Fillet yield, body composition and portioning of farmed Atlantic halibut (Hippoglossus hippoglossus)

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1 Contents

Abstract

The aim of the study was to estimate the fillet yield (before and after skinning) and proximal composition in farmed Atlantic halibut (Hippoglossus hippoglossus) as well as portioning the fillets and calculate their corresponding yields. This was performed not only to assess fillet yields but also as an early feasibility study to see whether portioning them could increase the value of the fillets. Fillet yield and body composition of Atlantic halibut was estimated from 12 fish in five different size categories harvested during winter (February 2013) and spring (April 2013). Four different methods where used to divide the fillets from winter harvested Atlantic halibut into two portions. The fillets of the spring harvested fish where cut into portions using two different methods. One method consisted of cutting out of the fillet a large, boneless and skinless portion that would have an even shape. Meanwhile, the remaining portions of the fillets where left large enough to be usable in making sashimi (Balanced method). The other method cut out an evenly shaped skinless, boneless portion that was as large as possible leaving the remaining pieces so small that they could only be used as cut-offs (MaxA method). The smaller portions from the balanced method were used to make sashimi. Two methods were used to cut the portions into sashimi, traditional and myotomal. The traditional method involved cutting long thin slices against the grain get the sashimi pieces. The myotomal method was performed by running the knife along the myosepta so that each sashimi piece consisted of mostly one myotome.

The highest fillet yield was in the largest fish (7-9kg) harvested in winter, 59±4% of gutted weight, (g.w), while the lowest yield came from the 4-5kg fish (50,6 % g.w.) that was harvested in spring. The lower yield in the smaller fish was at least partly explained by the proportionally larger head the smaller fish had (23,5±0,6% g.w.) when compared to the head size of larger fish (14,3±2,0 % g.w.). The fish harvested in winter had higher yields than fish harvested in spring (55,2± 0,3-58,8±3,5% g.w. and 50,6-55,0% g.w., respectively). Skinning the fillets decreased the yield by about 5-6% except in the 7-9kg spring harvested fish where the skin portion was a much higher (8,2% g.w.). The yield of the Dorsal right fillets was always highest and it was always lowest in the Ventral left fillet (15,5-16,8±2,4% g.w. and 8,6±0,41%-14,5±0,9% g.w., respectively).

The most successful method used to divide up the winter halibut fillets was subjectively cutting the fillets so that each part would be as evenly shaped as possible. The yields from these two portions were 18,1±3,0% g.w. and 9,8±2,5% g.w. for the dorsal fillets and 14,6±1,6% g.w and 4,5±1,1% g.w for the ventral fillets.

When the spring fillets halibuts were portioned, the Balanced method resulted in three distinct type of portions: (1) a large evenly shaped boneless skinless portion (25,2%-26,2% g.w.), (2) a smaller portion *suitable for making sashimi (9,3-9,8% g.w.), and (3) the remains of the fillets that could only be used as cut-offs (6,4-9,8% g.w) . The MaxA method produced a larger evenly shaped boneless, skinless portion (28,9±2,1-31,7% g.w.), but the remaining portions (12-12,09±1,2% g.w.) where only suitable for use as cut-offs. In the Balanced method the large boneless, skinless fillet was always smallest in the dorsal left fillet (4,4-8% g.w) and largest in the dorsal right fillet (8,3-11,6%). In the MaxA method the large boneless, skinless portion was smallest in the ventral left fillets (4,9±0,2% g.w.) and largest in the dorsal right fillets (10,4±0,1% g.w.)*

No significant differences in weight or dimensions were found between the sashimi cut traditionally or using the myotomal method. Large variation was found in the amount of sashimi pieces that could be obtained from each fillet (20,3±4,3), most likely due to the large size variations in the fillets.

The results in this study indicate that it could well be possible to increase the value of the fillets using portioning, especially in the 7-9kg fish that is harvested during winter, and that larger fish is expected to have higher yield.

1 Introduction

Atlantic halibut *(Hippoglossus hippoglossus)* is a highly sought after and commercially valuable food item. In recent years much work has been done to improve the farming of the species as wild stocks have dwindled due to overfishing (Hjörleifsson 2011, Bai 2005). Most of the research done has involved optimizing growth conditions and improving the aquaculture practises. To date very little work has been done in obtaining accurate yield assessments for farmed Atlantic halibut. Yield is of very high economic value as it indicates how large a portion of a fish is edible and can be sold at a premium price. Yield is also a measure of the cost effectiveness of the farming process as higher yields mean less waste during fish processing

The preference of the consumers has in recent years been shifting from large quantities and low prices to a higher quality and more expensive products that are also convenient to use. Aquaculture producers have become aware of this shift and are very interested in meeting this demand with new products. A boneless, skinless Atlantic halibut portion could be considered an ideal candidate for a new product as the fish has already a very good reputation as a high quality product. Thick and evenly shaped portions that are visually distinctive can be produced easily, due to the fishes' large size.

One of the main problems, when removing a high quality portion from a fillet, is that the remaining pieces have been drastically decreased in value, especially if they are classified as cut-offs. One way of addressing this problem is by using the remaining pieces to make other valuable products such as sashimi.

The aim of this research was to assess the fillet yield of farmed Atlantic halibut as well as their proximate composition. Furthermore the fillets were divided into large skinless, boneless portions and smaller portions that could be used as sashimi or cut-offs. The yield of each portion was then calculated.

2 Theory

2.1 Biology

The Atlantic Halibut is a commercially important flatfish species found in the North Atlantic Ocean. It is mostly known because it is a highly sought after food fish and members of the species can reach enormous sizes, up to 470 cm and 320 kg.

2.1.1 Taxonomy

The Atlantic Halibut is of the order *Pleuronectiformes.* Fish of that order are mostly found in a marine environment, occasionally brackish and rarely in freshwater. They are found in the Arctic-, Atlantic-, Indian- and Pacific Oceans. Both eyes are on the right side of the body as they lie on the bottom on their left side and the dorsal fins reach to the head. Mature fish do not have swimbladders. The left side of the fish is normally white while the right side is pigmented and able to change colours to match the bottom colouration. They mostly feed on benthic fishes and invertebrates and spawn in the pelagic region (Nelson 1994). *Pleuronectidae* are divided into the suborders *Solenoide* (soles) and *Pleuronectida (flounders)*. Of the two suborders, *pleuronectdae* are generally larger and more commercially important. It is to this suborder that Atlantic halibut belongs along with other commercially important species such as the Greenland halibut (*Reinhardtius hippoglossoides*), American plaice (*Hippoglossoides platessoides*) and the Winter flounder *(Pseudopleuronectes americanus)*.

The genus Hippoglossus contains only one other species besides the Atlantic halibut and that is the Pacific Halibut (*H. stenolepsis*). These two species are so similar in biology and morphology that prior to genetic markers there was debate whether to count them as one species or two (Trumble 1993). As is implied in the names, the Atlantic Halibut is found in the Atlantic Ocean while the Pacific Halibut is found in the Pacific Ocean.

2.1.2 Dispersion

The Atlantic Halibut, fig. 2.1., is a benthic fish mostly found in sandy- , clay- or gravelly bottoms. As a flatfish the fish spends a large amount of time at the bottom. It is found at depths of 20-2000m at temperatures of 1-15°C. Tag-recapture data has shown that the Atlantic Halibut undergoes long migration with the longest one recorded being 2500 km from Canada to the West coast of Iceland. During spring and summer the Atlantic Halibut keeps to shallow depths and then retreats to the depths during autumn and winter. The larger individuals are usually found in areas where the currents are strong (Jónsson 1991, Cargnelli 1999).

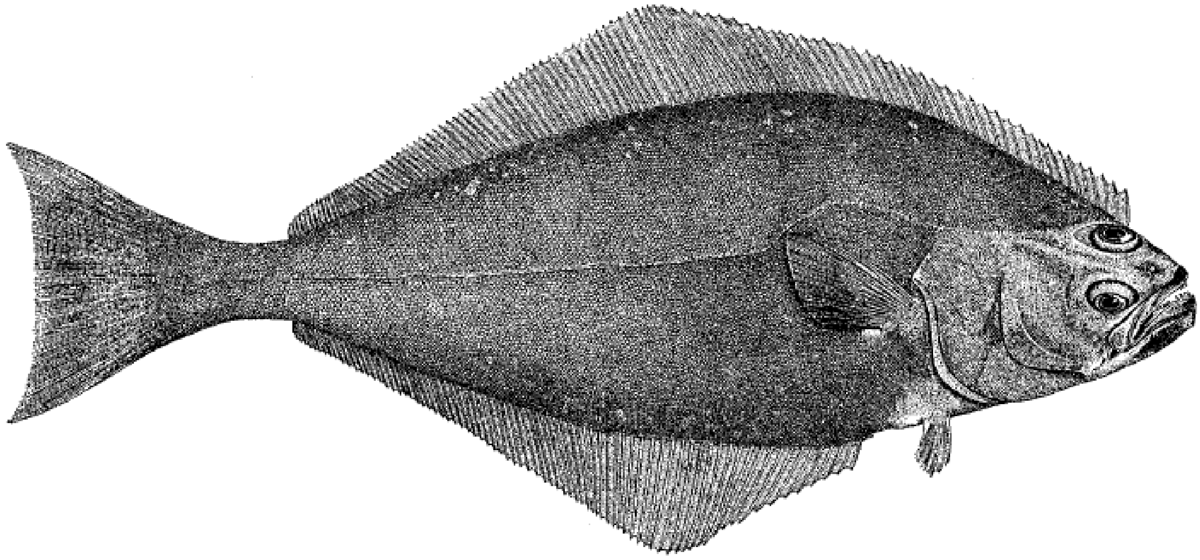

Figure 2.1. Atlantic halibut (*Hippoglossus Hippoglossus), from* Goode 1884.

2.1.3 Description

The Atlantic Halibut is elongated, oblong, with a large head and mouth that is filled with small but sharp teeth. The right side faces up. The mouth is slightly upturned. The eyes are small and protruding and the left eye is close to the lateral line on the head. The dorsal fin begins just front of the left eye while the anal fin begins adjacent to the pectoral fins. The pectoral fins are of average size while the ventral fin is small. The caudal fin is large and the tail broad and strong. Scales are small and the lateral line is evident and curves at the pectoral fins. The right side, which is darkly pigmented, has usually a uniform dark brown or black colour. The left side is white (Jónsson 1991).

2.1.4 Distribution

The Atlantic Halibut is found in the North Atlantic Ocean, Artic Ocean and the Barents Sea from Svalbard, Bear Island and Murmansk south along the Norwegian Coast and into the straits of Denmark. It is also found in the North Sea, English Channel and south into the Bay of Biscay and around the British Isles, Faroe Isles and Iceland. In the West North Atlantic it is found on both East- and West Greenland North into Disco bay. In North America it is found from the North around Labrador in Canada, South to Cape Cod in the USA (Jónsson 1991).

2.1.5 Life history

The eggs are very large and bathypelagic, suspended in the water column at depths from 50-700m. They incubate for 13-20 days at 4,7-7°C and the currents bring the eggs towards the coasts. During hatching 6,5-7 mm long fry emerge with a large yolk sac that provides them with nutrients until the fry start to feed when they are 4-6 weeks old. When the fry reach 16-20 mm size they start to metamorphose, acquiring the characteristic flatfish morphology, elongated body, left eye migration to the right side, etc. The metamorphosis is complete when the fish is between 3 and 5 cm long and then it settles fully to the bottom (Jónsson 1991). Sexual maturity is based on size, not age, with females maturing at larger sizes than the males. Males reach maturity when they have grown to 66-80 cm, when they are about 8 years old. The females do not reach sexual maturity until they are at least 105 cm, when they are between 7-12 years old (Cargnelli 1999). More recent studies have suggested that the onset of sexual maturation is more controlled by growth rates rather than age or size (Hagen 2008). Because of the large amount time Atlantic Halibut takes to mature, the minimum generation doubling time is 14 years (Musick et al. 2000).

