FILLET QUALITY AND YIELD OF FARMED ATLANTIC SALMON (salmo salar L.): variation between families, gender differences and the importance of maturation

Deependra Acharya

NORWEGIAN UNIVERSITY OF LIFE SCIENCES
Department of ANIMAL AND AQUACULTURAL SCIENCE
Master Thesis 60 credits 2011

Contents

List of tables

List of figures

Abstract

The aim was to study biometric parameters, yield and fillet quality traits of farmed Atlantic salmon (Salmo salar L.*) belonging to the 2008 year class of the breeding nucleus of SalmoBreed AS, Norway. The offspring analyzed belonged to 213 dams and 111 sires, in total 1181 individuals. The salmon were transferred to seawater March 2009 and the different families were kept together in commercial net-pens until the fish was processed July 2010. The mean body weight of the immature male and female salmon was 5.50 and 5.30 kg, respectively. The difference between the sexes was even greater for the sexually mature fish, where the male salmon weight 1.20 kg more than the females (7.24 vs. 6.02 kg). The mean slaughter yield was similar for male and female salmon (90.7%-90.8%). The average fillet fat content for male fish was about 16% whereas the fat content of female fish was about 15%. The breaking force of the mature salmon was significantly higher than of the immature salmon regarding both sexes. The fillet color was significantly higher of the females compared with the males. The maturation had no significant effect on the fillet color, although mature males had higher frequency of pale patches on the anterior fillet part (pale back). Immature females had significantly highest melanin deposition whereas the mature male had lowest melanin.*

The body weight, fillet yield, slaughter yield, condition factor, firmness, color, and fat content, varied significantly between the families but no family variation in pale back, melanin deposition in the belly or gaping was observed regarding offspring from dams or sires. Positive correlations between yield and some quality traits (color, pale back and fat content) were observed. The body weight was found to be positively correlated with the yield and condition factor.

The offspring from 5% of the dams and 11% of the sires had all the desirable quality traits: fat content less than 16%, intense visual color and firm texture. Among the dams and sires with offspring with desirable quality, one dam and one sire were selected that in addition to superior quality, also had high body weight at slaughter. The body weight of these fish was 6.7 and 7.6 kg for the dam and sire, respectively. These results are encouraging, and suggest that it is possible to obtain future generations of salmon with superior growth performance, high muscularity and yield, and also desirable fillet quality characteristics

Keywords: Atlantic salmon, yield, fillet quality, texture, selective breeding

1. Introduction

Aquaculture is the fastest growing animal food producing sector in the world. It has had anannual growth rate of 8.9% since 1970, compared with 1.4% for capture fisheries and 2.8% for terrestrial farmed meat production systems over the same period (FAO 2002). Currently, almost 50% of world's food fish is supplied by the aquaculture and has the potential to fulfill the food demand of the growing human population of the world. Progressive development of aquaculture is necessary because capture fishery failure to full fill market demand of fish protein.

Aquaculture is highly diverse and the sector consists of many species, systems, practices, people and cultures, environments, and operations. According to estimation of FAO, the value of fish traded internationally was US$ 51 billion per annum in 1998 and it provides opportunity to employment of over 36 million people directly. Moreover, 200 million people derive direct and indirect income from fish (FAO 2002). Hence, aquaculture has social and economic importance.

Atlantic salmon (*Salmosalar*, L.) is naturally found in the northern Atlantic ocean and its cultivation is among the most successful commercial intensive aquaculture in the world. Salmon farming is a main industry in Norway and has grown and developed significantly. There are various reasons that promoted to growth of the salmon industry in Norway, such as good culture practices, feed, and breeding. The family based breeding program started in Norway in 1975 by AKVAFORK (Gjedrem & Baranski 2009), and since then breeding programs have been successful in Norwegian salmon industry for various traits. The breeding goals in salmon include growth, age at sexual maturity, improved resistant to disease and a number of traits related to product quality (Gjedrem & Baranski 2009). The fillet quality is important from an economic point of view because the quality of fillets determine the price of fish and consumer acceptance.

Selective breeding for aquaculture hold high potential for genetic improvement of fish. According to results from AKVAFORK, the performance of selected familieswas more than twice compared with wild salmon (Gjedrem & Baranski 2009). The impact of selective breeding on growth performance and disease resistant has been already proved. Differences between families have only been scientifically verified for a few quality related characteristics, such as fillet colour (h^2= 0.47) and fat content (h^2= 0.30).

The consumers' preferences and interests are always of primary importance for aquaculturists. The consumer willingness to pay depends on the quality of the products (Alfnes, *et al*. 2006). Texture, color and fat content of fish fillets are the major parameters that determine the satisfactoriness of the consumer (Haard 1992). Fillets with quality deviations such as gaping, soft flesh, dark spots (melanin), pale and irregular color and deformities are main causes to quality down grading of farmed salmon, and hence also economic losses to the industry (Koteng 1992).

An ultimate goal for the salmon farming industry is to achieve fish that have all superior quality characteristic in combination with good growth performance and high yield. It is already documented that growth and certain quality characteristics show genetic variation, and hence there is a possibility to obtain improvement through breeding. There is, however, a lack of knowledge regarding phenotypic correlations between production parameters, yield and quality related characteristics of salmon flesh. Such information is valuable in order to elucidate the possibility to obtain salmon that has good growth and at the same time high yield and desirable product quality. Moreover, there is a lack of knowledge on gender differences and the impact of sexual maturation on growth and quality of fast growing salmon exposed to genetic selection. Based on the aforementioned lack of knowledge, the present study was conducted with the following objectives:

- To study differences in biometric traits, quality parameters and yield between Atlantic salmon families
- To study the impact of sex and sexual maturation on fillet quality
- To study whether there exist parents (dams and sires) that give offspring with superior quality characteristic in combination with good growth performance and high yield
- To study the relationship between the qualities related characteristics and also body traits

2. Theoretical background

The background consists of six main sections. First and second give the general information about performance and yield of salmon. Third section includes the composition of fillet that gives general information about composition of muscle, muscle fiber, fat and protein. Fourth section describes about appearance of fillet with details regarding color, melanin and gaping. Fifth section explains on texture of fillet and final part gives some idea about selective breeding to improve the quality and yield parameter of Atlantic salmon.

2.1 Performance of Atlantic salmon

Atlantic salmon are anadromous fish that spawn and hatch in fresh water. When the salmon parr has achieved a length of about 15 cm they migrate to the ocean, usually in May or June. At this time, the parr takes on a silvery appearance and they called are smolts. Adult salmons return to fresh water to reproduce. The performance of salmon is dependent on many factors including genetic background, environmental condition, heath, quantity and quality of food consumed and life stage (Stead & Laird 2001)

Light and temperature play an important role for the onset of smoltification. Hence, in commercial smolt production, artificial photoperiods and ample temperatures are employed for offseason smolt production (Fjelldal et al. 2006). As the salmon is a cold-blooded animal, the temperature plays an important role for its growth rate throughout the life cycle. The optimal temperature range is 8-14°C.

Growth, health and reproduction of fish and other aquatic animals are primarily dependent upon an adequate supply of nutrient, both in terms of quantity and quality, irrespective of the culture system in which they are grown. During the fish development from embryo until harvest size, several phases of growth occur which are regulated by diet and hormones (Johnston 2001). The weight gain, feed eaten, feed conversion efficiency, fat and energy digestibility were higher in the fish from a selected salmon line than those from a wild line (Helland & Grisdale-Helland 1998). It was concluded that feed consumption, growth and feed utilization may be improved by selection for increased growth. Thodesen et al. (1999) also found that the significant variation between families in daily feed intake, growth rate and feed efficiency indicate the ability to improve these traits in Atlantic salmon through selective breeding.

Feed utilization can be measured in-terms of feed conversion ratio (FCR). FCR is the amount of body weight gained for each kilogram of feed consumed. FCR can be affected by a number of physical, biological, nutritional and personnel factors (Stead & Laird 2001). Salmon has a FCR of around 1.2 which is substantially lower as compare to farmed terrestrial animal such as pork (FCR 3.0) and cattle (FCR 8.0). Wild salmon has an FCR of approximately 10.0. (http://www.marineharvest.com/PageFiles/1296/Handbook%202010.pdf). The combination of a low FCR and low non-edible meat gives salmon a favorably high volume of edible meat per kg of feed fed. The body weight and growth rate have assigned the highest importance traits in terrestrial livestock programs. There are also important traits for Atlantic salmon. The harvest weight at 2-3 years for salmon has generally been found to have moderate heritability. Therefore, body weight one of important trait in selection programmes. But, selection for harvest weight may lead to an increase in fillet fat percentage due to the high genetic correlation between the two traits (Powell, J. et al. 2008).

2.2 Slaughter parameters

Condition factor

The condition factor (CF) is defined as the ratio of the body weight (grams) and body length (cm) cubed, and is commonly used to measure the conformation of fish (Gjedrem 2005)). This trait is considered to be an important economic trait, suitable for breeding purposes. The CF determines the percentage of flesh present on the fish body, and it coincides with a high fillet yield (Rørå et al. 2001) This trait has a genetic correlation with lipid deposition and fillet lightness (Kause et al. 2011). The heritability of the CF is about 0.49 in European whitefish, *Coregonus lavaretus*) (Kause et al. 2011).

Fillet yield

Filleting implies removal of bones and fines from the flesh. Filleting and trimming are important for logistics, economics, and addition of value along the marketing chain and for separation of edible part from the inedible ones. Filleting can be done either by machine or by hand. Hand filleting is labor intensive and time consuming (Rørå et al. 2001). Therefore most large companies use machines for filleting. Fillet yield is the ratio between fillet weight and carcass weight and is a measure of the edible part of the body. The fillet yield (un-trimmed fillets) of farmed salmon is about 78% (Rørå et al. 1998).

The fillet yield has high economical importance, as fillets are the main and most valuable products of salmon (Gjedrem 2008). Fillet yield depends on the species and on the structural anatomy of the fish. Fish with smaller head and frames relative to their musculature gives a higher fillet yield than fish with large head and frames. The fillet yield for farmed species was found range from 40% to over 70% (Rørå et al. 2001).The fillet yield is highest for large and wide fish in Atlantic salmon. The normal variation in condition factor for Atlantic salmon is from 0.7 to 1.9; hence selection and grading before processing can improve the yield. Fillet yield is influenced by the feeding strategy before harvesting. For example, it was observed that reduced feeding before harvesting resulted in decreased fillet yield (Einen & Thomassen 1998).

2.3. Muscle structure and composition

The skeletal muscle (fillet) is the major part of the edible portion of fish. Unlike mammals and birds, whose skeletal muscles are arranged in very long bundles of fibers, the muscles of fish are shorter and arranged in muscle sheets which are termed myotomes or myomeres (Brown 2001). These sheets run parallel adjacent to each other by making a complex W shaped folded structure along the fillet (Fig 2.1). The myotomes are connected to each other by several thin membranes made up of connective tissue (myocommata).

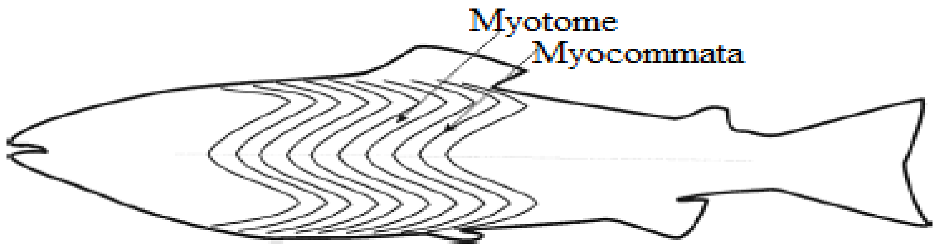

Fig. 2. 1. Schematic illustration of arrangement of myotomes and myocommata (Kiessling et al. 2006)

In almost of all adult fishes, the muscle fibers of the myotomes are mainly of two different kinds; red (slow) and white fibers (fast) which are easily distinguished in fish. The red muscle fibers are used for constant speed swimming and white muscle fibers used when fish to swim rapidly. The red muscle has smaller diameter than white muscle i.e., 20-50% of white muscle fibers (Bone & H. 2008). The red muscle is rich in myoglobin, mitochondria as compare to white muscle.

The proportion of fish flesh to total body weight varies between 40-65% depending of species, shape, age and the physiological status of the fish. The salmon has more elliptical cross sections and exhibit a much higher edible part than flatfish species with very big heads (Oehlenschlager & Rehbein 2009). Fish muscle structure holds water, protein and other nitrogenous compounds, lipids, carbohydrates, vitamins and minerals. The chemical composition of muscles varies from species to species, and also within specie the variation can be substantial. Atlantic salmon fillets contain 16-21% protein, 0.2-25% lipid, <0.5% carbohydrates and 1.2-1.5% ash (Murray & Burt 2001). The main structural factors that contribute to tenderness are muscle structure, amino acid content and collagen (Brown 2001). Factors influencing the composition will be further discussed in the subsequent sections.

Fillet protein

The protein content in salmon muscle is relatively constant, but may vary with season and fish size. In wild salmon, higher levels of protein were found in the feeding season and less around the spawning season (Belitz et al. 2009).

Muscle proteins are divided into three groups based on their solubility properties; sarcoplasmic, myofibrillar and insoluble protein (connective tissue protein). Fish sarcoplasma proteins consist largely of enzymes which are water soluble. Myofibrillar proteins are salt soluble. These proteins are primarily bound to the contractile network; hence they are called contractile proteins. The proportion of myofibrilar proteins and total protein in fish is higher than in mammalian muscle tissue. The heat stability of fish proteins is lower than that of mammals, and the protein denaturation induced by urea occurs more readily and protein hydrolysis by trypsin is fast (Belitz et al. 2009). These properties provide additional evidence of the good digestibility of fish proteins.

Collagen is the main component of the insoluble proteins with content of up to 90%. The remainder is mainly elastine. The shrinkage temperature of fish collagen is about 45 ^{0}C, i.e. much lower than for mammalian collagen (60-65 ^{0}C) (Belitz et al. 2009). The collagen content and characteristics has a significant influence on the texture of raw fish. The body of land animals has average 15 percent connective tissue by weight whereas fish has only 3 percent collagen. The low collagen content is a main reason why fish is much tenderer than terrestrial animals. But different composition of collagen and a lower content of certain amono acids (hydroxyproline) are another reason of tenderness of fish. When fish is cooked, the collagen breaks down more easily at a lower temperature and converts to gelatin (Brown 2001).

