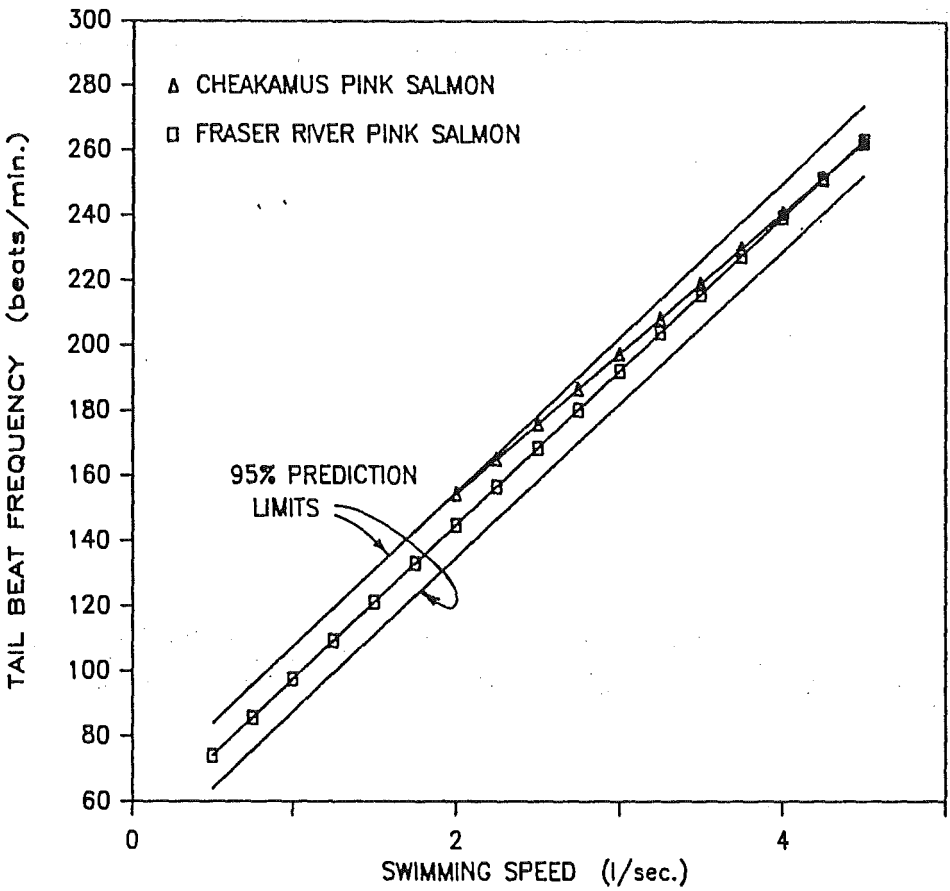

FIGURE 18—The regressions of tail beat frequency and swimming speeds (expressed as length per second; l/s) for Cheakamus and Fraser pink salmon. The 95% prediction limits are shown for the Fraser data.

from the T-A-S group, indicating that the L-Y group as a whole was composed of weaker swimmers (Fig. 21). The regression line for the spawning group has a higher slope indicating significantly greater divergence between the poor and good performers (Fig. 22).

Table 14. Physical measurements of the male and female pinks by group.

Capture Location	Stage of Maturity	N	Standard Length (cm) Mean	S.D.	Total Weight (g) Mean	S.D.
Males:						
Ft. Langley-Yale	Gravid	78	49.1	3.9	1796	481
Thompson Canyon-Ashcroft-Seton	Gravid	17	48.7	2.9	1798	350
All Locations	Spawning	65	49.0	3.5	1823	437
Females:						
Ft. Langley-Yale	Gravid	101	46.5	5.3	1595	298
Thompson Canyon-Ashcroft-Seton	Gravid	31	46.6	2.2	1590	218
All Locations	Spawning	97	46.1	3.2	1498	270
All Locations	Spawned	15	47.2	2.2	1361	197

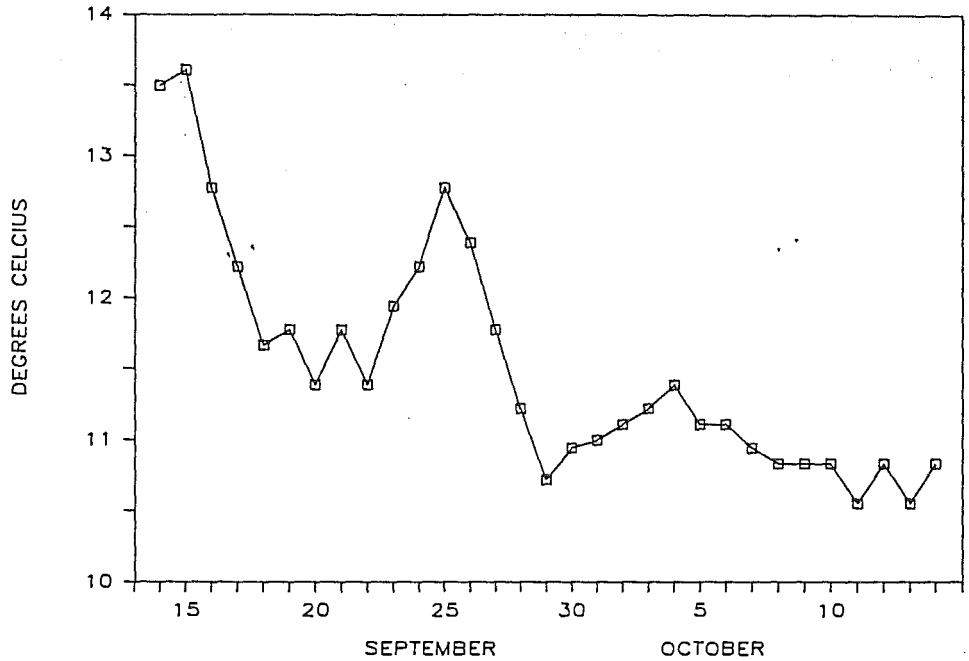

FIGURE 19—Mean water temperature measured at the outlet of the test apparatus in the Upper Seton spawning channel.

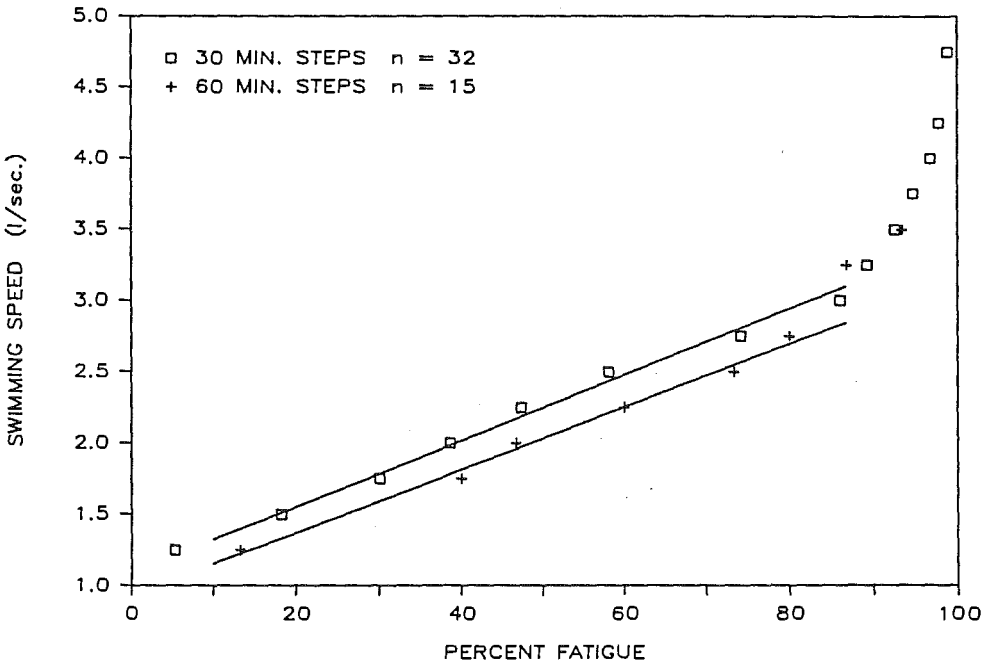

FIGURE 20—Regression of swimming speed versus percent fatigue for 30 and 60 minute tests (regression based on data from 10%–80%).