2.2 Exploitation

2.2.1 Fisheries

Atlantic Halibut has long been an economically important species and has been overfished since the 19th century. In the in the early days of Halibut fisheries caught females weighed on average 50-75 kg and average caught males weighed as much as 25 kg. Today fish of these sizes are only rarely caught. The stocks have not recovered and show a steady decline. Stock recovery is not only hampered by the long doubling time, but also by a low level of recruitment in recent years (Hjörleifsson 2012). Currently there is no direct fishing of Atlantic Halibut within North-American or European waters and the fish is only caught as a by-catch (Brodziak 2006).

2.2.2 Farming

Norway has a very successful intensive salmon farming program. In the year 2003, 600.000 tonnes of Salmon were produced and exported all around the world, accounting for more than 80% of total production in Norwegian aquaculture. Farmed salmon *(Salmo salar)* has become one of Norway´s biggest exports and aquaculture is believed to still have a large growth potential. The industry is now trying to develop aquaculture so that it is based on more than one species (Bai 2005).

Atlantic halibut is one of the species in which a large amount of interest has been shown in Norwegian aquaculture since it a prized food item and wild stock have been depleted due to overfishing (Cargnelli 1999, Bai 2005). Wild caught Atlantic halibut can have large individual variation in regards to quality. Farmed fish in contrast will always be more homogenous since aquaculture is able to have control over factors that influence the quality of the product such as breeding, feeding and handling during storage.

2.3 Processing

2.3.1 Slaughtering

The adverse effects of slaughtering stressed fish have been well documented. Stressed fish become very active, leading to ATP depletion and lactic acid build-up. If the fish is slaughtered once the biochemical changes have occurred, the muscles will have an early onset of rigour mortis and the fillet will most likely have gaping Starving the fish before slaughter also helps to alleviate these problems as that lowers the glycogen levels in the fish (Borederísa 2011). Specific studies on the Atlantic halibut have linked low muscle pH at slaughter and other adverse effects such as discoloration in the flesh (Roth 2009) and lower water-holding capacity (Olsson 2003).

2.3.2 Filleting

Filleting fish is usually done do meet the demands of the consumer and thereby increasing the value of the fish. This is usually performed using commercial filleting machines. Trimming Atlantic halibut fillets is revolves mostly about removing the notches as well as any visible fat and skin and bones. Different trim and filleting methods give different yields but other important factors are e.g. species, size and farming conditions such as water temperature and feed (Borderísa 2011). Of other species of farmed fish, Tilapia has the lowest fillet yield of about 33% while freshwater eel (*Anguillidae sp.*) has the highest fillet yield (60%). Salmon has fillet yields of more than 50% (Borderísa 2011). Yield is of enormous economic importance and closely linked to cost effectiveness. Small changes in yield % can drastically change the profitability of an operation.

2.3.2.1 Traditional cuts of Atlantic halibut

For the convenience of the consumer, fish is often cut up into pieces as they are intended to be cooked. Flat fish has four fillets sometimes called fletches. These can either be sold whole or further cut up into smaller portions. Escalopes are large skinless fillets and are often cut at angle towards the tail giving a thick slice. Suprêmes are a prized cut and sometimes called steaks they are boneless portions cut from large thick skinless fillets, basically thicker escalopes. Pavés, also known as roasts, are taken from large fish by cutting in half through the bone and then each half is cut into smaller portions. Tronçon are made by cutting the flatfish into portions through the bone. (www.chefpedia.org and www.mjseafood.com). The different types of cuts can be seen on fig. 2.2.

Figure 2.2. Different types of halibut cuts based on pacific halibut. 1) Fillets/fletches. 2) Tronçon 3) Pavés. 4) Cheeks. 5) Escalopes 6) Roast. 7) Split roasts. (Modified from http://northpacificseafoods.com).

2.3.2.2 Sashimi

Sashimi is a Japanese dish where very fresh meat or fish is cut into thin slices and then consumed raw. Only high quality cuts are considered fit for sashimi and they are usually prepared by cutting the fillets into thin slices at a 45°angel. If the fish flesh has a loose structure the cut is crosswise to the grains, e.g. salmon and tuna, but if the flesh has a firmer texture cutting at an angle can give the pieces a wavy pattern. In recent years, Japanese cuisine, with its focus on delicate tastes and textures, has been raised in prominence, especially in regards to sushi and, to a lesser extent, sashimi. The most popular seafood item in regards to sushi and sashimi in Northern Europe is salmon due to its fatty texture and distinctive red appearance. In north European markets, producers have focused on increasing the quality of sushi and sashimi products, and also increasing the shelf-life of these products without sacrificing quality. Today the sushi market for other types of fish, aside from salmon, is still small (Ryeng 2012).

2.3.3 Storage

Fish is considered spoiled once it has developed a bad odour or flavour, which is caused by microbial activity, autolytic enzymes and certain chemical reactions. The main chemical changes responsible for a shortened storage time are lipid oxidation, lipid hydrolysis, proteins denaturing and the breakdown of trimethylamine oxide (TMAO) into trimethylamine (TMA). TMA is the main odour compound responsible for the “fishy” smell characterizing spoiled fish. Lowering of quality will also happen if the fish is physically damaged, dehydrated or exposed to contaminants. As a general rule proper control of temperature is the single most important aspect in conserving the quality of fish (Hall 1997).

Preserving the quality of fish and shellfish has its own set of challenges not faced during the processing other types of meat such as mammals or poultry, for example only fish and shellfish contain TMAO. Seafood has proportionally much higher amounts of unsaturated fatty acids, especially omega-3 fatty acids. Fish is also much lower in carbohydrates than land animals resulting in higher carcass pH (around pH 6,0). Together these factors mean that fish carcasses will become rancid quickly and are moist environments with almost neutral pH value, making them ideal for the growth of spoilage bacteria and pathogens. Further exacerbating the problem is the high amount of non-protein nitrogen within fish that micro-organisms can use for growth. The other major challenge with preserving the quality of fish is their poikilothermic nature. Because of that, the enzymes in cold water fish like the Atlantic halibut have adapted to function at very low temperatures, even close to zero degrees Celsius, so that autolytic processes will continue even when stored in cold conditions (Sen 2002, Hall 1997).

Farmed Atlantic halibut is, however, well suited for long storage on ice (0°C). Studies using the quality index method have shown that quality characteristics decreased during the first eight days of on ice storage. After the eighth day, no significant changes occurred in regards to texture, liquid-holding capacity or colour until the experiment ended after 26 days of storage (Guillerm-Regost 2006). By using modified air packaging, off-odour analysis (smelling for TMA) has shown storage times of at least 28 days (Rotabakka 2008). The reason for this long storage time observed in the Atlantic halibut is not fully known. Research has shown that by controlling the fat content of the diet given to Atlantic halibuts in different size catergories, changes in the sensory estimates of freshness/rancidity could be achieved. Fish that were fed high fat diets and had reached at least 2 kg scored highest on freshness while small fish on high fat diets or large fish on lean diets scored highest on rancidity (Nordvedt 1998).

2.4 Anatomy and physiology of Atlantic halibut relevant to quality

2.4.1 Blood circulation system

The blood circulation and gas exchange system of the Atlantic halibut is compatible with other teleosts in that the heart pumps blood to the gills and there the blood takes up oxygen from the sea. The aerated blood distributes into the small capillaries where oxygen and nutrients flow from the blood to the surrounding tissue. The blood then flows to the intestines where nutrients are absorbed from digested food. The nutrients are transported via the circulatory system to the liver and later throughout the body. In the kidneys, the blood is filtered and waste products removed (Helfman 2009). Rough handling of the fish and certain methods such as electrical stunning can cause blood vessels to rupture so that blood spots form on the fillets giving them a visible defect. During the slaughtering process, as much blood as possible should be removed from the carcass to not only reduce blood spotting but also to minimize off-flavours that the blood can induce in the flesh (Robb 2002).

2.4.2 Guts

During processing the fish must be gutted and carefully washed. This is mainly done to prevent autolytic spoilage rather than bacterial spoilage (Borderísa 2011). The guts in particular contain digestive protolytic enzymes that can cause extensive damage to the flesh. These proteases have optimal pH at alkaline and neutral ranges (Ghaly 2010) and are able to operate at very low temperatures since the Atlantic halibut is poikilothermic and well adapted to living in cold conditions (Sen 2002, Hall 1997). More recent studies into the digestive enzymes of the closely related Pacific halibut confirm that the enzymes not only operate at low temperatures but they actually have optimal activity at lower temperatures than enzymes in fish from warmer areas. As predators, they furthermore, have higher levels of proteinase activity than plankton feeding flatfish found in the same area, i.e. starry flounder *(Platichthys stellatus)* (Korostelev 2005).

2.4.3 Muscles

Most fish, like the halibut, move by oscillating their body and/or tail. This is either done at cruising speeds, using economical movements often over long periods of time, or in short dramatic burst, usually to escape or catch prey (Helfman 2009). Atlantic halibut swims by oscillating its body and tail so that it forms a half-sinus wave, followed by a short gliding phase before it starts oscillating its body again. Most flatfishes utilize this swimming method. When swimming in short bursts, the Atlantic halibut increases its oscillation rate and amplitude.

To account for the two types of locomotion, all fish have developed two different sets of muscle systems, each with different fibre types, red and white. There is also an intermediary muscle type, sometimes called pink muscle (Helfman 2009).

The red muscle, also called slow muscle, is situated close to the lateral line and used when the fish is cruising. The much larger white muscle, also called fast muscle, allows the fish to exert a lot of energy over a short period of time. The slow red muscles have higher lipid content than the white muscles (Cabballero 2003). These two types of muscles have different enzymes acting within them and use different metabolic pathways. The muscle fibres in the slow muscles have furthermore about a 20-50% smaller diameter. The enzymes and metabolic pathways in red, slow muscles are based on aerobic functions while the enzymes and metabolic pathways in the white, fast muscles are based on anaerobic functions (Bones 2009).

2.4.3.1 *Red muscles*

The red muscle is usually situated near the lateral line on each side of the fish and is found right under the skin as a thin sheet, fig. 2.3. Its main function is to move the fish during sustained swimming at cruising speeds. These muscles get their name from the myoglobin found in the muscle fibres and the extensive network of blood vessels they possess. The high degree of vascularization and abundant myoglobin ensures that the muscles have ample access to oxygen and the mitochondria are large and generate energy using aerobic processes. During exertion the ample oxygen and large mitochondria make sure that the muscles do not tire easily and prevent build-up of lactic acid. In general the red muscle fibres have smaller diameters than white muscles, 18-75 µm (Helfman 2009). The red muscles are most developed in fish species that frequently have long periods of sustained swimming such as the yellowfin tuna (*Thunnus albacores) (*Sánchez-Zapata 2011).

The red muscles are edible but are not considered suited for human consumption because they have a strong taste. They therefore have little commercial value. The reason for the strong taste in the red muscles is because they generally have a higher fat content than the white muscles and it is when these lipids oxidase that the strong taste develops. The oxygen bound in the myoglobin and the type of mitochondria found in the red muscles, increase oxidation rates leading to an even stronger taste (Hui 2007, Huss 1995).

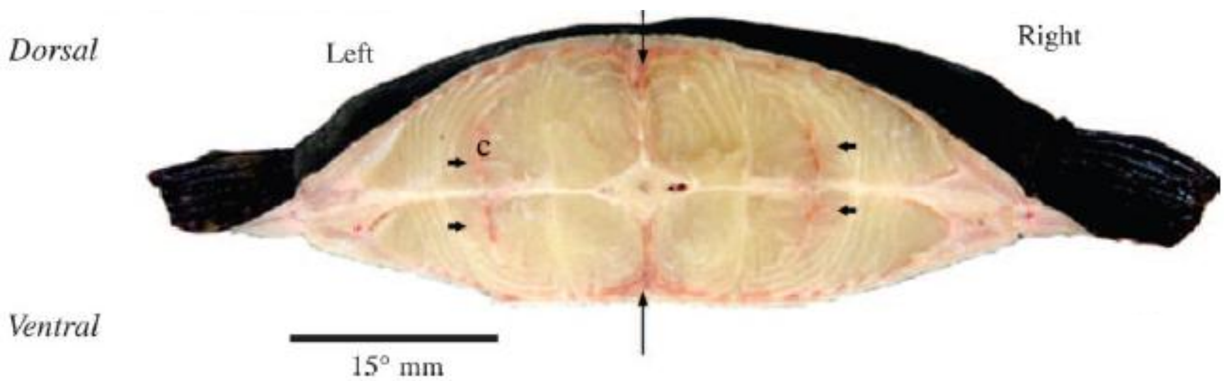

Figure 2.3. Distribution of red muscle in a transection of Atlantic halibut indicated by arrows. Found in the horizontal septum and inner strips. (modified from Haug 2008).

