The Proximate, Fatty Acid and Mineral Composition of the Muscles of Cultured Yellowtail (*Seriola lalandi*) at Different Anatomical Locations

by

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Declaration

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Opsomming

Die algemene samestelling van voedsel produkte, asook die vet inhoud en vetsuur samestelling daarvan, wek deesdae al meer besorgdheid by verbruikers. Dit is ook belangrik vir vis verwerkers as gevolg van die effek wat verskillende vlakke van proteïene, lipiede, water en minerale het op die tekstuur van vis asook die potensiaal om vis in verkoelers te stoor. ‘n Totaal van 17 *Seriola lalandi* (geelstert) is geöes vanuit ‘n net-hok eenheid op die kus van Port Elizabeth. Proksimale, vetsuur en mineraal analises was uitgevoer op vyf areas van die filet sowel as op die heel filet as ‘n kontrole. Verskille ($P < 0.05$) is opgemerk in die water en vet inhoud tussen die dorsale en ventrale monsters. Die hoogste voginhoud (71.5 ± 0.4%) was opgemerk in die stert gedeelte van die vis en hierdie gedeelte het ook die laagste vetinhoud gehad (4.3 ± 0.23%). Proteïen vlakke het nie verskil tussen enige van die monsters nie ($P < 0.05$). Die totale vetinhoud (g/100 g nat weefsel) van die heel filet (A, kontrole) was 5.3 ± 0.11 waarvan versadigde vetsure (SFA) 35.5 ± 1.13%, monoönversadigde vetsure (MUFA) 25.7 ± 0.51%, en polionversadigde vetsure (PUFA) 38.2 ± 0.88% uitgemaak het. Die oorheersende versadigde vetsuur was palmitiese suur (heksadekanoïese suur, C16:0) wat vlakke van 24.2 ± 1.25% bereik het in seksie E (middel ventraal). Die data wys dat seksie B (voorste dorsaal), seksie D (middel dorsaal) of seksie F (agterste ventraal en dorsaal) gebruik kan word as verteenwoordigende monsters van die heel filet wanneer proksimale analise uitgevoer word. Die maag gedeeltes van die vis het beduidend verskil ($P < 0.05$) van die heel filet. Die resultate van die mineraal en vetsuur analises het te veel gevarieer en daarom kon geen verteenwoordigende seksie van die heel filet geïdentifiseer word nie. Die eetbare dele van akwakultuur geelstert wat in hierdie studie ondersoek is, bevat 0.24% EPA en 10.90% DHA wat heelwat laer is as die van ander marine vis spesies. Hierdie verskil kan moontlik toegeskryf word aan die voer wat aan die geelstert gegee is aangesien dit voorheen bewys is dat die lipied profiel van die dieet ‘n uitwerking het op die lipied profiel van vis.

Abstract

The proximate composition of food products, and more importantly fat content and fatty acid composition, is of growing concern to consumers. It is also of concern to fish processors because of the effects that various levels of proteins, lipids, water and ash have on the cold storage potential and texture of fish. A total of 17 *Seriola lalandi* (yellowtail) were harvested from a net cage production unit off the coast of Port Elizabeth. Proximate, fatty acid and mineral analysis were conducted on five areas on the fillet, as well as on the whole fillet as a control. Differences ($P < 0.05$) were found in the water and fat content between dorsal and ventral samples. The highest amount (% wet weight) of moisture (71.5 ± 0.4%) was observed in the caudal region of the fish. This region was also found to contain the lowest levels of fat (4.3 ± 0.23%). Protein levels did not differ ($P > 0.05$) between sample regions. The total fat content (g/100 g wet tissue) of the whole fillet (A; control) was 5.3 ± 0.11 of which saturated fatty acids (SFA) accounted for 35.5 ± 1.13%, monounsaturated fatty acids (MUFA) for 25.7 ± 0.51% and polyunsaturated fatty acids (PUFA) for 38.2±0.88%. The most predominant saturated fatty acid was palmitic acid (hexadecanoic acid, C16:0) with levels reaching 24.2 ± 1.25% in the mid belly area, sample section E (mid ventral). The data shows that one could use either section B (anterior dorsal), section D (mid dorsal) or section F (dorsal and ventral posterior sections combined) as a representative sample of the whole fillet when doing proximate analysis. The belly sections of the fish differed significantly ($P < 0.05$) to the whole fillet. There was too much variation between samples with regards to the mineral and fatty acid analysis to identify a section that is representative of the whole fillet. The edible portion of the farmed yellowtail examined in this study contained eicosapentonic acid (EPA) and docosahexaenoic acid (DHA) levels of 0.24% and 10.90% respectively which is notably lower than other marine fish species. However, this could be linked to the feed that these specific yellowtail were fed, as the lipid profile of the diet has been shown to have an effect on the lipid profile of the fish.

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1. Introduction

Yellowtail (*S. lalandi*) belongs to the family Carangidae, a family of more than 140 species that inhabit the temperate and tropical waters around the world. Other species that are closely related to *S. lalandi* include *S. quinqueradiata* (Japanese yellowtail), *S. dumerili* (amberjack) and *Caranx delicatissimus* (amberjack) (Van der Elst, 1995; Aquaculture SA, 2002; Wild Fisheries Research Program, 2006/07; Nakada, 2008). The culture of yellowtail in South Africa is still very much in its infancy. Due to this fact, very little research has been done to date on the nutritional value of farmed yellowtail.

1.1 Objectives of Study

The purpose of this study was to investigate the proximate composition of *Seriola lalandi* at different anatomical locations and investigate the possibility of finding an area of the fillet that is chemically similar and representative of a whole fillet. Should an area of the fillet be identified, that is chemically similar to the whole fillet; sampling procedure could be greatly simplified. In doing this, the nutritional value and fatty acid composition of farmed *S. lalandi* was examined in depth as this could be useful to aquaculture and fish processing industries as it is the first study to be conducted on South African farmed yellowtail.

2. Literature Review

2.1 Introduction

The proximate composition of food products, and more importantly fat content and composition, is of growing concern to consumers (Rasmussen *et al.*, 2000; Dumas *et al.*, 2007). It is also of concern to fish processors because of the effects that various levels of proteins, lipids, water and ash have on the cold storage potential and texture of fish (Love, 1988). For example, a reduction in lipid content in fish muscle could be seen as beneficial from a processors point of view because of the associated reduction in the development of off or rancid flavours (Balogan & Talabi, 1985; Love, 1988). Differences in proximate composition can be found between species, geographical position and even on an individual fish according to the anatomical location of the sample. The anatomical location has an effect on proximate composition due to the fact that fish have a very complex swimming mechanism which leads to variations in the muscle type and composition along the length of a fish (Love, 1988).

