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RESPIRATORY METABOLISM AND GROWTH OF ATLANTIC SALMON IN RELATION TO VARIOUS LEVELS OF ROUTINE ACTIVITY.

by

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INTRODUCTION

In most studies dealing with the respiratory metabolism of fish either standard or active metabolic have been measured (Winberg 1956, FRY 1957). Brett (1970) points out the importance of measuring the activity level in any record of oxygen consumption and this can easily be done when a tunnel respirometer technique is used. (Brett 1964, 65, Rao 1968, Dickson and Kramer, 1971 and others). However, these studies are mainly working with single fish for short periods of time and not actively feeding and growing fish in groups. The construction of a fully controlled growth and metabolism tank (Brett et.al 1971) made such studies possible, where growth, metabolism and excretion can be followed in detail for long period, growth, (Brett and Zala, 1975).

A better knowledge of the total energy budget of a fish would be of great help in fish culture. Several important studies (Warren and Davis 1967, Brett 1970, Niimi and Beamish 1974, and Brett 1976) has given valuable information of the bioenergetics of growth and the possibilities of predicting production.

The present study was concerned with the average metabolic rate and growth of Atlantic salmon under controlled laboratory conditions at various levels of routine activity (low swimming speed). The aim of the present study was to find out a) the accuracy of the method, b) determine average metabolic rate for fed and unfed fish and c) see if any swimming speed were superior to other according to growth and gross growth efficiency. A few preliminary calculations of the bioenergetics of the salmon has also been done.

MATERIALS AND METHODS

The respiration experiments have been conducted in the periods Sept.- Dec. -75 and January - May -76, and the food-growth experiment from 12th January to 23rd March -76. Both studies will continue with new material, and the present study has not yet been finally analysed (proximate analyses and samples of ammonia excretion). It is therefore important to emphasize that this is only a preliminary report.

Experimental tanks.

Five oval 175 litres fibreglass "growth and metabolism" tanks of the type described by Brett et. al. 1971 were used. The technique are principally the same although some differences exists in design and equipment. Unfiltered sea-water of two temperatures (5^o and 20^oC) were mixed and controlled by means of a Stäfa electronically regulated magnetic valve. The valve, originally constructed for use in freshwater, with stands seawater for about a year. It is possible to regulate temperature within $\pm$ 0.2^{o}C if careful and regular control is exerted. One magnetic valve regulates all the five tanks. Flow is adjusted by PVC-regulation valves and water passes into a bubble trap on the lid before running into the tank. The tank is almost selfcleaning due to an overflow system of an outer encasing pipe and a lower outflow pipe in the centre of the tank. Water in the tank is constantly recirculated by a magnetic centrifugal pump of 0.1 HP placed on a platform below the tank. Water leaves the tank through small holes in the wall, passes the pump and returns to the tank in two vertical pipes standing opposite each other inside the tank (position in fig. 1). A jet-current is created when water is forced out through 8 holes (Ø3.2 mm) in each pipe. The strength of the current is regulated by two PVC-ball valves.

The open-circuit growth tank is changed into a closed respiration chamber as described by Brett et. al. (1971). Water samples is tapped off the recirculation system, and an oxygen probe can be mounted in the lid. Originally the probe was installed in a small sensor chamber below the tank, but failed to work, probably due to pressure problems.

Experimental technics.

Oxygen consumption was usually measured during one hour in the morning. In periods of continuous measurements, to cover the daily variations in metabolic rate, one hour close-circuit was followed by four hours open circuit. This was necessary in order to renew the water in the tank. A total coverage of all 24 hours in a day has not yet been carried out.

The lid was closed several days ahead of a test. The only preparation necessary before the start of an experiment was to close the drain valve, fill up the tank and incert rubber corks in the two corner holes of the lid. The fish kept swimming below a black plastic cover on the lid, leaving two crescent shaped light fields at each end of the tank.

In several experiments the temperature was measured manually in the tank before start which disturbed the fish slightly. In later experiments the same measurements were taken in a tank without fish, and in all tanks after the test. Fish was considered in fasting conditions 40 hours after feeding.

Water samples were monitored immediately before closing the drain and at a fixed time in closed conditions. Zero time (start of the respiration test) was defined as the point of time when the two corner holes were plugged.

In the growth experiment, length and weight were measured every two weeks, Fork length and weight were taken to the nearest 0.1 cm and 0.1 g. Fish were not fed within 48 hours before weighing. After a light anaesthetisation (benzocain saturated in 96% alcohol, Egidius 1973) in the tank, fish were further narcotized, measured and kept in flowing sea-water until the tank was thoroughly cleaned. Afterwards the fish were returned to the tanks in a bucket of water. Usually the fish accepted food shortly after measurements.

Source and culturing of fish.

The fish were hatched and cultured at Fisk og Forsøk, Matredal (Institute of Marine Research, Freshwater Laboratory) and transported to the institute in Bergen several months ahead of the experiments

Fish in the respiration series (Aug. - Dec. -75) were two year smolt in -74 and second generation of cultured salmon. Parents were wild salmon caught in seines at Måløy. They have been kept in the experimental tanks since January -75 and were given oxytetracyclin for 10 days in April. Temperature has all the time varied between 8 and 10°C, and at constant salinity 34.8^{o}/oo.

The second series of fish (respiration and growth exp.) originates from the river Suldalslågen and were two years smolt in 1975. They were acclimated for three weeks at about 8°C in the tanks before the experiments started.

Food and Feeding.

All the fish werw fed a Tess high caloric dry pellet feed no. 5. Composition and calorific value of diet are given by the producer.

Components.	Wet (%)	Dry (%)
Water	10	-
Protein	43	47.8
Fat	20.5	22.8
Ash	6.5	7.2
N-free extract	19.0	21.1
fiber	2.2	2.4
Calorific value M.E kcal/g	3.67	4.09

A ration of 3%/day (dry weight of food as a fraction of dry body weight) appeared to be in excess, and the fish were therefore fed to satiation. Food were distributed by hand twice a day, five times a week, once on Saturdays and not on Sundays. Fish were not fed within 48 hours in we weighing days.

Gross growth efficiency is determined on the basis of dry weight. The specific growth rate G is calculated as

$$G = \frac{\log_e W_t - \log_e W_o}{t - t_o} \quad 100$$

where W_t and W_o is weight (wet) at time t and t_o respectively.

In calculations of dry weight of fish the water content has been set to 75%.

Swimming speed.

Swimming velocity in the tanks were determined by use of a small single axis ultrasonic current meter (GYTRE, 1974), Table 1 and measuring of surface velocity with small plastic particles (Table 2). Comparative tests showed that measures of surface velocity were fully satisfactory as a routine procedure, and were performed in connection with all respiration tests. A pulasting current was observed indicating a complex pattern of currents in the tank. However, changes were fast and the average current observed at regular intervals kept remarkably constant. PVC-regulation valves were unfitted for control of velocity.

A change to PVC-ball valves made it possible to keep a stable speed for several weeks in all tanks. A complete wash-out of tubes, pipes and valves was necessarily after some months.

