A Feeding Guide for Juvenile Atlantic Salmon

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A FEEDING GUIDE FOR JUVENILE ATLANTIC SALMON

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ABSTRACT

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The influence of water temperature and of the number of meals consumed per day by juvenile Atlantic salmon (Salmo salar) on their growth rate and maximum daily food intake was determined in the laboratory from a 3 x 3 x 3 factorial experiment. The three levels of the temperature factor were 10°, 16° and 22°C; of the initial salmon weight factor, 1.4, 7.0 and 27.7 g; and of the meals-per-day factor, 3, 7 and 14. Daily food intake (percentage of body weight per day) by salmon of all size classes increased with temperature from 10° to 16°C. With a further increase to 22°C, the daily intake by smaller salmon (<10 g) remained relatively constant, while that of larger salmon (>25 g) showed a marked decline. Food intake at a given temperature was generally greatest when excess food was presented 7 times per day (2-hour intervals) or 14 times per day (1-hour intervals) and least when excess food was presented 3 times per day (4-hour intervals). For salmon of all size classes, growth rate increased with temperature from 10° to 16°C and then declined as temperature continued to increase to 22°C. Maximal growth rates at the different temperatures were usually recorded for salmon presented with 7 or 14 meals per day while growth rates were lower for salmon offered 3 meals per day. Maximum daily food intake (percentage of body weight per day) decreased with increasing salmon weight at all temperatures. Maximum values of daily food intake observed in the present study are similar to those which have been recorded for other salmonids. An Atlantic salmon feeding guide, specifying daily food intake for salmon of 2-70 g when held at temperatures of 5°-21°C and fed a dry diet, was derived from laboratory results and was tested at the Mersey Hatchery, Nova Scotia. Growth rates of juvenile salmon fed the daily rations specified in the new guide were equal to those of salmon fed the daily rations specified in an existing guide supplied by a food manufacturer. However, use of the new guide resulted in an improvement in feed efficiency because it specified smaller daily rations than did the manufacturer's guide.

Key words: juvenile Atlantic salmon, feeding guide, initial weight, water temperature, number of meals per day, growth rate, daily food intake (percentage of body weight per day), feed efficiency.

RÉSUMÉ

Farmer, G.J., D. Ashfield and T.R. Goff. 1983. A feeding guide for juvenile Atlantic salmon. Can. MS Rep. Fish. Aquat. Sci. No. 1718. vii + 13 p.

Dans un laboratoire, une expérience factorielle à 3 x 3 x 3 a été utilisée pour déterminer l'influence de la température de l'eau et du nombre de repas consommés quotidiennement par de jeunes saumons atlantiques (Salmo salar) sur le taux croissance et l'ingestion quotidienne maximale de nourriture. Les trois niveaux du facteur température sont 10°, 16° et 22° C; ceux du facteur poids initial des saumons, de 1,4; 7,0 et 27,7 g; enfin, ceux du facteur repas par jour, de 3, 7 et 14. La nourriture absorbée quotidiennement (pourcentage du poids somatique par jour) par les saumons de toutes les classes de taille augmente en fonction de la température, de 10° à 16° C. A partir de cette température et jusqu'à 22° C, l'ingestion quotidienne par les petits saumons (<10 g) demeure relativement constante, alors que celle des saumons plus gros (>25 g) diminue notablement. L'ingestion de nourriture à une température donée est généralement à son maximum quand une nourriture en excès leur est présentée 7 fois par jour (à intervalles de 2 heures) ou 14 fois par jour (à intervalles de 1 heure) et à son minimum quand la nourriture en excés leur est présentée 3 fois par jour (à intervalles de 4 heures). Chez les saumons de toutes les classes de taille, le taux de croissance augmente en fonction de la température, de 10° à 16° C, pour ensuite diminuer à mesure que la température augmente jusqu'à 22° C. Les taux de croissance maxima aux différentes températures se rencontrent généralement chez les saumons auxquels on offre 7 ou 14 repas par jour, alors qu'ils sont plus faibles chez des saumons auxquels on donne 3 repas par jour. L'ingestion quotidienne maximale de nourriture (pourcentage du poids somatique par jour) diminue à mesure que le poids des saumons augmente, à toutes les températures. Les valeurs maximales d'ingestion quotidienne de nourriture observèes dans l'étude présente sont identiques à celles qui ont été signalées chez d'autres salmonidés. On a préparé, à partir des résultats de laboratoire, un guide de l'alimentation du saumon atlantique, dans lequel est spécifiée l'ingestion quotidienne de nourriture de saumons de 2 à 70 g, maintenus à des températures de 5° - 21° C et auxquels on donne de la nourriture en boulettes sèches. Le guide a été essayé à établissement de pisiculture de Mersey, en Nouvelle-Ecosse. Les taux de croissance des jeunes saumons auxquels on donne les rations quotidiennes spécifiées dans le nouveau guide sont identiques à ceux des saumons auxquels on donne les rations quotidiennes spécifiées dans un guide existant fourni par le manufacturier de nourriture. Cependant, l'utilisation du nouveau guide résulte en un meilleur rendement alimentaire, car on y spécifie des rations quotidiennes plus petites que celles du guide du manufacturier.

INTRODUCTION

Each year, ten federal hatcheries located within the three Maritime Provinces produce approximately 700,000 Atlantic salmon smolts and 700,000 salmon parr, primarily for enhancement purposes. The salmon are fed a commercially prepared dry diet (Silver Cup, Murray, Utah) until their release. A feeding guide supplied by the food manufacturer was derived from experimental work conducted at the New York State Fish Hatchery and specifies daily rations for rainbow trout (Salmo gairdneri) held at temperatures of 2°-20°C. It has been observed by managers of Atlantic salmon hatcheries that some daily rations specified in the rainbow trout guide are excessive for salmon. Strict adherence to the guide has resulted in unnecessary wastage of food. This is partly attributable to the fact that the guide specifies an increase in rations as water temperature increases to 20°C; while for most salmonids, it has been demonstrated that the rates of several physiological processes - including food intake, conversion efficiency and growth - increase with temperature to about 15°C and then decline as temperature continues to rise (Brett 1979).

Although some hatchery managers have modified the rainbow trout guide for their use, a need was identified for the development of a new guide specifically for the feeding of dry diets to Atlantic salmon. Factors of importance which influence the daily food intake of salmon include their size, the water temperature and the number of meals they consume per day. Thus, laboratory experiments were designed to examine the influence of these factors on the maximum daily food intake and growth rate of juvenile Atlantic salmon. The objective of the study was the development of a feeding guide for Atlantic salmon that would improve feed efficiency and also provide maximal rates of growth.

