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TANK EXPERIMENTS ON THE CULTURE OF PAN-SIZE SOCKEYE (*ONCORHYNCHUS NERKA*) AND PINK SALMON (*O. GORBUSCHA*) USING ENVIRONMENTAL CONTROL

J.R. BRETT

Pacific Biological Station, Department of the Environment, Nanaimo, B. C., (Canada)
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ABSTRACT

Brett, J.R., 1974. Tank experiments on the culture of pan-size sockeye (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*) using environmental control. *Aquaculture*, 4: 341—352.

Experimentally, sockeye and pink salmon can be grown from a weight of 4 g to pan size at 230 g (8 oz) in at least 280 days; the fish were held at 15°C in salt water (10 and 28‰) on a photoperiod that increased from 15 to 18 h light/day. Growth rates of wild sockeye smolts were inferior to those of younger cultured sockeye when compared at the same size. Maximum growth rates were obtained with pink salmon fry (mean weight, 5.5 g), which grew at 4.5% body weight/day. A provisional table of growth rates for sockeye salmon is presented; it can be used to predict the expected weight (up to 500 g) for any temperature, time and starting size when on excess ration.

INTRODUCTION

In a previous account on "Improvement in the artificial rearing of sockeye salmon by environmental control" (Brett and Sutherland, 1970) it was demonstrated that the growth of juvenile sockeye (23 g starting weight) could be accelerated beyond that obtained by applying optimum temperatures if additional manipulation of the environment was practised. Favorable salinity, photoperiod, water velocity and cover (from direct light) were coupled with optimum temperature, resulting in a marked increase in growth rate over the maximum obtained previously — from 1.4 to 2.4% wt/day (Brett et al., 1969).

Because pink salmon (*Oncorhynchus gorbuscha*) are considered to have a faster growth rate than sockeye (*Oncorhynchus nerka*) in nature, and readily tolerate full-strength sea water as fry (Weisbart, 1968), experiments were conducted to compare the tank culture of this species with "wild" and "cultured" sockeye smolts. The latter distinction for sockeye relates to the sources and state of the separate stocks. Wild smolts were obtained as 1-year-old natural migrants, at which time they are generally small (3—6 g); cultured smolts were raised from eggs incubated in the Pacific Biological Station hatchery (about 20—30 g at 1 year). It was postulated that since wild smolts are growth retarded, from food limitations and low temperature, they might show a compensatory surge of growth above that expected for their particular size. The question posed was whether surplus wild smolts would make an advantageous source for aquaculture, over those raised artificially from eggs; and further, does size control growth independent of age?

METHODS AND MATERIALS

Controlled conditions

Three 500-gal (2 300 l), circular fiberglass tanks were set up with the controlled conditions, as expressed in Table I (± approximate range).

A temperature of 15°C is known to be optimal for sockeye growth in fresh water (Brett et al., 1969). It is not likely to be exactly the same for pink salmon, which generally are considered a colder water species. Their southerly distribution, as an abundant species, is more restricted than sockeye salmon.

Salinity may alter the optimum temperature. However, multifactorial experiments to date suggest that its influence in shifting the position of the thermal optimum would only be slight if at all (J.E. Shelbourn, personal communication, 1974).

Greatest salinity influence can be expected at the blood isosmotic level (as chosen for the sockeye, approx. 10‰), which is known to reduce maintenance metabolism by 20% in rainbow trout (Rao, 1968). This could be expected to result in a proportional increase in growth rate, at all temperatures.

To simulate the normal seasonal stimulus to the pituitary gland from increasing day length, a long spring day of 15 h of light was increased by 0.25 h/week. In the 3-month experimental period the day length rose to 18 h of light.

TABLE I

Controlled conditions (± approximate range) in the 2 300 l circular fiberglass culture tanks. (1 fc = 10.76 lux; 1 ft/sec = 0.305 m/sec)

Environmental factor	Wild sockeye	Cultured sockeye	Pink salmon
Temperature (°C)	15 ± 1	15 ± 1	15 ± 1
Salinity (‰)	10 ± 2	10 ± 2	28 ± 1
Photoperiod (h/day)	15 → 18	15 → 18	15 → 18
Photoperiod change (h/week)	+0.25	+0.25	+0.25
Light intensity (fc)	120 ± 20	120 ± 20	120 ± 20
Max. velocity (ft/sec)	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1
Av. oxygen (% satn)	92 ± 6	88 ± 8	90 ± 8

