Arctic Char, *Salvelinus alpinus*

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Introduction

Artic char (*Salvelinus alpinus*) is a relative newcomer to the aquaculture industry and first impressions were that this would be a highly successful freshwater species because of its ready acceptance by the consumer, the anticipated high price predicted for it relative to its closest competitor, rainbow trout (*Oncorhynchus mykiss*), and the fact that it was easy to culture. A recent review of the potential for Arctic-char culture in Norway by Heggberget *et al.* (1994) reports that pre-smolt char grew better than Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) and almost as fast as pink salmon (*Oncorhynchus gorbuscha*).

Most of the early culture efforts on char involved defining the growth characteristics of various char strains, such as the Canadian strains Nauyuk and Labrador and the Norwegian strains Sunndalsora, Hammerfest and Svalbard. Common features of the results from these studies were variation in size, early sexual maturation or precociousness of a component of all char populations and the reduced ability of char to absorb pigments. This meant that frequent grading was required and cultured char did not have the deep-red appearance of wild char. Nevertheless, there has been a steady effort in several parts of the northern hemisphere to understand nutritional requirements of char, using the rainbow-trout model.

Arctic char has the most northern distribution of all freshwater fish species and is widespread in the Arctic and subarctic regions of North America, Europe and Asia (Johnson, 1980). Slow-growing populations are restricted to land-locked systems, while the faster-growing and larger char feed in the marine environment during the open-water period. Char occur as monospecies in many Arctic lakes and also coexist with other freshwater species, such as lake trout (*Salvelinus namaycush*) and lake whitefish (*Coregonus clupeaformis*). In some

regions, such as northern Labrador, Arctic char hybridize with lake trout and brook trout (Hammar *et al.*, 1991).

Nutrient Requirements

Protein and amino acids

Gurure *et al.* (1995a) found that the highest growth response of char occurred at 350 g kg^{-1} digestible crude protein (DCP), but diets with 390–430 g kg^{-1} did not produce any improvements in weight for protein gain. Differences between Tabachek (1986) and Jobling and Wandsvik (1983) were discussed by Jobling (1991), but reasons for the differences between char growth probably relate more to strains of char and diet formulations than to tank design, as other studies using the same tanks reported a specific growth rate (SGR) of 1.6% (Papst *et al.*, 1992). Ringo (1995) and Torissen and Shearer (1992) studied the relationship between growth, protein digestiblity and food conversion of char in fresh and sea water. Torissen and Shearer (1992) used the Hammerfest strain (fast-growing and anadromous) and the Skogseid strain (slow-growing and non-anadromous). Experimental conditions included salinity levels of 0 and 27 p.p.t., temperature of 6°C and 10°C and small (33–90 g) and large (200 g) char. Torissen and Shearer (1992) found protein digestibility for the slow-growing and fast-growing strains to be 82.9% and 80.6%, respectively, but SGR was significantly higher for the fast-growing strain at 6°C. Ringo (1995) studied the digestibility of two char diets, consisting of capelin roe and a commercial diet, using the chromic oxide technique. Char were grown in fresh water and sea water. The protein content of capelin and the commercial diets was 670 and 500 g kg^{-1}, respectively, and the apparent digestibility of capelin roe was higher at 92% and 88.2%, when char were grown in fresh water and salt water, respectively, compared with the commercial diet, which had values of 89% and 85.7% for char grown in fresh water and sea water, respectively (Ringo, 1995). Generally there was a reduction in the digestibility of protein from both diets for char grown in sea water.

A few studies have evaluated the amino acid requirements of char. Using the Labrador strain of char, Yang (1994) reported that concentrations of arginine of 34.9 and 21.9 g kg^{-1} did not markedly alter growth rates, haematocrit values, haemoglobin, moisture in the liver and muscle or the hepatic somatic index. The levels used by Yang (1994) are high relative to those listed for rainbow trout (1.5%) and Pacific salmon (*Oncorhynchus nerka*) (2.04%) by the National Research Council (NRC, 1993).

Simmons *et al.* (1997) reported that methionine at 18 g kg^{-1} of dietary protein was required for optimum growth, but 23 g kg^{-1} dietary protein was necessary to prevent nutritionally induced cataracts. In a further study, Simmons *et al.* (1999), using char with an initial weight of 20.5 g and grown over 16 weeks, found that the requirement of methionine for optimal growth was 17.6 g kg^{-1} of dietary protein (estimated using a quadratic regression), while the requirements based on carcass quality and energy gains were 18.8 and

17.8 g kg^{-1} of dietary protein, respectively. Simmons *et al.* (1999) found that 26.7 g kg^{-1} dietary protein was required to prevent cataracts in char.

Lysine levels were evaluated by Gurure *et al.* (1995b) in char weighing 3.8 g and 30 g and fed a diet containing 36% DCP, 15.1% digestible crude lipid and 15.5 MJ digestible energy kg^{-1}. Practical ingredients supplied 50% of the protein and the remainder was added in the form of synthetic glutamic acid and essential amino acids. Lysine was added to the feed to obtain dietary lysine levels of 10–34 g kg^{-1} diet. Gurure *et al.* (1995b) found that SGR for all treatments ranged from a high of 1.95 day^{-1} to a low of 0.65% day^{-1}, carcass moisture and ash were generally similar and final carcass protein went up with increasing lysine levels to a high of 19 g kg^{-1}. Feed conversion ratios, carcass lipid and net lipid accumulation decreased with increasing lysine up to 19 g kg^{-1}. Using broken-line analysis, Gurure *et al.* (1995b) estimated the requirements for lysine to be 21 g kg^{-1} diet (58 g kg^{-1} in protein).

