Experiments on Thermal Requirements for Growth and Food Conversion Efficiency of Juvenile Chinook Salmon *Oncorhynchus tshawytscha*

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EXPERIMENTS ON THERMAL REQUIREMENTS FOR GROWTH AND FOOD CONVERSION EFFICIENCY OF JUVENILE CHINOOK SALMON

Oncorhynchus tshawytscha

by

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ABSTRACT

J. R. Brett, W. C. Clarke, and J. E. Shelbourn. 1982. Experiments on thermal requirements for growth and food conversion efficiency of juvenile chinook salmon, Oncorhynchus tshawytscha. Can. Tech. Rep. Fish. Aquat. Sci. No. 1127: iv + 29 p.

Feeding and growth experiments on Nechako River and Big Qualicum River chinook juveniles were conducted for 28 days at temperatures from 16° to 24°C (Nechako) and 14° to 25°C (Big Qualicum). On maximum daily ration, optimum temperature for growth was approximately 19°C, above which feeding and growth decreased particularly above 22°C. Mortalities reached 64% at 25°C, in agreement with earlier studies on lethal temperatures. In comparison with Qualicum chinooks, Nechako juveniles had a lower growth rate and food conversion efficiency at all but the highest temperatures.

Measures of growth rate of natural populations in the Nechako River showed that the rate corresponded to a feeding level of 60% of maximum daily intake. The effect of such a reduced ration on the optimum temperature for growth was deduced from a response model for sockeye salmon. This showed that the expected optimum in nature for growth of Nechako River chinooks would occur at 14.8°C. It was further deduced that sublethal growth stress (20% reduction in growth from optimum) would occur in the region of 18-19°C, and that for this feeding level no growth would be possible at 21.4°C.

Key words: chinook salmon, temperature effect, growth rates, food conversion, racial difference

RÉSUMÉ

J. R. Brett, W. C. Clarke, and J. E. Shelbourn. 1982. Experiments on thermal requirements for growth and food conversion efficiency of juvenile chinook salmon, Oncorhynchus tshawytscha. Can. Tech. Rep. Fish. Aquat. Sci. No. 1127: iv + 29 p.

Des expériences portant sur l'alimentation et la croissance ont été effectuées pendant 28 jours sur de jeunes saumons quinnats provenant des rivières Nechako et Big Qualicum à des températures variant respectivement de 16 à 24°C (Nechako) et de 14 à 25°C (Big Qualicum). Moyennant une ration quotidienne maximale, la température optimale de croissance des saumons était d'environ 19°C; à une température supérieure, il y a eu une diminution de l'alimentation et de la croissance, particulièrement au-dessus de 22°C. Le taux de mortalité a atteint 64% à 25°C, ce qui concorde avec des études antérieures portant sur les températures létales. À toutes les températures sauf aux températures les plus élevées, le taux de croissance et l'efficacité de la transformation de nourriture ont été plus faibles chez les jeunes saumons quinnats de la rivière Nechako que chez ceux de la rivière Qualicum.

Les mesures de taux de croissance des populations indigènes de la rivière Nechako ont montré que celui-ci correspondait à une alimentation équivalent à 60% de la ration quotidienne maximale. L'effet d'une ration aussi réduite sur la température optimale de croissance a été déduit à partir des réactions enregistrés chez le saumon rouge. Celles-ci ont montré que la croissance, dans la nature, des saumons quinnats de la rivière Nechako devrait être optimale à 14,8°C. On en a conclu également que le niveau sous-létal de croissance (baisse de 20% par rapport à l'optimum) serait atteint entre 18 et 19°C et que, à ce niveau d'alimentation, aucune croissance ne serait possible à 21,4°C.

Mots-clés: Saumon quinnat, effet de la température, taux de croissance, transformation de la nourriture, différence entre les races.

I. INTRODUCTION

Altered flows and reduced discharge of water in the Nechako River, British Columbia, have resulted in temperature elevations considerably above normal, on occasion temporarily exceeding the lethal temperature for most salmonids. The Aluminum Company of Canada (Alcan) holds the water licence for developing hydro electric power in the region[1]. Following the construction of Kenney Dam, located at the outlet of Natalkuz Lake, the headwaters of the Nechako River were diverted westward to the Kemano generating station; spill into the Nechako River was subject to full control by the operators.

In 1980, Alcan planned to reduce the spill discharge into the Nechako River to a lower level in order to provide additional water for power generation. This caused the Department of Fisheries and Oceans to become concerned for the safety of resident juvenile chinook salmon (*Oncorhynchus tshawytscha*) and migrant adult sockeye salmon (*O. nerka*). As a result, the Department entered into discussions with Alcan in order to ensure that discharge into the Nechako River was adequate to provide the salmon with sufficient habitat and to protect them from excessively high water temperatures.

The present study was undertaken to determine the effects of high water temperature on growth and food conversion efficiency in juvenile chinook salmon. Such information was required in addition to field observations in order to assess the potential for sublethal stress imposed by reduced feeding opportunity in warm water. Knowledge of temperature tolerance and sublethal stress responses of chinook salmon is far from adequate to define safe thermal limits. Indeed, the question of setting acceptable limits of natural environmental factors like temperature, which can range from beneficial to harmful effects, is a problematical one for precise definition. It is therefore considered necessary at the outset to outline the plan of research and its conceptual basis.

II. RESEARCH PLAN

The criteria for setting safe limits of temperature for fish have been considered by various authors (e.g., Coutant 1977; Alabaster and Lloyd 1980; Elliott 1981). It has been noted, for instance, that no *direct* relation exists between limits of distribution and upper lethal temperatures, the latter usually being 4°-6°C above the limits of normal environmental experience. One principle governing the criteria for determining tolerable

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[1]In 1950 the Government of British Columbia granted the right to Alcan to divert a portion of the waters of the Nechako and Nanika rivers into the Kemano River.

sublethal stress involves setting acceptable limits to the reduction of such vital functions as swimming speed, metabolic scope, reproductive capacity, growth, and food conversion efficiency. Because such information on chinook salmon was almost entirely lacking, recommendations for safe limits of temperature elevation were made initially by inference from knowledge of other salmonids, particularly sockeye salmon (Brett 1969; Brett et al. 1969). In general, abundance of sockeye juveniles is curtailed at high environmental temperatures where growth capacity and food conversion efficiency are reduced by about one-fifth of that for the optimum temperature, according to the feeding level or ration involved (Brett 1971). Because rising temperatures place an increasing demand for energy to sustain metabolism, high feeding rates are required to achieve good growth. Alternatively, if feeding opportunity is restricted, a shift in the curve relating growth rate to temperature occurs such that the optimum temperature for growth decreases. This temperature-shunt phenomenon has been determined experimentally for sockeye salmon (Fig. 1), brown trout, yellow perch, and white suckers (Brett et al. 1969; Kitchell and Stewart 1977; Elliott 1976; Koenst and Smith 1980). The principle would apply in a similar fashion to starving fish which would lose least weight when at the lowest tolerable temperature. The vertical migration of lake-dwelling young sockeye into cold, deep water in summer has been explained on the above energetic hypothesis, which is a further illustration of improved growth at lower temperature when food is limiting (Brett 1971; Biette and Geen 1980).

