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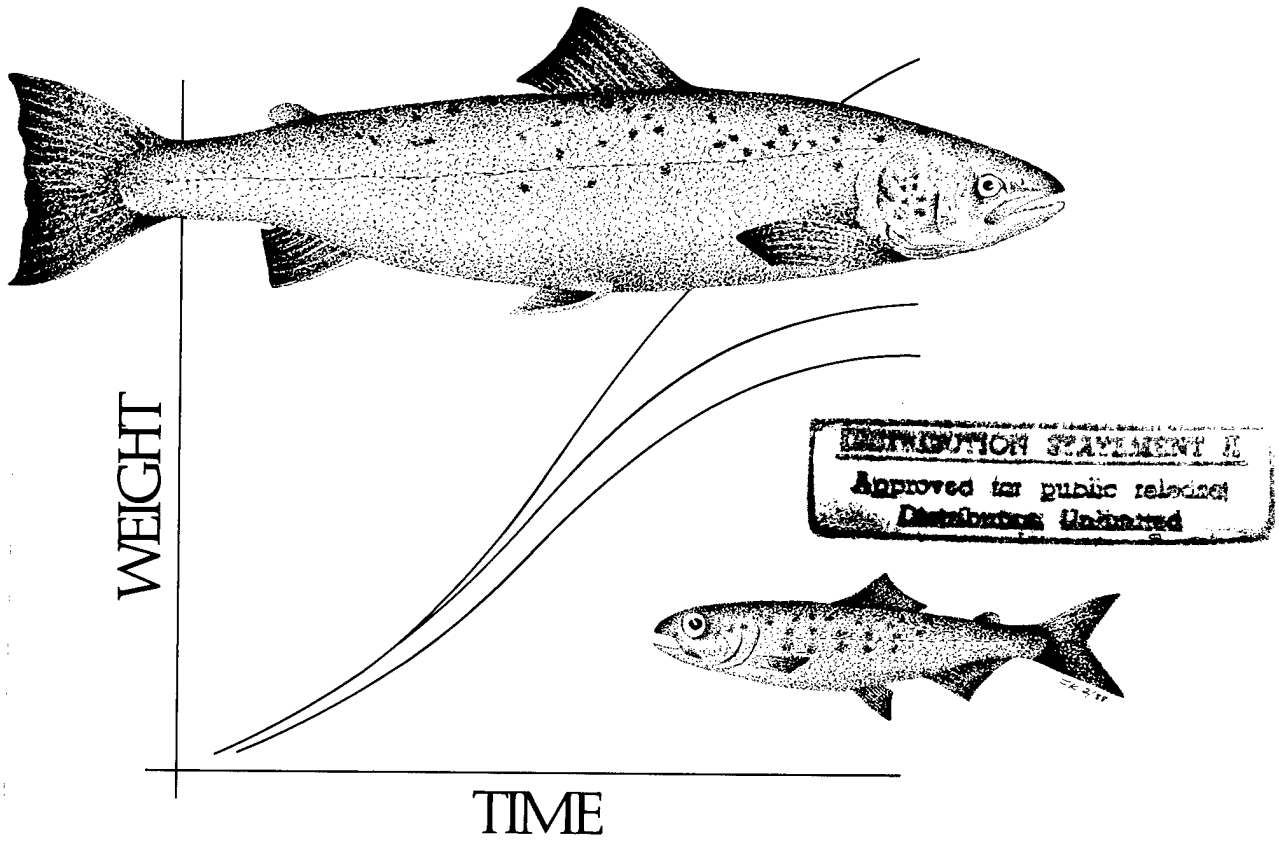
GROWTH, COMPOSITION, AND FIN QUALITY OF ATLANTIC SALMON FED DIFFERENT DIETS AT SEASONAL TEMPERATURES IN A LABORATORY AND HATCHERY



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Biological Report

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Growth, Composition, and Fin Quality of Atlantic Salmon Fed Different Diets at Seasonal Temperatures in a Laboratory and Hatchery

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Growth, Composition, and Fin Quality of Atlantic Salmon Fed Different Diets at Seasonal Temperatures in a Laboratory and Hatchery

Introduction

An understanding of the nutrition of Atlantic salmon (*Salmo salar*) is essential to the economical rearing of smolts that will survive in the ocean. Various investigations have shown that the nutritional status of Atlantic salmon during early life influences marine survival. Foda and Ritter (1977) and Peterson (1973) showed that the composition of the diet fed Atlantic salmon during hatchery rearing significantly affected the return of adults. Other nutritional studies have indicated that young Atlantic salmon thrive on a diet with about 45% to 50% usable protein and 23–27% unsaturated lipids from marine fishes (Bergstrom 1973; Lall and Bishop 1977; Lemm 1983; Peterson 1971; Sutterlin and Merrill 1978).

Inasmuch as various researchers have stressed the importance of smolt quality on survival at sea (Burrows 1969; Carlin 1968; Isaksson 1980; Penney 1976; Peterson 1971; Ritter and Carey 1980), the assessment of overall condition or quality of the fish is a major consideration in a smolt rearing program.

Diets that provide suitable nutrition when food intake is high may become inadequate when food intake is reduced, as it is during periods of low temperature. Although optimum temperature for growth of *Salmo* spp. is between 10° and 20°C (Huet 1972), the temperature of natural fresh waters in temperate North America is regularly 0–4°C for 3–4 months in winter. During this period, poor nutrition often causes losses in weight and general condition. Bergstrom (1973) reported that winter mortality of juvenile Atlantic salmon fed diets containing 4%, 8%, or 12% lipid was highest when the lipid content of the diet was 4% and lowest when it was 12%. In chinook salmon (*Oncorhynchus tshawytscha*) held at 5.2°C, mortality was lowest and growth fastest when the diet contained 50% protein and 20% lipid (Fowler 1980).

Although commercial diets specifically formulated for Atlantic salmon have been readily available in Europe (e.g., EWOS in Sweden, TESS in Norway), no comparable feeds have been marketed in the United States. Commercial diets used for rearing other salmonids in the United States have not been fully successful for Atlantic salmon (Lemm and Hendrix 1981).