Energy and digestibility

The energy requirement of food consumed has been estimated for natural food (Larsson and Berglund, 1998) and for pelleted diets (Tabachek, 1984; Larsson and Berglund, 1998). Tabachek reports values ranging from 3.15 to 3.72 kcal g^{-1} and Larsson and Berglund (1998) report values for *Neomysis integer* ranging from 20.0 to 21.0 MJ kg^{-1}. Gurure *et al.* (1995a) raised 2.56 g char at 9.5–13°C and fed practical diets containing 16.6 MJ digestible energy (DE) kg^{-1}. These char had specific growth rates of 2.86 day^{-1} and Gurure *et al.* (1995a) concluded that protein requirements of young growing char are similar to those of most salmonids. Digestible energy has been calculated for a number of experimental diets: 16.63–17.28 MJ kg^{-1} by Gurure *et al.* (1995a); 17.6 MJ kg^{-1} by Alanara and Kiessling (1996); 17.5 MJ kg^{-1} by Simmons *et al.* (1999); 18.36–19.07 kJ g^{-1} by Jobling and Wandsvik (1983). These values are similar to those of commercial rainbow-trout diets. Values ranging from 16.6 to 21 MJ kg^{-1} for formulated diets and a natural food source can be compared to the typical energy content of commercial rainbow trout diets of 3200 kcal DE kg^{-1} and Pacific salmon of 3600 kcal DE kg^{-1} (NRC, 1993).

Lipids and fatty acids

It is commonly known that the composition of lipids in fish is affected by the composition of dietary lipid (Sargent *et al.*, 1989). It is also well established for cold-water fish species that sparing of protein and lipids occurs because either can be used as a source of energy, and that polyunsaturated fatty acids (PUFAs) are important in cold-water fish diets (Dick and Yang, 1992, 1995). Marine fish feeding on various zooplankton and phytoplankton with high levels of n-3 PUFA, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), 20:5n-3 and 22:6n-3, respectively, have high levels of these lipids (Dick and

Yang, 1992). Freshwater fish generally feed on organisms with high levels of linoleic acid, 18:2n-6, and linolenic acid, 18:3n-3, and as a result have proportions of EPA and DHA lower than those for marine fish.

The fatty acid composition of muscle of wild char and other salmonids is an important starting-point for studying the dietary lipid requirements in fish (Castell, 1979; Table 15.1). The fatty acids 18:2n-6, EPA and DHA were higher in char than those reported for Atlantic salmon and rainbow trout, but 18:3n-3 was lower than that reported for Atlantic salmon and rainbow trout (Table 15.1). Values for char and Atlantic salmon are more similar than those for rainbow trout. Ringo and Nilsen (1987) found that the neutral lipid from the muscle of land-locked Arctic char had mostly 16:0, 16:1 and oleic acid (18:1n-9) fatty acids and Jobling (1991) reported that the PUFA content in the eggs was 35%, with EPA and DHA having the highest relative proportion, and in the first-feeding fry PUFA was about 40%. Ringo and Nilsen (1987) reported that the fatty acid composition of the neutral fraction of the wild char differed substantially from char fed on capelin and a commercial diet. Both 20:5n-3 and DHA increased in char muscle fed the capelin diet (Ringo and Nilsen, 1987).

The first studies on Arctic char nutrition reported that protein and lipid requirements ranged from 27.6% to 43.6% and from 11.4% to 17.3%, respectively (Jobling and Wandsvik, 1983). Tabachek (1984) reported that not all commercial trout or salmon diets produced optimal growth for char and suggested that char were more similar to coho salmon (*Oncorhynchus kisutch*) but different from trout in terms of the optimum ratio of dietary protein and lipids. The proportion of lipids in published char diets vary from 5 to 28% of the diet and a range of 2–16% has been reported for casein-based diets where information was sought on levels of essential fatty acids and possible interactions between fatty acids (Table 15.2).

Fish fed diets deficient in 18:2n-6 and 18:3n-3 usually exhibit poor growth, low feed efficiency, fatty livers (elevated total lipids and percentage of neutral lipids in the liver), increased water content in whole body or muscle, high hepatosomatic index and substantial accumulation of 20:3n-9 in tissue polar lipids (Henderson and Tocher, 1987). The general consensus is that freshwater fish are not capable of synthesizing 18:2n-6 and 18:3n-3 *de novo* but are able to desaturate and elongate these fatty acids to long-chain PUFAs, namely the C20 and C22 PUFAs. The process requires a common set of enzymes for desaturation and elongation which are influenced by levels of n-9, n-6 and n-3 in the diet (Henderson and Tocher, 1987).

Ringo (1989) reported that conventional commercial salmon diets supplemented with linoleic acid had negative effects on growth and protein and lipid digestibility in char. Olsen *et al.* (1991) reported that 18:3n-3 is the predominant PUFA in char. Olsen and Ringo (1992) found that char converted 18:2n-6 and 18:3n-3 into long-chain PUFA, but that 18:3n-3 was preferred to 18:2n-6 as a substrate. Yang and Dick (1993) reported that char fed increasing dietary 18:3n-3 from 0.1 to 2.0% had higher SGR and feed efficiency. Dietary 22:6n-3 was more effective than 18:3n-3 and 18:3n-3 was more effective than 18:2n-6 in promoting char growth. Yang and Dick (1993) concluded that dietary

Table 15.1. Composition of major fatty acids of muscle of wild Arctic char, Atlantic salmon and rainbow trout.