Temperature, salinity and oxygen.

Temperature in the tanks were measured twice a day and average temperature during the growth experiment were $8.25 \pm 0.41^{\circ}C$. In coming-water, measured in the bubble trap, showed $0.4 - 0.5^{\circ}C$ lower temperature.

A heat exchanger has not yet been installed in connection to the pump, and an increase in temperature of $0.3 - 0.6^{\circ}C$ is observed after one hour of respiration tests.

A mixture of seawater from 50 and 150 m depth were used and a variation in salinity of $34.8 \pm 0.2^{\circ}/oo$ was observed.

The oxygen content of the incoming water varied between 91 and 96% saturation, and from 90% (before feeding) to 60% (after feeding) in the tanks.

A drop in saturation from 85 to 65% were usually observed during a respiration test of one hour.

RESULTS

Metabolic rate of starved fish.

The fish responded quite well to the various swimming speeds in the tank and kept steady below the black cover, and between the outlet and tank wall about 10 cm above the bottom. At the lowest velocities (10 cm/sec. and below) restless behaviour and spontaneous movements were observed from time to time. Table 3 and Fig. 2a present the results of several experiments with grouped fish of about 25 cm, tested in one hour. All the measurements were performed in the morning between 09.00 and 11.00 from 44 to 70 hours after the last feeding. The highest obtained average water current was 26 cm/sec. If the relation between maximum sustained activity and length are similar for atlantic salmon and sockeye salmon (Brett and Glass, 1973) a speed of 26 cm are equal to 1/3 of maximal sustained activity of the experimental fish. A straight line was obtained when the logarithm of rate of oxygen consumption (ml. O_2/kg/hr.) was plotted against speed in fish length per second (L/sec). It can be described by the linear regression function $\log_{10} Y = a + bX$ where Y represent oxygen consumption (ml. O_2/kg/t) and X speed (L/sec).

where $\text{Log}_{10} Y = 1.70 + 0.18 X$

In several experiments, temperature were measured through a small hole in the lid just ahead of the test. Although great care were taken of not disturbing the fish, the measured values were 10 - 20 % higher than the undisturbed series. (Fig. 2a, Table 4). The figure also shows single measurements where the fish showed unusually high and restless activity before or during an experiment. These values are not included in the calculations.

Several experiments with other fish sizes and temperatures have been done, but these results have not been fulfilled and will be presented in a later report.

Metabolic rate of feeding fish.

In the morning the metabolic rate of the salmon was usually decreasing. A sudden increase took place during feeding as a result of the increased activity of the fish (Fig. 3). Within two hours the oxygen consumption decreased, for thereafter to increase gradually until a maximum was reached 3 - 6 hours after food intake. The exact time of maximum was difficult to measure due to the strong effect of light on the metabolism of the fish.

The Salmons of average 26.5 cm (183 g) fed 14.3 g. (2.8%) increased their metabolic rate from 65.7 ml. O_2/kg/hr before the meal to a measured maximum value of 127.5 ml. O_2/kg/hr 5 hours after the meal. This level was kept almost constant until light came on (0400). After that oxygen consumption decreased gradually until the level of starved fish, 17 - 24 hours after the meal. Numerous observations indicates that the calorigenic effect (SDA) disappeared within 24 hours after feeding a 3% meal to salmons of 25 cm. under the prevailing conditions. Fish of 350 g that were fed an average meal of 19.2 g (3.2% ration), did not return back to nonfeeding levels after 24 hours (Fig. 4a). Metabolic rate increased according to size of the meal (Fig. 4b) and the duration of the increased metabolic level was in a similar. was extended by an increase in meal size.

Daily pattern of oxygen consumption.

Large diurnal fluctuations in oxygen consumption were found throughout the whole experimental period in both starved and fed fish (Fig. 3). A minimum level of 56.4 ml. O_2/kg/hr in starved fish at a swimming velocity of 15.6 cm/sec. (0.6 L/sec) was found at 13.00 - 15.00 am. Metabolic rate rose sharply when light was switched off at 16.00 am, to a maximum value of 105 ml. O_2/kg/hr one hour later. Metabolic rate kept constant at 98 ml. O_2/kg/hr until light was turned on at 0.400 then oxygen consumption fell gradually to a minimum at 1300 am.

The abrupt change in light conditions had a strong effect on the fish. In day time the fish kept swimming below the black cover at a steady rate, and movements beyond this place was only seen at feeding time. During the dark phase the fish were often swimming restless around in the tank, and sudden violent movements were observed. For starved fish the metabolic rate increased at an average of 27% (observed range 16 - 34%) when light was switched off, and 15% (range 13 - 23) when light was turned on. Fig. 3b presents oxygen consumption measured in an open continuous flow through the tank. Several water samples were taken from tank and inlet and an oxygen electrode, placed in the lid, recorded continuously variations in the oxygen content of the water. The presented values are calculated on basis of both water samples and oxygen electrode recordings. Even though the values are relative, they give a detailed picture of the variations in the tank. Together these figures probably present a realistic picture of the daily variations in matabolic rate of the salmon at the present conditions.

Daily average metabolic rate of starved fish were calculated to 81 ml. O_2/kg/hr. After one meal (2.8% ration) average metabolic rate increased to 102 ml.O_2/kg/hr. For unfed fish the average metabolic rate during night and day were 95 and 59 ml.O_2/kg/hr respectively.

<u>Growth in relation to activity.</u>

Appetite was rather low in all the groups during the whole experimental period. Feeding more than twice a day was not successful, and each feeding period lasted about 20 minutes. Most of the food was eaten immediately, and after a while the salmon learned to pick up excess feed from the bottom. Loss was judged to be quite small except in tank no. 6. Before the growth experiment started, feed was almost neglected in this tank, so no. 6 are not comparable with the others.

As a result of the reduced food intake the recorded growth was small (Table 5) although minor differences were observed. An average swimming velocity of 15 cm/sec. (0.6 L/sec.) in tank no. 3 gave the best growth rate (0.22%) and highest gross growth efficiency (13.8%) during the experimental period of 71 days. The daily intake of food based on the whole period was calculated to 1.6% although actual figures per day could be 3%. Altogether, the fish were only fed in 51 of a total of 71 days. At average velocities of 23.4 cm/sec. (0.94 L/sec.) and 10.9 cm/sec. (0.44 L/sec.) growth rate and gross growth efficiency were equal. At a swimming speed of 6.1 cm/sec. (0.24 L/sec.) growth rate was negligible with a daily intake of feed of 1.1%. At this velocity a great portion of a pellets sunk down to the bottom before they were eaten, and loss is therefore expected to be greater here than in the other tanks.

DISCUSSION

Metabolic rate - unfed fish.

