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GROWTH OF RAINBOW TROUT (*Salmo gairdneri* RICHARDSON) IN A PILOT COMMERCIAL REARING SYSTEM

by

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ABSTRACT

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A pilot fish rearing system, designed to produce a minimum of 1 280 commercial size (200 to 250 g) rainbow trout every six weeks was described. The system utilizes eight modular recirculating rearing units. Heated water (13°C) for the rearing system was provided by a flat-plate solar collector array. The pilot system operated as an analog for a low grade waste heat system. The growth rates, food conversion efficiency and variation in growth rates of two strains of rainbow trout were assessed. Weight frequency distributions for the fish populations reared in the system were studied.

Approximately 35% of the growth trial populations, of both trout strains tested, reached harvest size by the end of the trials. A significant difference between the final mean weights of the two strains was observed. Marked week to week variations in growth rate were observed, suggesting that all variables affecting growth were not controlled. Population weight frequency distributions were stable over time with no behavioural interactions apparent. Log_e (specific growth rate) versus $\log_e$ (mean fish weight) regression lines were used to evaluate variations in fish growth with changing fish size. No inherent differences in growth rates were found among members of the same trial population, after differences in initial starting weight were adjusted for.

Key words: aquaculture; trout, rainbow; growth; waste heat; solar radiation.

RESUME

Papst, M.H., and G.E. Hopky. 1982. Growth of rainbow trout (Salmo gairdneri Richardson) in a pilot commercial rearing system. Can. Tech. Rep. Fish Aquat. Sci. 1112: iv + 18 p.

Description d'un système pilote de pisciculture visant à produire au moins 1 280 truites arc-en-ciel de taille commerciale (de 200 à 250 grammes) toutes les six semaines. Le système utilise huit unités modulaires de pisciculture à recirculation. L'eau chaude (13°C) servant au système provenait d'un dispositif comprenant un capteur solaire à faible perte de chaleur. On a évalué les taux de croissance de deux variétés de truites arc-en-ciel. On a étudié la répartition des fréquences de poids pour les populations de poissons cultivés dans ce système.

Environ 35% de la population des deux variétés de truites qui ont fait l'objet de l'expérience de croissance, ont atteint la taille d'exploitation commerciale à la fin des essais. On a observé une grande différence de poids moyen à la fin des essais entre les deux variétés. On a également observé d'importantes variations du taux de croissance semaine par semaine, ce qui semble indiquer que toutes les variables influant sur la croissance n'étaient pas contrôlées. La répartition des fréquences de poids dans la population était stable pendant une longue période et aucune interaction de comportement n'était apparente. On s'est servi de lignes de régression $\log_e$ (taux de croissance spécifique) par rapport à $\log_e$ (poids moyen du poisson) pour évaluer les variations de croissance par rapport à la taille changeante des poissons. On n'a trouvé aucune différence inhérente des taux de croissance parmi les membres du groupe qui l'objet des essais, après avoir fait les rectifications nécessaires dues aux différences de poids au départ.

Mots-clés: aquaculture; truite, arc-en-ciel; croissance; perte de chaleur; rayonnement solaire.

INTRODUCTION

Commercial trout farming in Canada has not been competitive in either the domestic or international markets for frozen trout (MacCrimmon 1974; Blum 1979; Robbins et al. 1980). Annual imports to Canada total nearly four million dollars worth of 'fair' quality trout, primarily from the United States and Japan (Robbins et al. 1980). One principal reason for the failure of Canadian producers to become competitive is the slow growth rates experienced when trout are reared in the cold waters (6 to 10°C) prevalent in Canada during the winter months, or year round if the culture facility uses groundwater.

Increased production could be achieved if commercial producers utilized low grade waste heat sources, such as gas line compressor stations and thermal or nuclear power plants, to raise the rearing water temperature closer to the optimum for trout culture (15°C). However, historically this approach has not been very successful largely because operation of the fish rearing facility was of secondary importance, and consequently operating conditions were determined at the convenience of the primary user (e.g. Gay et al. 1976; Tennessee Valley Authority 1977). In particular, the facility producing waste heat may not have been located near a source of high quality water which is the main prerequisite for the single pass raceway culture systems traditionally used in Canada. Operational problems also arose because the primary user determined the operational temperature and shut down schedules, which were most often not optimal for fish culture.

Therefore, a potentially successful trout production system which utilizes waste heat should have the capacity to operate efficiently using an intermittent heat source while incorporating a high degree of water conservation and stability of optimal water temperatures. Ayles et al. (1980) described a solar heated hatchery that successfully incorporated these operational criteria. Solar units are generally analogous to waste heat systems because the heating is intermittent and of comparable magnitude. The purpose of this report was to describe results from three growth trials of rainbow trout reared in the solar heated hatchery (Ayles et al. 1980).

The primary objectives of the first two growth trials were to compare the growth rates, conversion efficiencies, mortalities and percent marketability of two different trout strains, with each strain (one per growth trial) grown from an initially unimodal weight distribution. Canadian producers have traditionally not explored the potential of genetic selection as a means of improving production. Different harvesting strategies were also tested. In the third growth trial some characteristics of population weight distributions and variation in body weight were studied by rearing of a population with an initially bimodal weight distribution.

In addition to the competitive disadvantage Canadian producers experience because of low rearing temperatures, recent studies have also indicated that their economic success is further limited by a failure to produce, on a continuous production basis, a product of consistent size uniformity (Blum 1979; Robbins et al. 1980). Consequently, in the present study growth trials were conducted in a pilot commercial system utilizing a continuous production strategy.

METHODS

DESCRIPTION OF REARING SYSTEM

Growth trials were conducted at the Rockwood Experimental Fish Hatchery of the Freshwater Institute, Department of Fisheries and Oceans. The hatchery is located approximately 65 km north of Winnipeg (50°N, 97°W) on the Canadian prairies. Production trials were done in the solar annex facility as described in detail by Ayles et al. (1980).

Eight modular fish rearing units were employed in a continuous production strategy (Fig. 1) designed to produce a minimum of 1 280 commercial size (200 to 250 g) rainbow trout every six weeks. The production strategy employed four size groups or 'levels' of fish, with fish being transferred to the next level every six weeks. At the beginning of a period all 1 280 fish were in one tank; after 24 weeks they occupied three tanks.

Fish rearing units consisted of 1 500 L tanks, each mounted over an 1 100 L filter unit containing 0.73 m of granite filter media (Fig. 2). During operation of the pilot production system filters were backwashed every 14 days. Flow rates in the rearing units were 54 L m^{-1}, with 5.4 L m^{-1} or 10% of the total flow being make up, while the other 90% was recycled through the filter. Rearing tank water temperature was maintained at 13 ± 1°C. To ensure adequate supplies of heated water during the trials, make up water (5.4 L m^{-1}) was provided for 12 to 22 hours per day depending on availability of solar heated water. During the rest of the day the rearing units operated on 100% recirculation.

Rearing tanks were sampled daily for dissolved oxygen using a YSI model 54 temperature - oxygen meter and periodic samples for water quality were taken. All water quality values were similar to those reported by Ayles et al. (1980), with the exception of dissolved oxygen. A modification of the return spray bar maintained oxygen concentrations at 70 to 85% saturation compared to 50% reported by Ayles et al. (1980) for tanks with loading rates greater than 40 kg m^{-3}. A detailed report of water quality variables was not part of this study.