2.4.3.2 *White muscles*

The white muscles are so named because they have about three times less vascular structure than red muscles and they do not contain myoglobin. This also means that their oxygen supply is limited, making them only capable of sustaining short burst of speed before they tire. The fibres in the white muscles have a diameter that is much larger than in red muscles as they can reach up to 300 µm. The mitochondria in the white muscles are fewer and smaller than the ones found in the red muscles and are mainly involved in anaerobic metabolism. When the muscles are used, the oxygen and glycogen in the muscles dwindles very fast so that lactic acid builds up. The muscles take a long time to recover after a strenuous exertion and it can take as long as 12 hours for the lactate levels to drop to their pre-exertion levels (Helfman 2009). The white muscles form the biggest part of the body in most fish species and are what fish fillets are actually comprised of (Murray 1983).

2.4.3.3 Intermediate muscle

The intermediate muscles or pink muscles are found in the thin zone where the red and white muscles meet. They are not only called intermediate muscles because of their positioning but also due to their function. These muscles are able to contract their muscle fibres swiftly and have stamina and shortening speeds somewhere in between those of red and white muscles (Kiessling 2006).

2.4.4 Muscular structure

The Atlantic halibut swims by oscillating its body from the tail to the head. This is achieved by contrasting segmented muscles that surround the vertebrae. Each of these muscle segments is called a myomer and they are separated by fatty connective tissues called myosepta or myocommata. The myomers are attached to the collagenous septa that in turn are connected to the skin and backbones. When myomers on one side of the body contract and shorten, they pull on the vertebra and skin, causing the fish body to bend since the vertebrae does not compress. By contracting the muscles on one side of the body and relaxing them on the other the Atlantic halibut is able to swim (Helfman 2009).

The vertebra in most fishes is placed dorsally so that the majority of each myomer lies below the vertebrae column. If the myomers were straight the fish would simply bend over at the ends when the muscles contracted. To prevent this, Atlantic halibut, along with all other teleost fishes, form the myomers into a complex three-dimensional w-shaped structure that folds and overlaps with other myomer segments, fig. 2.4. (Bone 2008).

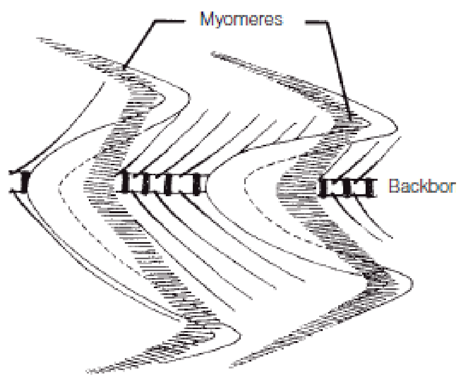

Figure 2.4. Two-dimensional picture of myomers in relation to the backbone in trout (*Salmo trutta*). (Bone 2008)

The internal structure of the myomers is also quite complex in regards to the muscle fibres they contain. In all except the most primitive of fishes, only the outermost fibres in the myotomes , that is those just under the skin, are arranged parallel to the backbone as one would expect. The rest of the fibres i.e. the ones that are found more inwardly form a spiral helix-like structure and can have angles from 30-40° in relation to the vertebrae, fig. 2.5. (Bone 2008, Hagen 2008)

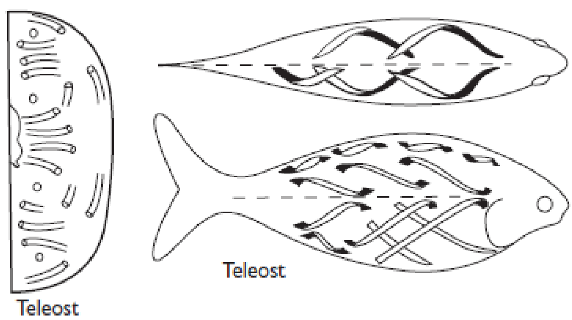

Figure 2.5. Left: a transverse section of myotomal muscle fibre bundles. Right: the helical structure formed by muscle fibres in successive myotomes along the body, shown both laterally and dorsally (Bone 2008).

The muscle fibres are 2-17 mm long and are packed together into bundles forming the macro structure of the myomer. The muscle fibre can be further divided into myofibrils. The myofibrils are formed from segments of sacromeres that are made out of myosin and actin units. Contraction of the bands within the actin and myosin units is the reasons muscles contract during exertion. The bands can vary in size and shape, figure 2.6 (Hagen 2008 and Bone 2008). Muscle fibre diameter has been measured in white muscle samples taken from throughout the body of Atlantic halibuts. The results showed that there is no significant difference in the size distribution of the muscle fibre diameter throughout the fillets (Hagen 2008a). This finding is quite interesting in light of the right/left asymmetry that has been observed in the Atlantic halibut in regards to both composition and morphology (Nordvedt 1998, Bone 2008, Hagen 2008, Hagen 2008a, Kiesseling 2006).

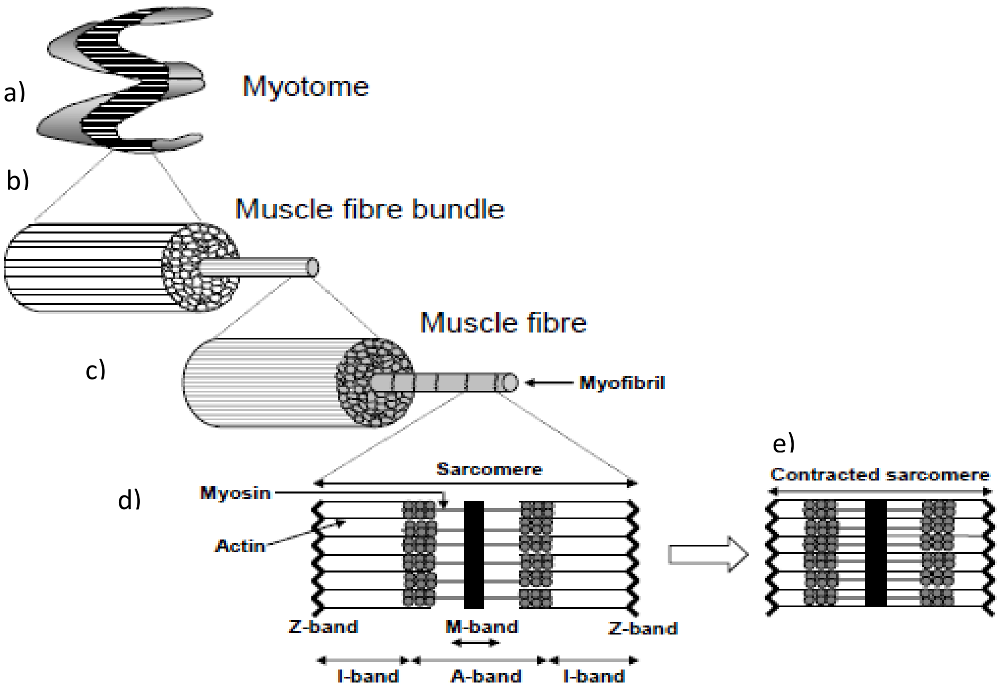

Figure 2.6. Structure of muscle fibres within a myotome: a) a myotome in the muscle, b) a bundle of muscle fibre within a myotome, c) an individual muscle fibre, d) structure of the main structural units within a sarcomere such as the Z, I, A and M-bands, actin and myosin, e) sarcomere that has contracted (Hagen 2008)

2.5 Composition

2.5.1 Protein

The parts of the fish that is usually eaten are the locomotion muscles. Theses muscles in fish have a similar structure as in other vertebrates but in fish they are a much larger proportion of total body weight (40-60%) (Helfman 2009).

Since about 20% of uncooked fish fillets are proteins they are the major source of energy in fish (Cabballero 2003), table2.1. Fish proteins also contain much lower amounts of collagen than mammals and poultry (Hagen 2008) and that is partly responsible for how digestible fish proteins are, but they have a digestive coefficient of almost 100 (Cabballero 2003).

Table 2.1. Food protein energy as a percentage of total food energy in selected fish and meats (Cabballero 2003).

Food Protein energy	%
Atlantic Halibut (Hippoglossus hippoglossus)	66
Cod fillet (Gadus callarias)	95
Albacore (Seriola lalandi)	90
Haddock (Melanogrammus aeglefinus)	96
Sole (Solea vulgaris)	85
Flounder (Pleuronectes flesus)	95
Herring (Clupea harengus), an oily fish	41,5
Chicken (white meat)	76
Lean beef	69
Medium-fat beef (cooked)	27,4

2.5.2 Lipids

Fish as food items are often divided into two broad categories: white fish or oily fish. White fish store their energy reserves mostly in the liver while red fish store their extra energy mostly in the connective tissue throughout the muscles segments. Halibut is considered a semi-fat white fish so that some lipids are stored in the connective tissue while most of them are stored in the liver (Murray 1983). This means that the fat content in a typical farmed Atlantic halibut fillet is more compatible with lean beef than a white fish like cod (*Gadus morhua*) or an oily fish like salmon *(Salmo salar)*. The fatty acid composition of the Atlantic halibut is, however, more beneficial to health than the fatty acids in lean beef, especially in regards to the amounts of omega-3 fatty acids, table 2.2.

Table 2.2. Amounts of fats and fatty acids in cod, Atlantic halibut and Atlantic salmon. The values are based on raw fillets. (Based on USDA 2013.)

Fats and fatty acids	Cod	Atlantic halibut	Atlantic salmon	Lean beef
Amounts per 100 g.				
Total Fat	0,7 g	2,3 g	13,4 g	5,9 g
Saturated Fat	0,1 g	0,3 g	3,0 g	1,7 g
Monosaturated Fat	0,1 g	0,7 g	3,9 g	2,5 g
Polyunsaturated Fat	0,2 g	0,7 g	3,9 g	0,2 g
Total trans fatty acids	-	-	-	-
Total trans-monoenoic fatty acids	-	-	-	-
Total Omega-3 fatty acids	195 mg	522 mg	2506 mg	20,0 mg
Total Omega-6 fatty acids	5,0 mg	30,0 mg	982 mg	187 mg

A large amount of the muscle fat in Atlantic halibut is found in the gel-like tissue called notches and is at the base of the dorsal and ventral fins. On average, the fat content in the fillets ranges from 3-7%

of the total wet weight (w.w.) while the fat content in the notches averages at about 46% w.w. and has an even higher fat percentage than the liver (24% w.w.) (Nortvedt 1998, Olsson 2003). It should be noted that the notches are only a very small part of the total weight of the fish while the liver comprises a much larger part. Therefore, the total fat content in the liver is much higher than in the notches despite the liver having a lower fat percentage.

When compared to lean white fish like cod or haddock (Melanogrammus aeglefinus), the lipids found in the muscles of Atlantic halibut are mostly neutral lipids (around 84%) while the muscle lipids in cod and haddock are more or less phospholipids, about 88% and 91% respectively (Duan 2010).

Neutral lipids in Atlantic halibut are mostly triacylglycerol and 18:1 is the most common type of fatty acid found in them. Of the fatty acids with polar groups, the most common types are the omega-3 fatty acids 20:5 and 22:6 (Haug 1988).

2.5.3 Effect of feed composition on farmed Atlantic halibut

Since farming of Atlantic halibut has become more common in recent years, issues of feed and how it affects the composition of Atlantic halibut fillets have been the focus of much research.