2.2 Yellowtail (*Seriola lalandi*)

Yellowtail (*S. lalandi*) belongs to the family Carangidae, a family of more than 140 species that inhabit the temperate and tropical waters around the world. Other species that are closely related to *S. lalandi* include *S. quinqueradiata*, *S. dumerili* and *Caranx delicatissimus*. Yellowtail derives its common name from the prominent yellow colouration on their caudal fin. The body of the fish has a white colour on the ventral side and a blue-green colouration on the dorsal side (Figure 2.1).

Figure 2.1. Yellowtail (*Seriola lalandi*).

Yellowtail occurs in the Indian and Pacific oceans along the coasts of New Zealand, Australia, the United States of America, South America and South Africa (Figure 2.2). In Southern Africa, Yellowtail can be found from Durban on the east coast to Angola on the west coast. Yellowtail is a schooling fish that naturally occur around rocky shorelines and reefs at a depth of around 50 metres. The natural diet of adults is small bait fish, crustaceans and squid. Adult Yellowtail will on average achieve a mass of 10 – 15 kg but have been recorded up to 70 kg (van der Elst, 1995; Aquaculture SA, 2002; Wild Fisheries Research Program, 2006/07; Nakada, 2008).

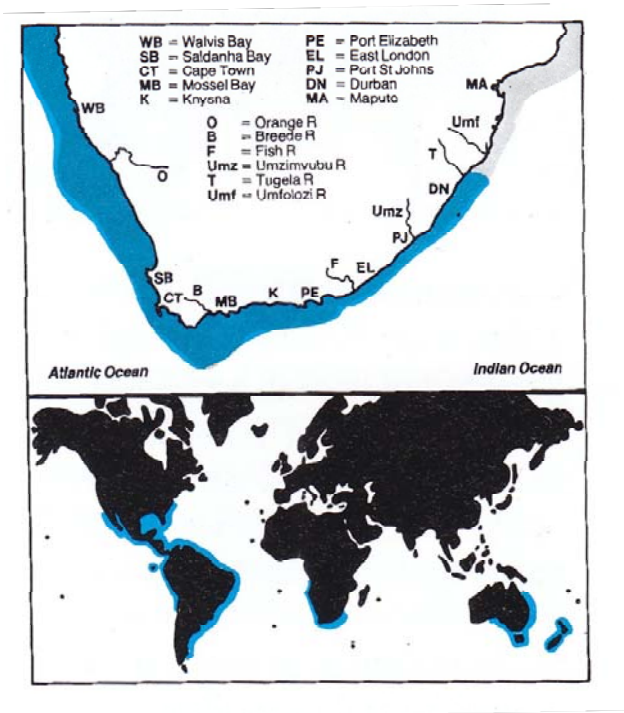

Fig 2.2. The distribution of *S. lalandi* (van der Elst, 1995).

2.2.1 Yellowtail Culture

For almost a century, Japan has successfully cultured *S. quinqueradiata*, a close relative of *S. lalandi*. This fish is highly sought after in Japan and farmed yellowtail is viewed as superior to wild caught yellowtail with regards to flavour and texture. At present, Japanese culture is based on large offshore cage systems that rely heavily on the wild capture of juveniles for stocking (Nakada, 2008). The juveniles congregate beneath floating seaweed and are netted in round haul nets (Kolkovski & Sakakura, 2004; Lovatelli & Holthus, 2008). Total annual production of this species in Japan often exceeds 150 000 tonnes and most of this production is consumed locally (Pillay, 1993, Aquaculture SA, 2002; Wild Fisheries Research Program, 2006/07). In Australia and New Zealand, yellowtail culture is based entirely on hatchery-reared fish (Kolkovski & Sakakura, 2004).

Yellowtail are fast growers and can reach between up to 2.5 kg in a 12 month period at optimum water temperatures. Optimal water temperature is in the region of 24 - 29 °C. Pillay (1993) notes feed conversion ratios (FCR) for *S. quinqueradiata* as 2.1:1 dry weight or 7:1 wet weight for fish up to 1.5 kg. The FCR for *S. lalandi* is not well documented but should be in line with that of *S. quinqueradiata*. In Japan, yellowtail were traditionally fed on trash fish but the demand for trash fish soon exceeded supply and farmers turned to sardines as an alternative. Sardines were frozen for storage purposes but this was also beneficial in the reduction of water pollution as the frozen sardines were less prone to disintegrate in the water. Farmers feeding their fish exclusively on a diet of sardines soon noticed nutritional deficiencies in their fish. This is partly due to the fluctuating levels of fat in the sardines depending on the location, and season, of capture. Commercially produced dry and moist pellets have become increasingly popular in yellowtail culture due to the balanced nutrients that they contain as well as improved feed conversion ratios (FCR) and a reduction in cost (Table 2.1) (Lovatelli & Holthus, 2008).

Table 2.1

Feed intake efficiency (feed conversion rates) and feed cost (¥/kg) in Japan (Lovatelli & Holthus, 2008).

Type of feed	**Yellowtail life stage**	**Feed intake efficiency (%)**	**Feed conversion rate (dry weight)**	**Feed price (Yen/kg)**	**Feed cost[1] (Yen/kg)**
Minced raw fish	Mojako	25	17.5 (6.1)	100	1750
Minced raw fish	Hamachi	25	12.5 (4.4)	80	1000
Granulated feed	Mojako	55	4.5	400	1800
MRF + binder	Hamachi	45	8.5 (3.2)	60	510
Round raw fish	Hamachi	50	10 (3.5)	45	450
Round raw fish	Buri	50	7.5 (2.6)	45	338
Moist pellet 0	Hamachi and Buri	50	11 (3.9)	55	605
Moist pellet 30	Hamachi and Buri	60	6.5 (4.0)	92.5	600
Moist pellet 50	Hamachi and Buri	70	5.0 (3.3)	117	585
Moist pellet 100	Hamachi and Buri	80	4	140	560
High fat dry pellet	Mojako	70	3.7	150	555
High fat dry pellet	Hamachi	75	5	140	700
Extrude pellet	Mojako	85	0.9	325	300
Extrude pellet	Hamachi	75	1.4	250	350
Extrude pellet	Buri	65	2.4	175	400

[1]Cost of feed to produce 1 kg of fish

2.3 Factors Affecting Proximate Composition of Fish

Various studies have shown that there is a link between a range of exogenous and endogenous factors (Figure 2.3) and the proximate composition of fish (Haard, 1992; Shearer, 1994). Exogenous factors are environmental and dietary influences and include water temperature, salinity and diet composition. Endogenous factors are genetic and linked to the life stage, size, sex and anatomical position in the fish. It is important to be familiar with the effects of these

factors when undertaking research involving proximate composition as results could easily be skewed by, for example, the fish making the transition from one life cycle stage to another at the time of sampling.

