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Selection for improved feed efficiency in Atlantic salmon

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Summary/recommendation:

See point 1.1

Summary/recommendation in Norwegian:

Se punkt 1.2

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1 Summary

1.1 English summary

Feed account for around 50% of the total cost in production of farmed Atlantic salmon. Improved feed efficiency ratio (FER, wet gain/feed intake) will reduce feed costs, increase resource efficiency of feed ingredients and reduce nutrient effluent to the environment. Direct selection for improved FER requires either individual records for growth rate and feed intake on large number of fish for which there is no technology available, or average growth rate and feed intake records of many families reared in separate tanks or cages which is very costly to obtain. Indirect selection for improved FER may be possible through selection for traits that are favourably genetic correlated to FER, e.g. increased growth rate and reduced body fat deposition, or traits in the energy budget like increased digestibility of the main nutrients (protein, fat and energy) in the feed. However, no estimate is available for the effect of a reduced body fat on FER or of genetic variation in digestibility of the main nutrients. Unfortunately, the most important experiment in the entire project from which we should obtain an estimate of the latter had to be terminated due to the development of cataract on the fish selected for this purpose.

In this project we addressed some of these topics that can be summarized in seven points as follows: (1) The daily “not eaten” feed pellets given into tanks with no fish can be recorded with high accuracy by collecting and counting their number on a grate outside each of the tank, and that this number of pellets provide a more accurate estimate of the “not eaten” feed than the dry matter of these pellets. (2) In an experimental set-up with single fish in separate tanks the fish used many days to be adjusted to the tank environment and grew slower as compared to the mean growth rate of several other fish in a common tank. Negative correlation between growth rate of single fish in separate tanks in a period as compared to when the same fish in a following up period were reared together in the same tank. This may be caused by compensatory growth of the fish in the following up period and should have been followed up in an additional growth period in which the effect of the compensatory growth was absent or minimal. (3) Fish fed a diet with relative high energy ratio between protein/fat (HP) showed favourable trait characteristics (growth, fillet yield, fillet fat, visceral fat) as compared to the fish fed a lower energy ratio between protein/fat (LP), and this strongly indicates that salmon need a feed with relatively high protein content to show its genetic potential for growth and with a favorable effects also on other traits. (4) We found a significant genotype by diet (HP vs. LP) interaction for growth. This may have a significant effect on the genetic gain for growth depending on the protein/fat ratio of the diet given to the breeding nucleus fish today as compared to in the future. What is the optimal protein/fat ratio of the diet will be determined by the relative price of protein and fat in the feed and the fish genetic potential for growth and body fat deposition. (5) Energy in the fillet accounts for only 60 % of the energy in the whole body, Energy in the whole body must therefore be taken into account when selecting for improved feed efficiency. (6) The estimated heritability for the digestibility coefficients of fat in the feed was 0.13 ± 0.04, while those for protein and energy were not significantly different from zero. As the digestibility coefficients of the feed nutrients may be affected by the feed intake, it remains to be answered if selection for improved digestibility of fat will result in a favorable correlated response in feed efficiency. (7) To detect a true significant difference in feed efficiency between two groups of fish with high and low genetic potential for body fat deposition, a minimum of 3 to 6 replicated tanks per experimental group is required, the lowest figure when a combined sib and

within family selection is applied when establishing the two high and low body fat groups, and the highest figure when applying sib selection only.

1.2 Norsk samandrag

Fôr står for rundt 50% av den totale kostnaden ved produksjon av Atlantisk laks. Betre fôrutnytting (tilvekst/fôrinntak) vil redusere fôrkostnaden, auke ressursutnyttinga av fôrkomponentane i fôret og redusere utsleppet av næringsstoff til miljøet. Direkte utval for betre FCR krev enten individuell registrering av tilvekst og fôrinntak på eit stort tal fisk som ikkje er mogleg på grunn av mangel på eigna teknologi, eller gjennomsnitt tilvekst og fôrinntak på mange familiar oppdretta separate kar eller merdar, noko som blir svært kostbart. Indirekte seleksjon for betre fôrutnytting kan vere mogleg gjennom seleksjon for eigenskapar som er gunstig genetisk korrelert med fôrutnytting, f.eks. auka tilvekst og redusert kroppsfeitt, eller for eigenskapar i energibudsjettet som betre fordøying av dei viktigaste næringsstoffa (protein, feitt og energi) i fôret. Det finst ikkje noko estimat for effekten av redusert kroppsfeitt på fôrutnytting eller for genetisk variasjon i fordøying av hovudnæringsstoffa. Og dessverre måtte det viktigaste forsøket i heile prosjektet, der vi skulle estimere den sistnemnde effekten, avbrytast fordi fisken som vart valt ut til dette føremålet fekk katarakt.