Photoperiod was set at 12 hours of light and 12 hours of darkness during the growth trials.

GROWTH SAMPLING

Fish growth was monitored on a weekly basis, with mean fish weight in each tank determined by hand counting four lots of 50 fish each from a tank, and weighing each lot separately. Throughout the experiment fish were fed at approximately 150% of the rations recommended in published tables (Bardach et al. 1972); an amount well in excess of maintenance requirements. Fish were hand fed three times per day with the amount corrected for changes in fish size as determined by the weekly weight census. Mortalities were collected and recorded daily, for each tank.

FISH STOCKS TESTED

Mt. Lassen - Stock from Hildebrand's Mt. Lassen trout farm, Red Bluff, California. The exact origins of this fish stock are unknown, but the Mt. Lassen hatchery has received fish of the Kamloops strain from both the Coleman fish hatchery in Washington, and Trout Lodge fish hatchery in Washington in 1962. No additional fish stocks from other sources have been added since. Fish used in growth Trial 1 were spawned at Hildebrand's Mt. Lassen trout farm, and the eggs were sent to the Rockwood Experimental Hatchery in December 1980.

Sunndalsora - Stock from a research hatchery in Sunndalsora, Norway. The exact origins of this stock are also unknown, but the original stock which was introduced to Norway from North America were from a freshwater strain, and rainbow trout culture in Norway began as far back as 1912. The stock was received at the Rockwood Experimental Hatchery in April 1975, and eggs for growth Trials 2 and 3 were spawned in January 1981.

GROWTH TRIALS

In total three growth trials were conducted, each following the production schedule illustrated in Fig. 1. In Trial 1, 1 500, 10 g (initial weight) rainbow trout of the Mt. Lassen strain were used, while in Trial 2, 1 280, 10 g (initial weight) rainbow trout of the Sunndalsora strain were used. In Trial 3 Sunndalsora strain trout, from the same tank stock used for Trial 2, were graded into two size groups and marked using a hot wire branding method (Bernard and Van der Veen 1974). Equal numbers (640 fish) from each size group were then combined to form a bimodal population of 1 280 fish in one 'A' level tank. When feeding tables indicated the need for different pellet sizes for each group, then feed for a tank was prepared with equal portions of each pellet size, to ensure that the small group was not at a feeding disadvantage. Tank populations, for the 'B' to 'D' levels, always consisted of equal numbers from each size group.

When growth Trial 1 ended (175 days) one of the 'D' level tanks was hand graded with all fish less than 200 g returned to the tank. In a second 'D' level tank fish were randomly removed - thinned - until the resulting density was equivalent to that in the hand graded tank. Mean fish weight in the thinned tank was approximately the same as before thinning. Fish in these two tanks were then reared for an additional six weeks, at which time 100 fish per tank were sampled for individual weights.

CALCULATIONS AND DEFINITIONS

Specific growth rates were calculated using mean weights from the census, by:

$$G = \frac{\ln W_2 - \ln Wi}{t_2 - t_1} \times 100$$

where W_i is wet weight, t is time in days, and G is expressed as a percent of body weight per day (Ricker 1975).

Ration was expressed as a percent of wet fish weight. Ration and growth rate were adjusted to a dry weight basis using conversion factors calculated by Uraiwan (1982) for these strains of trout at maximum ration. Gross conversion efficiencies were calculated as:

$$G.C.E. = (G/\text{Ration X F}) \times 100$$

where G is the specific growth rate and F is the wet to dry conversion factor.

The feed:gain ratio was calculated by dividing the total weight of food fed by the change in wet weight. The authors are aware that interpretation of this ratio's meaning is sometimes difficult as the moisture content of feed and fish are so different, and ratios of less than one can occur. Our experience is that this ratio is still widely used by the industry and is therefore included here.

At the beginning of each of growth Trials 2 and 3, 50 fish were sampled, anesthetized and photographed with a marked rule. Lengths were then converted to individual weights using conversions described by Uraiwan (1982) for this stock of Sunndalsora trout, at maximum ration and 12°C. At the end of each trial individual weights for 100 fish from each of the three 'D' level tanks were taken.

RESULTS AND DISCUSSION

UNIMODAL POPULATION GROWTH TRIALS:
MT. LASSEN AND SUNNDALSORA STRAINS

Both the Mt. Lassen (Trial 1) and Sunndalsora (Trial 2) fish populations grew significantly during the 24 week growth period (Fig. 3). Mean fish weight in the Mt. Lassen trial after 24 weeks (167 days) was 200 g, while mean fish weight in the Sunndalsora trial was 187 g (166 days) (Table 1). These means were significantly different ($p<0.001$; ANOVA). The Mt. Lassen trial was run for an additional week at the 'D' level, prior to beginning the grading versus thinning experiment, with a final observed mean weight of 219.6 g (175 days) (Table 1).

Overall mean specific growth rates of the Mt. Lassen and Sunndalsora strain growth trials were 1.6 and 1.7% Day^{-1}, respectively. Specific growth rates declined with increasing fish weight, in both trials (Table 1, Fig. 3). Large weekly variations in specific growth rate were observed, as indicated by the particularly low growth rates reported at the end of each growth week, on days 70, 92, 125 and 154 in the Mt. Lassen trial and on days 14, 81 and 117 in the Sunndalsora trial (Fig. 3). No explanation for these poor growth rates was evident. Gross conversion efficiency dropped markedly on these weeks of poor growth and the feed:gain ratios were correspondingly high (Fig. 3). The overall mean gross conversion efficiency in the Mt. Lassen trial was 19.7%, and 18.0% in the Sunndalsora trial. Feed:gain ratios increased over time (Table 1), and overall mean feed:gain ratios were 1.7 and 1.5 in the Mt. Lassen and Sunndalsora trials, respectively.

The overall mean growth rates and conversion efficiencies observed in these two trials were slightly less than the respective 1.91% Day^{-1} and 20.27% reported by Brett and Sutherland (1970) for sockeye salmon artificially reared at 14°C, but the salmon were reared over a smaller weight range (22.8 to 102.2 g versus ≈10 to ≈200 g for the trout). However, overall mean growth rates observed in Trials 1 and 2 were considerably better than the 1.2% Day^{-1} reported for rainbow trout reared in a waste heat raceway culture system (Hill 1976).

We hypothesized that the relationship between growth rate and fish size for these growth trials should be similar to that reported for other salmonid species, also grown at non-limiting ration levels under constant environmental conditions. This relationship between the $\log_e$ (specific growth rate) and $\log_e$ (weight) for a number of salmonid species was summarized by Brett (1979) (Table 2, Top).