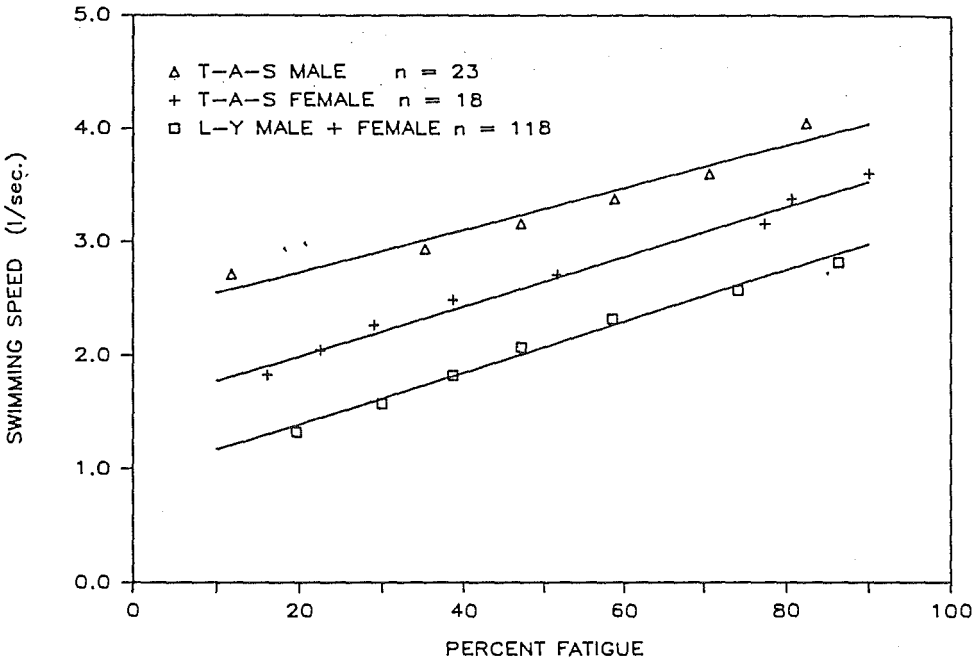

FIGURE 21—Regression of swimming speed versus percent fatigue for the Langley-Yale and Thompson-Ashcroft-Seton fish.

Table 15. Standardized 15°C Ucrit swimming speeds for the 1983 pink salmon.

		Male			Female		
			Length/Second			Length/Second	
Capture Location	Stage of Maturity	N	Mean	S.D.	N	Mean	S.D.
Ft. Langley-Yale	gravid	103	2.34	0.84	116	2.15	0.98
Thompson Canyon-Ashcroft-Seton	gravid	17	3.39	0.96	31	2.78	0.81
All locations	spawning	65	2.34	1.07	97	2.31	0.94
All locations	spawned	2	2.13	0.62	15	1.73	0.70

The gravid females from the T-A-S group had a significantly higher mean Ucrit at 2.78 l/s while the T-A-S gravid males had the highest at 3.39 l/s (Table 15). The spawned out females from the T-A-S group had the lowest mean Ucrit at 1.73 l/s and a slightly lower slope in the fatigue swimming speed regression than the gravid fish (Fig. 22).

The Ucrit swimming speed of the pinks at the cumulative fatigue level of 50% was lower than the mean Ucrit in every group (Table 16). The 50% fatigue Ucrit for gravid males and females from L-Y averaged 2.08 l/s while the mean Ucrits averaged 2.25 l/s. Similarly, the 50% fatigue Ucrits for the gravid T-A-S males and females, at 3.30 l/s and 2.65 l/s respectively, are slightly lower than the mean Ucrits at 3.39 l/s and 2.78 l/s.

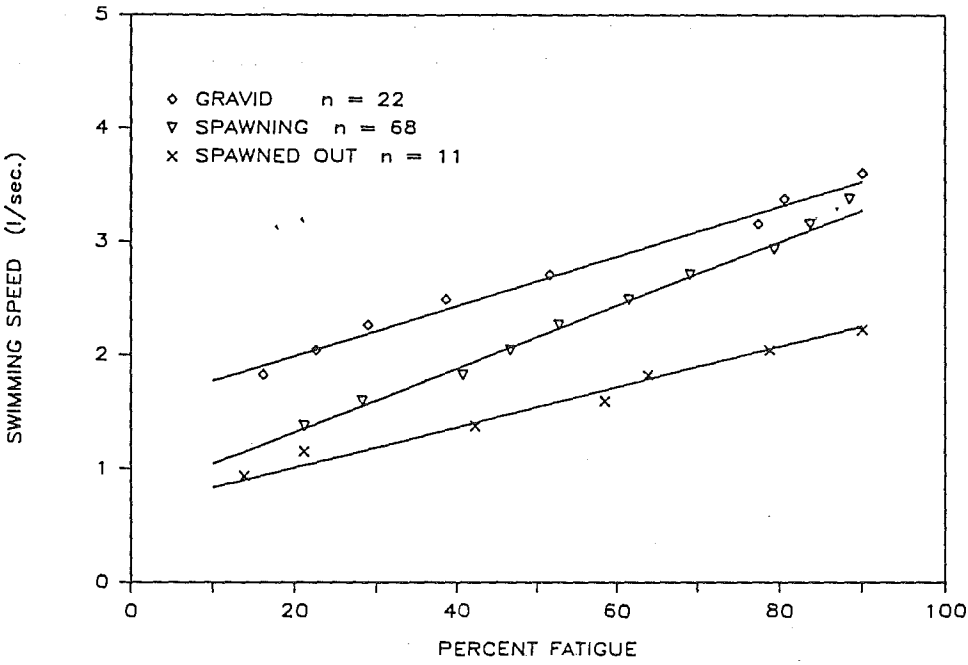

FIGURE 22—Regression of swimming speed and percent fatigue for gravid, spawning and spawned T-A-S female pinks.

Table 16. Standardized Ucrit swimming speeds at various cumulative fatigue levels.

Percent Cumulated Fatigue	Langley	Ashcroft			
	Gravid	Gravid		Spawning	Spawned
	Male-Female	Male	Female	Male-Female	Female
10.0	1.17	2.55	1.78	1.05	0.83
20.0	1.40	2.74	2.00	1.33	1.01
30.0	1.62	2.92	2.21	1.61	1.19
40.0	1.85	3.11	2.43	1.88	1.37
50.0	2.08	3.30	2.65	2.16	1.55
60.0	2.31	3.48	2.87	2.44	1.72
70.0	2.53	3.67	3.09	2.72	1.90
80.0	2.76	3.86	3.31	3.00	2.08
90.0	2.99	4.04	3.53	3.28	2.26

The free swimming maximum sustained speed was estimated from the 60 min Ucrit swimming speeds using the data analysis from Fig. 9 in Brett, 1982. A comparison of the log time-to-fatigue and the corrected velocities for the Cheakamus pink salmon (Brett, 1982) indicates that the maximum sustained swimming speed at the 50% fatigue level was approximately 75% of the 60 min fatigue velocity. Applying this to the Fraser River data, the free swimming maximum sustained swimming speeds for the gravid L-Y males and females becomes 1.7 l/s, while that for gravid T-A-S males and females becomes 2.3 l/s.