I dette prosjektet undersøkte vi nokre av desse problemstillingane og som kan samanfattast i sju punkt: (1) Dei dagleg «ikkje spiste" fôr pelletane gitt til kar utan fisk kan registrerast med høg grad av nøyaktigheit ved å samle dei opp på ei rist utanfor kvart av kara, og dette gir eit meir nøyaktig estimat av det "ikkje spiste" fôret enn ved å måle tørrstoffet til desse pelletane. (2) I eit forsøksoppsett med ein fisk i kvart sitt kar brukte fiskane mange dagar på å tilpasse seg karet og vaks dårlegare samanlikna med den gjennomsnittlege tilveksten til fleire andre fisk i eit felles kar. Vi fann ein negativ samanheng mellom tilvekst for fisk som gjekk i kvart sitt kar samanlikna med tilveksten til dei same fisken i ein oppfølgingsperiode då dei gjekk saman i same karet. Årsaka til dette kan vere kompenserande tilvekst i oppfølgingsperioden og burde vore fylgt opp i ein ekstra vekstperiode der effekten av denne kompenserande tilveksten var fråverande eller minimal. (3) Fisk som fekk eit fôr med eit relativt høgt energiforhold mellom protein/feitt (HP) viste gunstige eigenskapar (vekst, filetutbyte, filetfeitt, innvolsfeitt) samanlikna med fisk som fekk eit fôr med eit lågare energi forhold mellom protein/feitt (LP), og dette indikerer at laks trenge eit fôr med relativt høgt protein innhald for å vise sitt genetiske potensiale for tilvekst og med gunstige effektar også på andre eigenskapar. (4) Vi fann eit betydeleg genotype x fôr (HP vs. LP) samspel for tilvekst, noko som over tid kan ha ein effekt på storleiken av den genetiske framgangen for tilvekst, avhengig av kva protein/feitt forholdet det er i fôret til avlskjernefisken i dag og i framtida. Kva som er det optimale forholdet mellom protein/feitt i fôret er avhengig av den relative prisen på protein og feitt i fôret og fisken sitt genetiske potensial for tilvekst og feittavleiring. (5) Energien i fileten utgjer berre 60% av energien i heile kroppen. Difor må ein inkludere energien i heile kroppen når ein skal gjere utval for betre fôrutnytting. (6) Den estimerte arvegrada for fordøyingskoeffisenten av feitt i fôret var 0.13 ± 0.04, medan dei for protein og energi ikkje var statistisk ulike frå null. Ettersom fordøyingskoeffisienten av eit næringsstoff kan vere påverka av fôropptaket, bør ein undersøke om utval for høgare fordøyingskoeffisient av feitt vil resultere i ein gunstig korrelert respons i fôrutnytting. (7) For å kunne påvise ein sann signifikant skilnad i fôrutnytting mellom to grupper fisk med høgt og lågt genetisk potensial for avleiring av kroppsfeitt må ein ha minimum 3 til 6 gjentak per gruppe, det lågaste talet når ein brukar eit kombinert utval (mellom og innan familie) når et lagar dei to gruppene, og det høgaste talet når ein berre gjer utval mellom familiar.

2 Introduction

Feed account for around 50% of the total cost in production of farmed Atlantic salmon. (http://www.fiskeridir.no). Improved feed efficiency ratio (FER, wet gain/feed intake) will reduce feed costs, increase resource efficiency of feed ingredients and reduce nutrient effluent to the environment. Improvement of FER can be obtained through better feed and feed technology, as well as by better adjusting the feed composition to the fish' physiological needs which is continuously changing in response to selection for increased growth and other important economic traits.

To be able to improve FER further through selective breeding the trait must show genetic variation, which there is strong evidence for in Atlantic salmon (Thodesen et al., 1999; 2001; Kolstad et al 2004). Direct selection for improved FER requires either individual records for growth rate and feed intake on large number of fish for which there is no technology available, or average growth rate and feed intake records of many families reared in separate tanks or cages which is very costly to obtain. However, indirect selection may be possible through selection for traits that are favourably genetic correlated to FER, e.g. increased growth rate and reduced body fat deposition, or specific traits in the energy budget like increased digestibility of the main nutrients (protein, fat and energy) in the feed. The magnitude of this correlated response depends on the size of the genetic variation in feed efficiency and the genetic correlation of feed efficiency with body fat and growth which is not known in Atlantic salmon as well as in other farmed fish species. No estimate is available for the effect of a reduced body fat on FER but may be obtained by comparing the difference in feed efficiency of groups of fish with high and low genetic potential for body fat, but same growth rate.

High growth rate and desired carcass quality traits requires that the fish are fed a diet with optimal composition of both macro (fat, protein and energy) and micro (minerals, vitamins, colour) nutrients. Feed composition may need to be changed according to the fish genetic potential that is gradually improved through selective breeding. For example, a fish with high growth potential may require a feed with higher protein to energy ratio. If families rank differently for important traits, this may have implication on what type of feed the fish should be tested on, but which also have to be decided on based on both the present and future relative price of protein and fat in the feed.

From a feed recourse point of view, it is important to calculate the feed efficiency for the edible parts of the fish. However, the relative proportion of the main nutrients in the other parts of the body is also of interest as this may indicate what parts need to be addressed in order to improve the feed efficiency. More information about this we got as a spin-off of the experiment performed for objective 2.1.