Similarly, for each of the Mt. Lassen and Sunndalsora trials, linear regression equations were calculated using $\log_e$ (specific growth rate) versus $\log_e$ (mean weekly fish weight per tank). Regression lines for both trials (Fig. 4) were highly significant (H_0:b=o; $p<0.001$), while the slopes were similar (d.f. 1,85; $p>0.50$; ANCOVA) and comparable with those reported by Brett (1979) for other salmonids (Table 2). Brett and Shelbourn (1975) concluded that 'Environmental and genetic differences would have the greatest effect on the intercepts' of the growth rate versus size relationship. There was no difference between the regression line intercepts (d.f. 1,86; $p>0.50$; ANCOVA) of the Mt. Lassen versus Sunndalsora strain growth trials (Fig. 4). This might reflect the constancy of the rearing environment and/or the absence of any readily apparent strain-related genetic differences.

Coefficients of determination were not reported in Brett's (1979) summary (Table 2) of $\log_e$(specific growth rate) versus $\log_e$ (weight) regressions. Coefficients of determination for both the Sunndalsora and Mt. Lassen growth trial regressions were low, particularly for the latter in which growth rate was highly variable at the larger sizes (Fig. 4). For both trials, the high degree of variation in weekly growth rates (Fig. 3) also contributed to the low coefficients of determination. These results suggested that fish weight was not the principal factor contributing to changes in growth rate.

Temperature, ration and fish weight are the primary factors controlling fish growth. The latter two are classified as 'limiting factors' (Fry 1947; Brett 1979), while the former is considered a 'controlling factor' (Fry 1949). In these experiments ration levels were non-limiting and temperature was maintained at as constant and as close to the optimum for rainbow trout that the pilot system could sustain. Consequently, the highly variable growth rates probably resulted from factors other than fish weight, ration and/or temperature. Despite low values in the coefficients of determination these analyses are useful if only because they may help to identify sources of growth variation in the pilot system. If such variation can be controlled then pilot production will be enhanced.

The production schedule used in these trials provided that maximum densities would occur during the 'D' level of each trial (Table 1). Maximum densities of 68.5 and 52.3 kg m^{-3}, for the Mt. Lassen and Sunndalsora trials respectively, approached the maximum used for commercial rainbow trout production (Bardach et al. 1972).

Mortality in the Mt. Lassen trial was approximately 7% with the highest mortality occurring during level 'A' (Table 1). Mortality in the Sunndalsora trial was 3% (Table 1) with the highest mortality occurring during the 'B' level (second six week period). The majority of the observed mortalities were attributed to handling stress that resulted from weekly samplings, and from counting errors.

Sampling of all fish (n=1 402) in the 'D' level tanks from the Mt. Lassen trial, after 175 rearing days, indicated that approximately 34% of the population was marketable (>200 g). Weights from a sub-sample (n=302) of the Sunndalsora trial 'D' level tanks, after 166 rearing days, indicated that 34% of that population was marketable.

After an additional six weeks of rearing, the thinned Mt. Lassen 'D' level tank had 90% of the population at market size, while the Mt. Lassen 'D' level tank that was graded on day 175 to remove all fish greater than or equal to 200 g had 82% of fish at market size (Table 3). Brown (1977) reported that the optimum market size range for supermarkets was 200-250 g fish, with two fish in each pack. Although the thinned tank contained a slightly higher percent of marketable fish than the graded tank (90% versus 82%), a considerably greater proportion of these fish were 260 g or greater (Table 3), which approached or exceeded the uppermost limit of optimum marketability. This suggests that the optimal harvest strategy would be to grade fish at the end of the 24 week production cycle, removing all market size fish, and then rearing the remaining population for an additional six weeks with perhaps one grading at three weeks.

This practice would limit the additional space required for 'finishing' and would maximize the number of fish harvested within the optimum market size range. Alternatively, efforts could be concentrated on selection of stocks which exhibit more uniform growth rates, and consequently a more uniform finished size.

In summary, as suggested from both growth trials the goal of attaining a mean fish weight of 200 g after 24 weeks in the solar heated production facility is feasible. There were strain-related differences in mean weight, but more significantly, in the relationship between strain mean weight and the percentage of each population marketable. That is, even after an additional growth week and attainment of a much larger mean weight, the percent of Mt. Lassen strain fish marketable was the same (34%) as for the Sunndalsora strain population, suggesting that market production testing of strains is better evaluated by use of individual fish weights rather than by population mean weights.

Finally, because of growth variability between individuals, the original objective of harvesting all 'D' level fish at once is not as optimal a strategy as one which employs 'continuous' cropping. This study showed that grading for removal of market size fish, and allowance for additional growth of pre-market size ones, was a better 'continuous' cropping strategy than simple random thinning.

BIMODAL POPULATION GROWTH TRIALS: VARIATION IN BODY WEIGHT

The term 'growth depensation' refers to an increase in the variance of a size frequency distribution with time; typically, the large fish grow even larger while the small lag further behind (Brett 1979). Its occurrence has been reported in cultured populations of brown trout (Brown 1957) and rainbow trout (Kato and Sakamoto 1969). 'Growth depensation' might be the result of two different causes: (1) genetic variability, with some fry hereditarily incapable of as high a specific growth rate as others, or (2) from some fish beginning to feed earlier than others, hence acquiring an initial size advantage which is then maintained by establishment of a size hierarchy.

To determine if 'growth depensation' was a factor influencing the weight frequency distributions observed at harvest, in the pilot production system, the initial and final coefficients of variation [C.V. = 100X (s.d./mean) in percent] from the unimodal Sunndalsora growth trial (Trial 2) and the bimodal Sunndalsora growth trial (Trial 3) weight distributions were calculated. Yamagishi (1969) emphasized the importance of the coefficient of variation in the detection of 'growth depensation'. That is, if a given weight distribution's coefficient of variation does not change over time, then there is no 'growth depensation'.

The coefficient of variation did not increase in either of the Sunndalsora growth trials (Table 4). In the bimodal growth trial (Trial 3), as the standard deviations of the means of the 'small' and 'large' groups increased, with increased mean fish weight (Table 4), there was an increased overlap between the two size groups (Fig. 5). However, because the coefficient of variation for each group did not increase, 'growth depensation' did not occur. These results suggested that the pilot production system, where feed is not limiting, does not facilitate establishment of a size hierarchy as indicated by 'growth depensation'.

In Trial 3, the 'large' group was significantly heavier than the 'small' group at the end of the growth trial ($p < 0.001$; ANOVA) (Fig. 6). However, these final mean weights were not adjusted for the significant difference between initial mean weights of the two groups (Table 4). Either this initial difference in mean weight, or hereditarily lower growth rates in fish of the 'small' group, could explain the significantly different mean harvest weights.

To test if there was an inherent hereditary difference between growth rates of the two groups their $\log_e$ (mean weights) versus time regression lines were compared (Fig. 7). For both the 'small' and 'large' groups two growth stanzas were identified. The initial growth stanza ended at 55 and 40 days for the 'small' and 'large' groups, respectively (Fig. 7). Covariance analysis between group regression lines for this initial growth stanza indicated no significant differences between slopes (df. 1,50; $p = 0.177$). In contrast, covariance analysis of regression lines for the second growth stanza indicated a significant difference between slopes (d.f. 1,268; $p<0.001$), with the 'small' group's regression line having the greater slope (0.016 versus 0.014). This difference could have resulted from a declining growth rate with increased fish size, with 'large' group fishes' growth rate slowing, relative to that of the 'small' group fishes'. To test if growth rates of fish in the 'large' and 'small' groups were significantly different at equivalent weights, covariance analysis of the $\log_e$ (specific growth rate) versus the $\log_e$ (mean weight) regression lines for the 'small' versus 'large' groups was made (Fig. 8). There were no significant differences in slopes (df. 1,76; $p = 0.657$) or most importantly, adjusted mean weights (d.f. 1,77; $p = 0.972$), which suggested that at an equivalent weight fish from either group had equal growth rates.