MATERIALS AND METHODS

The laboratory experiments were designed to determine the influence of the number of meals consumed per day and of water temperature on the food intake and growth rate of juvenile Atlantic salmon. The experimental design was a 3 x 3 x 3 factorial:

	Factors		
Level	Temp. (°C)	Meals per day	Initial weight (g)
1	10	3	1.4
2	16	7	7.0
3	22	14	27.7

The groups of salmon receiving 3, 7 or 14 meals daily were fed to satiation at intervals of 4, 2 or 1 hour, respectively. Experiments utilizing salmon of each weight class were performed separately between August and December, as the larger salmon became available. Thus, each of the experiments with salmon of a given weight class consisted of nine combinations of the water-temperature and meals-per-day factors.

Juvenile salmon of Medway River stock were obtained from the Mersey Hatchery, Nova Scotia, on three different dates - on each occasion, at least one month before the beginning of an experiment. Upon their arrival in the laboratory, the salmon were equally distributed among nine 300-L, circular, fibreglass tanks (0.9-m diameter), which received dechlorinated tap water at a temperature similar to that measured at the Mersey Hatchery. Salmon were allowed four weeks to adapt to the experimental conditions. During that time, they were exposed to a 15-hour photoperiod and fed to satiation daily with Silver Cup food in accordance with the experimental design. Temperature adaptation was achieved by changes of 1°C/day until a particular experimental temperature was attained. The energy content (kilojoules per gram wet weight) and proximate composition (percentage wet weight) of the three sizes of Silver Cup food fed to the three weight classes of salmon during the experiments were:

Food size	Moisture (%)	Lipid (%)	Protein (%)	Ash (%)	Energy content (kJ/g)
#2	6.3	15.4	49.0	8.5	20.40
#3	7.4	11.8	48.7	10.3	19.89
#4	5.2	11.1	48.7	10.3	20.11

Salmon were deprived of food for 24 hours at the end of each 4-week adaptation period and five fish from each tank were then sacrificed for the determination of moisture and energy content. To determine their total weight, the salmon remaining in each tank were captured by dip net, quickly blotted on absorbent towelling and then transferred to a pre-weighed container of water placed on a balance. The salmon were counted as they were returned to their respective tanks and a maintenance ration was offered to the various groups for two days before the start of a feeding experiment. This allowed appetite to develop after the stress of handling. For experiments with salmon of 1.4, 7.0 and 27.7 g initial weight, each tank contained 40, 30 or 15 individuals, respectively.

During each 10-day experimental period, all salmon were fed Silver Cup food daily from pre-weighed containers between the hours of 0700 and 2000. Portions of each meal were presented by hand at 10-second intervals until all the salmon within a particular tank had ceased feeding. The uneaten food was left in the tanks for an additional 5 minutes, and then the remaining particles were counted and siphoned from the tanks. The weight of food recovered from each tank was estimated by multiplying the number of particles by a mean particle weight, previously calculated for each size of food. The food containers were reweighed so that weights of the individual meals could be calculated. At the end of a 10-day experiment, the groups of salmon were again deprived of food for 24 hours and reweighed. Ten salmon from each group were sacrificed at that time for moisture and energy determinations.

The salmon and food samples were freeze-dried to constant weight for the determination of moisture content and then ground in a laboratory mill. The energy content of sub-samples of tissue and food was then determined with either an oxygen microbomb calorimeter (10- to 20-mg samples) (Philipson 1964) or a Parr adiabatic calorimeter (1-g samples). Lipid content of the food samples (1 g) was determined by extraction for 4 hours with chloroform-methanol (2:1) (Folch et al. 1957). Ash content was estimated by heating 1-g samples at 550°C for 24 hours (A.O.A.C. 1970). The ammonia released from food samples (1 g) after Kjeldahl digestion was measured with an ammonia-sensing glass electrode (Orion #95-10) to provide a measure of nitrogen content. Protein content was then calculated by multiplying the nitrogen estimates by 6.25. The instantaneous growth coefficient for each group of salmon was calculated from $\log_e W2 - \log_e W1$, where W1 and W2 are the initial and final mean weights in grams during a 10-day experimental period.

The measurements of maximum food intake and instantaneous growth coefficient obtained during the laboratory studies were subjected to stepwise multiple regression analysis (Draper and Smith 1966) to derive a new feeding guide for use by Atlantic salmon culturists. The new guide was evaluated during feeding trials at the Mersey Hatchery, where salmon grow rapidly and attain smolt size within their first year of feeding. Thus, during 1979-80, two groups of juvenile salmon, held in 7.6-m Swedish-type rearing ponds, were fed Silver Cup food 7 times daily (at 2-hour intervals), in accordance with the rations shown in the new guide. Their growth was compared to that of two similar groups of salmon fed 14 times daily (at 1-hour intervals) according to the rations shown in the guide supplied by the food manufacturer. Feeding at hourly intervals had been the customary practice at the Mersey Hatchery. It became apparent that salmon were unable to consume the amounts of food specified in the manufacturer's guide and rations for those groups were therefore reduced by 10%-60%, depending on ambient water temperature. The reduced ration levels represented an approximation of the maximum which the salmon were capable of consuming. Individual meals were automatically delivered to all experimental ponds by flinger-type feeders (Neilsen Metal Industries Inc., Salem, Oregon) during intervals of 30-50 seconds for the groups receiving 7 meals/day, and during intervals of 10-20 seconds for those receiving 14 meals/day. The number of daily meals was reduced during the winter months. Salmon were weighed at approximately 30-day intervals by capturing most fish in a particular pond by seine and then transferring from 100 to 900 individuals to a pre-weighed container of water placed on a balance. The salmon were then counted as they were returned to the ponds so that their mean weight could be calculated.

At the beginning of the trial (July, 1979), each experimental pond contained from 8,100 to 9,900 salmon or from 27 to 31 kg. The number of juveniles in the ponds was reduced during September, so that they contained from 5,000 to 5,100 individuals or from 72 to 83 kg. The experiment was terminated during March, 1980, when the weight of salmon per pond ranged from 170 to 200 kg.

To further evaluate the new guide, a similar feeding trial was performed at the Mersey Hatchery during the August-February period, 1980-81. Three ponds of salmon were fed Silver Cup food from dawn to dusk, according to the rations specified in the manufacturer's guide (reduced as previously), while three ponds of salmon were fed the daily rations specified in the new guide. The number of meals per day was increased for this trial and all six ponds of salmon were fed at 30-minute intervals during August (maximum of 32 meals/day) and every 45 minutes during September, October and November (minimum of 15 meals/day). The numbers of meals which were fed per day during the December-February period were considerably fewer and dependent upon temperature and ice conditions. For each meal, the automatic feeders were activated for periods of <10 seconds. The numbers and weights of salmon in the experimental ponds were similar to those maintained during the 1979-80 feeding trial.