This report is on the main results from the experiments performed for each of the objectives in Chapter 2, except for objective 1.3, 2.2, and 3 that could not be conducted due to the following reasons:

- *Objective 1.3* due to the results obtained in objectives 1.1 and 1.2.
- *Objective 2.2* because the selected experimental fish developed cataract.
- *Objective 3* because SalmoBreed decided not to give it priority.

The project has been run by the following

Board
SalmoBreed; Håvard Bakke, Rudi Ripmain Seim, Borghild Hillestad from SalmoBreed; Nofima: Bjarne Gjerde, Torbjørn Åsgård and Bjarne Hatlen (replaced Marie Lillehammer).

Project group

SalmoBreed: Rudi Ripmain Seim (adm. Project leader), Borghild Hillestad; Stofnfiskur: Jonas Jonasson, Olafur H. Kristjansson; Akvaforsk Genetics: Morten Rye, Jørn Thodesen; Nofima: Bjarne Gjerde, (scientific project leader), Bjarne Hatlen, Torbjørn Åsgård, Solomon Antwi Boison (replaced Marie Lillehammer).

3 Primary and secondary objectives

Primary objective

Investigate possibilities for direct and indirect selection for improved feed efficiency in Atlantic salmon

Secondary objectives

1 *Reliable records of growth and feed efficiency for single fish in separate tanks*.

- 1.1. Investigate if wasted feed can be collected with high accuracy for single fish in separate tanks.
- 1.2. Investigate if single fish can obtain good growth in separate tanks.
- 1.3. Obtain an estimate of the genetic variation in gross feed efficiency for single fish in separate tanks.

2 *Feed efficiency of fish with high and low potential for lean growth.*

- 2.1. Estimates of genetic (co)variation for important feed efficiency traits (growth, filet fat, abdominal fat, digestibility of fat, protein and energy) for fish fed two diets with different protein/energy ratio.
- 2.2. Estimate difference in feed efficiency between four groups of fish with high and low breeding value for lean growth (sibs of fish tested in objective 2.1).
- 2.3 Estimate magnitude of genetic variation in digestibility of fat, protein and energy.

3 *Energy loss and digestibility as indirect measures for feed efficiency.*

- 3.1. Estimate magnitude of genetic (co)variation for lean growth during feeding and energy loss during feed deprivation.
- 3.2. Estimate differences in feed efficiency between four groups of fish with high and low breeding value for lean growth during feeding (HG, LG) and high and low breeding value for high and low energy loss during feed deprivation (sibs of fish tested in objective 3.1).

4 *Investigate how many replicated tanks are needed to detect a predicted difference in feed efficiency between the four experimental groups in 2.2 and 3.2.*

4 Results from the conducted experiments

Objective 1

1.1. Investigate if wasted feed can be collected with high accuracy for single fish in separate tanks

We investigated if the daily not eaten (wasted) feed by single fish in separate tanks can be collected with high accuracy. Five tanks (550 L, Figure 1) without fish were given two different numbers of 4 mm pellets over 2 x 6 days, and two different numbers of 6 mm pellets over 2 x 6 days. For each tank, the number of pellets recovered on the bottom and on a grate outside of each tank was recorded daily, as well as the dry matter of all these pellets. Of the number of pellets given on average 95 % could be recovered on the grate, while of the dry matter of the given pellets only 85 % could be collected on the grate. The variation between tanks in the number of recovered pellets on the grate accounted for 5 % (4 mm pellets) and 11 % (6 mm pellets) of the total variation in the number of given pellets. Results from a stochastic simulation study showed that this quantity is relatively low compared to the variation in the expected number of eaten pellets among individual fish.

Appetite of fish may vary among days in a non-predictable manner, resulting in a much higher number of not eaten pellets per day than investigated in 1.1 (17 and 29 4 mm; 11 and 13 6 mm). In a following up study we investigated if also a much higher number of not-eaten pellets can be collected with high accuracy. In five tanks without fish we added 100 4 mm pellets per day, while into another set of 6 tanks we added 100 6 mm pellets per day, both sets of tanks over a period 6 days. For each tank, the number of pellets recovered on the bottom and on a grate outside of each tank was recorded daily, as well as the dry matter of all these pellets. For the 4 mm pellets on average 93.4 % of the number of pellets given and 81.7 % of their dry matter could be recovered on the grate, while for the 6 mm pellets the corresponding figures were 99.2 % and 88.4 %. The variation between tanks in the number of recovered pellets on the grate accounted for 1.2 % (4 mm pellets) and 2.8 % (6 mm pellets) of the total variation in the number of given pellets, while the variation among days accounted for 0.4 % (4 mm) and 3.8 % (6 mm). The above figures are of similar magnitude as found above for the much lower number of pellets given per day, and very low compared to the variation in the expected number of eaten pellets among individual fish. From the above we concluded that the “not-eaten feed” can be recorded with high accuracy by counting the number of the not-eaten pellets on a grate outside each of the tanks, and that this number of pellets provide a more accurate estimate of the “not-eaten feed” than the dry matter of these pellets.

Therefore, if we can obtain good growth of single fish in separate tanks (see 1.2), the recording of growth and feed intake of single fish in separate tanks may be used to measure feed efficiency of Atlantic salmon, and providing that the single fish rank similar with respect to growth as compared to their growth when reared together in the same tank.

