

Best practice protocol for aquaculture production of juvenile Arctic charr

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Definition: In this protocol, juvenile refers to the life stages from the fish have been first fed and onwards: the on-growing stages.

Generally for all types of aquaculture and in all life stages, the farmer should seek to adopt conditions in accordance with the natural biology of the fish. In some cases this is not possible, and under such circumstances the conditions should violate the natural needs of the fish as little as possible.

Recording and storage of data on biological and environmental factors, including all variables measured (such as fish weight, water temperature, oxygen etc.), is important to the build up of knowledge on each farm. The resulting database forms unique farm-based knowledge necessary for good production planning, quality control and farming practice. To utilise this basis knowledge, it is important to keep updated graphical illustrations/tables of developments, and implement these in planning. This will be the history of your fish.

Water quality

Water quality standards on chemical quality are given in table 1.

Oxygen (O₂)

The need for water flow is really the need for oxygen. As the metabolism takes place, oxygen is consumed, at a rate dependent on metabolic ratio. The oxygen demand is increased as the fish grow, but the metabolic rate relative to bodyweight decrease as body weight increase. Thus, 1 Kg of 10 gram fish needs more oxygen than 1 Kg of 100 gram fish. The oxygen consumption is dependent on factors such as activity rate, temperature, metabolic state and growth rate. Usually, average consumption per 24 hours in charr is in the region 100-200 mg O₂ Kg⁻¹ h⁻¹, with fish showing high growth being above 150mg O₂ Kg⁻¹ h⁻¹. Following feeding the demand may peak at 40-50% above average consumption.

The availability of oxygen depends on the partial pressure of the gas. In water saturated under normal atmospheric composition and pressure (760 mmHg), oxygen holds a pressure of 158 mmHg (approx. 21%). That is, when the water is fully saturated, only 21% of the gas is oxygen, most of it is nitrogen (approx. 78%). The partial pressure of each gas is their contribution to the total gas saturation in the water. Oxygen uptake across the gills is passive, and depends on this partial pressure as a driving force. Under conditions with low oxygen content in the water (hypoxia), the fish can compensate by increasing the water flow over the gills, increase their gill surface or reduce the oxygen demand. The compensation eventually has a cost, leading to reduced feed intake and growth. Between 100 and 70% saturation, no negative effects on performance have been reported. Below 70% saturation feed intake and growth is reduced (Christiansen *et al.* 1990), and represent the lowest gas saturation recommended under farming conditions. In the case of fry and alevins, this lower threshold should be increased to 80%.

Some advocate the use of absolute oxygen content, as in mg or ml per litre of water, whereas other prefer to use a relative measure such as percentage of fully saturated water. The reasoning behind the use of relative measures is based on the reduced solubility of gases in water with temperature increase. Thus, 9.9mg oxygen per litre of water represent 100% saturation at 10° C, but only 88% at 5° C. It is important to realise that the partial pressure of a particular gas depends upon its fractional concentration in the overall gas mixture and the barometric pressure, but not on the absolute quantity of gas present.

Procedures under hypoxia. Increase waterflow, stop feeding, reduce temperature. Under extreme conditions, when it is a matter of keeping fish alive, it may help to reduce the water level to such an extent that the fish are kept moistured, but can get oxygen from the air. Everything else should have been tried, and proved to fail, before trying this, as high mortality are to be expected. However, as a last resort you may be able to save some of your fish. Many bony fishes in fact shift to an aquatic surface respiration under severe hypoxia (Jobling 1994).

Supersaturation of oxygen (hyperoxia) is usually not a problem in aquaculture. Under handling and transportation, it may be necessary to add oxygen to the water. Fish responds to hyperoxia by reducing the ventilation rate and volume.

Increased oxygen content in the water by adding pure oxygen, or using modified atmosphere under aeration of water, increases the partial pressure of oxygen, making more oxygen available per litre of water. This reduces the water needs, which may be favourable and even necessary under some conditions. By removing nitrogen before adding oxygen, the total gas saturation may be held under 100% even when the oxygen content is increased.