An important question in the present study has been to know the accuracy of the technique. A direct comparison with other studies, using different methods and at various environmental conditions are rather difficult. Such a comparison should if possible deal with Atlantic Salmon, but few informations are available. Winberg (1956) refers to various Russian studies, Nikiforov (1953) and Privolnev (1953) on young salmon of 0.17 - 20 g. By using Privolnevs data and Winbergs table for adjusting metabolism to temperature, a metabolic rate of 71 ml. O_2/kg/hr. for salmon of 20 g was attained, which probably represented a basal rate value. Lindroth's (1942) data, using the same method, gave a metabolic rate of 55 ml. O_2/kg/hr for fish of the same size (3 years old) and 49 ml. O_2/kg/hr for 25 g salmon (4 years old).

For parr of 40 g Lindroth (1942) found an oxygen consumption of 80 ml. O_2/kg/hr at 10°C, in comparison to 61 ml. O_2/kg/hr (Power 1959) for an Ungave parr of equivalent weight and temperature (basal consumption) measured in the field. Smolt showed a reduced metabolic rate (Power, 1959), but this reduction could just as well be a result of weight difference. None of the above mentioned studies are comparable to the present results.

Few species have been studied more in detail according to metabolic rate than sockeye salmon Oncorhynchus nerka (Brett 1964, 1965, 1967, Brett and Glass 1973, Brett and Zala 1975). A direct comparison to this species is possible by the use of isopleths of metabolic rate and critical swimming speed (Brett and Glass, 1973).

Five unfed Atlantic salmon (average 34 cm and 444 g) at a swimming speed of 23.2 cm/sec. and 8.6°C (Fig. 4a) had an average metabolic rate of 59.9 ± 3.3 ml. O_2/kg/hr. (six experiments). Comparative data for sockeye salmon (single fish in freshwater and with tunnel respirometer technique) was 54 - 63 ml. O_2/kg/hr at 8° and 9°C respectively (from isopeth diagrams). A second series of experiments with Atlantic salmon (25 cm, 159 g) at 26.1 cm/sec and 8.5°C (Table 3) had an average metabolic rate of 77.8 ± 6.8 ml. O_2/kg/hr. For sockeye salmon the comparative value was 77 ml. O_2/kg/hr.

According to Brett and Glass (1973) the active metabolic rate of sockeye salmon exceeds that determined for other salmonida by 30 - 40%. If this also applies to Atlantic salmon, the equation for rate of oxygen consumption and swimming speed Log Y = 1.70 + 0.18 X cannot be used, because b (0.18) is to low.

At routine levels of about 1 L/sec Atlantic salmon and sockeye salmon seems to be close to each other. At lower levels the present average data for Atlantic salmon are too high. This is clear from the data in Table 3 where single measured values have been 20% below the average. A comparison of Table 3 and 4 also show that even minor manipulations affect the fish in a considerable way.

Metabolic rate - fed fish.

The increase in metabolic rate after food intake (SDA) has long been known (Kleiber 1961) and is thought due mainly to deamination of proteins (Warren and Davis, 1967). Harper (1971) quoted by Beamish (1974) has stated that the heat production in homeothermic animals is equivalent to the caloric content of the diet (30% of the protein, 13% of lipid and 5% for carbohydrate), and as its maximum 0.3 x ration. (Weatherley 1976). The magnitude of SDA is essentially linearly related to ration size (Beamish, 1974) a fact the few present data also showed (Fig. 4b).

The experiments further indicated that elevated oxygen consumption lasted for longer periods of time when the fish grew bigger also in accordance with Beamish is (1974) studies. The elevation in metabolic rate, that Beamish (1974) called the apperent SDA were calculated to 11% of the metabolizable energy of a 2.8% ration (Fig. 3). In comparison, Muir and Niimi (1972) found that elevevated oxygen consumption for the euryhaline 44 g fish aholehole (Kuhlia Sandvicenses) after 2.3% and 4.5% rations were equivalent to 16% of the energy of the ration. Beamish (1974) determined an overall mean apperent SDA of 14.19 ± 4.19% of the energy ingested for largemouth bass Micropterus Salmonides.

Diurnal fluctuations.

Diurnal fluctuations in the metabolism of fishes have been shown by a number of authors (Power 1959, Brett and Zala 1975) and Winberg (1956) who has in his extensive review work critically examined a number of the older studies. According to Winberg quite conflicting results appeared; in some studies considerable differences were observed, while other studies found no variations. Winberg (1956) states that "there is not and cannot be one single type of diurnal pattern of metabolism common to all fish". He says further: "with change in the rythm of diurnal change of light and other stimuli, the type of diurnal fluctuation in metabolism changes accordingly". This statement is in full agreement with the above findings. When light was changed to 24 hours daylight, no diurnal fluctuation was observed. When the light period was changed, the metabolic rate changed in the same way.

Abrupt changes in light conditions appeared to be the stimulating factor of greatest importance in the experiments. These changes in particular affected the activity of the salmons. This may be attributed to a natural cycle in feeding activity with maximum in the evening as shown by Hoar (1942). However, in the present experiment feeding were only performed during day time. Power (1959) recorded maximum oxygen consumption at midnight and midday for Atlantic salmon smolts measured under natural conditions, with temperature variations that almost followed the fluctuations in metabolic rate. Brett and Zala (1975) recorded a diurnal pulse for sockeye salmon (29 g) for both starved and fed individuals. They found minimum values after midnight for both groups.

It is uncertain if the observed diurnal variation in metabolic rate is a natural phenomena or only an artificial reaction found at the prevailing laboratory conditions. New experiments should make use of a gradual and more natural change in light during the experimental period.

Growth and conversion efficiency

As seen from Table 5, ration and growth was quite small during the whole experimental period. Several factors are probably responsible for the reduced appetite and growth, and one is supposed to be the size of fish in relation to the volume of the tank. The salmon was probably too large for growth experiments. According to Burrows (1972) the space factor is assumed to affect growth in some species of salmonids. Whitworth (1968) pointed out the possible interaction between size of fish and test chamber and low growth in brook trout. The oxygen content also varied considerably during the experimental period, a factor that might have reduced appetite and hence growth rate. Doudoroff and Shumway (1970) claims that large diurnal fluctuations in oxygen level can impair the appetite and growth even at reduced rations.

Salmon are by nature an active fish and it was assumed that both appetite and growth would increase at an optimal swimming speed. The present results support such an assumption although further experiments are needed. Ware (1975), in a reanalyse of an earlier study of young bleak by Ivelev (1960) found maximum values for growth rate and the growth efficiency at different swimming speeds.

Fig. 5 indicate a daily maintenance ration close to 1.3% of the ration for salmon at an average swimming speed of 23.4. Although the data are scarce, it is quite evident that less food is needed as swimming velocity goes down. Brett <u>et. al.</u> (1969) determined a maintenance ration of 1% at 10°C for sockeye salmon of 5 - 20 g.

Bioenergertics

As a result of the growth and metabolic experiments a preliminary examination of the bioenergetics can be done. Winberg's (1956) balanced equation can be within

$$0.80 \cdot Q_c = Q_g + Q_r$$

where $0.80 \cdot Q_c$ = the physiologically useful ration, Q_r = energy of metabolism (total) and Q_g = energy of weight increase. Winberg estimated that the physiologically useful relation comprised 80% of the total energy of the ration.