1.2. Investigate if single fish can obtain good growth when reared in separate tanks

We recorded growth and feed intake of single fish reared in separate tanks in two consecutive four weeks growth periods: Period 1 with 10 tanks with 1 fish/tank, and two tanks with 10 fish/tank; Period 2 with 5 of the 10 tanks with 1 fish/tank; and the two tanks with 10 fish/tank. Average body weight of the fish was about 350 g at start and 780 g at the end of the experiment.

Figure 2 show the feed intake (g/day) of the single fish in the 10 separate tanks, and of the fish in the two tanks with 10 fish per tank (no. 115 and 121), in growth Period 1. The feed intake and growth of the fish in the 10 tanks with 1 fish/tank was in general low (TGC 1.25) as compared to the fish in the two tanks with 10 fish/tank (TGC 2.69). In Period 2 the growth of the single fish in the separate tanks was much higher than in Period 1 (TGC 2.96), but 11.4 % lower than the fish in the two tanks with 10 fish/tank (TGC 3.34).

Figure 3 shows the number of pellets eaten per day for the 5 single fish in the separate tanks, and the mean number of pellets eaten by the fish in the two tanks with 10 fish per tank (no. 115 and 121), in growth Period 1 and 2. Figure 4 shows the mean feed intake (g/day) for the five fish and for the fish in the two tanks with 10 fish per tanks that were present in all the three growth periods.

In a following up Period 3 of four weeks, the 5 fish that in Period 2 had been reared in 5 separate tanks were reared in the same tank, including also the two tanks with 10 fish/tank. In this period the growth of the five fish in the common tank was higher (TGC 2.94) than the fish in the tanks with 10 fish/tank (TGC 2.23). The correlation coefficient between TGC of the 5 fish in Period 2 and 3 was negative (Figure 5, -0.72), as compared to 0.62 and 0.63 between TGC of the fish in the two tanks with 10 fish/tank. These results indicate that fish grow different when reared alone in a tank as compared to together with other fish in the same tank. However, the negative correlation between growth rate of the five fish in Period 2 and 3 may be due to a compensatory growth of the fish in Period 3.

Unfortunately, the growth of the 5 fish were not followed up in an additional fourth growth period which could have shed more light on the growth rate relationships in the different growth periods. This needs to be followed up in an additional study. Until this has been done, we cannot recommend measuring feed efficiency of salmon in an experimental growth rate, feed intake and feed efficiency study with 1 fish/tank as was planned for in objective 1.3.

Objective 2

The fulfillment of this objective and its secondary objectives were based on data recorded on two groups of +0 smolts, each with 1500 fish, and a group of 5000 1+ smolt that were reared in separate tanks at Stofnfiskur Hf, Iceland. The 1+ smolt group and one of the 0+ group were fed commercial low protein/fat ratio feed (LP=1.25; 37.9% protein, 30.3% fat, 23.9 MJ/kg) from early February 2017 (mean weight about 420 g), while the other 0+ smolt group received a high protein/fat ratio feed (HP=1.70; 43.3% protein, 25.6% fat, 23.3 MJ/kg) . The two +0 groups were slaughtered in Nov/Dec 2017 at an average body weight of 2.85kg at which their individual body weights, filet fat and visceral fat was recorded. The group of 1+ smolt was fed the commercial LP feed.

2.1. Estimates of genetic (co)variation for important feed efficiency traits (growth, filet fat, abdominal fat, digestibility of fat, protein and energy) for fish fed two diets with different protein/energy ratio

The results of this objective were based on data recorded on the two groups of +0 smolts. We studied if salmon families ranked differently with respect to important traits when fed the LP feed or the HP feed. The fish group that received the HP feed showed favourable trait characteristics as compared to the fish group that received the LP feed (difference=HP-LP): +3.8% for body weight; +1.4%-units for fillet yield, -1.3%-units for fillet fat, +0.89 mg/kg for fillet pigment, -0.17 for abdominal fat score (1-5) and -1.70%-units for percent viscera. This indicates that the salmon needs a feed with relatively high protein content to show its genetic potential for growth and that this has also a favorable effect on the other studied traits. However, as there was only one tank per feed, the estimated differences between the two feeds are not reliable, but in agreement with published results. Estimated heritability for harvest weight, fillet fat and fillet pigment were about 0.4, and about 0.15 for abdominal fat score and visceral index. The genetic correlations between the same trait recorded on the fish fed the two diets were all high to very high: 0.81±0.06 for body weight; 0.99±0.00 for fillet fat, 0.99±0.00 for fillet pigment, 0.99±0.00 for percent viscera and 0.89 ± 0.13 for abdominal fat score, and indicates a significant genotype by diet (HP vs. LP) interaction for growth rate but a negligible interaction for the other studied traits. The magnitude of the genetic correlation for body weight (0.81) indicates that families rank somewhat different when tested on feed with different protein/fat ratio. This may have a significant effect on the magnitude of the genetic gain for growth rate depending on the protein/fat ratio of the diet given to the breeding nucleus fish today as compared to in the future. What protein/fat ratio should be used in the diet will to a large extent be determined by the relative price of protein and fat in the feed, but also by the fish genetic potential for growth rate and body fat deposition.