RESULTS

FOOD INTAKE AND INSTANTANEOUS COEFFICIENT OF GROWTH

The average daily food intake (percentage of wet body weight per day) for each group of salmon was calculated from measurements of the number of individuals in the group, their mean weight and the total weight of food they consumed during a 10-day experimental period. Thus in Experiment A, for salmon having an initial average weight of 1.4 g (Fig. 1), daily food intake of all groups increased with temperature from 10° to 16°C. With a further temperature increase to 22°C, intake remained relatively constant and was similar to that observed at 16°C. Food intake was greatest over the 10°-22°C temperature range for salmon fed 14 meals/day, slightly lower for those fed 7 meals/day and lowest for those which consumed only 3 meals/day. Instantaneous growth coefficients of all groups increased with temperature from 10°-16°C and then showed a marked decline when temperature was further increased to 22°C. At all experimental temperatures, growth rate was generally greater for salmon fed 7 or 14 meals/day than for those fed 3 meals/day.

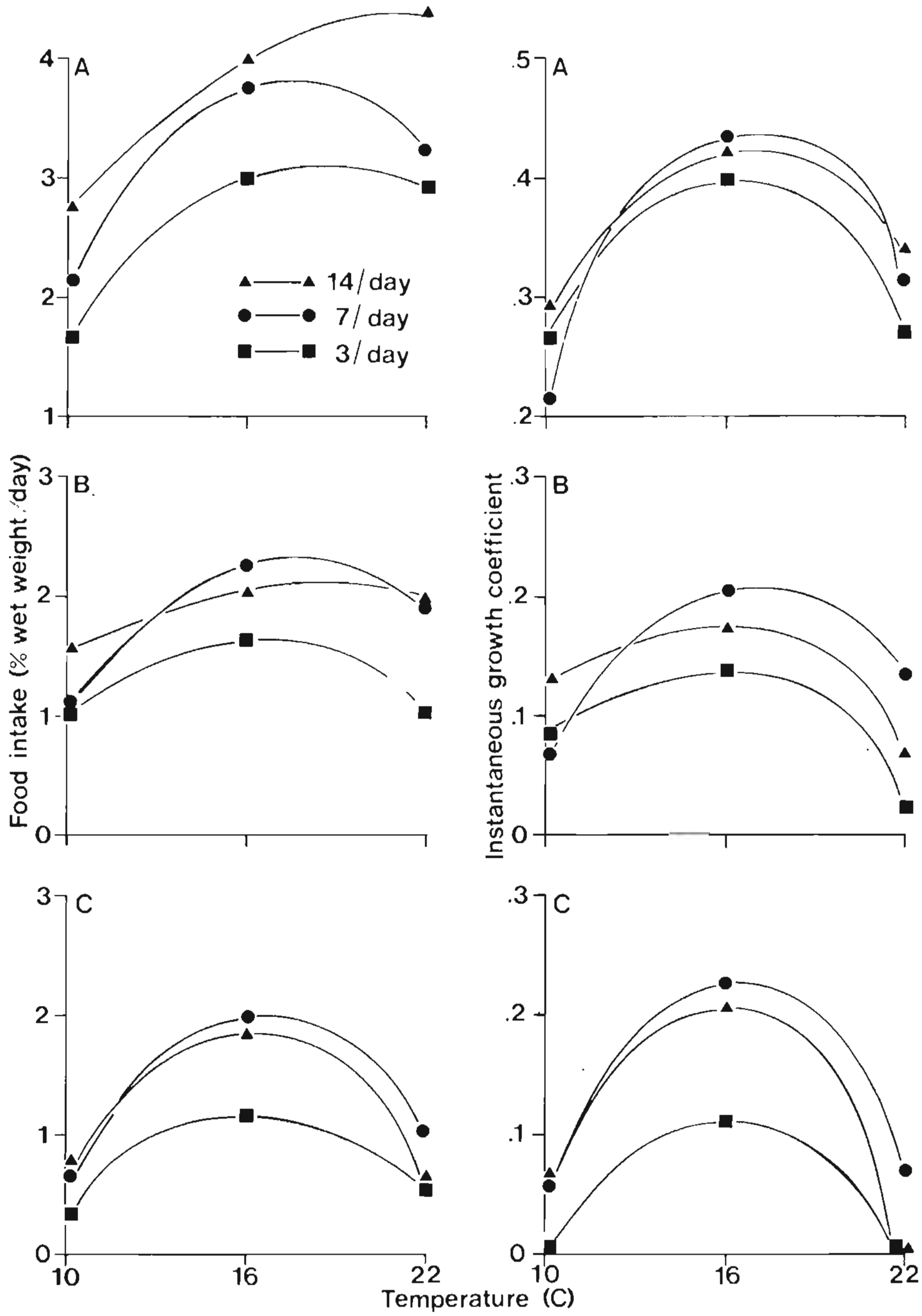

FIG. 1. Food intake (percentage of wet body weight/day) and instantaneous growth coefficient of juvenile Atlantic salmon held at temperatures of 10°, 16° or 22°C and fed 3, 7 or 14 meals/day. (Salmon utilized in experiments A, B and C had mean initial weights of 1.4, 7.0 and 27.7 g, respectively.)

In Experiment B, daily food intake by salmon having an initial average weight of 7 g (Fig. 1) also increased with temperature from 10°-16°C. With a further temperature increase to 22°C, intakes showed a slight decline from those recorded at 16°C. Again food intake was greater over the 10°-22°C temperature range for groups fed 7 or 14 meals/day than for those fed 3 meals/day. Instantaneous growth coefficients for all groups increased with temperature to 16°C and then showed a marked decline at 22°C. Over the 10°-22°C range, growth rates were generally maximal for groups fed 7 meals/day, slightly lower for those fed 14 meals/day and lowest for those which consumed only 3 meals/day.

In Experiment C, for salmon of 27.7 g initial average weight (Fig. 1), daily food intake also increased with temperature to 16°C but showed a marked decline when temperature was further increased to 22°C. Food intake was greatest at all temperatures for groups fed 7 or 14 meals/day and lowest for those fed 3 meals/day. Instantaneous growth coefficients over the 10°-22°C range followed a similar pattern as observed for food intake and were maximal for groups fed 7 meals/day and minimal for those fed 3 meals/day.

GROSS CONVERSION EFFICIENCIES

In Experiment A, the gross conversion efficiencies (in energy equivalents) of salmon having an initial average weight of 1.4 g (Table 1) ranged from 25% to 39% and were dependent on water temperature and on the number of meals consumed per day. Efficiencies were generally greater for salmon held at 10° and 16°C than for those held at 22°C and greater for those fed 3 or 7 meals/day rather than 14 meals/day. The lowest conversion efficiency was recorded for salmon held at 22°C and fed 14 meals/day.

For salmon having an initial average weight of 7 g (Experiment B), conversion efficiencies ranged from 7% to 41% and were greatest for the groups held at 10° and 16°C and lowest for those held at 22°C. Efficiencies at a given temperature were

TABLE 1. The gross conversion efficiency (in energy equivalents) of juvenile Atlantic salmon which consumed 3, 7 or 14 meals/day when held at temperatures of 10°, 16° or 22°C.