Fish stocks

Migrating sockeye smolts were obtained on April 24th from a weir at Cultus Lake, near Chilliwack, B.C. (courtesy of the International Pacific Salmon Commission). During the following 10 days the stock of about 1 000 fish (mean weight, 4.1 g) was introduced gradually to the prescribed temperature and salinity. An initial poor response to feeding on Oregon Moist Pellets (OMP; Table II) was overcome by introducing marine zooplankton (mostly *Calanus plumchrus*) together with the pelleted food. This feeding stimulus was subsequently reduced to adding extracted plankton fluid only. The latter was curtailed at the end of the third week by which time good acceptability of OMP had been established.

One-year-old cultured sockeye salmon, originally obtained as eggs from Weaver Creek (Fraser River watershed), were transferred from the Station hatchery to the experimental tanks on May 11th (mean weight, 22.2 g). By May 14th the fish had reached the prescribed environmental conditions. Throughout their early rearing they had been fed OMP.

TABLE II

Percent composition of Oregon Moist Pellets (OMP). The ingredients are mixed with water to provide a ration with approx. 29% moisture (Crawford and Law, 1972)

	%
Cotton seed meal	15.0
Herring meal	28.0
Shrimp or crab meal	4.0
Wheat germ meal	4.0
Corn distillers dried solubles	4.0
Dried whey products	5.0
Albacore tuna viscera, without livers	15.0
Turbot/dogfish/salmon viscera	15.0
Kelp meal	2.0
Vitamin mixture	1.7
Soybean oil (antioxidant)	5.8
Choline chloride	0.5
Total	100.0

Cultured pink fry were held in sea water ($\cong 28 \pm 1‰$ salinity) and transferred to experimental conditions on June 1st. The stock had been obtained from Big Qualicum River hatchery (Vancouver Island), and also had been raised from first feeding stage on OMP.

Feeding of fish in all tanks was conducted at 09.00 h and at 16.00 h. On each occasion food was presented continuously until voluntary food intake ceased (satiation).

Culling and sampling

The initial lot of fish for each tank was selected by eye from the original stocks; fish sizes were taken as "average" to "large", excluding the very largest and below-average fish. Subsequently each tank was further culled of the smaller fish once, except the pink salmon which were culled twice. The main reason for culling was to reduce the total weight of fish in a tank to avoid crowding and low oxygen conditions, and to include a practice that is not uncommon in overstocked hatcheries. The percent difference in mean weights before and after culling ranged from 5.3 to 17.9% (Table III).

At the start and finish of each experiment a sample of approx. 50 fish was removed (Table III). Between these times, additional samples of 20 ± 2 fish were taken at 2-week intervals. Each fish was rolled in a dampened, absorbant cloth to remove external moisture, and weighed immediately. The whole sample was then set aside for dry weight determinations.

Dry weights

Each fish was placed in a weighed strip of aluminum foil and slit longitudinally through the body musculature and body wall. Dry weights were determined after 24 h in a convection-type drying oven at 105°C.

RESULTS AND DISCUSSION

Growth rates

The increase in weight for each group of salmon is plotted in Fig.1 as the logarithm of weight against time. A straight line was drawn by eye through each set of points, between cullings. Two points are shown at each time of culling. The initial set of growth points terminates with the pre-culling sample point; a new line starts with the post-culling sample point. The only exception is that for wild sockeye; in this case growth achieved during introductory feeding with zooplankton is plotted separately (first 28 days). Each linear segment of the total growth curve is termed a "stanza".

When young salmon are held under constant environmental conditions and given ample opportunity to feed, it is known that their growth rate is size dependent, decreasing with increasing weight (e.g. Cooper, 1961). The use of straight lines, as in Fig.1, is basically unacceptable unless the data allow no other interpretation, or some limiting factor is present that restricts the full capacity for growth. The depicted change in slope, decreasing between culled growth stanzas, is indicative of this size influence. The instantaneous growth rates (% wet body weight/day) were calculated for each stanza (Table III; Fig.2) and plotted against the geometric mean weight within the stanza (i.e. the arithmetic mean of the logarithms, as used in the semi-log plot of Fig.1).