Carbon dioxide (CO₂)

Increased CO₂ increases the concentration of hydrogen protons (H⁺) in the water, and thereby reducing pH. This initiates a response in the blood carrying protein (haemoglobin), known as the Bohr-effect, that reduces the affinity for O₂ thereby reducing the fish's ability to take up and transport O₂ in the blood. Carbon dioxide occupies the same binding seats on the haemoglobin that carries O₂, and the partial pressure of O₂ have to be increased to load an unchanged amount of O₂ when CO₂ is increased. Recommended levels under farming conditions are below 10mg L⁻¹ at alkalinity lower than 100mg L⁻¹ and less than 15mg L⁻¹ at higher alkalinity (Johnston 2002). Increased CO₂ also increase the toxicity of ammonia.

Degassing the water solves problems with high concentration of CO₂.

pH

The pH balance essential for fish metabolism (Oxygen uptake, salt-water balance and acid-base regulation). pH is a measure of free hydrogen protons (H⁺), given in a logarithmic scale from 1 to 14, where 7 is neutral. Water with pH below 7 (high in H⁺) is acidic, whereas water above neutral are alkaline. Arctic charr may be less sensitive to changes in water pH than other salmonids. Although salmonids can tolerate pH within the range of 5 to 9, maximum productivity occurs at pH between 6.5 and 8.5 (Jobling 1994).

Ammonia

Principal excretory product of fish. Total ammonia in water consists of un-ionised ammonia (NH₃) and ionised ammonium (NH₄⁺), with the former being the more toxic to the fish. The toxicity of ammonia strongly depends on water pH, and in addition on temperature, CO₂ and salinity. Concentration of ammonia-N should be kept below 0.01 mg L⁻¹ during first feeding and juvenile stages.

Temperature

The preference and tolerance for temperature changes with life stage. Maturing females probably having the narrowest tolerance limits. The temperature that results in highest growth rate not only changes with age. There seem to be some population differences involved, and temperatures from 11.8 (Jensen, 1985; Nesjøen, Norway) up to 16°C (Swift, 1964; Windermere, England) have been reported. Larsson (2002) studied 11 populations, and found an overall mean temperature for optimal growth at 15.8°C, and this coincides well with findings of Lyttikäinen and co-workers (1997). In Hammerfest strain juveniles, growth rate peaks at 12-14°C. It should be stressed that these temperatures are only valid when growth is not limited by feed supply. When feed is restricted, optimum temperature for growth decrease. High-density intensive farming impose practical limits on temperature, as both oxygen consumption and ammonia excretion increase dramatically with temperature (Lyttikäinen & Jobling 1998). Fungus and bacterial diseases become a problem at

temperatures above 15° C (Glebe and Turner 1993). Twelve degrees Celsius seems a reasonable compromise, giving high growth, good feed utilisation and reduced risk at contracting diseases as well as low fungus growth, to juvenile Arctic charr. Optimal feed utilisation is gained at a lower temperature than optimal/maximal growth, reported to be approximately 9° C in to different works (Uraivan, 1982; Larsson, 2002).

Salinity

The highly variable life strategies seen in Arctic charr affect the salinity tolerance in this species. Anadromous charr tolerate full strength seawater (33-35 ppt.) during the about 2 month seaward migration period in mid summer. During the rest of the year charr seem to cope well with brackish water (20 ppt), but this is very dependent on fish size and temperature with increasing problems as these decline.

Table 1.

Water quality standards for the culture of Arctic charr. Data source: Boyd 1979; Piper et al. 1982; Daily & Economon 1983; Sigma Consultants 1983; Johnston, 2002.