The authors recognize that statistical assumptions relevant to both the linear regression and covariance analyses were violated (Steel and Torrie 1960), but results were not invalidated because these analyses and subsequent F-tests are very robust to assumption violation (Glass et al. 1972).

Results from the bimodal growth trial suggest that initial size differences in the two groups were responsible for differences in final harvest weights, and that 'small' group fish were not hereditarily incapable of as high a specific growth rate as 'large' group fish. Further, these results suggest that initial weight differences between fish from the same stock tank arose from differences in the time of first feeding. This is in general agreement with Reestie (1980), but conflicts with Kato and Sakamoto (1969), who observed real differences between size groups which were attributed to genetic variability.

The management implications of this experiment to the pilot production system are: that grading for uniformity of product should be done at the beginning of a production run (level 'A'); that 'size hierarchy' effects are not a problem in the system when different groups are present in proportional numbers, and that the weight frequency distribution of a production population appeared stable over time. This stability suggests that the assumption of a fish's independence of growth from its previous growth history (ie. Markovian) made by Arnason et al. (1981), for a production model of this system, was justified.

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Table 1. Summary by level, of days duration, mean live weight, mean specific growth rate, mean feed:gain ratio, densities and mortalities for the growth trials of Mt. Lassen (Trial 1) and Sunndalsora (Trial 2) strains.

Trial	Level	Duration in Days	Mean Live Weight (g)		Mean (±S.E.)		Density (kg m^{-3})		Mortality	
			Initial	Final	Specific Growth Rate (% Day^{-1})	Feed:Gain Ratio	Minimum	Maximum	Number	Percent
Mt. Lassen (Trial 1)	A	63	9.7	42.3	2.3 (0.09)	1.08 (0.07)	9.7	40.6	61	(4.1)
	B	29	42.0	72.5	1.9 (0.28)	1.53 (0.44)	20.1	34.5	13	(0.9)
	C	33	72.5	131.4	1.8 (0.25)	2.14 (0.68)	34.5	62.5	0	(0.0)
	D	50	132.4	219.6	1.0 (0.13)	2.07 (0.39)	41.9	68.5	24	(1.7)
Sunndalsora (Trial 2)	A	41	10.4	37.6	3.1 (0.56)	0.94 (0.15)	8.9	31.9	7	(0.5)
	B	42	37.0	68.7	1.7 (0.10)	1.36 (0.11)	15.5	28.5	17	(1.3)
	C	41	68.7	114.5	1.2 (0.12)	1.64 (0.20)	28.5	47.8	3	(0.3)
	D	42	116.7	187.0	1.1 (0.09)	1.70 (0.16)	32.1	52.3	14	(1.1)

Table 2. Intercepts and slopes for the $\log_e$ (specific growth rate) versus $\log_e$ (mean fish weight) regression equations for various salmonids as summarized in Brett (1979) and from results of this study.

Species	Weight Range (g)	Temperature (°C)	Intercept (a)	Slope (b)	Source
Brook Trout	1.5 - 60	11.0	4.66	-0.33	Haskell (1959) In Brett (1979)
Brook Trout	2.5 - 350	10.0	6.49	-0.47	Cooper (1961) In Brett (1979)
Brown Trout	5 - 300	15.0	2.50	-0.31	Elliott (1974) In Brett (1979)
Sockeye Salmon	3 - 45	15.0	4.47	-0.42	Brett & Shelbourn (1975) In Brett (1979)
Pink Salmon	5.0 - 60	15.0	9.78	-0.45	Brett (1974) In Brett (1979)
Rainbow Trout (Mt. Lassen)	10 - 220	13.0	2.11	-0.41	Present Study (Trial 1)
Rainbow Trout (Sunndalsora)	10 - 187	13.0	2.20	-0.44	Present Study (Trial 2)
Rainbow Trout (Sunndalsora)	9 - 161	13.0	1.65	-0.29	Present Study (Trial 3, 'small')
Rainbow Trout (Sunndalsora)	17 - 220	13.0	1.82	-0.33	Present study (Trial 3, 'large')

Table 3. Harvest summary of the thinned versus graded treatments for the Mt. Lassen (Trial 1) 'D' level tanks.

Treatment Type	'D' Level - Week 0			'D' Level - Week 6						
	Number	Mean Weight (g)	Density ($kg \cdot m^{-3}$)	Weight(±S.E.)	C.V.[c]	Percent Per Weight Class (g)				
						≥200	200-240	240-260	200-280	320
Thinned[a]	292	213	41.4	292.1 (7.17)	24.5	90	19	36	47	26
Graded[b]	321	195	41.8	244.0 (5.46)	22.4	82	40	54	70	4

[a] Randomly thinned.

[b] Graded to remove all trout ≥ 200 g.

[c] C.V. is coefficient of variation in percent.

Table 4. Comparison of Sunndalsora strain unimodal (Trial 2) and bimodal (Trial 3), 'small' and 'large' group, mean live weights and specific growth rates at the start and finish of each production trial.

Production Trial	Day	Tank	N	Live Weight (g) Mean (±S.E.)	C.V.[a]	Specific Growth Rate (% Day^{-1})
Unimodal	8	1	50	15.3 (0.64)	29.2	
	166	6	102	196.4 (5.02)	25.8	1.52
		7	100	179.3 (4.07)	22.7	1.47
		8	100	185.7 (4.14)	22.3	1.49
Bimodal 'small'	7	1	51	8.8 (0.23)	18.2	
	165	6	100	152.6 (2.92)	19.2	1.73
		7	100	160.9 (2.91)	18.1	1.76
		8	100	168.9 (3.14)	18.7	1.79
Bimodal 'large'	7	1	50	16.9 (0.40)	16.5	
	165	6	100	209.8 (4.30)	20.5	1.53
		7	100	214.6 (3.39)	15.8	1.54
		8	100	237.2 (4.12)	17.4	1.60

[a] C.V. is coefficient of variation in percent.