Fatty acid	Arctic char*	Arctic char†	Atlantic salmon‡	Rainbow trout§
14:0	0.97 ± 0.16	2.3	1.5 ± 0.01	3.8 ± 0.01
15:0	–	0.4	–	–
16:0	15.86 ± 0.6	12.9	14.2 ± 0.14	22.8 ± 1.8
16:1	–	25.7	–	–
16:1n-9	0.41 ± 0.03	–	5.5 ± 0.1	–
16:1n-7	3.66 ± 0.44	–	–	9.5 ± 0.8
17:0	–	0.2	–	–
18:0	5.48 ± 0.12	2.3	5.3 ± 0.04	4.3 ± 0.1
18:1	–	24.9	–	–
18:2	–	5.2	–	–
18:1n-9	11.27 ± 0.17	–	12.6 ± 0.19	21.6 ± 2.8
18:1n-7	3.93 ± 0.35	–	–	–
18:2n-6	6.76 ± 0.65	–	3.1 ± 0.06	4.9 ± 1.3
18:3n-6	0.02 ± 0.01	–	–	–
18:3n-3	1.81 ± 0.14	–	2.2 ± 0.05	6.9 ± 1.6
18:4n-3	0.43 ± 0.07	–	–	–
20:1	–	0.5	–	–
20:1n-9	0.53 ± 0.05	–	0.8 ± 0.05	0.8 ± 0.3
20:2	–	0.8	–	–
20:2n-6	0.54 ± 0.08	–	–	–
20:3n-6	0.71 ± 0.03	–	–	–
20:4n-6	8.26 ± 0.29	–	8 ± 0.06	1.7 ± 0.3
20:3n-3	0.16 ± 0.01	–	–	–
20:4n-3	0.46 ± 0.06	–	–	–
20:5n-3	8.03 ± 0.54	–	4.6 ± 0.01	5.3 ± 1.1
20:4w-3	–	0.8	–	–
20:5w-3	–	5	–	–
22:1	–	3	–	–
22:1n-9	0.09 ± 0.01	–	–	–
22:4	–	0.7	–	–
22:4n-6	0.68 ± 0.09	–	1.3 ± 0.05	–
22:5n-6	1.09 ± 0.13	–	2 ± 0.08	–
22:5n-3	3.3 ± 0.27	–	3.3 ± 0.15	–
22:5w-3	–	1.9	–	–
22:6n-3	18.26 ± 2.28	–	15.4 ± 0.27	11.7 ± 1.9
22:6w-3	–	4.6	–	–
24:1n-9	0.76 ± 0.12	–	–	–
Saturates	23.36 ± 0.95	–	24.4 ± 0.06	–
Monoenes	22.26 ± 0.79	–	26.5 ± 0.13	–
PUFA	50.20 ± 1.87	–	45.3	–
n-6	18.14 ± 0.31	–	15.8 ± 0.04	–
n-3	32.06 ± 2.1	–	27.2 ± 0.4	–

* Yang (1994).
† Ringo and Nilsen (1987).
‡ Ackman and Takeuchi (1986).
§ Suzuki *et al.* (1986).

Table 15.2. Ingredients for Arctic char casein-based diets.

Ingredients	Olsen *et al.* (1991) (% dry weight)	Olsen *et al.* (1999) (g kg^{-1})	Olsen *et al.* (2000) (g kg^{-1})	Yang and Dick (1993)* (% dry weight)
Casein	56	500	593–793	50
Dextrin	17	150	150	10
Gelatin	1.7	17	17	4
Fish protein	14.65	144.3	–	–
Mineral mix	3	–	–	–
Premix I, II, III	34.05	–	42	–
Premix I, II, III, IV	–	5.35	–	–
Coconut oil	–	–	–	–
Lipid supplement	5.3†	150‡	50–160§	5.0

* Also included starch, alpha-cellulose, carboxymethylcellulose, methionine, arginine, mineral premix and vitamin premix.
† 43% Coconut oil + 1% methylesters of 18:2n-6, 18:3n-3, 20:4n-6.
‡ Marine and/or coconut oil.
§ Linseed oil.

18:2n-6 had a minimal effect on growth if there were adequate amounts of 18:3n-3 (somewhere between 1.0 and 2.0%). Yang and Dick (1994b) showed that the conversion of 18:3n-3 to long-chain PUFA reaches a maximum of about 17 g dietary 18:3n-3 kg^{-1} diet in the liver of char. When equal levels of dietary 18:2n-6 and 18:3n-3 were fed to char, there were more products from 18:3n-3 conversion than from 18:2n-6, especially more DHA than arachidonic acid, 20:4n-6, in liver and polar lipids. This indicates that 18:3n-3 is preferentially elongated and desaturated. High levels of 18:3n-3 markedly inhibited the conversion of 18:2n-6, whereas inhibition of dietary 18:2n-6 on 18:3n-3 conversion was noted only when dietary 18:2n-6 to 18:3n-3 changed from 1.0 to 1.5%. Both Labrador and Nauyuk char require 1.0–1.7% 18:3n-3 in the presence of 0.5% 18:2n-6 (Yang and Dick, 1994a,b; Yang *et al.*, 1994). This suggests that juvenile-char lipid requirements are similar to those of Atlantic salmon, chum salmon (*Oncorhynchus keta*) and Chinook salmon (*Oncorhynchus tshawytscha*).

Olsen *et al.* (2000) concluded that feeding diets high in PUFA and low in saturated fats promotes the accumulation of lipid droplets and generates pathology, but, when 40 g kg^{-1} of 16:0 was added to 160 mg kg^{-1} of linseed oil, the enterocyte damage index was reduced significantly. Further support for the role of saturated fats is noted by Yang and Dick (1994b), where replacement of 12:0 with 18:1n-9 resulted in a decline in SGR and feed efficiency, and by Dick and Yang (1995), where char fed a diet containing 20% full-fat flax meal and 40% casein, plus 2.2% animal fat, had SGR of 3% day^{-1}. To summarize, the amount of n-6 and the amount and type of n-3 fatty acids and the ratio between n-6 and n-3 and saturated lipids are important for optimizing dietary lipid utilization by char.