Parameter	Standard (mg/L)	Exceptions to standard
Alkalinity (as CaCO ₃)	20-400	
Aluminium (Al)	< 0.01	
Ammonia-N (NH ₃ + NH ₄)	< 2.0	
Ammonia (NH ₃)	< 0.0 15	< 0.005 in hard water
Arsenic (As)	< 0.05	
Barium (Ba)	< 5.0	
Cadmium (Cd)	< 0.004	< 0.003 in hard water
Calcium (Ca)	20 160	
Carbon dioxide (CO ₂)	< 5.0	< 10.0 in hard water
Chlorine (Cl)	< 0.003	
Chromium (Cr)	< 0.03	
Copper (Cu)	< 0.006	< 0.03 in hard water
Fluorine (F)	< 0.5	
Hardness (as CaCO ₃)	20-400	Considered hard water if > 100
Hydrogen cyanide (HCN)	< 0.005	
Hydrogen sulphide (H ₂ S)	< 0.002	
Iron (Fe)	< 0. 1	
Lead (Pb)	< 0.02	
Magnesium (Mg)	< 15.0	
Manganese (Mn)	< 0.01	
Mercury (Hg)	< 0.0002	
Nickel (Ni)	< 0.01	
Nitrate (NO ₃)	< 1.0	
Nitrite NO ₂	< 0.015	< 0. 1 in hard water
Nitrogen (N ₂)	< 103 % saturation	< 107 % in larger fish (> 100 g) but see text above
Oxygen (O ₂)	< 6.5	
Ozone (O ₃)	< 0.005	
pH	6.5-8.5	
Polychlorinated biphenyls (PCB)	< 0.002	
Potassium (K)	< 5.0	
Selenium (Se)	< 0.01	
Silver (Ag)	< 0.003	
Sodium (Na)	< 75.0	
Sulphur (S)	< 1.0	
Sulphate (SO ₄)	< 50.0	
Temperature	< 15 (°C)	
Total dissolved solids (TDS)	< 400	
Total suspended solids (TSS)	<80	< 15 mg/L above background levels
Uranium (U)	< 0. 1	
Vanadium (V)	< 0. 1	
Zinc (Zn)	< 0.005	
Zirconium (Z)	< 0. 1	

Feed quality

Feeds used for charr farming is generally similar to salmon feed, and in many cases identical. The requirement for macronutrients is the same as other salmonids. Generally it is changing as the fish grow, with protein demand reduced as fish weight increase. This enables us to save proteins by including more fat in diets to larger fish. Recommended diets for juvenile arctic charr are given in table 2.

Table 2.

Recommended diets for Arctic charr (based on Johnston 2002).

Dietary component (% dry weight)	Starter	Grower	Finish	Brood
Crude protein	60	54	52	50
Total lipid	20	20	22	28
Carbohydrate	8	13	13	13
Fiber	1	4	4	1
Ash	11	9	9	8
Carotenoid pigment (mg/kg)	50	22	78	67
Linolenic acid 18: 3 (n-3)	12-20	11-18	11-18	11-18
Methionine (% of total protein)	2.7	2.7	2.7	2.7
Vitamins (mg/kg dry diet)	All diets	Minerals (mg/kg dry diet)	All diets	
Thiamine (B 1)	15	Calcium (Ca)	3000	
Riboflavin (B2)	30	Cobalt (Co)	5-10	
Pyridoxine (B6)	20	Copper (Cu)	5	
Pantothenic acid	50	Iodine (I)	0.3	
Niacin	200	Iron (Fe)	40	
Folic acid	10	Magnesium (Mg)	500	
Cyanocobalamin (B 12)	121	Manganese (Mn)	15	
Myo-inositol	400	Phosphorus (P)	6000	
Choline	1000	Potassium (K)	700	
Biotin	1.5	Selenium (Se)	0.3	
Ascorbic acid (C)	400	Sodium (Na)	6000	
Vitamin A	7000 IU	Zinc (Zn)	30	
Vitamin D	3000 W			
Vitamin E	350			
Vitamin K	350			

Feeding practice

The gastrointestinal system in charr is relatively short, with limited storage capacity in the stomach. It is therefore recommended to feed the fish on a daily basis. Charr is able to feed from the bottom of the tank, and also feed during darkness. However, best growth rate is obtained under long daylength, but this is probably more closely connected to season. The time of day at which feed is administered seem to be of less importance, as feeding at dusk did not result in differences in feed intake and growth when compared to fish fed at dawn (Dalen 1997).

