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Chinook salmon (*Oncorhynchus tshawytscha*) feed conversion efficiency: evaluation and potential for selection

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Abstract

Improving performance through selective breeding is a key priority for the New Zealand Chinook salmon (*Oncorhynchus tshawytscha*) aquaculture industry. The family selective breeding programme operated by The New Zealand King Salmon Company has successfully improved growth and quality after six generations of selection. However, feed conversion efficiency is not currently a direct breeding goal. Research was established to analyse daily feed intake and feed conversion ratio, a measure of feed efficiency, in 160 families over two spawning year classes. Daily feed intake assessment methodology employing digital X-radiography was validated and used to obtain repeated measurements of daily feed intake. Measurements of growth, and feed conversion ratio up to harvest size were also obtained. Genetic parameter estimates for daily feed intake and feed conversion ratio indicated that there are family differences for these traits. As a result the continued measurement of feed conversion ratio in The New Zealand King Salmon families and incorporation of the traits into The New Zealand King Salmon breeding programme is being considered.

Keywords: feed intake; feed conversion; quantitative genetics; heritability; chinook salmon

Introduction

Selection in the New Zealand King Salmon Company Ltd. (NZKS) salmon stock primarily began with the objective of enhancing growth performance. Sexual maturation and fillet quality are also now included as breeding goals for New Zealand Chinook salmon (*Oncorhynchus tshawytscha*). Improved feed conversion efficiency (FCE) has also been identified as a priority but is not part of the main breeding goal given the perceived difficulties and costs associated with measuring this phenotype.

In the 1980s two methods were developed to measure feed intake in individual fish reared in groups using either feed labelled with radioisotope ^{131}I or with X-ray opaque particulate markers such as lead glass beads (Talbot & Higgins 1983; Talbot 1985). For health and safety reasons the X-radiography method has been the preferred technique. With the increased affordability of portable digital X-radiography systems this technique has become more accessible and it is possible to assess daily feed intake (DFI) in hundreds of fish in one day prior to gut evacuation taking place.

The aims of the present study were to firstly assess the suitability of X-radiography for accurately and repeatedly measuring DFI and feed conversion ratio (FCR) using Chinook salmon families from the NZKS family based breeding programme and secondly to determine the heritability of DFI and FCR.

Materials and methods

Fish

Individually passive integrated transponder tagged Chinook salmon from 160 full-sib families, 80 per year class from two different spawning years (2008 (n = 3,710) and 2010 (n = 3,632)) were sourced from the NZKS breeding programme at Tentburn Hatchery and transferred to the National Institute of Water and Atmosphere (NIWA), Bream Bay Aquaculture Park. Both spawning years each sire and dam contributed to only one family, and the overall level of relationship among selected parents was optimised to maintain acceptable genetic diversity in the population over the long term.

After a period of acclimatisation to seawater the fish were sorted equally by family into two 40 m^3 rearing tanks. Temperature was controlled to match NZKS sea pen conditions and photoperiod was either the same as the ambient day length in the Marlborough Sounds (2008 families) or constant 24 hour light (2010 families). Fish were fed once daily to satiation using a standard commercially available extruded pelleted feed composed of 38.5% protein, 25.5% lipid and 20.5 MJ/kg of digestible energy.

Measuring daily feed intake and feed conversion

The X-radiography method used to measure DFI was based on the method outlined by Talbot & Higgins, 1983. The X-rays images were obtained using an Atomscope HF80/15+ portable X-ray Unit (Mikasa, Tokyo, Japan) and 90-479 Tru-DR flat panel

amorphous silicon digital radiographic receptor (DLC Australia Pty Ltd, Melbourne, Australia). The fish feed manufacturer Skretting (Cambridge, Tasmania, Australia), provided the extruded pelleted feed (3 mm, 4 mm, 6 mm and 9 mm) containing the X-ray opaque ballotini beads. The ballotini used were ceramic zirconium silicate type ZS (9305, 0.4-0.6 mm) and leaded glass Type H (8503, 0.75-1.0 mm) SiLibeads® supplied by Sigmund Lindner GmbH. The beads were added to the feed during its manufacture to 1 % (0.4-0.6 mm ballotini in 3 and 4 mm feed pellets), 0.75 % (0.75-1.0 mm ballotini in 6 mm feed pellets) and 0.5 % (0.75-1.0 mm ballotini in 9 mm feed pellets) of the total mass of the feed. For each diet, a series of samples of known weight were taken from the pellets containing ballotini and X-rayed. The number of beads present in each sample was counted and diet-specific regression equations obtained. Following feeding to satiation, DFI was estimated based on the number of ballotini on the X-ray images of the fish alimentary canal and the known ratio of the number of ballotini to feed mass. The number of ballotini in the X-ray images were counted using a semi-automated method using the proprietary batch processing "Bead Counter" software developed by AgResearch (P Smale, Personal communication) and validated by comparison with manual counts. The timing of the initiation of evacuation of feed was determined by repeated X-rays of the same fish. This meant that X-rays carried out to determine DFI could be timed to be prior to any evacuation of ballotini.