For a random sample of 40 fish of the 0+ fish slaughtered in Nov/Dec 2017 (20 of the HP group and 20 of the LP group) we obtained the chemical composition of the fillet, head&backbone and viscera. Energy of viscera and head&backbone accounted for 19.7 and 20.6 %, respectively of the whole-body (sum og the tree body parts) energy. Consequently, as the energy in the fillet account for only 60 % of the energy in the whole body, the energy in the other body parts must also be considered when selecting for improved feed efficiency.

2.2. Estimate difference in feed efficiency between two groups of fish with high and low breeding value for lean growth (sibs of fish tested in objective 2.1)

This experiment was performed based on data recorded on two groups of +0 smolts, each with 1500 fish, and a group of 5000 1+ smolt. The 1+ smolt group and one of the 0+ group were fed commercial low protein feed from early February 2017 (mean weight about 420 g), while the other 0+ smolt group received a high protein feed. The two +0 groups were slaughtered in Nov/Dec 2017 (average body weight was 2.85 kg). The families were ranked with respect to their predicted breeding values for body fat (2/3 weight on filet fat and 1/3 weight on abdominal fat). In January 2018, a total of 1600 fish were selected from the 5000 1+ fish; 800 fish from the 30 highest ranking families with respect to body fat, and 800 fish from the 30 lowest ranking families with respect to body fat. At selection the body fat of all the 1600 selected fish were measured with Distell fat meter. One week later, the 160 highest ranking and the 160 lowest ranking fish with respect to breeding value for body fat were selected and transported from Stofnfiskur to the close by Hafró Experimental Center at which the 160 fish from each group were randomly distributed on 2 x 8 replicated 7m3 tanks. Unfortunately, a large proportion of the fish developed cataract and the feed efficiency experiment had to be terminated. The same happened two weeks later with another sample of 240 fish selected from the remaining 1280 fish.

2.3. Estimate magnitude of genetic variation in digestibility of fat, protein and energy

Two weeks prior to the slaughter the 1500 0+ fish that were fed the commercial diet (see chapter 2.2) were given a feed with Y_2O_3 and all fish were stripped for feces. Near Infrared (NIR) and X-ray fluorescence (XRF) spectroscopy spectra of freeze-dried faeces samples from 1300 of the fish were used to predict digestibility coefficient of the fat, protein and energy in the feed for each animal. The overall mean digestibility (%) was 92.3 for fat, 82.5 for protein and 77.8 for energy. The estimated heritability for the digestibility coefficients of the main nutrients were low; 0.13 ± 0.04 for fat, 0.07 ± 0.03 for protein and 0.06 ± 0.03 for energy; those for protein and energy were not significantly different from zero. The genetic correlation of digestibility of energy with fat (0.54 ± 0.25) and protein (0.75 ± 0.16) were higher than that between the digestibility of fat and protein (0.38 ± 0.25), as might be expected since fat and protein are the two main energy carriers in the feed. The genetic correlation of each of the three digestibility coefficients with percentage of fat in the filet and viscera were all low and not significantly different from zero. These results indicate that in A. salmon the digestibility of fat in the feed can be improved through selective breeding, without an unfavorable correlated response in the digestibility of protein and energy. However, if this will result in a favorable correlated response in feed efficiency remains to be answered as the digestibility coefficients of these nutrients may be affected by the feed intake which we do not know.

Objective 4

Investigate how many replicated tanks are needed to detect a predicted difference in feed efficiency between the four experimental groups in 2.2 and 3.2.

For the purpose of conducting a well-designed experiment for Objective 2.2 (which unfortunately had to be terminated) we investigated how many replicated tanks are needed to detect a true difference in feed efficiency between two groups with high and low genetic potential for body fat deposition; which is dependent on several parameters: heritability of feed efficiency, genetic correlation between body fat and feed efficiency, variation in feed efficiency between replicated tanks, and whether we use randomly selected fish from the high and low body fat families or fish with high and low body fat from these high and low body fat families, respectively. For 150 families, variation in feed utilization between replicated tanks of 3% of total variation, heritability of 0.30 for both feed efficiency and body fat, and genetic correlation 0.5 between the two traits, minimum 6 replicated tanks per group is required when using random fish from the families, and 3 tanks if we can apply within family selection for body fat. If the variation between replicated tanks is lower than 3%, we need fewer tanks, while more tanks is required if the genetic correlation between feed utilization and body fat is less than 0.5, or the heritability for feed efficiency is less than 0.3.

5 Main results and recommendations

- The daily “not-eaten” feed given into tanks with no fish can be recorded with high accuracy by counting the number of the “not-eaten” pellets on a grate outside each of the tanks, and that this number of pellets on the grate provide a more accurate estimate of the “not-eaten” feed than the dry matter of these pellets.

- Single fish in separate tanks used many days to be adjusted to the tank environment and grew slower as compared to the mean growth rate of several fish in the same tank.