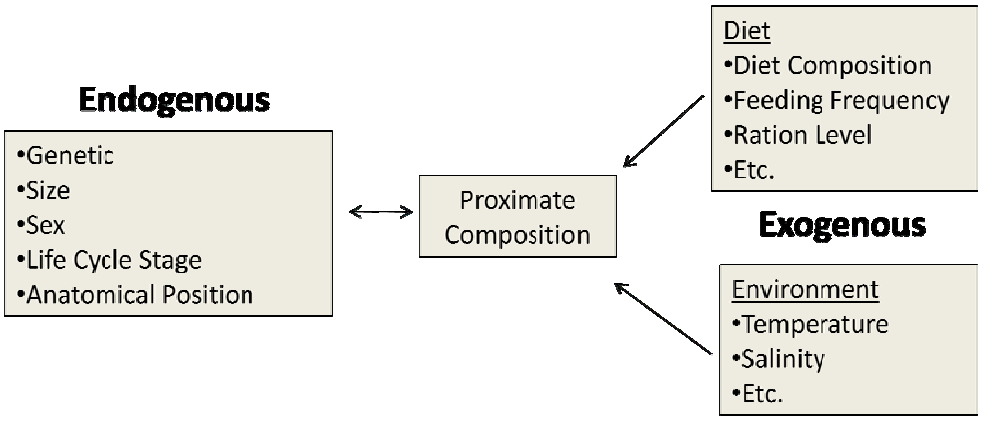

Figure 2.3. Factors influencing the proximate composition of fish (Adapted from Shearer, 1994).

2.3.1 Endogenous Factors

2.3.1.1 Size

In most fish, sexual maturity is reached at a certain size rather than age. Therefore there is a link between size and proximate composition. Not all species display the same relationships between size and proximate composition (Love, 1970). Table 2.2 shows the relationship between size, nutrients and anatomical location in different species of fish.

Dumas and colleagues (2007) showed that the whole body chemical composition of *Oncorhynchus mykiss* (Rainbow trout) can be expressed mathematically and these equations show the link between fish size and proximate composition (Figure 2.4). Regression analysis was done to discover allometric and isometric relationships between body weight and nutrient content. In essence, they examined the rate of nutrient deposition as a function of body weight. Ash was shown to increase at a much slower rate as a function of body weight when compared to protein or lipids. Lipid levels increased the most rapidly when compared to protein and ash.

Table 2.2

Changes in various nutritionally important substances in fish with increase in size (adapted from Love, 1970, 1980).

Substance	**Tissue**	**Species**	**Common Name**	**Change with Growth**
Amino acids	Muscle	*Clupea harengus*	Atlantic herring	Increase
Free amino acids	Muscle	*Labeo rohita, Cirrhina mrigala, Catla catla*	roho, mrigal carp, catla	Increase
Calcium	Blood	*Clarias batrachus*	walking catfish	Decrease
	Whole fish	*Fundulus heteroclitus*	mumichog	Increase
Glucose	Blood	*Carassius auratus*	goldfish	Decrease over part of size range
		Clarias batrachus, Catla catla	walking catfish, catla	Increase
Glucose-6-phosphatase	Liver	*Hippoglossoides platessoides*	American plaice	Increase
Lipid saturation		*Clupea harengus*	Atlantic herring	Increase
Protein	Blood	*Salmo gairdneri, Catla catla*	steelhead trout, catla	Increase
Sodium	Blood	*Carassius auratus*	goldfish	Increase
Vitamin B_{12}		Tuna-like fishes		Decrease

One of the main benefits of using these equations is that body composition can be estimated without having to slaughter the fish. These equations are also useful when planning feeding regimes, predicting growth and estimating waste output. These equations can also be utilized in reverse. It is possible to determine body weight of a fish by measuring the body protein (Dumas *et al.*, 2007). This however, is not of as much use from an industry perspective.

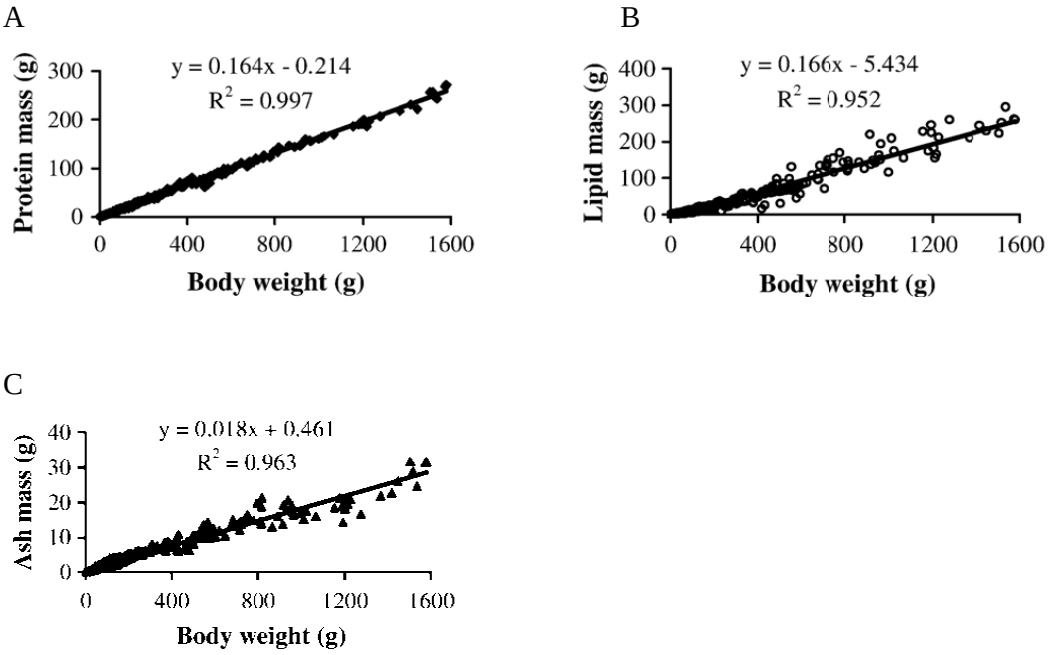

Figure 2.4. Whole body content of (A) protein, (B) lipid and (C) ash at different body weights in *Oncorhynchus mykiss* (Dumas *et al.*, 2007).

No scientific data on the effect of size on the chemical composition of yellowtail could be sourced.

Love (1988) found a link between fish size and muscle pH (Figure 2.5). The research was done on well nourished cod caught from the Faroe Bank region and the muscle pH was measured one day after death.