Proximate Composition

The chemical changes occurring in salmon during spawning migration have been the subject of several investigations. The extensive studies conducted with Fraser River sockeye salmon have shown that the chemical changes in body composition permit a quantitative assessment of the energy expenditures during spawning migration if they are determined under proper conditions (Idler and Clemens, 1959; Gilhousen, 1980). In the present investigations this approach was used to study the energy sources and expenditures of pink salmon during migration in the Fraser and Thompson Rivers. The information gained in this study contributes to a better understanding of the role played by the body reserves in the spawning of Fraser pink salmon.

Analytical determinations of the soma and gonads of 80 males and 89 females from six sample sites have been completed (Table 3). Fish of the same length range were selected for the analytical determinations to assure more uniformity.

The pink salmon caught in Johnstone Strait before the beginning of the Fraser River migration had an appreciably higher fat and protein content than the fish collected at Fort Langley. Both the fat and protein content of the soma of males and females decreased from fish sampled at Fort Langley to spent fish on the spawning grounds. The males and females had similar percent fat levels at each sample site with the male percent fat content slightly less than the females. There was a small decrease in fat content between Fort Langley and Yale and between Thompson Canyon and Ashcroft (Fig. 23). The greatest changes occurred between Yale and Thompson Canyon where there was a 38% drop in fat and between arrival and post spawning where there was a 69% drop in fat content. These data indicate that the fish used approximately 44% of the fat available at Fort Langley for spawning.

The protein content of the females dropped relatively steadily from Fort Langley to Ashcroft, while the data for males indicate a small drop from Fort Langley to Yale and a significant change from Yale to Ashcroft (Fig. 24). The greatest change in protein content for both males and females occurred on the spawning grounds. The protein content in females dropped from 16.7% at arrival to 14.2% in spent fish, and in males it dropped from 15.7% at arrival to 13.3% in spent fish (Tables 17, 18).

The utilization of fat and protein during the spawning migration was associated with an increase in water content of the soma. In both sexes the water content showed a significant correlation ($p<0.01$) with fat (males, corr. coeff. -0.984; females, corr. coeff. -0.988) (Fig. 25) and protein content (males, corr. coeff. -0.978; females, corr. coeff. -0.950) (Fig. 26). On the average, the migration from Fort Langley to the time of spawning caused a 7% increase in water content of the soma.

The average chemical composition of the gonads at the various sampling sites is shown in Table 19 for males and Table 20 for females. During the river migration there were no large changes in fat or protein content of the testis. Similarly, only small fluctuations in the composition of ovaries occurred during the river migration. These data indicate that the pink salmon entered the river in an advanced state of maturity.

Metabolic Rates

The energy expended by the fish at any given velocity is equal to the cost of locomotion plus any excess due to excitement and/or repayment of oxygen debt incurred by sudden darts in the swimming chamber. On occasion this may result in the apparently

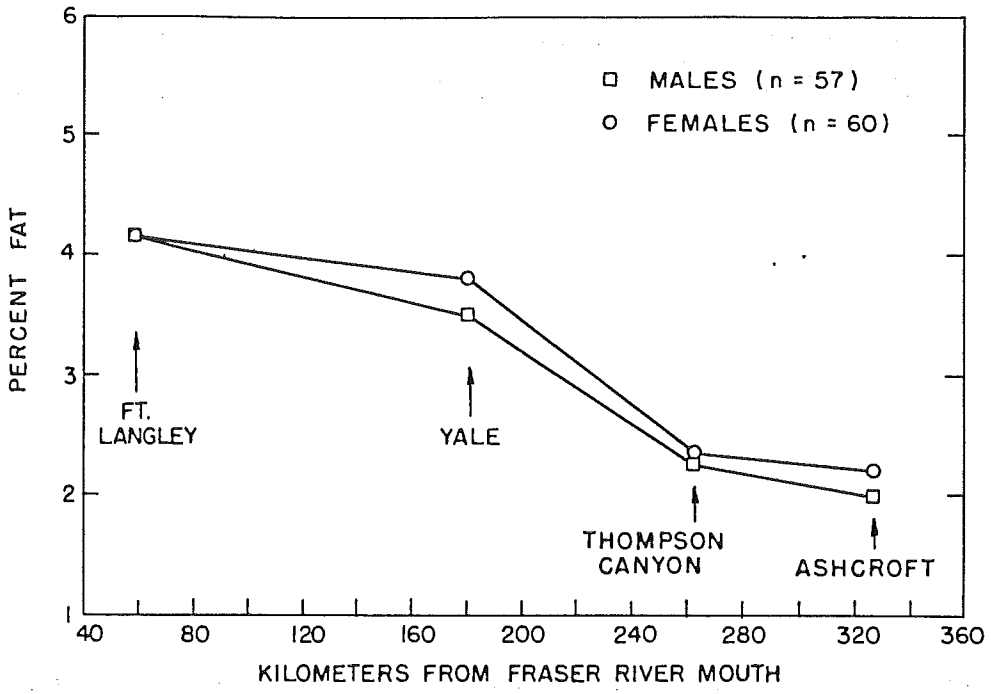

FIGURE 23—Percent fat at various stages of river migration.

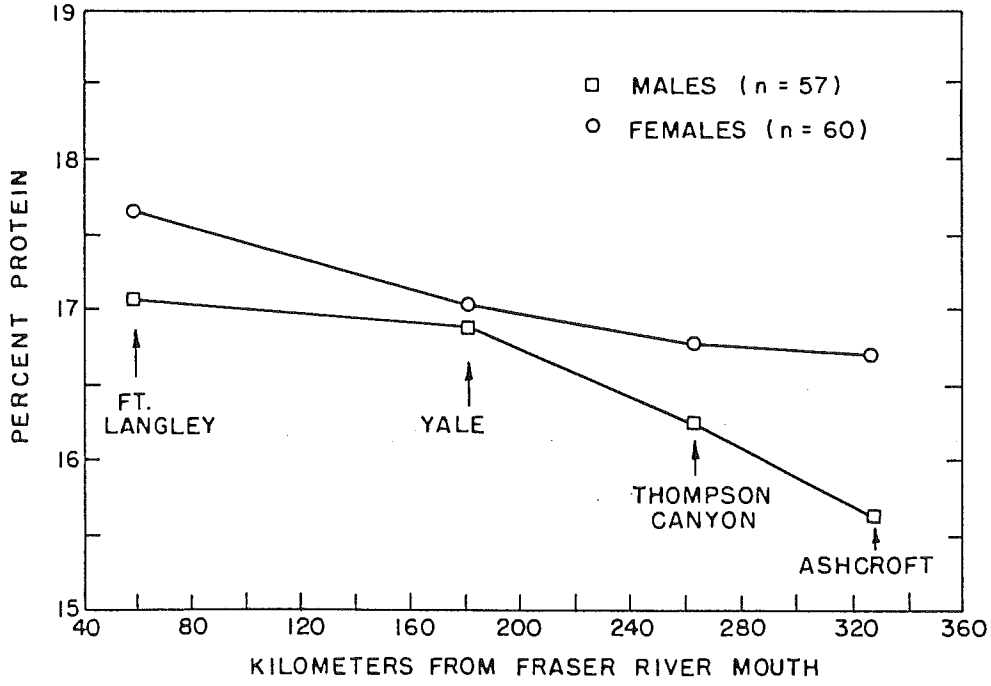

FIGURE 24—Percent protein at various stages of river migration.