In the present 2-year, two-part study, we compared growth and general quality of Atlantic salmon fed different diets and held at seasonal temperatures of 1–18°C. The fish were fed six diets in the laboratory at the National Fishery Research and Development Laboratory (NFRDL) and four of the same diets at the Green Lake (Maine) National Fish Hatchery (NFH) under production conditions. We examined the utility of various factors in evaluating the quality of the fish produced: fin condition, proximate composition (especially lipid content), histology of certain tissues, and sodium regulation.

Materials and Methods

Procedures in the Laboratory

Fish used in this experiment were progeny of sea-run Atlantic salmon from Green Lake NFH that were reared to a total length of about 5 cm at NFRDL. Groups of 200 fish were weighed, counted, and randomly assigned to 18 474-L circular tanks in which water temperature was 13.2°C. All fish were fed the Abernathy diet during a 2-week acclimation period. On the first day of the study (3 September 1981), each group of fish was removed from its tank and weighed, and the weight of the 200 fish adjusted so that the starting weight of the fish in each tank was 2.1 ± 0.2 g (mean $\pm$ SE).

Each tank was fitted with a center standpipe and a lid that covered two-thirds of the surface area with screen and one-third with plywood. Well water (7–9°C) and stream water (1–20°C) were mixed to produce a total inflow of water at 20 L/min. Except during the high and low seasonal temperature extremes, water temperature in the laboratory study was adjusted to simulate seasonal water temperatures in Atlantic salmon hatcheries in the northeastern United States (Fig. 1). An outside photocell controlled overhead fluorescent lights to simulate natural day length. Light intensity at the tank water surface was 10–15 lux. Total hardness of the water from the two sources was 30–40 mg/L (as $CaCO_3$) and pH was 6.8–7.3; dissolved oxygen was maintained above 90% saturation and total dissolved gas at $\leq 103\%$ saturation.

Test diets (Table 1) included two closed-formula commercial diets – BioDiet from BioProducts, Warrenton, Oregon, and a commercial salmon diet (here termed COMSD) from Murray Elevators, Murray, Utah – and four open-formula diets of the U. S. Fish and Wildlife Service : the Atlantic salmon diet ASD2-30, an Abernathy salmon diet (mixture of A18 and A19), and two trout growth diets prepared with either cottonseed meal (TGC) or soybean meal (TGS). Each diet was randomly assigned to three groups of fish. Proximate composition of the diets was determined according to standard procedures of the Association of Analytical Chemists (Horwitz 1975) and gross energy was measured with a Parr calorimeter. All diets were obtained as needed and kept frozen until used.

Fish were fed a specified percentage of body weight daily, based on water temperature and fish size, as suggested for Murray Elevators salmon feeds by the manufacturer on the basis of work done by Deuel et al. (1952). During part 1 of the study (weeks 1–34), feed was dispensed hourly from 0800 to 1700 hours each day from MODO automatic feeders. Thereafter, during part 2 (weeks 35–82), all fish were hand-fed four times per day when the water temperature was 5°C or higher and twice daily when it was below 5°C. At 2-week intervals, all fish in each tank were removed and weighed, and daily feeding rate was adjusted for increased biomass. Fish in each tank were counted and weighed monthly until they were at least 10 cm long, and every 2 months thereafter; after weighing we reduced the number of test fish (when necessary), to maintain a biomass of 4.8 kg or less per square meter of tank bottom area. Dead fish were removed and mortalities recorded daily. Although tanks were essentially self-cleaning, they were brushed with crystalline table salt whenever the fish were removed to be counted and weighed.

At the end of part 1 (week 34), we weighed, counted, and sorted all fish in each tank into two length groups, one of fish ≥ 14 cm long and the other of smaller fish. The larger fish, which were designated as 1-year smolts, were removed from the study. Fish shorter than 14 cm that had been fed the same diet were then pooled. From this pooled group, 3 samples of 75 fish each were randomly drawn, weighed, and returned to the test tanks for part 2 of the study. Growth data for part 1 and part 2 were handled separately.

Fin condition was evaluated at the beginning of the study and before and after each of the two winters. A random sample of 20 to 25 fish was removed from each tank (total of 60 to 75 fish per diet) and anesthetized with tricaine methanesulfonate (1:20,000); each fish was weighed to the nearest 0.1 g, measured to the nearest millimeter, and examined to determine the condition of the dorsal, caudal, and pectoral fins. The fins were scored according to procedures established by Roger Dexter at Craig Brook (Maine) NFH (personal communication) and later modified by Lee Peterson at

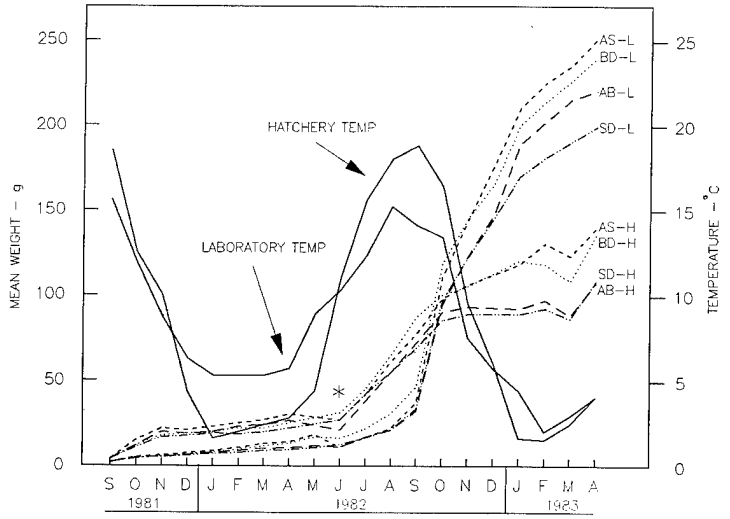

Fig. 1. Growth of Atlantic salmon fed the same diets (AS = ASD2-30, BD = BioDiet, AB = Abernathy, SD = COMSD) and reared under seasonal temperatures at the National Fishery Research and Development Laboratory (L) and at the Green Lake National Fish Hatchery (H). Asterisk indicates point when fish 13-14 cm long or longer were removed (see text for discussion).