To determine the relation of environmental temperature to the growth capacity of young chinook salmon generally, and more particularly for the level of feeding opportunity of the Nechako River population, a series of steps involving laboratory experiments, field observations, and the application of salmonid growth models was necessary. These entailed:

(1) Laboratory tests to establish the relation between temperature, ration and growth -- from which food conversion efficiency could also be determined. The experiments involved local stocks of an appropriate river size, and were conducted during the season of maximum environmental temperature;

(2) Field studies of resident populations with representative samples taken through the growing season to establish natural growth rates;

(3) The application of developed growth models (for coho and chinook salmon) involving the parameters of ration, temperature, and fish size, which would permit determining the natural feeding rates of the juvenile salmon for the particular river growth they achieved;

(4) Further, because of the possibility of racial adaptation to the thermal characteristics of a given watershed, some comparative studies on chinook from an entirely different location were conducted.

In brief, the objective was to develop the curve that represented the expected temperature-growth relations for the daily feeding level of the natural population. From this, an informed estimate of limits of maximum suitable environmental temperature could be ascertained.

III. MATERIALS AND METHODS

A. EXPERIMENTAL STUDIES

(1) Source and supply of fish

Chinook fry (n = 280) were obtained in early May by seining in the upper Nechako River. They were then shipped by air to the Pacific Biological Station, Nanaimo, B.C. On May 11, 1981, a sample of 30 fry had a mean length of 3.85 cm ± 0.37 SD and mean weight of 0.41 g ± 0.21 SD. The yolk was mostly absorbed, all fry being "buttoned up". As indicated by the variance, the range in length and weight was considerable, with some of the fry in fairly poor condition bordering on pinheads. For experimental purposes, these were subsequently weeded out, using only those that fell within ±1SD of the mean.

A comparable stock (n = 440) from the Big Qualicum River hatchery (Vancouver Island) was obtained in February, 1981, as eggs. The hatched fry were held at 5°C. When sampled (n = 30) on the same date as the Nechako fry (May 11) they had a mean length of 3.88 cm ± 0.05 SD and a mean weight of 0.44 g ± 0.05 SD. Although of very similar average size to the Nechako fry, the Big Qualicum fry were not fully buttoned-up and were of very uniform size without any suggestion of being underfed.

(2) Culture and temperature history

The two stocks were raised on Oregon Moist Pellets (OMP) following an initial appetite stimulant of brine shrimp. Feeding was three times per day to near satiation. Temperatures were maintained at approximately 10°C until July 27, then raised to 15°C for 1 wk. At that time the fish were transferred from the culture tanks to randomly assigned experimental tanks (23) in which the temperatures were uniformly set at 20°C. A total of 30 fish was weighed for each tank on August 5, the start of the 28-day experiment. The assigned experimental temperatures were then set for each tank on that day. A sample of 25 fish from each of the river stocks was drawn from the remaining reserves for determining initial dry weights. Final dry weights were obtained for five fish from each of the 23 tanks following the last weighing. The dry weight of the feed was also determined at the start and finish of the experiments.

(3) Experimental design

Because of interest in the effects of warm water on the viability of young salmon, experimental temperatures were chosen in the vicinity of the expected optimum (between 15° and 20°C) rising to the limit of temperature tolerance, in the vicinity of the upper lethal temperature at about 25°C (Brett 1952). In essence the sockeye model (Fig. 1) was used as the prototype; however, the sensitivity of the present study was increased considerably by testing at 1°C intervals instead of the wide-ranging 5°C intervals used previously for sockeye.

With the lesser number of fry available for the Nechako stock, the selected temperatures were: 16°, 19°, 20°, 21°, 22°, 23°, and 24°C, with replicates performed at 20°, 22°, and 24°C (total of 10 tanks). The Big Qualicum stock was tested at a slightly wider range of temperatures: 14°, 16°, 18°, 19°, 20°, 21°, 22°, 23°, 24°, and 25°C, with replicates at 20°, 22°, and 24°C (total of 13 tanks).

Food was carefully weighed out each day, with the last feeding continued until pellets were rejected. This was estimated (by counting uneaten pellets) to be 5% in excess of satiation. In this way the maximum daily ration (R_{max}) was established. Food conversion efficiency was determined by relating the total dry weight of food consumed to the dry weight of growth achieved. In the few cases where fish were injured or died between weighings the assumed quantity of food eaten was prorated according to the fraction of the period that the fish were alive.

B. FIELD STUDIES

Sampling of Fish

Juvenile chinooks were trapped or seined within 2 km of Irvine's Lodge on the upper Nechako River approximately 10 km downstream from Cheslatta Falls, the outfall of Murray Lake. The fish were either measured and weighed immediately (trapped), or preserved in alcohol (seined) and weighed later.

Sample size was usually 50 fish, but on occasion only smaller numbers were caught ranging down to 20 and 10.

Fishing began on March 22nd, 1981, and continued on a daily basis to May 8, 1981. Late in May and early June some more samples were obtained with a lapse until September when intensive sampling was renewed lasting throughout the month. River temperatures were recorded at Irvine's Lodge.

RESULTS AND DISCUSSION

A. EXPERIMENTAL STUDIES

(1) Mortalities and lethal temperature

Because of the limited number of Nechako chinooks available, only the Big Qualicum juveniles were exposed to a temperature over 24°C. One tank was assigned a temperature of 25°C. Over the 28-day period, the temperature averaged 24.8°C $\pm$0.4 range. Although most fish appeared to be feeding at the start (they had come from 20°C), within a week it was apparent that many had ceased to feed. The first fish died on the 8th day, and fish continued to die sporadically reaching a cumulative total of 64% dead by the 28th day (Table 1, Fig. 2). Moribund fish were frequently bloated with water and usually developed popeye.

At 24°C, two Big Qualicum fish died on the 7th and 8th days without any further loss. Since a mean growth rate of 1.6% wt/day characterized the stock as a whole (2 Qualicum tanks and one Nechako tank, for a total n=75) no direct lethal temperature significance was attached to these 2 cases. Presumably, temperature had precipitated death from other causes.

The upper lethal temperature for juvenile chinook salmon (4.4 cm, 1.03 g) from Dungeness River hatchery, Washington, U.S.A. was determined by Brett (1952) to be 25.1 °C ± 0.1 SE. Fish were tested for a period of just over 1 week. At 24.5°C the resistance times were reported to exceed the allotted test time i.e., less than 50% death was recorded. At a test temperature of 25.0°C the times to 50% death were determined as 7.4 days when acclimated to 20°C, and 8.5 days when acclimated to 24°C. This illustrates the fact that lethal temperatures are a sensitive physiological index. At the critical thermal level a change of no more than 0.2°C can make the difference between life and death.

The present experiments were not directed at determining lethal temperatures, but the tank temperatures were elevated to border on the known lethal level. From the results at 24.0°C and 24.8°C the temperature causing 50% death (LT_{50}) in 28 days was 24.7 °C. There is insufficient evidence to conclude that any significant difference in lethal temperature occurred between any of the present stocks (Qualicum and Nechako) and the earlier tests (Dungeness stock). In general, they confirm the previous findings as far as lethality is concerned.

(2) Growth rate x temperature (satiation ration)

As expected from results with other salmonids the growth rate rose with temperature, passing through an optimum and then falling rapidly as the lethal temperature was approached (Table 2; Fig. 3 and 4). The apparent small but positive growth rate at 24.8°C for Big Qualicum fish contains a bias in that the size achieved was that of the survivors - 36% of the total. Loss of weight and subsequent death characterized the balance, meaning that if they had lived the net result would have been negative growth. With this exception and the loss of 2 fish at 24°C (Big Qualicum), the points represent the mean growth rates over the period of 28 days.