Table 17. Fraser River pink salmon investigation (1983). Proximate composition of the soma. **Males**

Sampling Site	Water %	Fat %	Protein %	Ash %
Johnstone Strait	73.76 ± 2.37 (15)	5.62 ± 1.65 (15)	17.96 ± 0.76 (15)	2.12 ± 0.12 (15)
Fort Langley	76.64 ± 1.32 (14)a	4.17 ± 0.84 (14)a	17.07 ± 0.56 (14)a	2.14 ± 0.12 (14)a
Yale	77.31 ± 1.87 (15)a	3.50 ± 1.06 (15)a	16.90 ± 0.98 (15)ab	2.16 ± 0.12 (15)a
Lytton	79.35 ± 1.66 (14)b	2.26 ± 0.81 (14)b	16.26 ± 0.87 (14)b	2.29 ± 0.25 (14)ab
Ashcroft - not spawned	80.19 ± 1.68 (14)b	2.00 ± 0.84 (14)b	15.66 ± 0.69 (14)c	2.09 ± 0.23 (14)a
Ashcroft - spawned	84.06 ± 0.93 (8)c	0.73 ± 0.14 (8)c	13.32 ± 0.65 (8)d	2.37 ± 0.29 (8)b

Mean, ± SD, number of fish analyzed indicated in parentheses.
In each vertical column means marked with different letters are significantly different from each other ($p<0.05$).

Table 18. Fraser River pink salmon investigation (1983). Proximate composition of the soma. **Females**

Sampling Site	Water %	Fat %	Protein %	Ash %
Johnstone Strait	72.56 ± 1.25 (14)	5.98 ± 1.37 (14)	18.22 ± 0.42 (14)	2.06 ± 0.21 (14)
Fort Langley	75.68 ± 1.51 (15)a	4.16 ± 1.05 (15)a	17.66 ± 0.34 (15)a	2.23 ± 0.20 (15)a
Yale	76.80 ± 1.63 (15)a	3.80 ± 1.06 (15)a	17.05 ± 0.63 (15)b	2.27 ± 0.21 (15)a
Lytton	78.85 ± 1.19 (15)b	2.35 ± 0.66 (15)b	16.79 ± 0.60 (15)b	2.29 ± 0.32 (15)a
Ashcroft - not spawned	78.97 ± 1.21 (15)b	2.21 ± 0.62 (15)b	16.73 ± 0.54 (15)b	2.27 ± 0.23 (15)a
Ashcroft - spawned	83.05 ± 1.06 (15)c	0.78 ± 0.18 (15)c	14.23 ± 0.96 (15)c	2.34 ± 0.18 (15)a

Mean, ± SD, number of fish analyzed indicated in parentheses.
In each vertical column means marked with different letters are significantly different from each other ($p<0.05$).

Table 19. Fraser River pink salmon investigation (1983). Proximate composition of gonads. **Testis**

Sampling Site	Water %	Fat %	Protein %	Ash %
Johnstone Strait	80.33 ± 1.34 (15)	1.45 ± 0.13 (15)	16.37 ± 1.53 (15)	2.47 ± 0.18 (15)
Fort Langley	78.04 ± 1.31 (14)a	1.70 ± 0.29 (14)a	19.53 ± 1.63 (14)a	2.88 ± 0.29 (14)a
Yale	78.51 ± 1.58 (15)ab	1.71 ± 0.20 (15)a	19.13 ± 1.64 (15)a	2.84 ± 0.29 (15)a
Lytton	77.29 ± 1.51 (14)a	1.95 ± 0.36 (14)b	20.95 ± 1.37 (14)b	3.01 ± 0.19 (14)a
Ashcroft - not spawned	79.94 ± 2.44 (14)b	1.73 ± 0.13 (14)a	18.51 ± 2.45 (14)a	2.90 ± 0.40 (14)a

Mean, ± SD, number of fish analyzed indicated in parentheses.
In each vertical column means marked with different letters are significantly different from each other ($p<0.05$).

Table 20. Fraser River pink salmon investigation (1983). Proximate composition of gonads. **Ovaries**

Sampling Site	Water %	Fat %	Protein %	Ash %
Johnstone Strait	57.48 ± 0.91 (14)	8.54 ± 0.46 (14)	26.98 ± 0.88 (14)	1.48 ± 0.05 (14)
Fort Langley	58.97 ± 0.74 (15)a	7.72 ± 0.36 (15)ab	27.18 ± 0.28 (15)a	1.47 ± 0.05 (15)a
Yale	58.63 ± 1.09 (15)a	8.01 ± 0.42 (15)a	27.25 ± 0.59 (15)a	1.46 ± 0.04 (15)a
Lytton	59.22 ± 1.39 (15)a	8.03 ± 0.86 (15)a	26.62 ± 1.47 (15)ab	1.45 ± 0.05 (15)a
Ashcroft - not spawned	60.24 ± 0.98 (15)b	7.39 ± 0.95 (15)b	26.05 ± 0.58 (15)b	1.47 ± 0.07 (15)a

Mean, ± SD, number of fish analyzed indicated in parentheses.
In each vertical column means marked with different letters are significantly different from each other ($p<0.05$).

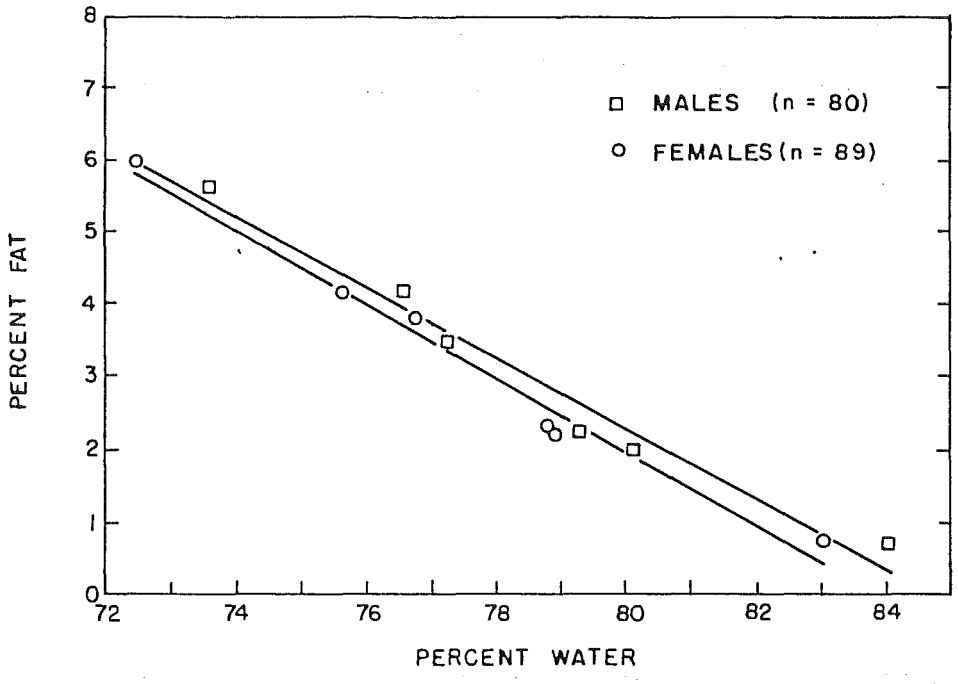

FIGURE 25—Regression of percent fat versus percent water in the 1983 pink salmon.

incongruous relation where less energy is expended while performing at a higher velocity. In consequence the power-performance curves* must be estimated from a line relating the lower points on a graph, not the mean or line-of-best-fit.