TABLE III

Average weights and growth rates of salmon stocks at start, culling time and finish of culturing. The "mean weight" is the geometric mean for the size interval indicated, i.e. for a stanza. "Culling difference" is the percent difference in wet weight of the sample (n = 20) taken before and after culling

Stock	Time (days)	Wet weight (g)	Mean weight (g)	Growth rate (wet; %/day)	Dry weight (g)	Growth rate (dry; %/day)	Culling difference (%)
Sockeye (cultured)	0	22.23		—	5.56	—	—
			50.2				
	100*	113.31		1.63	33.99	1.81	—
			54.5				
	100**	133.50		1.79	40.05	1.97	17.9
			188.2				
	197	265.25		0.71	84.88	0.77	—
	Overall		76.8	1.26	—	—	—
Sockeye (wild)	0	4.00		—	0.76	—	—
			6.3				
	28	9.91		3.24	2.11	3.65	—
			19.5				
	108*	38.20		1.69	10.12	1.96	—
			20.2				
	108**	41.07		1.77	10.88	2.05	7.6
			67.3				
	206	110.33		1.01	31.22	1.08	—
	Overall		21.0	1.61	—	—	—
Pink	0	2.87		—	0.55	—	—
			5.4				
	28*	10.09		4.49	2.15	4.87	—
			5.5				
	28**	10.62		4.67	2.26	5.05	5.3
			19.4				
	77*	35.54		2.47	8.89	2.80	—
			20.2				
	77**	38.51		2.63	9.63	3.00	8.4
			59.7				
	133	92.63		1.57	25.01	1.70	—
	Overall		16.3	2.61	—	—	—

* Sample taken before culling.
** Sample taken after culling.

Fastest growth occurred with young pink salmon. Their wet weight increased at the rate of 4.49%/per day at a mean weight of 5.5 g, falling to 1.57%/per day in the third stanza (mean weight, 59.7 g). The final weight of these fish was just under 100 g, after 133 days of growing from fry of 3 g weight. A severe, unidentified disease broke out, curtailing further culturing.

Wild sockeye of approximately the same weight range as the pink salmon had a lesser growth rate, falling from 3.24% (mean weight, 6.3 g) to 1.01%