A paired t-test for treatments at comparable temperatures (10) indicated that the Big Qualicum fish grew significantly faster than the Nechako fish ($p < 0.05$). However, growth rate is known to be inversely related to body size (Brett and Shelbourn 1975). If the growth rates were adjusted to account for the larger starting size of the Big Qualicum fish, the mean difference between stocks would increase from an average of 0.15%/day to 0.59%/day, i.e., a highly significant difference (see Fig. 6, and later discussion).

Fig. 3 and 4 illustrate the growth performance of each stock in relation to temperature. The lines represent nonlinear quadratic fits to the data (Table 3). The standard deviations for the growth rates predicted by the regression equations at 19°-23°C were 0.02%-0.03%/day; however the mean difference in growth rate between all replicates was ± 0.11 %/day (Table 2). The peak growth response on maximum ration was estimated to occur at 20.5°C for the Big Qualicum stock (3.32%/day) and 18.9°C for the Nechako stock (3.15%/day).

Despite the lack of comparable temperature precision in earlier experiments it is clear that chinooks have a higher optimum temperature, of the order of 3-4°C above sockeye. This is undoubtedly in keeping with their habit of occupying streams during the summer months, unlike sockeye which daily descend to cool, deep waters during July and August.

(3) Feeding response

Daily records were kept of the appetite displayed by the fish in each tank. At every temperature up to 22°C the response was at least good, and mostly excellent. There was no noticeable change during the 4-week period. At 23°C an initial good appetite fell off by the 3rd week to fair. At 24°C, the appetite sequence was recorded as good → fair → poor → irregular in the final week. For the highest temperature, at 25°C, an initial fair response quickly fell off to poor and then to nil (with food rejected) by the second week. This coincided with the start of mortalities.

(4) Food conversion efficiency

Food conversion efficiency in both stocks exhibited little change at temperatures from 16-21°C (Table 2; Fig. 5). However, the difference between the stocks was more pronounced than for growth rate. A paired t-test for the ten comparable treatments demonstrated that the food conversion efficiency of the Big Qualicum fish was significantly greater than for the Nechako fish ($P<0.001$). In contrast to growth rate, food conversion efficiency is not known to be size-dependent for juvenile fish. Hence, the difference in starting size between stocks would not be expected to influence the comparison.

Despite the broad dome shape of the relationship, optima were computed from the nonlinear quadratic equations. These were 19.6°C (30.9% conversion efficiency) for the Big Qualicum chinooks and 19.8°C (25.1% conversion efficiency) for the Nechako chinooks. These optima differ from those determined for growth rate by about 1°C. However, the curves are so flat in this region that 1°C alters conversion efficiency by less than 0.2%--certainly not a biologically significant difference.

(5) Temperature relations for common size

In order to further the growth comparison between the two stocks, the specific growth rates (G) were corrected for initial size difference by applying the general equation developed for salmonids: $\ell n\, G = 5.42-0.40\, \ell n Wt$

(Brett and Shelbourn 1975). A common starting weight of 3.0 g was adopted. It was assumed that the equation parameters applied equally at all temperatures. The correction called for adding 0.12% wt/day to the observed values for Big Qualicum and subtracting 0.32% wt/day for the Nechako growth rates. The uncorrected average difference of 0.15% wt/day became 0.59%/day.

It was also possible to extend the curve relating G to temperature by reference to studies performed by Banks (1971; Banks et al. 1971) and modelled by Stauffer (1973). Results obtained for temperatures at 7.5°, 10°, 12.5° and 15°C were applied to the Big Qualicum curve by prorating the values starting at 15°C with an average G of 3.05% wt/day (Fig. 6).

Lacking the actual growth data for the full range of tolerable temperatures (0°-25°C), the above extension provides the best approximation of how the dome-shaped curve would appear for this salmonid species. It is deduced from the composite information that the optimum temperature for growth of chinook juveniles occurs at about 19°C when on maximum ration.

(6) Stock difference

It is of interest that the greatest difference between the two stocks of fish occurred in the region of the optimum temperature, with least difference appearing in the proximity of the upper lethal temperature. This suggests a selective mechanism operating to produce a genetic difference at the point where physiological capacity to convert food and to grow is greatest. Since abundance and distribution depend on being prosperous, it would appear that selection for suitability would occur at temperatures where viability was greatest. As stated, salmon do not normally occur in the vicinity of their lethal temperature.

Because the Big Qualicum fish were from hatchery stock, it could be argued that selection for growth was occurring amongst those fish best able to digest and use artificial food - Oregon moist pellets. However, successful hatching and release of significant numbers of chinook juveniles did not occur until 1972[2]. With a maturation time of 3-5 yr only three generations could have reproduced in the time-span involved, hardly enough for any significant genetic change.

Alternatively, the consistently milder climate of the coast could have brought about a shift of the temperature response system to be more growth productive in the intermediate range of tolerable temperatures. Whatever the cause, the significant fact is that the experiments clearly show that the Nechako River chinooks possess no advantageous adaptation towards survival in warmer waters than do chinooks from a coastal stream.

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[2]First experimental releases of chinook fry (160,000) began in 1967, but survival was poor and fertility low. Similar releases occurred in 1968 and 1970. In 1972 the first major successful release (300,000) was made (1971 brood), with precocious males returning in 1974. Since then ever-increasing egg collection has grown to the point where over 3,000,000 are now cultured.

B. FIELD STUDIES

(1) Growth of Nechako River juveniles

From the start of sampling on March 22nd to late May, the average weight of fry (0.4 g) did not increase perceptibly. Apparently young fish were arriving at the sampling point from upstream as a continuous production of recently hatched fry without resident growth. Early in June, the weights started to rise and were recorded in late summer and early fall as ranging from 6 to 9 g (Fig. 7). This is considered a resident population not subject to major immigrations or emigrations.

From the growth curve presented, the average weight on June 1st was 0.5 g. The estimated average weight achieved by September 30th was 8.5 g. The accompanying mean monthly temperatures are shown in Fig. 7. These rose from 4.0°C in April to peak at 17.7°C in August, falling back to 14.8°C in September.

(2) Size prediction

Growth models for predicting expected size of hatchery fish have been developed that take into account the initial size, the temperature sequence, and the effect of level of feeding as a fraction of the maximum ration - R_{max} (McLean 1979). The most appropriate simulation model for application to chinook salmon is that developed by Stauffer (1973) derived from studies on coho and chinook salmon in Washington State hatcheries.

When applied to the Nechako chinook fry, starting on June 1st as 0.5 g fish, the prediction most closely approximating the attained growth by September 30th corresponded to a ration equal to 60% of the maximum ($R_{0.6}$). Thus, for example, the weight predictions according to ration were as follows: R_{max} = 17.4 g, $R_{0.8}$ = 14.7 g, $R_{0.6}$ = 8.6 g, $R_{0.4}$ = 3.2 g. The approximation of the $R_{0.6}$ feeding level is very close to the 8.5 g average observed.

(3) Deduced thermal optimum

As described in the research plan, and illustrated in Fig. 1, there is a particular growth rate x temperature curve for every level of ration up to R_{max}. Only the maximum curve was established for chinook juveniles, fed to satiation. The consequence of reduced ration was modelled by applying the proportional effect derived from the sockeye data. This is depicted in Fig. 8.

The deduced optimum temperature for a feeding level of $R_{0.6}$ occurred at approximately 14.8°C with an expected growth rate of 1.8%/day. The temperature for which $R_{0.6}$ would just provide for maintenance (i.e. zero growth) was estimated at 21.4°C.

Applying the safety criterion of accepting a 20% reduction in growth rate (to 1.44%/day), the corresponding temperature providing for this growth occurs at 17.8°C. At 20°C the reduction in growth rate (0.7%/day) would be approximately 50% of that provided by the $R_{0.6}$ optimum temperature.