The data on metabolic rates showed an exceptionally wide scatter of points compared to data collected on sockeye. Examination of the data showed three types of metabolic response. The first type indicated a fairly normal power-performance curve while the second type had elevated intermediate points between the low and high velocities. The third type had elevated points throughout the velocity range. Therefore, only the lower points were considered biologically reasonable. Data from type two and three fish may have involved a large fraction of excitability. Therefore the power-performance curve from the type one fish is used to determine the metabolic rates for pink salmon. The standard metabolic rate is estimated as 66 mg O2/kg/h, and the active metabolic rate as 830 mg O2/kg/h (Fig. 27). Type one fish were comprised of all females so that a difference in rates between sexes could not be determined from this test-type. However, males and females occurred in almost equal proportion in the type three fish. Analysis of covariance showed no significant difference between the two (at p .05 level); however, at 1.56 l/s the velocity adjusted mean metabolic rates of females was 430 mg O2/kg/h whereas that for males was 15% higher at 495 mg O2/kg/h. This tendency for a higher male power-performance curve could be attributed to greater drag caused by the development of the secondary sexual characteristics in mature male pinks.

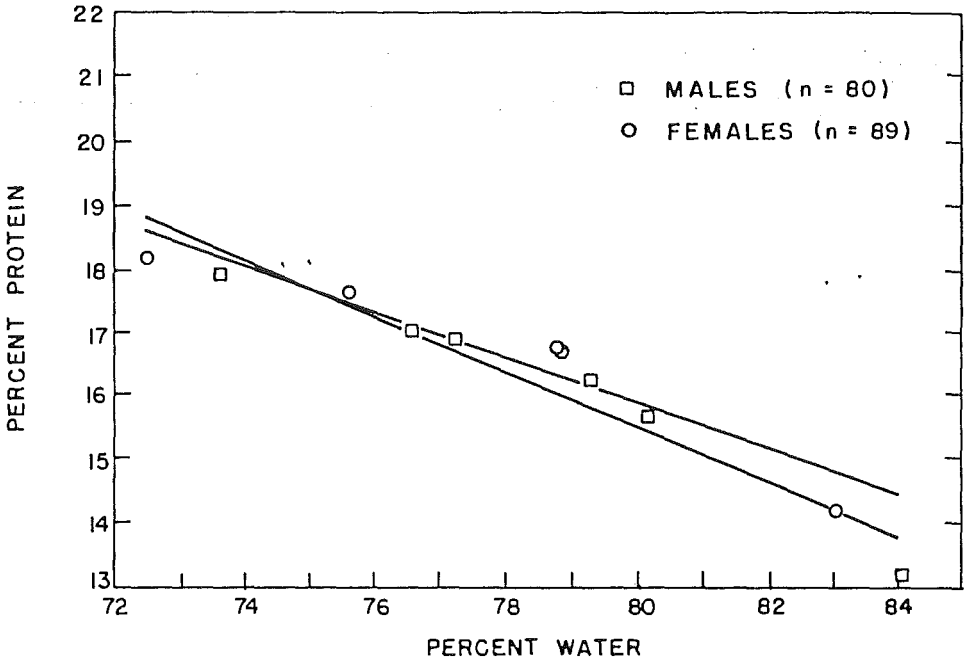

FIGURE 26—Regression of percent protein versus percent water in the 1983 pink salmon.

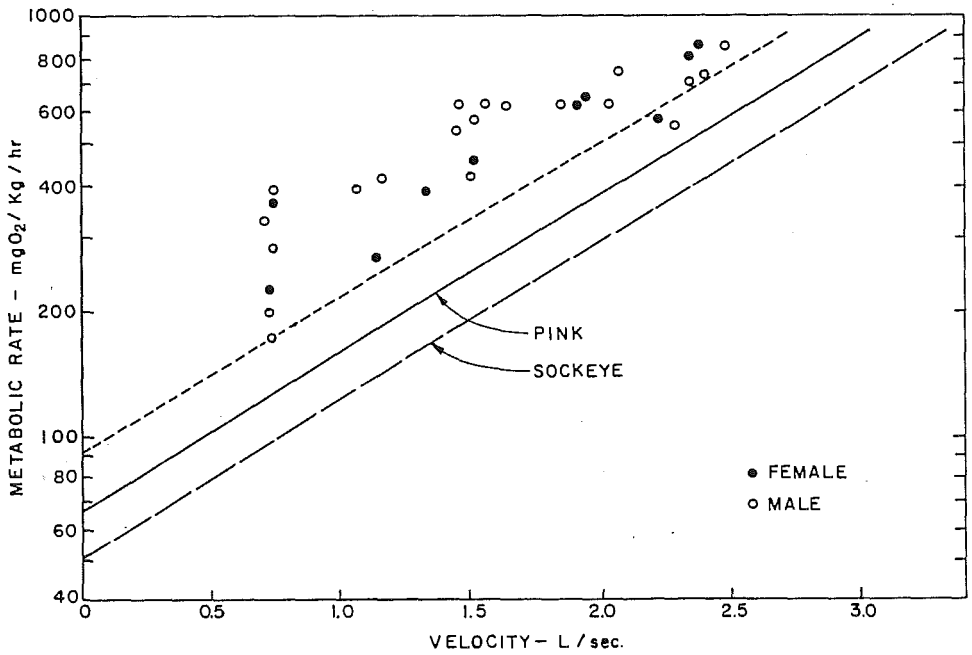

FIGURE 27—Metabolic rate of 10 mature pink salmon (6 male, 4 female) in relation to imposed water velocity, expressed in terms of lengths/second. Upper dotted line represents likely locomotor requirement for these more excitable mature fish.

Energy Expenditures

The energy expenditure of pink salmon during the river migration and spawning was calculated from the observed changes in the composition of soma (Tables 21, 22). All the values are expressed per kg soma. The total energy expenditure for river migration and spawning amounted to approximately 500 kcal/kg (510 kcal/kg for males, and 486 kcal/kg for females). The large differences in body composition between spawned and not spawned fish collected at the spawning grounds suggest that in both sexes the spawning could be associated with an important expenditure of energy. The possibility that the samples may not be from a homogenous population cannot be excluded. The amount of energy required for the river migration was probably reduced due to the fact that pink salmon entered the Fraser River at an advanced stage of sexual maturity, thus requiring less energy for gonad development.

The relationship existing between the energy expenditure and the distance covered by salmon during river migration is shown in Fig. 28 for males and Fig. 29 for females. The energy expenditure per km varied with the segment of route travelled and, as might be expected, it reached the highest levels during the passage of canyons between Yale and Thompson Canyon (Tables 21, 22). The average values for the entire river migration amounted to 0.99 kcal/kg/km for males and 0.82 kcal/kg/km for females.

Data on the relative importance of fats and proteins as the energy source are presented in Tables 21 and 22, and Figs 28 and 29. In both sexes over 70% of the energy required for the river migration was provided by the depletion of fat. Sex differences were apparent at various stages of river migration. In males the contribution of protein to the energy expenditure increased progressively during the river migration. In females comparatively larger amounts of protein were utilized at the initial stages of the river migration. Fat contributed to approximately 60% and protein to 40% of the total energy expenditure (river migration and spawning) of males or females.