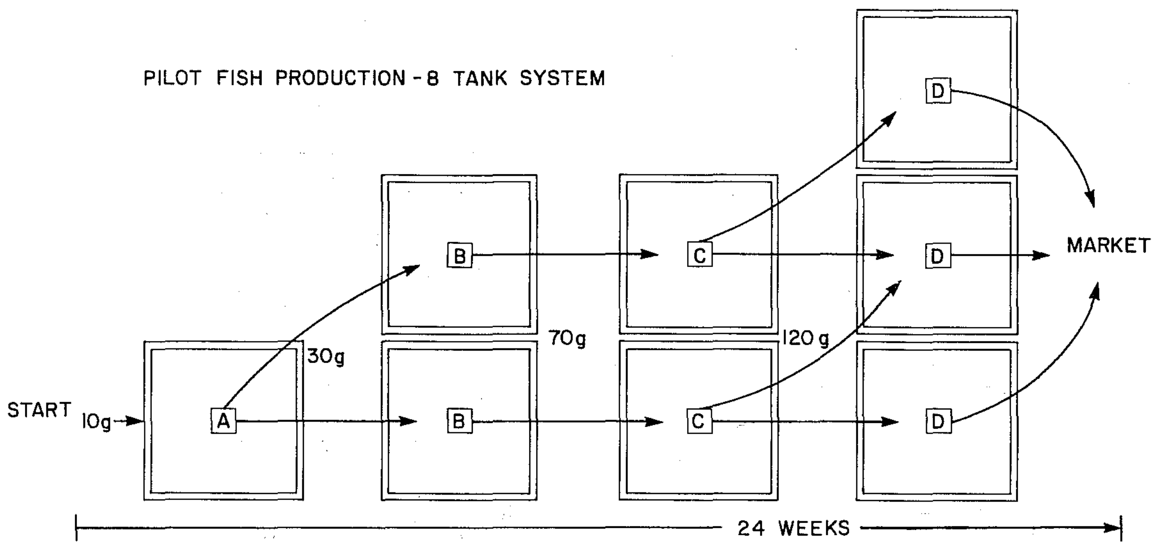

Figure 1. Schematic layout of tanks in pilot fish production system. Letters represent 'levels' and weight (g) represents approximate mean weight at transfer.

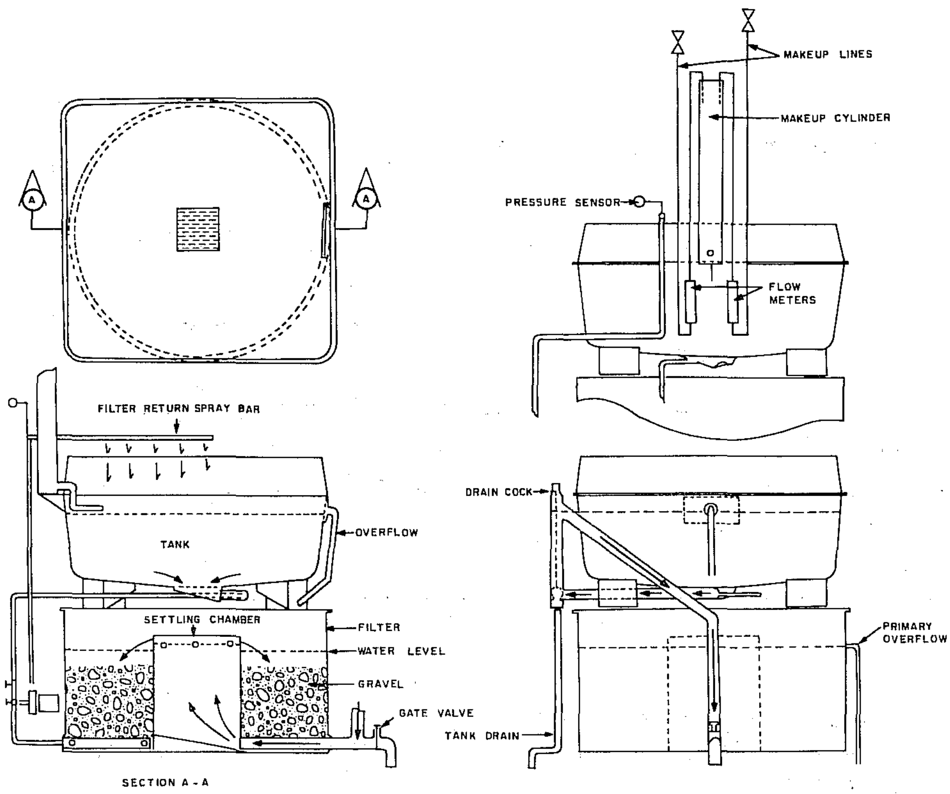

Figure 2. Standard fish rearing modules, with a 1500 L fish tank and an 1100 L filtering unit.