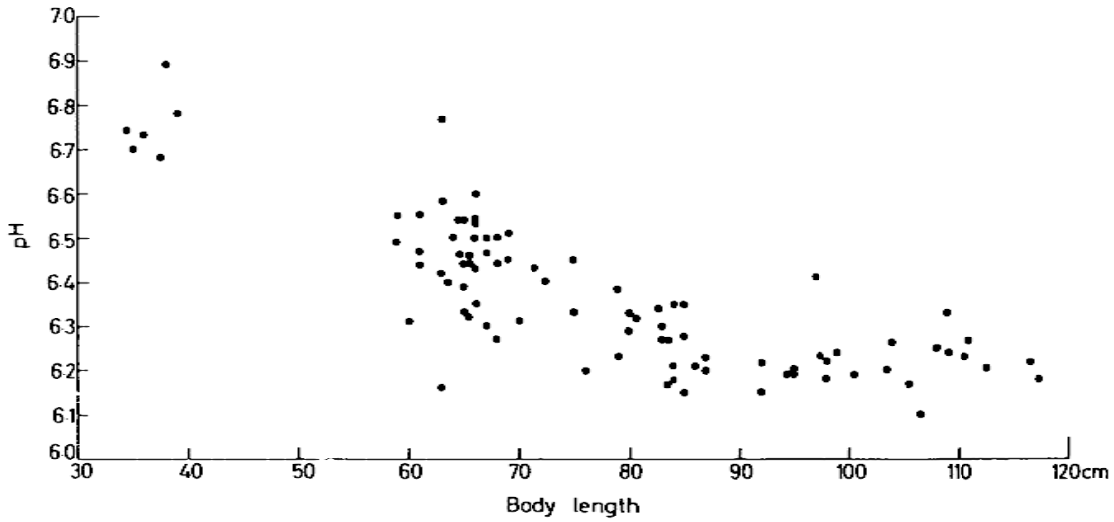

Figure 2.5. Graph illustrating the relationship between body length of Faroe Bank cod and pH of muscle one day after death (Love, 1988).

Although muscle pH is not indicative of nutritional quality, it has definite implications on texture and storage potential. Flesh with a near-neutral pH is more prone to bacterial spoilage because the bacteria involved in the spoilage are generally neutrophilic. It was found that larger fish have a slightly lower pH, and were tougher, than smaller fish. Love (1988) does not offer an exact explanation for this phenomenon. Again no pH values for yellowtail could be sourced in the scientific literature.

2.3.1.2 Sexual Maturity

As a fish matures, gonad development takes place and the fish must produce gametes. The related processes are very energy intensive and require protein and lipids. It has been found that during these phases protein and lipid levels decrease in the liver and muscle tissue and increase in the gonads. It would seem that the amounts of protein and lipids needed for gonad development far exceed the amounts that the fish would acquire through regular food intake and hence the removal of proteins and lipids from the muscle (Love, 1970; Shearer, 1994; Zaboukas *et al.*, 2006).

There is also evidence that body composition may influence the timing of transitions between the different life stages. Thorpe (1986) found that smoltification and reproduction in

salmanoids may be triggered by a threshold energy storage level rather than age or size which contradicts the findings of Love (1970).

The changes that take place in the tissues of fish, at the onset of maturation, are often different in males and females. This is caused by differences in size of the fish, fish behaviour and the size of the gonads. In many species of fish, the male gonad is smaller than the female and thus the depletive effects of maturation are somewhat less severe (Love, 1970, 1988). Differences in male-female nutrient levels in many species are often not evident during immaturity or in mature fish that are not spawning. This shows that the differences are linked to reproductive processes that draw on somatic and visceral tissue reserves at different rates (Love, 1970, 1988).

The relationship between sexual maturity and the levels of protein, lipids and water in *Sarda sarda* (Atlantic bonito) is illustrated in Table 2.3 (Zaboukas *et al.*, 2006). In this table, the proximate composition is presented at six different sexual maturity levels (I, immature; II, resting; III, developing; IV, mature; V, spawning; VI, spent). The table indicates a decrease in protein and lipids in the muscle tissue and an increase in protein and lipid in the gonads. Ash levels were not affected by the stage of maturity. There is also an evident relationship between the nutrients. As protein and lipid levels decrease in the muscles of certain fish species, water levels increase. The opposite is true for the gonads, where water content decreased as protein and lipid levels rise. Love (1970) recorded muscle water content of 87.2% in a large *Gadus morhua* (Atlantic cod) during the spawning season. This has very real implications for the fish processor, as it is not desirable to market flesh that is mostly water and devoid of any substantial amounts of nutrients. It will also affect other quality aspects such as texture. Fish devoid of protein are more prone to “drip” when thawed (Love, 1988).

With a reduction in lipid content, the flesh will be perceived as being drier. This has beneficial implications for the processor that intends to hold the fish for extended periods in cold storage as the reduction in lipid content will in turn cause a reduction in the formation of rancid or off flavours (Love, 1988).

The depletion of muscle tissue in fish during spawning poses quite a problem for fisherman, as they have no control over the reproductive cycles of wild fish. The aquaculturalist, on the

other hand, has options available to him. One of the options is photoperiod manipulation. Inhibition of sexual maturation in *Melanogrammus aeglefinus* (Haddock) has been achieved through the application of continuous illumination (Davie *et al*., 2007). This technique removes the environmental signals or triggers that would usually cause the fish to spawn. The signal in certain species is the shortening of day length after the summer solstice. It was noted that by inhibiting sexual maturation, there was no pause in growth or loss in condition. The main drawback of this method, from an industry point of view, is its inefficiency in large outdoor operations such as offshore yellowtail cages (Davie *et al*., 2007).

Gillanders *et al*. (1999) found that 50% of female yellowtail were mature at 834 (± 12) mm fork length and 50% of male yellowtail were mature at 471 (± 32) mm fork length. In this study, the smallest mature female recorded was 698 mm fork length (FL) and the smallest male was 360 mm FL. It can therefore be expected that at these lengths, there will be changes in the proximate composition of the muscles as the gonads develop into maturity. Poortenaar *et al*. (2001) evaluated the patterns of gamete development, size at sexual maturity, seasonal changes in gonadal condition and reproductive endocrinology in the yellowtail kingfish (*Seriola lalandi lalandi*). They noted that yellowtail exhibited multiple group synchronous oocyte development and the presence of all developmental stages of oocytes in mature ovaries indicated a capacity for multiple spawning within a reproductive season. The smallest mature female was 775 FL, 50% of females reached sexual maturity at 944 mm FL and 100% at 1275 mm FL. The smallest mature male was 750 mm FL, 50% of males reached sexual maturity at 812 mm FL and 100% at 925 mm FL. Gonadosomatic index (GSI) provided a useful basic measurement of gonadal anabolism. Seasonal changes in gonad stage and GSI indicated that *S. lalandi lalandi* were spring–summer spawners. It is interesting to note that the male and female yellowtail caught off the East and West coasts of New Zealand (Poortenaar *et al*., 2001) were larger than that reported by Gillanders *et al*. (1999) caught off the coast of New South Wales, Australia. Poortenaar *et* al. (2001) attributes these differences in size and age of sexual maturity to different growing conditions, e.g. warmer water temperatures in NSW, or behavioural and physiological differences between populations. No data could be sourced on the size that South African yellowtail reach maturity.

