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An evaluation of 30 years of selective breeding in the Arctic charr (*Salvelinus alpinus* L.) and its implications for feeding management

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ABSTRACT

The Swedish breeding program for Arctic charr (*Salvelinus alpinus* L.) has been running for 30 years and includes seven selected generations. In this study, we evaluated the differences in growth between the first generation of selected Arctic charr and the present generation. We demonstrate that not only has growth been improved through selective breeding but also that a change in the seasonal growth capacity has occurred. Selection has induced a high winter growth capacity, but the largest weight gain between generations was seen during summer. As a result of selective breeding, the production time to reach a slaughter weight of 600–700 g has been reduced by 10 months since the start of the breeding program in 1985, and improvements in the final weight have been of the magnitude of 11% per generation. To be able to keep up with the faster growth and altered seasonality of this strain, feeding management needs to be adapted. In this study, a model based on the theoretical energy need of the Arctic charr is presented, which makes it possible to make such adaptions in feeding management.

1. Introduction

Fish breeding has resulted in large improvements for the growing aquaculture industry over the last 40 years (Gjedrem and Robinson, 2014). The first family-based breeding program was started in 1975 for the Atlantic salmon, (Gjedrem, 2010) and in Europe approximately 80% of all stocks are genetically improved through selective breeding (Janssen et al., 2017). Body weight is the trait that has most often been selected for; however, other desirable traits, such as the timing of sexual maturity, morphology, disease resistance and filet yield have also been considered for modification in farmed fish (Aquabreeding, 2009; Gjedrem and Robinson, 2014; Gjerde et al., 2012). Breeding of fish has been demonstrated to be extremely successful and the genetic gain in body weight has reached approximately 13% per generation (Gjedrem and Robinson, 2014; Janssen et al., 2017). In Sweden, a breeding program for Arctic charr (*Salvelinus alpinus* L.) was initiated in the early 1980s, facilitating the development of a sustainable industry (Nilsson et al., 2010). The progress in breeding has resulted in a fast-growing and late-maturing strain of Arctic charr (Eriksson et al., 2010); however, the program has not been thoroughly evaluated.

The Arctic charr shows typical seasonal shifts in feed intake, displaying a high motivation to feed in early spring and a peak during midsummer, but becoming almost anorectic towards autumn (Damsgard et al., 1999; Pálsson et al., 1992; Saether et al., 1996; Striberny et al., 2015; Tveiten et al., 1996). Thus, the motivation to feed is low during a long period of time, from October to February, i.e., a winter depression in appetite and growth (Alanärä et al., 2001). Temporal cycling in food intake has been described in several animals, and it appears that species living at high latitudes exhibit the greatest seasonal fluctuations (Bairlein and Gwinner, 1994; Loudon, 1994). Earlier data on the Arctic charr from the Swedish breeding program indicate that the selection for fast growth has resulted in an increased capacity to grow at low temperatures from February to May as well as that the length of the winter depression has been shortened (Eriksson et al., 2010).

The delay of sexual maturation for fish in culture has been a breeding target in several breeding programs (Janssen et al., 2017). Sexually mature salmonids typically show reduced growth, lower flesh quality and often higher mortality rates, hence, they are not desirable in production (Gjedrem, 1983, 2010). The frequency of early sexual maturation in males, occurring before 20 months of age in the Arctic charr, however, was rather low in the first generations of the breeding program (Nilsson et al., 2010).

Improved growth and seasonality in appetite implies that the feeding management strategy for the Arctic charr must be flexible. It has been demonstrated that a poor concern of seasonal fluctuations in the appetite may result in feed waste under commercial rearing conditions (Smith et al., 1993). Most feed requirement models cannot be modified based on local stock requirements and do not include any

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variable that accounts for the seasonal variation in appetite (Alanärä and Strand, 2015). Alanärä et al. (2001) have developed an adaptive model for the estimation of the daily energy requirements and calculation of feed budgets for fish in culture. The model is based on two major components–the daily growth increment of the fish and the amount of digestible energy needed to obtain one unit of biomass gain. Values for both components can be retrieved under practical rearing conditions and can be updated regularly. Such adaptive feeding management models have previously been successfully tested for the rainbow trout (Bailey and Alanärä, 2001) and the Eurasian perch (Alanärä and Strand, 2015).

We collected historical and new fish growth data from the Swedish breeding program for the Arctic charr and evaluated how the progress in breeding over 30 years has affected the growth potential and the seasonality in growth capacity. Based on daily growth data and data on the energy needs for the latest selected generation of fish, we also present an adaptive feeding management model for the Arctic charr.

2. Material and methods

2.1. Fish and rearing

The breeding program for the Arctic charr was initiated in 1982 with a common garden experiment to assess the growth and maturity patterns in three different strains (Eriksson et al., 1992). Fish were held under net-pen farming conditions and the best performing strain in terms of growth and rate of maturity was the one from Lake Hornavan. Fish from the Lake Hornavan strain were moved to the Aquaculture Centre North (ACN) in Kälarne, Sweden in 1984. The Arctic charr breeding program is family-based, using traditional quantitative genetic methods based on relatedness and trait measurements and selection for faster growth has been the main task (Nilsson et al., 2010).