Fillet fat

Lipids present of fish skeletal muscle may be divided into two major groups; phospholipids and triglycerides. The phospholipids have an important role for the structure of the cell membranes (structural lipids), whereas the triglycerides are lipids used for storage of energy in fat depots (FAO 2005).

Fat content in salmon fillets is essential for the texture, flavor and color. The fat content in farmed adult salmon shows a high variation between and within the same population of fish, (Mørkøre et al.

2001). In sexually immature, healthy fish, the fat and water contents normally add up to about 80% of the muscle weight (Haard 1992). The fat level in muscle of adult salmon depends on feed composition, feeding intensity as well as season. Mørkøre & Rørvik (2001) reported that salmon accumulate substantial amounts of fat during the autumn, whereas the authors observed that the fillet fat content dropped slightly (by 1.5% units) during the winter. Certain reports state that farmed salmon are fatter today than for ten years ago (Stead & Laird 2001). Higher standards of fish health and husbandry and improvements in diets and feeding regimes have lead to higher growth rates in farmed stocks. The feeding regime is influencing the fat content in salmon fillets, and is negatively correlated to feed ration level (Einen et al. 1999). The fat content increases with increasing the body sized of fish (Shearer et al. 1994) but the relationship between fish size and fillet fat content is less pronounced fish larger than 2-2 kg (Mørkøre & Rørvik 2001).

The ability of salmon to accumulate relatively high levels of fat in the muscle is a consequence of their evolution. The tendency for salmon to lay down muscle fat is under a high degree of genetic control so that there is a good potential for managing the muscle fat level through selective breeding. Flesh lipid levels are typically higher in grilse as compared to immature salmon of same weight and, as a result grilse may be less favored by processors for curing into traditional smoked products. The flesh of grilse may contain more than 20% lipid per kg in a mid-dorsal section of the muscle (Stead & Laird 2001).

2.4. Appearances of the fillet

Fillet color

Coloration plays an important role in fillet. The body color of fish is predominately dependent on the presence of special cells in the skin, called chromatophores (Anderson 2000). This chromatophore has pigmentation. There are four main groups of pigment that can be used to provide color in the cells; carotenoids, melanin, pteridines, and purines (Anderson 2000). Carotenoids, which are lipid soluble, dominate in giving them to red colors. Pteridines are water-soluble compounds and result in bright coloration like carotenoids, but their role in coloration is small when compared to carotenoids. In the purine compounds, guanine predominates and large amounts of guanine can be found in the silvery belly skin of most species of fish. The basic compounds can be combined with other components, like proteins, to produce the blue, violet, and green color ranges seen in fishes (Anderson 2000).

In the flesh, the carotenoids are the dominant pigment. Carotenoid is the generic name for the most common groups of naturally occurring pigments found in the animal and plant kingdoms. Carotenoids are the major pigmenting compounds and cannot typically be synthesized by fish. In contrast most other pigmenting compounds can be made by the fish. The delicate pink flesh colour that unique to salmonid fishes is caused by deposition of carotenoids such as astaxanthin and canthaxanthin in the muscle. In the red fleshed fish such as the salmonids, the color of the muscle is very important for the sensory quality. The main carotenoid in Atlantic salmon is astaxanthin and the color of the harvested fish muscle depends on both the level of dietary carotenoid used and on the strategy chosen for feeding the carotenoids (Bjerkeng et al. 1997).

Astaxanthin accounts for more than 90% of the total carotenoid content found in the flesh of wild salmonids. In the wild, salmonids absorb astaxanthin from the crustaceans. The absorbed carotenoid is then transported in the blood to the muscles and skin where it is deposited. However, astaxanthin is expensive, in conventional salmon farming astaxanthin accounts for approximately 15% of the feed costs. Feed costs in turn accounts for nearly 50% of total production costs (Alfnes et al. 2006). Hence, coloring is a relatively important cost in salmon farming. Astaxanthin is poorly utilized for fillet pigmentation in Atlantic salmon and fillet retention rarely exceed 10-15 of the dietary amount, because of poor intestinal absorption and poor retention of the absorbed astaxanthin in the muscle (Bjerkeng et al. 1999).

Color measurement

The internationally recognized method for salmon color measurement is by comparing the salmon fillet flesh with the colors in the salmofan (Alfnes et al. 2006). The salmofan is a color fan developed on the basis of the color of salmonid flesh pigmented with astaxanthin (figure 2.2). The color of conventional farmed salmon fillets sold in the Norwegian market normally range from twenty three to thirty on the salmofan and most common are fillets ranging from twenty five to twenty seven . In a consumer study conducted by Roche vitamin, the producer of astaxanthin for the salmon farming industry they used color twenty six as their base product.

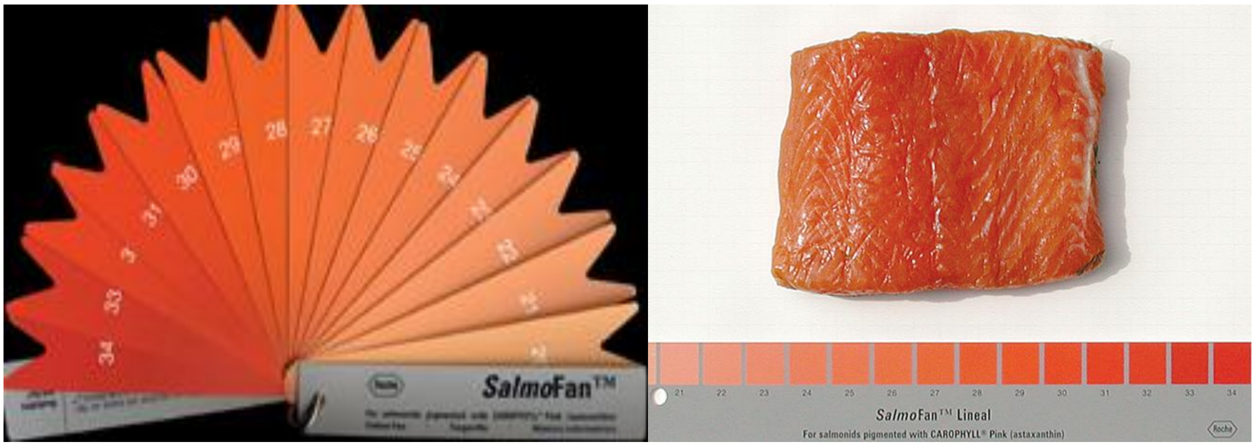

Fig. 2. 2. Roche SalmoColour Fan™ (Source: http://www.focs.ca/fishfarming/index.asp)

Traditional measurements of carotenoid concentration include pigment determination by high-pressure liquid-chromatography (HPLC) (Bjerkeng et al. 1997) Such methods are reliable, but slow, costly and destructive. Visual colour of salmon is frequently evaluated by comparing the fillets against the Roche SalmoColour Fan™. Near infrared reflectance spectroscopy (NIRS) is a physical and nondestructive technique. During the last 20 years, the use of NIR spectroscopy has gained importance in the evaluation of food quality parameters. NIRS is a suitable tool for fish freshness determination during storage time in ice (Nilsen et al. 2002). The method proved viable both for salmon and cod. This indicates applicability to both fat and lean fish species. A prototype of a VIS/NIR spectroscopy instrument was developed with the aim of measuring fat and pigment contents non-invasively in live or whole/gutted slaughtered salmon (Folkestad et al. 2008). VIS/NIR spectroscopy enables rapid, non-intrusive, and low-cost measurements, and these characteristics meet the needs in the fish sector for development of industrial methods. Blood and melanin spot in salmon evaluated by NIRS. NIR has been used for the determination of free fatty acids in mackerel (Cozzolino et al. 2002). The NIR region of the electromagnetic spectrum lies between the visible and infra-red region (750±3000 nm), while the spectra appear as smooth, but they consist of many overlapped bands (Cozzolino et al. 2002).

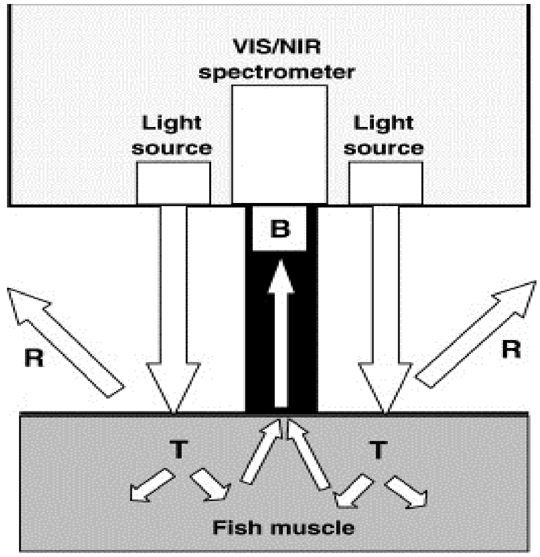

Fig. 2. 3. VIS/NIR spectrometer (Folkestad et al. 2008)

Discoloration, melanin and blood

Any discoloration in fillet causes the loss of money. Pale back and the melanin are the form of discoloration in salmon fillet. Pale back is generally caused by direct contact of fillet with water and ice. Blood spot in fillet is not considered as a good quality. Increased blood level in the muscle also has a pro-oxidative effect and may influence the change in flesh color during storage and processing (Heia et al. 2002). Presence of grey to dark pigment spot in the fillet also determines the poor quality of fillet. These spots are due to melanin (Fig. 2.4). The occurrence of melanin in fillet due to the biological phenomenon as well physical damage of muscle during vaccination is reported.

Fig.2.4. Image showing melanin spot in fillet of Atlantic salmon (Source: Nofima)

Gaping:

Gaping spoils the appearance of fillets, making them difficult to sell and makes skinning difficult. Gaping is caused by rupture of the connective tissue, which produces flaking of the fillet. The cause of gaping can crudely be described as the interaction between forces pulling the muscle apart, and the strength of the tissue (Kiessling et al. 2004). The biological mechanism underlying gaping is not fully understood. The heritability for gaping was found less than 0.04 in European whitefish, *Coregonus lavaretus* (Kause et al. 2011). But, it is generally considered to be a post-mortem phenomenon.

Fig.2.5. Image showing gaping in fillet of Atlantic salmon (Source: Nofima)

Gapping is affected by the method of slaughter, handling, high temperature rigor, freezing, seasonal variation, and smoking (Lavety 2001). Gaping is generally accompanied by tissue softening, indicating a relationship between gaping, tissue strength and structure. However, gaping may occur even though the flesh itself is firm (Mørkøre & Rørvik 2001). Muscular contraction in a whole fish during rigor can be a cause of gaping. The contraction becomes stronger and the connective tissue weaker as fish temperature rises, eventually resulting in gaping when the fish is filleted (Fig. 2.5).

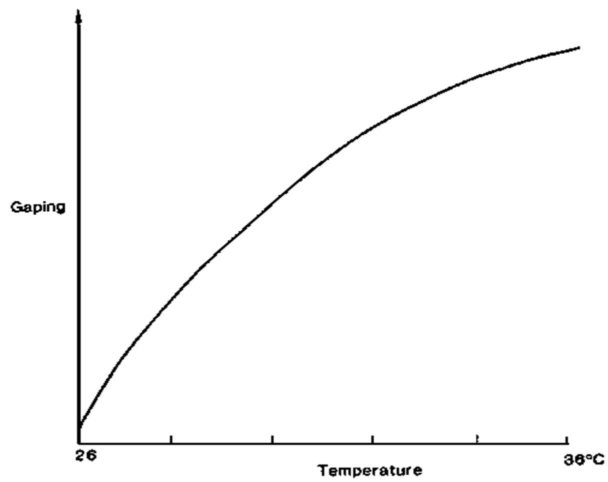

Fig. 2.6. Effect of fish temperature on gaping of trout (Lavety 2001)

Farmed salmon gape more when harvested in summer than in winter, because the chemical composition of the muscle changes after the fish resume feeding actively in the spring (fig. 2.6). The period of maximum gaping is linked to the date of resumption of feeding after the winter cold, and so can vary from year to year, but the peak is typically between June and August.

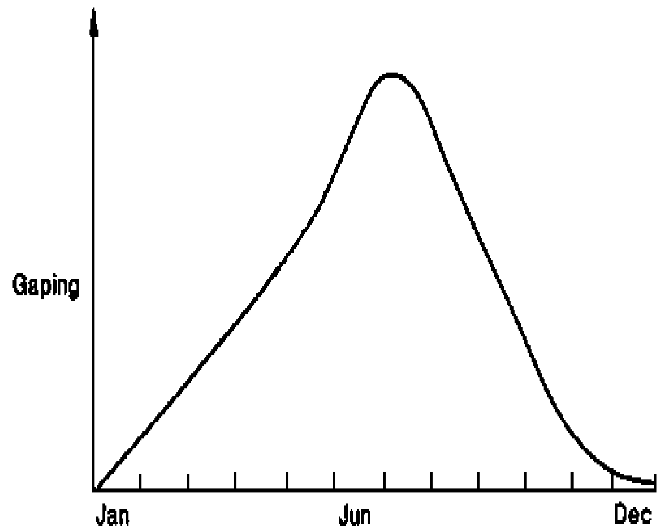

Fig. 2.7. Seasonal variation of gaping in salmon (Lavety 2001)

Generally, gaping is higher in the well-fed farmed fish as compared to the wild counterparts and the intense feeding regime results in lower end pH. Freezing should be done quickly enough to be completed before the onset of rigor. Salmon do not rigor until 18 hours after death of fish which is advantage to have sufficient time to freezing.

Texture

Texture is an important parameter that determines the sensory quality perception of the fish fillet (Coppes-petricorena 2010). Several factors influence the texture of fillet of salmon such as age, size of fish, fat content, amount and properties of protein and connective tissue and handling stress. Besides from the above factors, the post mortem factors are also important, these include rate and extent of pH decline, rigor mortis, rate and extent of proteolysis causing breakdown of myofibrils and connective tissue, degradation of nucleotides and temperature during the length of storage period (Coppes-petricorena 2010).

The firmness of salmon muscle decreases during the first four days of storage (Bahuaud et al. 2010). Kiessling et al. (2004) reported that disappearance of texture differences with storage time is the result of protein hydrolysis with concomitant structural deterioration of the tissue. The growth rate of fish also determines the texture of fillet. Mørkøre & Rørvik (2001) found that the breaking strength decreased as the body weight increased and concluded that rapid growth can promote softening of salmon flesh.