Table 2.3

Mean values of the content (% wet weight) of water, crude protein, lipid, and ash of the white muscle, red muscle, liver and gonads of *Sarda sarda* (Atlantic bonito) at different stages of sexual maturity (Zaboukas *et al.*, 2006)

	Water				**Protein**				**Lipid**				**Ash**			
SSM	**White Muscle**	**Red Muscle**	**Liver**	**Gonads**	**White Muscle**	**Red Muscle**	**Liver**	**Gonads**	**White Muscle**	**Red Muscle**	**Liver**	**Gonads**	**White Muscle**	**Red Muscle**	**Liver**	**Gonads**
IM	70.84	63.03	55.54	76.14	17.73	17.73	11.07	18.17	10.08	17.87	24.83	4.83	1.08	1.08	0.05	0.05
FII	71.98	66.26	60.15	74.90	17.74	17.27	11.12	18.24	9.05	15.98	19.16	5.78	1.08	1.08	0.05	0.05
FIII	72.77	65.23	57.16	70.74	17.51	17.33	11.19	17.78	8.47	15.94	20.25	9.64	1.07	1.08	0.05	0.05
FIV	76.63	72.32	67.34	66.02	17.59	17.59	11.25	19.20	4.43	8.72	10.07	14.00	1.08	1.08	0.05	0.05
FV	77.40	74.58	72.36	65.87	17.12	16.90	10.93	19.44	4.11	6.78	8.67	14.08	1.08	1.08	0.05	0.05
FVI	75.17	70.52	68.86	71.67	17.72	17.73	11.04	17.72	5.68	10.56	11.18	9.33	1.08	1.08	0.05	0.05
MII	72.24	65.59	60.37	75.30	17.59	17.80	11.23	17.54	8.80	15.93	18.93	6.34	1.08	1.07	0.05	0.05
MIII	73.25	67.33	60.45	73.02	17.78	17.71	11.04	18.25	7.67	13.59	19.48	7.98	1.08	1.08	0.05	0.05
MIV	75.22	70.82	67.73	72.48	17.67	17.20	10.89	18.33	5.62	10.56	12.07	8.64	1.08	1.08	0.05	0.05
MV	76.94	73.06	71.46	69.23	16.90	16.81	11.15	19.62	4.69	8.63	7.02	10.63	1.08	1.08	0.05	0.05
MVI	73.90	68.80	69.25	73.51	17.86	17.75	11.18	18.02	6.77	11.94	10.66	7.49	1.08	1.08	0.05	0.05
Overall mean ± S.E.	74.21 ± 0.27	68.87 ± 0.50	64.61 ± 0.90	71.72 ± 0.50	17.56 ± 0.02	17.44 ± 0.14	11.10 ± 0.11	18.39 ± 0.27	6.85 ± 0.25	12.42 ± 0.46	14.72 ± 0.74	8.98 ± 0.46	1.08 ± 0.00	1.08 ± 0.00	0.05 ± 0.00	0.05 ± 0.00

Sexual Maturity: I, immature; II, resting; III, developing; IV, mature; V, spawning; VI, spent. Sex: M, male; F, female; S.E, Standard error.

2.3.1.3 Anatomical Position

The effect that anatomical location has on proximate composition is due to the fact that fish have a very complex swimming method and therefore there are variations in the muscle type and composition along the length of a fish (Love, 1988; Nakamura *et al*., 2007). The skeletal muscle in a fish can be divided into two groups; red or slow-twitch muscle, and white or fast-twitch muscle (Raven & Johnson, 2002). Red muscle occur in a thin band down the lateral line and will not usually represent more than 10% of the total muscle fibre in the fish. These muscles are used for sustained contractions, or "normal swimming" without tiring. The capillary supply to these muscles is well developed and respiration in these muscles is almost completely aerobic. The red muscle also contains many mitochondria as well as high levels of myoglobin and cytochromes. It is due to these high levels of the red pigment, myoglobin that this muscle type is referred to as red muscle (Kiessling *et al.*, 2006; Raven & Johnson, 2002). White muscle make up the bulk of the fish muscle, usually more than 70%, and are used for quick bursts of high speed swimming – typically used by predatory fish when attacking prey (this muscle is also known to be used in the "fight or flight" response). These muscles are specifically adapted to respire anaerobically as is evident in the lower levels of myoglobin and fewer capillaries and mitochondria in comparison to the red muscles. In the white muscle, energy is largely supplied by the breaking down of intramuscular glycogen in an anaerobic environment (Kiessling *et al*., 2006; Raven & Johnson, 2002).

In wild bluefin tuna (*Thunnus thynnus*), levels of eicosapentaenoic acid (EPA) and docosahexanoic acid (DHA) differed between individuals as well as between different areas on the same fish (Nakamura *et al*., 2007). In this study, samples were taken from the cephalal (Ce) and caudal (Ca) regions at different times of the year. These samples were subsequently divided into dorsal (D) and ventral (V) ordinary muscle (OM). Figure 2.6 graphically illustrates these sample regions. In the full-cycle cultured fish, the protein and moisture levels were lowest in the Ce-VOM region and this region displayed the highest lipid levels (Table 2.4). It is evident from Nakamura and colleagues (2007) that the anatomical position of a sample will influence the proximate composition results. Very little literature is currently available on this subject as pertaining to Yellowtail.