- Negative correlation between growth rate of single fish in separate tanks in a period as compared to when the same fish in a following up period were reared together in the same tank. This may be caused by compensatory growth of the fish in the following up period and should have been followed up in an additional growth period in which the effect of the compensatory growth was absent.

- Fish fed the HP feed showed favourable trait characteristics as compared to the fish that received the LP feed, and this strongly indicates that salmon need a feed with relatively high protein content to show its genetic potential for growth and with a favorable effects also on other traits.

- The significant genotype by diet (HP vs. LP) interaction for growth may have a significant effect on the magnitude of the genetic gain for growth rate depending on the protein/fat ratio of the diet given to the breeding nucleus fish today as compared to in the future. What protein/fat ratio should be used in the diet will to a large extent be determined by the relative price of protein and fat in the feed, but also by the fish genetic potential for growth rate and body fat deposition.

- The energy in the salmon fillet accounts for only 60 % of the energy in the whole body. Therefore, the energy in the whole body must also be considered when selecting for improved feed efficiency.

- The estimated heritability for the digestibility coefficient of fat in the feed was 0.13 ± 0.04, while those for protein and energy were not significantly different from zero. The digestibility coefficients of the feed nutrients may be affected by the feed intake. It therefore remains to be answered if selection for improved digestibility of fat will result in a favorable correlated response in feed efficiency.

- To detect a true significant difference in feed efficiency between two groups of fish with high or low genetic potential for body fat deposition, a minimum of 3 to 6 replicated tanks per experimental group is required, the lowest figure when a combined sib and within family selection is applied when establishing the two high and low body fat groups, and the highest figure when applying sib selection only.

6 Deliverables

6.1 Oral presentations

Gjerde, B. Åsgård, T., Hatlen, B. Tilvekst hos laks når ein har berre ein fisk per kar. Havbruk 2018, Raddison Blue Plaza Hotel, Oslo, 18.-20. april 2018

Gjerde, B., Boison, S.A., Kristjansson, O., Åsgård, T. Seim, R.R., Hatlen, B. Genotype x Fôr (Høgt vs. Lågt protein/feitt forhold) samspel for viktige eigenskapar hos laks. Havbruk 2020, Quality Hotel Edvard Grieg Bergen. Avlyst på grunn av coronaviruset.

6.2 Publications

Boison, S.A., Martinsen, K. H. and Gjerde, B. Experimental design to detect a true difference in feed efficiency between two groups of Atlantic salmon with high and low genetic potential for body fat deposition. *The paper almost ready to be submitted.*

Gjerde, B., Boison, S. A., Hatlen, B., Kristjansson, O. H., Åsgård, T. Estimates of genetic variation in digestibility of fat, protein and energy in Atlantic salmon*. All tables and figure ready – paper remains to be written.*

Gjerde, B., Boison, S. A., Hatlen, B., Kristjansson, O. H. and Åsgård, T. Estimate of genotype by feed interaction for Atlantic salmon fed diets with high and low protein fat ratio. *All tables and figure ready – paper remains to be written.*

Gjerde, B., Hatlen, B. and Åsgård, T. Chemical composition of whole body and body processing parts of Atlantic salmon. *A spin-off paper. All tables and figure ready – paper remains to be written.*

Gjerde, B., Hatlen, B. and Åsgård, T. Growth rate and recovery of wasted feed for single fish in separate tanks. *All tables and figure ready – paper remains to be written.*

7 Use of resources

This has been a very demanding project, both with respect to some unforeseen challenges and the lost opportunity, heavy workload and disappointments as consequence of this. Of most importance was the development of the cataract on the selected fish in Iceland which forced us to terminate the most important experiment (2.2) of the entire project after having completed two successful large experiments that lasted more than a year and that was required for this. Due to the lack of technology to record feed intake in Atlantic salmon, as well as other fish species, our knowledge on the magnitude of both the phenotypic and genetic variation in feed efficiency among individuals, and its genetic correlation to important traits like growth and body fat was and are still very limited.

Consequently, this project as well as future project on how to improve feed efficiency through selection in Atlantic salmon and other fish species, is more suited for a pure research funded rather than an IPN (Innovation for industry) funded project, as this project was defined as. Mainly because this is basic knowledge that when published can be implemented by any breeding company in their breeding program.

8 Figures

Figure 1 The tanks used for objective 1.1 and 1.2.