Carbohydrates

Carbohydrates are sources of low-cost energy in fish diets but their utilization by cold-water species is not well understood. Generally, most diets developed for cold-water species have relatively low levels of carbohydrates. The carbohydrate content for several diets fed to char ranges from 17 to 25%, but for other studies where carbohydrate has not been determined directly both the total carbohydrate content and its source are more variable (Table 15.3) – for example, precooked grains (65% wheat and 35% oats) at 11% of the diet and maize meal at 11% of diet (Jobling and Wandsvik, 1983); wheat middlings at 31.9% (Tabachek, 1986); dextrin at 170 g kg^{-1} (Ringo and Olsen, 1991); maize starch (170 g kg^{-1}), wheat middlings (150 g kg^{-1}) and soy meal (Simmons *et al.*, 1999); maize gluten at 25–200 g kg^{-1}, wheat middlings at 111.5–362.1 g kg^{-1} and raw maize starch at 0–139 g kg^{-1} (Gurure *et al.*, 1995a); 15.2% starch and 10% dextrin in a semipurified diet (Yang and Dick, 1993); 20% full-fat ground flax, 10% wheat germ, 5% soybean meal, 8.5% glucose and 2% starch (Dick and Yang, 1995); 15% dextrin (Olsen *et al.*, 1999). Not all these studies were attempting to optimize growth nor was the carbohydrate component in the diet the main aspect of the study. Nevertheless, the data indicate that char seem to be able to handle a wide range of total carbohydrates, and in different forms.

Vitamins and minerals

Fish fed diets inadequate in vitamin C, zinc, copper or iron usually display retarded growth, poor feed utilization and anaemia (John *et al.*, 1979; Halver, 1989; Lall, 1989). Few studies have determined vitamin and mineral requirement for char. However, many of the studies on char nutrition report the amount of vitamins and mineral used. Table 15.4 outlines the levels of selected vitamins from a number of different laboratories and it is apparent that the amounts are variable. Only occasionally are the amounts an order of magnitude different (such as vitamin C). Generally the amount of vitamins and minerals used in diets for char is higher than that reported for rainbow trout and Pacific salmon (NRC, 1993).

Pigments

Red coloration of the flesh is a desirable consumer trait for salmonids and the factors considered to influence pigment deposition are size, growth rate and sexual maturation. Wild populations of char have a remarkable deep red colour of the flesh and skin. The predominant carotenoid in wild char is astaxanthin (Scalia *et al.*, 1989), but idoxanthin, a metabolite of astaxanthin, has been identified by Aas *et al.* (1997); and considered to be part of the char's normal development and is size-dependent, with the smallest fish having the highest concentration.

Table 15.3. Experimental diets for Arctic char.

	Hatlen *et al.* (1995)	Simmons *et al.* (1999)	Gurure *et al.* (1995a)	Ringo and Nilsen (1987)	Jobling and Wandsvik (1983)	Tabachek (1986)
Ingredients	(g 100 g^{-1})	Basal diet (g kg^{-1})	DCP 390‡ (g kg^{-1})	Capelin roe* (% weight)	MP diet (% weight)	Control diet (% weight)
Strain of char	Hammerfest		Labrador			Labrador
Agar	–	10	–	–	–	–
Amino acids	–	200	–	–	–	–
Maize gluten meal	–	–	90	–	–	–
Maize starch	–	170	6.4	–	–	–
Fish-meal	57	–	–	–	44	–
Fish silage	3.8	–	–	–	–	–
Herring meal	–	–	447.2	–	–	35
Gelatin	–	50	–	10	–	–
Maize meal	–	–	–	–	17	–
Torula yeast	–	–	–	–	7	–
Fish-oil	12.5	150	113.3	–	–	–
Cod-liver oil	–	–	–	–	12	–
Herring oil	–	110	–	–	–	10
Soybean meal	–	120	–	–	–	20
Wheat middlings	–	150	329.2	–	–	31.9
Micronutrients	–	–	–	–	–	–
Vitamins and minerals	–	40	–	–	1	–
Mineral	–	–	10	–	–	1
Vitamin	–		10	9.8	–	1.5
Choline chloride	–	–	–	–	–	0.4
Powdered chalk	–	–	–	–	1	–
Chromic oxide	–	–	–	–	1	–
D,L-Methionine	–	–	–	–	–	0.2
Wheat, crushed	26.1	–	–	–	–	–
Precooked grain	–	–	–	–	17	–
Micronutrient premix†	0.61	–	–	–	–	–
Ascorbic acid	–	–	1.3	–	–	–

* Capelin roe about 80% of the diet
† Medium protein (44%) diet
‡ Calculated digestible crude protein of 390 kg^{-1}
DCP, digestible crude protein; MP, medium protein.

Table 15.4. Composition of vitamin premixes used in Arctic char diets (mg kg^{-1} diet).

Ingredients	Yang and Dick (1993)	Tabachek (1986)	Olsen *et al.* (1999)	Simmons *et al.* (1999)	Olsen *et al.* (2000)
Biotin	1.2	1	0.28	0.75	1.4
Carnitine	300	–	–	–	–
Folic acid	6	5	2	15	13
Thiamine HCl	24	10	2	45	15.8
Pyridoxine HCl	18	10	10	45	22
Riboflavin	24	20	12	75	30
D-Capantothenate	–	40	40	225	150
Ascorbic acid	600	100	100	60	300
Myo-inositol	400	300	–	–	450
Niacin	48	150	20	300	200
BHA	–	–	–	–	1000
p-Amino benzoic acid	–	200	–	–	–
Vitamin K	48	10	2	45	26.3
Vitamin B_{12}	1	0.02	0.04	0.045	0.2
Vitamin A	1	3125	5000	7500	5000
Vitamin D_3	1	5000	4000	4500	2600
Vitamin E	–	–	100	150	250
Choline chloride	3000	3000	3000	–	2000