Table 2.4

Proximate compositions of cephalal (ce-) and caudal (ca-) parts of dorsal (D) and ventral (V) ordinary muscles (OMs) of full-cycle cultured (FC) and wild Pacific bluefin tuna (Nakamura *et al*., 2007)

		FC1	**FC2**	**FC3**	**FC4**	**FC5**	**Wild**
Ce-DOM (%)	Moisture	67.9^{a} ± 4.4	68.0^{a} ± 4.4	64.7^{a} ± 4.0	63.4^{a} ± 2.1	55.3^{b} ± 4.9	72.8* ± 0.2
	Protein	23.3^{ac} ± 0.9	24.5^{ab} ± 1.3	25.8^{b} ± 0.1	22.6^{c} ± 0.5	21.8^{c} ± 1.4	26.1* ± 0.1
	Lipid	11.0^{a} ± 6.2	9.7^{a} ± 2.8	11.5^{a} ± 5.6	14.9^{ab} ± 3.7	23.0^{b} ± 8.0	2.0* ± 0.4
	Ash	1.6^{a} ± 0.2	1.6^{a} ± 0.1	1.6^{a} ± 0.1	1.2^{ab} ± 0.5	0.9^{b} ± 0.2	1.6* ± 0.1
Ca-DOM (%)	Moisture	67.8^{a} ± 3.4	71.3^{a} ± 1.9	69.6^{a} ± 2.6	67.7^{a} ± 2.6	-	-
	Protein	24.2^{a} ± 1.2	24.4^{a} ± 0.0	22.1^{b} ± 0.8	26.1^{c} ± 0.3	-	-
	Lipid	8.9^{a} ± 7.5	5.8^{a} ± 3.2	7.6^{a} ± 6.0	10.8^{a} ± 2.4	-	-
	Ash	2.1^{a} ± 1.1	1.8^{a} ± 0.3	1.4^{a} ± 0.2	1.2^{a} ± 0.1	-	-
Ce-VOM (%)	Moisture	46.7^{a} ± 9.2	51.0^{a} ± 13.5	49.5^{a} ± 4.0	45.0^{a} ± 9.3	37.7^{a} ± 7.5	63.8* ± 1.7
	Protein	16.2^{a} ± 3.8	18.1^{a} ± 5.7	15.8^{a} ± 0.3	15.4^{a} ± 3.8	14.6^{a} ± 3.0	24.0* ± 1.2
	Lipid	39.2^{a} ± 12.5	38.2^{a} ± 15.6	39.6^{a} ± 1.7	45.7^{a} ± 10.8	55.1^{a} ± 11.2	16.2* ± 2.7
	Ash	1.2^{a} ± 0.4	1.1^{a} ± 0.3	1.2^{a} ± 0.3	0.6^{b} ± 0.2	0.3^{b} ± 0.1	1.4*± 0.1
Ca-VOM (%)	Moisture	69.2^{a} ± 4.8	69.1^{a} ± 1.2	69.1^{a} ± 3.7	67.3^{a} ± 2.9	-	-
	Protein	24.4^{a} ± 1.7	23.9^{a} ± 1.4	24.0^{a} ± 1.1	25.3^{a} ± 0.7	-	-
	Lipid	8.0^{a} ± 5.6	10.3^{a} ± 2.0	7.8^{a} ± 3.5	7.7^{a} ± 1.1	-	-
	Ash	1.8^{a} ± 0.3	1.6^{a} ± 0.5	1.2^{a} ± 0.2	1.3^{a} ± 0.4	-	-

Values are means and standard deviation of three specimens.

Different lower case letters (a,b,c) indicate significant differences among PC 1-5 ($P < 0.005$, LSD test).

* Denote significant differences between FC and wild Pacific bluefin tuna ($P < 0.05$, *t*-test).

Slaughter dates are FC1: April 2004; FC2: July 2004; FC3: November 2004; FC4: February 2005; FC5: May 2005.

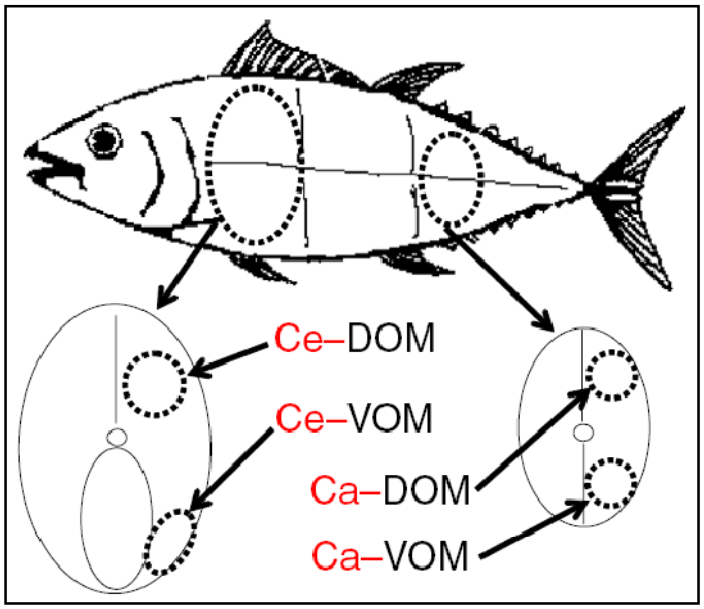

Figure 2.6. Sample regions used in Nakamura *et al*. (2007).

2.3.2 Exogenous Factors

The main exogenous factor affecting proximate composition is diet. Various studies have examined the effects of temperature, light, salinity, pH and oxygen concentration on the proximate composition of fish but these factors would seem to have very limited effects, if any. Both Haard (1992) and Shearer (1994) point out that many of these studies are flawed in the interpretation of the results and suggest that more research is needed in this area.

The proximate composition of cultured fish has been found to differ from that of wild fish with lipid content of cultured fish often being higher than that of their wild counterparts. This can be attributed to the high energy content of the feed, overfeeding, and a lack of exercise within the culture system (Nakamura *et al.*, 2007).

Feed composition, as well as ration size, is a major contributing factor to the proximate composition of fish. Wild fish will experience a variation in diet according to season and location. Shirai *et al*. (2002) found a similarity in the fatty acid composition of the Japanese sardine (*Sardinops melanostictus*) and the plankton that the fish were feeding on in a

particular season. In this study it was also noted that sardines caught in the sea of Hyuga-Nada have a different fatty composition to fish from other areas, thus showing that the area, and more specifically the plankton in the area, affect the proximate composition of sardines.

In a study by Alasalvar *et al*. (2002), the proximate composition of wild and cultured sea bass (*Dicentrarchus labarax*) was examined and compared. This study showed that fat levels were higher, and water levels were lower, in the cultured sea bass. This is attributed to the high fat content of the feed that was used and reduced physical activity within the culture unit (Alasalvar *et al*., 2002; Nakamura *et al.*, 2007). Table 2.5 lists the fatty acids examined in the study as well as the amounts of each as a percentage of the total fatty acid content of the flesh. The total monoenoic fatty acid content of cultured sea bass was significantly higher than that of the wild sea bass and Alasalvar (2002) suggests that this is linked to the high levels of monoenoic fatty acids in the feed used.