CONCLUSIONS

(1) On a satiation ration, chinook salmon have an optimum temperature for growth that is 3° to 4°C higher than that for sockeye salmon. It appears to occur at about 19°C.

(2) In the region of the optimum temperature, Nechako chinook juveniles show a significantly reduced capacity to grow when compared with Big Qualicum chinooks.

(3) Growth rates of summer populations of chinook juveniles in the Nechako River indicate that the feeding level is 60% of that required to satiate them.

(4) On such a ration, the optimum occurs at about 15°C; a temperature of 20°C would only permit 50% of the maximum growth capacity. At 21.4°C no growth at all would occur.

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Table 1. Record of daily mortalities of juvenile chinook salmon from Big Qualicum River exposed to 24.8 ± 0.4°C range.

Time (days)	No. dead	Cum. dead	Dead (%)
8	1	1	4
9	1	2	8
11	1	3	12
18	1	4	16
21	1	5	20
24	1	6	24
25	3	9	36
28	7	16	64

Table 2. Weight, growth rate and food conversion efficiency in relation to temperature for juvenile chinook salmon from Big Qualicum River stock (A) and Nechako River stock (B). Period of growth was 28 days, using 25 fish per tank. Dry weights are the total gained for all fish per tank with the total dry weight of food eaten.

Assigned temp. (°C)	Mean temp. (°C)	Mean wet wt. Init. (g)	Mean wet wt. Final (g)	Growth rate %/day	Dry wt. gain (g)	Dry wt. food (g)	Conv. effic. (%)
(A)							
25	24.8	3.18	3.53*	0.37**	1.57	32.1	4.9
24	23.9	3.21	5.37	1.84	13.71	70.0	19.6
24	24.0	3.43	5.65	1.78	13.63	69.4	19.6
23	23.0	3.16	6.50	2.58	22.04	85.3	25.8
22	22.0	3.34	8.26	3.23	32.84	101.4	32.4
22	21.8	3.34	7.98	3.11	30.97	100.8	30.7
21	20.9	3.35	8.82	3.46	36.51	116.0	32.7
20	19.9	3.24	8.32	3.37	33.91	108.3	31.3
20	19.9	3.14	7.79	3.25	31.04	107.5	28.9
19	19.0	3.30	7.65	3.00	29.04	100.5	28.9
18	18.1	3.29	8.56	3.42	35.18	111.5	31.6
16	16.0	3.27	7.31	2.87	26.97	88.6	30.4
14	13.9	3.35	7.71	2.98	29.10	90.5	32.2
(B)							
24	23.9	2.09	3.48	1.82	9.00	58.1	15.5
24	23.7	2.48	3.82	1.54	8.68	65.2	13.3
23	23.0	2.49	4.78	2.33	15.11	83.2	18.2
22	21.9	2.56	5.62	2.81	20.43	90.2	22.6
22	21.8	2.48	5.63	2.93	23.43	91.7	25.6
21	21.0	2.30	5.60	3.18	22.03	93.7	23.5
20	20.0	2.46	5.84	3.09	22.56	94.9	23.8
20	19.9	2.64	6.22	3.06	23.36	85.1	27.5
19	19.0	2.28	5.50	3.14	21.49	90.6	23.7
16	15.9	2.31	5.44	3.06	20.96	90.3	23.2

*Mortality of 64%; weights are those of 9 surviving fish.

**Growth rate of surviving fish; not a true representation of total sample, which would be characterized by negative growth.

Table 3. Parameter values derived for fitting a nonlinear quadratic equation to the specific growth rates (G) and food conversion efficiencies (CE) of Big Qualicum and Nechako juvenile chinook salmon in relation to temperature. Form of equation: $y\delta = b_0 + b_1 X\alpha + b_2 X^2\alpha$.

	Gamma	b_0	b_1	b_2	Alpha
Big Qualicum - G	0.98	0.83	0.94	-1.75	6.71
Nechako - G	2.65	0.87	0.81	-1.69	4.03
Big Qualicum - CE	0.12	0.97	0.03	-0.99	18.0
Nechako - CE	0.69	0.70	0.98	-1.64	4.95

<u>Erratum</u> p. 14

For equation read

$$y^{\gamma} = b_0 + b_1 x^{\alpha} + b_2 x^{2\alpha}$$

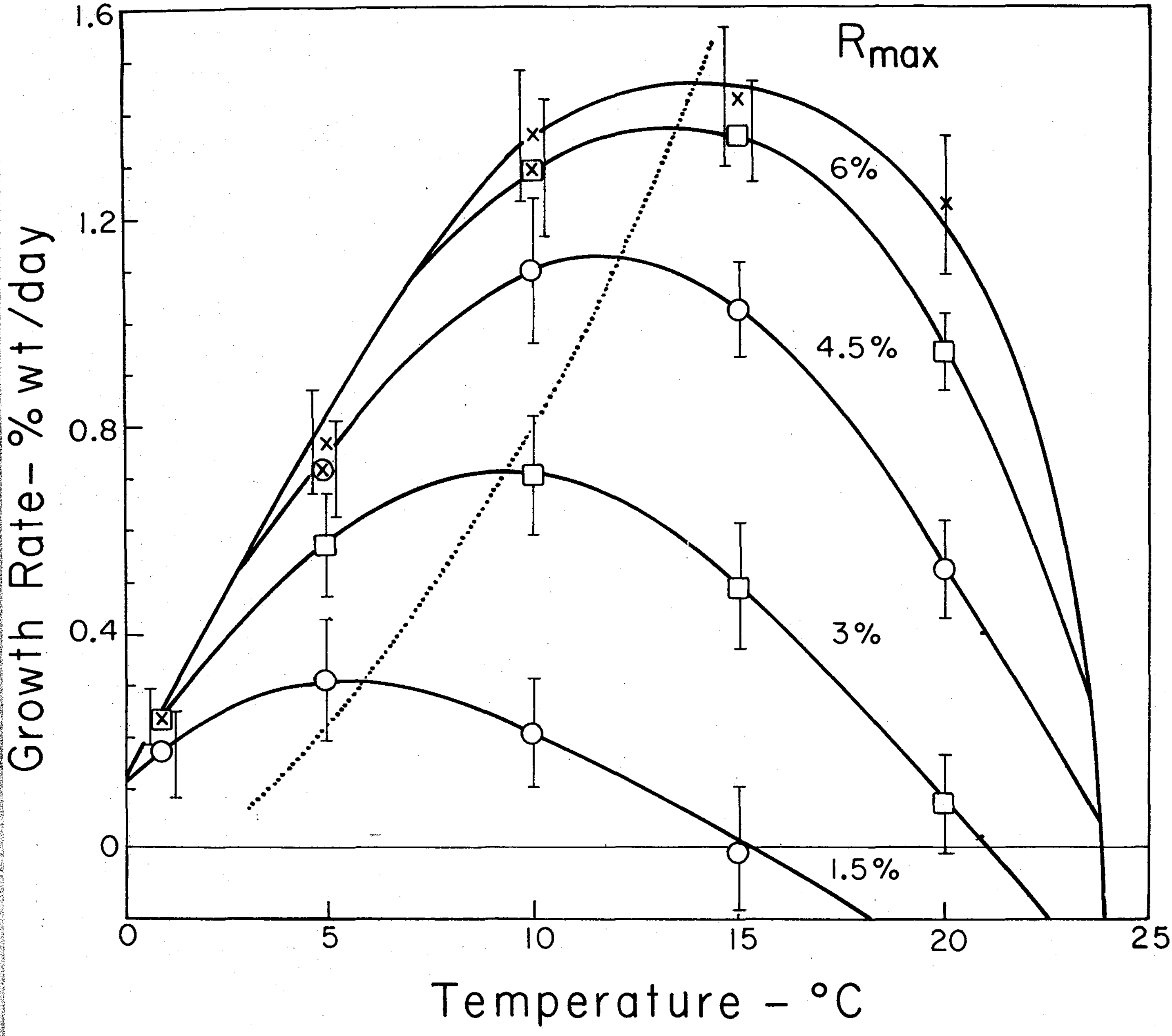

Fig. 1. The relation of growth rate (+2 SE) of sockeye salmon juveniles to temperature for different levels of ration. Determinations computed in terms of dry weights (% per day). Dotted line passes through the optimum temperature and maximum growth rate for each ration level. R_{max} = maximum daily ration. From Brett et al., 1969.