Various instrumental methods are using for measure the texture quality of fillet. The type of instrument using depend on the product whether cooked or raw fillet. The most common instrumental methods used are automatic pentrometer, cylindrical plunger, Rheological gel, TA-XT2 texture analyzer and Differential scanning calorimetry (Coppes-petricorena 2010).

TA-XT2 is most common used to analysis fish fillet texture (Coppes-petricorena 2010). Probes are most frequently used are: flat-ended cylinder knife, knife edged blade, Kramer cell, warner bratzler blade. Breaking force most commonly used indicator of texture quality of fillet Affect of texture on quality, measurement procedures. The required force N to puncture the surface of the fillet considered to measure the breaking force.

Fig. 2.8. Showing TA-TX2 texture analyzer (http://www.texturetechnologies.com)

2.5 Selective breeding for improved fillet quality

The purpose of selective breeding in aquaculture is to improve the performance, yield, quality of fish and disease resistance (Gjedrem 1997). Family based Norwegian breeding programmes are among the most advanced in international aquaculture. At present the breeding goals are focused on growth in fresh water, body weight, sexual maturity, disease resistance, dressing percentage, fillet yield, fillet color, fillet fat, deformity and body shape in Norwegian salmon farming (Gjedrem et al. 2007).

In order to increase quality traits through selective breeding, information on multiple parameters for each trait is required. Heritability is defined as the proportion of the total phenotypic variation of the trait that is caused by additive genetic effects. Hence in addition to calculating trait averages and standard deviations, the heritability for each trait and phenotypic and genetic correlations between the traits in question must be known (Gjedrem 2008). The heritability for some quality parameter of salmon is already known (see table 2.1).

Table. 2. 1. Average heritability estimates for quality traits for Atlantic salmon (Reproduced from (Gjedrem 2005).

Traits	Average	Coefficient of variation	Heritability*	No. of estimates
Fillet yield	68.2	2	0.23	2
Fat percentage	18.8	17	0.38	2
Fat distribution	8.3	21	0.37	2
Color score	3.5	17	0.05	2
Color image	7.7	18	0.47	1
Texture	9.7	4	0.26	1

*Heritability (h^2)= $\sigma G^2/\sigma\ p^2$

The heritability relationship between the qualities trait and yield are already known for some parameters (Gjedrem 1997). There is a positive correlation between body weight and the other traits. The figures in the table indicate that the quality traits will improve when selecting for increased body weight. Table 2 shows the phenotypic correlation between body weight and quality traits.

Table 2.2. Phenotypic correlation between body weight and quality traits (Gjedrem 1997)

Trait	Body weight	Fat %	Flesh color	Condition factor	Dressing %
Body weight					
Fat %	0.63				
Area of fat depot	0.53	0.86			
Flesh color	0.19	0.03			
Condition factor	0.51	0.45	0.04		
Dressing %	0.26	0.09	0.05	0.12	

3. Materials and Method

3.1. The fish material

The fish used were 1181 farmed Atlantic salmon (*Salmo salar* L.) belonging to the 2008 year class of the breeding nucleus of SalmoBreed AS, Norway. The fish were produced at Salten Havbruk in Nordland, in Norway. A nested mating design was using one male to two females. Each year class had 300 full sib groups, and 150 half sib groups.

Fig. 3.1. Map of Norway showing location of fish farm

The fish were hatched in January 2008 and start fed from March 2008. The offspring analyzed belonged to 213 dams and 111 sires. The fish were individually Pit-tagged and vaccinated, and kept together in fresh water until March 2009 when they were transferred to seawater in Skjærstadfjorden, Nordland, Norway (Fig 3.1). The salmon from the different families were kept together in commercial net pens until they were harvested and processed at Norsal AS, Helnessund (Nordland, Norway) in July 2010.

The fish were transported with a well boat from the rearing cage to the processing plant where they were kept in resting net pens outside the processing plant for 1-2 days before they were pumped into the processing line. The salmon was slaughtered and gutted according to standard commercial procedures at the processing plants. The fish was killed by percussive stunning. Both gill arches were cut and the fish were bled in circulated water at ambient temperature for 45 minute. The salmon were gutted, cleaned and immediately filleted by hand by experienced workers. The time from slaughtering until filleting was less than one hour. The pre-rigor fillets were kept in Styrofoam boxes with ice in a cooling room (4°C) for two days before analyzing. Some quality criterions were developed for selection of family (Table 3.2). These values of quality criterions were taken from various previous studies. The purpose of selection of family was to find out the fish that have all superior quality, yield and growth performance.

Table 3.1. The number of fish used for different proposes

Number of individuals	Study purpose	Remarks
1181	Overall correlations	
1160	Distribution pattern of biometric traits, yield and quality – also frequency of maturation and deformity	21 excluded due to lack of Pit-tag, i.e. family identity
1142	Study impact of sex and maturation	18 excluded because sex was not determined

Table 3.2. The criteria for family selection.

	Traits	Selected
1	Slaughter yield, %	≥ 90
2	Fillet fat content, %	≤ 16
3	SalmonFan, score	≥ 26
4	Firmness, (breaking force, N)	≥ 10

3.2 Fat content

Norwegian quality cut (NQC) of the sample was sampled 5-7 days after slaughtering and stored in sealed plastic bag at -20^{0} C for pigment analysis at Sunndalsøra. Fat content in fillet was determined by using near infrared (NIR) spectroscopy measurement (Folkestad et al. 2009).

3.3. Gaping

The gaping was measured visually according to Andersen et al. (1994) as the amount and size of slights in the fillet. A scale from 0-5 was used; 0 (no gaping), 1 (few small (< 2 cm) slit i.e., less than 5), 2 (some small slits i.e. less than 10), 3 (some small slits i.e., less than 10), 4 (many slits i.e., more than 10 or a few large (>2 cm), 5 (extreme gaping, the fillets falls aparts).

3.4. Fillet color

Visual colour was evaluated by comparing the fillets against the *Salmo*Colour Fan™ (DSM) which has a scale ranging from 20-34; where score 20 is the palest colour and score 34 is the most intense colour. The colour card readings were performed in two different locations on the ventral fillet part, between the posterior part of the dorsal fin and the gut (NQC) and under the anterior part of the dorsal fin.

Fig. 3.1. Illustrating visual color evaluation of the salmon fillets at the processing plant

3.5. Biometric traits

The traits recorded at harvest were sex, body length (cm), round body weight (g), gutted body weight (g) and fillet weight (g). Condition factor and fillet yield (%) were calculated relative to the whole body weight and gutted weight, respectively. These parameters were calculated by using following formulae.

$$\text{Condition factor (K)} = \frac{\text{Round body weight,}\ \ \text{g} * 100}{(\text{length,}\ \ \text{cm})3}$$

$$\text{Slaughter yield (\%)} = \frac{\text{Gutted weight,}\ \text{g} * 100}{\text{Body weight,}\ \text{g}}$$

$$\text{Fillet yield (\%)} = \frac{\text{Fillet weight,}\ \text{g} * 100}{\text{Body weight,}\ \text{g}}$$

3.6. Melanin

Black/grey spots, presumably due to melanin deposition, were graded visually according to their size and intensity according to a scale from score 0-3 in belly region (untrimmed).

3.7. Texture Analysis

Texture properties of salmon fillets were measured using texture analyzer TA-XT2. (SMS Stable Micro System Ltd., Surrey, England) equipped with a 30 kg load cell. A flat-ended cylinder probe of 12.5 mm diameter (type P/0.5) was used for the analyses. The resistance force in Newton (N) was recorded continuously as the probe was pressed downwards at a constant speed of 1 mm s^{-1} until it had reached 90 % of the fillet height just anterior to the dorsal fin, above the lateral line. The resistance force (N) required to puncture the surface of the fillet (termed breaking force) was recorded from the force-time graphs by a computer and analysed using the Texture Expert for Windows software (version 4.0.9.0., 2007, Stable Micro Systems Ltd, Surrey, UK). The relationship between the breaking force and sensory determination of firmness is shown to be significant (Mørkøre & Einen 2003); hence in the Result chapter, the breaking force is termed “firmness”.

Figure 3.2. Illustrating texture analyses performed at the processing plant.

3.8. Data analysis

The data were processed and diagrams were created using the Microsoft Excel program. Statistical analyzes were performed using ANOVA general linear models (GLM), and the results are presented as least square means Pearson‘s correlation coefficient using SAS 9.1 (SAS Institute Inc.). The level of significance was set at 5% ($P < 0.05$).

4. Results

The result chapter is divided into three main sections. The first and largest section deals with the overall population, sex, maturation and family with respect to biometric parameters, yield and quality traits. The second section describes the relationship between the various traits recorded and the third section describes selected families based on preferred traits and superior parents.

4.1. Population, sex, maturation and family

4.1.1. Body weight

The overall body weight ranged from 2 – 12 kg, whereof about 85% of the fish weighed from 4 to 8 kg. The average body weight was 6.2 kg (Fig. 4.1).

The amount of male and female fish was approximately equal (n=561 and 581, respectively) and 39 fish were unidentified sex. The mean body weight of the male fish was 6.66 kg whereas the mean weight of the female salmon was 5.69 kg. The gutted weight of the male and female fish was 6.00 and 5.17 kg, respectively (Table 4.1). The male fish were significantly larger than the female fish (Table 4.3) and the variation between individual fish slightly higher (CV 23% vs. 19% of female fish) (Table 4.1).

Separating female and male fish into mature and immature fish, similarly showed that the body weight was significantly higher of the males compared with the females, both regarding immature and mature fish (Table 4.3).The immature males weighed 200 grams more than the females (5.50 vs. 5.30 kg), whereas the weight difference was 1.20 kg for the mature fish, also in favor of the males (7.24 vs. 6.02 kg). For both sexes, the mature fish were significantly larger (Table 4.3). The gutted body weight showed a similar pattern, although the difference was less pronounced, being 160 g for immature fish and 1.05 kg for mature fish.

The average body weight varied significantly between the families, both regarding offspring from dams and sires (Table 4.2 and Fig. 4.4).The average body weight was 6.10 kg and 6.20 kg for the dam and sire offspring, respectively (Fig. 4.4).

4.1.2. Condition factor (CF)

Condition factor was calculated on the basis of body weight and gutted weight. The overall condition factor ranged from 0.97 to 1.97 on body weight basis (Table 4.1). The condition factor ranged from 0.89 to 1.74 on gutted weight basis. Average condition factor of overall population was 1.38 on body weight basis (Fig 4.1) whereas condition factor of overall population was 1.25 on gutted weight basis.

The mean condition factor on body weight basis for male and female was 1.39 and 1.37, respectively (Table 4.1). The condition factor on gutted weight basis was 1.26 and 1.24 for male and female, respectively (Table 4.3). The results showed no significant difference between male and female on condition factor on body weight basis (Table 4.2).

The condition factor was significantly higher for males than the females, both regarding immature and mature fish (Table 4.3). The condition factor of mature fish has significantly higher than of the immature fish for both sexes on the basis of both, body weight and gutted weight (Table 4.2).

The condition factor was significantly different between the families both regarding offspring from dams and sires on the basis of both, body weight and gutted weight (Table 4.2 and Fig. 4.4). The average condition factor was 1.38 for both the dam and sire offspring on body weight basis (Fig. 4.4).

4.1.3. Slaughter yield

The overall slaughter yield ranged from 87% to 93.6% (Table 4.1). The average slaughter yield was 90.7%.

The mean slaughter yield was 90.7% and 90.8% for male and female salmon, respectively (Table 4.1). There was no variation found between sexes for slaughter yield (Table 4.2). The coefficient of variation for both male and female fish was low and similar, (CV 1.20-1.25%) for male and female.

The slaughter yield was found higher in immature male and mature female than of the immature female and mature male (Table 4.3).

The slaughter yield was significantly different between the families for both the dam and sire offspring (Fig. 4.6 and Table 4.2). The mean slaughter yield was 90.7% for both dam and sire offspring (Fig. 4.6).

4.1.4. Fillet yield

Overall fillet yield ranged from 62.4% to 78.9%. The average fillet yield was 72.2% (Fig. 4.1).

The mean fillet yield for male was 72.0% whereas 72.4% was observed for female (Table 4.1). Female salmon has significantly higher fillet yield with compare to male salmon.

The fillet yield was significantly higher in female compared with the male, both regarding immature and mature fish (Table 4.3). The mature fish has significantly higher fillet yield for both sexes, (Table 4.2).

The average fillet yield varied significantly between the families, both regarding offspring from dams and sires (Fig. 4.6 and Table 4.3). The average fillet yield for dam and sire offspring were 72.3%, and 72.2% respectively (Fig. 4.6).

4.1.5. Fillet fat content

For the whole population, the fillet fat content ranged from 7.7% to 23.2% (Table 4.1). The average fillet fat content was 15.4%.

Fillet fat content was significantly higher in male salmon than female salmon (Table 4.2). The average fillet fat content for male fish was about 15.7% where as for female was found 15.1%.

Mature fish had significantly higher fat content than the immature fish for both males and females (Table 4.3). The fillet fat content was higher in both mature and immature male fish compared with female fish (Table 4.3).

Fat content varied a significantly between families for offspring from dams and sires (Table 4.2 and Fig. 4.7). The average fat content for dam and sire offspring was similar, 15.4% (Fig. 4.7).

4.1.6. Fillet color, SalmoFan score

The overall SalmoFan score ranged from 23 to 29 with an average of 26 (Table 4.1). 95% of the total fish population had observed SalmoFan score between 25 to 27 (Fig. 4.2). The mean SalmoFan score was 26 for both male and female (Table 4.2).

Separating female and male fish into mature and immature fish, the fillet color was significantly higher of the females compared with the males but the maturation had not affected the color of the fish (Table 4.3).

Fillet color varied significantly between families both regarding offspring from dams and sires (Table 4.2 and Fig. 4.7). Average SalmoFan score was 26 for both dam and sire offspring (Fig. 4.7).

4.1.7. Pale back

About 85% of the fish had score 0 for pale back (Fig. 4.3). The mean pale back in fillet was score 0.15 for male and score 0.12 for female salmon (Table 4.1). No significant difference in pale back was observed between the sexes (Table 4.2).

Mature male fish had highest pale back score (Table 3). 13.7 % of the total mature male has observed pale back in fillet whereas 8.0 % of total immature fish has observed pale back in fillet (Tale 4.3).

No family variation in pale back was observed regarding offsprings from dams or sires (Table 4.2 and Fig. 4.8).