Jobling (1991) reported that char fed 40 mg cantaxanthin kg^{-1} diet resulted in 2 mg kg^{-1} in the flesh, but this was lower than the 3–4 mg kg^{-1} that is considered an acceptable level by the consumer. More recently, several studies have focused on the influence of the age and size of the char on pigmentaion. Hatlen *et al.* (1995) added astaxanthin at 63 and 114 mg kg^{-1} to the diets of 1-, 2- and 3-year-old char (Hammerfest strain). Significant differences were seen among year classes for flesh, skin and plasma carotenoid concentrations. At 13 weeks of feeding, the carotenoids in the flesh were lowest in the 1-year-old fish and highest in the 3-year-old fish. Even after 25 weeks, no differences were seen in pigmentation between 2- and 3-year-old fish but 1-year-old fish were still less pigmented. Metusalach *et al.* (1996) used canthaxanthin at concentrations of 65 mg kg^{-1} in diets fed to post-juvenile char (Labrador strain) weighing 150 g. The major pigments in the diet were canthaxathin, leutein and echinenone. After 24 weeks, flesh had the highest amount of carotenoids at 1.738–2.585 mg kg^{-1}, but concentrations of 9.38 mg kg^{-1} in the skin, 6.02 mg kg^{-1} in the flesh, 5.23 mg kg^{-1} in the liver and 2.16 mg kg^{-1} in the gonads were reported as well. Olsen and Mortensen (1997) evaluating the effects of temperature on the deposition of astaxanthin on flesh colour found a positive correlation between dietary astaxanthin up to 70 mg kg^{-1}, after which a plateau in pigmentation was reached. In addition, flesh coloration was positively correlated to specific growth

and char maintained at 8°C had significantly higher pigmentation than char grown at higher temperatures.

Bjerkeng *et al.* (1999) found that sex steroids strongly influenced carotenoid distribution and that male fish contained more carotenoids in the fillets than females. Bjerkeng *et al.* (1999) recommended that the induction of sexual maturation should be avoided in a production operation and that perhaps growers should evaluate the possibility of using all-male or all-female char. Hatlen *et al.* (1995) concluded that char must reach a certain size before maximum pigmentation occurs. Hatlen *et al.* (1995) recommended that fish farmers planning to produce a 300 g char should include astaxanthin for the entire production period and for larger fish astaxanthin should be added to the diet when char are 200–300 g. Pigments are being used in production facilities at concentrations of 40 p.p.m. and at 60 p.p.m. with good success (Delabbio, 1995). To summarize, the process of metabolism and pigmentation of char tissues seems to be similar to that of salmon and rainbow trout and astaxanthin and cantaxanthin can be added to the diet. However, to optimize pigmentation, producers should consider the strain, size, sex and stage of sexual maturation of char and the grow-out temperature.

Practical Diets

There are a number of reports where char have been fed diets produced by commercial-diet companies (Table 15.5) and practical diets (Table 15.3). Among the first practical diets tested for Arctic char were those of Jobling and Wandsvik (1983) and Tabachek (1984). The diet by Jobling and Wandsvik (1983) consisted of fish-meal (28–60%), precooked grain (11–23%), maize meal (11–23%), torula yeast (7%), cod-liver oil (8–16%), powdered chalk (1%) and a vitamin/mineral mix (1%). Digestibility of these diets, estimated using chromic oxide, varied from 75.97% to 82.95%, but digestibility values for char were 5–10% lower than those for rainbow trout. Tabachek (1984, 1986) reported on the result of feeding trials using several commercial and one experimental diet. Char strains (Sunndalsora from Norway and Labrador strain from Canada) were evaluated for weight gain, feed conversion and mortality. More recently, practical diets have been reported for char by Dick and Yang (1995), Gurure *et al.* (1995a) and Simmons *et al.* (1999).

Particle size is known to have a significant effect on SGR of char. The highest growth rate for char was when particle size was generally 0.015–0.018 times the fork length for 73–109 mm (3–12 g) and 0.023–0.024 times fork length for 121–133 mm (16–21 g) char. This corresponds to 21% of mouth size for 3–7 g char, 23–25% of mouth size for 9–12 g char and 31–33% of mouth size for the 16–21 g char (Tabachek, 1988). Yang (1994) found particle sizes from semipurified diets for 3–5 g char as follows: 0.60–0.85 mm (17.8%), 0.85–1.0 mm (36.7%), 1.0–1.18 mm (45.8%) optimized food intake. Consumption time is shortest and the number of missed pellets is lowest when pellet length is approximately 2–3% of fork length (Linner and Brannas, 1994).

Table 15.5. Commercial diets fed to Arctic char.

Study	Char size at start (g)	Char strain	Temperature (°C)	SGR	Type diet	Source
Eales and Shostak (1985)	2 years	Labrador	12	0.65	Trout grower	EWOS 4-P pellets, Rundle Feed Mills, Ontario
Ringo and Nilsen (1987)	8	–	8	8 to 40 g in 75 days	NG	Skretting (Tess Elite)
Jorgensen and Jobling (1989)	–	–	–	–	NG	Ewos ST 40
Jobling *et al.* (1989)	49.1–69	–	6.1	0.388–1.333	NG	Ewos ST 40, 4 mm
	49.9–79.3	–	–	0.600–1.301	NG	
Miglavs and Jobling (1989)	5–10	–	6.5	1.5–2	NG	Tess Elite Plus, Skretting A/S
Christiansen *et al.* (1992)	10	Hammerfest	6.3	0.99–1.37	NG	EWOS ST 40/4 granulate
Torrissen and Shearer (1992)	33	Hammerfest	6.4	0.26 ± 0.03	NG	Tess Elite Plus
	88	Skogseid	6.4	0.12 ± 0.04	NG	T. Skretting A/S, Stavanger,
Jorgensen	52–55	Hammerfest	6.2	0.8–1.1	NG	Norway FK start 3 mm pellet
et al. (1993)	–	–	–	–	NG	–
Yang and Dick (1993)	–	Labrador	10	2.02	Rainbow trout	Martin Feed Mills, Elmira, Ontario
Hatlen *et al.* (1995)	202–980	Hammerfest	8.2	0.1	Arctic char	Royefor 6 mm pellets, Felleskjopet A/S, Stavanger, Norway containing 50 mg astaxanthin
Metusalach *et al.* (1996)	100	Labrador	4.9–6.3	–	NG	Moore-Clark Co. Inc., St Andrews, New Brunswick contained 65 μg conthaxanthin kg^{-1}
Alanara and Kiessling (1996)	~210	Hornavan	2.1–14.5	210 to 340 g in 60 days	NG	EWOS, Sodertalje, Sweden, Vextra Super
Olsen and Mortensen (1997)	130	–	8.1–12.5	0.74 (12.5)	Arctic char	Skretting Elite 3.5 mm
	–	–		0.62 (8)	NG	
Damsgaard *et al.* (1999)	1–2	Hammerfest	0.3–12.5	Up to 1.7	NG	Felleskjopet, Sandnes, Norway
	–	Svaldard		1.8	NG	FK – Vekst