Experiment	Meals/day	Temperature (°C)	Mean weight[1] (g)	Gross conversion efficiency[2] (%)
	3	10	1.26	38.4
	7	10	1.32	35.5
	14	10	1.53	33.5
	3	16	1.86	36.2
A	7	16	1.65	38.9
	14	16	1.83	27.9
	3	22	1.70	30.2
	7	22	1.68	30.1
	14	22	1.83	24.9
	3	10	6.70	27.5
	7	10	6.45	38.2
	14	10	7.33	41.4
	3	16	7.87	23.7
B	7	16	8.01	35.1
	14	16	8.60	36.9
	3	22	7.75	06.9
	7	22	7.44	25.5
	14	22	6.90	20.2
	3	10	28.36	19.1
	7	10	32.93	28.9
	14	10	26.01	19.2
	3	16	27.50	31.9
C	7	16	32.94	44.4
	14	16	27.10	30.3
	3	22	29.23	05.2
	7	22	26.54	28.9
	14	22	29.33	02.6

[1] Mean weight during the 10-day feeding trial.

[2] Gross conversion efficiency was calculated as:

$$\frac{\text{energy utilized for growth}}{\text{energy of food consumed}} \times 100$$

greater for salmon fed 7 or 14 meals/day than for those fed 3 meals/day.

Conversion efficiencies of the larger salmon having an initial weight of 27.7 g (Experiment C) ranged from 3% to 44% and were greatest for groups held at 16°C, intermediate for those held at 10°C and lowest for those held at 22°C. At a particular temperature, efficiencies were greatest for salmon fed 7 meals/day and considerably lower for those fed 3 or 14 meals/day.

The mean moisture and energy content of the groups of smaller salmon (Experiment A) ranged from 74.4% to 77.1% and from 21.76 to 23.66 kJ/g dry weight, respectively. Ranges of moisture and energy content for groups within Experiment B were from 74.2% to 77.1% and 22.76 to 24.07 kJ/g dry weight, respectively, and for those within Experiment C from 72.5% to 74.1% and from 23.60 to 24.93 kJ/g dry weight.

THE FEEDING GUIDE

The measurements of daily food intake by salmon held at temperatures of 10°, 16° and 22°C and fed 3, 7 or 14 meals/day were used to derive the regression:

$$(1)\quad \log_e I = -2.015 \log_e W + 0.808 \times 10^{-2} (T \times M) - 0.178 \times 10^{-4} (T^2 \times M^2) + 0.216 (T \times \log_e W) - 0.664 \times 10^{-2} (T^2 \times \log_e W) + 0.668$$

The coefficient of multiple determination (R^2) is 0.903, where I is daily food intake (percentage of wet body weight per day), T is water temperature (°C), W is mean salmon weight (g) and M represents the number of meals consumed per day (5, 21 df).

The response surface described by Equation 1 shows food intake increasing with temperature to 16°C for salmon of all weights and then decreasing as temperature continues to rise to 22°C. Predicted daily food intake by salmon over the 10°-22°C temperature range was generally greatest when they were fed 14 meals/day, slightly lower when fed 7 meals/day and lowest when consuming 3 meals/day. At all temperatures, food intake (percentage of wet body weight per day) decreased with increasing salmon weight.

The measurements of instantaneous growth coefficient for salmon held at 10°, 16° or 22°C and fed 3, 7 or 14 meals/day were used to derive the equation:

$$(2)\quad \log_e G = -4.066 \log_e IW + 0.020 (T \times M) - 0.604 \times 10^{-4} (T^2 \times M^2) + 0.490 (T \times \log_e IW) - 0.016 (T^2 \times \log_e IW) - 2.071$$

The coefficient of multiple determination (R^2) is 0.760, where G is the instantaneous growth coefficient during a 10-day period, IW is the mean initial weight (g) of a group of salmon at the beginning of that period, T is water temperature (°C) and M is the number of meals consumed per day (5, 21 df).

The response surface described by Equation 2 shows, for salmon of all weights, that growth rate increases with temperature to 16°C and then declines as temperature continues to rise to 22°C. Over the 10°-22°C temperature range, growth was generally greatest for salmon fed 7 or 14 meals/day and lowest for those fed 3 meals/day. The lowest growth coefficients were recorded for salmon which consumed 14 meals/day at 22°C.

The daily food intake (percentage of wet body weight per day) for salmon of 2-70 g, held at temperatures of 5°-21°C and fed 14 meals/day, were calculated from Equation 1 to derive the feeding guide (Table 2). The value of 7 substituted in the equation for meals per day would have also provided reliable estimates of daily food intake for use in the guide. Because all uneaten food particles had been counted, an estimate of the amount of waste food associated with the different feeding regimes was known. The relationship between the amount of waste food (percentage food fed per day) and salmon weight showed a curvilinear decrease with increasing fish weight. Thus, waste food represented about 30% of the amount fed each day to 2-g salmon, 20% of that presented to 10-g fish, and 10% of that fed to those ≥30 g. The daily intakes estimated from Equation 1 were increased by these percentages so that rations specified in the guide would represent a small excess and ensure maximal daily food intake by salmon under hatchery conditions. Rations for 5°-9°C were further increased by 20% and those for 10° and 11°C by 10%. These latter adjustments were considered necessary because rations at temperatures <10°C had been estimated by extrapolation of Equation 1 and a poor feeding response of any experimental groups held at 10°C could have resulted in under-estimates of ration level for salmon held at the lower temperatures. The feeding guide did not include rations for salmon weighing <2 g, since a small excess of food can be beneficial during the early feeding stages. In addition, because of the small biomass of salmon present at that time, only a small reduction in feed expenditure can be realized by strict adherence to a guide. A maximum weight of 70 g (19 cm fork length) was specified in the guide, because rate of adult survival is believed to increase with smolt weight at release to about 70 g, where survival reaches an asymptote with further weight increases (Ritter 1977). At temperatures < 5°C, the daily ration specified for 5°C can be used or reduced at the discretion of the manager.

TABLE 2. Atlantic salmon feeding guide (percentage of wet body weight per day).