The energy diverted for the development of gonads during the river migration was also estimated. It appears that in the case of males it is negligible since there was no gain in weight of gonads after the fish entered the river system (Table 4). The energy utilized for the formation of the ovaries could be calculated as follows. As shown in Table 5, the increase of ovaries during the river migration amounted to 2.34% of the total body weight* or 23.4 g/kg. Based on the average composition (Table 19), the ovaries of pink salmon contain 222 kcal/100 g**. Thus, the energy consumed for the increase in ovaries which occurred between Fort Langley and Ashcroft amounted to 52 kcal/kg body*** or approximately 10% of the total energy expenditure.

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* - 16.23% − 13.89% = 2.34%
** - 8 g fat x 8.66 kcal + 27 g protein x 5.66 kcal = 222
*** - 23.4 g x 2.22 kcal = 52 kcal

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* - Power = rate of energy expenditure (mg 02/kg/h) (1 mg 02 = 3.25 cal);
- Performance = swimming speed (l/s, or m/s).

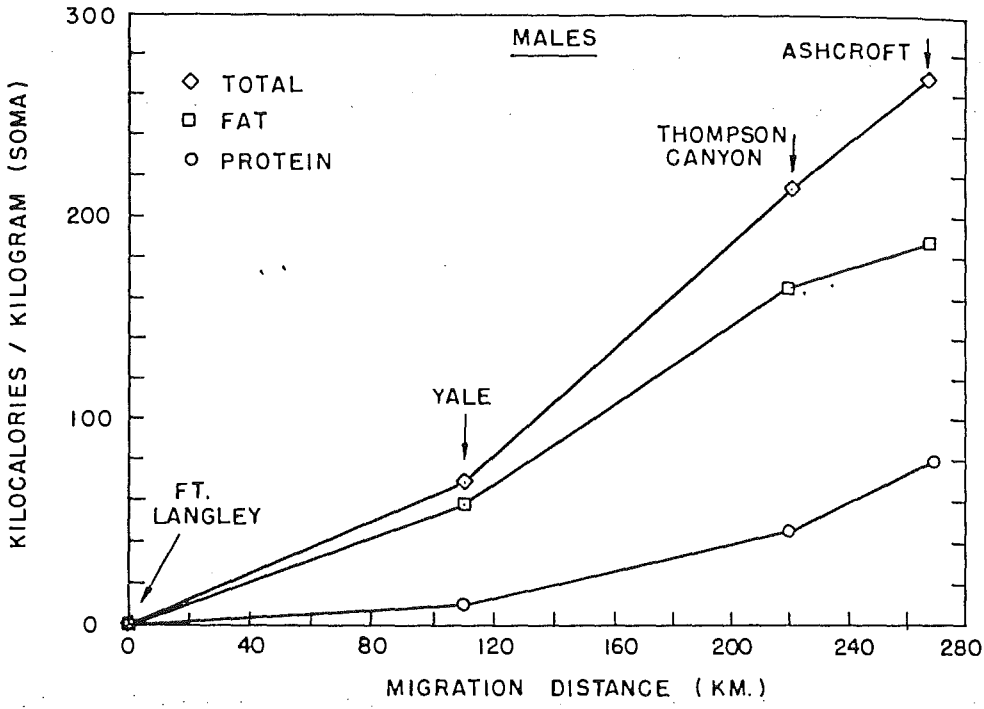

FIGURE 28—Male energy expenditure from Fort Langley to Ashcroft.

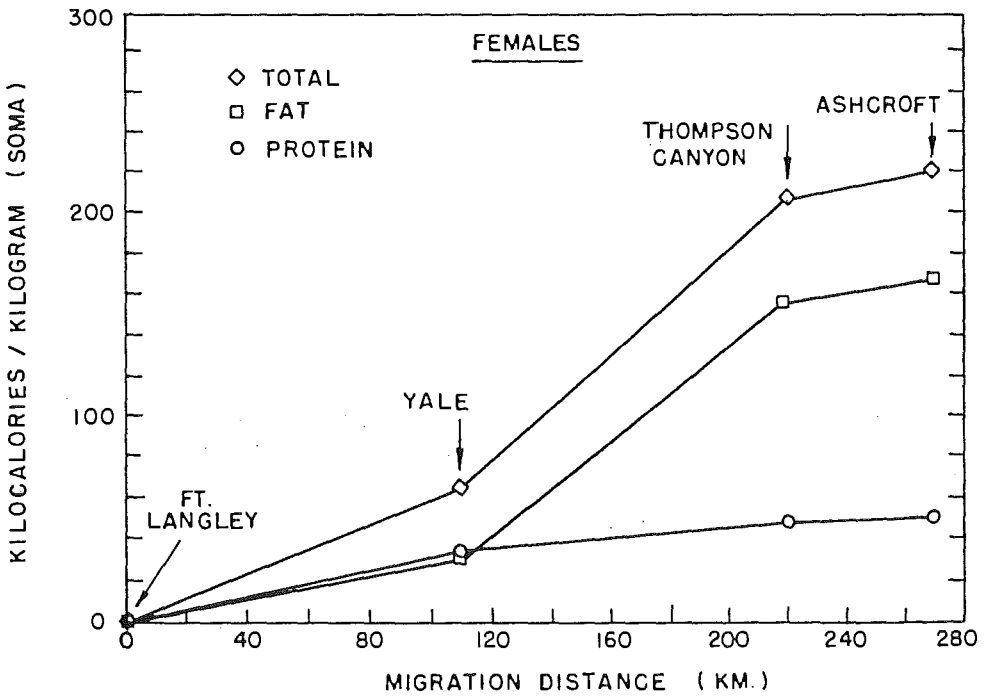

FIGURE 29—Female energy expenditure from Fort Langley to Ashcroft.

Table 21. Fraser River pink salmon investigation (1983). Energy expenditures during the river migration and spawning. **Males**

	Depletion of Reserves		Energy Expenditure			
	Fat	Protein	Fat	Protein	Total	
Migration Stage	g/kg	g/kg	kcal/kg	kcal/kg	kcal/kg	kcal/kg/km
Fort Langley to Yale	6.7	1.7	58 (85)*	10 (15)*	68	0.62
Yale to Lytton	12.4	6.4	107 (75)	36 (25)	143	1.30
Lytton to Ashcroft	2.6	6.0	23 (40)	34 (60)	57	1.14
Total river migration (Fort Langley to Ashcroft)	21.7	14.1	188 (70)	80 (30)	268	0.99
Spawning at Ashcroft	12.7	23.4	110 (45)	132 (55)	242	—
River migration and spawning	34.4	37.5	298 (58)	212 (42)	510	—

All data are expressed per kg body (excluding gonads).

* - Values in parentheses indicate in percentages the contribution of fat and protein to total energy expenditure.

Table 22. Fraser River pink salmon investigation (1983). Energy expenditures during the river migration and spawning. **Females**

	Depletion of Reserves		Energy Expenditure			
	Fat	Protein	Fat	Protein	Total	
Migration Stage	g/kg	g/kg	kcal/kg	kcal/kg	kcal/kg	kcal/kg/km
Fort Langley to Yale	3.6	6.1	31 (48)*	34 (52)*	65	0.60
Yale to Lytton	14.5	2.6	126 (89)	15 (11)	141	1.28
Lytton to Ashcroft	1.4	0.6	12 (80)	3 (20)	15	0.30
Total river migration (Fort Langley to Ashcroft)	19.5	9.3	169 (76)	52 (24)	221	0.82
Spawning at Ashcroft	14.3	25.0	124 (47)	141 (53)	265	—
River migration and spawning	33.8	34.3	293 (60)	193 (40)	486	—

All data are expressed per kg body (excluding gonads).

* - Values in parentheses indicate in percentages the contribution of fat and protein to total energy expenditure.