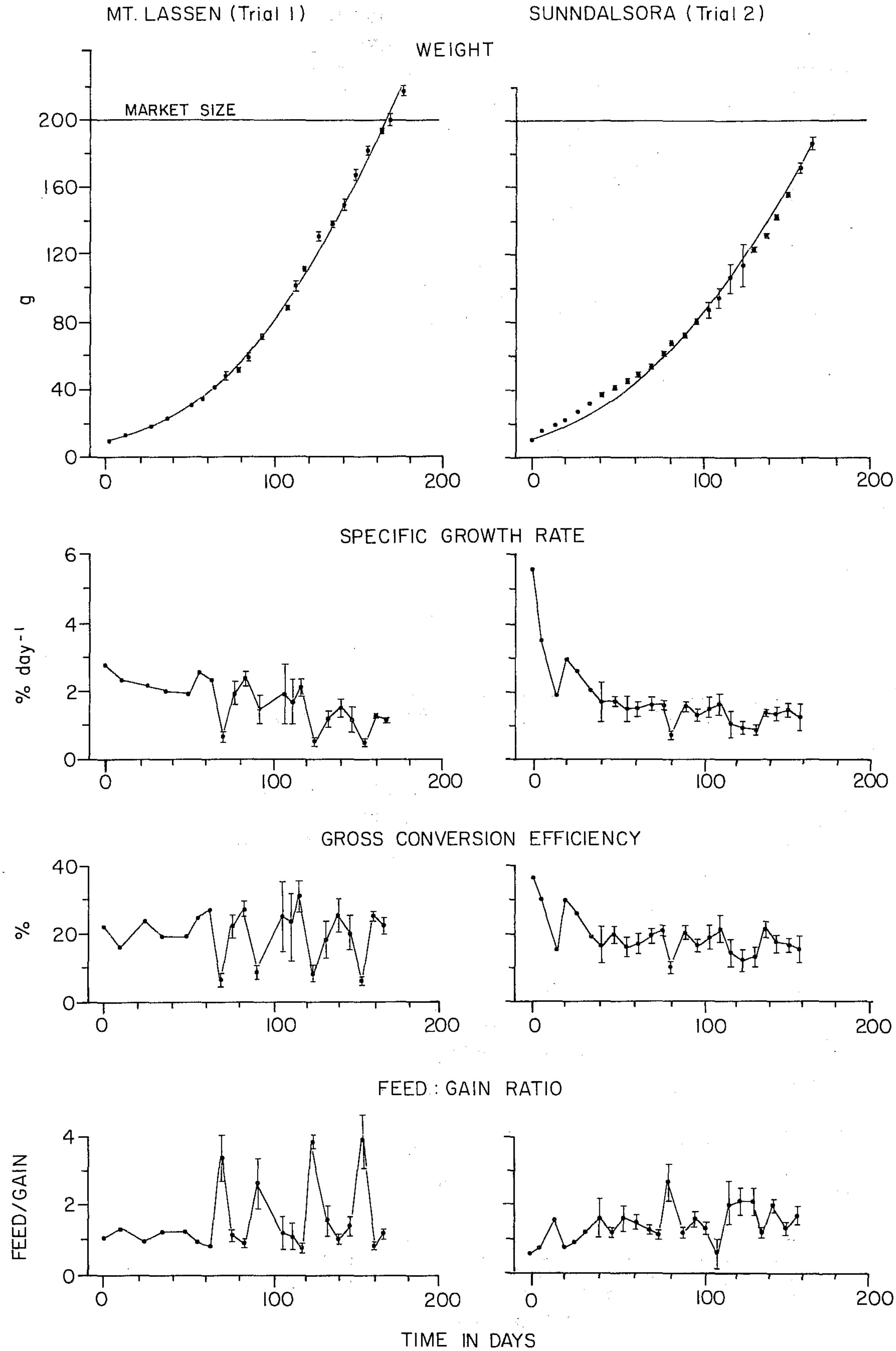

Figure 3. Changes in mean live weight, specific growth rate, gross conversion efficiency and feed: gain ratio with time (days) for the Mt. Lassen and Sunndalsora strain growth trials. Vertical bars equal ± 2 S.E.

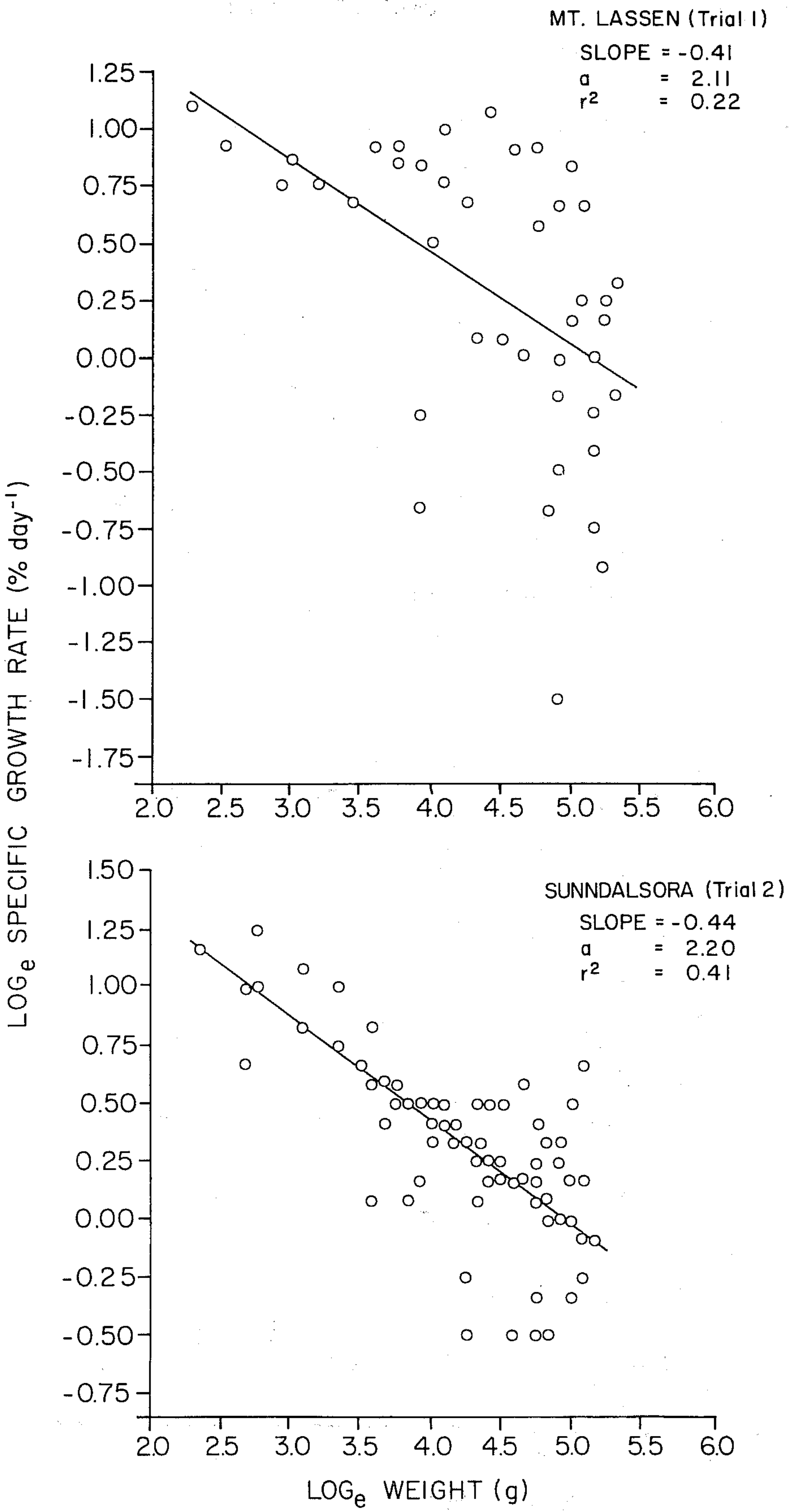

Figure 4. Regression lines of $\log_e$ (specific growth rate) versus $\log_e$ (weight) for the Mt. Lassen (Trial 1) (Top) and Sunndalsora (Trial 2) (Bottom) strains.