Table 1. *Composition (% wet weight) of U.S. Fish and Wildlife Service open-formula diets.*[a]

		Trout growth (TG) diets		
	Abernathy salmon	With soybean meal (TGS)	With cottonseed meal (TGC)	ASD2-30
Fish meal (65-67.5% protein)	50-55.0	35.0	35.0	----
Herring meal (protein ≤ 67.5%)	----	----	----	50.0
Soybean flour	----	----	----	20.3
Soybean meal	----	30.0	----	----
Cottonseed meal	----	----	30.0	----
Dried whey	10.0	----	----	----
Shrimp meal	5.0	----	----	5.0
Blood flour	5.0	10.0	10.0	10.0
Wheat flour	----	15.3	15.3	----
Wheat middlings	9.0-14.0	----	----	----
Brewer's yeast	5.0	----	----	----
Fish oil	9.0	7.0	7.0	12.0
Pellet binder	----	2.0	2.0	2.0
Vitamin and mineral supplement	2.0[b]	0.75[c]	0.75[c]	1.0[c]

[a]The exact composition of the two commercial (closed-formula) diets used in this study (BioDiet and COMSD) are not known. The general composition follows. BioDiet: fish meal, cooked hydrolyzed fish and krill, delactosed whey, fish oil, wheat germ meal, carboxymethylcellulose, wheat gluten, crab meal, and a vitamin supplement. COMSD: animal protein products, plant protein products, processed grain, lecithin, fish oil, soybean oil, lignin sulphonate, salt, and a vitamin and mineral supplement.

[b]Vitamins (mg/kg of diet unless otherwise specified): ascorbic acid, 891; d-biotin, 0.59; vitamin B12, 0.06, cholin, 3500; folacin, 12.7; myoinositol, 264; vitamin K, 11; niacin, 220; d-pantothenate, 105.6; pyridoxine HCl, 30.8; riboflavin, 52.8; thiamine, 42.9; vitamin E 502 IU; vitamin A 6600 IU; vitamin D3, 440 IU. Minerals (mg/kg of diet): $ZnSO_4$ $7H_2O$, 184.8; $MnSO_4$ H_2O, 206.8; $FeSO_4$ $7H_2O$, 49.5; KIO_3, 0.8; $CuSO_4$ $5H_2O$, 3.9.

[c]Vitamins (mg/kg of diet unless otherwise specified): ascorbic acid, 750; d-biotin, 0.35; vitamin B12, 0.02; choline, 1125; folacin, 8.8; vitamin K, 11; niacin, 220; d-pantothenate, 105; pyridoxine HCl, 30; riboflavin, 52.8; thiamine, 35.2; vitamin E, 352 IU; vitamin A, 6600 IU; vitamin D3, 440. Minerals (mg/kg of diet): $ZnSO_4$ $7H_2O$, 184.8; $MnSO_4$ H_2O, 206.8; $FeSO_4$ $7H_2O$, 49.5; KIO_3, 0.8; $CuSO_4$ $5H_2O$, 3.9.

the Green Lake NFH (personal communication). In part 1 of the study only the dorsal fin was evaluated. This fin was compared to a silhouette of a typical, normal dorsal fin and given a score of 6 if complete and undamaged, 3 if 2/3 of the fin remained, 1 if 2/3 to 1/3 of the fin remained and 0 if 1/3 or less of the fin remained. In part 2 of the study, a total fin score was obtained by summing the scores for the dorsal (different values from those used in part 1) and two pectoral fins. If all 3 fins were complete and undamaged the score was 21 (9 + 9 + 3). Scores for individual fins when different percentages of the fin remained are given in Table 2.

Liver, kidney, gill, and thyroid tissues of three fish from each diet group, removed at random at the beginning of the study and at the end of parts 1 and 2, were prepared for histological examination; they were preserved in Bouin's solution, embedded in paraffin, cut to 4 μm, and stained with hematoxylin and eosin.

Proximate composition of fish was determined from a composite sample collected at the beginning of the study and from samples of fish from each diet group collected during weeks 34 and 56 and at the end of the study (week 82). Moisture content was determined by measuring the water loss of fish when they were freeze-dried. Lipids were measured after extraction for 7 h with chloroform-methanol (2:1) in a Goldfisch fat extraction apparatus (Folch et al. 1957). Protein and ash were determined according to standard procedures of the Association of Official Analytical Chemists (Horwitz 1975).

We made seawater challenges monthly, March to August, during part 2 of the study, using the procedure developed by Clarke and Blackburn (1977) to distinguish parr from smolts by measuring the ability of the fish to regulate blood sodium after a 24-h exposure to seawater. We weighed and measured three fish from each diet group, marked their caudal fins with a hand-held paper punch, and transferred them directly into individual 20-L buckets containing 30-33‰ Jungle synthetic sea salt. A central chilling unit regulated the

Table 2. *Fin evaluation scores used in part 2 of the laboratory study of Atlantic salmon diets. A silhouette of a typical, fully developed fish was used in estimating the amount of erosion and assigning a score.*[a]

	Percent of fin remaining				
Fin	100	90	90-75	75-50	50
Dorsal	3	2	1	0	0
Left pectoral	9	8	6	3	0
Right pectoral	9	8	6	3	0

[a] In part 1 (weeks 1–34) of the study, scores (0 to 6) were based only on the fraction of the dorsal fin remaining. The fractions and score follow: all, 6; 2/3, 3; 2/3 to 1/3, 1; and 1/3 or less, 0. In part 2 (weeks 35–82) the total fin score was the sum of the scores assigned to the five fins, e.g., perfect score (100% of all fins remaining) was 9 + 9 + 3 (dorsal) = 21.

water temperature and aerated and circulated the water in the test buckets. After the fish had been in seawater for 24 h, we collected blood by caudal puncture, using ammonium heparinated syringes. We analyzed total plasma sodium by atomic absorption spectroscopy, following the modified procedures of Willis (1960). To establish pre-challenge plasma sodium concentrations each month, we collected blood from a composite of five to seven fish not subjected to the seawater challenge.