DISCUSSION

The 1983 Pink Salmon Study was designed (1) to provide a baseline biological status of the fish and (2) to aid in the assessment of the possible impacts of changed river passage on the Thompson River pink salmon population. This study involved a variety of disciplines, each requiring a high level of expertise.

The 1983 pink salmon run to the Fraser River system was the second largest on record. The percentage of the total Fraser system escapement to the Thompson River (11.6%) was disproportionate compared to the average of the previous four cycles (36.2%), with most of the fish spawning in the main Fraser (Table 1). There appears to be a trend that, as total run size increases, a greater percentage of pinks spawn in the main Fraser River and a lower percentage spawn in the Thompson River. However, the 1983 distribution diverged significantly from the recent trend, indicating an unusual situation (Fig. 5). This could be caused by numerous factors, including differences in the rate of production in the Fraser and Thompson Rivers. While this is no doubt true to some extent, the differences would have had to be extreme to account for the 1983 spawning distribution.

The data collected for this report suggest a hypothesis that under certain conditions, combined with unusually small pinks, the Fraser River and Thompson River canyons may block the weaker swimmers, thus reducing the relative size of the Thompson pink population.

First, the Ucrit swimming speeds for the Thompson Canyon-Ashcroft Seton (T-A-S) pinks, both males and females, are significantly higher than the Ucrits for pinks captured from the Fraser River, suggesting that the stronger swimmers were able to move upstream of the Fraser Canyon, assuming spawners return to their specific origin sites. It could be argued that the duration of migration would affect the swimming performance of the fish, thus biasing the T-A-S group which had longer migration times and shorter travel times. Besner and Smith (1983) have shown that the endurance in coho salmon increased in exercised fish compared with control groups and the improvement was maintained after two months of rest. It is possible that the increased swimming ability of the T-A-S group was enhanced by the increased duration of effort required to negotiate the Fraser and Thompson canyons.

If there was a clear relationship between duration of exercise and swimming ability then one would expect the Yale group to have a greater Ucrit than the Langley group. However, in fact the Yale group, while not statistically different than the Langley group, had a lower mean Ucrit than the Langley group. Further work is required to examine this hypothesis in migrating adult pink salmon.

Another concern is the effect of capture on the various groups. It could be argued that the effect of capture and the duration of transport to the test facilities would favor the T-A-S group as they were captured closest to the test facility. This is a valid concern. However, holding the lower Fraser fish up to 12 days did not improve their swimming performance. Also the Yale group, which had significantly less transport time than the Langley group, actually had a lower mean Ucrit than the Langley group and the females from Yale had a lower mean Ucrit than the Langley females transported to Bamfield, B.C (close to twice the transport time of the Yale fish) for metabolism testing. Therefore the influences of capture and travel, although no doubt influencing the test results in some way, are not major factors in the different swimming performance levels from the upper and lower river fish. The swimming performance data suggest that the stronger pinks migrated and spawned in the Thompson River.

Second, the 1983 pinks had the smallest landed weight on record in the commercial fishery. This small size would suggest that the population in general would have a harder time negotiating areas of difficult passage. It was observed that the migration was blocked to some degree at Saddle Rock above the sampling site at Yale, B.C (personal communication; P. Saxvik, IPSFC). If this was the case, then the weaker swimmers would tend to concentrate in that area, thus lowering the mean Ucrit for fish sampled there. While the mean Ucrit of the gravid Yale sample was not significantly different from the mean of the gravid Langley fish, it was the lowest for gravid fish at any of the locations. In addition, the timing of this run was 7 to 10 days later than average (personal communication, J. Woodey, IPSFC). However, the average life span of 23.5 days from Fort Langley to death on the spawning grounds was similar to 1979 pinks at 23.9 days (Killick, 1980), but shorter than the life span of 25.5 days calculated for the 1957 pinks (Ward, 1959). The calculated mean migration time to the Ashcroft spawning grounds was 12 days in 1983 compared to 14 and 11 days in 1957 and 1979 respectively (Killick, 1980). This allows a life span on the spawning ground of 11.5 days for the 1983 pinks compared to 11.5 and 12.9 days for 1957 and 1979 pinks.

Obviously the Thompson River pink's life span from Fort Langley to death, although lower than 1979 and 1957, was not affected to the degree that the timing might suggest and the migration rate was not significantly slower in spite of the smaller fish (Table 2).

Third, the pinks entered the Fraser in an advanced state of maturity. The female gonads gained very little weight compared to sockeye as reflected in the mean gonadosomatic index (G.S.I.), which changed from 14.6 at Fort Langley to 16.6 at the spawning grounds. The male G.S.I was largest at Yale (5.24) and higher than that of males captured at Thompson Canyon (4.17) suggesting a concentration of male pinks in an advanced stage of maturation possibly caused by the difficult passage at Saddle Rock (Table 4). However, the sex hormone profile did not corroborate this. In conjunction with the final development, the endocrine assessment indicated that they were ready to spawn upon arriving at the spawning grounds. The drop in female pink salmon plasma levels of estradiol and vitellogenin and the dramatic rise in progesterone and gonadotropin between Yale and Ashcroft indicate that the maturation process was completed during river migration. Yolk synthesis was completed between Yale and Thompson Canyon and final maturation occurred between Thompson Canyon and Ashcroft (Fig. 10). These pink salmon were ready to spawn or almost ready to spawn on arrival at the Ashcroft spawning grounds. The spawning activity of captured pinks shortly after they were released to the holding pens at the Seton test site, corroberated these observations. These data suggest that any significant delay in the migration would prevent the Thompson River pinks from reaching their traditional spawning grounds. These data also support the hypothesis that only the stronger Thompson River pinks spawned on their traditional spawning grounds and that the disproportionate percentage of spawners in the Lower Fraser early run was at least in part due to the inability of the weaker pinks to negotiate the Fraser Canyon. If this hypothesis is true, then any further disruption could have very serious consequences for the Thompson River pink salmon population.

Another indication that delays could have serious impact on the Thompson River pinks is the rapid deterioration of the overall health of the 1983 population. All species of salmon, particularly pink salmon, go through a very rapid phase of increasing senility during migration and spawning. However, the 1983 data indicate the degenerative processes associated with sexual maturation and concomitant senility are established at the time of entry into freshwater. The pinks at Fort Langley, approximately 24 days from death, were in a much healthier state than many sockeye populations examined 24 days prior to death. However, at Yale there were significant pathological changes in the gill tissue of some fish. This was accompanied by the invasion of *Dermocystidium* and VEN. As the fish migrated to the spawning grounds the frequency of these diseases increased along with increased numbers of pinks showing deteriorating gill tissue. As far as is known, these diseased fish are a normal part of the pink population and they spawn successfully; however, they are no doubt weaker than less infected fish. One of the factors which will hasten this deterioration is stress. The response to stress enhances survival over a very short term, but there is a cost. It causes deterioration of the immune system and increases the proteolytic power of the plasma, thus it can increase susceptibility to infectious processes (Wedemeyer, 1970). Cortisol determinations from fish sampled in the Thompson Canyon, a site of difficult passage near Thompson Canyon, indicate that these difficulties not only tax the swimming ability of fish, but also elicite the stress response, thus contributing to deterioration of health. Therefore delay and/or additional

difficulties in passage could result in pink salmon dying before reaching their targeted spawning areas or even before spawning.

Another very real concern with migration delay is the possibility of pink salmon depleting their energy reserves prior to spawning. The metabolic rates of pink salmon determined in this study indicate that the pinks have a metabolic rate approximately 1.3 times greater than that of sockeye salmon. It is estimated that the energy utilization in pink salmon males during migration was 0.99 kcal/kg/km. The estimate for Adams River sockeye utilizing the same migration path is 0.84 kcal/kg/km (Gilhousen 1980). This is 1.2 times greater for pink salmon.