4.1.8. Firmness, Breaking force (Fb)

The breaking force showed on overall ranged from 5 N to 19.7 N (Fig. 4.2). The mean breaking force of male the fish was 11.1 N whereas the breaking force of the female fish was 10 N (Table 4.1). Difference between the male and female salmon was significant.

The breaking force of the mature salmon was significantly higher than of the immature salmon regarding both sexes. The breaking force of the mature male had highest significantly (11.5 N, Table 4.3).

The breaking force varied significantly between families regarding offspring from dams and sires (Table 4.2 and Fig. 4.7). In figure 4.7, the value in the box shows the criteria for selection of family to get the superior parents. Average breaking force was 10.7 and 10.6 N for dam and sire offspring, respectively (Fig. 4.7).

4.1.9. Melanin

Overall melanin in fillet ranged from score 0 to score 3 (Table 4.1). Melanin in fillet was significantly lower in males (score 0.9) than in females (score 1.0) (Table 4.2).

Separating female and male fish into mature and immature fish, the Immature female had significantly highest melanin whereas the mature male had lowest melanin (Table 4.3).

Melanin scores did not vary significantly between the families, but there was a clear trend for both offspring from dams (p=0.068) and sirs (p=0.078).

4.1.10. Gaping

The overall gaping in fillet ranged from score 0-5 (Table 4.1). Fig. 4.2 shows, about 65% of fish had no gaping. The mean gaping score in fillet was score 0.6 for both male and female fish.

Mature female salmon had significantly highest gaping scores (Table 4.3). Table 4.3 further shows that the mature fish had higher gaping score than immature the regarding both sexes. No family variation in gaping score was observed regarding offspring from dams or sires. The family variation on gaping score was not observed regarding offspring from dams and sires (Table 4.2 and Fig. 4.8). The average gaping score in fillet was 0.7 score and 0.6 score for dam and sire offspring, respectively (Fig. 4.8).

4.1.11. Deformity

Evaluation of fillets showed 96% of the fish were without deformities. Average deformities for male and female fish was same (score 0.03).

There was no family variation found for deformity regarding offspring from dams and sire (table 4.2 and Fig 4.8). Table 4.3 indicates that mature male had highest deformities.

Table 4.1. Biometric traits, yield and quality characteristics of the male and female Atlantic salmon. Results are given as mean values, range, standard deviation (SD) and coefficient of variations (CV, %).

Parameters	Female (n=581)				Male (n=561)			
	Average	Range	SD	CV	Average	Range	SD	CV
Body weight, g	5693	2220-9897	1082	19.0	6606	2630-11792	1544	23.4
Gutted weight, g	5171	2000-8900	994	19.2	6001	2430-10610	1391	23.2
CF[1]	1.37	1.05-1.80	0.12	9.30	1.39	0.97-1.90	0.15	10.81
CF[2]	1.24	0.95-1.66	0.11	9.46	1.26	0.89-1.74	0.14	10.81
Slaughter yield, %	90.8	86.9-93.6	1.1	1.3	90.7	87.2-93.9	1.1	1.2
Fillet yield[1], %	72.4	63.4-78.9	2.5	3.5	72.0	62.4-77.7	2.9	3.3.
Fillet yield[2], %	79.7	67.4-91.4	2.8	3.5	79.4	69.6-84.7	2.5	3.2
Fillet fat, %	15.1	8.2-21.4	2.3	15.4	15.7	7.7-23.2	2.3	14.6
Firmness, N	10.3	5.4-16.9	2.1	19.4	11.2	5.7-19.7	1.8	20.6
Gaping, score	0.6	0-5	1.1	267.8	0.6	0-5	1.1	163.6
Fillet color, score	26.0	23-28	0.7	2.7	26	23-29	0.7	2.7
Pale back , score	0.12	0-1	0.31	265.30	0.15	0-1	0.35	233.25
Melanin, score	1	0-3	0.53	53.02	0.93	0-3	0.51	55
Deformity, score	0.03	0-1	0.16	564.41	0.03	0-1	0.15	516

[1] Calculated based on whole body weight

[2] Calculated based on gutted body weight

Table 4.2. p-value of family, sex, maturation and model of dam and sire with respect to biometric, yield and quality parameters.

Parent	P-value Family	P-value Sex	P-value Maturation	P-value Model	R^2
Sire					
Body weight	<0.0001	<0.0001	<0.0001	<0.0001	12.7
CF [1]	<0.0001	0.2497	<0.0001	<0.0001	37.0
CF [2]	<0.0001	0.2593	<0.0001	<0.0001	36
Slaughter yield	<0.0001	0.1170	0.0690	<0.0001	25.3
Fillet yield[1]	0.0084	0.0055	<0.0001	0.0001	16.0
Fillet yield[2]	0.1235	0.0344	<0.0001	0.0023	14.6
Fillet fat	0.0107	0.0005	<0.0001	<0.0001	19.0
Firmness	<0.0001	<0.0001	<0.0001	<0.0001	21.0
Gaping, score	0.5921	0.7036	0.1589	0.5814	9.0
Fillet color, score	<0.0001	0.0105	0.9122	<0.0001	17.0
Pale back , score	0.1747	0.3100	0.1897	0.1613	15.5
Melanin, score	0.0677	0.1216	0.0192	0.0277	17.3
Deformity, score	0.9710	0.9263	0.9083	0.9763	7.6
Dam					
Body weight, g	<0.0001	<0.0001	<0.0001	<0.0001	51.9
Gutted weight, g	<0.0001	<0.0001	<0.0001	<0.0001	51.6
CF[1]	<0.0001	0.1140	<0.0001	<0.0001	48.81
CF[2]	<0.0001	0.0148	<0.0001	<0.0001	48.8
Slaughter yield	<0.0001	0.0135	0.4919	<0.0001	39.0
Fillet yield[1]	0.0014	0.0004	0.0002	<0.0001	29.50
Fillet yield[2]	0.0067	0.0064	<0.0001	0.0002	28.72
Fillet fat	<0.0001	0.0003	<0.0001	<0.0001	34.54
Firmness	0.0002	<0.0001	<0.0001	<0.0001	32.37
Gaping, score	0.4497	0.8001	0.1882	0.4392	21.09
Fillet color, scale	<0.0001	0.0414	0.9146	<0.0001	29.4
Pale back , score	0.1579	0.6538	0.5272	0.1517	30.56
Melanin, score	0.0783	0.0190	0.0224	0.0437	32.60
Deformity, score	0.6499	0.7073	0.8204	0.6721	20.3

[1] Calculated based on whole body weight

[2] Calculated based on gutted body weight

Table 4.3. Average value of biometric traits, yield and quality parameters with respect to sex and maturity.

Parameters	Female		Male	
	Immature (n=264)	Mature (n= 317)	Immature (n= 205)	Mature (n=356)
Body weight, kg	5.3±05d	6.0±0.05b	5.5±0.06c	7.2±0.04a
Gutted weight, kg	4.8±0.04d	5.5±0.04b	5.0±0.05c	6.7±0.04a
CF [1]	1.33±0.05d	1.40±0.05b	1.29±0.06c	1.45±0.004a
CF [2]	1.21±0.005c	1.27±0.004b	1.17±0.006d	1.31±0.004a
Slaughter yield, %	90.7±0.05b	90.9±0.04a	90.9±0.56a	90.5±0.42b
Fillet yield[1], %	72.0±0.11c	72.7±0.10a	71.6±0.12d	72.3±0.09b
Fillet yield[2], %	79.3±0.11c	80.0±0.10a	78.6±0.13d	79.8±0.10b
Fillet fat, %	14.6±0.09d	15.4±0.09c	14.8±0.11b	16.2±0.09a
Firmness, N	10.0±0.09c	10.4±0.08b	10.4±0.10b	11.5±0.085a
Gaping, score	0.6±0.47ab	0.7±0.04b	0.6±0.05b	0.7±0.04a
Fillet color, scale	26.0±0.03a	26.0±0.02a	25.9±0.03b	25.9±0.02b
Melanin, score	1.05±0.02a	0.99±0.02b	1.02±0.02b	0.90±0.02c
Pale back, %	8.0	9.3	8.14	13.69
Deformity, %	3.1	3	3	4

Different letter in the same raw denotes the significantly different ($p<0.05$).

[1] Calculated based on whole body weight

[2] Calculated based on gutted body weight

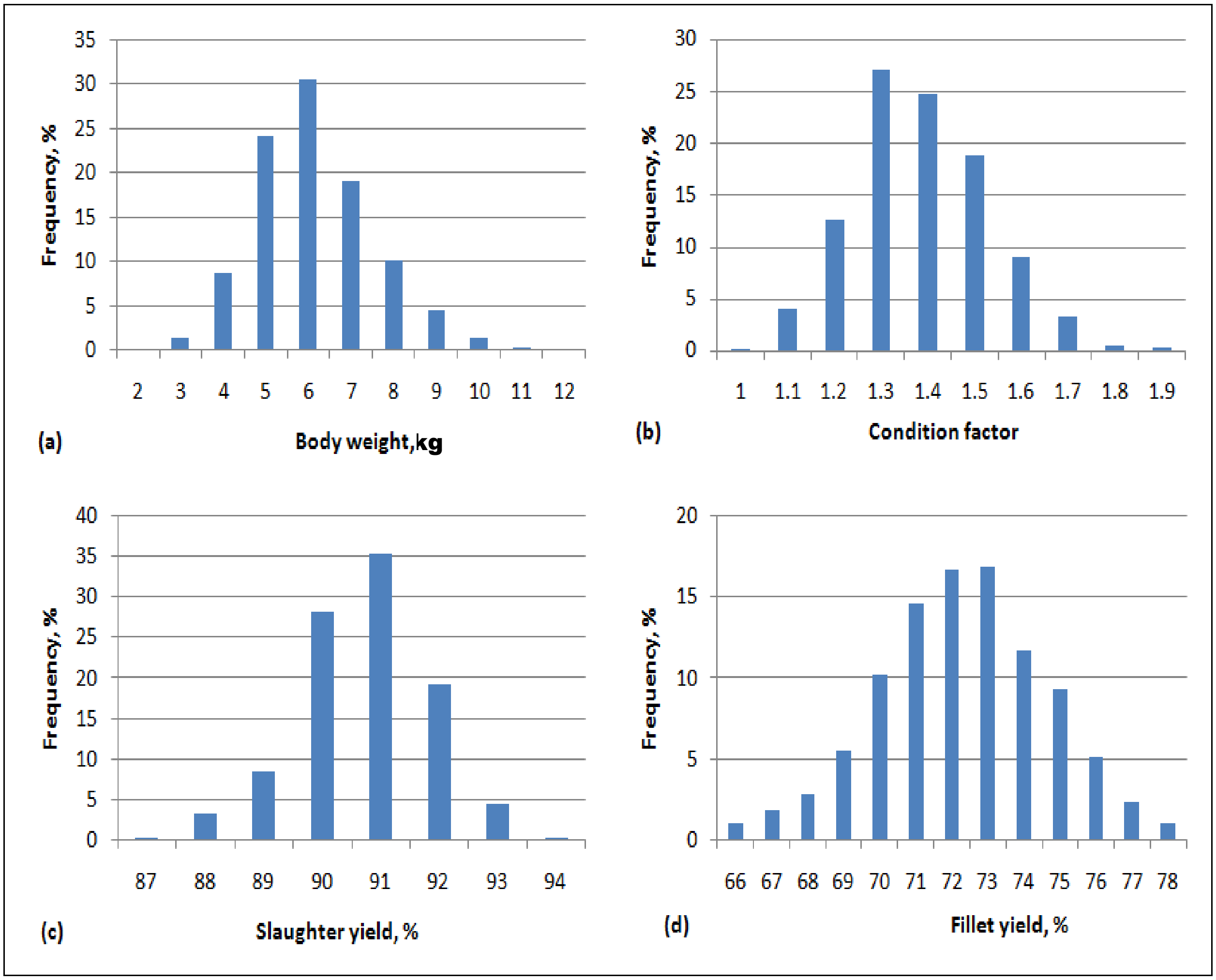

Fig. 4.1. Distribution of (a) body weight (kg), (b) condition factor, (c) slaughter yield (%) and (d) fillet yield (%) of farmed Atlantic salmon (*Salmo salar* L.) (n=1181).

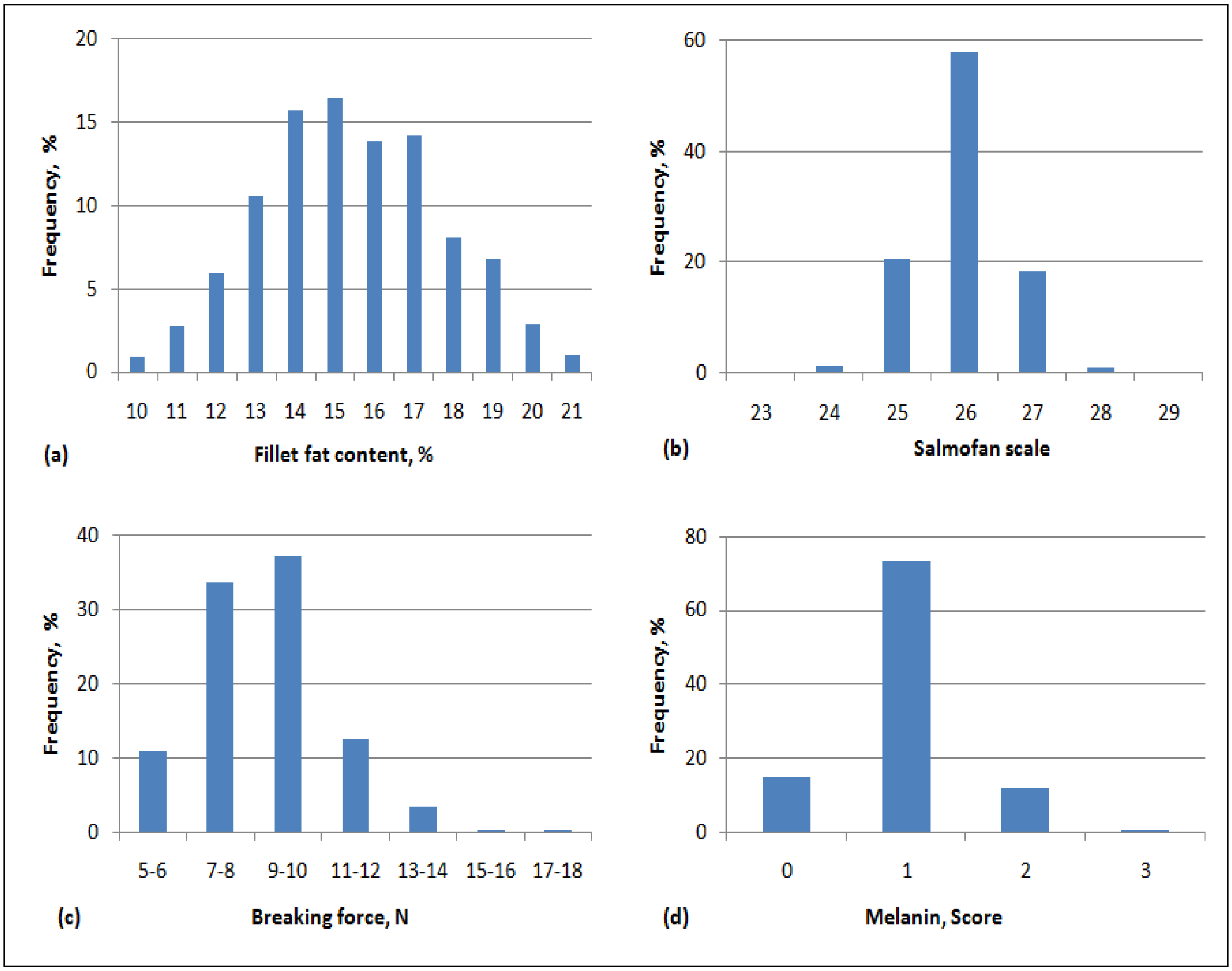

Fig. 4.2. Distribution of (a) fillet fat content (%), (b) SalmoFan score, (c) breaking force (N) and (d) melanin score of farmed Atlantic salmon (*Salmo salar* L.) (n=1181).