Charr have a smaller mouth compared to salmon, and generally it is recommended to use a pellet size one grade smaller than what is used to salmon, but as for salmon it is recommended to increase pellet size as the fish grow. For start feeding, practical experience by Norwegian farmers have shown best results with a granulated start feed as small as 0.4 mm (Håkon Dalen, pers. comm.). Linnér & Brännäs (1994) found that pellet sizes (diameter) of 2% of the fish's body length (fork length) gave shortest consumption time and lowest number of missed pellets. This fits reasonably with Tabachek (1988) who found highest growth rates in fish fed particle sizes that were 2.3-2.4 % of body length in

small charr (about 10 cm). She used crumbled pellets that were sieved into different particle size ranges, not pelleted feed as Linnér & Brännäs.

Competition for feed is often seen in groups of Arctic charr. If allowed to, the most competitive fish, often referred to as social dominants, gains access to the feed at the expense of others. By forming such feeding hierarchies, these individuals grow at a higher rate, eventually leading to large size variability in the group. Size differences escalate, as large fish seems more likely to gain access to feed. Under extreme conditions and even if the feed resource is not limited, i.e. if all got an even share every fish should have excess amounts of feed, dominant fish controls the feed to such an extent that sub-ordinate fish cease feeding. Predictability of where and when feed is delivered increase competition and is likely to result in large size variation. Ensuring that the feed is presented in the whole water column during feeding reduces the opportunity of monopolising the feed, and thereby also the chances of dominant fish establishing feeding hierarchies. This reduces the competition and aggression in the fish group. Aggression is stressful, and reduces growth potential, immunocompetence, and compromise animal welfare. Control of formation of aggression based social hierarchies can be achieved by regular measurement of individual fish size (every month during fast growth periods, and every second month in periods with slow growth), and calculate variability. It is advised to use a size independent measure of variability, such as coefficient of variation, to enable direct comparisons of variability over time as the fish grow. Coefficient of variation (CV) = standard deviation divided by average times 100. In experiments with low variability, CV-weight lies between 20 and 30.

There exist several feeding rate tables made for Arctic charr. These may be estimating the growth reasonably well over a long period of time, i.e. a year, but can lead to vastly over or under feeding at times. The growth potential changes with external factors, such as temperature, but is also controlled by endogenous factors. The growth seems connected to season (Sæther and co-workers, 1996), possibly an adaptation to varying availability of food and large differences in opportunity for growth between seasons. Most feeding and growth models do not consider this, and should therefore be used with great care. The best feeding practice seems to be the ones controlled by the fish's own appetite.