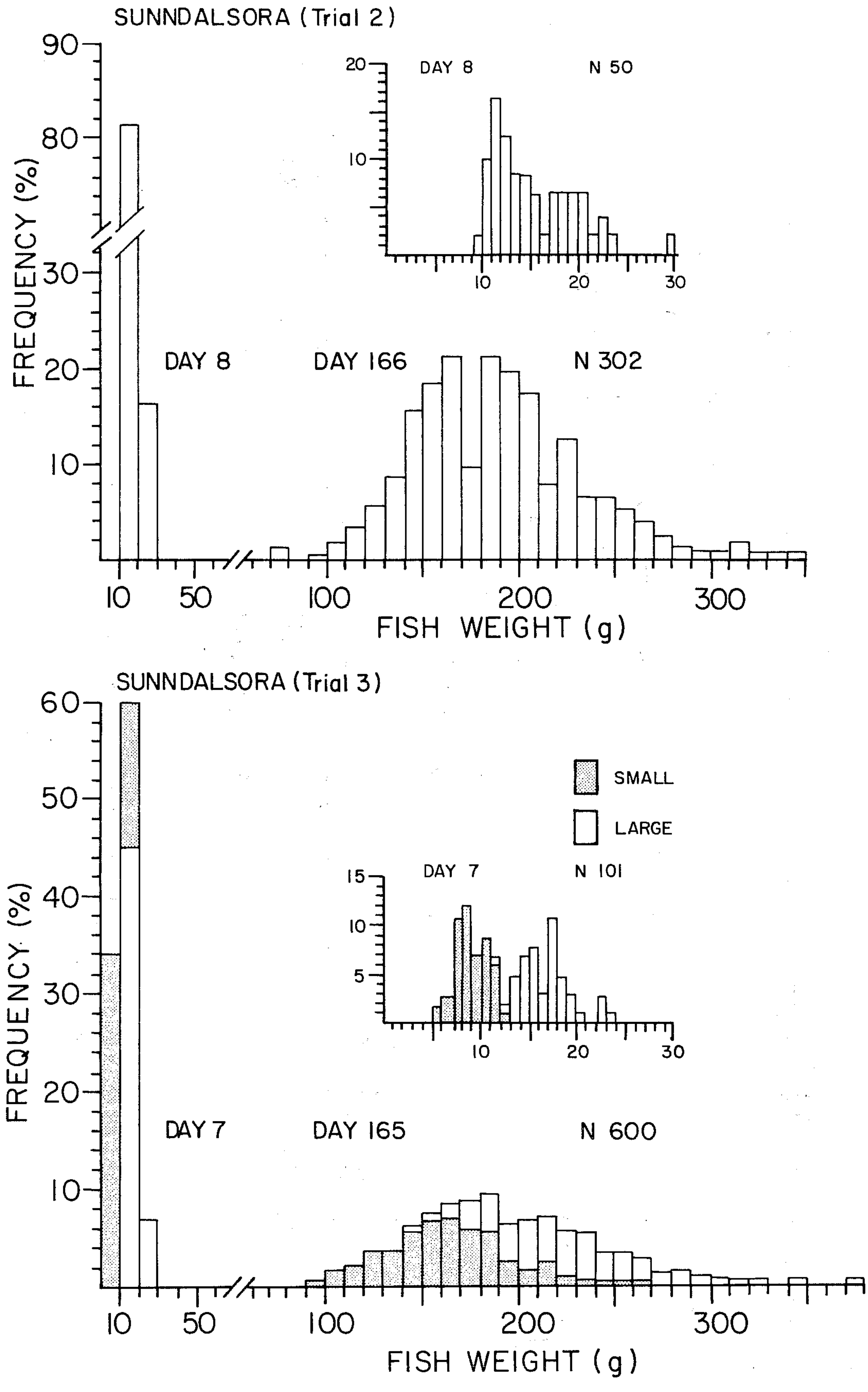

Figure 5. Weight frequency distributions at start and finish of the Sunndalsora strain growth Trials 2 (Top) and 3 (Bottom), with unimodal and bimodal distributions respectively. Enlarged starting distributions are shown in inserts.

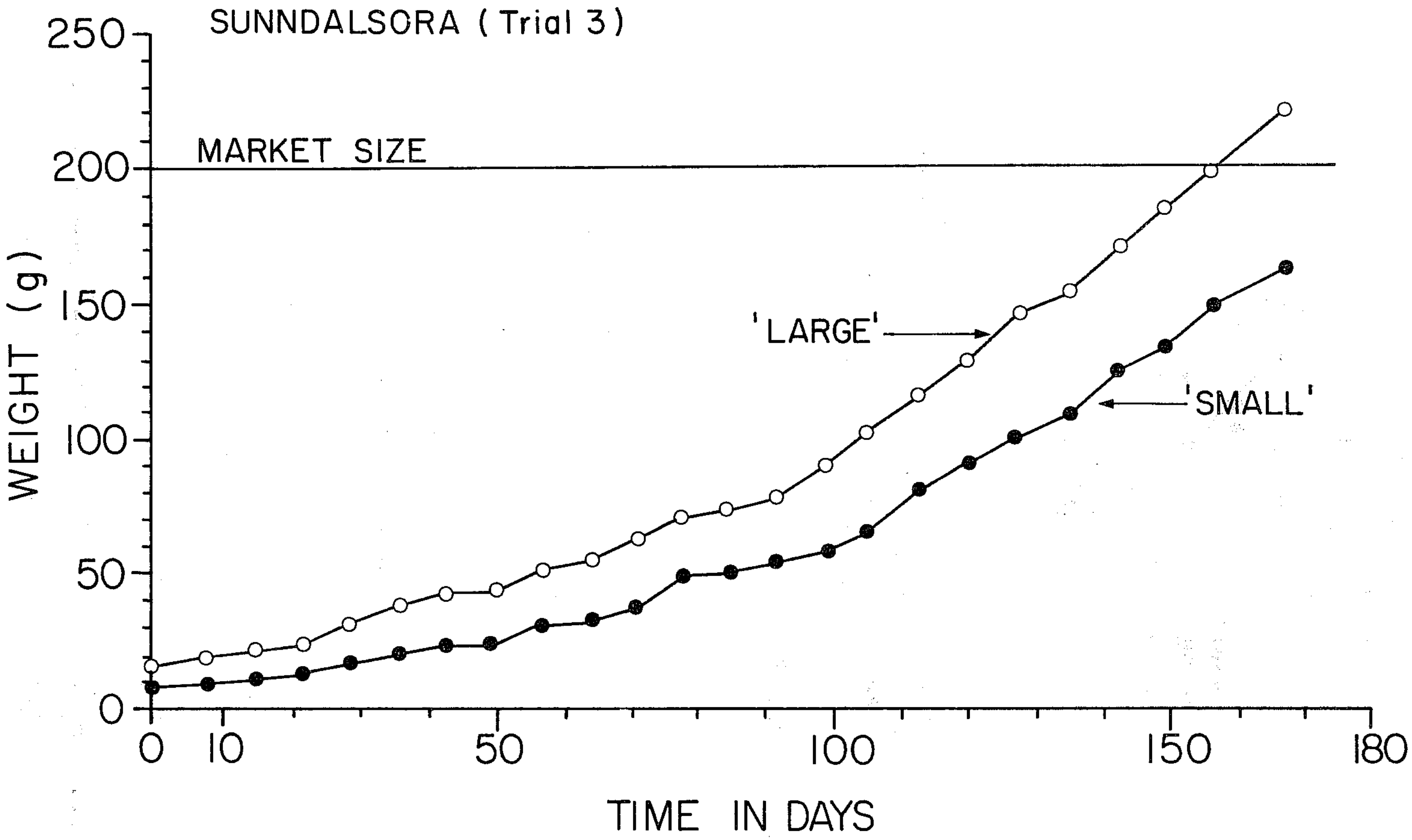

Figure 6. Growth in weight over time of Sunndalsora strain (Trial 3) 'small' and 'large' groups.