The data for female pink salmon indicate an energy utilization of .82 kcal/kg/km compared with 1.3 kcal/kg/km for female Adams sockeye. This ratio is 0.6 to 1.0. This is a contradiction, as the metabolic rates of female pink salmon in this study are significantly higher than the metabolic rates determined for female sockeye.

The calculated swimming speed of pinks determined from energy utilization were 1.75 l/s for males and 1.23 l/s for females. These swimming speeds are lower than the Ucrits determined for pinks. Given the logarithmic nature of the activity metabolism versus swimming speed, it is possible that swimming slower or resting are ways pink salmon conserve energy during migration. For example, the 1983 male pinks had a total of 268 kcal/kg to use for migration and the females had 221 kcal/kg. They reached the spawning grounds in 9.5 and 10.5 days respectively. If these fish were required to increase their swimming speed to approximately 2.4 l/s, they would be using approximately 600 mg/oxygen/kg/h. Their energy reserves would last only 5 days and the absolute distance travelled would be reduced by approximately 30%. Therefore, although the 1983 pink salmon were later than normal and ready to spawn, it is possible they could not afford the faster swimming speed. The energetics of the 1983 pink salmon indicate that the male pinks utilized 510 kcal/kg of energy to migrate from Fort Langley and complete spawning on the Ashcroft spawning grounds. The females used slightly less at 486 kcal/kg.

Data from this study indicate that males have a slightly higher rate of metabolism (15%) for the same relative swimming speed. In addition it was found that males had a slightly higher tail beat frequency for the same velocity (l/s) therefore it is not unreasonable to expect the males to utilize more energy. However, the energy utilization between arrival at the spawning grounds and completion of spawning was slightly higher for females at 265 kcal/kg than for males at 242 kcal/kg. This may be due to a larger energy requirement for the female pink during spawning.

These data suggest that the pinks used a similar number of calories per day on the spawning grounds (22 kcal/kg/day) as they used for migration (24 kcal/kg/day). A part of this demand on energy reserves would be the spawning behaviour, digging and defending territory. One would not necessarily expect the demand from spawning behaviour plus the necessity to hold position in the river to be this high, however the Bamfield data indicated significantly higher metabolic rates in the sexually mature pinks. These fish, labelled "excitable" for lack of a better expression, have a greater locomotor requirement and therefore a greater demand on the remaining energy reserves (Fig. 27). The higher metabolic rates in pink salmon, the indication that male pinks use more energy per kilometer, and the indication that the demand increases in fully mature fish, suggest that an obstruction or series of increased velocity areas which may have little effect on sockeye would have a very serious effect on the pinks.

All of the data collected and analyzed to date confirm that pink salmon would be much more sensitive than sockeye to changes in conditions in their migration path. Further, any encroachments demanding more from the upriver pink populations, will likely result in reduced effective pink salmon spawning populations. The data suggest a hypothesis that the lateness of the run, the small size of the fish, the higher metabolic demands on energy reserves, and the inferior swimming ability of the lower river fish, contributed to the unusual distribution of spawners in 1983.

SUMMARY

1. This report is a broad examination of applicable biological parameters designed to provide baseline data on Fraser River pink salmon to assist in the assessment of current and potential environmental impacts on the Fraser and Thompson River pink salmon populations. The results from information collected in 1983, a year which was not an average pink salmon year, need corroboration by further study.
2. The pink salmon population was the second largest run on record. The fish were the smallest pink salmon on record at 1.86 kg. The peak abundance of migrating fish was 7-10 days later than average.
3. Total early-run escapement to the Fraser River was 4.627 million. Approximately 76% of these fish spawned in the Lower Fraser River below Thompson Canyon, while 11.7% spawned in the Thompson River. This distribution is a significant shift of spawners from the Thompson River to the Lower Fraser River.
4. The speed of migration with a travel time of 10 days from Fort Langley to the Thompson Canyon was very similar to the travel time of nine days over the same distance in 1979.
5. Pink salmon entered the Fraser River in an advanced stage of maturity. The endocrinology of the pinks suggested that the pinks were ready to spawn immediately upon arrival at the Ashcroft spawning grounds. Observations on the behaviour of captured pinks supported this.
6. Four major fish pathogens were found in the pink salmon population. These were a virus (ENV) which causes Viral Erythrocytic Necrosis (VEN), a blood disorder; a protozoan parasite (*Ceratomyxa shasta*) which causes Ceratomyxosis, a severe illness causing lesions and death; a bacterium (*Aeromonas salmonicidi*) which causes furunculosis, an illness causing the breakdown of blood vessels leading to death; and finally *Dermocystidium salmonis*, possibly a fungi or a protozoan parasite (undetermined) affecting all species of Pacific salmon. The latter has been known to cause losses in sockeye salmon.
7. The haematocrits of migrating fish were normal with the means from each location ranging from 34.5 to 43.8% packed cell volume.
8. Histophysiology of the pinks showed the rapid deterioration of tissues and organs associated with the normal course of sexual maturity and senility leading to death in Pacific salmon. The deterioration in pink salmon was more rapid than that for sockeye; however, the fresh water life span during migration and spawning is considerably shorter in pink salmon.

9. Cortisol analysis indicated that pink salmon negotiating points of difficult passage are stressed. Fish captured at Fort Langley and Yale were unstressed, but fish captured at Thompson Canyon showed elevated cortisol levels indicating the fish were stressed. The cortisol levels dropped in fish arriving on the spawning grounds.

10. There was a significantly lower critical swimming speed (Ucrit) determined for gravid fish captured from the Lower Fraser River (Fort Langley and Yale) compared to gravid fish captured from the upriver sites (Thompson Canyon, Ashcroft and Seton) (T-A-S). The Ucrit of the Fort Langley-Yale (L-Y) group was approximately 2.25 lengths/second (l/s) for males and females combined compared to 3.08 l/s for the T-A-S males and females. Sustained swimming speeds were calculated at 1.70 l/s for the L-Y group and 2.37 l/s for the T-A-S group. Spawned out fish had a significantly lower Ucrit than pre-spawning fish.

11. The proximate composition of pink salmon from each of the test sites indicated that the average utilization of fat for migration energy was 5.2 g/kg between Fort Langley and Yale, 13.5 g/kg between Yale and Thompson Canyon and 2.0 g/kg between Thompson Canyon and Ashcroft. The fish used 34.1 g of fat/kg from arrival to death. The pink salmon protein depletion averaged 35.9 g/kg from Fort Langley to death.

12. The analysis of metabolic rates indicate that the pink salmon standard metabolic rate is 66 mg 02/kg/h and the active metabolic rate is 830 mg 02/kg/h. This compares to 50 and 750 mg 02/kg/h for sockeye. While swimming at the same velocity, pink salmon average 30% higher energy expenditure than sockeye salmon.

13. Energy expenditure for the river migration from Fort Langley to Ashcroft averaged 0.99 kcal/kg/km for males and 0.82 kcal/kg/km for females. In both sexes over 70% of the energy required for the river migration was provided by utilization of fat. The energy diverted for gonad development was negligible in males and 10% for females.

14. The data reported here suggest that any encroachment demanding more from the Thompson population would have resulted in reduced spawning populations.

15. The rapid deterioration of health, the higher metabolic demands in comparison with sockeye on energy reserves, the inferior swimming ability of the lower river fish and possibly other findings in this report may have been to some extent influenced by the unusual lateness of the run, and small size. A repetition of the studies undertaken in 1983 would be desirable to determine the physiological changes under different conditions.

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