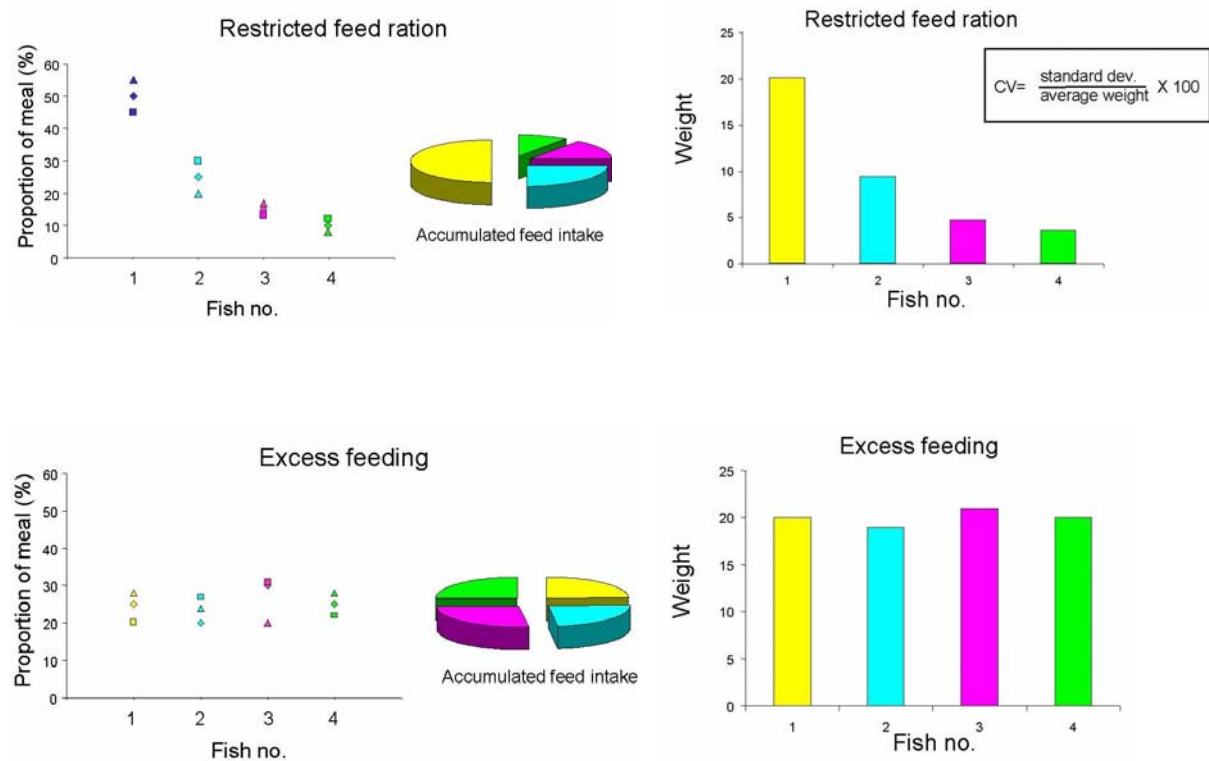


Figure 1. Theoretical distribution of feed and consequences for individual growth within a small group of fish.

The fish in figure 1 is ranked by feed intake. The upper left panel show a situation where feed availability is limited (restricted). Under such situations social hierarchies often results, leading to a large and consistent variability in feed intake between fishes but little variability between days for individual fish (here exemplified over three meals as indicated by different symbols). This leads to increased variability in size (right panel). Feed intake, but more easily, size variability can be used as an indicator of social hierarchies. Such hierarchies are based on competition for feed often accompanied by an increase in aggression levels, and are compromising animal welfare. The increased aggression also leads to increased stress and higher incidence of wounded fish. Monitoring the development of variability in weight within tanks may be a helpful tool for assessment of social conditions in the tank. The reason for using CV instead of just a direct measure of variability is that one have to adjust for size difference between consecutive measurements. Hopefully the fish has grown between measurements, and the variability is then expected to increase, however, a relative measure of variability should not. CV is a size adjusted measure of variability. In the lower panel the situation looks stable and healthy. There are no consistent rank in feeding level, and low variability in feed intake between fish and between days (left panel) enables all individuals to gain feed and produce homogenous growth (right panel). This situation does not indicate high aggression levels, or social hierarchies.

The take home message would then be to feed the fish should to satiation every day, and that the feed should be evenly distributed in the whole water column during feeding.