In this case $0.80 \cdot Q_c$ can be replaced by the metabolizable part of the ration or from page (4) 4.09 kcal/g dry feed. (using Phillips' (1969) physiological factors, except for carbohydrate, kcal per gram for protein= 3.9, fat= 8.0 and carbohydrate= 1.9.)

Energy for growth was estimated as the mean increase in body weight (gram dry weight/day) multiplied by the energy content of the body which was estimated to 5.6 kcal/g (Winberg, 1971) (proximate analysis are in preparation).

For tank nr. 2.

Food	8.13 x 4.09	= 33.35 kcal
Growth	0.71 x 5.6	= 3.98 kcal
metabolism		= 29.27 kcal

This corresponds to a metabolic rate of 125.8 ml. O_2/kg/hr if all the given food was eaten and a caloric equivalent of 4.8 kcal/l O_2 is used.

However some loss of food will always take place. If 90 % of the food was consumed the daily average metabolic rate would be 111.6 ml. O_2/kg/hr.

A comparison of the estimated value from the balanced equation with the measured average value from the respiration experiments are presented below.

	no. food loss		10% food loss
Estimated value	125.8 ml. O_2/kg/hr	-	111.6 ml. O_2/kg/hr
measured	102,- ml. O_2/kg/hr	-	102. ml. O_2/kg/hr
Difference	23.3 ml. O_2/kg/hr		9.6 ml. O_2/kg/hr
Difference in % of measured value	+ 23.3%	+	9.4%.

The maintenance ration was calculated, with the use of the measured value 102 ml. O_2/kg/hr.

$$\text{Daily requirement} \quad \frac{102 \quad 2.019 \quad 4.8}{1000} = 23.72 \text{ kcal/day}$$

where 2.019 represent the total fish weight in kg.

$$\text{The maintenance ration } R_m = \frac{23.72}{4.09} = 5.8 \text{ g/day}$$

or 1.35% pr. day a value in agreement with Fig. 5a.

These preliminary calculations indicate that the measured oxygen consumption are accordance with the estimated values.

ABSTRACT

Studies on the respiratory metabolism and growth of young Atlantic salmon (132 - 475 g) in seawater at 8.5^{o}C have been conducted. The experiments were performed in the laboratory using five "growth metabolism" tanks. The average metabolic rate at swimming speeds from 5 - 25 cm/sec. were determined and compared with similar data for sockeye salmon. Both fed and starved salmons were examined and a daily average metabolic rate of 81 ml. O_2/kg/hr for starved fish (173 g) and 102 ml. O_2/kg/hr for fed fish were found. Both groups displayed a higher oxygen consumption during the night than at daytime due to increased activity. Growth and gross growth efficiency varied according to activity and a velocity of 15 cm/sec. (0.6 L/sec) gave the best results. Preliminary bioenergetic calculations indicated that the measured metabolic rate were in agreement with the calculated value from food-growth experiments.

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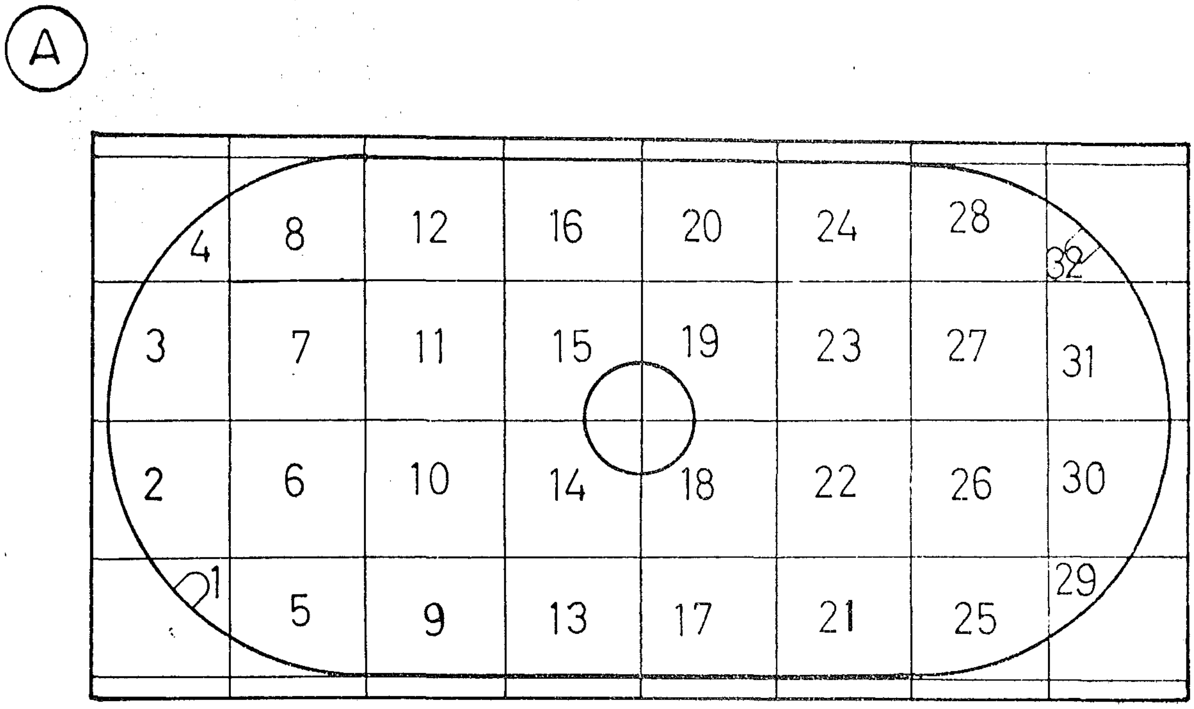

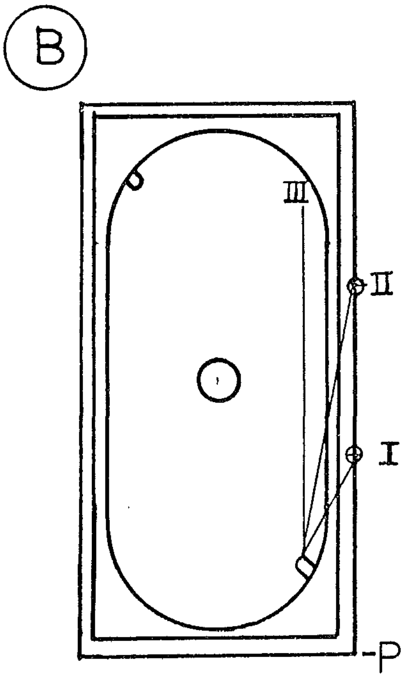

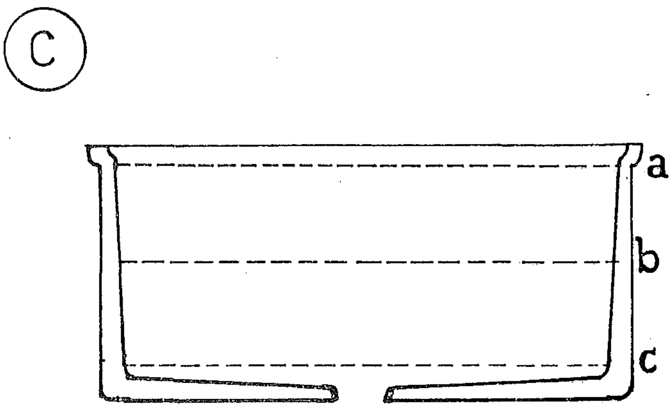

Fig. 1 Current measurement in the "growth-metabolism" tank.
A. Horisontal measuring positions in the tank.
B. Direction of the horisontal water "fan" in recirculation.
C. Vertical measuring position of the tank.