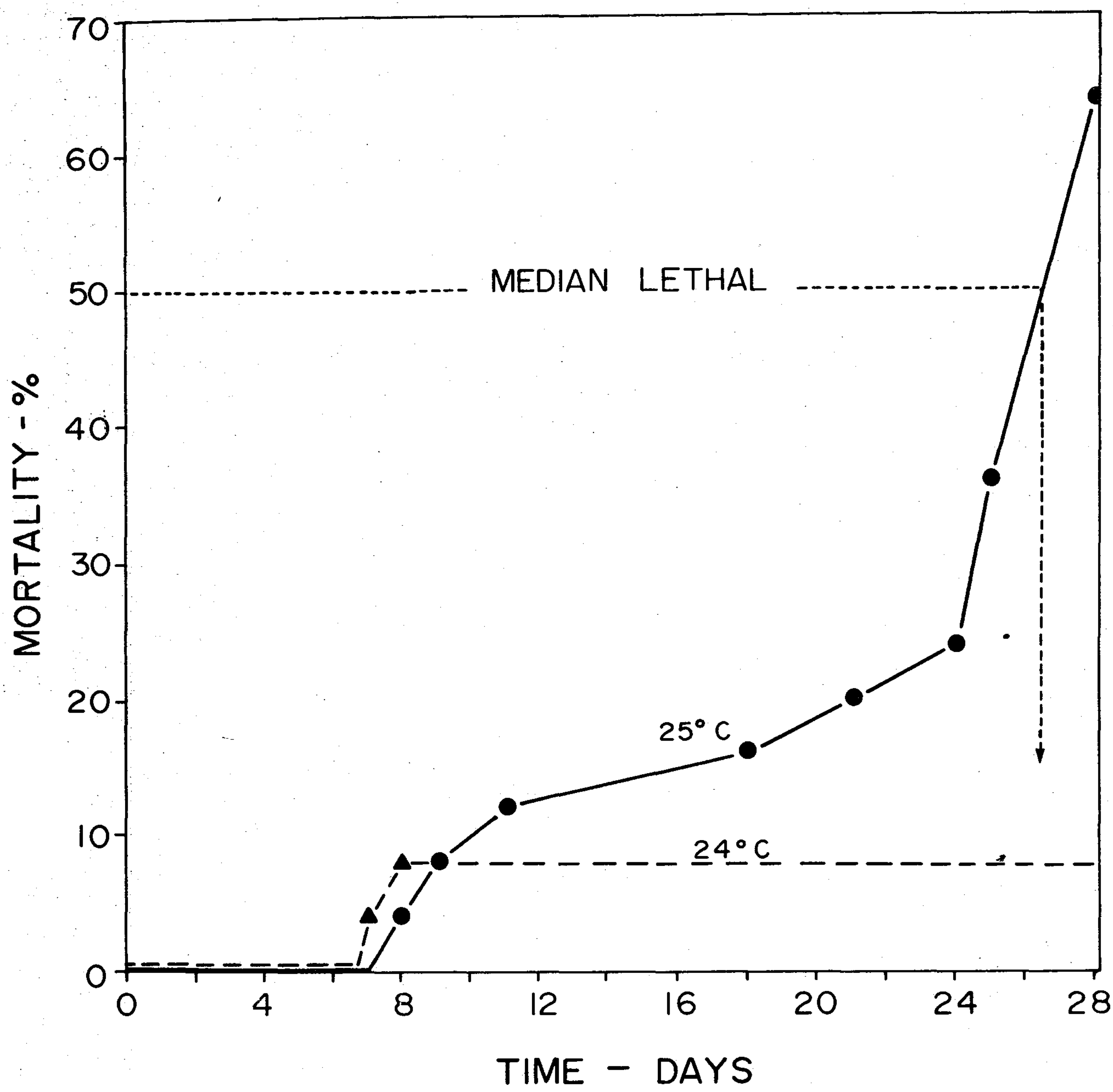

Fig. 2. Progress of mortality of chinook salmon juveniles from Big Qualicum River when held for 28 days at approximately 24° and 25°C. Actual mean temperatures (± 2 SD) were 24.0 ± 0.2°C and 24.8 ± 0.3°C.