Some research has shown that at long as the feed fulfils the nutrient requirements of the Atlantic halibut, different feed compositions have very little effect on the final composition of the fillets. No significant changes have been found in fishes fed with different dietary regimes in regards to fatty acid composition, protein digestibility or muscle composition (Suontama 2007, Berg 1991). Other research has linked increased fat content in the feed with increased fat content in the fillets (Nordvedt 1998).

2.5.4 Lipid distribution

Nordvedt 1998, divided the Atlantic halibut into portions A, B, C…I, fig. 2.7. The H and I fillets are the notches found in Atlantic halibut and are a part of the fish that is not normally eaten. G fillet is part of the head while F fillet is the thin stomach and these parts are often not considered edible. Among the main fillets (A, B, C, D, E and F) the lowest fat content found was in the E fillet, 1,9±0,8% w.w., and the highest was in fillet B, 7,1±2,1%w.w.. Fillet A, the largest fillet, was approx 12% of w.w. and had 4,1±1,5% w.w. fat content. Among the other parts the nothces had by far the highest fat content, more than 45% w.w., while the I fillet, the head, had 11,5±3,4% w.w. fat. The right side fillets had 33,3±16,5% higher fat content than the left side (Nordvedt 1998), table 2.3.

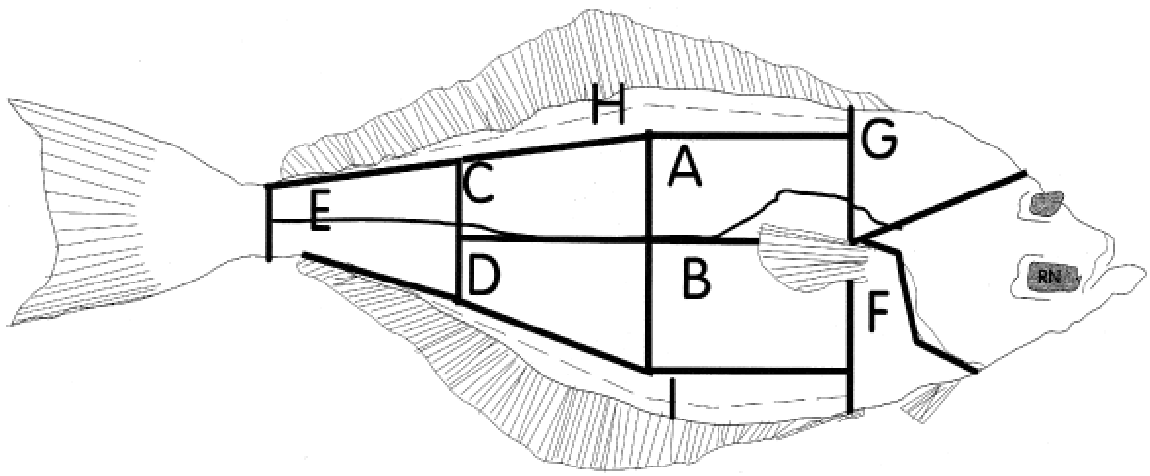

Figure 2.7. Fillet cuts A, B, C…I in the Atlantic halibut. The dashed lines within the H and I fillets indicate the base of the fin rays (Nordvedt 1998).

Table 2.3. Mean fat content in Atlantic halibut fillets with 95% confidence interval. Fat content based of wet weight (modified from Norvedt 1998).

Fillet	Fat content %
A	4,1±1,5
B	7,1±2,1
C	3,2±1,7
D	3,2±1,4
E	1,9±0,8
F	11,5±3,4
G	5,5±3,1
H	46,7±5,1
I	45,2±5,9

In farmed Atlantic halibut no seasonality has been observed in lipid content and composition, while wild Atlantic halibut has higher fat content during the summer months (May-August) (Olsson 2003b).

2.5.5 Water

Water is the main component of the fast muscle in fish and white fish usually have higher water content than red fish (Murray 1983). In the Atlantic halibut, water constitutes 74,5±7,63% w.w. of fresh fillets. Their moisture content is lower than in leaner types of white fish such as cod (80,2±1,08% w.w) and Saithe *(Pollachius virens)* (78.99±1.05% w.w.) but higher than in fattier fish such as herring *(Clupea harengus)* 67,44±2,20 % w.w.) and mackerel *(Scomber japonicus)* (63,84±3,57% w.w.) (ElMasry 2008).

2.5.6 Carbohydrates

As with other types of white fish the amount of carbohydrates in the fillets are almost insignificant. The USDA, for example, lists raw Atlantic halibut fillets as containing 0% carbohydrates (Murray 1983, USDA 2008).

2.5.7 Connective tissue

The different muscle segments, the myomers, are separated by connective tissue called myosepta if they are horizontal and myocommata if they are transversal. The myosepta are found in straight lines while the myocommata are set out in w-like formation (Belitz 2009), fig. 2.8.

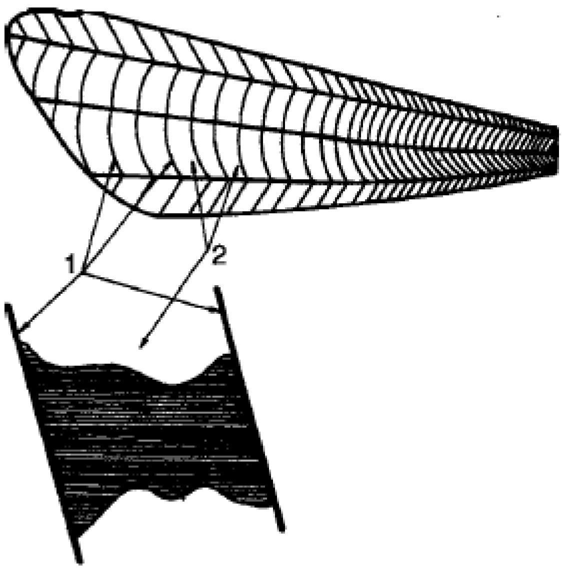

Figure 2.8. Connective tissue structure in fish fillets. 1) Myosepta/myocommata, 2) myomers. (modified Berlitz 2009).

Each myosepta/myocommata consists of a network of interconnected and overlapping collagen fibres that can be deformed but not elongated when the fish is in motion. The outer ends of the myocomata are connected to the connective tissue in the skin while the inner borders are connected to the vertebrae. The main role of the myosepta/myocommata, is generally considered being, to reduce the flexibility of the fish body and only allowing lateral body movements (Bone 2008).

Many types of collagen types exist and at least 27 have been identified. They have in total 42 different R chains and more than 20 types of proteins that have collagen-like domains, are known (Li 2005). In fish muscles, collagen I is the main component of the connective tissue and collagen V is also present as a minor component (Hagen 2008). Collagen fibres in fish are much shorter than in mammals and are destroyed at much lower temperatures (Belitz 2009) and they start to denaturalize into gelatine at 30°C (Hagen 2008). In fish, collagen constitutes a much lower percentage of total protein content in the body when compared to mammals. The collagen percentage of total protein content is usually about 2-5% while in mammals it is commonly 20-30% (Hagen 2008). As mammals and fish age, the amount of cross-links in collagen increase and cross-links between the collagen become more thermo-stable. This leads to tougher flesh that needs more cooking time for the collagen to dissolve (Hagen 2008, Cabballero 2003).

2.5.8 Growth

Fish growth is dependent on a large variety of factors. While growth is mostly controlled by the function and secretion of growth hormones, other variables are also very important such as water temperature, amounts of dissolved oxygen, salinity and photoperiods (Kiesseling 2006). All these variables and their interactions influence the growth rate of the fish along with other factors such as quality and quantity of available food, competition levels and the age and sexual maturity of the fish (Kiesseling 2006).

In aquaculture, growth is an important factor when estimating the health of farmed fish and the economic viability of the farm. If the fish is growing at a fast rate it indicates that the fish is well fed and healthy. Conversely, if growth rate of the fish is slow that could indicate that the fish is not in good health and/or feeding poorly. Growth is measured by changes in weight, length and length/weight relationships over time. Growth rates in male and female Atlantic halibuts are about the same until they are 6 years old when the males start to undergo sexual maturity and their growth rate decreases (Hagen 2008a).

Once teleost fish have hatched, growth takes place by two mechanisms: hyperplasia and hypertrophy. Hyperplasia is the addition of new fibres, increasing the number of fibres, while hypertrophy is the growth of the existing fibres, increasing the fibre diameter. Muscle fibres have a limit to how large their diameter can become based on the diffusion of oxygen and metabolic diffusion (Bone 2008, Hagen 2008a). This means that when a fish has reached a certain size, muscle tissue can only continue to grow by adding fibres. In teleosts, new muscle fibres are formed well into adulthood until the fish has reached a certain size. When the recruitment of new muscle fibres is switched off depends on the ultimate size of the fish. So that a fish that has a small final size stops recruiting new muscle fibres at a smaller size than a fish that has a larger final size (Kiessling, 2006 Hagen 2008).

For the Atlantic halibut this means that an individual that is 200g has about 32.000 muscle fibres while an individual that is 96kg has c.a. 1,7 million muscle fibres. It also means that the females continue recruiting new muscle fibres at larger sizes than the males due to their final size being much larger (Hagen 2008a).

2.6 Biological factors influencing quality

There are of course a vast number of factors that influence the fillet quality such as rearing conditions, types of feed, proper handling, fish stress during slaughter, proper storage of fillet and so on and so forth. Most of the post mortem changes in the fillets that influence quality are caused by have enzymatic activity and pH value of the fillets.

2.6.1 Texture

Because of the delicate taste of fish, texture is a key factor when determining the quality of fish fillets. What texture a fish has is influenced by many factors. Intensive feeding, stress and improper slaughtering methods can lead to a lowering of pH. This causes protein denaturation and loss of firmness (Biorderísa 2011, Olsson 2003). Trained panels have found that increased fat content in Atlantic halibut fillets lead to juicer texture along with other positive sensory attributes (Nordvedt 1998). The myofibril structure in the white muscle is also considered to be of special importance along with the connective tissue. This is understandable since fish fillets are almost entirely white muscles with the connective tissues forming a supporting network throughout the muscle (Kiesseling 2006).

The diameter of the muscle fibre has been linked to the firmness of cooked flesh. Studies have shown that by serving different species of cooked fish, each with a different fibre diameter, to a trained panel a negative correlation has been found between firmness and muscle fibre diameter So that the dab *(Limanda limanda)* that had the smallest average muscle fibre diameter and scored highest on firmness while flying fish (*Exocotidae.sp*) had the largest muscle fibre in regards to diameter and scored lowest in regards to firmness (Hurling 1996).

Increased muscle fibre density has been shown to increase the firmness in fish flesh of fresh and smoked salmon (Johnston 2000). These findings seem to be at odds with what is known about Atlantic halibuts. Females of the species have higher muscle fibre density before sexual maturation representing their larger final size (Hagen 2008a) but despite that no significant difference in texture variation has been found between males and females (Hagen 2007).

The connective tissue in fish is weak so that it breaks down into gelatine at 30°C (Hagen 2008) and is therefore not expected to have an impact on texture in cooked fish. The same cannot be said about raw fish. During storage the amount of collagen decreases. This is thought to be a caused by cross-links between the collagens breaking down, most likely because of proteinase activity (Hagen 2008).

Collagen I and collagen V are the most common collagens found in fish muscle and are connected with hydroxylysyl pyridinoline (PYD) cross-links. Studies have found that the concentration of these cross-links explain 25% of the variation found in muscle firmness in raw salmon *(Salmo salar)* (Li 2005). In Atlantic halibuts the PYD cross-links have a large impact in the firmness of fillets and explained 64% of texture variation found (Hagen 2007). The same study reported an increase in PYD cross-link concentrations during the winter when protein levels drop due to less intensive feeding so that in spring PYD cross links had increased by as much as 70%. This increase was most pronounced in males.

2.6.2 Gaping

Gaping in fillets is a serious and well-known problem that has detrimental effects on quality. It is defined as tears and splits in the fillets that can be slim separation at the surface of the fillets up to complete separation all the way to the skins of the fillet. The appearance of fillets that have gaping is considered defective leading to a meaningful decrease in market value. Skinning these fillets is very difficult or impossible. It is caused by the myocommata not any longer holding together the myotomal muscle (Hagen 2008). The best ways of preventing gaping is proper handling during the slaughtering process and using correct temperature during storage (Borderísa 2011). Flatfish has been shown to gape less than other common types of food fish like salmon and cod. Muscle fibre density, which is influenced by muscle fibre diameter, has been shown to have an effect on gaping in salmon. Of the salmon tested the, ones that had muscle fibre density of more than 95/mm, showed little or no gaping (Hagen 2008).