Table 2.5
Fatty acids (as % of total fatty acids) in cultured and wild sea bass (*Dicentrarchus labarax*) (adapted from Alasalvar *et al*., 2002)

Fatty Acid	**Cultured**	**Wild**
Saturated	29.2	33.4
Monoenoic	34.6	19.4
Polyenoic	36.1	47.4

Alasalvar *et al*. (2002) found that the total mineral content of wild and cultured sea bass was similar but there were significant differences in individual minerals analysed. Iron was found to be significantly higher in wild sea bass. According to the study, this is due to the fact that wild sea bass are more active than their captive counterparts and therefore have a higher percentage of dark muscle compared to light muscle in their bodies.

There is also a link between firmness of flesh and diet. Dentex (*Dentex dentex*) were fed diets containing differing levels of protein, lipids and carbohydrates and the firmness of the flesh

of the fish fed these diets was measured (Suárez *et al*., 2009). It was found that dietary protein content played a major role in firmness whilst other dietary components played a lesser role. Fish fed a lower protein diet (38%) displayed increased firmness as well as increased water holding capacity when compared to fish fed on higher protein diets (Suárez *et al*., 2009).

As the cage farming/ranching of yellow tail in South Africa is still relatively new, no research has yet been conducted that evaluates the effect of diet on the various quality parameters of the fillets.

2.4 Relationships between Nutrients

There is a relationship between the different nutrients in fish (Love, 1970; Tudor, 1984; Salam *et al.*, 2001; Dumas *et al.*, 2007). These relationships are mostly species specific. There is also a difference in the way that these constituents can be expressed; either as total gain or loss in the whole fish or as concentration in a specific tissue within the fish (Love, 1970).

Figure 2.7 shows the "fat-water line" that occurs in many species of fatty fish. A "protein-water line" in non-fatty species also exists. As the protein content increases, the water content also increases (Dumas *et al.*, 2007). These "lines" can be useful in determining protein or lipid levels in a sample by means of a water test (gravitational moisture determination), which is often a cheaper alternative to determining absolute protein and lipid levels (Love, 1988).

Dumas and colleagues (2007) found relationships in whole body composition between protein and water and between lipids and water in *Oncohynchus mykiss* (Figure 2.8). It was found that for every 1 g of protein deposited, there was a related increase of 3.9 g of water. It was also found that an inverse relationship between lipids and water exists where a 1 g increase in lipids equals a 1.06 g decrease in water. Tudor (1984) noted relationships between protein and lipid levels with water in the white muscle of young *Liza saliens* (leaping mullet). It was found that as protein or lipid levels decrease, water levels increase. Salam *et al.* (2001)

found that in *Oreochromis mossambicus* (Tilapia) body protein, body lipid and body ash were all inversely related to body water. This shows that these relationships are species specific as *Oncorhynchus mykiss* shows a linear body protein/body water relationship (Dumas *et al.*, 2007), while in *O. mossambicus*, body protein and body water are inversely related (Salam *et al.*, 2001).

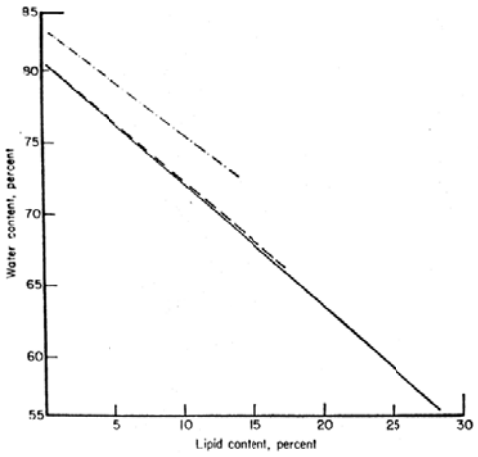

Figure 2.7. The "fat-water" line that occurs in many species of fish (Love, 1988).

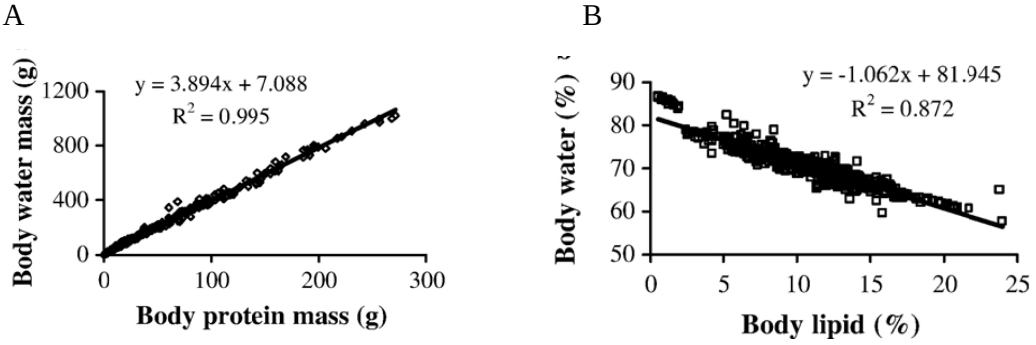

Figure 2.8. Relationship between (A) body protein and body water and (B) body lipid and body protein in *Oncorhynchus mykiss* (Dumas *et al.*, 2007).

2.5 Conclusion

There is a general lack of information available regarding the proximate composition of yellowtail and no studies have been done on the effect of anatomical position on the

proximate composition of yellowtail. Similarly, no studies have been conducted on the nutritional quality of farmed yellowtail. Different areas of the fish are used for different culinary applications; certain areas are eaten raw in the form of sushi and others are cooked before eating. Having a better understanding of the composition of the muscle at different locations could be useful for the processing and culinary industries in predicting the storage potential, reaction to cold, reaction to heat and even predicting flavour and texture.

3. Materials and Methods

3.1 Sampling

The fish used in this study were spawned in December 2007 from wild caught stock at a hatchery in Gansbaai (South Africa) and held there for two months. The fingerlings were transferred to Port Elizabeth and placed in offshore net cages on the 31st of January 2008 for 14 months of grow out where they all received the same commercial diet (Nutrosciecne, South Africa) of extruded pellets. The nutritional value of the feed is displayed in Table 3.1. The fish were harvested in March 2009 and immediately frozen. Male and female fish were present in the catch and at an average length of 548.1 mm ± 23.88 fork length. A visual appraisal of the gonads indicated that the fish were not sexually mature and therefore the effect of gender is not included in this study. A subsample of fish (n = 17) were randomly removed from the harvested catch and transported frozen from Port Elizabeth to Stellenbosch and remained frozen at -20ºC until needed. The fish were defrosted at 5°C for 12 hours. Prior to dressing and filleting, the fish were weighed and measured. Fork length was measured using a steel tape measure; the measurement was taken from the tip of the snout to the fork of the caudal fin. Height and width were measured using veneer callipers and measurements were taken at the first ray of the dorsal fin. The fish were gilled and eviscerated and the gills and viscera were weighed together. The fillets were removed from the fish and weighed with skin on. The head was severed behind the pectoral fin and weighed. Table 3.2 shows the physical properties of the fish used in the study.