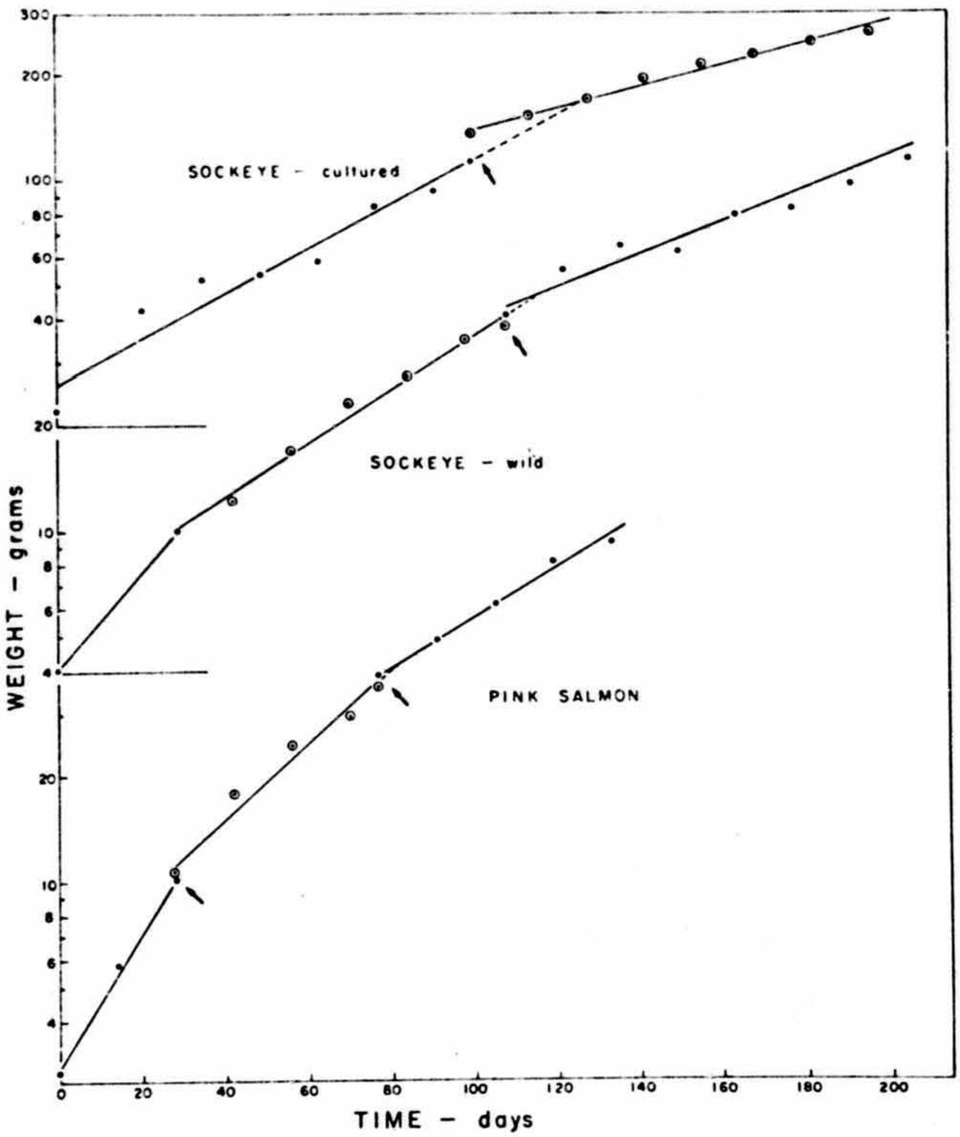

Fig.1. Increase in average weight of two stocks of sockeye salmon and one of pink salmon. Arrows indicate times when stocks were culled. Lines were drawn by eye for each growth stanza. Note that the ordinate scale divisions are not altered but the numbering has been changed to suit each growth sequence. See text for controlled environmental conditions.

(mean weight, 67.3 g). This parallel decline is shown in Fig.2.

Cultured sockeye, being larger to begin with but the same age as the wild sockeye, grew at a rate of 1.63% (mean weight, 50.2 g) falling to 0.71% (mean weight, 188.2 g).

When compared at the same weight, it is apparent that the cultured sockeye grew at a rate equal to that of the pink salmon and greater than that for the wild sockeye (compare between 50 and 70 g, Fig.2). This indicates that accelerated young stocks can grow faster than older wild stocks, and

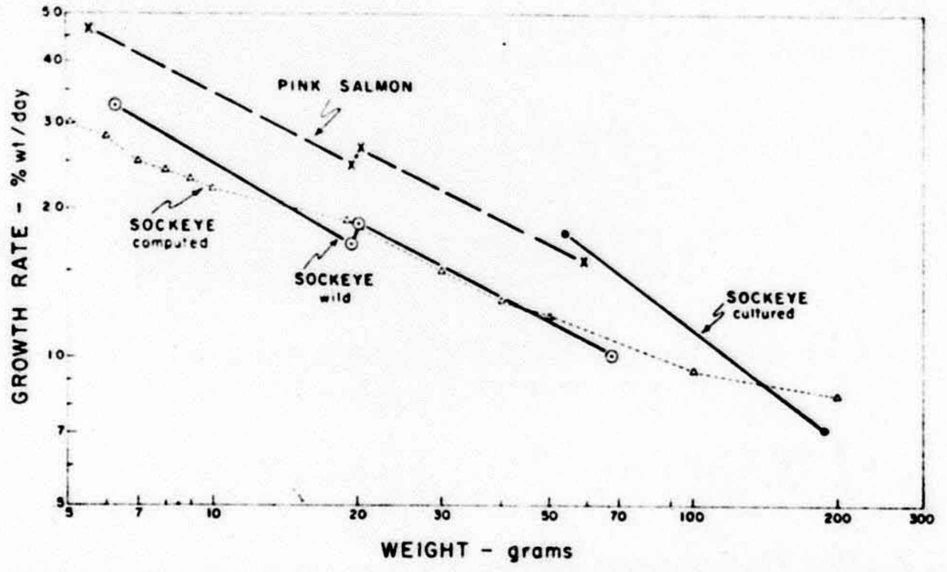

Fig.2. Specific growth rates (× 100) of the three stocks of salmon shown in Fig.1. Each point represents the logarithm of the growth rate for a given stanza plotted against the logarithm of the geometric mean weight. Double points represent the growth rate of the sample before and after culling (see Table III). The dotted line for "computed sockeye" growth rates comes from the listing in Table IV.

that pink salmon do not appear to have any particular advantage over sockeye on the basis of growth capacity when under optimum conditions of environment and food.

The above statement presupposes that the reasons for the comparative growth relations go beyond the chance selection of widely different genetic strains of sockeye, and that isosmotic salinity for pink salmon would not have conferred a significant increment of enhanced growth. Both these possibilities need exploring.