Water currents

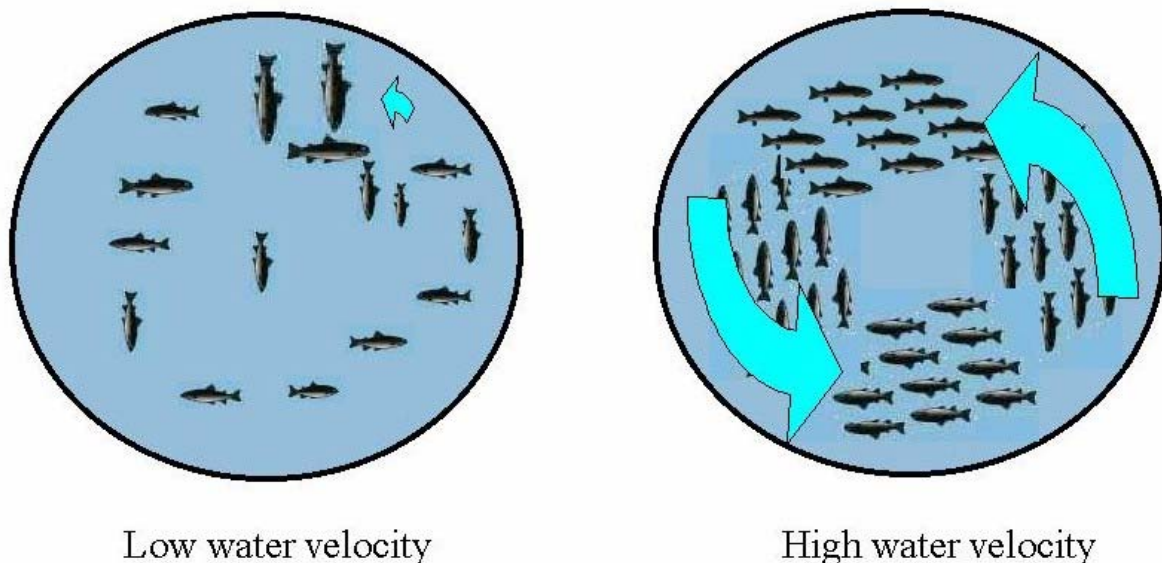


Figure 2. Water currents in fish tanks. Left panel (indicated by small arrow): low water current speed. Fish not very organised, poor dispersal of feed makes it easy to monopolise, large size variability. Large fish defend the area under the feeder and get first access to feed. Right panel: High water current speed (indicated by large arrows). Fish are evenly distributed in the tank, all swimming in the same direction. The water currents helps distribute the feed to the whole group, reducing the possibility for potential aggressive fish to defend the feed. Small size variability.

The water current is necessary for self-cleaning in most tank systems, and circular tanks require 4-6 cm sec⁻¹. Water currents affect the behaviour of the fish. At low water speeds, the fish swims less organised in the tank and seems to engage in more aggressive interactions (Fig. 2). Dominant fish wants to hold territories, preferably nearby feeding spots. At higher water speeds, the fish organises and start to school in the tank. The fish is evenly distributed and are less occupied by social interactions, which is reflected in reduced level of fin damage (Jørgensen and Jobling 1993). The water current also helps distributing the feed in the water column. As the fish prefer to hold the same position in the tank when schooling, the water current also becomes the swimming speed. The exercise effect of increased swimming speed leads to improved growth and feed utilisation (Fig. 3).

The threshold speed for schooling is probably somewhere between 0.5 and 1 body length per second. The growth rate increases until 1.5-1.75 body lengths per second.