Water temp. (°C)	Wet body weight (g)														
	2	5	10	15	20	25	30	35	40	45	50	55	60	65	70
	Percentage of wet body weight per day														
5	2.21	0.96	0.43	0.38	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.25	0.25
6	2.61	1.20	0.61	0.42	0.35	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
7	3.06	1.44	0.78	0.55	0.41	0.34	0.32	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
8	3.54	1.87	1.11	0.83	0.66	0.56	0.49	0.44	0.40	0.37	0.35	0.34	0.32	0.30	0.30
9	4.01	2.29	1.44	1.11	0.90	0.77	0.68	0.62	0.57	0.53	0.50	0.47	0.44	0.41	0.38
10	4.16	2.64	1.71	1.43	1.19	1.05	0.94	0.87	0.81	0.77	0.73	0.69	0.66	0.62	0.59
11	4.56	2.99	1.98	1.74	1.48	1.32	1.19	1.11	1.05	1.00	0.95	0.91	0.87	0.83	0.80
12	4.59	3.23	2.32	2.01	1.74	1.58	1.44	1.36	1.30	1.24	1.19	1.15	1.11	1.07	1.04
13	4.86	3.46	2.65	2.28	2.00	1.83	1.69	1.61	1.54	1.48	1.43	1.39	1.35	1.31	1.28
14	5.10	3.70	2.90	2.53	2.24	2.06	1.92	1.83	1.76	1.70	1.65	1.61	1.56	1.52	1.48
15	5.24	3.94	3.14	2.77	2.47	2.29	2.14	2.05	1.98	1.92	1.87	1.82	1.77	1.72	1.68
16	5.30	3.97	3.17	2.80	2.50	2.32	2.17	2.08	2.01	1.95	1.89	1.84	1.79	1.75	1.71
17	5.28	3.99	3.20	2.83	2.53	2.35	2.20	2.11	2.04	1.98	1.92	1.87	1.82	1.78	1.74
18	5.17	3.81	3.00	2.63	2.34	2.16	2.02	1.93	1.86	1.80	1.75	1.70	1.65	1.60	1.56
19	4.98	3.62	2.80	2.43	2.15	1.97	1.83	1.75	1.68	1.62	1.57	1.52	1.47	1.42	1.37
20	4.72	3.27	2.46	2.10	1.84	1.73	1.54	1.46	1.39	1.34	1.29	1.25	1.20	1.16	1.12
21	4.41	2.92	2.12	1.76	1.52	1.48	1.24	1.17	1.10	1.05	1.01	0.97	0.93	0.90	0.87

When automatic feeders are used, rations shown in the chart are to be divided to allow 14 feedings daily at one-hour intervals. When hand feeding, rations shown in the chart are to be divided to allow 7 feedings daily at two-hour intervals. For each hand feeding, best results will be obtained when food is slowly presented to each pond of salmon over a 2- to 3-minute period. At temperatures < 5°C, the rations specified for 5°C can be used or reduced at the manager's discretion. When temperatures are < 10°C or > 20°C, only 1-3 meals/day are required.

HATCHERY FEEDING TRIALS

Instantaneous growth coefficients during the 1979-80 trial were similar for the groups fed according to the manufacturer's guide and for those fed according to the new guide (Table 3). An exception occurred during the September 17-October 15 period, when a temperature-recording device malfunctioned and the ponds fed according to the new guide received less than the specified amount of food. This factor contributed to the slower growth rate by these groups during that period. By December 18, when growth of the salmon was minimal because of low water temperatures, the mean weight of salmon in the two ponds fed according to the new guide was 4.5 g less than that of those fed according to the manufacturer's guide. Some loss of food in the pond drains was seen to occur for all groups but the practice of feeding at 2-hour rather than at 1-hour intervals appeared to increase the loss. Feed efficiencies of the four groups were similar when water temperatures were within the range which is optimal for growth (14°-19°C), but were considerably better among the groups fed according to the new guide when temperatures were outside of this optimal range. Feed efficiencies of 0.55-0.57 during the November 19-December 18 period for the groups fed according to the new guide are probably not attainable and may have been the result of the low growth rate at that time and the variability inherent in our method of sub-sampling to determine the mean weight of the individuals within each pond. From a comparison of the daily rations specified in the new and manufacturer's guides (Table 3), it is apparent that at some temperatures the rations specified by the manufacturer can be reduced by one-half without sacrificing growth. However, at the temperatures which are optimal for growth, the two guides are in relative agreement on required ration levels.

During the feeding trials conducted in 1980-81, the ponds of salmon fed according to the new and manufacturer's guides received equal numbers of meals/day (from dawn to dusk at 30-minute intervals during August and at 45-minute intervals during the September-November period). This procedure reduced the loss of food in the pond drains which occurred during the 1979-80 trial, particularly when automatic feeders were set to deliver larger amounts of food 7 times/day (2-hour intervals). Again, daily rations specified in the manufacturer's chart were reduced because the salmon were not capable of consuming those amounts. Growth rates of salmon fed according to the manufacturer's guide (reduced) and of those fed according to the new guide were equal during all periods (Table 4). The former groups averaged 37 g by December 2 and the latter groups 38 g. Because the salmon which were fed according to the new guide received less food, their feed efficiency was superior to that of salmon which were fed according to the manufacturer's guide. Thus, average feed efficiency during the trial (August-February) for groups fed in accordance with the new guide was 1.14 and for those fed according to the reduced version of the

TABLE 3. Comparison of the new and manufacturer's feeding guides, from feeding trials conducted at the Mersey Hatchery during 1979-80.

Feeding period	Groups[1]	Water temp.[2] (°C)	Mean initial weight (g)	Ration fed[3] (%)	Ration specified[3] (%)	G[4]	Feed[5] efficiency
Jul 16-	New	20.2	3.3	3.6	3.3	2.64	1.43
Aug 13/79	New	20.2	3.4	3.8	3.3	2.53	1.57
	Man.	20.2	3.1	4.5	6.9	2.65	1.79
	Man.	20.2	3.3	5.1	6.9	2.89	1.86
Aug 13-	New	19.4	6.9	2.8	2.8	2.08	1.42
Sep 17/79	New	19.4	6.9	2.7	2.8	2.12	1.31
	Man.	19.4	6.5	3.0	5.1	2.27	1.39
	Man.	19.4	7.4	3.2	5.1	2.24	1.52
Sep 17-	New	14.4	14.3	2.0	2.2	1.84	1.15
Oct 15/79	New	14.4	14.5	1.8	2.2	1.83	1.03
	Man.	14.4	14.4	2.4	2.7	2.07	1.20
	Man.	14.4	16.2	2.3	2.7	1.99	1.19
Oct 15-	New	10.0	23.9	1.1	0.9	0.87	1.32
Nov 19/79	New	10.0	24.2	1.1	0.9	0.79	1.44
	Man.	10.0	25.7	1.8	2.0	0.89	2.04
	Man.	10.0	28.3	1.7	2.0	0.68	2.67
Nov 19-	New	5.0	32.4	0.1	0.2	0.25	0.55[6]
Dec 18/79	New	5.0	31.9	0.1	0.2	0.25	0.57[6]
	Man.	5.0	35.2	0.5	1.1	0.37	1.21
	Man.	5.0	35.9	0.4	1.1	0.28	1.57
Dec 18/79-	New	1.1	34.8	0.04	0.2	-0.05	-
Mar 17/80[7]	New	1.1	34.2	0.04	0.2	0.00	-
	Man.	1.1	39.1	0.08	-[8]	-0.03	-
	Man.	1.1	38.9	0.08	-[8]	-0.02	-

[1]New = new feeding guide; Man. = manufacturer's feeding guide.

[2]Mean temperature during period.

[3] $\frac{\text{Wet food weight}}{\text{Wet fish weight}} \times 100$

[4]Instantaneous coefficient of growth calculated as: $\frac{\log_e W_2 - \log_e W_1}{\Delta t} \times 100$

where: W_1 and W_2 are the initial and final mean weights during the period t measured in days.