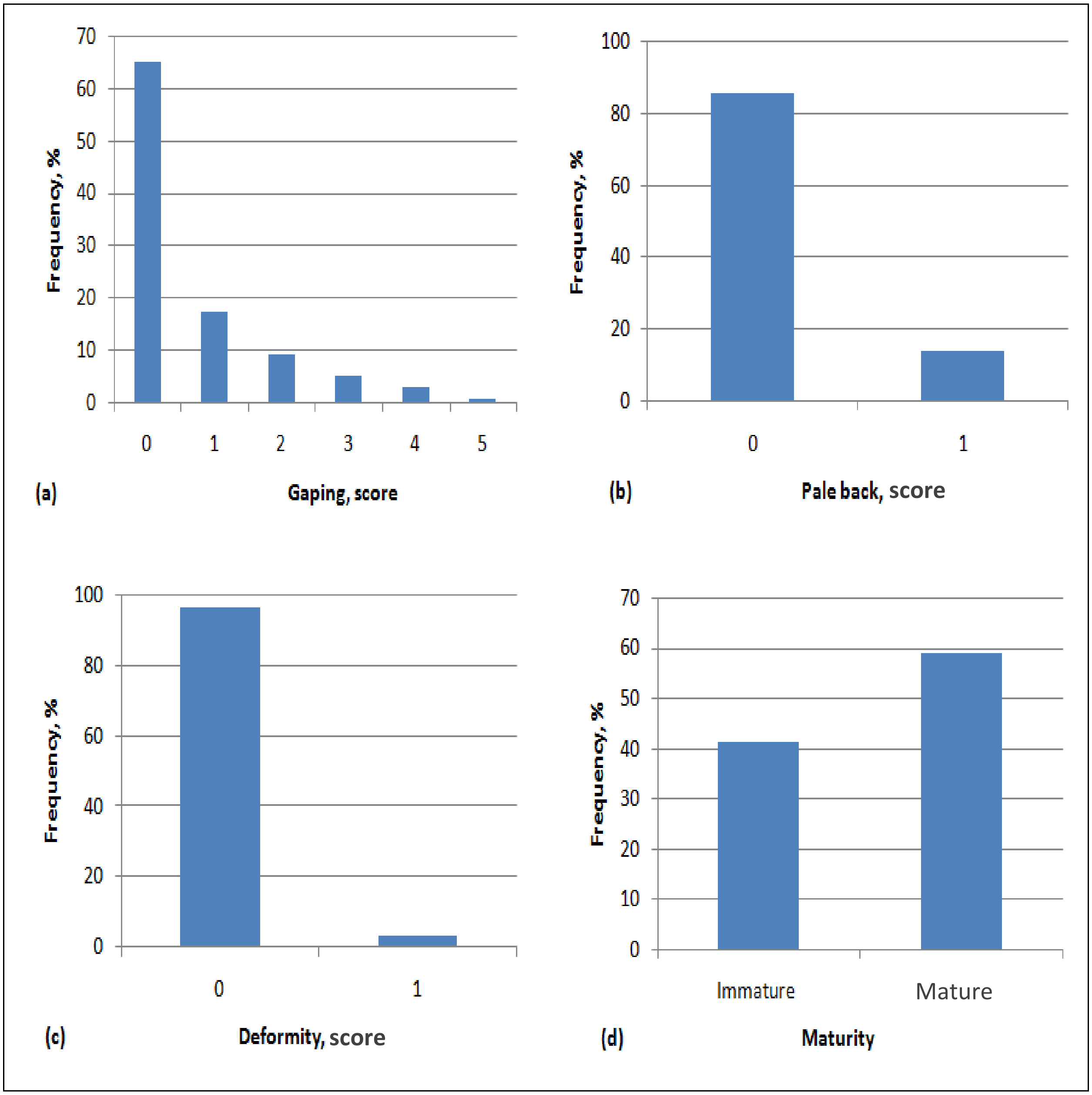

Fig. 4.3. Distribution of (a) gaping (score), (b) pale back (score), (c) deformity (score) and (d) maturity of farmed Atlantic salmon (*Salmo salar* L.) (n=1181).

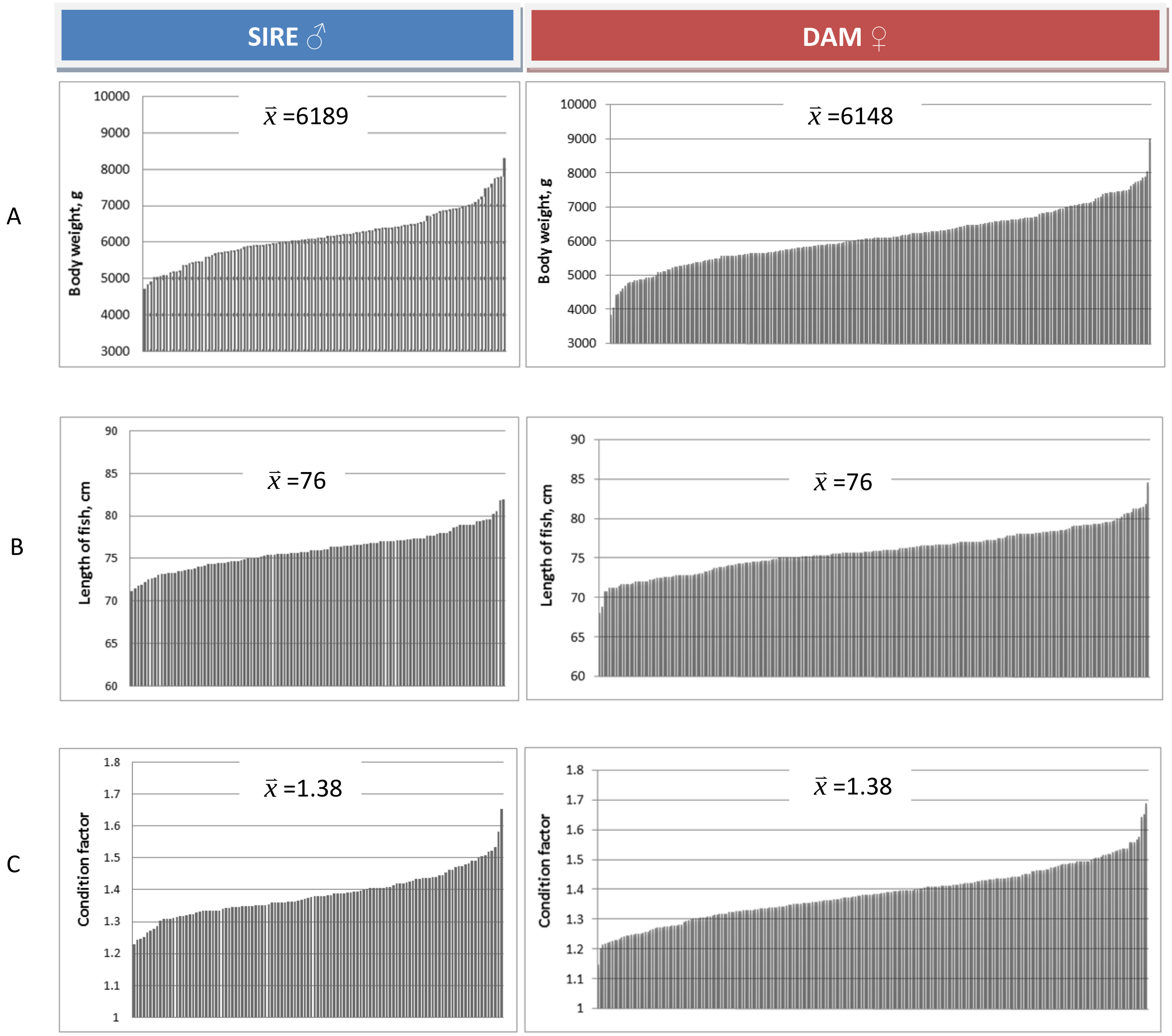

Fig. 4.4. Body weight (A), body length (B) and condition factor (C) of Atlantic salmon families. Each bar represents average values of offspring from sires (left panel) (n= 111) and dams (right panel) (n=213), respectively. Average number of individual fish within each family was n=10 (range 3-25) for offsprings from sires and n=5 (range 3-11) for offsprings from dams.

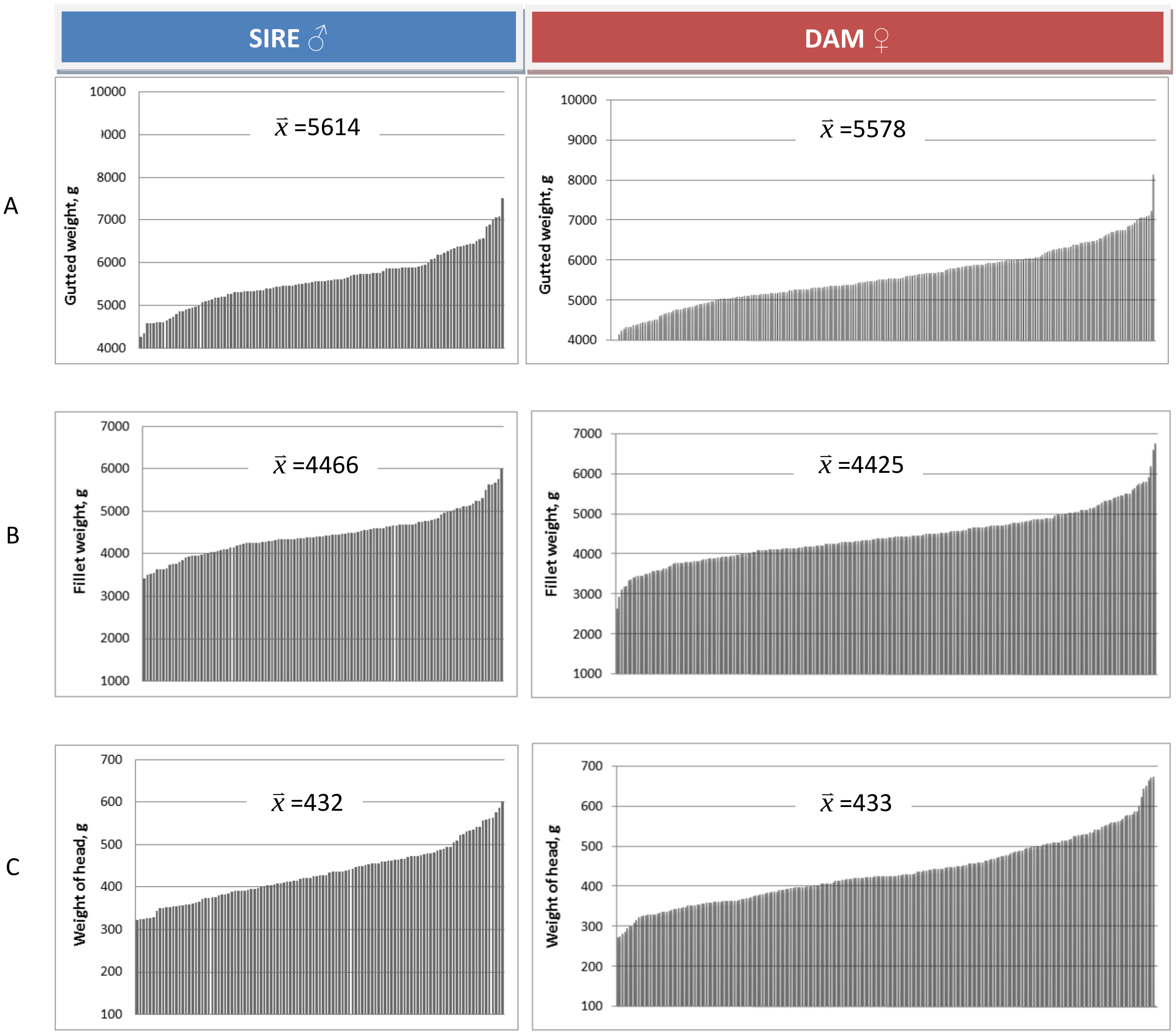

Fig. 4.5. Gutted weight (A), fillet weight (B) and head weight (C) of Atlantic salmon families. Each bar represents average values of offspring from sires (left panel) (n= 111) and dams (right panel) (n=213), respectively. Average number of individual fish within each family was n=10 (range 3-25) for offsprings from sires and n=5 (range 3-11) for offsprings from dams.