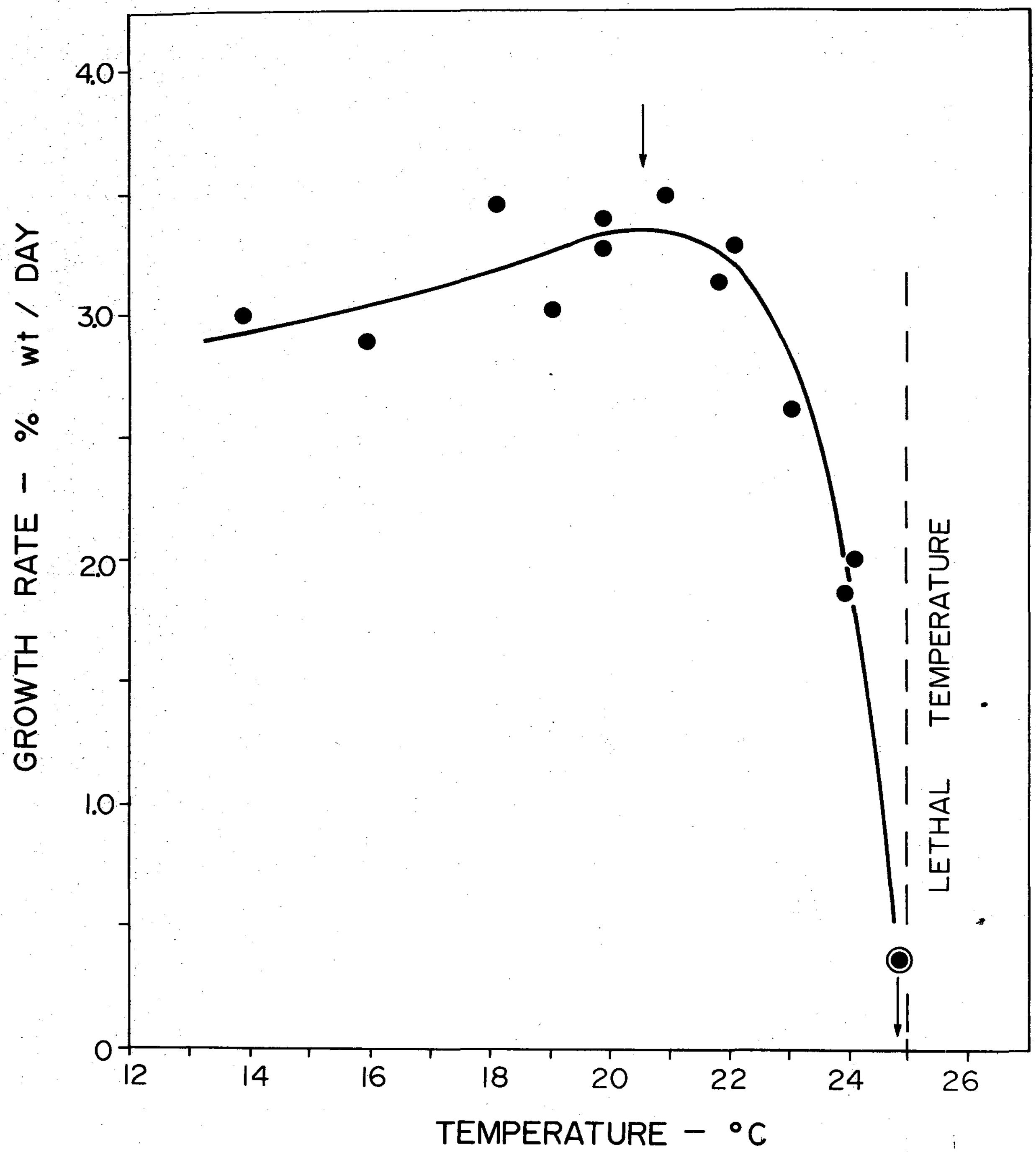

Fig. 3. The relation of growth rate to temperature for juvenile Big Qualicum River chinook salmon fed to satiation. Initial mean weight = 3.28 g. The line was fitted by a nonlinear quadratic equation (Table 3). The arrow indicates calculated optimum temperature. Circled point with arrow is based on 36% of fish that survived for 28 days at 24.8°C. The lethal temperature limit is from Brett, 1952.

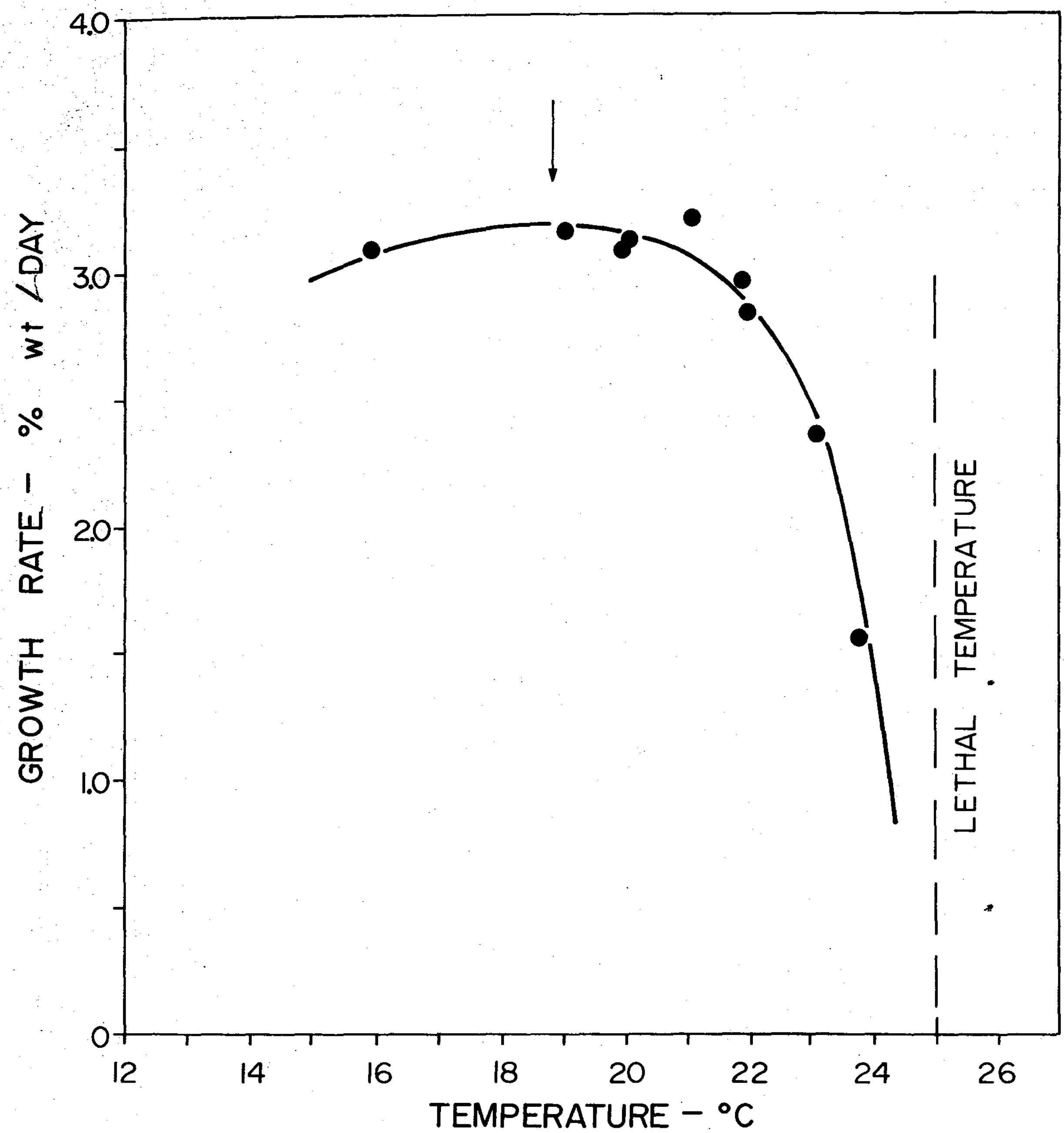

Fig. 4. Temperature relation for growth rate of juvenile Nechako River chinook salmon fed to satiation. Initial mean weight = 2.41 g. Fitted line and arrow for optimum temperature calculated as stated in Fig. 3.