In order to validate the X-radiography technique and to assess its accuracy for estimating DFI, 16 of the 2008 families were reared in individual 1.5 m^3 tanks with 30 fish per tank. Uneaten feed was recovered from each tank to compare the feed intake directly for each tank of fish with the feed intake estimated using X-radiography. Each family was assessed two to four times, including weight assessments at each time point. The DFI was determined by X-radiography at the beginning and end of each period and the total feed eaten by each family estimated:

Feed eaten (g) = (DFI at beginning (g) + DFI at end (g)) / 2 x Number of days between measurements x Number of fish in tank.

This was then compared to the actual total feed eaten for the period based on the amount fed minus the recovered uneaten food.

Feed conversion ratio (FCR) was used as a measure of the feed conversion efficiency and represents the feed intake per unit weight gain for the period. FCR for individual fish between two live weight measurements was calculated as:

FCR = Feed eaten (g) / Weight gain (g).
A low FCR is favourable.

Family evaluation

Due to high levels of early sexual maturation in the 2008 spawning year many individuals displayed a repressed feeding response towards the end of the study. This meant that FCR could only be assessed accurately for a small number of individuals in this group. Early maturation was avoided in fish from the 2010 spawning year by exposing them to constant light. Only the 2010 DFI and FCR family data will be presented in this paper. Eighty families were evaluated with between 7 to 17 fish assessed from each family. Live weight (WT) and DFI were measured on four occasions in 2011, namely 10 and 12 May (WT 1, DFI 1), 21 and 23 June (WT 2, DFI 2), 23 and 25 August (WT 3, DFI 3), 11 and 13 October (WT 4, DFI 4). The total number of fish assessed was reduced from 1,744 to 725 during this period to maintain total biomass in each tank within acceptable limits. All fish were X-rayed following feeding to satiation, one tank per day. Mean DFI for

Table 1 Summary statistics of mean ± standard deviation, coefficient of variation and sample size for the feed conversion traits for the 2010 spawning families at the four time points.

Measurement	Time	Mean	Coefficient of variation	Sample size
Live weight (g)	May	574 ± 99	17.2	2,780
	June	865 ± 160	18.5	1,772
	August	1,420 ± 279	19.7	982
	October	2,067 ± 412	19.9	730
Daily feed intake (g)	May	8.1 ± 2.7	33.4	1,744
	June	11.8 ± 4.2	35.4	1,661
	August	11.9 ± 7.1	59.7	977
	October	11.7 ± 7.3	62.2	725
Mean daily feed intake (g)	May - June	10.0 ± 3.0	30.5	1,614
	June - August	12.2 ± 4.7	38.4	867
	August - October	12.6 ± 5.6	44.7	667
Feed conversion ratio	May - June	1.49 ± 0.33	22.0	1,647
	June - August	1.39 ± 0.40	28.4	864
	August - October	0.95 ± 0.35	36.7	665

Table 2 Genetic parameters for feed intake and feed conversion traits for the 2010 spawning year families at four time points. Heritability estimates are in bold on the diagonal, phenotypic correlations are above the diagonal and genetic correlations are below the diagonal. Range in standard errors for heritability estimates were 0.05 to 0.08, for phenotypic correlations were 0.01 to 0.04 and for genetic correlations were 0.01 to 0.04.
DFI = Daily feed intake; MDFI = Mean daily feed intake; Log_e FCR = Log_e Feed conversion ratio; 1 = May; 2 = June; 3 = August; 4 = October.

Trait	DFI 1	DFI 2	DFI 3	DFI 4	MDFI 1-2	MDFI 2-3	MDFI 3-4	Log_e FCR 1-2	Log_e FCR 2-3	Log_e FCR 3-4
DFI 1	**0.39**	0.56	0.39	0.34	0.83	0.55	0.44	0.46	0.21	0.20
DFI 2	0.99	**0.36**	0.37	0.36	0.93	0.73	0.43	0.50	0.42	0.16
DFI 3	0.73	0.83	**0.29**	0.39	0.44	0.91	0.82	0.11	0.66	0.64
DFI 4	0.67	0.72	0.89	**0.30**	0.40	0.46	0.84	0.16	0.21	0.64
MDFI 1-2	1.00	1.00	0.80	0.70	**0.47**	0.75	0.50	0.54	0.39	0.20
MDFI 2-3	0.88	0.94	0.98	0.88	0.93	**0.41**	0.81	0.34	0.67	0.55
MDFI 3-4	0.73	0.81	0.97	0.97	0.78	0.97	**0.37**	0.18	0.51	0.78
Log_e FCR 1-2	0.50	0.44	0.46	0.15	0.46	0.50	0.33	**0.18**	0.38	0.13
Log_e FCR 2-3	0.47	0.49	0.55	0.45	0.50	0.54	0.55	0.77	**0.24**	0.60
Log_e FCR 3-4	0.27	0.31	0.80	0.73	0.32	0.63	0.78	0.26	0.69	**0.24**

individual fish was calculated between assessments as DFI 1 (May) to DFI 2 (June) (42 days), DFI 2 (June) to DFI 3 (August) (63 days), DFI 3 (August) to DFI 4 (October) (49 days). FCR for each fish assessed at the beginning and end of each period was calculated using the calculated mean DFI for each and their recorded live weight gain during each period.