2.1.1. Breeding evaluations

Data were obtained from the breeding program and from scientific trials (Table 1). All fish used in the evaluation of the growth capacity were subjected to similar rearing conditions at ACN, with the exception of water temperatures for eggs and fry. For the first generation, eggs and fry were reared in ambient water temperatures. Start-feeding of the fry began in mid-May and the fry reached a size of one gram by mid-July. In 1990, during the second generation of the breeding program, the hatchery was improved with possibilities to increase the water temperature for eggs and fry, i.e., earlier hatching and start-feeding. Water was heated to 6.0 °C (± 0.5) for eggs and fry, until the natural water temperature reached 6.0 °C in May. Start-feeding began in mid- to late-March and fry reached a size of one gram by mid-June. For all generations, juveniles were reared in plastic tanks (0.8 m^3) during the first summer and transferred to large concrete pools during winter as they reached 30–50 g. Water was taken from Lake Angsjön situated nearby and the light regime during spring, summer and autumn reflected natural conditions; however, in winter, the day-length was never shorter than nine hours. Feeding was conducted to satiation using commercial pelleted feeds.

For comparisons of early sexual maturation between generations, three data sets from ACN (1986, 2009 and 2013) were used and additionally three data sets from other commercial fish farms, Kiruna (1986), NORAC, Skelleftehamn (1986) and Sälla, Arjeplog (2009) were used.

Table 1
Data used for evaluation of breeding effects and seasonality of the Arctic charr.

Generation	Year	Start date Weight (g)	Final date Weight (g)	Weightings	Reference
1	1985–86	20-Aug-85 3.3	2-Dec-86 208.6	14	Näslund et al. (1990)[a]
1	1986–87	22-Aug-86 3.56	10-Dec-87 237.4	14	Näslund et al. (1990)[a]
1	1987–89	8-Apr-87 29.1	26-Apr-89 651.2	5	Unpublished data[b]
6	2009–11	11-Nov-09 33.7	18-May-11 980.2	6	Nilsson et al. (2016)
6	2012–13	10-Oct-12 32.7	4-Dec-13 667.9	11	Carlberg et al. (2018)[a]
7	2013–15	10-Dec-13 48.6	27-May-15 879.4	4	Unpublished data[b]

[a] Data series used for creating seasonality profile.
[b] Unpublished data from the breeding program.

2.1.2. Den-model

Data used for constructing a model for the digestible energy need (DEN) to produce one unit of weight gain in the Arctic charr came from trials with waste feed collection (Table 2). Feed intake and growth of individual fish was recorded from a lab set up (described in Strand et al., 2007b), while data for fish at a group level were recorded at ACN in tanks (1 × 1 m, 800 l) with feed waste collection (Hølland Teknologi, Norway).

2.2. Calculations

Growth capacity was calculated as the thermal growth coefficient, TGC, as $TGC = (W_2^{1/3} - W_1^{1/3})/(T * D) * 1000$ (Cho, 1990), where W_1 is initial weight and W_2 is the final weight, T is water temperature and D is the number of days between W_1 and W_2.

To analyse the effect of heated water (6 °C) compared to ambient water temperature during the egg-incubation and start-feeding periods, data from Alanärä (1990) and Näslund et al. (1990) were used. In 1988–89, using the first generation of the Arctic charr, the water was experimentally heated to 6 °C during the entire egg incubation period (Alanärä, 1990). When incubated at 6 °C, start-feed began in mid-February and the fish reached one g in size by late-May. In ambient water temperatures, start-feeding began in mid-May and the fish were one g in size by mid-July. The data from Näslund et al. (1990) includes average weight measures of the fish from August to December for two consecutive years (Table 1). The eggs were held in ambient water temperatures and hatched in mid-May. By combining the data from the two studies, monthly TGC values were obtained for the period between mid-July and December. These TGC values were then used to calculate the theoretical growth of fish subjected to a situation where the water was heated to 6 °C during egg incubation and start-feeding occurred in mid-May. The growth was calculated as follows: $[W_1^{(1/3)} + (TGC/1000 * T * D)]^3$ where W_2 was the estimated weight (g), W_1 was the initial weight (g), T was the temperature (°C) and D was the number of days. Here we assumed that the TGC values are temperature-independent, a relationship that has been observed in other fish species (Alanärä and Strand, 2015). This calculation allowed for comparisons of the weight of fish in late autumn during the first year, independently, whether they had been raised under ambient water temperatures or heated water during the egg incubation and the start-feeding period.

To analyse the effect of selective breeding on the seasonal growth capacity of the Arctic charr, three studies using fish from the first breeding generation and three studies from the sixth and seven breeding generations were used (Table 1). Compilations from generation six and seven are hereafter referred to as the present generation. The duration of the growth period and number of sampling occasions differed largely between studies (Table 1). To obtain data from the whole growth period for each study, the daily weight increment was calculated using a TGC-based growth model. To take into account the variation in the growth capacity at different times of the year, data from three out of the six studies was used to create a seasonal growth capacity factor. The fish in these three studies were weighed at monthly intervals over the entire study period (Table 1). The growth capacity