I. 30 cm from end of the tank - P.
II. 60 cm from end of the tank - P.
III. Parellel to the long-side.

a) - surface, b) - $\frac{1}{2}$ depth. c) - near bottom.

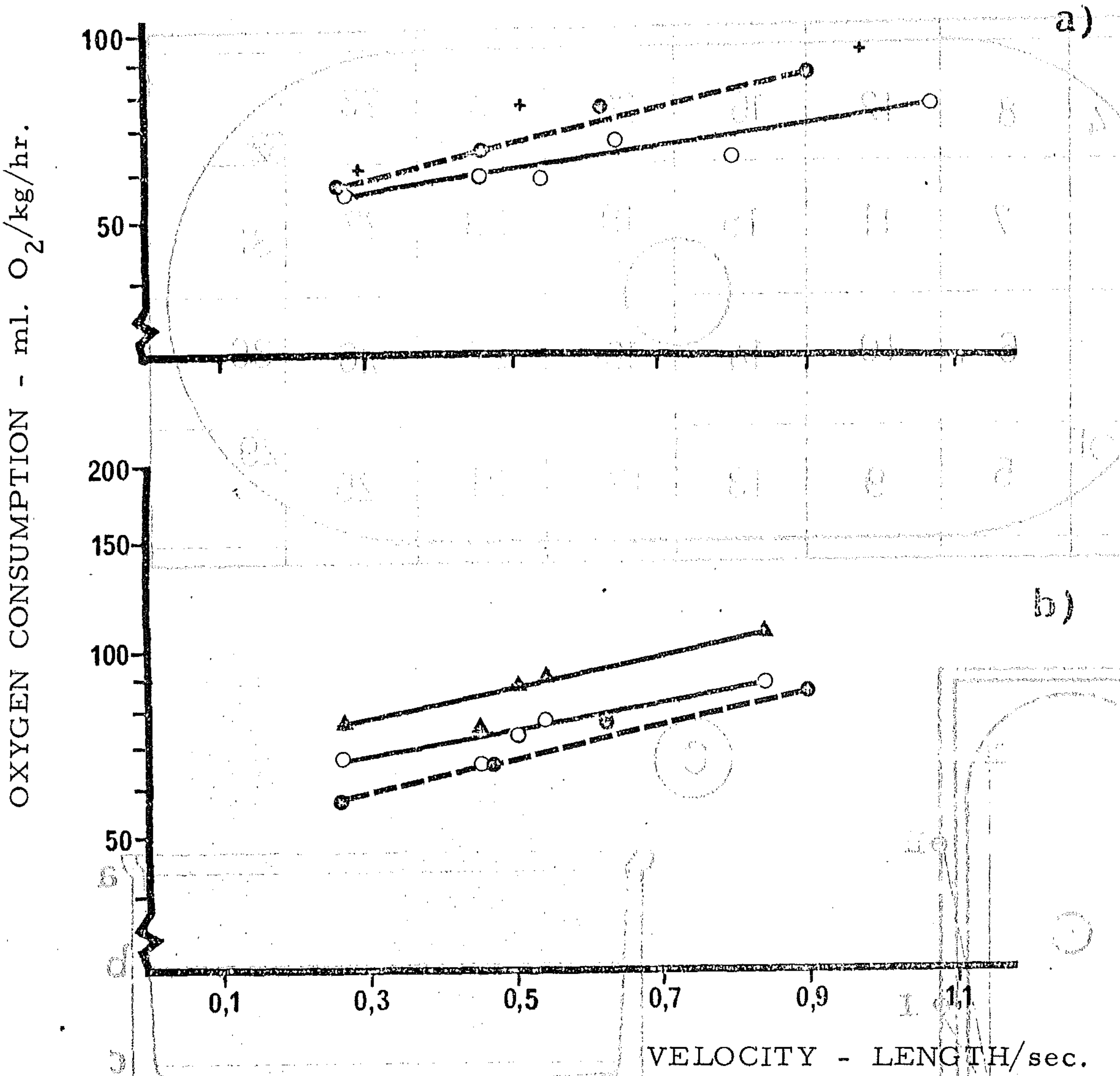

Fig. 2a. Oxygen consumption and activity of groups of 10 - 14 Atlantic slamons at 8.5 + 0.5 °C, 44 - 70 hr. after feeding. o——o undisturbed fish (average 23.8 - 26.8 cm, 132.5 - 186 g). ●---● minor disturbances (average 23.2 - 24.8 cm, 134 - 153 g). + restless behaviour (average 24.3 - 25.5 cm, 137.5 - 159.5 g). (for further informations see table 3-4).

Fig. 2b. Oxygen consumption and activity of groups of 13 - 14 Atlantic salmon (average 23.8 - 24.8 cm, 132.6 - 153 g) at 8.5 + 0.5 °C after feeding a 10.5 g dry feed (2% ration). ▲——▲ 6 hr. after feeding. o——o 22 hr. after feeding. ●---● 44 - 48 hr. after feeding. (average of 3 exp.) Temperature was measured manually in all tanks ahead of the experiments (minor disturbances).