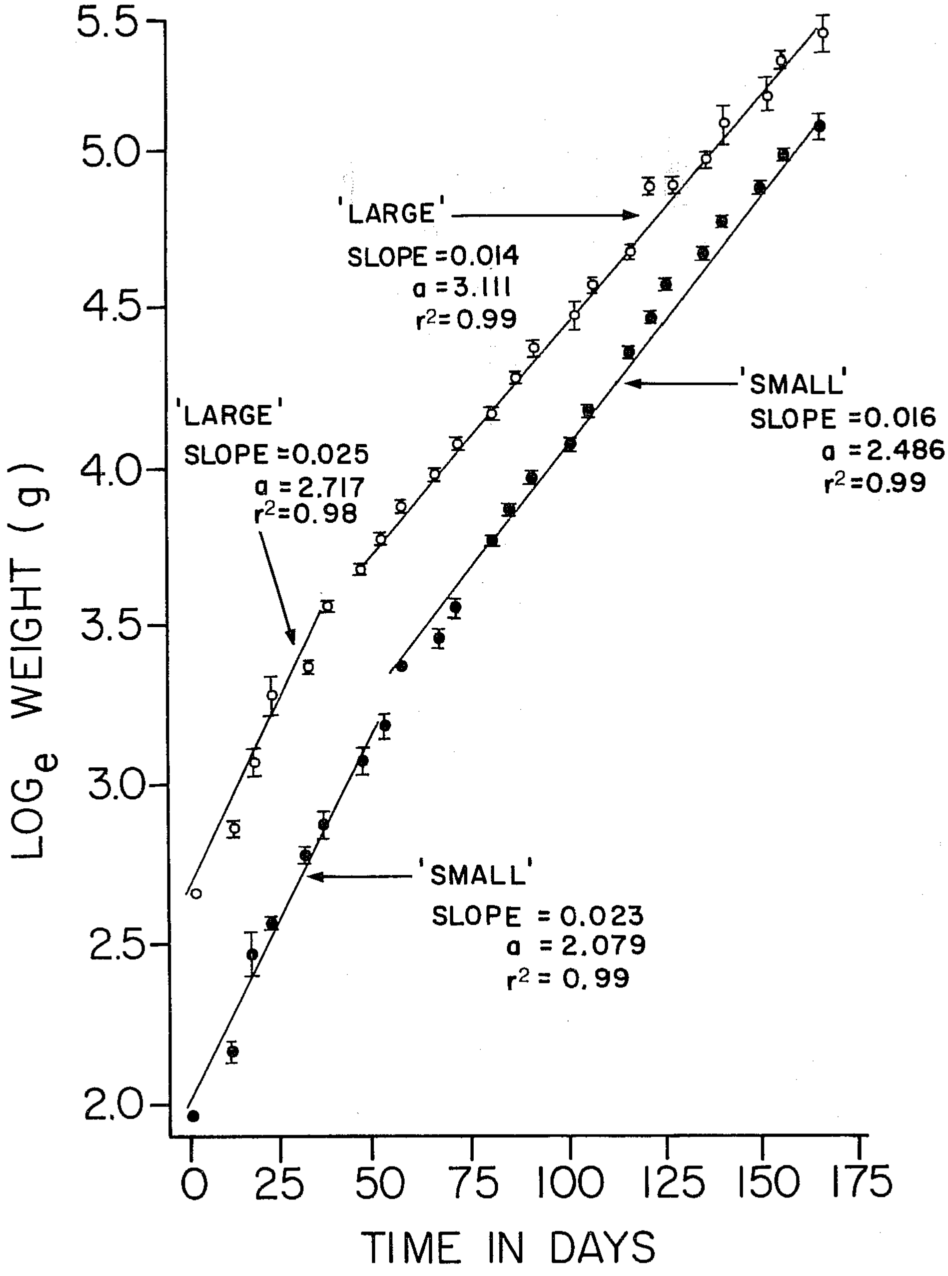

Figure 7. Regression lines, by growth stanza of log$_e$ (weight) versus time for each of the Sunndalsora strain (Trial 3) 'small' and 'large' groups. Vertical bars are ± 2 S.E.

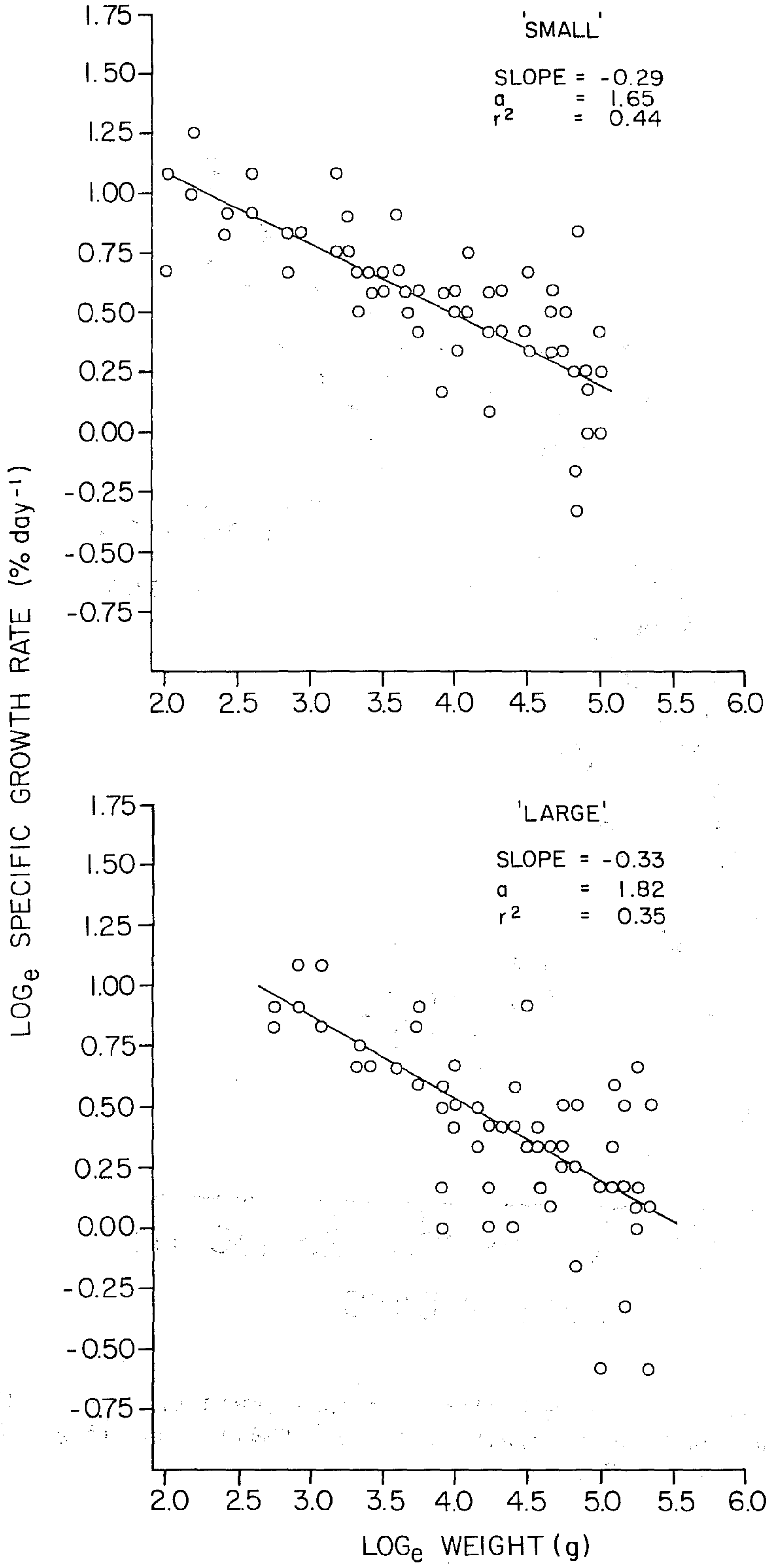

Figure 8. Regression lines of $\log_e$ (specific growth rate) versus $\log_e$ (weight) for the Sunndalsora strain (Trial 3) 'small' (Top) and 'large' (Bottom) groups.