It is worth noting that this is the first experimental evidence known to the author that size and age (unconfounded) may be quite distinct in their separate influences on growth for immature fish. It is further apparent that growth-retarded fish do not carry a stored potential (e.g. growth hormone); such a potential would lead to an unexpected surge of growth if the fish were introduced to an ideal environment.

The weight changes for the three lots of fish have been plotted in Fig.3; the starting weights of the larger salmon have been superimposed to correspond with the position of achieved weight of the smaller salmon. Starting at a weight of 3 g, it is evident that a pan-size salmon (230 g or 8 oz) would be obtained in about 270–280 days if held at 15°C.

Dry weights

The young pinks and small sockeye smolts had a moisture content of about

TABLE IV

Provisional table of specific growth rates (% body weight/day) of sockeye salmon raised in fresh water. Temperatures are shown as the middle temperature for each degree, e.g. 3.5°C covers 3–4°C, etc. The growth table is set up as a series of small steps for a process which is in fact continuous. For tabulation, the weight intervals selected are 0.21–0.30 (first row), 0.31–0.40, . . . ; 200.01–500.00 (last row)

Weight (g)	Temperature (°C)														
	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5
0.30	1.40	1.80	2.40	3.10	3.90	4.50	5.50	5.90	6.40	7.40	8.20	8.90	9.50	9.50	8.90
0.40	1.20	1.60	2.10	2.70	3.40	3.90	4.70	5.30	5.70	6.50	7.10	7.70	8.20	8.20	7.70
0.50	1.10	1.40	1.90	2.40	3.10	3.60	4.30	4.80	5.20	5.90	6.40	6.90	7.50	7.50	6.90
0.60	1.00	1.30	1.70	2.20	2.80	3.40	4.00	4.40	4.80	5.50	6.00	6.40	6.90	6.90	6.40
0.70	0.92	1.20	1.60	2.10	2.60	3.10	3.70	4.00	4.40	5.10	5.50	6.00	6.40	6.40	6.00
0.80	0.88	1.20	1.50	2.00	2.50	2.90	3.50	3.80	4.20	4.80	5.20	5.60	6.00	6.00	5.60
0.90	0.80	1.10	1.40	1.80	2.30	2.80	3.30	3.60	4.00	4.60	5.00	5.40	5.80	5.80	5.40
1.00	0.78	1.00	1.40	1.70	2.30	2.60	3.20	3.40	3.80	4.40	4.80	5.20	5.50	5.50	5.20
2.00	0.66	0.85	1.20	1.50	1.90	2.20	2.70	3.00	3.20	3.70	4.00	4.30	4.60	4.60	4.30
3.00	0.55	0.70	0.94	1.20	1.60	1.80	2.20	2.40	2.70	3.00	3.30	3.50	3.70	3.70	3.50
4.00	0.46	0.60	0.81	1.10	1.40	1.60	2.00	2.10	2.30	2.70	2.90	3.10	3.30	3.30	3.10
5.00	0.42	0.55	0.76	0.96	1.30	1.50	1.80	1.90	2.10	2.50	2.70	2.90	3.00	3.00	2.90
6.00	0.39	0.50	0.68	0.88	1.20	1.40	1.70	1.80	2.00	2.30	2.50	2.70	2.80	2.80	2.70
7.00	0.38	0.48	0.64	0.80	1.10	1.30	1.50	1.70	1.90	2.10	2.30	2.40	2.50	2.50	2.40
8.00	0.35	0.45	0.60	0.78	1.00	1.20	1.50	1.60	1.80	2.00	2.20	2.30	2.40	2.40	2.30
9.00	0.33	0.42	0.58	0.76	0.92	1.10	1.40	1.50	1.70	1.90	2.10	2.20	2.30	2.30	2.20
10.00	0.31	0.40	0.56	0.72	0.90	1.10	1.30	1.40	1.60	1.80	2.00	2.10	2.20	2.20	2.10
20.00	0.26	0.33	0.46	0.58	0.75	0.90	1.10	1.30	1.40	1.60	1.70	1.80	1.90	1.90	1.80
30.00	0.22	0.28	0.37	0.47	0.60	0.74	0.92	1.00	1.10	1.20	1.30	1.40	1.50	1.50	1.40
40.00	0.19	0.24	0.32	0.41	0.54	0.65	0.80	0.84	0.98	1.10	1.20	1.30	1.30	1.30	1.30
50.00	0.17	0.21	0.29	0.37	0.47	0.58	0.72	0.78	0.86	1.00	1.10	1.20	1.30	1.20	1.10
100.00	0.14	0.17	0.24	0.30	0.38	0.47	0.59	0.64	0.72	0.82	0.88	0.92	0.94	0.92	0.88
200.00	0.11	0.13	0.19	0.23	0.29	0.36	0.46	0.50	0.58	0.64	0.75	0.80	0.84	0.80	0.75
500.00	0.10	0.11	0.15	0.18	0.22	0.30	0.40	0.45	0.53	0.58	0.67	0.72	0.76	0.72	0.67