Specific growth rate (SGR), expressed as percent weight gain per day, was calculated by the following equation (Brown 1957):

$$SGR = \log_e \text{final weight} - \log_e \text{beginning weight/days} \times 100$$

The SGR enables the comparison of growth of fish that differed in initial weight (Allen 1951). To study growth at different water temperatures, we used the temperature unit system originally devised by Haskell (1959) and applied to trout by Dwyer et al. (1981*a*, *b*, *c*). We compared the effect of diets on growth by calculating the temperature units (TU) required to increase fish length 1 cm (TU/cm). The TUs were equal to the total Celsius degrees above zero during each 30-day interval, divided by the total gain in length in centimeters during that interval.

Analysis of variance and Duncan's multiple range test (Duncan 1955) were used to establish significant differences between measurements made on fish fed the various diets during the study. We accepted the level of statistical significance as being $P \leq 0.05$ (unless otherwise indicated).

Procedures in the Fish Hatchery

Although the procedure we followed at the hatchery were closely similar to those used in the laboratory, they were not identical because the facilities and scale of operation differed. Fish used in the studies were from the same source and year class. Because the number of tanks available for our use was limited, we tested only four of the diets—COMSD, BioDiet, Abernathy, and ASD2-30. Each diet was randomly assigned and fed to three groups of 5,000 fish each. Average weight of fish at the start of the study (15 August 1981) was 4.0 g. The fish were usually hand-fed to satiation, hourly for 8 h each day except during cold-weather periods, when they were fed twice per day. Size of feed particles and method of storage followed standard procedures.

Tanks were under an outdoor shelter that provided reduced, uniform lighting. Light levels were usually higher than those we maintained in the laboratory. During part of the study the tanks were covered with cloth netting to prevent bird predation. Circular cement tanks used in part 1 (weeks 1–34) of the study were 6.1 m in diameter (water 0.45 m deep; volume 13,344 L). In part 2 (weeks 35–86) all fish on the same diets (three tanks) were combined and redivided between two cement tanks 9.1 m in diameter (water 0.38 m deep; volume 24,715 L). Water inflow rates were 208 L/min for the small tanks in part 1 and 303 L/min for the large tanks in part 2. The weight of fish per unit of surface area was kept below 4.8 kg/m^2 (as in the laboratory study) in all groups, to reduce the possible effect of crowding on fin erosion. To avoid exceeding this weight during part 2 (in August and September), we divided the fish in each 9.1-m tank into two equal groups, placed them into separate 9.1-m tanks, and increased the flow rate from 303 to 378 L/min.

In April of the first year (week 34), all fish were sorted by size; the fish >14 cm long were considered 1-year smolts and removed from the study. Salmon ≤14 cm long were held for part 2. We removed, weighed, measured, and counted fish in samples from each tank at 2-week intervals and counted and weighed all fish in each tank on four dates—August and October 1981, April 1982, and April 1983. In April 1982 and 1983, we evaluated only the dorsal fins.

Table 3. *Growth rate and growth efficiency of Atlantic salmon fed each six diets during part 1 and 2 of the laboratory study. Each value is the mean for three groups of fish.*[a]

Diet	Mean fish weight (g)[b] at end of each part of study		Specific growth rate (%/day)		Temperature units per 1-cm length increase	
	Part 1	Part 2	Part 1	Part 2	Part 1	Part 2
Abernathy	11.7	229.7	0.74^{y}	0.94^{y}	12.8^{y}	5.2^{x}
COMSD	10.7	198.6	0.69^{y}	$0.88^{y,z}$	13.8^{y}	5.8^{y}
BioDiet	16.7	239.9	0.89^{z}	0.82^{z}	10.0^{z}	$5.6^{x,y}$
ASD2-30	18.2	251.2	0.93^{z}	0.95^{y}	9.4^{z}	5.0^{x}
TGC	11.9	140.5	0.73^{y}	0.85^{z}	12.8^{y}	6.6^{z}
TGS	12.2	140.5	0.74^{y}	0.82^{z}	12.6^{y}	$6.3^{y,z}$
SEM			(0.035)	(0.021)	(0.77)	(0.23)

[a]Part 1 of the study extended from weeks 1 to 34 and part 2 from weeks 35 to 82. Means within a column followed by different superscript letters are significantly different ($P \leq 0.05$). Standard error of mean is shown in parentheses.
[b]Average weight of fish at the beginning of part 1 of the study was 2.0 g.

Tanks were cleaned daily and dead fish removed. Disease treatment was administered when required. Temperature of the water from Green Lake varied seasonally from 1.6° to 18.8°C (mean, 9.9°C; SE, 1.35°C); dissolved oxygen averaged 10.6 mg/L (range, 8.5-12); hardness (as $CaCO_3$), 6.3 mg/L (range, 6-7); and pH, 6.6 (range, 6.3-6.8). Dissolved oxygen was never below 85% saturation. The SGRs, and the TUs required per centimeter of length increase, were determined by the same procedures used in the laboratory study.

Results and Discussion

Growth

By the end of part 1 of the laboratory study, weight was significantly greater and SGR more rapid in fish fed BioDiet or ASD2-30 than in fish fed any of the other four diets (Table 3). Fish fed BioDiet or ASD2-30 required 10.0 or 9.4 TUs to produce 1 cm of growth, compared with 12.6–13.8 TUs required for fish fed the other diets. During part 2 of the study, fish fed ASD2-30 (but not those fed BioDiet) continued to grow more rapidly than fish fed any other diets (Table 3). Growth efficiency of fish fed the various diets differed significantly among some of the diets during part 2 of the study (Table 3); TU/cm ranged from 5.0 for ASD2-30 to 6.6 for TGC.