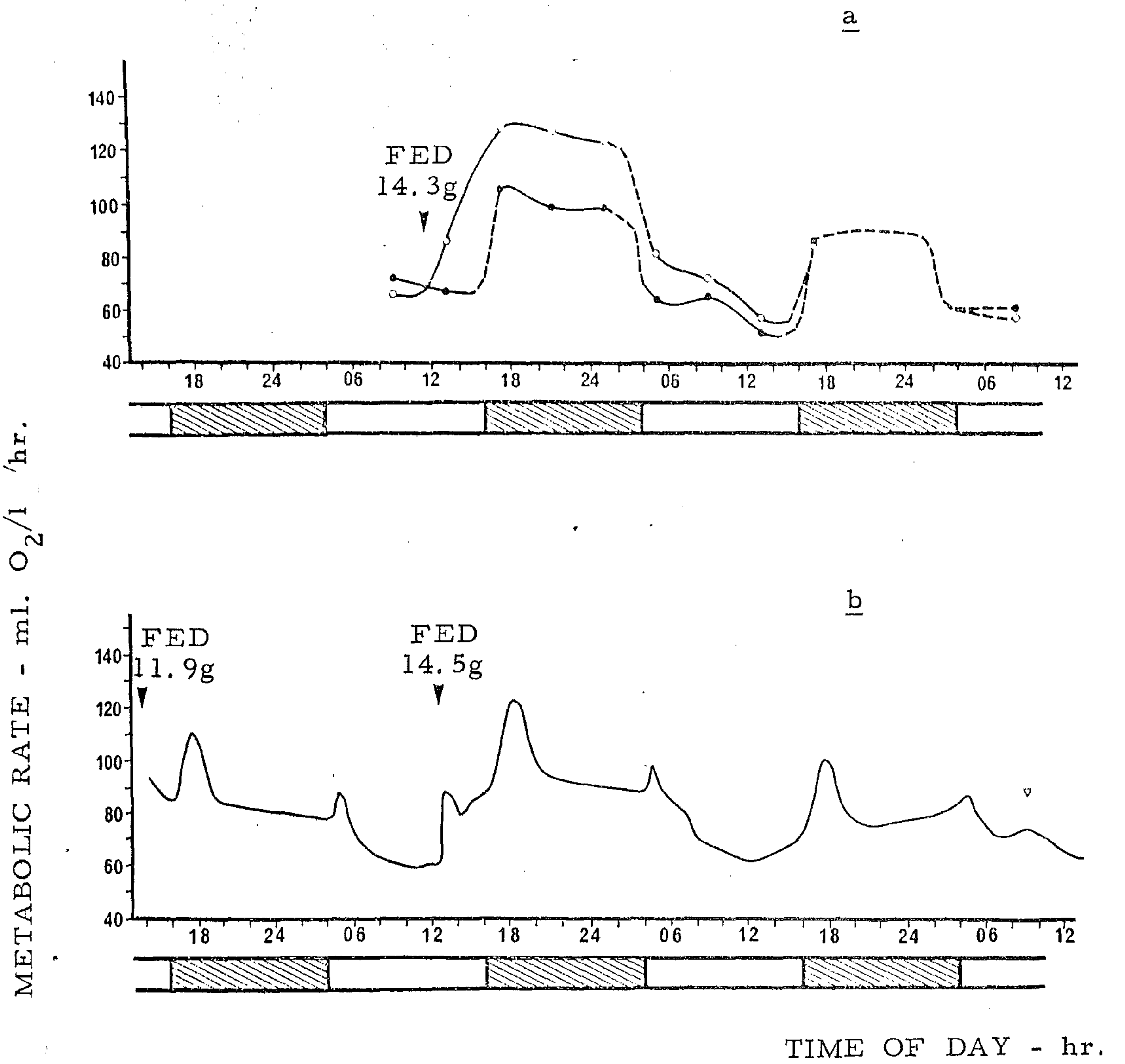

Fig.3 a) Diurnal variation in metabolic rate of fed and starved Atlantic salmon at 8.7 + 0.4°C. Groups of 10 salmons have been tested together in closed tanks with intervals of 4 hr. between each experiment. o—o Fed 14.3 g (2.8% ration) average size 26.6 cm, 182.6 g, swimming velocity 20.9 cm/sec. (0.79 L/sec.). •—• starved 5 days, average size 25.8 cm, 172.8 g. Photoperiod 12 hr. dark (1600 - 0400).

3 b) Diurnal variation in metabolic rate of 14 Atlantic salmons (average: 25.1 cm, 151.4 g) at 8.3°C with a swimming velocity of 26 cm/sec. (1.04 L/sec.). Respiration was measured in an open tank. (continuous flow) by means of water samples and YSI-57 oxygen electrode. Δ Respiration measured in a closed tank.

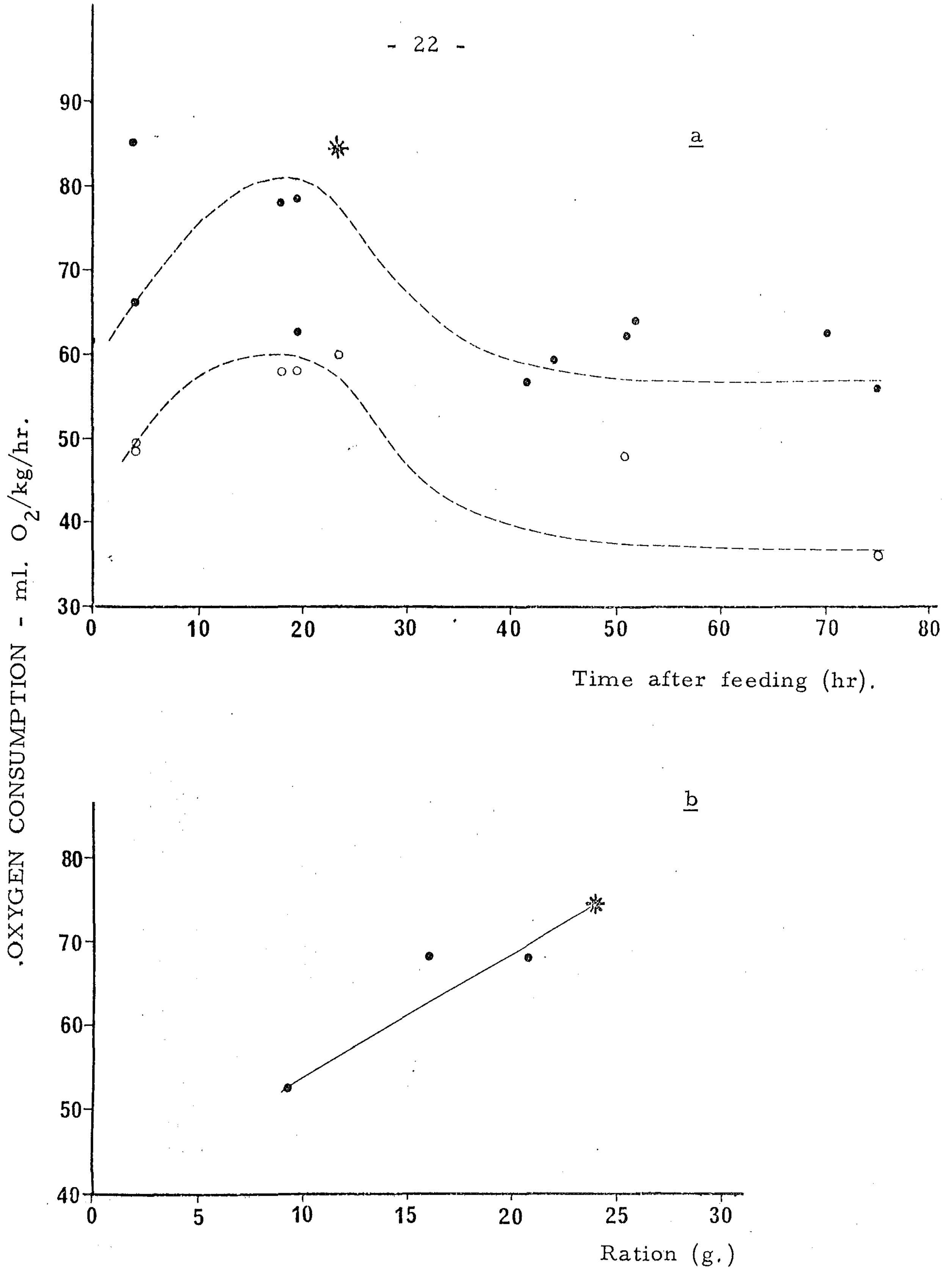

Fig.4a. Elevation in oxygen consumption of Atlantic salmon (average 33.8 - 35.3 cm, 422 - 475 g) after feeding, measured in a closed tank. (15 different experiments). Average temperature 8.2 - 9.7°C. Swimming velocity 20.6 - 25.8 cm/sec. Average consumption of feed the last 30 hr.: 19.2 g. (range: 9.2 - 29.1 g). * Experimental temperature 10.5 ± 0.3°C.