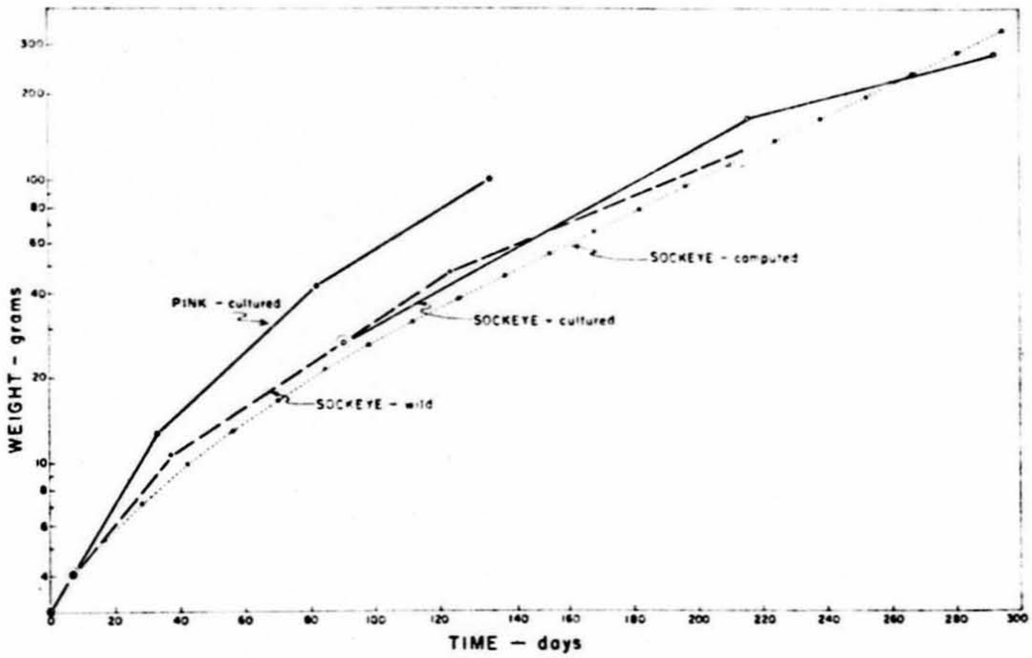

Fig.3. Weight increase of the three stocks of salmon plotted so that the starting weights correspond to an existing weight of another stock, i.e. superimposed at the circled points. This was done to project the sequence of observed growth from late fry size (3—4 g) to pan size fish (225—250 g). The computed growth of sockeye, using the prediction table (Table IV), is represented by the dotted line.

80%. This fell steadily with increasing size and time (11 weeks) to 76% for pinks and 73.5% for sockeye (Fig.4). The larger, cultured sockeye (fatter) remained fairly constant at 75% moisture for the first 6 weeks and then decreased to 71.5% by the 10th week. (Two obviously aberrant points were deleted at the start and finish of the series.)

Because of the fairly large mass of fish being dried, it is suspected that the moisture determinations in the convection-type oven may have been somewhat low, i.e. the fish were not completely dried. Since this possible error would tend to be distributed uniformly along the sequence of points, the relative change in moisture content would be unaltered. This permits calculation of the growth rates in terms of dry weight change, a better basis where food value or energetics are under consideration (Table III).

Size prediction table

Growth experiments on sockeye salmon have been conducted for 10 years at the Pacific Biological Station. Sufficient information on this species is now available to estimate the growth rate for any size and temperature, when the fish are on a full ration*. A provisionary table was drawn up (Table IV)

*Fish were fed two or three times a day to excess, depending on temperature. Records of the exact amount eaten were not always taken. Maximum food intake of sockeye in relation to weight at 15°C is recorded in Brett (1971).