In part 1 of the hatchery study, the SGR of Atlantic salmon did not differ significantly among fish fed the different diets (Table 4). By the end of part 2, however, the SGR was significantly larger for fish fed ASD2-30 and Abernathy diets than for those fed BioDiet and COMSD. Although fish fed COMSD were larger than those fed the Abernathy diet at the end of part 2, the lower SGR for the fish fed COMSD reflects a lower weight gain during the test period (i.e., the starting weight was heavier). For fish fed Abernathy and ASD2-30 about 2.2–2.6 more TUs were required per centimeter of length increase in part 2 than in part 1. Neither the number of TUs required nor SGRs differed among the dietary groups in part 1.

In both the laboratory and hatchery studies, the final mean weight (i.e., weight at the end of part 2) was highest for fish fed ASD2-30; fish fed BioDiet ranked second. The SGRs for fish fed Abernathy improved in part 2, equaling those of fish fed ASD2-30 in both studies. Increased growth in part 2 of fish fed the Abernathy diet may have been due to the higher lipid content in batches of feed fed later in the study (Table 5). Although hatchery fish were heavier at the beginning (4.0 g vs. 2.1 g) and end (about 21–31 g vs. 10–18 g) of part 1 of the study, the SGR tended to be higher for laboratory fish because of the difference in the initial and final weights of the two groups. Even though

Table 4. *Growth of Atlantic salmon fed the same diets at the Green Lake National Fish Hatchery and the National Fishery Research and Development Laboratory.*

Location and Diet	Mean fish weight (g) at the end of each part of study				Specific growth rate (%/day)[a]		Temperature units per 1-cm length increase[b]	
	Initial		Final					
	Part 1	Part 2	Part 1	Part 2	Part 1	Part 2	Part 1	Part 2
Hatchery								
Abernathy	4.0	20.8	26.5	107.3	0.76^{x}	0.44^{x}	10.0^{x}	12.6^{x}
COMSD	4.0	27.4	21.9	108.0	0.69^{x}	0.36^{z}	10.6^{x}	10.2^{z}
BioDiet	4.0	30.6	25.2	135.5	0.74^{x}	0.40^{y}	11.5^{x}	11.4^{y}
ASD2-30	4.0	26.9	30.4	139.2	0.82^{x}	0.44^{x}	8.9^{x}	11.1^{y}
SEM					(0.132)	(0.0158)	(2.80)	(0.221)
Laboratory								
Abernathy	2.1	10.0	11.7	229.2	0.74^{m}	0.94^{m}	12.8^{m}	5.2^{n}
COMSD	2.1	10.3	10.7	198.6	0.69^{m}	$0.88^{m,n}$	13.8^{m}	5.8^{m}
BioDiet	2.1	11.6	16.7	239.9	0.89^{n}	0.82^{n}	10.0^{n}	$5.6^{m,n}$
ASD2-30	2.1	10.1	18.2	251.2	0.93^{n}	0.95^{m}	9.4^{n}	5.0^{n}
SEM					(0.030)	(0.033)	(0.633)	(0.182)

[a]Growth computations were based on 238 and 376 days at the hatchery and 238 and 336 days at the laboratory for parts 1 and 2 of the study, respectively.

[b]Temperature calculations were based on 1731 and 3151 total Celsius degrees above zero at the hatchery and 1780 and 2889 total degrees above zero at the laboratory for parts 1 and 2 of the study, respectively. Because SGR and TU/cm for hatchery and laboratory fish are statistically different ($P \leq 0.01$) the Duncan comparison is made only for fish within those groups. Means within hatchery and laboratory groups followed by different superscript letters are significantly different ($P \leq 0.05$).

hatchery fish were still heavier than laboratory fish at the end of part 1 of the study, by the end of the study the laboratory fish were 1.8–2.1 times heavier and specific growth rates were more than 2 times greater than those of hatchery fish (Tables 3 and 4). The change in weight relations between laboratory and hatchery fish did not appear until November 1982, when growth rate suddenly decreased in the hatchery but increased in the laboratory until the falling temperatures reached 4°C (Fig. 1). Although the number of fish per tank, the number of fish per unit of bottom area, and the weight per unit volume were usually somewhat higher in the hatchery study, these biomass differences probably did not cause the decrease in growth rate, which came 8 weeks after we reduced the number of fish per tank by 50% in week 54 of the study. The number of TUs available was greater in the hatchery than in the laboratory, but the sudden decrease in growth rate in the hatchery (especially during part 2) followed a rapid decrease in temperature of the water supply that accompanied the fall overturn in Green Lake. It appeared that after Atlantic salmon were held for about 6 weeks at temperatures above that required for optimum growth (15°C; McCauley and Casselman 1981) the sharp drop in water temperature (from about 18.8°C to 4°C) decreased growth more severely than would be anticipated from changes in temperature alone.

Mortality

In the laboratory, we observed no mortality related to diet. In the hatchery study, mortality during part 1 was significantly higher in fish fed COMSD (1.4 fish per day) than in fish fed the other diets (0.46–0.58 fish per day). During part 2, daily mortalities ranged only from 0.07 to 0.13.

Mortality in neither the laboratory nor hatchery significantly affected the diet comparisons. We believe that a nominally higher mortality in the hatchery in part 1 (data not shown) was caused by the much larger scale of operation and the less care and attention that could be given to the 5,000 fish per tank there than to the 200 fish per tank in the laboratory.