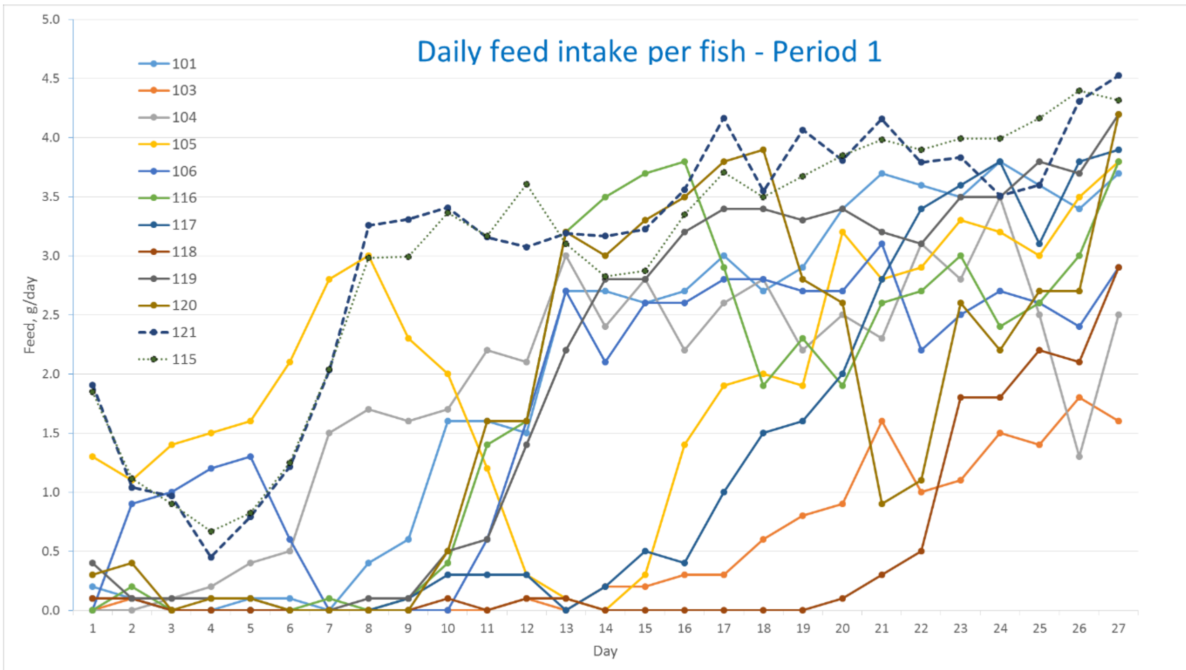

Figure 2 Feed intake (g/day) of the single fish in the 10 separate tanks, and of the fish in the two tanks with 10 fish per tank (no. 115 and 121), in growth Period 1.

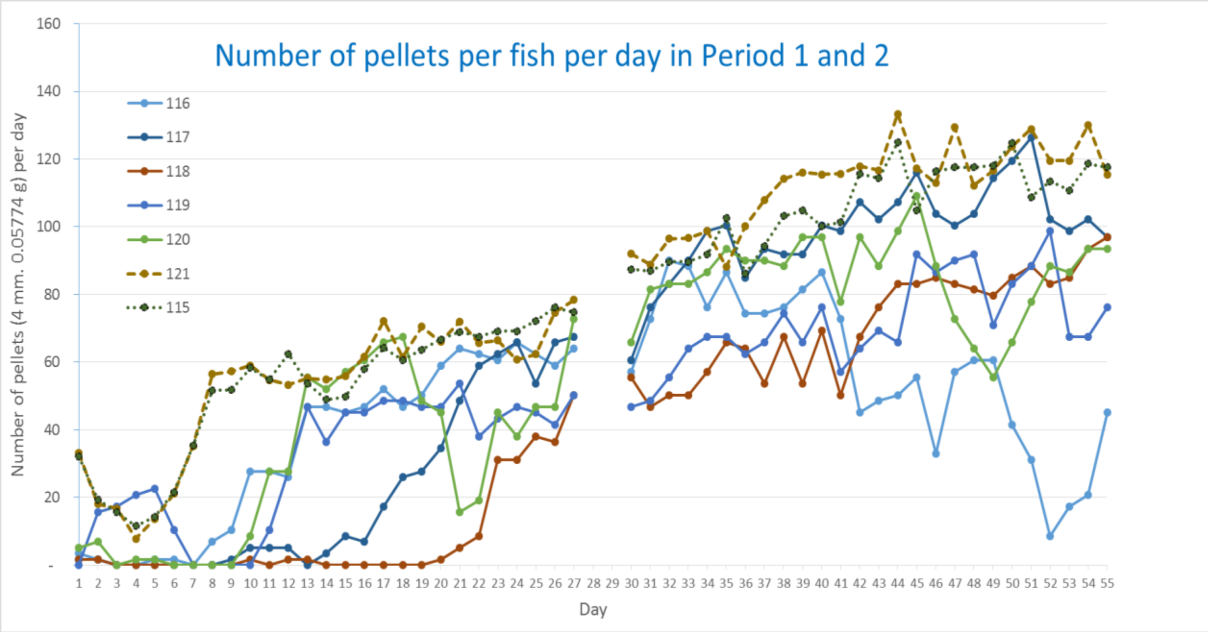

Figure 3 *Number of pellets eaten per day of the 5 single fish in the separate tanks, and the mean number of pellets eaten by the fish in the two tanks with 10 fish per tank (no. 115 and 121), in growth Period 1 and 2.*