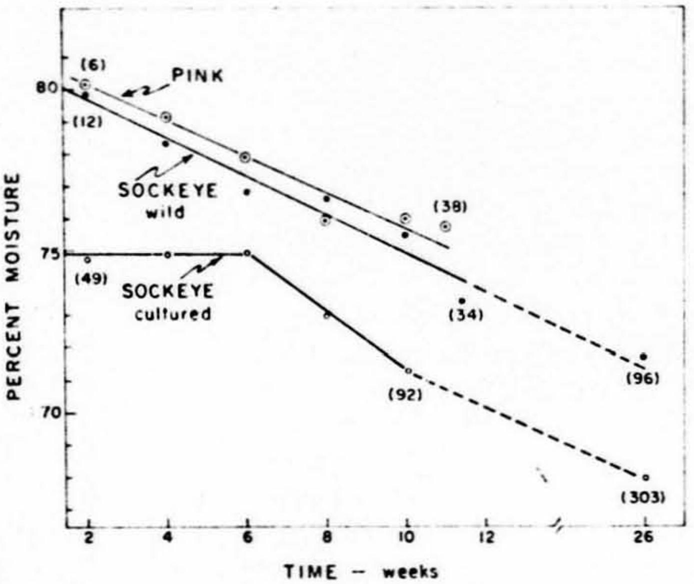

Fig.4. Moisture content of samples of 20 fish, starting 2 weeks after introduction to controlled environmental conditions. Straight lines were drawn by eye up to the 12th week and extended as broken lines to final determinations on the 26th week. Mean wet weights (g) of fish indicated in brackets. The figure illustrates the progressive change in body composition with growth when on excess feeding. Within the accuracy limits of the technique used, sockeye and pinks are not significantly different; also, cultured sockeye (92 g, 10th week) are not significantly different from wild sockeye (96 g, 26th week) when compared at approximately the same weight.

projecting the growth rates for temperatures between 3 and 18°C, and for a weight range from 0.2 to 500 g. Greater confidence surrounds the temperatures between 5 and 18°C and the size range of 1 to 50 g, since the entries beyond these limits were determined by extrapolation. In general, extremes of size and temperature are based on relatively few data. It is expected that the table will be progressively up-dated as more information is obtained. The need for such a compilation was pressing because of the start of experimental and operational fish farms on the Pacific coast using controlled temperature to accelerate early growth.

Calculation of the expected progress in weight is possible, starting from any size and following any temperature regime. Such a plot is included in Fig.3 starting at 4 g at a constant temperature of 15°C. It can be seen that the predicted curve runs slightly under the observed relation up to 225 g where the predicted curve crosses the line for cultured sockeye. By chance, the time to reach pan size is predicted almost exactly. The calculated weights would be expected to run below the observed weights since they are based on fresh water rather than isosmotic conditions, and involved non-culled stocks. It is apparent that Table IV contains growth rates that are either too high for weights over 100 g, or else a partial reduction in growth took place in the largest fish raised. That the latter might be true is suggested in the downward trend of the growth rate of cultured sockeye below the general slope for the other lots (see position of last point, near 200 g; Fig.2). However, the general accuracy of the table is supported.

CONCLUDING COMMENT

Environmental control continues to show great promise as a physiological tool in the experimental production of cultured fish. Particularly high growth rates in young salmon, before reaching the 10 to 20 g size, hold greatest possibility for economical application in fish farming; for these small, fast-growing stages the space and water requirements for individual fish remain low.

Prediction tables will permit determining the consequences (and computed costs) of any strategy of temperature—time manipulation of fish stocks. For instance the staging of sub-lots to arrive at a marketable size over a number of months can be readily predetermined. One potential limitation of the growth rate table is that is applies only to stepwise, static temperatures on a rising sequence. Oscillating temperatures or falling temperatures, as in nature, have not been tested experimentally. This remains an unknown and highly challenging area for research, involving the consideration of metabolic acclimation to an almost infinite combination of possible temperatures, not to mention salinities and photoperiods. Considerable advancement and refinement in the practice of "growth acceleration" of cultured fish can be expected.

Finally, since a change in more than one environmental variable was imposed in this set of experiments, as well as in the earlier production tests reported (Brett and Sutherland, 1970), it should be noted that no attempt to sort out the separate environmental influences was intended. This was essentially an exercise in applied research using established physiological principles.

ACKNOWLEDGEMENTS

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