2.6.3 Water-holding capacity

A good indicator for describing changes in fillet quality is water-holding capacity (WHC) it measures how well the muscles in the fillet are able to retain the water found within them. When the fish fillets are fresh, the water is bound to the proteins in the muscular structure. Storing the fillets by either cooling or freezing, results in structural changes so that the proteins lose their ability to retain all the water and some of it is lost from the fillets (liquid loss) (Murray 1983). The structural changes that have been linked to a decrease in WHC are shrinkage of the myofilamet lattice and myosin denaturation. So that lowering of WHC will not only lead to a drier product but to a loss in firmness due to the protein denaturation (Olsson 2003, Olsson 2003a). During storage, collagen concentrations in the fillets have been found to decrease and this decrease has been positively correlated with lowering of WHC in fish (Suarez Mahecha 2007).

Research into structural changes and WHC of Atlantic halibut showed that low pH had negative effects on the WHC (Olsson 2003a, Olsson 2003b). When pH < 6,3 liquid loss increased as the pH got lower. In fillets where pH > 6,3 no connection has been found between pH and liquid loss (Olsson 2003b). Farmed Atlantic halibut harvested between July and August had lower pH values than fish harvested during other times of the year. This corresponds with increase feeding by the fish due to longer light cycles and higher ambient temperatures as these factors have been shown to increase appetite in fish. More intense feeding leads to higher glycogen levels in the fish that then leads to lower pH in the fillets (Olsson 2003b). More recent studies have refuted these findings and have found no seasonal variation in white muscle pH in Atlantic halibuts (Hagen 2007).

During storage on ice Atlantic halibut fillets showed increasing liquid loss rates for the first eight days of storage and after eight days liquid loss consistently lowered until the end of the experiment after 18 days. The reason for this decrease in liquid loss is as of yet not fully understood. Authors speculated that bacterial growth lead to an increase in pH and therefore a decrease in liquid loss. Further experiments in the same study refuted this hypothesis (Olsson 2003a). It is of note that basic drying theory was not discussed that is how liquid loss decreases as products become drier (Ibaraz 2003).

2.6.4 Colour

The colour of fish fillets is a very important factor that consumers use as a quality indicator. It is even more important today than before since most of the fish bought in stores is in sealed packages and/or frozen, limiting the ways consumers have to estimate the quality of fish fillets. Even where fish is stored openly on ice, such as at the fishmonger, glass separates the consumer from the product so that only visual cues can be used.

The colour of fresh flatfish fillets is white and as time passes then change from an opaque, bluish cream colour to a milkier yellow colour. There are many factors that can influence the colour of fish flesh such as blood that was not drained and slaughter conditions (Borderísa 2011). The fat content, lipid oxidation, and storage conditions are well known contributors to colour (Guillerm-Regost 2006). Low final pH values in Atlantic halibut fillets also increase discolouration and decreasing the glycogen level in the fish using starvation before slaughtering helps to increase the pH values and improve the colour (Roth 2009).

3 Materials and methods

3.1 Fish

A total of 12 Atlantic halibut were supplied to us by Aga Halibut AS. The fish was slaughtered, gutted and cleaned on Wednesday, at the Aga Halibut facilities just outside Dønna, Norway and filleted and cut the following Monday and Tuesday at UMB, Ås, Norway so that it was stored for no more than five or six days before it was cut. All of the halibut where stored in Styrofoam boxes with ice so that the temperature inside the boxes was 0°C. The boxes where at all times stored at 4°C except when they were being flown to Oslo from Bergen and later when driven from Oslo to UMB in Ås. The fish was sent in two batches of six fishes each and had been divided up into predetermined size categories by the producer. The first batch arrived during winter (early Feb. 2013) and was divided into two categories (5,5-6,5kg and 7-9kg) with three fish in each category. In spring (late April 2013) the second batch arrived and contained six fish in four categories, three 2-3,5 kg fish and one in each of the following categories: 4-5kg, 6-7kg and 7-9kg. The flesh of some the fish received showed considerable gaping, especially the spring batch, and in general larger fish showed more gaping than smaller ones. The colour of the flesh was also not the opaque bluish-white colour normally associated with fresh fish but had more of a milky-white colour usually found in Atlantic halibut that has been stored for some time and lost its freshness. It was decided to treat the results from each batch as different experiments because of the difference observed in the condition of the winter/spring fish and because the producer had divided them into overlapping size categories.

3.2 Measuring the fish

For both batches, all the fish was weighed. Length, width and height were also measured to the closest centimetre. The fish fillets where weighed both before and after skinning to calculate the amount of skin and each portion was individually weighed. Trim percentage was calculated on weight differences between the skinned fillets and trimmed fillets. All weight measurements were done to the closest gram.

3.3 Filleting of the fish and portioning

All twelve fish where filleted into four fillets and skinned. The remaining carcass was then divided up into head, vertebra, notches and cheek (cut only from the left side), fig. 3.1. The skin from the filleting and the rest of the filleted carcass were defined together as waste. Based on the naming system proposed by this thesis (see chapter 4.1. Defining fillets) the four fillets where divided up into four types: Dorsal left (DL), Dorsal right (DL), Ventral left (VL) and Ventral right (VR).

The fillets from the fish that was harvested in winter where divided into two portions using four different methods: a) having each half as similar in size an appearance to the other one as possible (even cut), b) dividing up the fillets according to where the myotomal patterns observed in the fillets meet (muscle line), see below for clarification on the myotomal pattern c) Objectively dividing the fillets up into portions that where of different size but had even outlines (upper/lower), d) cutting the fillets up so that one portion was as large as possible while having somewhat even outlines while the other portion was quite small.

The fillets from the fish obtained in spring where trimmed before being further subdivided using two methods: a) try to get either as large bone- and skinless cut as possible while leaving enough of the fillets to be able to easily cut out sashimi pieces (Balanced) or b) get as large bone- and skinless cut as possible (MaxA), not taking into account the appearance or yield of the remaining pieces.

Figure 3.1. Top row, from left: Head, cheek. Bottom row, from left: Ventral left fillet, ventral right fillet, notch, vertebrae, notch, dorsal right fillet, dorsal left fillet.

In each fillet the myotomal structure forms two distinct patters in the muscle, one is found close to the vertebrae while the other is closer to the dorsal or ventral sides. The balanced portioning, fig. 3.2.a, was made first by cutting along the posterior-anterior axis on the borders of where the two myotomal patterns meet. The thicker and larger of these halves was then further cut to ensure a uniform shape and thickness. The cut piece on the posterior end was called C while the cut piece on the anterior end was called E. The reaming piece had uniform thickness and outline and was named A. MaxA cut, figure 3.2.b, is made by cutting along the posterior-anterior axis so that one half of the fillet would be as big as possible while still having relatively uniform shape and thickness. The bigger half was then trimmed to ensure uniform shape in the same way that the bigger half was trimmed when applying the balanced cut. The smaller half (B) had very irregular shape and thickness making any further trimming unnecessary.

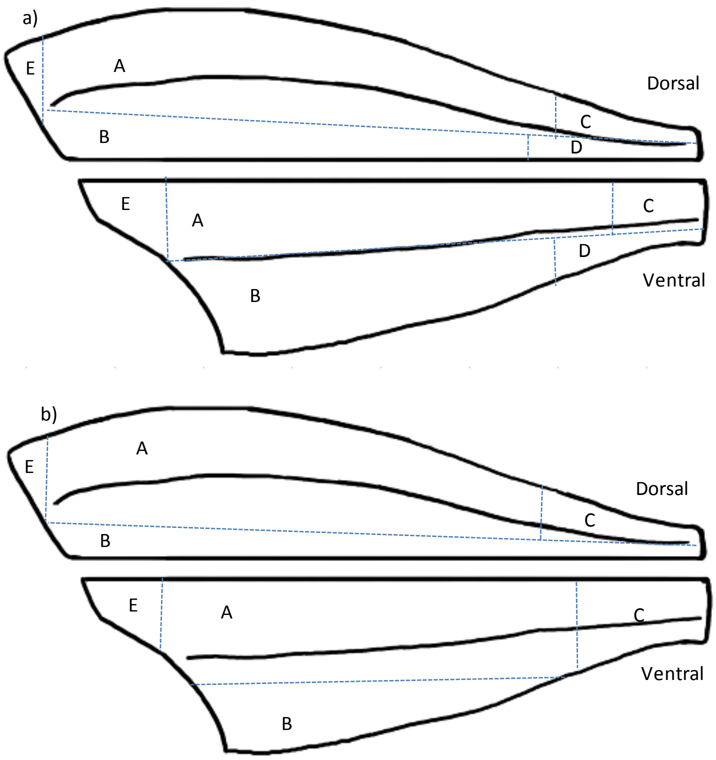

Figure 3.2. The dorsal and ventral fillets in Atlantic halibut and how they are portioned by a) Balanced method and b) MaxA method. Dashed lines indicate the cuts made.

3.4 Preparation of sashimi

The sashimi was cut either traditionally or by cutting each piece of sashimi so that it was more or less made out of one myotomal segment (myotomal method). The traditional sashimi cut was made by cutting crosswise against the grains (muscle fibres) with the knife at a 45° angle towards the fingers. The myotomal method involved using the knife to aling the lines in the portions formed by the myosepta that lies between the myotomes (myotomal). This meant that each sashimi piece cut using the myotomal method is almost the same as a flake from cooked Atlantic halibut, except of each piece is served raw. Cursory attempts at cutting sashimi along the grain only resulted in chewy and stringy textures of the cuts.

3.5 Measuring the sashimi

Five pieces of sashimi were selected randomly from each B portion cut into sashimi. Height and width of the pieces was measured to the nearest centimetre and they were weighed to the nearest gram. Any leftovers of the B portion that could not be used to make sashimi were weighed to the nearest gram and trimming (%) was calculated using total trimmings/ g.w. ×100.

3.6 Data handling and statistics

Fillet yield (%) was calculated as fillet weight/g.w. ×100, where g.w. was the gutted weight of the fish. Skinned fillet yield (%), trimmed fillet yield (%), waste (%), the individual portions yields (%) and sashimi were calculated in the same way. Students T-test was performed using Microsoft Excel 2010 (P.C. version) on the weights (g), length (cm) and width of the sashimi pieces to compare the myotomal and traditional sashimi preparation methods.

4 Results

4.1 Defining fillets

In regards to other fish species the flatfish lies on its side, either right or left. Because of this, confusion can arise when discussing the different fillets found in the Atlantic halibut and when comparing them to similar fillets in other species of fish. A standardized naming for the fillet is therefore proposed using the body plan of the non-flatfish species as a model.

Using that body plan, the Atlantic halibut lies on its left side, the dorsal fin is on the dorsal side and the anal fin is on the ventral side, fig. 4.1. Based on this, the four fillets can be named using their position relative to the body plan. The fillets should therefore be called dorsal right (DR), dorsal left (DL), ventral right (VR) and ventral left (VL), fig. 4.2.