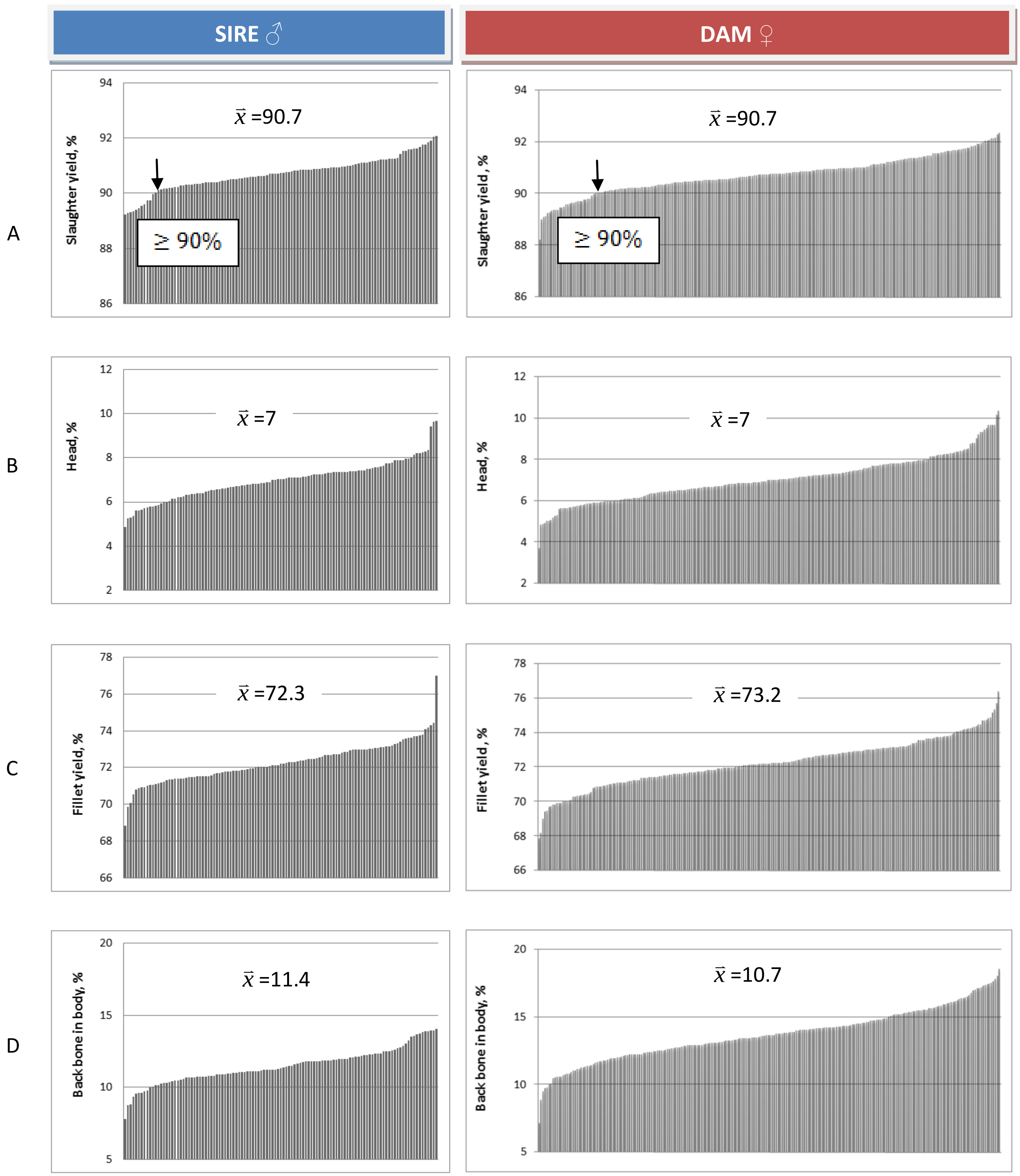

Fig. 4.6. Slaughter yield (A), head percentage (B), fillet yield (C), and back bone percentage in body (D) of Atlantic salmon families. Each bar represents average values of offspring from sires

(left panel) (n= 111) and dams (right panel) (n=213), respevtively. Average number of individual fish within each family was n=10 (range 3-25) for offsprings from sires and n=5 (range 3-11) for offsprings from dams. The value in the box shows the criteria for selection of family to get the superior parents.

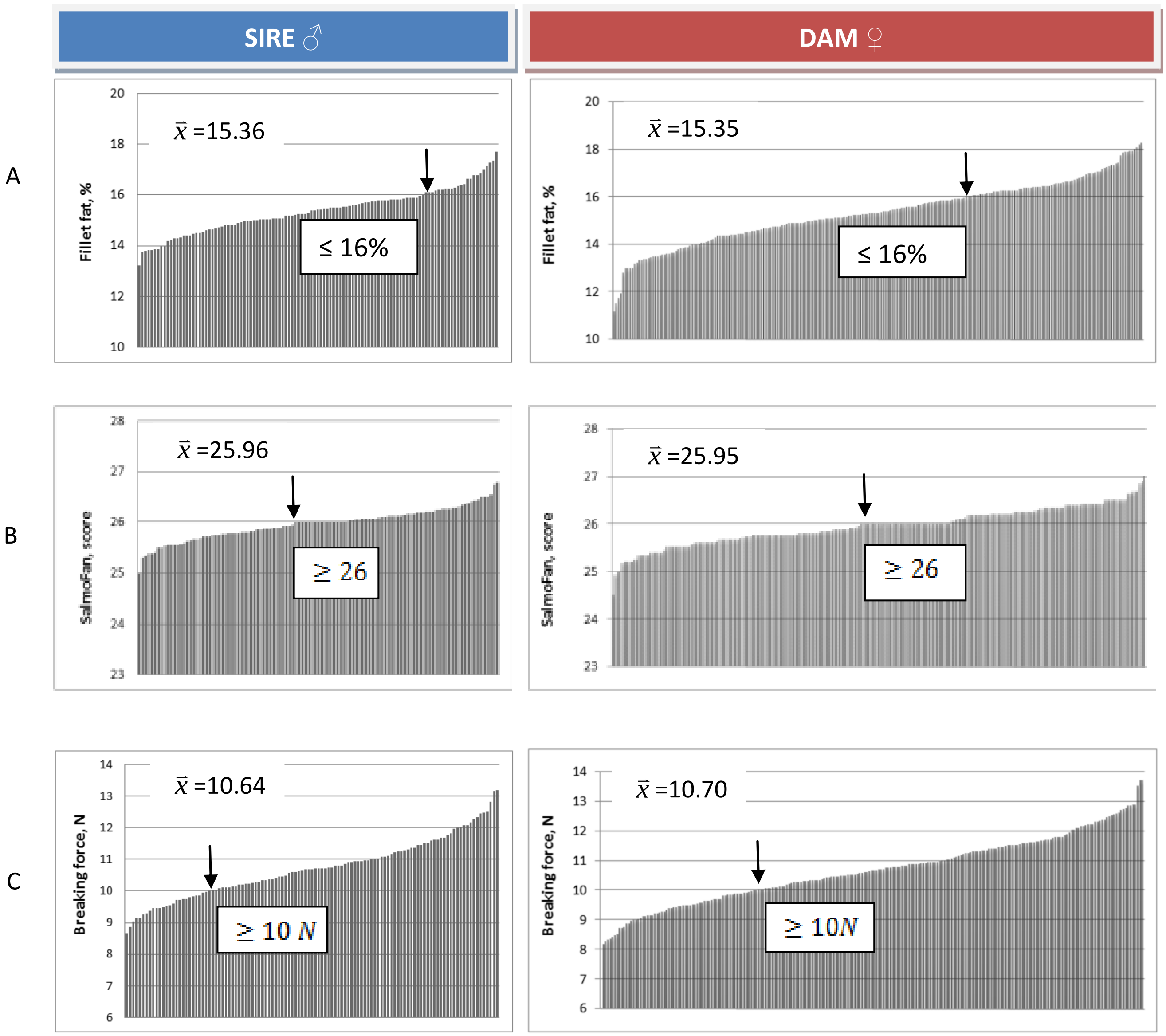

Fig. 4.7. Fillet fat content (%) (A), visual colour (SalmoFan score) (B) and breaking force (N) (C) of Atlantic salmon families. Each bar represents average values of offsprings from sires (left panel) (n= 111) and dams (right panel) (n=213), respectively. Average number of individual fish within each family was n=10 for offsprings from sires and n=5 for offsprings for dams.

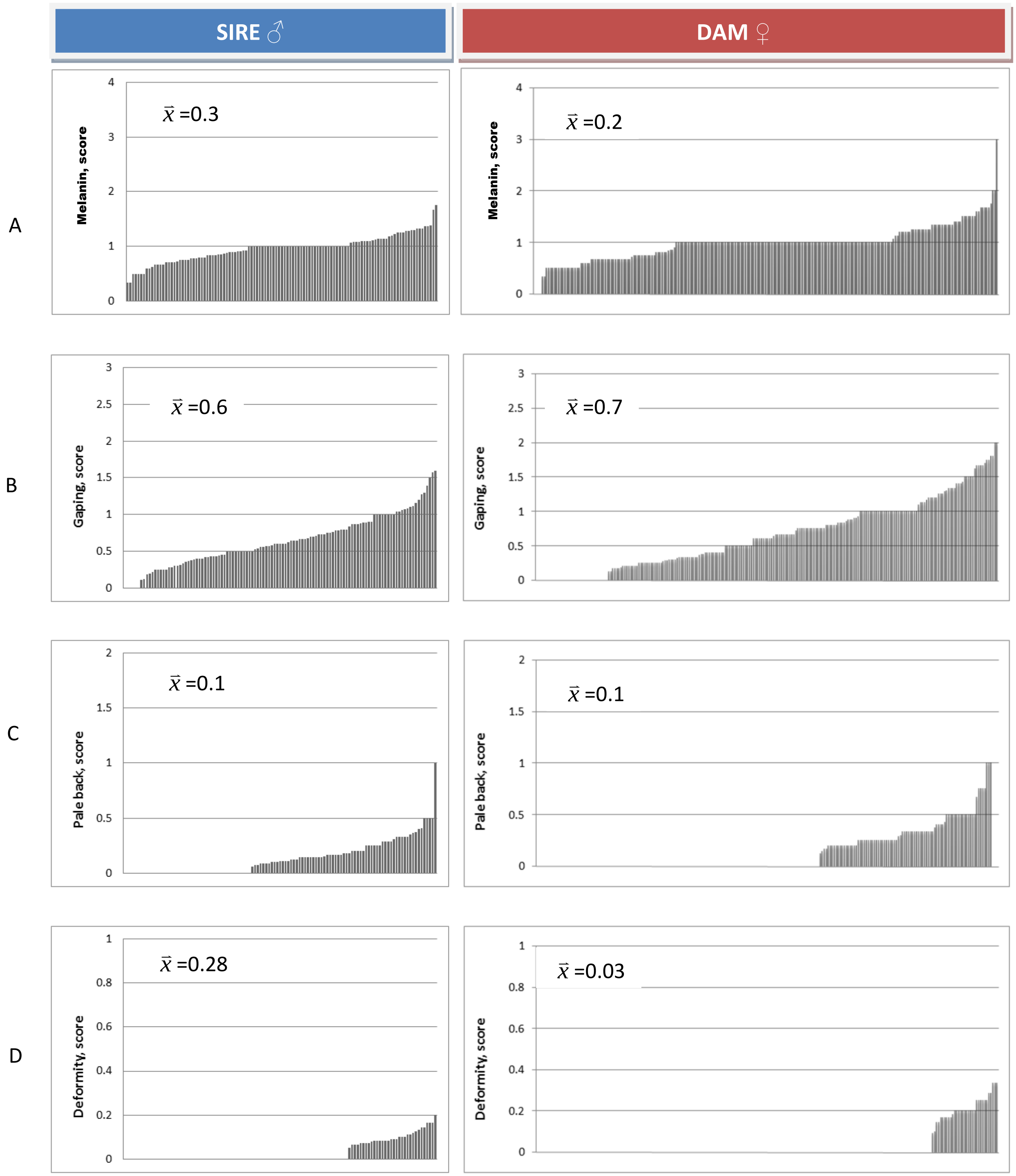

Fig. 4.8. Melanin in belly (score 0-3) (A), Gaping (score 0-5) (B), pale back (C) and deformities (score 0-1) (D) of Atlantic salmon families. Each bar represents average values of offsprings from sires (left panel) (n= 111) and dams (right panel) (n=213), respectively. Average number of

individual fish within each family was n=10 (range 3-25) for offsprings from sires and n=5 (range 3-11) for offsprings from dams.

4.2. Correlation between the biometric, yield and quality traits

Positive correlation between body weight and fillet yield was observed from the result (Table 4.5). Similarly, body weight and gutted weight had correlated positively with condition factor, fat content and pale back. Regarding quality parameters negative correlation between gaping and fillet color was observed. Firmness and gaping showed no significant correlation with biometric traits or other quality parameters (Table 4.5).

Table 4.4. Correlations between biometric parameters, yield and quality traits of Atlantic salmon (*Salmon salar* L.) (n=1180).

parameter	Body weight	Gutted weight	CF BW	Slaughter yield	Fillet yield	Fillet fat	Firmness	Gaping	Fillet color	Pale back	Melanin
Body weight	-										
Gutted weight	0.99	-									
CF	0.66	0.66	-								
Slaughter yield	ns	0.44	ns	-							
Fillet yield	0.22	0.26	0.34	0.42	-						
Fillet fat	0.51	0.50	0.40	ns	0.26	-					
Firmness	ns	ns	ns	ns	ns	ns	-				
Gaping	ns	ns	ns	ns	ns	ns	ns	-			
Color	ns	ns	0.14	ns	0.13	ns	ns	-0.19	-		
Pale back	0.18	0.19	0.23	0.12	0.18	ns	ns	ns	ns	-	
Melanin	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-

ns indicates non significant (($p<0.05$).

4.3. Selected families and Superior parent

The value in the boxes in Fig. 4.6 and Fig. 4.9 show the criteria for family selection to get superior parent from the total, 231 dams and 111 sires (Table 4.5). The offspring from the 11 dams and 19 sires had all defined traits (Table 4.5). The body weight of the offspring of the selected dams ranged from 4.9 to 6.9 kg, whereas for selected the sires range was 5.2 kg to 7.6 kg (Table 4.4). The gutted weight of the offspring of the selected dams ranged from 4.2 kg to 4.3 kg and of the selected sires the range was 4.6 to 6.8 kg. The condition factor of the offspring ranged from 1.3 to 1.5 for both selected dams and sires. Slaughter ranged from 90.2% to 92% and 90.2% to 91.9% for selected dams and sires, respectively. The results from the study showed that the fillet yield ranged from 71.4% to 73.2% and 68.8% to 74.0% for selected dams and sires respectively.