Genetic parameter estimation

Genetic parameters were estimated with ASReml (Gilmour et al. 2008). Fixed effects included contemporary group following transfer to Bream Bay until measurement, age of female parent (two or three years) and date of fertilisation as a covariate. Additive genetic effects were fitted as a random effect using the numerator relationship matrix calculated from the recorded pedigree; a pedigree that extended back to the 1995 spawning year. For FCR, outliers that were either ≤ 0 or > 10 were removed before analysis, as these fish had either a low or negative weight gain or were not feeding. This trait was analysed on the natural log-transformed scale as this appeared to improve the stability of the analysis. A bivariate analysis was run for each pair of traits to estimate correlations, while heritabilities are given as the mean estimates over all bivariate analyses for that trait.

Results

Feed efficiency measurement

The feed intake of the 16 salmon families in the small tanks estimated using the X-ray technique was highly correlated to the intake based on the feed supplied to the fish and the uneaten feed recovered over the same periods ($R^2 = 0.89$, $P < 0.001$).

Genetic parameter estimation

Summary statistics for live weight, DFI and FCR for the 2010 spawning year families are presented in Table 1, including the raw means, phenotypic standard deviations, coefficients of variation and the sample size. Table 2 presents the estimates of the heritabilities and the genetic and phenotypic correlations among the feed intake and log_e FCR traits for the 2010 spawning year families. Heritability estimates were moderate to high (0.29 to 0.47), for DFI measured at four different times, high (0.37 to 0.47) for mean DFI across the three measurement periods and moderate (0.18 to 0.24) for log_e FCR across the three measurement periods.

Genetic correlations between the four DFI measurements and between the consecutive log_e FCR estimates were all positive and high. In the case of the genetic correlation between log_e FCR estimated during the first and last period the derived correlation was still positive at 0.26 but reduced compared to adjacent measures of 0.77 and 0.69.

Discussion

The results in this study show that X-radiography and ballotini feeding is a practical method of recording individual feed intake from large numbers of fish reared in a common tank with up to 900 fish being able to be assessed in one day. Some researchers have expressed concern over the accuracy of this technique and report relatively low repeatabilities for DFI (Grima et al. 2008; Kause et al. 2006a; Kause et al. 2006b). We found a high correlation of DFI estimated using X- radiography with the actual DFI of family groups reared in separate tanks. Coupled with the high phenotypic and genetic correlations between subsequent measurements of DFI at a point in time and the subsequent measurements of mean DFI over a period for the family fish reared

communally, this indicates that this method was an accurate and repeatable technique for measuring DFI of families in this study.

Feed represents up to 60% of the costs of aquaculture production (FAO, 2006). While it is recognised that improving FCE is an important trait to target, it has been considered too difficult and expensive to measure in fish selection programmes (Gjedrem, 2000; Gjedrem, 2010). In this study we have shown that the use of portable digital X-ray technology provides a feasible method for assessing FCE and report high heritabilities for mean DFI and moderate heritablities for $\log_e$ FCR.

Until recently the majority of genetic studies on DFI and FCE in fish have been based on the average performance of full-sib families held in individual family tanks (Kinghorn, 1983; Thodesen et al. 2001; Kolstad et al. 2004), which may have led to overestimates of heritabilities. Studies utilising X-radiography to determine DFI of individual fish reared communally have reported heritabilities of 0.41 for DFI in catfish (Silverstein et al. 2001), 0.10 for DFI in rainbow trout (Kause et al. 2006b), and 0.21 for DFI and 0.06 for FCE in whitefish (Quinton et al. 2007).

In some fish stocks there is some evidence of a positive genetic correlation between growth rate and DFI and/or conversion efficiency (Gjedrem, 2010; Kause et al. 2006b; Kolstad et al. 2004; Thodesen et al. 2001). However, Mambrini et al. (2004) did not detect any improvement in FCE when selecting brown trout for growth gain. Therefore, rather than assuming that selecting for faster growth rates will lead to gains in FCE the relationship between the relevant traits should be confirmed for each stock. Quinton et al. (2007) showed that selecting for growth will indirectly improve FCE in whitefish. However, selection for fast growth with simultaneous selection for reduced feed intake would at least double the genetic response in FCE compared to selection for growth alone. Therefore, it is possible that some fish breeding programmes selecting for growth without measuring any FCE traits are forgoing significant and valuable gains in FCE.

The heritability for $\log_e$ FCR of 0.18 to 0.24 indicates that it should be possible to make gains in this trait within the NZKS breeding stock. Future planned work includes two further assessments of the 2010 spawning year, calculation of residual feed intake, and a cost benefit analysis that takes into account the genetic correlations of the FCE traits with other production traits such as live weight.

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