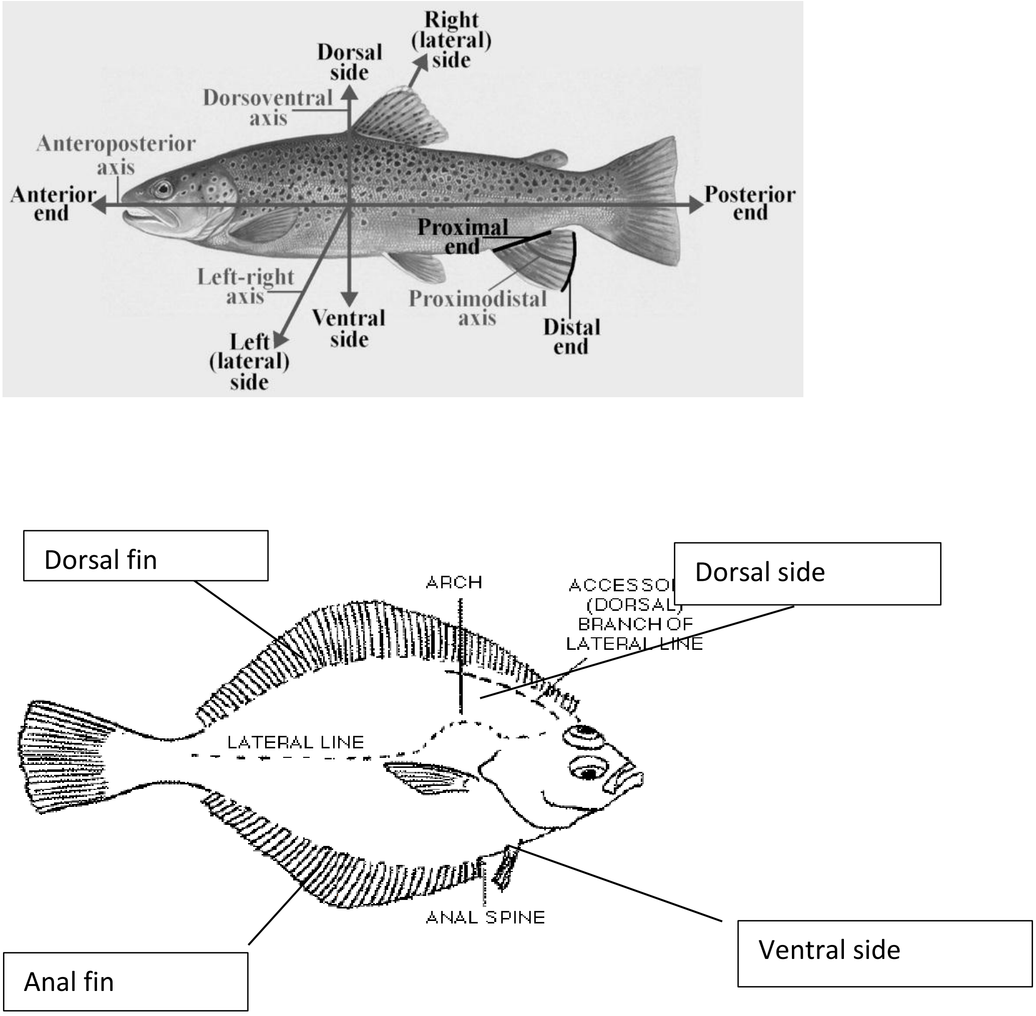

Figure 4.1. Body plans of salmonidae (upper) and a flatfish (lower) that lies on its left side. (Upper image from Wikipedia.org and lower modified from www.dfw.state.or.us)

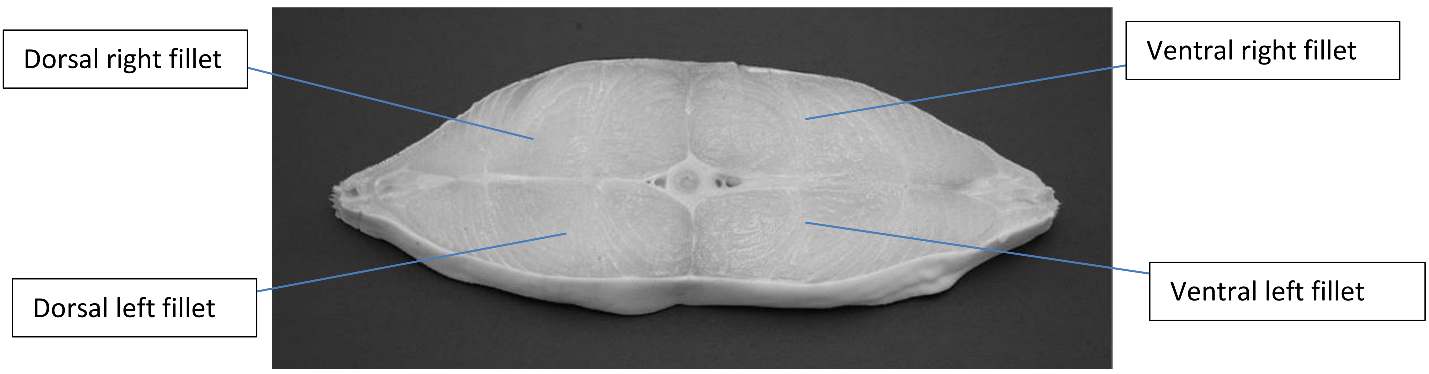

Figure 4.2. Proposed names of the four fillets that can be harvested from the Atlantic halibut based on their position in the flatfish body plan (modified from http://www.seacoreseafood.com).

4.2 Yield and portioning of winter harvested Atlantic halibut

4.2.1 Yield

Measurements showed that the larger fish had higher fillet yield (58,8±3,5% g.w.) than the smaller fish (55,2±0,3% g.w.) and that skinning resulted in roughly a 6% g.w. drop in yield for both size classes so that skinned fillet yield was 52,9±2,9% g.w. and 49,0±1,6% g.w., table 4.1.

Table 4.1. Summary for length, total weight, fillet weight, yield and waste for Atlantic halibut for two weight classes both before and after skinning along with standard deviation. Yield is calculated from gutted weight of the fish.

	Fillet		**Skinned fillets**	
Parameter	**5,5-6,5 kg**	**>7 kg**	**5,5-6,5 kg**	**>7 kg**
Length (cm)	80,33±1,15	88,50±3,5	80,33±1,15	88,50±3,5
Total Weight (g)	6169±305	8087±+864	6169±305	8087±864
Fillets (g)	3403±176	4756±777	3025±179	4280±179
Fillet yield (%)	55,2±0,3	58,8±3,5	49,0±1,6	52,9±2,9
Waste (g)	2721±80	3127±189	3025±127	3603±184
Waste (%)	44,1±0,9	38,7±4,7	44,6±1,4	44,6±4,1

4.2.2 Fillets

The dorsal right fillets were the largest fillets (14,5±0,4-16,8±2,4% g.w.) depending on size and whether the fillets had been skinned or not. The dorsal right fillet was proportionally larger in the larger fish (17,6±0,2% g.w.) than the smaller (16,0±0,2% g.w.) and skinning the dorsal right fillets from the larger fish had less effect on the yield than when the dorsal right fillets from the smaller fish was skinned (0,8% g.w. and 1,5% g.w. drops in yield respectively). It seems that the fillets are larger on the right side than the left and larger on the dorsal side than on the ventral side (12,0±1,0-16,8±2,4% g.w. and 10,8±0,4-13,4±0,9% g.w. respectively), table 4.2.

Table 4.2. Weight and yields of total amount of fillet weights and individual fillets along with standard deviation.

	Fillets		Skinned fillets	
Parameter	**5,5-6,5 kg**	**7-9kg**	**5,5-6,5 kg**	**7 -9kg**
Total Fillet (g)	3403±176	4756±777	3099±179	4280±668
Fillet (%)	55,2±0,3	58,6±0,3	50,2±1,6	52,7±2,9
Dorsal right (g)	986±42	1429±262	895±20	1314±225
Dorsal right (%)	16,0±0,2	17,6±0,2	14,5±0,4	16,8±2,4
Ventral right (g)	849±73	1140±218	799±64	1021±202
Ventral right (%)	12,9±0,2	14,0±0,6	13,4±0,9	13,1±1,3
Dorsal left (g)	836±60	1174±202	740±63	1044±149
Dorsal left (%)	13,6±0,9	14,50,9	12,0±1,0	13,4±0,6
Ventral left (g)	756±62	1013±153	665±55	902±140
Ventral left (%)	12,2±0,4	12,2±0,4	10,8±0,4	11,6±0,9

4.2.3 Waste

The average head size for the smaller fish was 1180g while the average head size of the larger fish was 1136g. At the same time the head proportions where quite different for the 5,5-6,5kg fish (19,2±2,0% g.w.) and the 7-9kg fish (18,2±1,8% g.w.) so it seems that within the size ranges studied head size changes little despite changes in body size. Notch size increased the most proportionally, from 4,9 to 5,8% g.w., with increased size. Changes in skin proportion between the two fish sizes were little to none, table 4.3.

Table 4.3. Weights and % of the total waste and each waste component from the filleting process.

Composition of waste		
Parameter	**5,5-6,5 kg**	**>7 kg**
Total Waste (g)	3024,7±80,1	3603,3±184,4
Waste (%)	49±1,4	44,8±4,1
Vertebrae (g)	1151,3±153	1466,7±115,3
Vertebrae (%)	18,6±1,8	18,2±1,8
Head (g)	1180,0±100,5	1136,3±113,7
Head (%)	19,2±2,0	14,3±2,0
Notch (g)	378,0±20,9	502,7±48,7
Notch (%)	6,1±0,6	6,3±0,6
Skin (g)	304,0±86,1	476,3±86,1
Skin (%)	4,9±0,6	5,8±1,3

4.2.4 Body composition summary

Figures 4.3 and 4.4 summarize the body composition of 5,5-6,5kg and 7-9kg farmed Atlantic halibuts and show the differences in the two size classes. The proportion of the dorsal right fillet increases with size (15 to 17% g.w). The head in the larger fish (about 14% g.w.) is proportionally smaller than in the 5,56,5 kg fish (about 19% g.w.) remaining parts where of compatible portions in the two size classes.

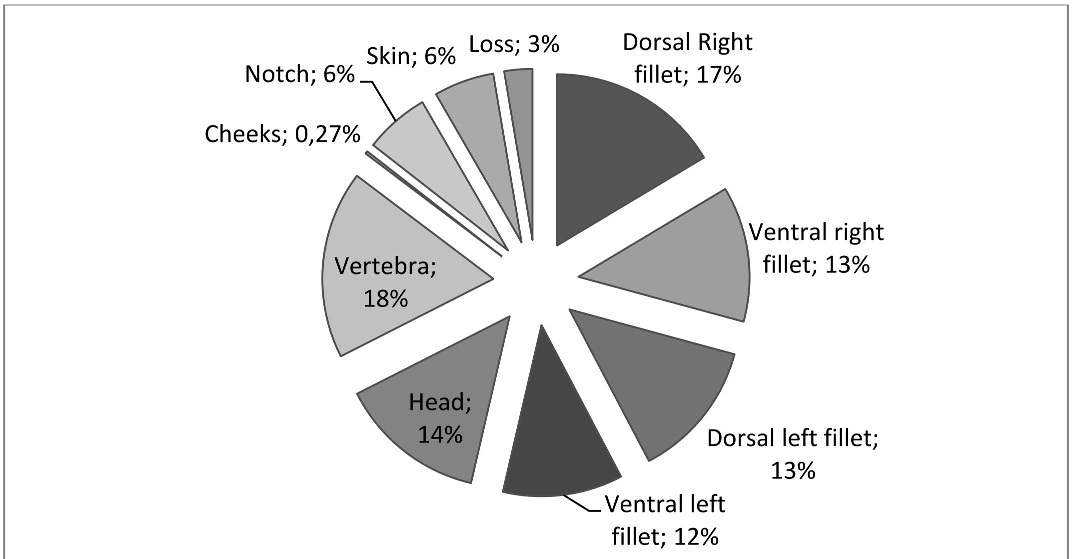

Figure 4.3. Composition of 7-9kg Atlantic halibut in % g.w.