[5] $\frac{\text{Weight of food fed during period}}{\text{Weight gain by fish during period}}$

[6]See discussion in text.

[7]Feeding dependent upon weather and ice conditions.

[8]Manufacturer's guide does not specify rations for temperatures <2.2°C.

TABLE 4. Comparison of the new and manufacturer's feeding guides, from feeding trials conducted at the Mersey Hatchery during 1980-81.

Feeding period	Groups[1]	Water temp.[2] (°C)	Mean initial weight (g)	Ration fed[3] (%)	Ration specified[3] (%)	G[4]	Feed[5] efficiency
Aug 5-	Man.	20.0	8.8	2.7	4.0	2.54	1.16
Sep 2/80	Man.	20.0	8.0	3.1	5.5	2.17	1.53
	Man.	20.0	6.5	3.5	5.5	2.48	1.53
	New	20.0	9.0	2.3	2.3	2.17	1.16
	New	20.0	9.4	2.0	2.2	2.30	0.94
	New	20.0	7.5	2.5	2.4	2.31	0.95
Sep 3-	Man.	17.8	17.9	2.1	3.5	1.50	1.48
Sep 30/80	Man.	17.8	14.7	2.2	3.5	1.89	1.24
	Man.	17.8	13.0	2.1	3.5	2.03	1.08
	New	17.8	16.5	2.1	2.2	1.57	1.39
	New	17.8	17.9	1.8	2.3	1.38	1.36
	New	17.8	14.3	2.1	2.4	1.92	1.15
Oct 1-	Man.	11.7	26.8	1.5	1.8	0.96	1.62
Oct 29/80	Man.	11.7	24.5	1.5	1.8	1.18	1.29
	Man.	11.7	22.5	1.4	1.8	1.28	1.18
	New	11.7	25.2	1.6	1.4	1.08	1.55
	New	11.7	26.0	1.4	1.4	1.08	1.34
	New	11.7	24.0	1.4	1.4	1.33	1.08
Oct 30-	Man.	4.4	35.1	0.8	1.0	0.22	3.65
Dec 1/80	Man.	4.4	34.1	0.7	1.0	0.36	1.92
	Man.	4.4	32.2	0.6	1.0	0.29	2.43
	New	4.4	34.1	0.3	0.2	0.31	1.10
	New	4.4	35.2	0.3	0.2	0.24	1.44
	New	4.4	34.8	0.3	0.2	0.30	0.99
Dec 2/80-	Man.	1.6	37.7	0.06	-[7]	0.09	-
Feb 22/81[6]	Man.	1.6	38.2	0.07	-[7]	0.06	-
	Man.	1.6	35.3	0.07	-[7]	-0.08	-
	New	1.6	37.7	0.04	0.2	-0.05	-
	New	1.6	38.0	0.03	0.2	0.04	-
	New	1.6	38.3	0.03	0.2	-0.10	-

[1]New = new feeding guide; Man. = manufacturer's feeding guide.

[2]Mean temperature during period.

[3] $\frac{\text{Wet food weight}}{\text{Wet fish weight}} \times 100$

[4]Instantaneous coefficient of growth calculated as: $\frac{\log_e W_2 - \log_e W_1}{\Delta t} \times 100$

where: W_1 and W_2 are the initial and final mean weights during the period t measured in days.

[5] $\frac{\text{Weight of food fed during period}}{\text{Weight gain by fish during period}}$

[6]Feeding dependent upon weather and ice conditions. Salmon could not be fed on 21 days of this period.

[7]Manufacturer's guide does not specify rations for temperatures $< 2.2°C$.

manufacturer's guide, 1.45. It is estimated that feed efficiency would have been 2.06 if the daily rations specified in the manufacturer's guide had not been reduced.

DISCUSSION

Some factors of importance which affect the growth rate and maximum daily food intake of fishes include water temperature, fish size, diet composition, the number of meals consumed per day and feeding interval (Brett 1979). Regarding temperature, Brett and Higgs (1970) have demonstrated that food intake, gross conversion efficiency and growth rate of fingerling sockeye salmon (Oncorhynchus nerka) increase with temperature to 15°C and then decline with further temperature increases to 24°C. The slow rate of digestion at low temperatures limits appetite and thus growth, while at high temperatures the combination of declining appetite and conversion efficiency, coupled with increases in metabolic expenditure, are limiting for growth.

Although we have used only three experimental temperatures, a similar pattern is apparent for the food intake and growth rate of juvenile Atlantic salmon. These processes appear to increase with temperature to the 14°-18°C range, before declining with further temperature increases (Fig. 1). The shape of the food intake and growth curves with temperature suggest that maximal rates of these processes may be near the upper part of the 14°-18°C temperature range for smaller juvenile salmon (≤7 g), shifting to the lower part of the range for larger salmon (≥28 g). Although maximal growth rates of sockeye salmon were observed to occur within the same temperature range as observed for Atlantic salmon, the optimal temperature for growth was not influenced by their weight, which ranged from 0.3 to 500 g (Brett 1974). Temperatures between 13° and 18°C also resulted in maximal food intake by brown trout (S. trutta) offered one meal per day (Elliott 1975). Because rate of digestion increases with temperature, maximum daily intake by this species occurred at the highest temperature (18°C) when several meals were consumed each day. The loss of appetite by Atlantic salmon at 22°C was also observed to occur for brown trout at temperatures >19°C.

Brett (1979) shows the relation between growth rate and ration level for juvenile sockeye salmon as a curve which rises from a minimum negative growth rate at zero ration to cross a point of zero growth at the maintenance ration. Growth rate continues to rise with further increases in ration to pass through the optimum ration (where the growth rate:ration ratio is maximal) before beginning to flex at higher rations. With further increases in ration, the curve reaches a plateau of maximum growth at the maximum ration. In most cases, the higher the ration level of fishes, the greater is their growth rate (Brett and Groves 1979). Because of this fact and the low water temperatures during the winter which limit the growth of salmon at Maritime hatcheries, maximal rations are fed during the remainder of the year to maximize growth. At some locations, this has resulted in the production of smolts (12-20 cm) after one year of feeding without the use of heated water. No attempt has been made to maximize the growth:ration ratio by feeding sub-maximal or optimal rations, because sea-survival of cultured salmon increases with their size at release up to a fork length of about 19 cm (Ritter 1977). Development of a guide specifying optimal daily rations for use at stations which presently produce 2-year-old smolts > 20 cm might prove beneficial in terms of reducing food expenditures and pond densities.

The relation between gross conversion efficiency and ration follows a dome-shaped curve, so that efficiency is zero at the maintenance ration and the peak of the dome corresponds to the optimal ration (Brett 1979). In the range of the dome, there is a lower ration (below the optimal ration) and a higher ration (up to the maximal ration) which result in the same conversion efficiency. At temperatures below 10°C, conversion efficiency reaches a peak at an intermediate ration while at 17°C and above the highest efficiency occurs near the maximum ration (Brett and Groves 1979). Similarly, conversion efficiencies of salmon in our study were generally maximal and equal at 10° and 16°C despite the greater rate of food intake which occurred at 16°C. In all cases, conversion efficiency was lowest at 22°C.