NG, not given.

Char will take a larger pellet by expanding the length of the pellet compared with round pellets and there was a preference for large over small pellets, given a choice.

Feeding Practices

Feeding practices for char have been quite variable due to the nature of the research question and range from feeding to excess, to apparent satiation or the use of demand feeders. Generally, char are fed two to four times daily, with the amount of food calculated using commercial feeding tables, such as those of Hilton and Slinger (1981). For fish > 1 g, the ration is adjusted periodically based on changes in total wet weight of fish in the tank. Particle size for a specific size class of fish generally follows that for rainbow trout and is based on feeding guides produced by feed companies. However, for char at swim-up and small fry, it is better to hand-feed to apparent satiation rather than to follow rigidly a set of feeding tables. Due to the considerable variation in size of char shortly after swim-up, particle size should be variable to ensure that all individuals can feed. It is important to establish an adequate ration, as Papst (1994) reported that char (1 and 20 g initial weight) fed 50% of the ration produced the lowest variation in growth and char fed 100 and 150% of the ration produced the highest variation in growth and the highest SGR. There is some debate on whether char feed in the water column and/or on the bottom of the tank, but some of the confusion may be due to strain differences, as substantial numbers of the Nauyuk strain prefer the bottom of the tank. Most of the initial studies on char growth used sinking feeds but larger char grow equally well when fed either sinking or floating diets.

Alanara and Kiessling (1996) reported that char (mean weight 215 g) held under culture conditions were unable to adjust their demand-feeding activity based on the energy content of the food, but were able to adjust their demand-feeding activity to either low (0.33 g), medium (0.87 g) or high (1.53 g) rewards and thereby regulate their food supply. Alanara and Kiessling (1996) suggested an optimum reward level of 0.1 g kg^{-1} for char during spring and summer, but this value should be reduced by ten times during the autumn. Char stocked at low densities and subjected to current grew better than those in standing water, but char at high densities did not have increased growth rates.

Conclusions

Although many approaches have been used to the study char nutrition, char has not met expectations as a cultivable species due partly to its direct competitors in the market-place, rainbow trout and Atlantic salmon. This is surprising given that char can be grown at much higher densities, grow better at lower temperatures and exhibit what appear to be broad nutritional requirements. While it was known from initial culture efforts with char that rainbow trout and some Atlantic salmon diets were adequate for char growth, it is evident that char have some special dietary requirements, especially relating to lipid type and amounts and perhaps to type and amount of carbohydrates. The versatility of char in the utilization of key nutrients is evident by the varying proportions (30–75% protein, 5–15% lipid and 0–52% carbohydrates) reported in diets. This suggests

that char may be able to utilize a wider range of ingredient types in their diets than other salmonids.

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References

Aas, G.H., Bjerkeng, B., Hatlen, B. and Storebakken, T. (1997) Idoxanthin, a major carotenoid in the flesh of Arctic charr (*Salvelinus alpinus*) fed diets containing astaxanthin. *Aquaculture* 150, 135–142.

Ackman, R.G. and Takeuchi, T. (1986) Comparison of fatty acids and lipids of smolting hatchery-fed and wild Atlantic salmon *Salmo salar*. *Lipids* 21, 117–120.

Alanara, A. and Kiessling, A. (1996) Changes in demand feeding behaviour in Arctic charr, *Salvelinus alpinus* L., caused by differences in dietary energy content and reward level. *Aquaculture Research* 27, 479–486.

Bjerkeng, B., Johnsen, K., Mayer, I., Storebakken, T. and Nilssen, K.J. (1999) Influence of 11-ketotestosterone, 17B-estradiol, and 3,5,3′-triiodo-L-thyronine on distribution and metabolism of carotenoids in arctic charr, *Salvelinus alpinus* L. *Fish Physiology and Biochemistry* 21, 353–364.

Castell, J.D. (1979) Review of lipid requirements of finfish. In: Halver, J.E. and Trews, K. (eds) *Finfish Nutrition and Finfish Technology*. Heenemon Verlagsgesellschaft, Berlin, Germany, pp. 59–84.

Christiansen, J.S., Svendsen, Y.S. and Jobling, M. (1992) The combined effects of stocking and density and sustained exercise on the behaviour, food intake, and growth of juvenile Arctic charr (*Salvelinus alpinus* L.). *Canadian Journal of Zoology* 70, 115–122.

Damsgard, B., Arnesen, A.M. and Jobling, M. (1999) Seasonal patterns of feed intake and growth of Hammerfest and Svalbard Arctic charr maturing at different ages. *Aquaculture* 171, 149–160.

Delabbio, J. (1995) Artic charr culture in Atlantic Canada. In: Boghen, A.D. (ed.) *Cold-water Aquaculture in Atlantic Canada*. Tribune Press, Sakville, New Brunswick, Canada, pp. 85–106.