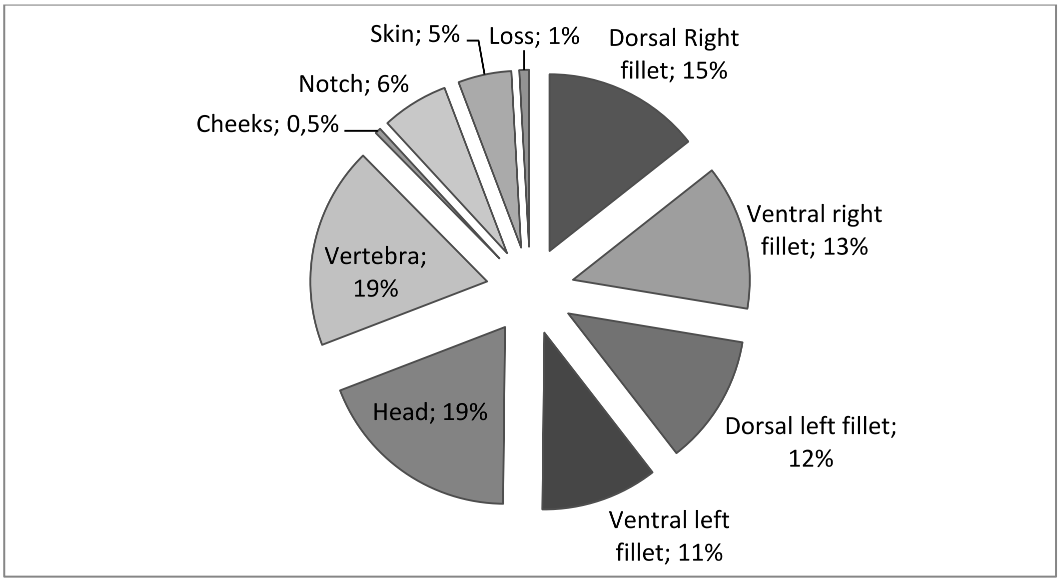

Figure 4.4. Composition of 5,5-6,5kg Atlantic Halibut in % g.w.

4.2.5 Portioning the fillets

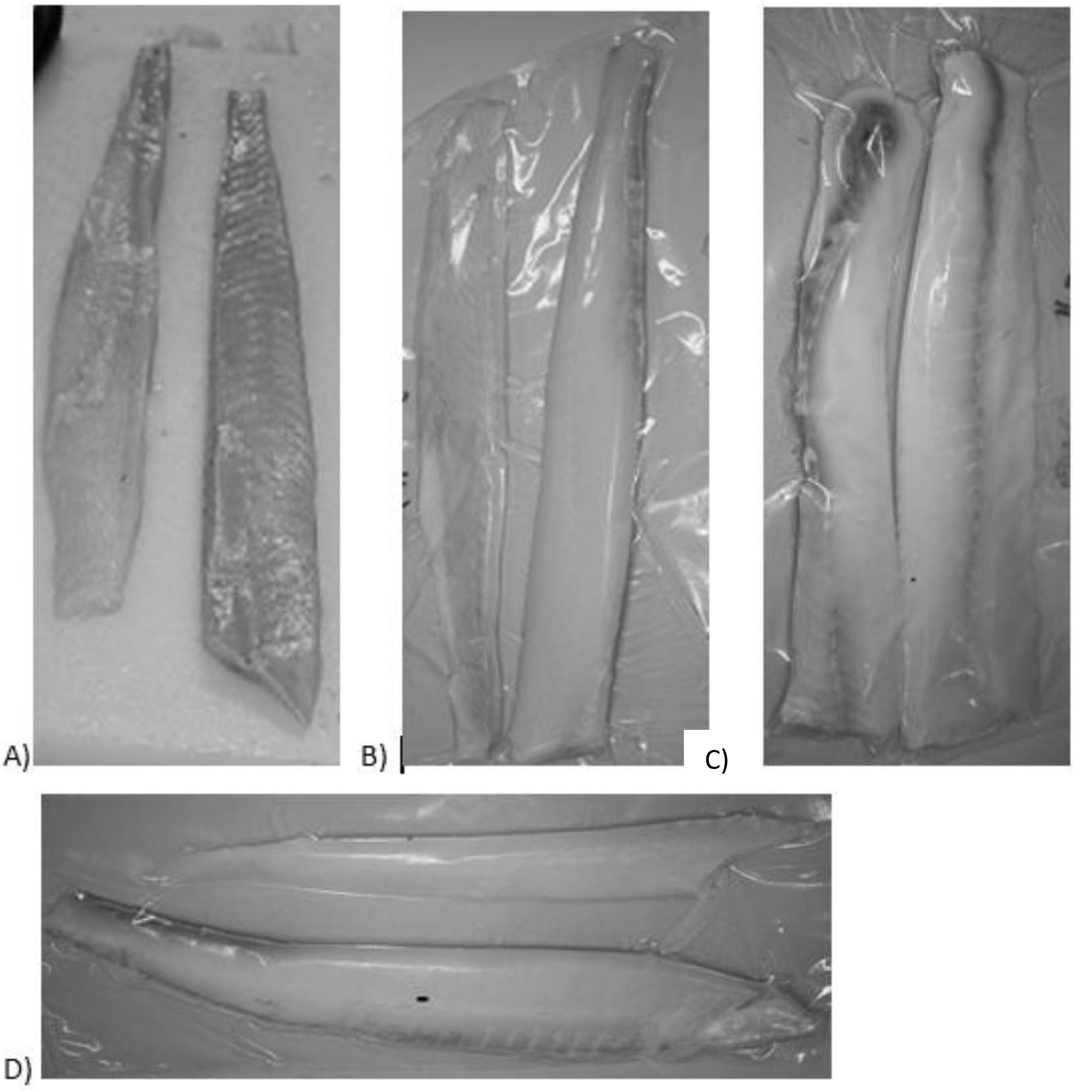

Figure 4.5. A) Even cut portioning of a dorsal fillet. B) Muscle line portioning of a dorsal fillet in a vacuum packaging. C) Upper/lower portioning of a dorsal fillet. D) Upper/lower portioning of a vacuum packed ventral fillet.

The upper/lower cut resulted in two good looking portions of quite different sizes and variable depending on whether they were cut from the dorsal fillet (18,1±3,0% g.w. and 9,8±2,5% g.w.) or ventral fillet (14,6±1,6 g.w.and 4,5±1,1% g.w.). The biggest difference in size of the two portions came from the large/small cut (19% g.w. and 4% g.w). The most evenly sized portions came from the even cut (11,9±2,1% g.w and 11,1±2,5% g.w.). Using the muscle line method also resulted in two quite evenly sized portions (10,8% g.w. and 13,1% g.w.). Only the upper/lower cuts resulted in portions that could be called evenly shaped, table 4.4, fig. 4.5.

Table 4.4. Fillet weight and yield of the two portions based on cutting method and the body plane the fillet had been harvested from. Yield calculated both from total fillet weight and individual fillet weights.* no standard deviation since there are no replicates.

				Portion yield		Within fillet yield	
Method	Body plane	Portion 1 (gr.)	Portion 2 (gr.)	Portion 1 (%)	Portion 2 (%)	Portion 1 (%)	Portion 2 (%)
Even cut	Ventral	408±74	382±85	11,9±2,1	11,1±2,5	52±1	48±1
Muscle line	Dorsal	556*	675*	10,8*	13,1*	45,3*	54,7*
Upper/lower	Dorsal	807±253	419+13	18,1±3,0	9,8±2,5	65,1±7,9	34,9±7,9
Upper/lower	Ventral	542±54	168±40	14,6±1,6	4,5±1,1	76,5±2,5	23,5±2,5
Large/small	Dorsal	650*	127*	19*	4*	83,7*	16,3*

4.3 Yield and portioning of spring harvested Atlantic halibut

4.3.1 Yield

The fillet yield of the fish before skinning and trimming was lowest in the 4-5kg fish (50,6%) and highest in the 7-9kg fish (55,6% g.w.), the other weight classes had yields rates falling somewhere in between these classes. When the fillets had been skinned, differences in yield between the classes evened off and became quite similar with the highest yield found with the 6-7kg fish, (47,1% g.w.) and lowest for the 2-3,5kg fish (45,4±1,85% g.w.) The biggest yield drop as a result from the skinning process was the 7-9kg fish which had a yield drop of 8,2% (from 55,0%-46,8%) while the other fish had much lower yield drops due to skinning, table 4.5. Waste amount and rate was calculated after skinning and trimming and interestingly the largest fish had the highest waste rate, (58%,2) despite having the highest yield before skinning and trimming, while the 6-7kg fish at the lowest rate (52,9%), table 4.5.

Table 4.5. Summary for length, total weight, skinned fillet weight, trimmed fillet weights, corresponding yields and waste for Atlantic halibut harvested in spring. * no standard deviation due to lack of replicates

Parameter	2-3,5kg	4-5kg*	6-7kg*	7-9kg*
Total length (cm)	63±2,6	71	82	88
Total weight (g)	2870±360,3	4244	6710	7598
Total fillet (g)	1482,7±191,9	2146	3594	4178
Total fillet yield (%)	51,7±1,4	50,6	53,6	55,0
Skinned fillet (g)	1304±197,5	1970	3158	3554
Skinned fillet yield (%)	45,4±1,85	46,4	47,1	46,8
Trimmed fillet (g)	1238±206,12	1854	2976	3220
Trimmed fillet yield (%)	43±2,1	43,7	44,4	42,4
Waste (g)	1604±167,5	1764	3552	4420
Waste (%)	56±1,35	56,6	52,9	58,2

4.3.2 Fillets

The skinned dorsal right fillet was always the single largest fillet in each weight class, ranging from 14,5-16,3% g.w. The smallest fillet was the ventral right one with sizes between 8,6-9,2% g.w. In general it was found for all the weight classes that the right size was larger than the left side. The right side fillets where on average 25,7% larger than the left side ones. The samples were too few to make an estimate of right/left size ratios for each weight class, table 4.6.

Table 4.6. Summary of trimmed and skinned fillets and the four different fillet types along with their corresponding yields and standard deviation. * no standard deviation due to lack of replicates.

	2-3,5kg	**4-5kg***	**6-7kg***	**7-9kg***
Trimmed fillet (g)	1238±206,12	1854	2976	3220
Trimmed fillet yield (%)	43,0±2,1	43,7	44,6	42,3
Dorsal left (g)	304,67±26,10	452	738	764
Dorsal left (%)	10,65±0,54	10,7	11	10,1
Dorsal right (g)	685±104,61	620	960	1104
Dorsal right (%)	15,2±1,85	14,6	16,3	14,5
Ventral left (g)	396±43,19	364	616	702
Ventral left (%)	8,6±0,41	8,6	9,2	8,6
ventral right (g)	434±76,39	418	662	334
Ventral right (%)	9,29±1,47	9,8	9,9	9,2

4.3.3 Waste

The weight of skin shows the largest proportional variability, with the largest fish, 7-9kg having the highest ratio of skin (8,2% g.w.) while the other size classes had 4,2-6,5% g.w. skin. The 6-7kg and 7-9kg fish had smaller head ratios on average than the 2-3,5kg and 4-5kg fish (20,5% g.w.and 22,16% g.w. versus 23,5% g.w. and 24,7% g.w.). The amount of trimmings was highest in the largest Atlantic halibut (4,4% g.w.) but otherwise was quite similar across the size classes (2,35-2,7% g.w.), table 4.7.

Table 4.7. Composition of the waste from the filleting, skinning and trimming processes in grams and ratios with standard deviation. * no standard deviation due to lack of replicates.

	2-3,5kg	4-5kg*	6-7kg*	7-9kg*
Head (g)	674,67±96,4	1050	1376	1684
Head (%)	23,5±0,6	24,7	20,5	22,16
Vertebrae (g)	510,7±49,7	846	1204	1310
Vertebrae(%)	17,84±0,7	19,9	17,94	17,24
Cheek	12±2,0	10	22	12
Cheek (%)	0,4±0,1	0,24	0,33	0,16
Notch (g)	162±38,3	204	332	456
Notch (%)	5,56±0,7	4,8	4,95	6,0
Skin (g)	178,7±10,3	176	436	624
Skin (%)	6,3±0,9	4,2	6,5	8,2
Trimming (g)	66±10,3	116	182	334
Trimming (%)	2,35±0,7	2,7	2,7	4,4

4.3.4 Portioning the fillets

Since the 2-3,5kg fish was portioned using two different methods, trimmed fillet yield was calculated again. Instead of grouping all the fish in 2-3,5kg size category together they were divided up first depending on what cutting procedure was performed before the yield for each type was calculated. Within the 2-3,5kg size category, the fish cut using the Balanced method had the highest trimmed fillet yield of all measured fish (47,7% g.w.) while the lowest yield was in the 2-3,5kg fish that was cut using the MaxA method.