Table 5. *Proximate composition (% wet weight) and energy content (Kcal/kg wet weight) of Atlantic salmon fed different diets and sampled at different times during the laboratory study: S82 (spring 1982, during part 1 of the study), and F82 (fall 1982) and S83 (spring 1983) during part 2.*[a]

Diet	Component and (in parentheses) value at start of experiment											
	Protein (12.9)			Lipid (8.2)			Moisture (77.9)			Energy (1311)		
	S82	F82	S83	S82	F82	S83	S82	F82	S83	S82	F82	S83
Abernathy	16.5^{z}	15.7^{w}	17.9^{y}	7.6^{w}	10.1^{w}	9.2^{x}	74.0	72.2	70.8	1140^{v}	1648^{v}	1704^{v}
COMSD	16.8^{z}	$15.8^{w,x}$	17.8^{y}	6.6^{x}	9.0^{x}	8.8^{z}	74.4	73.4	72.1	1429^{v}	1487^{w}	1520^{w}
BioDiet	15.6^{y}	15.6^{w}	17.0^{z}	9.0^{y}	11.5^{y}	11.7^{y}	73.0	71.2	70.8	1656^{w}	1732^{x}	1758^{x}
ASD2-30	15.7^{y}	16.1^{x}	17.1^{z}	9.1^{y}	11.3^{y}	12.2^{y}	73.6	70.9	69.7	1594^{x}	1712^{x}	1843^{y}
TGC	15.4^{y}	17.3^{y}	16.9^{z}	5.9^{z}	8.3^{z}	8.9^{x}	76.3	72.8	72.0	1300^{y}	1585^{y}	1511^{w}
TGS	15.6^{y}	16.6^{z}	18.1^{y}	6.6^{x}	8.0^{z}	7.1^{z}	75.2	73.6	73.3	1830^{z}	1483^{w}	1483^{z}
SEM	(0.08)	(0.11)	(0.12)	(0.15)	(0.18)	(0.20)				(12.47)	(7.21)	(5.49)

[a]Sampling times were as follows: S82, April 1982 (week 34; post-winter); F82, October 1982 (week 57; pre-winter), and S83, April 1983 (week 82; post winter). Values for components at the start of the experiment came from a composite of 100 fish. Means within a column followed by different superscript letters are significantly different ($P \leq 0.05$). Standard errors are shown in parentheses.

Proximate Composition

Determination of proximate composition was limited to fish held in the laboratory. Lipid content increased between fall of 1981 and spring of 1982 and between fall 1982 and spring 1983 in fish fed ASD2-30 and BioDiet, indicating that these fish continued growing during the winter. In fish fed the other four diets (data not shown), lipid content decreased during both winters except in fish fed TGC between fall 1982 and spring 1983 (Table 5, Fig. 2).

Since appetite and rate of digestion decline as water temperature decreases, the importance of diet composition probably increases for fish held in cold water during part of the year. If the nutrient content of food eaten during low temperature periods is not sufficient to meet the needs for metabolism, the fish presumably draw on body stores. Since the lipid content of fish fed ASD2-30 or BioDiet (both of which, unlike the other diets, contained more than 17% lipid; Table 6) increased during both winters and was significantly higher than that in all other fish after each winter, it appears that these diets contained sufficient energy to meet maintenance requirements and allow for small weight increases, even though total food intake was reduced.

It seemed beneficial to feed a nutrient-dense diet to Atlantic salmon, not only during periods of rapid growth but also during cold-water periods of slow growth. Atlantic salmon fed diets containing less than 12% lipid (Abernathy, COMSD, TGC, and TGS) presumably obtained insufficient nutrients from the food consumed during winter to meet their metabolic requirements—as evidenced by an overwinter decrease in lipid content. The number of TUs required for growth was significantly lower in part 1 of the laboratory study in fish fed the 17.4–17.7% lipid diets (ASD2-30 and Biodiet; Table 3) indicating that they used it more efficiently. In part 2 the number of TUs required for 1 cm of growth for fish fed the Abernathy diet with increased lipids (14.6%) was not significantly different from that of either ASD2-30 or Biodiet (Table 3). A decrease in lipid content of Atlantic salmon during parr–smolt transformation in spring, reported by Foda (1974) and Farmer et al. (1977), was probably a result of increased energy requirements related to physiological changes (Fessler and Wagner 1969) and increased activity in smolts (Hoar et al. 1957). Farmer et al. (1977) retarded the rate of lipid loss by feeding a diet containing 14.6% lipid for 3 months before the fish were released. Body lipid levels were elevated in fish fed either ASD2-30 (12.2%) or BioDiet (11.7%) in April 1983, when our study ended (Table 5). We believe that continued feeding of these or other high-lipid diets during the last 5-6 weeks before release would help ensure that Atlantic salmon smolts have sufficient energy stores for downstream migration and adaptation to the sea; however, the possible superiority of the smolts fed these high lipid diets can be tested only by evaluating their relative rate of return to natal streams as adults.

Histology

No pathological changes observed in fish reared in the hatchery or laboratory were severe enough to be of

Table 6. *Proximate composition (% wet weight) and energy content (Kcal/g dry weight) of test diets fed to Atlantic salmon during parts 1 and 2 of the laboratory study.*[a]

Growth period and diet	Component(%)					Gross energy[c] (Kcal/g)
	Protein	Lipid	Moisture	Ash	Carbohydrate[b]	
Part 1 (weeks 1–34)						
Abernathy	44.1	12.0	9.0	11.1	23.8	4.6
COMSD[d]	44.5	11.7	6.1	11.3	26.4	4.8
BioDiet	36.1	17.3	21.0	13.2	12.4	4.2
ASD2-30	48.2	20.4	5.2	12.0	14.2	5.3
Trout diet TGC[e]	47.8	11.9	6.9	8.3	25.1	4.9
Trout diet TGS[f]	45.3	12.1	6.7	8.2	27.7	4.9
Part 2 (weeks 35–82)						
Abernathy	44.5	14.6	7.5	11.7	21.7	4.7
COMSD[d]	47.5	12.7	9.3	9.9	20.6	4.7
BioDiet	37.9	17.4	19.4	13.0	12.3	4.3
ASD2-30	53.2	17.7	6.1	11.3	11.7	5.2
Trout diet TGC[e]	40.5	11.2	7.9	8.1	32.3	4.6
Trout diet TGS[f]	40.5	10.8	7.5	7.5	33.7	4.6