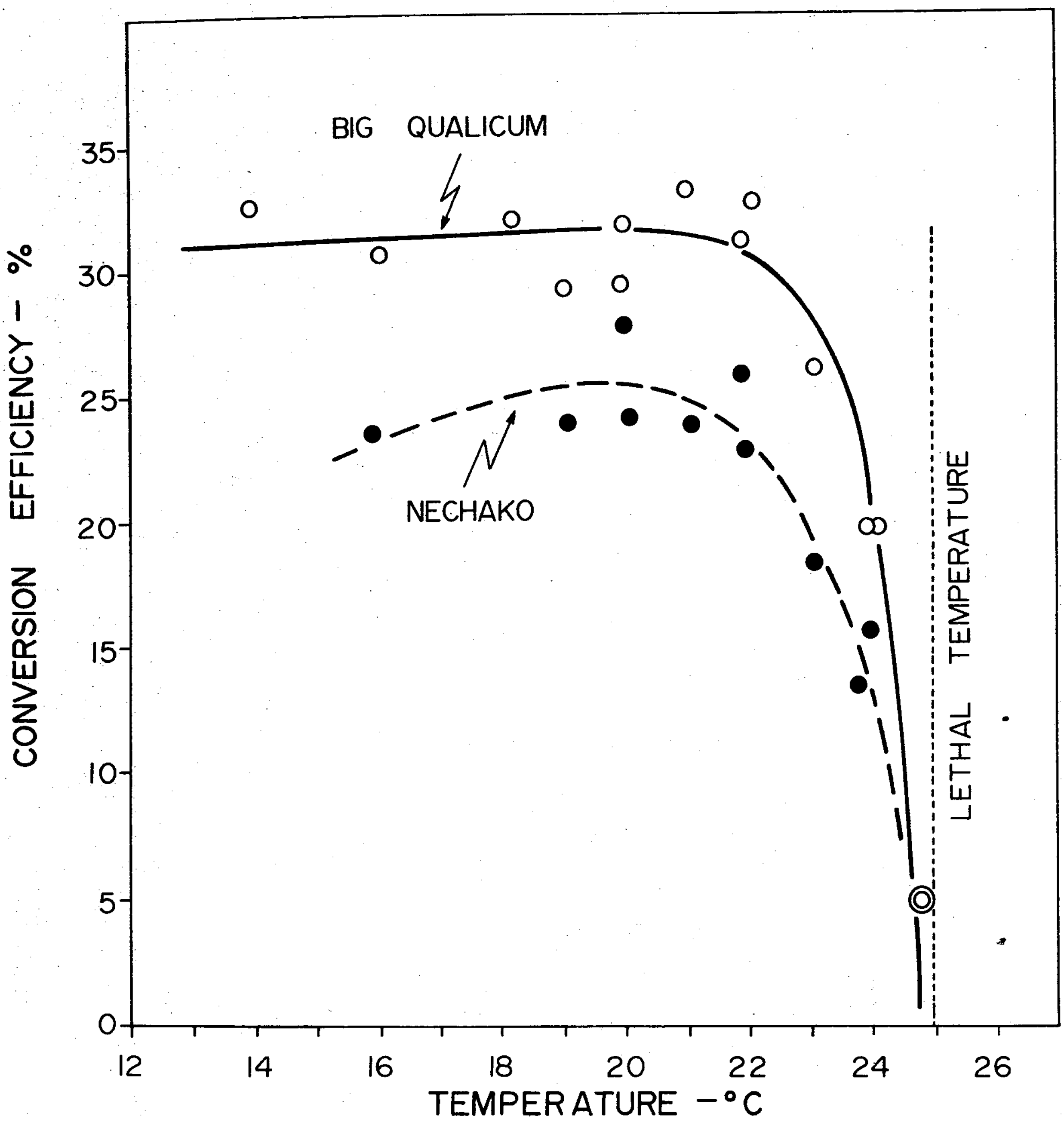

Fig. 5. The relation of food conversion efficiency to temperature for chinook salmon juveniles from Nechako and Big Qualicum rivers. The curves were fitted by a nonlinear quadratic equation (see Table 3). Circled point is based on the 36% of fish that survived for 28 days at 24.8°C.

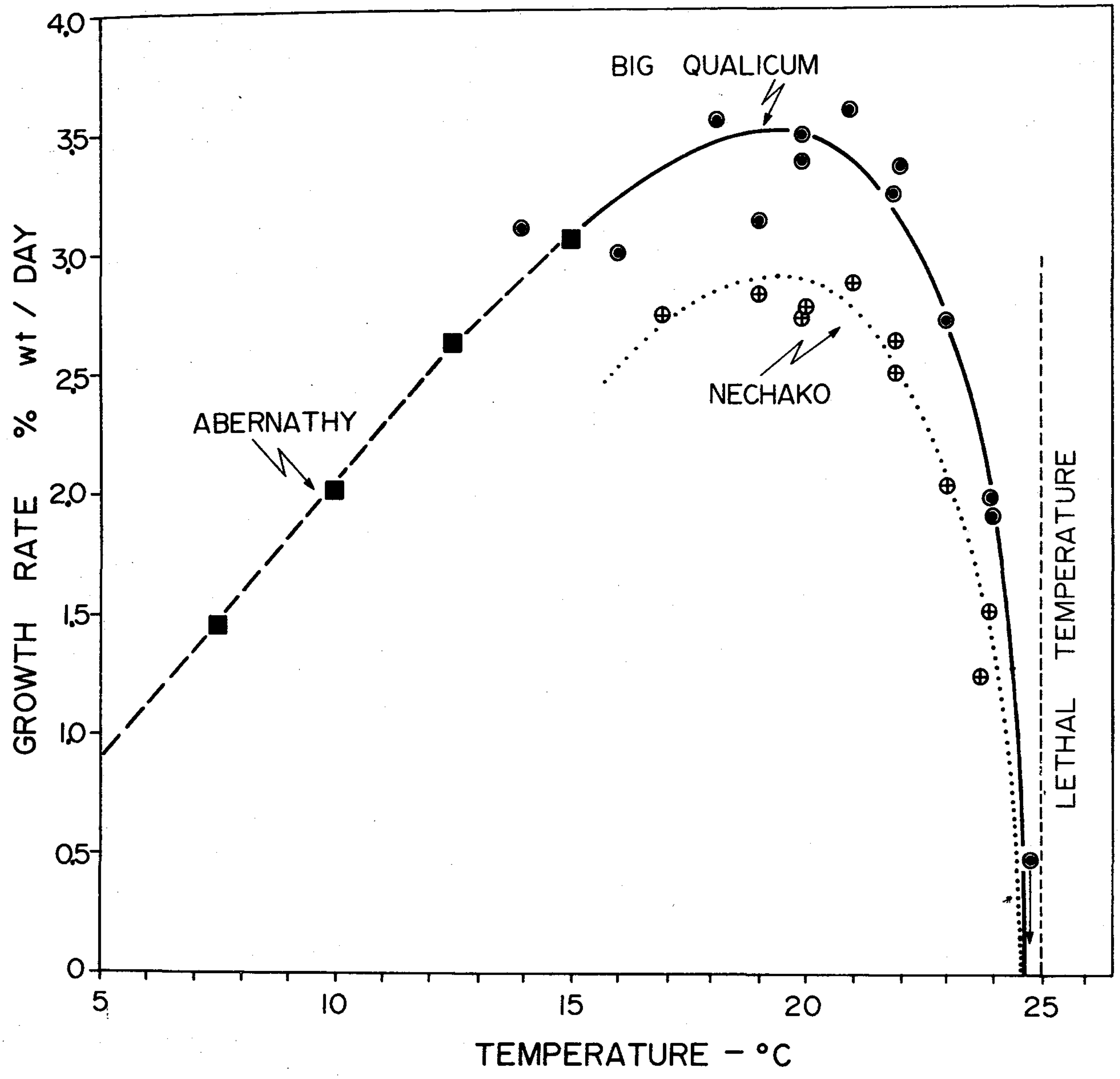

Fig. 6. The relation of growth rate to temperature for juvenile chinook salmon fed to satiation. Growth rates adjusted to a common initial size of 3.0 g. Points for Abernathy derived from model of Stauffer (1973) based on data of Banks (1971). They show the expected relative position for Big Qualicum chinook salmon. Lines drawn by eye.