Dick, T.A. and Yang, X. (1992) A-linolenic acid metabloism in fish. *Nutrition* 8, 218–220.

Dick, T.A. and Yang, X. (1995) Flaxseed in Arctic char and rainbow trout nutrition. In: Cunnane, S.C. and Thompson, L.U. (eds) *Flaxseed in Human Nutrition*. AOCS Press, Champaign, Illinois, pp. 295–314.

Eales, J.G. and Shostak, S. (1985) Correlations between food ration, somatic growth and thyroid function in Arctic charr, *Salvelinus alpinus* L. *Comparative Biochemistry and Physiology* 80A, 553–558.

Gurure, R.M., Moccia, R.D. and Atkinson, J.L. (1995a) Optimal protein requirements of young Arctic charr (*Salvelinus alpinus*) fed practical diets. *Aquaculture Nutrition* 1, 227–234.

Gurure, R., Moccia, R. and Atkinson, J. (1995b) Dietary lysine requirements for young growing arctic charr (*Salvelinus alpinus*) fed nine semi-practical diets. In: *87th Annual Meeting of the American Society for Animal Science*, Abstract 3. Orlando, Florida, p. 180.

Halver, J.E. (1989) The vitamins. In: Halver, J.E. (ed.) *Fish Nutrition*. Academic Press, San Diego, California, pp. 32–109.

Hammar, J., Dempson, J.B. and Verspool, E. (1991) Natural hybridization between arctic charr (*Salvelinus alpinus*) and brook trout (*S. fontinalis*) evidence from northern Labrador. *Canadian Journal of Fisheries and Aquatic Sciences* 48, 1437–1445.

Hatlen, B., Aas, G.H., Joergensen, E.H., Storebakken, T. and Goswami, U.C. (1995) Pigmentation of 1, 2 and 3 year old Arctic charr (*Salvelinus alpinus*) fed two different dietary astaxanthin concentrations. *Aquaculture* 138, 303–312.

Heggberget, T.G., Grotnes, P., Klemetsen, A., Richardsen, R. and Ugedal, O. (1994) Culture of Arctic char – possibilities in Norway. *Transactions of the American Fisheries Society* 123, 435–444.

Henderson, R.J. and Tocher, D.R. (1987) The lipid composition and biochemistry of freshwater fish. *Progressive Lipid Research* 26, 281–347.

Hilton, J.W. and Slinger, S.J. (1981) Nutrition and feeding of rainbow trout. *Canadian Special Publication of Fisheries and Aquatic Sciences* 55, 15.

Jobling, M. (1991) Arctic char, *Salvelinus alpinus* L. In: Wilson R.P. (ed.) *Handbook of Nutrient Requirements of Finfish*. CRC Press, Boca Raton, Florida, pp. 1–4.

Jobling, M. and Wandsvik, A. (1983) An investigation of factors controlling food intake in Arctic charr, *Salvelinus alpinus* L. *Journal of Fish Biology* 23, 397–404.

Jobling, M., Baardvik, B.M. and Jorgenson, E.H. (1989) Investigation of food-growth relationships of Arctic charr, *Salvelinus alpinus* L. using radiography. *Aquaculture* 81, 367–372.

John, T.M., George, J.C., Hilton, J.W. and Slinger, S.J. (1979) Influence of dietary ascorbic acid on plasma lipid levels in the rainbow trout. *International Journal Vitaminology and Nutrition Research* 49, 400–405.

Johnson, L. (1980) The Arctic char, *Salvelinus alpinus*. In: Balon, E.K. (ed.) *Charrs: Salmoide Fishes of the Genus* Salvelinus. W. Junk Publishers, The Hague, Belgium, pp. 15–98.

Jorgenson, E.H. and Jobling, M. (1989) Patterns of food intake in Arctic charr, *Salvelinus alpinus*, monitored by radiography. *Aquaculture* 81, 155–160.

Jorgensen, E.H., Christiansen, J.S. and Jobling, M. (1993) Effects of stocking density on food intake, growth performance and oxygen consumption in Arctic charr (*Salvelinus alpinus*). *Aquaculture* 110, 191–204.

Lall, S.P. (1989) The minerals. In: Halver, J.E. (ed.) *Fish Nutrition*. Academic Press, San Diego, California, pp. 219–257.

Larsson, S. and Berglund, I. (1998) Growth and food consumption of 0+ Arctic charr fed pelleted or natural food at six different temperatures. *Journal of Fish Biology* 52, 230–242.

Linner, J. and Brannas, E. (1994) Behavioral response to commercial food of different sizes and self-initiated food size selection by Arctic char. *Transactions of the American Fisheries Society* 123, 416–422.

Metusalach, Synowiecki, J., Brown, J. and Shahidi, F. (1996) Deposition and metabolism of dietary canthaxanthin in different organs of Arctic charr (*Salvelinus alpinus* L). *Aquaculture* 142, 99–106.

Miglavs, I. and Jobling, M. (1989) Effects of feeding regime on food consumption growth rates and tissue nucleic acids in juvenile Arctic charr, *Salvelinus alpinus*, with particular respect to compensatory growth. *Journal of Fish Biology* 34, 947–958.

NRC (National Research Council) (1993) *Nutrient Requirements of Fishes*. National Academy of Sciences, Washington, DC, 114 pp.

Olsen, R.E. and Mortensen, A. (1997) The influence of dietary astaxanthin and temperature on flesh colour in Arctic charr *Salvelinus alpinus* L. *Aquaculture Research* 28, 51–58.

Olsen, R.E. and Ringo, E. (1992) Lipids of Arctic charr, *Salvelinus alpinus* (L.) 2. Influence of dietary fatty acids on the elongation and desaturation of linoleic and linolenic acid. *Fish Physiology and Biochemistry* 9, 393–399.