[a]Values are the mean of three to six batches of each diet fed throughout each phase of the feeding period, sampled at the laboratory.
[b]Carbohydrate content was not measured but was determined by difference.
[c]Complete combustion in calorimeter.
[d]Salmon diet obtained from Murray Elevators, Murray, Utah.
[e]U.S. Fish and Wildlife Service trout diet made with cottonseed meal (TGC).
[f]U.S. Fish and Wildlife Service trout diet made with soybean meal (TGS).

concern to fish culturists. In the laboratory study, liver cells of fish fed the TGC diet showed little vacuolization (hence little glycogen storage). At the end of the study, we observed a low incidence of granulomatosis in kidneys of fish fed the Abernathy, BioDiet, TGC, and TGS diets, but none in fish fed either ASD2-30 or COMSD. In fish fed the Abernathy or TGC diet, granulomas in the visceral fat persisted throughout the study. (They were still present in kidneys of these fish 2 months after the study ended.) Visceral granulomas have been related to mineral metabolism dysfunctions in fish. Since cottonseed meal has been implicated in the increased incidence and severity of visceral granuloma in brook trout, *Salvelinus fontinalis* (Dunbar and Herman 1971), it might be expected in fish fed the TGC diet. Inasmuch as these lesions were not commonly observed until the fish were nearly 2 years old, we believe that changes in mineral metabolism that accompany smoltification may have produced a mineral imbalance that was not compensated for by minerals in either the fish or the diet.

No differences were noted in the appearance of the thyroid tissue, regardless of diet, size of fish, or sampling date. No abnormalities, other than those typical for hatchery-reared Atlantic salmon, were observed in the structure of the gills. The absence of even minor pathological changes in fish fed the ASD2-30 diet

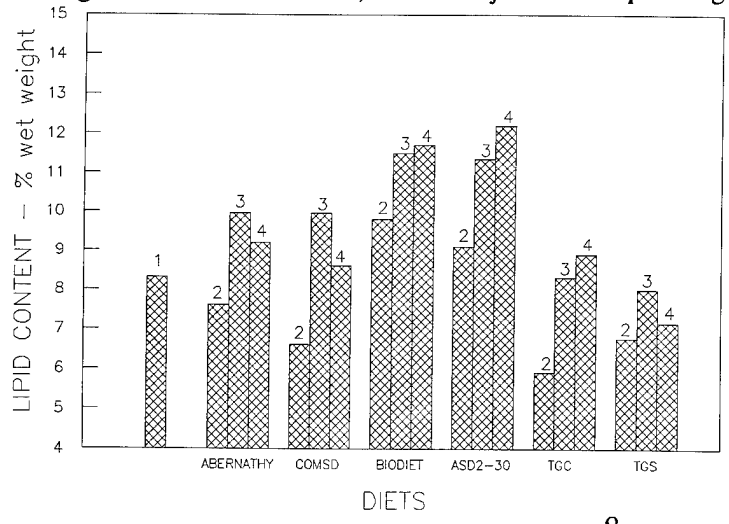

Fig. 2. Lipid content of Atlantic salmon at different periods before and after the first and second winter of the laboratory study (1 = pre-winter, September 1981, initial measurement at beginning of the experiment; 2 = post-winter, April 1982; 3 = pre-winter, October 1982; and 4 = post-winter, April 1983).

seemed to favor the long-term feeding of this diet to Atlantic salmon.

Seawater Challenges

Laboratory reared Atlantic salmon from all diet groups, when exposed to seawater for 24 h, were able to regulate blood sodium levels only in May; by June this ability had been lost. The mean blood sodium concentrations (μM/L) for test fish after 24 h in seawater and control fish not exposed to seawater follow.

	Mar	Apr	May	Jun	Jul	Aug	Range in SE
Test fish	185	188	167	176	184	188	1.4 – 2.4
Controls	156	160	155	151	148	149	1.4 – 4.4

All mean blood sodium concentrations were significantly higher in fish challenged in seawater than in control fish tested in fresh water ($P \leq 0.01$). The observation that regulation occurred in May was based on the guidelines of Clarke and Blackburn (1977), who showed that smolts of coho salmon (*Oncorhynchus kisutch*) and steelhead (*Salmo gairdneri*) could maintain blood sodium concentrations below 170 μM/L within 24 h after direct transfer to seawater. In Atlantic salmon this occurred only in May. Blood sodium concentrations in Atlantic salmon during early sea life are not known and are probably never as low as those in salmon in fresh water. Average weight loss by fish transferred from fresh water to seawater (i.e., 30–33‰ sea water) for 24 h was 8% in March and April and 11–13% in May and later months. Weight loss in control groups handled in the same way but not exposed to seawater was 3%—probably a response to handling stress. Although blood sodium levels were lower in fish fed some diets than for others, we found no relation between blood sodium level and diet composition.

Fin Condition

Frantsi et al. (1972) considered fin condition as a factor in a smolt grading system because they believed that it reflected the general physiological condition or health of the fish.

In our laboratory study, the dorsal fin scores for fish in part 1 differed significantly among diets in April 1982, after the first cold-water rearing period (Table 7). Fins were in the best condition in fish fed either BioDiet or ASD2-30 (mean scores 5.5 or 5.6); the score for fish fed COMSD, which had the poorest fins, was only 2.2. Mean dorsal fin scores of fish fed Abernathy, COMSD, and each of the trout growth diets (TGC, TGS) decreased during the cold-water period (Table 7), whereas those for fish fed BioDiet or ASD2-30 remained essentially unchanged during winter.

Examination of the fish in October (1982) in part 2 of the laboratory study revealed some regeneration of dorsal fin tissue during spring and summer (Table 7). This regeneration is consistent with the observations by Schneider and Nicholson (1980) that fin rot began in fall and that it progressed during periods of low water temperature, followed by partial remission in late spring. Although dorsal fin deterioration was generally less severe during the second than during the first winter of our study, some pectoral and pelvic fin damage occurred during the second winter.