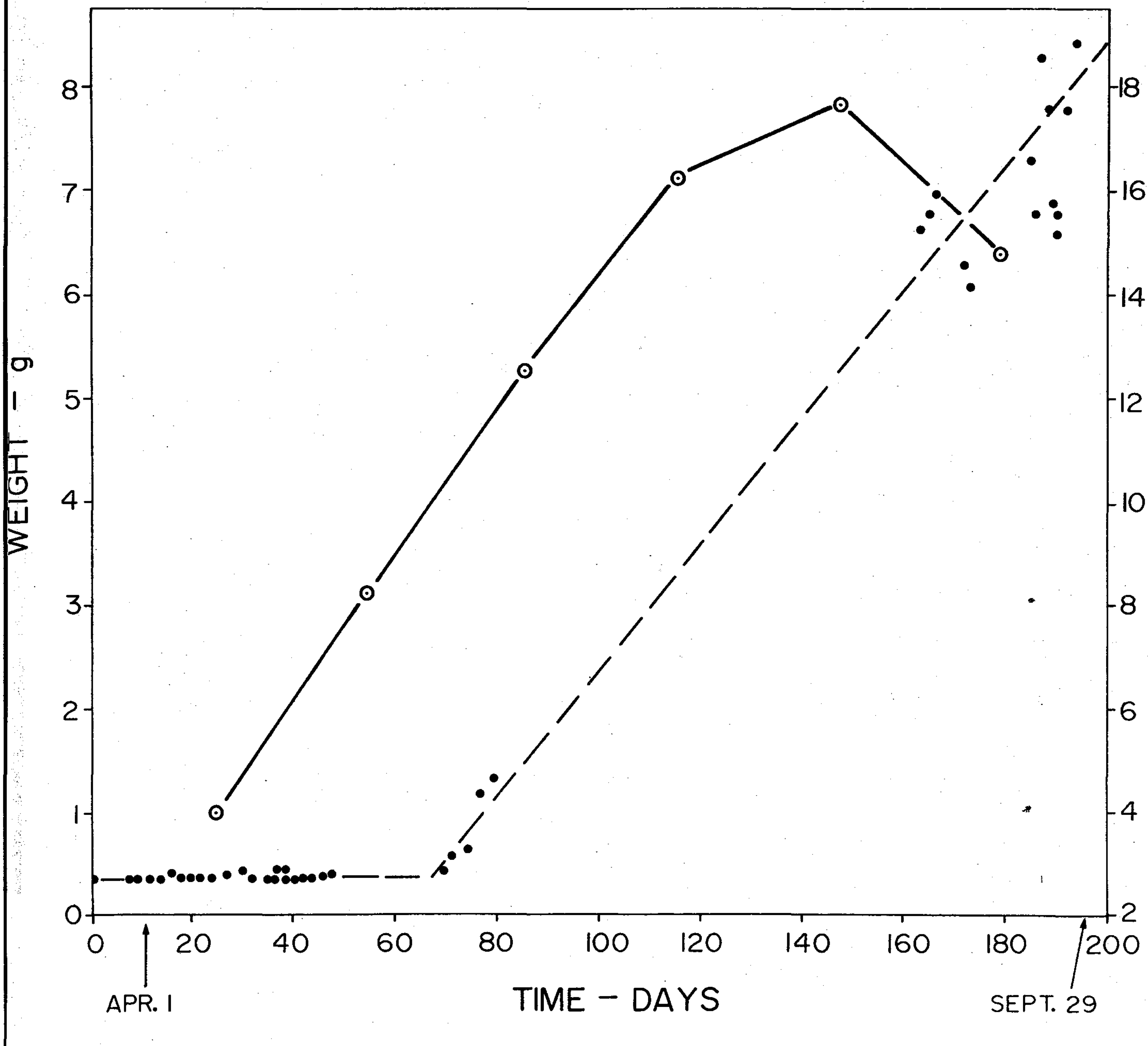

Fig. 7. Mean wet weights (n=50) of chinook salmon juveniles caught in the Nechako River from March 22nd to September 29th, 1981. Fish were not sampled from June 10th to August 29th. Growth curve drawn by eye (broken line). Mean monthly temperatures shown with solid line.

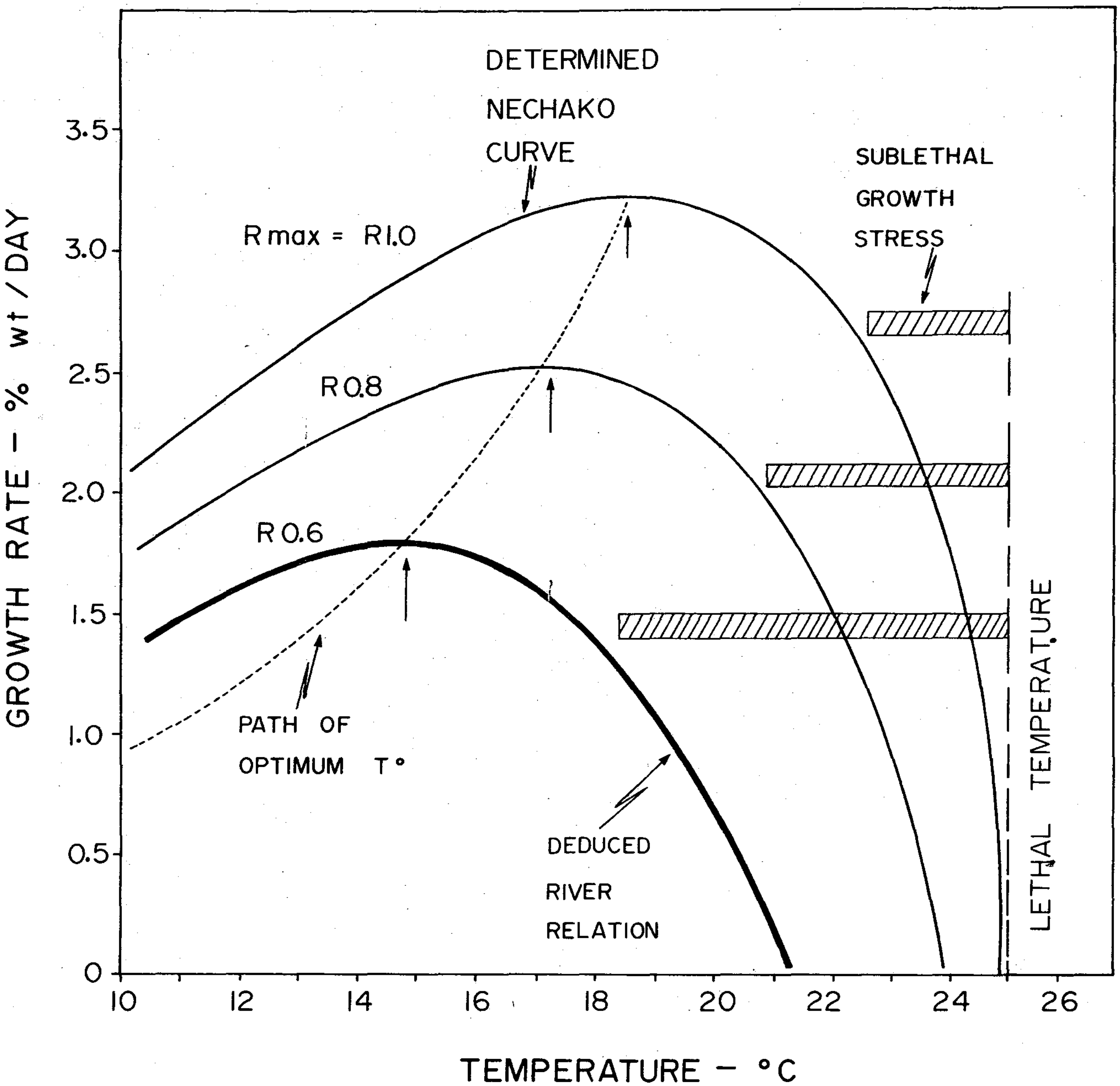

Fig. 8. Growth rate vs temperature curves for Nechako River juvenile chinook salmon. Top curve is from data presented in Fig. 4 for fish fed a maximum ration (R_{max}). Additional curves drawn for reduced daily rations ($R_{0.8}$ and $R_{0.6}$) according to the relation obtained for sockeye salmon juveniles (Fig. 1). Broken line indicates path of optimum temperature shifting to a lower value as feeding level falls. The hatched bars indicate the temperature range in which growth rate is reduced by 20% or more from that achieved at the optimum temperature.