Olsen, R.E., Henderson, R.J. and Ringo, E. (1991) Lipids of Arctic charr, *Salvelinus alpinus* (L.). 1. Dietary induced changes in lipid class and fatty acid composition. *Fish Physiology and Biochemistry* 9, 151–164.

Olsen, R.E., Loevaas, E. and Lie, O. (1999) The influence of temperature, dietary polyunsaturated fatty acids, alpha-tocopherol and spermine on fatty acid composition and indices of oxidative stress in juvenile Arctic char, *Salvelinus alpinus* (L.). *Fish Physiology and Biochemistry* 20, 12–29.

Olsen, R.E., Myklebust, R., Ringo, E. and Mayhew, T.M. (2000) The influences of dietary linseed oil and saturated fatty acids on caecal enterocytes in Arctic char (*Salvelinus alpinus* L.): a quantitative ultrastructural study. *Fish Physiology and Biochemistry* 22, 207–216.

Papst, M. (1994) Variation in growth of hatchery reared Arctic charr, *Salvelinus alpinus* (L.). PhD dissertation, University of Manitoba, Canada.

Papst, M.H., Dick, T.A., Aranason, A.N. and Engels, C.E. (1992) Effect of rearing density on the early growth and variation in growth of juvenile Arctic charr, *Salvelinus alpinus* (L.). *Journal of Aquaculture and Fisheries Management* 43, 21–27.

Ringo, E. (1989) The effect of linoleic acid (18:2 n-6) on lipid and protein digestibility and growth in Arctic char, *Salvelinus alpinus* (L.) *Physiology and Ecology Japan (Special Volume)* 1, 473–482.

Ringo, E. (1995) Hatchery-reared landlocked Arctic char, *Salvelinus alpinus* (L.), from Lake Takvatn reared in fresh and sea water: effect of salinity on digestibility of protein and individual amino acids in a capelin roe diet and commercial feed. *Aquaculture Research* 26, 221–223.

Ringo, E. and Nilsen, B. (1987) Hatchery-reared landlocked Arctic charr, *Salvelinus alpinus* (L.), from Lake Takvatn, reared in fresh and sea water. 1. Biochemical composition of food, and lipid composition of fish reared in fresh water. *Aquaculture* 67, 343–351.

Ringo, E. and Olsen, R.E. (1991) The effect of diet on aerobic bacterial flora associated with intestine of Arctic charr (*Salvelinus alpinus* L.). *Journal of Applied Microbiology* 86, 22–28.

Sargent, J., Henderson, R.J. and Tocher, D.R. (1989) The lipids. In: Halver, J.E. (ed.) *Fish Nutrition*. Academic Press, San Diego, California, pp. 154–209.

Scalia, S., Isaksen, M. and Francis, G.W. (1989) Carotenoids of the Arctic charr, *Salvelinus alpinus* (L.). *Journal of Fish Biology* 34, 969–970.

Simmons, L., Moccia, R.D., Bureau, D.P., Sivak, J.G. and Herbert, K. (1997) Dietary methionine requirement of juvenile Arctic char (*Salvelinus alpinus*). *Bulletin of the Aquaculture Association of Canada* 97(2), 36–38.

Simmons, L., Moccia, R.D., Bureau, D.P., Sivak, J.G. and Herbert, K. (1999) Dietary methionine requirement of juvenile Arctic charr *Salvelinus alpinus* (L.). *Aquaculture Nutrition* 5, 93–100.

Suzuki, H., Okazaki, K., Hayakawa, S., Wada, S. and Tamura, S. (1986) Influence of commercial dietary fatty acids on polyunsaturated fatty acids of cultured freshwater

fish and comparison with those of wild fish of the same species. *Journal of Agricultural and Food Chemistry* 34, 58–60.

Tabachek, J.L. (1984) Evaluation of grower diets for intensive culture of two strains of Arctic charr (*Salvelinus alpinus* L.). *Canadian Technical Report of Fisheries and Aquatic Sciences* 1281, 25.

Tabachek, J.L. (1986) Influence of dietary protein and lipid levels on growth, body composition and utilization efficiencies of Arctic charr, *Salvelinus alpinus* L. *Journal of Fish Biology* 29, 139–151.

Tabachek, J.L. (1988) The effect of feed particle size on the growth and feed efficiency of Arctic charr (*Salvelinus alpinus* L.). *Aquaculture* 71, 319–330.

Torrissen, K.R. and Shearer, K.D. (1992) Protein digestion, growth and food conversion in Atlantic salmon and Arctic charr with different trypsin-like isozyme patterns. *Journal of Fish Biology* 41, 409–415.

Yang, X. (1994) Effects of dietary polyunsaturated fatty acids on growth and lipid metabolism of arctic charr, *Salvelinus alpinus* (L). PhD dissertation, University of Manitoba, Canada.

Yang, X. and Dick, T.A. (1993) Effects of dietary fatty acids on growth, feed efficiency and liver RNA and DNA content of Arctic charr, *Salvelinus alpinus* (L.). *Aquaculture* 116, 57–70.

Yang, X. and Dick, T.A. (1994a) Arctic char (*Salvelinus alpinus*) and rainbow trout (*Oncorhynchus mykiss*) differ in their growth and lipid metabolism in response to dietary polyunsaturated fatty acids. *Canadian Journal of Fisheries and Aquatic Sciences* 51, 1391–1400.

Yang, X. and Dick, T.A. (1994b) Dietary alpha-linolenic and linoleic acids competitively affect metabolism of polyunsaturated fatty acids in Arctic charr (*Salvelinus alpinus*). *Journal of Nutrition* 124, 1133–1145.

Yang, X., Tabachek, J.L. and Dick, T.A. (1994) Effects of dietary n-3 polyunsaturated fatty acids on lipid and fatty acid composition and haematology of juvenile Arctic charr *Salvelinus alpinus* (L.). *Fish Physiology and Biochemistry* 12, 409–420.