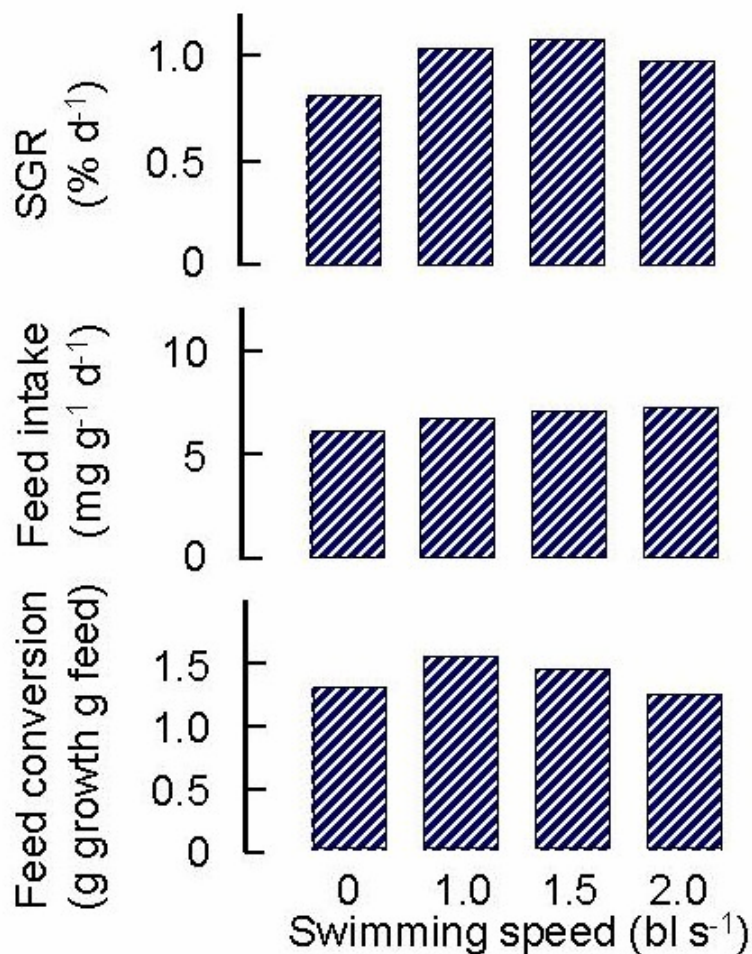


Figure 3. From Jørgensen & Jobling (1993).

Percent weight gain per day (SGR), Feed intake and Feed utilisation (FCR) in Arctic charr held under different water current speeds. Growth rate increase until 1.5 bodylengths per second. Feed intake increase with increasing water current, whereas utilisation of the feed seems to be best at 1-1.5 bodylengths per second.

The water current in the tank therefore serves several purposes; self-cleaning, distribution of feed, reducing aggression and fin damage to the fish (schooling) and exercise to the fish.

Grading

Grading fish may give fish that are lagging behind in growth an opportunity to increase their growth rate, as more competitive, and therefore larger fish, are removed. If the growth is highly variable due to social interactions, there is more to gain by grading the fish. The improved overall growth following grading is due to compensatory growth in fish that previously have had depressed growth rate. The larger fish may not show any change in growth rate following grading.

The handling stress to the fish involved with the grading process may be eased by light anaesthetic/tranquillisation. This will also most likely reduce negative effects on feeding following handling. The fish most likely compensates for growth depensation due to reduced feeding motivation following handling by increasing feed intake when appetite returns.

Water depth

Low water depth may cause swim bladder stress syndrome. In juvenile charr (weight 20 g) critical water depth appears to be 15 cm (Kolbeinshavn and Wallace, 1985). However, they also recorded higher mortality due to SBSS at 24 cm water depth (10%) as compared to 37 cm (3%), thus, recommend minimum water depth is perhaps closer to 35 than 15 cm.

Density

Arctic charr tolerate high densities without negative effects on feed intake and growth. In fact, low density should be avoided as it increases social interactions within groups (Jørgensen and co-workers 1993). At 15 kg m⁻³ charr showed poorer growth rate, and larger variability in growth rate when compared to charr held at 60 kg m⁻³. An increase to 120 kg m⁻³ did not lead to reduced growth, nor changes in individual growth variability. In another study, a density of 30 kg m⁻³ showed higher degree of fin damage, and a higher degree of weight loss, than charr at 90 or 150 kg m⁻³, probably due to aggressive behaviour at low density (Siikavuopio and Jobling 1995). Sixty kilos per 1000 litres of water should be considered minimum density under growing conditions. The upper limit is uncertain, but it seems clear that at least 120 kg m⁻³ is not a problem. In commercial scale fish tanks (10 m³), practical experience indicate that densities can be reduced to some extent without increased problems with aggression. For instance, 20-30 kg m⁻³ did not caused problems, and this may be favourable when farming small fish during summer time with high temperatures and limited oxygen.