Fig.4b. Oxygen consumption of Atlantic salmon in relation to ration size 18 - 24 hr. after intake of food. (Conditions similar to a).

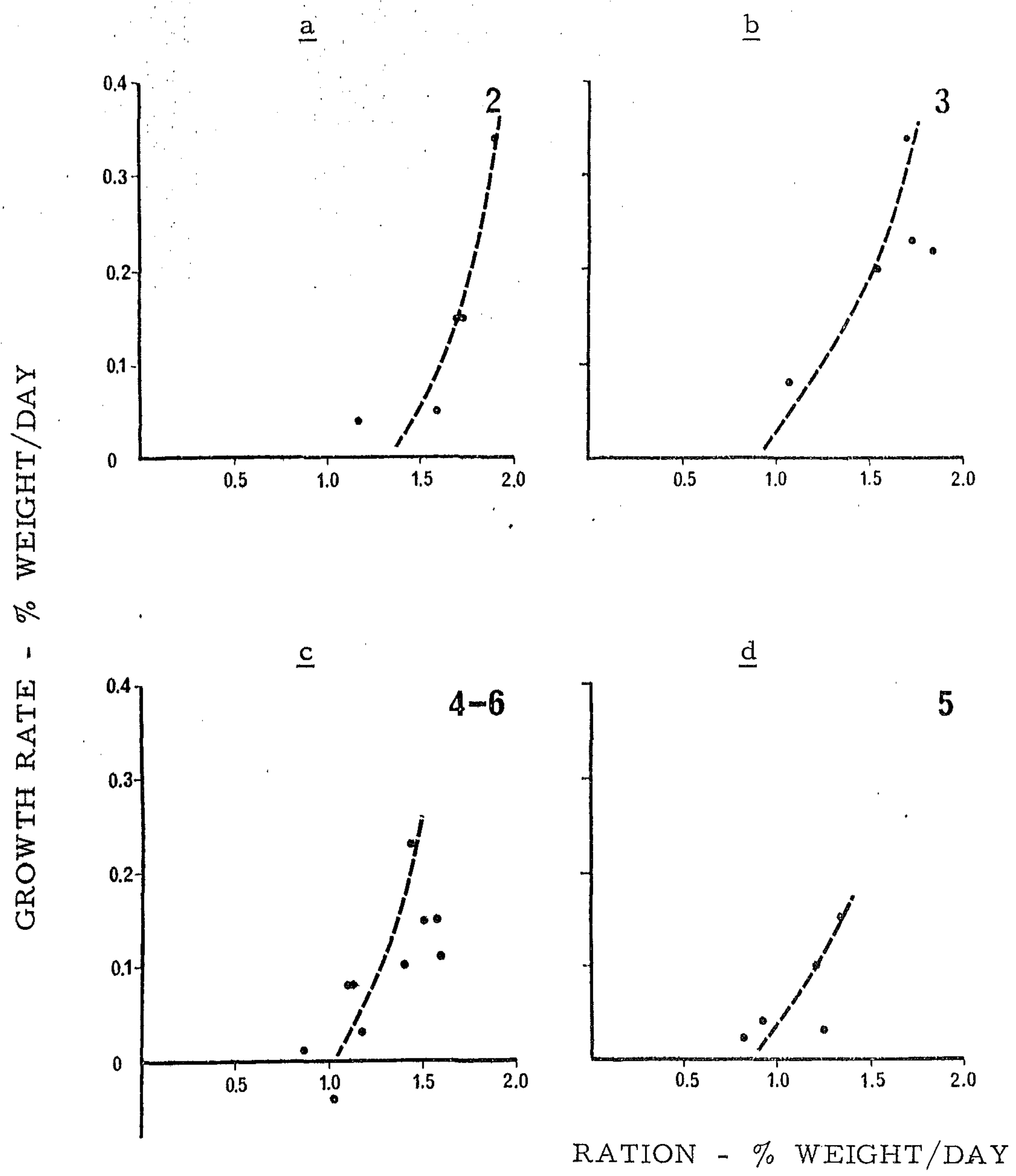

Fig.5 Relation of growth rate of Atlantic salmon to ration at four swimming velocities. a) tank 2: 23.4 cm/sec. b) tank 3: 15.0 cm/sec. c) tank 4 and 6: 10.8 and 11.3 cm/sec. d) tank 5: 6.1 cm/sec. Average temperatur 8.5 ± 0.5 °C. Salinity 34.8%. Experimental period 71 days (Jan. - March -76). Further informations in table.

Table 1. Current velocity in the experimental tank measured with small single axis ultrasonic current meter. Each figure represent average values of 20 spots (outer circle) and of 12 spots (inner circle) obtained during 1 - 1½ minutes measurement. I, II and III refers to direction of the horisontal water "fan" to the water in recirculation. (See Fig.).

Current velocity	OUTER CIRCLE						INNER CIRCLE					
	I (30)		II (60)		III (P)		I (30)		II (60)		III (P)	
	x̄	S.D	x̄	S.D	x̄	S.D	x̄	S.D	x̄	S.D	x̄	S.D
Current												
-in surface	27.8	6.0	30.3	5.9	25.2	6.5	18.3	4.5	21.8	5.9	20.3	1.8
-in the middle	29.2	5.0	31.2	4.2	26.9	3.3	15.1	4.3	20.3	3.7	22.9	2.3
-near bottom	27.7	6.9	29.6	4.2	26.9	4.4	15.7	4.2	23.0	4.8	24.7	3.2
Average current	28.2	6.0	30.4	4.8	26.3	4.7	16.4	4.3	21.7	4.8	22.6	2.4

Table 2. Current velocity in five experimental tanks. (March 9th 1976.). Surface current was measured lengthways of the tanks by means of small plastic particles, drifting a distance of 50 cm. (On each side of the tanks). Standard deviation is given together with velocity in cm/sec.