In their calculations of the average partitioning of the dietary energy of carnivorous fishes feeding above the maintenance level, Brett and Groves (1979) suggest that the value 29% ± 6% is indicative of the gross conversion efficiency of young, fast-growing fish and is a reflection of adequacy of diet, ration level, state of health and environmental suitability. The mean conversion efficiency of 28%, measured for Atlantic salmon fed a Silver Cup diet in our laboratory, was markedly similar to the value given by Brett and Groves (1979), despite the low conversion efficiencies which were observed for Atlantic salmon held at 22°C.

When daily food intake is expressed on a dry-weight basis (dry food weight/dry fish weight x 100) for purposes of comparison, small salmonids (< 3 g wet weight) held at temperatures near 15°C are able to consume food at a rate of about 20% of their body weight/day, while larger salmonids (> 1,000 g wet weight) frequently require less than 1%/day to satisfy their energy demands (Brett 1979). Maximal daily food intakes by Atlantic salmon held at 10° and 15°C were estimated for individuals of 2-50 g wet weight from Equation 1, and the values were expressed on a dry-weight basis for comparison with the maximal intakes recorded for sockeye salmon (Brett 1971) and for brown trout (Elliott 1975) (Fig. 2). This comparison provides some indication of the adequacy of our experimental methods and of

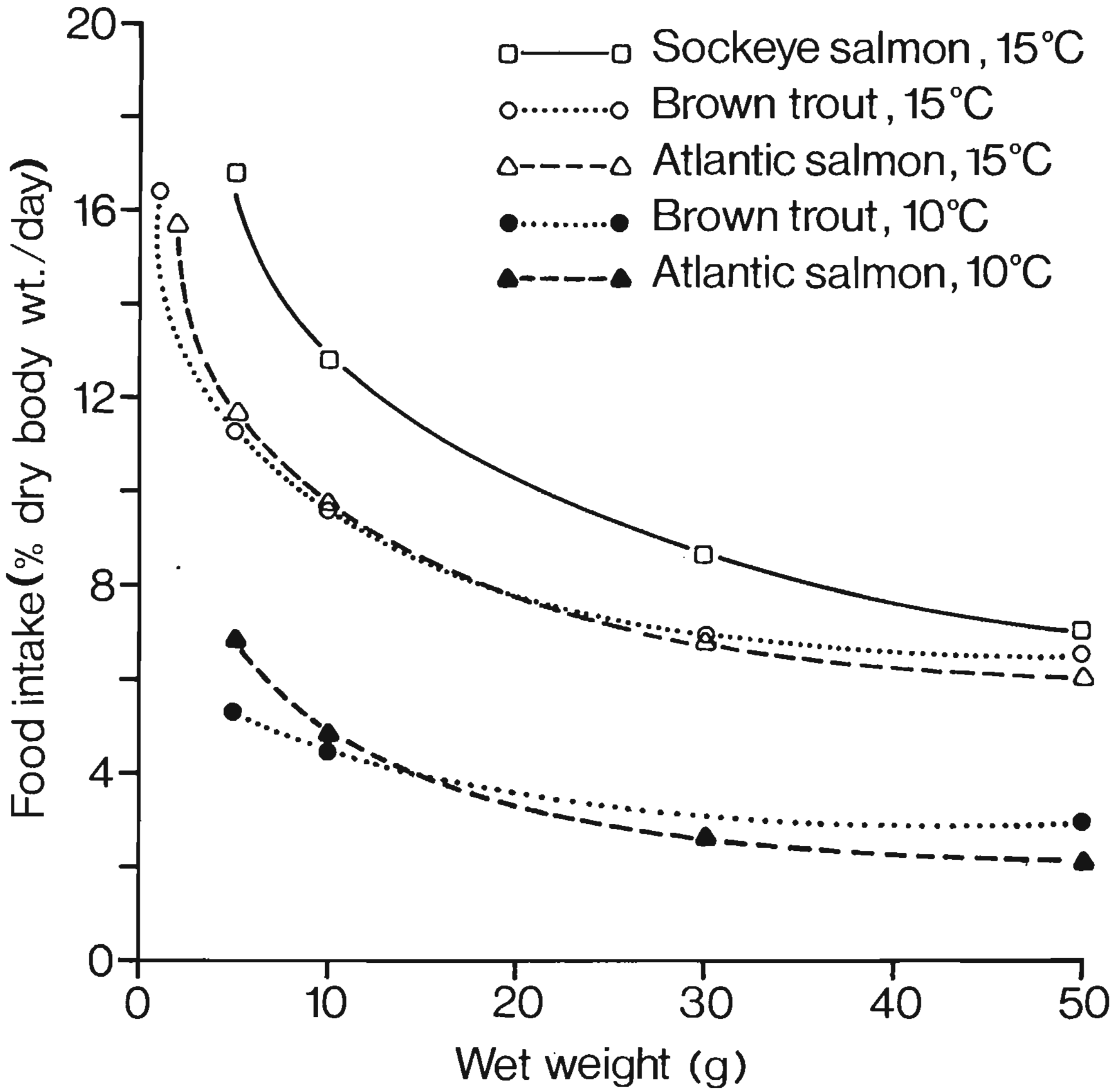

FIG. 2. Maximum food intake (percentage of dry body weight/ day) of Atlantic salmon, brown trout (Elliott 1975) and sockeye salmon (Brett 1971) of 1-50 g wet weight, when held at temperatures of 10° and 15°C.

the accuracy of the data from which the feeding guide was derived. Maximal intakes for these three species are similar at 15°C and decrease from the 15.7% to 16.9%/day range for individuals of 1-4 g wet weight to the 6.0% to 6.9%/day range for those of 50 g wet weight. Intakes at 10°C for S. salar and S. trutta were also markedly similar over the 5- to 50-g weight range.

The sockeye salmon utilized in Brett's (1971) experiments were given Abernathy pellets at 2-minute intervals for periods of up to 1 hour. This procedure was repeated three times daily and provided the salmon with an unlimited opportunity to feed because they were presented with 3-4 times the amount of food that they actually consumed. The slightly greater intakes observed for O. nerka compared with those recorded for S. salar (Fig. 2) may be attributable to the lower energy content of the Abernathy pellets consumed by the sockeye salmon, to the method of food presentation, to a species difference or a combination of these factors. Regarding diet energy content, fish, like other animals, eat to satisfy their energy requirements (Rozin and Mayer 1961) and are able to compensate for a diet of low energy density by feeding at a higher rate. Maximum intakes recorded for brown trout and Atlantic salmon were also markedly similar despite differences in diet composition, method of diet presentation and feeding interval. The brown trout were fed to satiation four times daily with a crustacean (Gammarus pulex) which had a lower energy content than Silver Cup food. Despite these differences, maximum intakes, expressed on a dry-weight basis, are markedly similar for the three salmonids and suggest that the data used to derive the Atlantic salmon feeding guide are representative of the maximum level of food intake for that species.