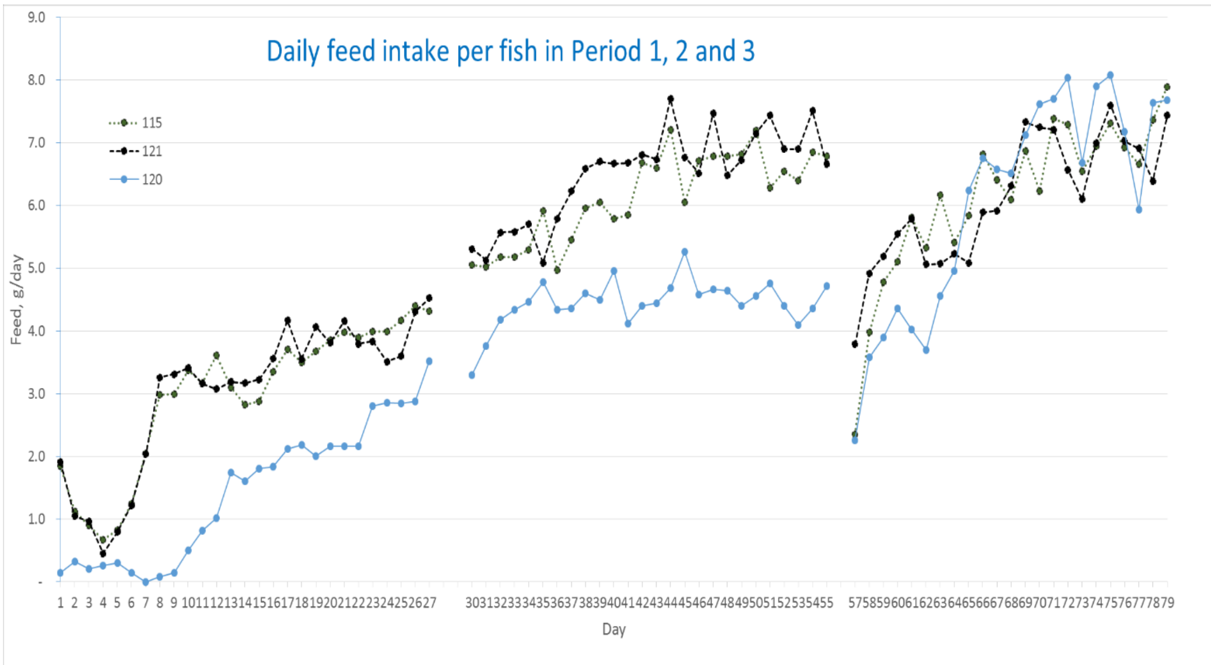

Figure 4 *Mean feed intake (g/day) for the five fish (tank no. 120) and for the fish in the two tanks with 10 fish per tanks (tank no. 115 and 121) and that were present in all the three growth periods.*

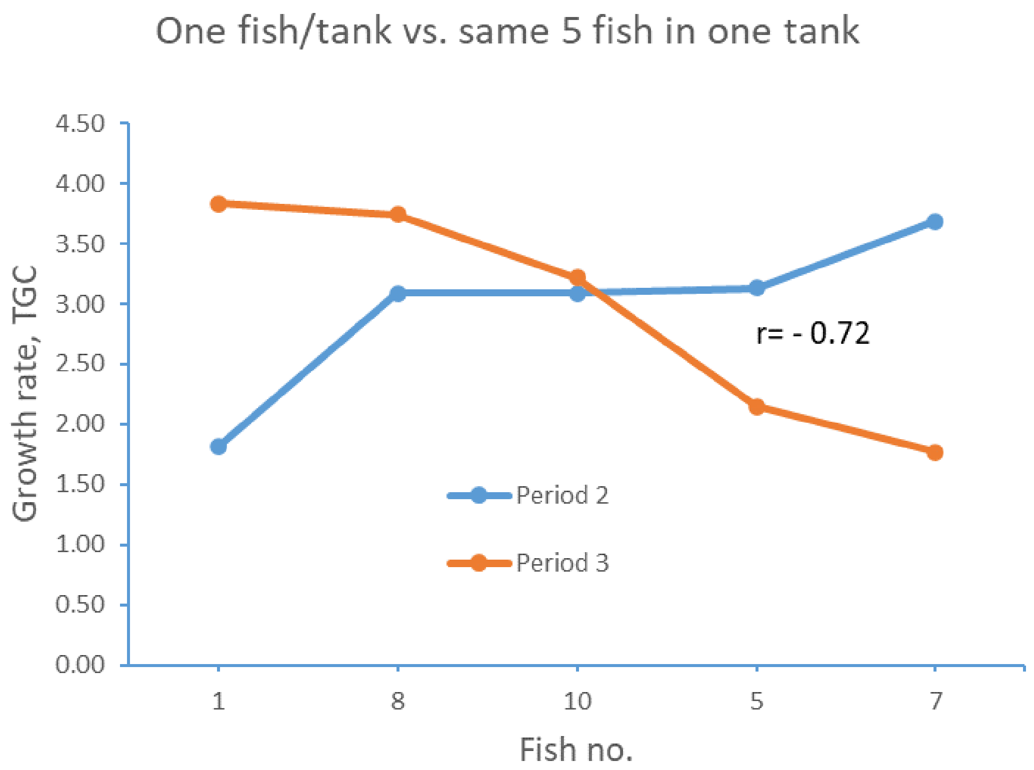

Figure 5 *Growth rate of the 5 single fish in separate tanks in Period 2 and when reared in the same tank in Period 3.*

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