The fillet fat content ranged from 13.8% to 15.9% for both dams and sires. Firmness was range from 10 to 13.7% and 10 to 12.3% for the selected dams and sires. The fillet color was the same for both selected parents within SalmoFan score ranging from 26 to 26.5 for both dams and sires.

The result from the study showed that for pale back ranged from 0 to 1 scale for both dams and sires. Melanin score of the selected families for dams ranged from 0.5 to 1.3, whereas for sires it was 0 to 0.25. There were no deformities observed in offspring from the selected dams whereas for sires the range was from 0 to 0.9. The average sexual maturity ranged from 0.1 to 1 for the selected families (Table 4.5).

Table 4.5 shows the characteristics of superior/best parents regarding the various traits. The body weight was about 6.7 and 7.6 kg for dam and sire, respectively. The condition factor for the superior parents was 1.5 calculated based on whole body weight for both dam and sire. There was no gaping or deformities in superior sire whereas the superior dam was free from pale back or deformities. The result showed that all offsprings from superior sires were sexually mature.

Table 4.5. The range and average of biometric, yield and quality traits of selected and superior families.

Parameter	Selected families		Superior/Best	
	Sire (n=19 families)	Dam (n=11 families)	Sire (n= 5 individuals)	Dam (n= 6 individuals)
Body weight, g	4906-6881	5204-7603	6693	7603
Gutted weight, g	4420-6277	4686-6883	6035	6885
CF[1]	1.30-1.5	1.30-1.5	1.5	1.5
CF[2]	1.07-1.4	1.1-1.4	1.4	1.3
Slaughter yield,%	90.2-92.0	90.2-91.9	90.2	90.5
Fillet yield[1], %	71.4-73.2	68.8-74.04	71.5	74.04
Fillet fat, %	13.8-15.9	13.8-15.9	15.5	15.7
Firmness, N	10-13.7	10-12.3	12.9	12.3
Gaping, score	0.2-0.8	0-0.8	0.2	0
Fillet color, SalmoFan, score	26-26.5	26-26.5	26.0	26.2
Pale back, score	0-1	0-1	0	0.2
Melanin, score	0.5-1.3	0-0.25	1.0	1.0
Deformity, score	0-0	0-0.9	0	0
Sex maturity, 0-1	0.16-0.83	0.2-1	0.83	1.0

[1] Calculated based on whole body weight

[2] Calculated based on gutted body weight

5. Discussion

The discussion chapter is divided into four main sections. The first section discusses the effect of sex and maturation with respect to biometric parameters, yield and fillet quality traits. The second section describes the variation between families, whereas the third section discusses the selected and superior families. The fourth and last section discusses correlations between the various traits determined.

5.1. Sex and maturation

The growth rate is a trait of high economic importance in Atlantic salmon culture as rapid growth implies production of more marketable fish in a shorter time. Growth rate of salmon is often expressed as the daily weight gain in percent (SGR = [(ln Final body weight (W2)– ln Initial body weight(W1)) / (Days)] x 100), or as the Thermal-unit Growth Coefficient (TGC), which is calculated as 1000 x ($W2^{1/3}$ – $W1^{1/3}$) / Sum(Days x Temp(^{o}C)) (Cho 1992). In breeding, however, growth is most often registered as the body weight at a fixed age or at the normal time of slaughter. In the present study, fish were a part of a breeding population and there were no calculations of growth during the production phase; rather the body weight at slaughter was used to determine the growth.

According to the world's largest salmon farming company, Marine Harvest, the on-growing period of salmon in seawater to a body weight of 4.5-5.5 kg is around 16-22 months (http://marineharvest.com/PageFiles/1296/Handbook%202010.pdf). Hence, the weight gain of the salmon in the present study was significantly higher than expected in that the average body weight reached 6.2 kg after 16 months in seawater. Salmon provide one example of the efficiency of breeding. After five generations of breeding for growth, the time required for salmon to reach slaughter weight has halved (Gjedrem & Baranski 2009), (Gjedrem & Matthew 2009). Reduction of early sexual maturation is another breeding goal that has resulted in improved production efficiency and product quality (Gjedrem & Baranski 2009), (Gjedrem & Matthew 2009), but the present results show that sexually maturing males and females grew faster than non-maturing fish. These results are similar with those observed previously by (Shearer et al. 1994). In particular maturing males have a greater potential in terms of mass production within a given period of time, since they had at least 1.2 times higher body weight than immature fish. Body weight at harvest also determines the price paid to growers by processor (Quinton et al. 2005). Therefore production of mature male fish can provide higher economic return for salmon growers.

For the salmon processing industry, the carcass weight is of highest economical importance, since the viscera including gonads comprise product losses. Therefore, if the body weight is higher due to enlargement of gonads, the weight gain is not of any beneficial importance to the processing industry. In the present study the gutted weight of the mature fish was considerably higher than of immature fish for both male and females, demonstrating that the higher weight of mature fish was not primarily due to bigger gonads.

Michie (2001) proposed that sexually mature Atlantic salmon have reduced flesh quality and distinctive skin coloration causing downgrading to low value products. In the present study skin coloration was not evaluated objectively, but to our opinion the skin color was within the range of acceptability of salmon graded as superior. In a study published about 25 years ago (Aksnes et al. 1986) showed that changes in the skin colour of maturing fish took place in July/August. Hence, it is possible that the time of slaughter (early July) was performed prior to the time where the salmon develop altered skin coloration. The present study thus suggests that mature salmon slaughtered in July in Northern Norway has a great feasibility to provide economic return for the farmers.

The slaughter and fillet yield of the salmon showed a similar range as observed previously (Rørå et al. 2001). The results of yield parameters in the present study suggest that mature fish have a potential to provide high profit because this trait has high economic importance, as fillets are the main and most valuable products of salmon (Gjedrem 2008). The yield is a function of both size and shape of the body and increase up to a condition factor of 1.5 (Rørå et al. 2001). The condition factor for all fish was below than 1.5. In the present study mature males had lower yield than mature females, suggesting that the weight loss during filleting and trimming was higher in mature males as compare to mature females. Because fillets are the final products for the processing units, the results suggest that the mature females provide higher economic return for processor than mature males.

Fillet fat content varies between species and size of fish (Powell et al. 2008). In the present study, the males had significantly higher fillet fat content than the females, which is similar with results found in a previous study (Rye & Gjerde 1996). The fat content is reported to decrease in mature salmon (Aksnes et al. 1986), but the mature fish in the current study had higher fillet fat content, probably due to the early stage of maturation and due to the higher body weight. The relationship between body weight and fat content of salmon is reported to be curve-linear (Mørkøre & Rørvik 2001). High fat content in salmon fillets is unfavorable (>18%), leading to negative consumer responses (Gjedrem 1997). The mean fillet fat content of the salmon in the present study was below 18% for all groups (14.6-16.2%), suggesting that the fillets could be sold superior products to demanding costumers.

The present study shows that mature fish had better firmness than immature fish which is in agreement with observations in European white fish (Kause et al. 2011). The mature males had significantly highest firmness although they had highest growth rate. The results are thus in disagreement with a previous study with immature salmon showing that high growth rate was associated with softening of salmon muscle (Mørkøre & Rørvik 2001). The fiber distribution of the muscle has been found to affect the texture in fish muscle (Kiessling et al. 2006). Hence the higher firmness in mature male might be related to differences in fiber density although it is more likely that it was caused by higher content of connective tissue, as also the the degree of gaping was higher in immature fish. According to Lavety et al. (1988), gaping is highly influenced by the strength of the connective tissue, primarily collagen. Soft flesh was correlated with higher gaping scores in the present study, but Mørkøre et al. (2001) reported that gaping may also occur in salmon with firm flesh. Fillet firmness and incidence of gaping can be influenced by post-mortem storage time and conditions (Ando et al. 1991). The post-mortem storage time and conditions of the fillets in the present study was similar for all fish fillets so that the firmness and gaping variations were most probably related to the *de novo* conditions of the fish.

In the present study, the fillet color was not affected by sexual maturation which varies from a previous study that showed paler fillet color in mature salmon However, the variation in fillet colour between sexes coincides with previous observations (Aksnes et al. 1986; Norris & Cunningham 2004). The sexually mature males had a higher frequency of pale patches on the anterior loin part. These results coincide with anecdotal reports saying that mature fish have more uneven fillet coloration. The degree of discoloration was recorded as presence or not presence of “pale back”. Therefore, there is no information of the degree of discoloration, hence standardized procedures should be developed for determination of colour uniformity of salmon fillets. The time of filleting affects the color of salmon fillets (Skjervold et al. 2001), but in case of our study the time of filleting and storage period were the same for all fish.

In the present study, the melanin score was lower in males than females which disagrees with a previous study that documented that the male fish had higher melanin scores than females (Gjerde et al. 2009). Average melanin score for all fish corresponded with score 1, approximately. During analysis of melanin we used a visual score from 0 to 3 score.

5.2. Variation between families

The heritability of body weight of salmon is reported to be up to 0.32 (Quinton et al. 2005; Shearer et al. 1994), whereas the heritability for fillet yield is 0.23 (Gjedrem 2008). Hence, these traits have the potential to be improved by selective breeding. Family variation with regard to the phenotypic body weight and yield were clearly shown in the present study.

Fillet texture showed significant differences between families, which is in agreement with a previous study reported by Salem et al. (2005). Bahuaud et al. (2010) showed that fillet shear force in rainbow trout was significantly different between strains. Heritability estimates of texture in Atlantic salmon for was 0.26 (Gjedrem 2005). The present study showed that also fat content varied between the families. This variation is transferred to the next generation since the heritability for fat content varies from 0.19 (Quinton et al. 2005) to 0.35 (Gjedrem 2008).

The family variation in fillet color observed in present study is in agreement with previous studies (Norris & Cunningham 2004), suggesting that the fillet color allows selective breeding for improved fillet colour since the heritability is estimated to at least 0.14 (Quinton et al. 2005).

The family variation did not show on gaping, melanin, pale back and deformity. These traits are important quality defects leading to downgrading of the fillets. Future studies should implement more accurate analysis than those used in the present study in order to obtain a better basis for calculations of the heritability for these traits.

5.3. Selected and superior families

Family selection refers to a selection method in which family groups are ranked according to the mean performance of each family and whole families are saved or discarded (Fjalestad 2005). In our study, the family selection was done according to mean performance of families.

The European markets are becoming more concerned about the quality related characteristics of salmon fillets, although the demands vary among consumers and applications. Fillet fat greater than 18% is generally considered as undesirable (Gjedrem 1997), and (Alfnes et al. 2006) reported that consumer's willingness to pay increased at color intensities above score 25 on the SalmoFan scale. Regarding firmness, Mørkøre (2008) proposed that firmness above 8 Newton can be considered as acceptable.

In the present study, families were selected according to desired criteria based on yield and quality traits in order to assess the extent to which there are families with all the desired criteria. We considered a slaughter yield above 90% as desirable. Additionally, three quality traits were chosen, including fillet fat content below 16%, firmness above 10 Newton and visual fillet color above score 26. These are the major quality parameters considered in most markets (Gormley 2009). The offspring from 5% of the dams and 11% of the sires had all the defined desirable traits, suggesting that it is possibility to obtain both high yield and desired phenotypic quality traits within the same family and hence also the probability to obtain offsprings with all the desired properties.

5.4. Relationship between the traits

The positive correlation between body weight and fillet yield of the salmon is in agreement with other studies that suggest that a higher body mass contributes to higher fillet yield due to a lower proportion of head, bones and fins (Mørkøre et al. 2001). Furthermore, positive phenotypic correlations ($r = 0.51$) between the body weight and fat content were found, indicating that selection for increased body weight may result in increased fat content. Similar positive correlations between body weight and fat content were also found in other studies (Gjedrem 1997; Powell et al. 2008; Quinton et al. 2005). The relationship between body weight and fat content is not desirable because selection for faster growth will tend to increase fat percentage (Gjedrem 1997). However, when selecting for faster growth rate, the fish will reach market size at younger physiological ages. A general law in physiology is that young animals use most energy for growth of muscles while older animals deposit more fat. Therefore, this positive correlation between body weight and fat percent may give not long term problems. Fat content also correlated positively with gutted weight, condition factor and fillet yield, suggesting that larger fish have a higher body mass and thus give higher fillet yield. Similar results were found by Rye and Gjerde (1996). A positive correlation between body weight and visual fillet color was found in this study as expected. This relationship is favorable and will result in a correlated response when selecting for growth rate only and a higher response when selection for both traits is performed simultaneously (Gjedrem 1997).

The fillet color and gaping were negatively correlated, indicating that selection for high fillet color could lead to lower fillet gaping. However, it was to a large degree fillets with severe gaping that were pale, and thus these fillets to a large extent determined the significant correlation. No significant relationships were found between gaping and body weight or yield traits. These results are in disagreement with previous study where they found positive relationship ($r = 0.21$) with body weight (Espe et al. 2004; Kiessling et al. 2004).

6. Conclusion

The present study demonstrated significant variation in biometric traits and quality parameters between the families.

Fillet texture, fat, color and yield varied significantly between families, while gaping, melanin deposition in the belly region, frequency of pale patches in the anterior fillet loin and deformities, determined as presence of cartilage showed no family variations.

The impact of sex and maturity on fillet yield and quality traits were clearly verified. Production of mature male fish can provide higher economic return for salmon growers as well as processor because these fish were significantly larger; they had higher fillet yield and also firmer flesh. A negative effect of sexual maturation of male fish seemed however to be a higher frequency of pale patches in the anterior loin (observed in 14% of mature males vs 8-9% in immature males and in females).The fillet fat content was higher in mature males, as there was a positive correlation between body weight and fat content.

The offspring from 5% of the dams and 11% of the sires had all the desirable traits that are valued throughout the value chain: less than 16% fat, intense fillet colour and firm flesh. This study also revealed that there exist parents with superior quality characteristic in combination with good growth performance and slaughter yield. These results are encouraging, suggesting that it is possible to obtain future generations of salmon with both superior growth performance, high muscularity, thus high fillet yield, and also desirable fillet quality characteristics.

Acknowledgement

I am heartily thankful to my supervisor, Dr. TuridMørkøre, whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject.