The laboratory studies of Ishiwata (1968), Brett (1971) and Elliott (1975) indicate that the satiation time of fishes can vary from periods of <15 minutes to 1 hour and is dependent upon such factors as the weight or age of a particular species, water temperature, feeding interval, particle size and diet energy content. During our laboratory experiments, satiation time for each particular meal was always <10 minutes, regardless of temperature and feeding interval; while at the Mersey Hatchery, where automatic feeders were employed during testing of the guide, salmon generally had <5 minutes to consume a particular meal. It is apparent from the previous comparison of food intake by different salmonids and from the feeding trials at the Mersey Hatchery that maximal daily intakes of food can result from two different feeding strategies: (1) by providing small meals frequently at regular intervals and allowing the fish a brief time period to consume each meal (<10 minutes); (2) by increasing the feeding interval to provide fewer but larger meals, which are presented slowly over a longer time period (>10 minutes).

The practice of feeding at 2-hour intervals (7 meals/day) appeared to maximize the food intake, conversion efficiency and growth rate of the salmon utilized in our laboratory experiments. Although the food intake of salmon fed at 1-hour intervals (14 meals/day) was also maximal, their conversion efficiency and thus growth rate was slightly lower, presumably because of increased metabolic costs associated with more frequent feedings. The food intake of salmon presented with meals at 4-hour intervals (3 meals/day) was generally below that which resulted in maximal growth. The number of meals per day which maximized the daily food intake and growth of the six species studied by Kono and Nose (1971) ranged from 2 to 12. They concluded that the suitability of different time sequences of feeding was influenced by stomach size and that fish lacking stomachs or those with small stomachs required more frequent feeding. Carnivorous species such as trout or salmon that possess well-developed stomachs which temporarily store food require meals less frequently (Goddard and Scott 1980). For example, when automatic feeders were used to disperse food from 1 to 24 times/day, the growth and conversion efficiency of 50-g channel catfish (Ictalurus punctatus), a species possessing a well-developed stomach, were found to be greatest when they fed to satiation twice/day (28°C) (Andrews and Page 1975). Catfish fed most frequently had lower growth rates and conversion efficiencies. In contrast, the continuous feeding of 0.9-g sockeye salmon fry for 15 hours/day (20°C) resulted in significantly more growth than when they were fed to satiation three times daily (Shelbourn et al. 1973). Thus, the number of meals per day and the feeding interval that results in the maximal food intake and growth of fishes is variable and dependent upon several factors, such as species, age, diet composition, pond density, method of food presentation and water temperature.

The previous experiments and ours suggest that, except for very young stages such as salmon fry, feeding at hourly intervals or more frequently may not always be necessary. In this context, Brett and Higgs (1970) have demonstrated for juvenile sockeye salmon held at 20°C that only 25% of a meal has been digested 1 hour after feeding. However, at hatcheries, salmonids may not always be graded to size, their densities may be relatively great, and they are often presented with food by automatic feeders. These conditions do not ensure an even distribution of food or its availability to all individuals and may necessitate the feeding of more than 7 meals/day (2-hour intervals), a practice which was found to be optimal in our laboratory experiments.

To test our feeding guide and the strategy of feeding at 2-hour intervals (7 meals/day), two ponds of salmon at the Mersey Hatchery received food every two hours from automatic feeders, according to the rations specified in the new guide;

while two ponds received meals at 1-hour intervals (14 meals/day), according to the rations shown in the manufacturer's guide (manufacturer's rations were reduced). Growth rates of the different groups were quite similar despite the greater rations which were received by those fed according to the manufacturer's guide. At the end of the 8-month feeding trial, the average weight of the groups fed in accordance with the manufacturer's guide exceeded that of those which had been fed the rations specified in the new guide by 4.5 g. Part of this weight difference was probably attributable to the differing amounts of food which were lost in the pond drains. In this context, the groups fed at 2-hour intervals received almost twice as much food per meal as groups fed at 1-hour intervals. Because automatic feeders delivered each meal during a relatively brief period (<1 minute), some food was observed to escape in the pond drains before being consumed by salmon, particularly in those ponds which received food 7 times/day (2-hour intervals). Replacement of the timing devices which control the automatic feeders to allow an intermittent delivery of each meal over a longer period of approximately 2-3 minutes would probably reduce the loss of food. In addition, deflectors can be installed to prevent the feeders from delivering portions of each meal in the area of the central pond drains. However, when pond densities are high and automatic feeders are used without these modifications, our data suggest that feeding needs to be performed at about hourly intervals (approximately 14 times/day) when temperatures are near the optimum for growth, to ensure that food is made available to all fish. Presumably, maximal growth rates can be attained at stations where hand-feeding is practiced by using the new feeding guide in conjunction with a 2-hour feeding interval (7 meals/day). When water temperatures are <10°C or 20°C only 1-3 meals/day are required. Rations for salmon weighing <2 g were not specified in the guide because it may be beneficial to ensure that a small excess of food is available for fish of that size, as they digest and assimilate it rapidly in response to the demands of rapid growth.

Studies conducted at the Mersey Hatchery during 1980-81 suggest that feeding more than once per hour may be beneficial when automatic feeders are being used. For example, groups of salmon fed at 30-minute intervals during August and at 45-minute intervals during September, October and November, according to the rations specified in the new guide, grew at a slightly greater rate than did the experimental groups during the 1979-80 feeding trial. However, other factors, such as yearly variation in temperature regime, food quality and pond densities, might also account for part of the year-to-year difference in growth rate. Most importantly, the more frequent feedings during 1980-81 did not result in a reduction in growth rate and the groups fed according to the manufacturer's and the new guide grew at equal rates. Feed efficiency during the trial period was 1.45 for the groups fed according to the manufacturer's guide and 1.14 for those fed the daily rations specified in the new guide. It is estimated that feed efficiency of the former groups would have been 2.06 if the specified rations had not been reduced.

Our feeding guide, derived from laboratory experiments, provides an approximation of the amount of dry food required for the maximal growth of juvenile Atlantic salmon. The daily rations are quite similar to those specified in a feeding guide derived at the Mactaquac Hatchery from observations of feeding behaviour and growth rate during several years of operations (J.W. McAskill, pers. comm.[1]). Managers of Atlantic salmon hatcheries are encouraged to modify the guide for their own use, when experience indicates that ration adjustment will enhance growth rate and feed efficiency. The use of the guide for feeding diets which vary appreciably in moisture (5%-7%) or energy content (19.9-20.4 kJ/g wet weight) from the diet used in our experiments could result in salmon receiving either excessive or sub- optimal amounts of food. In addition, daily rations specified in the guide may not always be applicable to other salmonids. For example, domestic strains of rainbow trout and brook trout (*Salvelinus fontinalis*) cultured at Maritime hatcheries have been observed to consume greater daily rations than do Atlantic salmon.

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