The balanced cutting resulted in large boneless, skinless A portions, consisting of about 25-26% g.w. The B portion could be used to make sashimi except the in smallest 2-3,5kg fish since the size of the B portion was not sufficient to fulfil the sashimi requirement. The B portions that could be used to make sashimi where 9,3-9,8% g.w. The C portion was large enough to cut into sashimi but had a large myoseptal structure running through the middle of the portion so these pieces would tear apart easily, making them unsuitable for use as sashimi. The D and E portions where too small to be used as sashimi and along with the C portions designated as secondary cuts. The total amount of cut-offs using the balanced method was lowest in the largest fish (6,4% g.w.) but increased as the fish got smaller with the 2-3,5kg MaxA fish having the largest amount of cut-offs (11,9%g.w.), not counting the B portion. When the fish was cut in the MaxA fashion the supreme portions yield increased to 28,9-31,7% g.w. All the other portions (B, C, D, E) where too small to make sashimi and therefore grouped together as secondary cuts and consisted of 28,9-31,7% g.w., table 4.8.

Table 4.8. Weights and yield of different portions of Atlantic halibut based on size and cutting method along with standard deviation. *no standard deviation due to lack of replicates.

	2-3,5kg*	**2-3,5kg**	**4-5kg***	**6-7kg***	**7-9kg***
Portioning	Balanced	MaxA	MaxA	Balanced	Balanced
Trimmed fillet (g)	1544	1123±75,0	1854	2976	3220
Trimmed fillet Yield(%)	47,7	41,9±1,0	43,7	44,4	42,4
A portion (g)	824	774±64,7	1346	1694	1992
A portion yield (%)	25,4	28,9±2,1	31,7	25,2	26,2
B portion (g)	336	N/A	N/A	624	742
B portion yield (%)	10,4	N/A	N/A	9,3%	9,8
Cut-off.(g)	384	349±63,6	508	658	486
Cut-off yield. (%)	11,9	12,9±1,2	12,0	9,8	6,4

The proportionally largest A portions where obtained from the Dorsal right fillets (8,3-11,6% g.w.) and the smallest came from the Ventral left fillets (4,9-5,9% g.w.) The differences in A portion yields were most pronounced in the Dorsal left fillets where MaxA A portions were almost twice as large as the corresponding Balanced A portions (7,7-8% and 4,4-5,2% respectively), table 4.9.

Table 4.9. Weights and yield of A portion, supreme, within each fillet for the different size categories along with standard deviation.*no standard deviation due to lack of replicates.

	2-3,5kg*	**2-3,5kg**	**4-5kg***	**6-7kg***	**7-9kg***
Portioning	Balanced	MaxA	MaxA	Balanced	Balanced
Dorsal left, A (g)	144	201±1,4	338	336	398
Dorsal left, A yield (%)	4,4	7,5±0,7	8	5	5,2
Dorsal right, A (g)	270	280±22,6	494	570	824
Dorsal right,A yield (%)	8,3	10,4±0,1	11,6	8,5	10,8
Ventral left, A (g)	192	132±5,6	232	358	376
Ventral left,A Yield (%)	5,9	4,9±0,2	5,5	5,3	4,9
Ventral right, A (g)	192	161±15,6	282	430	394
Ventral right,A yield (%)	6,7	6,0±1,1	6,6	6,4	5,2

4.3.5 Sashimi

Only the B portions of the balanced cut fillets could be used for making sashimi. There was no statistical difference found between the weight, length and width the two methods for cutting sashimi. Only one B portion was cut traditionally to make sashimi and all of it was used leaving no trim while the myotomal cut resulted in an average of 1,4±0,1% g.w. of trimmings once all the B portion had been sliced. The number of sashimi pieces obtained from each B portion averaged 20,3±4,8 pieces, table 4.10. The high standard deviation observed is mostly due to the varying sizes of the sashimi portions used as larger B portions resulted higher quantities of sashimi pieces being obtained from that portion (see table 4.8. for B portion sizes).

Table 4.10. Average weight, length, width and quantity of sashimi pieces based on cutting method used along with standard deviation. Average sashimi trimmings and yields. Results of T-tests on weight, length and width between the two methods. *No standard deviation due to lack of replicates.

Parameter	Myotomal	Against grain	T-test
Weight	8,2±2,5g	10,4±3,3g	$0,08^{ns}$
Length	5,5±1,45cm	5,6±2,4cm	$0,94^{ns}$
Width	3,4±0,9cm	4,0±1,7g	$0,17^{ns}$
Total sashimi trim (g)	37±7,1	0	
Trimmings (%)	1,4±0,1	0	
B portion waste (%)	2,2±1,3	0	
Quantity per B-portion	20,3±4,8	26*	

5 Discussion

12 fish were filleted and due to the large differences in the qualities of winter and spring harvests, the fish were divided into two experiments based on harvesting time and then further subdivided into five size categories. This meant that there were very few replicates and any differences found between size categories and harvesting time had less significance.

Gaping in the fillets, especially in the 7-9kg fish harvested in spring, made the fish difficult to work with and complicated the skinning process. The fillet amounts and yields where almost certainly affected by the gaping. Any observed differences in the 7-9kg spring and 7-9kg winter fish could, at least partly, be explained by the higher level of gaping observed in the spring fish. Increased gaping and lower fillet quality in spring harvested Atlantic halibuts has been linked to lower flesh pH (Olsson 2003) and fewer PYD crosslinks (Hagen 2007).

None of the fish filleted had the opaque bluish-white colouring of a freshly slaughtered fish but where instead more milky-white, like fish that is not of the highest quality. Atlantic halibut can be stored on ice (0°C) for at least 26 days so the loss in quality already observed in the fillets after just 5 days of storage at 0°C was interesting.

The fillet yield was about 45-59% g.w. which is quite high. Compared to other flatfishes, the skinned fillet yield is also quite high as average skinned fillet yield for flatfish species is 34% with yields in some species being a lot lower such as 27% for Dover sole (*Microstomus pacificus)* or as high as 48% for winter flounder (*Pseudopleuronectes americanus)* (FAO 1989). In regards to farmed fish, the rearing conditions e.g. feed, water temperature and light cycles can have an effect on the yield. Salmon is the most commonly farmed fish in Norway (Bai 2005) and has fillet yields >50% (Borderísas 2011) or skinned fillets yields of >45% based on the fact that skin is usually around 5% of fillets (FAO 1989). Fresh water eels have the highest yield of farmed fish (60%) while tilapia (*Oreochromis sp.*) has the lowest yield (33%) (Borderías 2011).

Skinning the fillets led to the largest drop in yield for the large 7-9kg winter harvested fish (8,2%) while in the other fish the yield decreased about 4,2-6,5%.

The single largest skinned fillet in each fish was the dorsal right (14- 16,8% g.w.), while the smallest one was the ventral left (8,6±0,4-12,2±0,4% g.w). The right side fillets were larger than the corresponding left side fillets and research has estimated that the right side fillets are about 30% larger than the left ones (Nordvedt 1998).

Smaller fish in the 2-3,5kg and 4-5kg categories had proportionally larger heads (23,5±0,6% g.w. and 17,84±0,7% g.w. respectively) than the bigger fish where head size became as low as 14,3±2,0% g.w. in 7-9kg spring Atlantic halibuts. This could indicate the increased fillet yield in larger fish is due to them having proportionally smaller heads. The largest amount of gaping was observed in the 7-9kg fish, especially the ones harvested in the spring. This made skinning the fillets difficult and could explain the disparity in skin proportions.

When the fillet from the winter Atlantic halibut where portioned into two parts, the portions yields had large variations depending on the method of cutting used (4-19% g.w.). The portioning method that showed the most promise was the large/small method. Both portions had even shapes and one portion was quite larger than the other. Interestingly enough, the ventral and dorsal fillet gave different yields. The yield for the two dorsal pieces from the large/small cut was 18,3±3,0% g.w. and 9,8±2,5 g.w. while the portions from the ventral fillets were 14,6±1,6% g.w. and 4,5±1,1% g.w. The other types of portioning did not give portions that had even outlines and would therefore not be visually attractive to the consumer. Packaging any portions that do not have even outlines in vacuum packaging could perhaps smooth out some of the edges and perhaps make the portions more marketable.

Portioning the fish according to the MaxA method gave us a large boneless skinless fillet, portion A, that was 28,9±2,1% g.w. in the smaller 2-3,5kg fish and 31,7% g.w. in the 4-5kg fish. The rest of the portions (B, C, D, E) could only be used as cut-offs. The proportion of the cut-off of was larger in the smaller fish than the larger fish and ranged from 12-12,9±1,2% g.w. The Balanced cut resulted in a smaller A portion 25,2-26,3% g.w. but portion B in the 6-7kg and 7-9kg fish could be cut into sashimi pieces, was 9,3-9,8% g.w. and the amount of cut-off was 6,4-9,8% g.w.

It was not surprising that in both MaxA and Balanced cutting methods, the proportionally largest A portion was in the proportionally largest dorsal right fillets (8,3-11,6% g.w.). The smallest A portions were in the dorsal left fillets (4,4-8,0% g.w.). The A portion obtained from the ventral right and ventral left fillet were proportionally of similar size (4,9 -5,9% g.w. and 5,2-6,7% g.w. respectively). The B portion of the 2-3,5kg fish was not large enough to easily make sashimi pieces that were large enough to fulfil the sashimi size requirements.

There was no significant difference in the weight, length and width of sashimi pieces whether they were cut traditionally or with the myotomal method. Only one A portion was cut with the traditional method while the remaining sashimi was prepared using the myotomal method. 20,3±4,8 pieces of sushi were prepared from each of the fillets using the myotomal method. The high standard deviation is most likely caused by the large size differences between the fillets.

The findings in this report demonstrate that more work should be done on the observed differences in yields both between the winter and spring harvested fish and the between the size categories. Having more replicates would have improved the significance of the results and perhaps led to further insights into the effects size and harvesting time have on fillet yield and portioning.

The cost effectiveness of the portioning methods needs to be calculated and marketability of the different portions evaluated. The methods used for portioning the fish are by no means meant to represent the only way of dividing up Atlantic halibut fillets and future research into how to best portion the fillets is recommended.

6 Conclusion

Fillet yield was shown to increase with increased body size in fish during winter mostly because smaller fish had proportionally larger heads. The fish slaughtered in spring showed more gaping and had lower yields. The fish harvested in spring showed no link between yield and size. Within each fish the dorsal right fillet was always largest and the ventral left was always smallest. More gaping was observed in the larger fish than the smaller fish.

The fish harvested during winter was portioned into two parts along the anterior-posterior axis using four different methods. The subjective upper/lower method showed most promise, as that was the only method where the portions had regular outlines. The yields of the two portions were quite different based on whether the fillet they came from was from the dorsal side (18,3±3,0% g.w and 9,8±2,5 g.w.) or ventral side (14,6±1,6% g.w. and 4,5±1,1% g.w.).

Two different types of portioning methods were tested in the fish harvested in spring, Balanced and MaxA. The Balanced method cut up the fillets into a boneless, skinless A portion that was 25,2-26,2% g.w. and smaller portions that were 9,3-9,8% g.w. and could be cut up and used as sashimi. The B portion in the 2-3,5kg fish was too small to be cut into sashimi pieces. The amount of cutoff was 6,4-9,8%. MaxA portioning resulted in a larger boneless skinless A portion that was 28,9±2,1-31,7% g.w. and a cut-off that ws 12,0-12,9±1,2% g.w. The largest boneless skinless A portions where in the Dorsal right fillets.

On the portions from which sashimi was cut, two different methods were used, traditional and myotomal. No significant difference was found in the weight, length and width of these pieces. The amount of pieces obtained from each portion showed some variety mostly due to the variance in size of the portions.

These results suggest that it is possible to obtain a large boneless, skinless section from Atlantic halibut fillets that has an even shape and could potentially be used as a high quality product. Furthermore, at least a part of the remaining pieces within each fillet can be used in making other valuable products instead of being relegated as cut-offs.

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