Thanks also goes to M.Sc. Ingunn Thorland, Akvaforsk Genetic Centre AS, Sunndalsøra, andto SalmoBreed AS, Norway for providing the fish materials.In particular I wish to thank Dr. Håvard Bakke at SalmoBreed AS for involving me in their test slaughtering and suggestions regarding material description,

I am obliged to the "The Fishery and Aquaculture Industry Research Fund" for providing the financial support in the accomplishment of the current thesis. The funding was managed by Dr. T. Mørkøre, NofimaAS

Lastly, I offer my special appreciation to my wife Sudha Sharma who always supported
and encouraged me during my studies at UMB.

DeependraAcharya

Ås, December 2011

References

Aksnes, A., Gjerde, B. & Roald, S. O. (1986). Biological, chemical and organoleptic changes during maturation of farmed Atlantic salmon, Salmo salar. *Aquaculture*, 53 (1): 7-20.

Alfnes, F., Guttormsen, A. G., Steine, G. & Kolstad, K. (2006). Consumers willingness to pay for the color of salmon: a choice experiment with real economic incentives. *American Journal of Agricultural Economics* 88 (4): 1050-1061.

Anderson, S. (2000). *Salmon Color and the Consumer*. International institute of fishery and economics trade (IIFET 2000): Microbehaviar and microresults, Oregon, USA.

Ando, M., Toyohara, H., Shimizu, Y. & Sakaguchi, M. (1991). Post-mortem tenderisation of rainbow trout (Oncorhyncus Mykiss) muscle caused by gradual disintegration of the extracellular matrix structure. *Journal of the Science of Food and Agriculture*, 55 (4): 589-597.

Bahuaud, D., Gaarder, M., Veiseth-Kent, E. & Thomassen, M. (2010). Fillet texture and protease activities in different families of farmed Atlantic salmon (Salmo salar L.). *Aquaculture*, 310 (1-2): 213-220.

Belitz, H. D., Grosch, W. & Schieberle, P. (2009). *Food chemistry.* Berlin: Springer. 1070 pp.

Bjerkeng, B., Hamre, K., Hatlen, B. & Wathne, E. (1999). Astaxanthin deposition in fillets of Atlantic salmon Salmo salar L. fed two dietary levels of astaxanthin in combination with three levels of α-tocopheryl acetate. *Aquaculture Research*, 30 (9): 637-646.

Bjerkeng, B., Refstie, S., Fjalestad, K. T., Storebakken, T., Rodbotten, M. & Roem, A. J. (1997). Quality parameters of the flesh of Atlantic salmon (Salmo salar) as affected by dietary fat content and full-fat soybean meal as a partial substitute for fish meal in the diet. *Aquaculture*, 157 (3-4): 295-307.

Bone, Q. & H., M. R. (2008). *Biology of fishes.* 3rd ed. New York: Taylor and Francis group. 487 pp.

Brown, A. (2001). *Understanding of food: principles and preparation.* USA: Wadsworth Publishing. 688 pp.

Cho, C. Y. (1992). Feeding systems for rainbow trout and other salmonids with reference to current estimates of energy and protein requirements. *Aquaculture*, 100 (1-3): 107-123.

Coppes-petricorena, Z. (2010). Texture measurements in fish and fish products In Alasalvar, C., Miyashita, K., Shahidi, F. & Wanasundara, U. (eds) *Handbook of Seafood Quality, Safety and Health Applications*, pp. 576: Wiley-Blackwell, UK

Cozzolino, D., Murray, J. & Scaif, J. R. (2002). Near infrared re¯ectance spectroscopy in the prediction of chemical characteristics of minced raw fish. *Aquaculture nutrition*, 8 (1-6).

Einen, O. & Thomassen, M. S. (1998). Starvation prior to slaughter in Atlantic salmon (Salmo salar): II. White muscle composition and evaluation of freshness, texture and colour characteristics in raw and cooked fillets. *Aquaculture*, 169 (1-2): 37-53.

Einen, O., Mørkøre, T., Rørå, A. M. B. & Thomassen, M. S. (1999). Feed ration prior to slaughter—a potential tool for managing product quality of Atlantic salmon (Salmo salar). *Aquaculture*, 178 (1-2): 149-169.

Espe, M., Ruohonen, K., Bjørnevik, M., Frøyland, L., Nortvedt, R. & Kiessling, A. (2004). Interactions between ice storage time, collagen composition, gaping and textural properties in farmed salmon muscle harvested at different times of the year. *Aquaculture*, 240 (1-4): 489-504.

FAO (2002). The state of world fishery and aquaculture. Food and agriculture organization. Rome 150 pp

FAO (2005). Fishery and aquaculture topics. Lipids. Topics fact sheet. In: FAO fisheries and aquaculture department (online). Rome. Updated 27 May 2005. Cited 16 November 2011) Available at: http://www.fao.org/docrep/x5738e/x5738e05.htm

Fjalestad, K. T. (2005). Selection methods In Gjedrem, T. (ed.) *Selection and breeding programs in Aquaculture*, pp. 159-171. The Netherlands: Springer.

Fjelldal, P. G., Lock, E.-J., Grotmol, S., Totland, G. K., Nordgarden, U., Flik, G. & Hansen, T. (2006). Impact of smolt production strategy on vertebral growth and mineralisation during smoltification and the early seawater phase in Atlantic salmon (*Salmo salar*, L.). *Aquaculture*, 261 (2): 715-728.

Folkestad, A., Wold, J. P., Rørvik, K.-A., Tschudi, J., Haugholt, K. H., Kolstad, K. & Mørkøre, T. (2008). Rapid and non-invasive measurements of fat and pigment concentrations in live and slaughtered Atlantic salmon (*Salmo salar* L.). *Aquaculture*, 280 (1-4): 129-135.

Folkestad, A., Wold, J. P., Rørvik, K.-A., Tschudi, J., Haugholt, K. H., Kolstad, K. & Mørkøre, T. (2008). Rapid and non-invasive measurements of fat and pigment concentrations in live and slaughtered Atlantic salmon (Salmo salar L.). *Aquaculture*, 280 (1-4): 129-135.

Gjedrem, T. (1997). Flesh quality improvement in fish through breeding. *Aquaculture International*, 5 (3): 197-206.

Gjedrem, T. (2005). Breeding plan. In Gjedrem, T. (ed.) *Selection and breeding program in aquaculture*. pp. 251-277. The Netherlands: Springer.

Gjedrem, T. (2008). Improving farmed fish quality by selective breeding In Øyvind, l. (ed.) *Improving farmed fish quality and safet*, pp. 265-274. England: Woodhead publishing limited.

Gjedrem, T. & Baranski, M. (2009). Selective breding in aquaculture: In introduction. *Reviews: Methods and Technologies in Fish Biology and Fisheries*, vol. 10. USA: springer.pp 221

Gjedrem, T., Sonesson, A. & Rye, M. (2007). Selective breeding and genetics-Atlantic salmon. In Gjedrem, T. (ed.) *Aquaculture-production of aquatic organisms (2000-2005): Aquaculture research: From cage to consumption*, pp. 268-284. Norway: The research council of Norway.

Gjerde, B., Evensen, Ø., Bentsen, H. B. & Storset, A. (2009). Genetic covariation of vaccine injuries and innate resistance to furunculosis (Aeromonas salmonicida) and infectious salmon anaemia (ISA) in Atlantic salmon (Salmo salar). *Aquaculture*, 287 (1-2): 52-58.

Gjerde, B., Simianer, H. & Refstie, T. (1994). Estimates of genetic and phenotypic parameters for body weight, growth rate and sexual maturity in Atlantic salmon. *Livestock Production Science*, 38 (2): 133-143.

Gormley, T. R. (2009). A note on consumer preference of smoked salt colour. *Fish Journal of agriculture and food research* 31: 199-202.

Haard, N. F. (1992). Control of chemical compostion and food quality attributes of cultured fish *Food Research International* 25: 289-307.

Heia, K., Sivertsen, A. H. & Birkeland, S. (2002). *Automated quality control of salmon fillets-hyperspectral imaging for on-line inspection*. Poster presentation at the 14th international Conference on near infrared spectroscopy, Bangkok, Thailand, 9-13 November.

Helland, S. & Grisdale-Helland, B. (1998). Growth. Ieed utilization and body composition of juvenile Atlantic halibut (Hippoglossus hippoglossus) fed diets differing in the ratio between the macronutrients. *Aquaculture*, 166.

http://www.marineharvest.com/PageFiles/1296/Handbook%202010.pdf

http://www.texturetechnologies.com.

Johnston, I. A. (2001, May 7-10). *Muscle structure and muscle growth patterns are key determinants of product quality in Atlantic salmon*. Proceeding of the International symposium on cultivation of Atlantic salmon, Bergen, Norway.

Johnston, I. A., Li, X., Vieira, V. L. A., Nickell, D., Dingwall, A., Alderson, R., Campbell, P. & Bickerdike, R. (2006). Muscle and flesh quality traits in wild and farmed Atlantic salmon. *Aquaculture*, 256 (1-4): 323-336.

Kause, A., Quinton, C., Airaksinen, S., Ruohonen, K. & Koskela, J. (2011). Quality and production trait genetics of farmed European whitefish, Coregonus lavaretus. *Journal of Animal Science*, 89 (4): 959-971.

Kiessling, A., Espe, M., Ruohonen, K. & Mørkøre, T. (2004). Texture, gaping and colour of fresh and frozen Atlantic salmon flesh as affected by pre-slaughter iso-eugenol or CO_2 anaesthesia. *Aquaculture*, 236 (1-4): 645-657.

Kiessling, A., Ruohonen, K. & Bjørnevik, M. (2006). Muscle fibre growth and quality in fish. *Arch. Tierz., Dummerstorf* 49: 137-146.

Koteng, A. (1992). Markedsundersùkelse norsk laks (Market investigation of Norwegian salmon). *Prosjekt god fisk*. 165 pp.

Lavety, J. (2001). *Gaping in farmed salmon and trout.* London. Torry research station.

Lavety, J., O.A. Afolabi., O.A. & Love, R.M. (1988). The connective tissues of fish: IX. Gaping in farmed species. *Int. Journal of food science technology,* 23: 23–30.

Michie, I. (2001). Causes of downgrading in the salmon farming industry. In Kestin, S. C. & Warriss, P. D. (eds) vol. 4 *Farmed fish quality* pp. 129–136: Fishing news book Blackwell Oxford, UK

Murray, J. & Burt. (2001). *The compostion of fish.* London. Torry research station

Mørkøre, T. & Einen, O. (2003). Relating Sensory and Instrumental Texture Analyses of Atlantic Salmon. *Journal of Food Science*, 68 (4): 1492-1497.

Mørkøre, T. & Rørvik, K.-A. (2001). Seasonal variations in growth, feed utilisation and product quality of farmed Atlantic salmon (Salmo salar) transferred to seawater as 0+smolts or 1+smolts. *Aquaculture*, 199 (1-2): 145-157.

Mørkøre, T., Vallet, J. L., Cardinal, M., Gomez-Guillen, M. C., Montero, P., Torrissen, O. J., Nortvedt, R., Sigurgisladottir, S. & Thomassen, M. S. (2001). Fat content and fillet Shape of Atlantic Salmon: relevance for processing yield and quality of raw and smoked products. *Journal of Food Science*, 66 (9): 1348-1354.

Mørkøre. (2008). *Tekstur i oppdrettslaks—Kunnskapsstatus og forhold som bidrar til fasterefille*. norske sjømatbedrifters landsforening. Available at: www.nsl.no/filer/fou/loe/loe5.pdf2008Las.

Nilsen, H., Esaiassen, M., Heia, K. & Sigernes, F. (2002). Visible/Near-Infrared Spectroscopy: A new tool for the evaluation of fish freshness? *Journal of Food Science*, 67 (5): 1821-1826.

Norris, A. T. & Cunningham, E. P. (2004). Estimates of phenotypic and genetic parameters for flesh colour traits in farmed Atlantic salmon based on multiple trait animal model. *Livestock Production Science*, 89 (2-3): 209-222.

Oehlenschlager, J. & Rehbein, H. (2009). Basic fact and fighur In Rehbein, H. & Oehlenschlager, J. (eds) *Fishery products:quality, safety and authencity*, pp. 1-18. Oxford, UK: Blackwell publishig.

Powell, J., White, I., Guy, D. & Brotherstone, S. (2008). Genetic parameters of production traits in Atlantic salmon (Salmo salar). *Aquaculture*, 274 (2-4): 225-231.

Quinton, C. D., McMillan, I. & Glebe, B. D. (2005). Development of an Atlantic salmon (Salmo salar) genetic improvement program: Genetic parameters of harvest body weight and carcass quality traits estimated with animal models. *Aquaculture*, 247 (1-4): 211-217.

Rye, M. & Gjerde, B. (1996). Phenotypic and genetic parameters of body composition traits and flesh colour in Atlantic salmon, Salmo salar L. *Aquaculture Research*, 27 (2): 121-133.

Rørå, A. M. B., Mørkøre, T. & Einen, O. (2001). Primary processing (Evisceration and filleting). In Kestin, S. C. & Warriss, P. D. (eds) vol. 4. *Farmed fish quality*, pp. 249-260: Fishing news book Blackwell Oxford, UK

Rørå, B. A. M., Kvåle, A., Mørkøre, T., Rørvik, K.-A., Hallbjoørn, S., Thomassen, S. & Magny, S. (1998). Process yield, colour and sensory quality of smoked Atlantic salmon (Salmo salar) in relation to raw material characteristics. *Food Research International*, 31 (8): 601-609.

Salem, M., Yao, J., Rexroad, C. E., Kenney, P. B., Semmens, K., Killefer, J. & Nath, J. (2005). Characterization of calpastatin gene in fish: Its potential role in muscle growth and fillet quality. *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology*, 141 (4): 488-497.

SAS Institute Inc., C., N.C., USA.

Shearer, K. D., Åsgård, T., Andorsdòttir, G. & Aas, G. H. (1994). Whole body elemental and proximate composition of Atlantic salmon (Salmo salar) during the life cycle. *Journal of fish biology*, 44: 785-797.

Skjervold, P. O., Fjæra, S. O., Østby, P. B., Isaksson, T., Einen, O. & Taylor, R. (2001). Properties of salmon flesh from different locations on pre- and post-rigor fillets. *Aquaculture*, 201 (1-2): 91-106.

Stead, M. S. & Laird, L. M. (2001). *Handbook of salmon farming*, pp. 502. London.

Thodesen, J., Grisdale-Helland, B., Helland, S. J. & Gjerde, B. (1999). Feed intake, growth and feed utilization of offspring from wild and selected Atlantic salmon (*Salmo salar*). *Aquaculture*, 180 (3-4): 237-246.