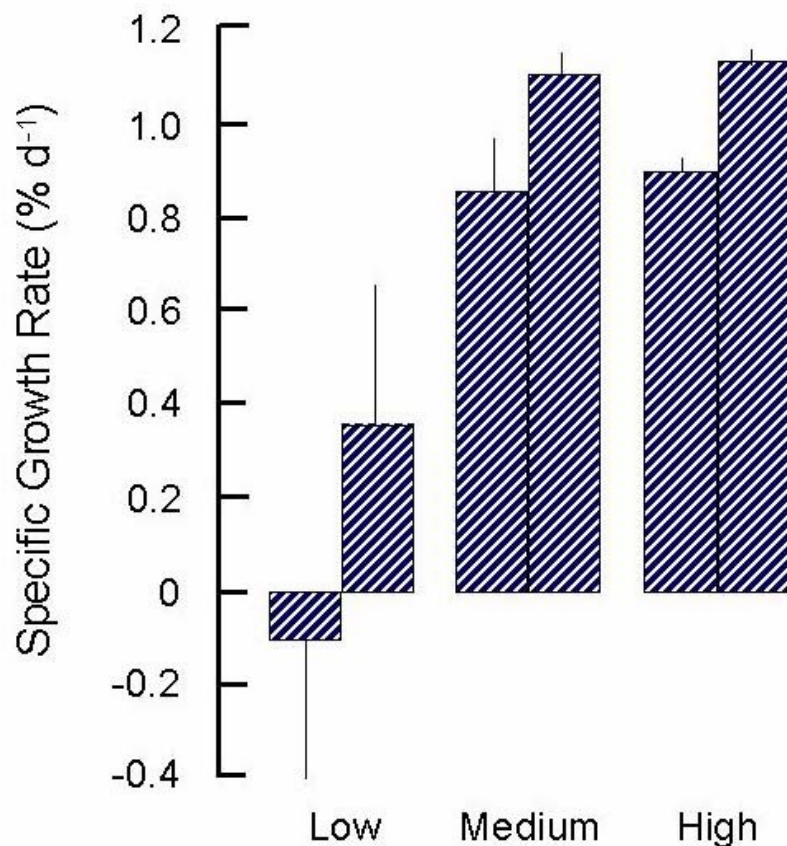


Figure 4. From Jørgensen and co-workers (1993).

Effects of fish density on growth rate in Arctic charr. Low density= 15 kg/1000l, Medium= 60 kg/1000l, High= 120 kg/1000l. Charr held at the lowest density clearly showed lowest growth, and largest variability in growthrate. There was no difference in growthrate or variability in growthrate between 60 and 120 kg/1000l.

Light

The fish are affected by photoperiod (daylength). The most rigid environmental cue that can be used as calendar is changes in daylength. Salmonids use changes in daylength to time important seasonal events, such as parr-smolt transformation and maturation. Changes like these are complex, involving morphological, behavioural and physiological changes and exact timing of these is of immense importance. If the fish is expected to follow the seasonal changes seen in nature, they need to get information about change of season through change in daylength. The fish has an ability to generate the calendar it self, as is it equipped with one or more biological clocks. However, these continuously need adjustment, as they tend to lag behind or move to fast in the absence of environmental cues. That means that if fish are held under constant conditions, they will still go through the seasonal changes, but these changes will drift according to season. This can also be utilised by farmers, as time of smolting or spawning can be shifted in a controlled manner by manipulating the changes in daylength. Simulated changes in seasons, does not have to include daily changes in daylength, but can be achieved by adjusting the daylength to the fish for instance at weekly intervals. It is easy to go wrong when manipulating with biological clocks, so care should be taken when dealing with them.

Salmonids are able to conceive light at very low densities (below 1 lux, Zachmann and co-workers, 1992). When comparing growth and mortality in juvenile Arctic charr exposed for light intensities from 0 to 700 lux, Wallace and co-workers (1988) found highest growth rate at 50 lux, with survival rate only beaten by fish held in darkness (0 lux). Charr at 10 and 200 lux had similar growth with the latter having slightly lower survival. Poorest growth and highest mortality were recorded in the group held at 700 lux. It therefore seems that charr show best performance in terms of growth and survival at relatively dim light, and light intensity around 50 lux is recommended.

The difference between day and night is more important than the absolute intensity for the fish's perception of day and night (Zachmann and co-workers, 1992). When using low intensity light, it is therefore important to keep the night as dark as possible.

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