Overall fin scores were highest in fish fed BioDiet (pectoral fins were full, evenly transparent, and showed little sign of fraying at the edges, and few fins were split along the rays) and second highest in fish fed the ASD2-30. When pectoral fin damage was evident, it usually was most serious on the side of the fish that sometimes touched the tank wall as the fish swam against the water current. We believe that most of the damage was due to mechanical abrasion of fins against the sides of the tank. Nevertheless, fish fed BioDiet had no pectoral fin damage and those fed ASD2-30 had little damage, even though rearing conditions were the same for fish fed each of the six diets.

Although fish biomass was suggested by Westers and Copeland (1973) as a factor contributing to poor fin condition, Schneider and Nicholson (1980) observed that crowding did not appear to be a significant factor in progression of fin rot, once it started. We do not believe that fish concentration caused the differences in fin condition we observed. In general, for the more rapidly growing fish, fin erosion was least in those reared at the highest concentration (ca. 4.8 kg/m^2).

In the hatchery after the first winter (April 1982), the average total fin scores (perfect fins = 21) for fish fed different diets (shown in parentheses) were 11.6 (COMSD), 15.0 (Abernathy), 16.4 (ASD2-30), and 16.7 (BioDiet). After the second winter (in April 1983) for the same diets in the same order, the scores were 7.2, 7.6, 12.8, and 15.1. The poorer fin scores after the second winter accompanied the pattern of reduced growth (Fig. 1) observed in these fish. Although the fin scores were lower for hatchery fish than for laboratory fish, the highest scores after the first and second winter were for fish on the same two diets in both studies. Fin condition was poorest after the first winter in the laboratory study and after the second winter in the hatchery study. The overall poorer fin condition in hatchery fish was probably related to their decreased growth, the larger numbers of fish per tank, and differences in handling procedures required for the larger numbers. Except for fish fed the Abernathy diet, good fin condition and good growth were strongly associated.

Table 7. *Fin score (± standard error) for Atlantic salmon before and after their first winter (October 1981 and April 1982) and second winter (October 1982 and April 1983) in the laboratory study. Values are the mean for 60 to 75 randomly sampled fish.*[a,b]

	First Year				Second Year			
	Pre-winter		Post-winter		Pre-winter		Post-winter	
Diet	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Abernathy	4.3^{x}	0.6	3.8^{x}	0.4	17.5^{y}	0.5	16.8^{y}	0.5
COMSD	$4.8^{x,y}$	0.4	2.2^{y}	0.3	17.8^{y}	0.4	17.1^{y}	0.5
BioDiet	5.5^{z}	0.3	5.5^{z}	0.2	19.5^{z}	0.3	18.6^{z}	0.3
ASD2-30	$5.3^{y,z}$	0.4	5.6^{z}	0.2	19.0^{z}	0.3	18.3^{z}	0.2
TGC	$5.2^{y,z}$	0.3	3.5^{x}	0.4	18.1^{y}	0.3	18.0^{z}	0.3
TGS	5.6^{z}	0.4	3.5^{x}	0.3	17.7^{y}	0.6	18.1^{z}	0.4
SEM	(0.203)		(0.174)		(0.24)		(0.21)	

[a]Means within a column followed by different superscripts are significantly different ($P \leq 0.05$).
[b]In October 1981 and April 1982, only the dorsal fin was considered (perfect score = 6.0;see footnote, Table 2) in October 1982 and April 1983 the fin score was the sum of the scores for the dorsal and the two pectoral fins (complete, undamaged fins = 9+9+3=21 points).

Conclusions and Recommendations

Our findings agree with those of Lall and Bishop (1977), which indicated that Atlantic salmon can tolerate much higher levels of dietary lipid than other species of animals without apparent adverse affects. Despite high lipid levels in fish fed BioDiet and ASD2-30, no pathological changes developed. We believe that the decline in body lipid that normally occurs during winter and early spring during smoltification (Foda 1974; Farmer et al. 1977) can be reduced or eliminated by feeding a high lipid diet during hatchery rearing. Our results agree with those of Peterson et al. (1971) and Bergstrom (1973), which indicated that Atlantic salmon require a diet high in digestible protein and lipid and that diets regularly fed to rainbow trout are not well suited to Atlantic salmon. For example, a preliminary comparison of the ASD2-30 diet with tuna and herring oil suggested that tuna oil, (even though from a marine fish) was not an acceptable lipid source for use in Atlantic salmon diets (B. Dennison, manager Green Lake NFH, personal communication).

Fin erosion of Atlantic salmon progresses during winter, when water temperatures are low, and is probably a result of inadequate nutrition. Temperature extremes and sudden changes in temperature sometimes greatly reduce growth rates of Atlantic salmon. Fin condition was generally best in the fastest growing fish. Long-term feeding of a diet containing cottonseed meal produced granulomas in the kidneys and visceral fat that may be harmful to Atlantic salmon. We suggest that feeding the open-formula diet ASD2-30 in optimum feed particle sizes (Wankowski and Thorpe 1979) and at recommended frequency of feeding and control of photoperiod (Isaksson 1980) should result in the production of large numbers of healthy yearling Atlantic salmon smolts. If Atlantic salmon fed high-fat diets do not smoltify in 1 year, or if survival is reduced, diets may have to be modified to prevent the heavy accumulation of body fat that sometimes results from efforts to produce large 1-year smolts. Even though several of the feeds tested in our study produced favorable results when fed to Atlantic salmon reared in a hatchery, the final indication of the success of any feed must be reflected in the percentage of the salmon returning as adults after the release of large numbers of smolts having a common dietary history.

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In a two-year laboratory and hatchery study, growth and general quality were compared in Atlantic salmon fed different diets and held at seasonal temperatures. Fish were fed six diets at the laboratory and four of the same diets at the hatchery. At the end of the first year of growth, fish greater or equal to 14 cm (presmolts) were removed and the study continued with a reduced number of smaller fish, presumed to be nonsmolts. During the study, fish quality was evaluated on the basis of fin condition, proximate composition, histology, and sodium regulation.

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