Tank no.	SIDE A				SIDE B				BOTH SIDES			
	n	$\bar{x}$	S.D	average velocity cm/sec.	n	$\bar{x}$	S.D	average velocity cm/sec.	n	$\bar{x}$	S.D	average velocity cm/sec.
2	16	1.91	0.27	26.2	16	2.07	0.36	24.2	23	1.99	0.32	25.1
3	16	3.12	0.59	16.0	17	3.18	0.70	15.7	33	3.15	0.64	15.9
6	14	3.91	0.63	12.8	14	3.70	0.60	13.5	28	3.80	0.62	13.2
4	14	4.25	0.62	11.8	15	5.03	1.10	9.9	29	4.65	0.97	10.8
5	16	7.76	1.66	6.4	16	6.99	2.40	7.2	32	7.4	2.07	6.8

Table 3. Oxygen consumption and swimming speed of groups of 10 - 14 Atlantic salmons at 8.5 $\pm$ 0.5^{o}C in the period Feb. - May -76. Undisturbed conditions. Range average sizes: 23.8 - 26.8 cm, 132.5 - 186.4 g. Range O_2-saturation: 85 - 65%, salinity 34.8^{o}/oo. All tests 44 - 70 hr. after feeding.

Average swimming speed			Number		Oxygen Consumption				
cm/S	range	L/S	experiments	fish in each tank	m/O_2/kg/hr	range	S.D	S.E	mg O_2/kg/hr
6.6	5.8 - 6.8	0.27	4	14	55	53.2 - 58.5	2.4	1.2	78.6
10.8	10.3 - 11.4	0.45	6	13 - 14	59.3	52.7 - 63.9	4.6	1.9	84.7
12.9	12.6 - 13.2	0.54	2	14	58.9	58.1 - 59.6	-	-	84.1
16.1	15.2 - 17.1	0.64	10	10 - 14	68.7	54.8 - 77.6	6.9	2.2	98.1
21.3	20.9 - 2.2	0.80	3	10 - 14	64.9	57 - 72	7.6	4.4	92.7
26.1	24.7 - 28	1.07	7	14	77.8	67.3 - 87.4	6.8	2.6	111.1

Table 4. Oxygen consumption and swimming speed of groups of 13 - 14 Atlantic salmons at $8.7 \pm 0.4^{o}C$. Temperature was measured in the tank before the experiment and fish were slightly disturbed. Average size: 23.2 - 24.8 cm, 134 - 153 g (januar-76). range O_2-saturation: 86 - 65%, salinity: $34.8^{o}/oo$. All tests 45 - 48 after feeding.

Average swimming speed			Number		Oxygen Consumption				
cm/S	range	L/S	experiments	fish in each tank	$m/O_2/kg/hr$	range	S.D	S.E	mg O_2/kg/hr
5.5	4.6 - 6.1	0.26	3	14	57.4	53.4 - 56.4	4.6	2.7	82
10.8	10.1 - 12.1	0.46	4	13 - 14	65.3	61.1 - 68	3.0	1.1	93.5
14.7	13.5 - 15.7	0.62	3	14	77.5	70.5 - 82.2	6.2	3.6	110.7
21.4	20.2 - 22.5	0.90	3	14	87.6	85.6 - 89.3	1.9	1.1	125.1

Table 5. The effect of activity on length, weight, growth rate, ration size, conversion factor and gross growth efficiency of Atlantic salmon in an experimental period of 71 days.

Time (days)	Swimming velocity (cm/sec.)	No. fish (n)	Initial wet. wt. (g)	Terminal wet. wt. (g)	Initial length (cm)	Terminal length (cm)	Growth rate (%/day)	Ration (%/day)	Conversion factor	Gross growth efficiency (%)
TANK 2										
0-14	21.5 - 22.4	14	137.0	137.9	23.6	23.9	0.05	1.59	9.2	3.0
14-29	22.4 - 17.7	14	137.9	149.9	23.9	24.1	0.15	1.73	3.3	8.3
29.43	23.6 - 26.5	14	140.9	141.6	24.1	24.3	0.04	1.17	9.0	3.1
43-58	26.5 - 25.1	14	141.6	144.8	24.3	24.7	0.15	1.70	3.2	8.8
58-71	24.0	14	144.8	151.4	24.7	25.1	0.34	2.00	1.6	17.0
Average 0-71	23.4						0.14	1.6	3.2	8.8
TANK 3										
0-14	15.7 - 14.8	14	142.9	148.0	23.8	24.4	0.25	1.73	1.9	14.4
14-29	14.8 - 11.3	14	148.0	153.0	24.4	24.8	0.22	1.84	2.3	12.2
29-43	16.6 - 17.1	14	153.0	154.8	24.8	25.1	0.08	1.07	3.6	7.7
43-58	17.1 - 15.9	14	154.8	159.5	25.1	25.5	0.20	1.54	2.1	13.0
58-71	13.0	14	159.5	166.7	25.5	26.0	0.34	1.71	1.4	19.6
Average 0-71	15.0						0.22	1.6	2.0	13.8
TANK 4										
0-14	11.4 - 10.2	14	138.4	140.6	23.5	24.0	0.11	1.59	4.0	6.9
14-29	11.2 - 9.3	14	140.6	143.9	24.0	24.2	0.15	1.59	2.9	9.7
29-43	10.6 - 11.4	14	143.9	145.5	24.2	24.5	0.08	1.11	3.8	7.3
43-58	11.4 - 10.8	14	145.5	147.8	24.5	24.7	0.10	1.40	3.7	7.4
58-71	10.8	14	147.8	150.7	24.7	24.9	0.15	1.52	2.5	9.9
Average 0-71	10.9						0.12	1.4	3.3	8.5

Table 5. Contd.

Time (days)	Swimming velocity (cm/sec.)	No. fish (n)	Initial wet. wt. (g)	Terminal wet. wt. (g)	Initial length (cm)	Terminal length (cm)	Growth rate (%/day)	Ration (%/day)	Conversion factor	Gross growth efficiency (%)
TANK 5										
0-14	6.3 - 5.7	14	133.6	134.2	23.3	23.6	0.03	1.25	11.4	2.4
14-29	5.7 - 2.7	14	134.2	136.2	23.6	23.9	0.10	1.21	3.4	8.2
29-43	5.8 - 6.8	14	136.2	136.6	23.9	24.1	0.02	0.81	9.2	3.0
43-58	6.8 - 6.8	14	136.6	137.5	24.1	24.3	0.04	0.91	5.7	4.9
58-71	7.1	14	137.5	140.2	24.3	24.5	0.15	1.35	2.5	11.2
Average 0-71	6.1						0.07	1.1	4.5	6.3
TANK 6										
0-14	10.1 - 10.9	13	132.7	131.9	23.2	23.4	-0.04	1.02	-	-
14-29	10.9 - 10.3	13	131.9	132.6	23.4	23.8	0.03	1.17	9.8	
29-43	9.8 - 10.3	13	132.6	132.7	23.8	23.8	0.01	0.86	22	1.3
43-58	10.3 - 13.2	13	132.7	134.3	23.8	24.0	0.08	1.12	3.8	7.4
58-71	12.6	13	134.3	138.3	24.0	24.2	0.23	1.44	1.8	15.7
Average 0-71	11.3						0.06	1.1	5.2	5.4