Table 3.1

The nutritional value of the Nutroscience feed used in this study

Component	% of Total
Protein	45%
Fat	15%
Ash	5%
Fiber	2.50%
Carbohydrate	20%
Total Calcium	1.3%
Available Phosphate	1.2%
Moisture	1%

The whole right side fillet was skinned, deboned and homogenized in a food processor. The left side fillet was skinned, deboned and divided into specific portions as illustrated in Figure 3.1. Section A is the whole fillet (control), B is an anterior dorsal section, C is an anterior ventral section, D is a mid dorsal section, E is a mid ventral section and F is the dorsal and ventral posterior sections combined. These portions were individually homogenized in a food processor. All homogenized samples were individually vacuum packed and re frozen at -20ºC. The samples were stored in a black box and were not exposed to any light during storage.

Table 3.2

Physical properties of the yellowtail

Parameter	Max.	Min.	Average ± SD (n=17)
Fork Length (mm)	590.0	504.0	548.1 ± 23.88
Weight Whole (g)	2390.9	1891.5	2080.0 ± 158.43
Height (mm)	140.0	119.0	124.7 ± 5.46
Width (mm)	77.0	62.0	67.5 ± 4.33
Weight Gills and Viscera (g)	213.0	174.0	195.1 ± 12.38
Weight Skeleton and Head (g)	933.2	705.2	818.6 ± 65.69
Weight Head (g)	629.0	470.5	530.7 ± 49.58
Fillet Weight (g)	640.0	425.3	530.5 ± 60.10
Total Fillet Yield (% of total weight)	54.3	47.5	51.2 ± 2.40

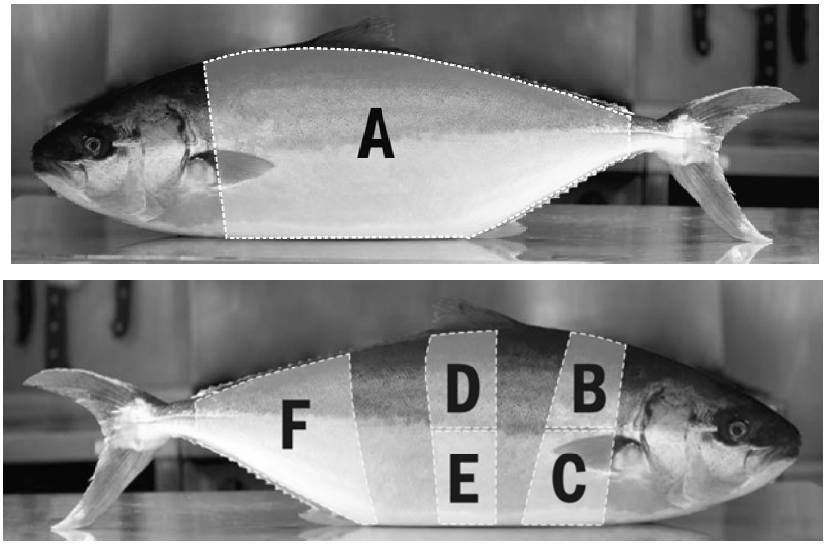

Figure 3.1 Graphical illustration of the anatomical position of samples used in this study.

3.2 Determination of Moisture Content

The moisture content was determined according to the AOAC official method 934.01 (AOAC International, 2002). Clean, empty porcelain crucibles were dried for two hours at 100ºC. The crucibles were placed into desiccators and allowed to cool for 30 minutes. Each crucible was weighed and the weights recorded. Homogenised meat sample (2.5 g) was placed into each crucible. The crucibles containing the samples were then placed into an oven at 100ºC for 24 h. After the 24 h, the crucibles were placed in desiccators and allowed to cool for 30 min. The crucibles, containing the moisture free sample, were weighed again and the weights recorded.

The percentage of moisture per sample was calculated as follows:

$$\%\ Moisture = \frac{(A + B) - C}{B}\ x\frac{100}{1}$$

A = Weight of empty, clean crucible

B = Weight of sample

C = Weight of crucible and dry sample

3.3 Determination of Ash Content

The ash content was determined according to the AOAC official method 942.05 (AOAC International, 2002). The oven dry samples from the moisture test, in the original crucibles, were placed in an incinerator oven at 500ºC for six hours. After the oven was turned off, the samples were left in the oven for a further two hours and then transferred to desiccators to cool for 30 minutes. The crucibles containing the ash were then weighed.

The percentage of ash per sample was calculated as follows:

$$\%\ Ash = \frac{D - A}{B}\ x\frac{100}{1}$$

A = Weight of empty, clean crucible

B = Weight of sample

D = Weight of crucible and ash

3.4 Determination of Fat

The fat content was determined using the method described in Lee *et al*. (1996). Clean glass fat-beakers were dried in an oven overnight at 100ºC. The beakers were allowed to cool in desiccators for 30 minutes before being weighed. Portions of homogenised meat sample (5 g) were placed into 800 ml beakers where after 50 ml of chloroform/methanol (1:2, v/v) was added to the meat sample and mixed with a Bamix® stick blender (Bamix® of Switzerland) for

1 min. This solution was then filtered through Whatman no. 1 filter paper into a separation funnel. The used filter paper was retained for the protein analysis. 20 ml of 0.5% (w/v) NaCl solution was added to each separation funnel and each funnel was shaken four times to mix. After standing for 30 min, a clear separation was visible and the bottom layer was tapped off into a 100 ml Erlenmeyer flask. Five millilitres of this liquid was pipetted in the pre-weighed fat-beakers and the beakers placed on a sand plate for 45 minutes. These fat-beakers were then cooled for 30 minutes in desiccators and weighed.

The percentage of total fat per sample was calculated as follows:

$$\%\, Fat = \frac{(fat\ beaker + fat) - (fat\ beaker)}{sample\ mass}\ x\ \frac{(chloroform\ volume)}{5}\ \mathrm{x}\ \frac{100}{1}$$

3.5 Determination of Protein

To determine the protein content, dried and defatted muscle was ground with a pestle in a mortar to a fine powder. Samples of 0.150 g were inserted into a foil wrap designed for the Leco protein analyzer (LECO FP-528) using the Dumas combustion method 992.15 (AOAC, 2002c) and results were expressed in % Nitrogen (N). The nitrogen content was multiplied by 6.25 to calculate the protein concentration in the sample. An EDTA calibration sample (LECO Corporation, 3000 Lake View Avenue, St. Joseph, MI 49085-2396, USA, Part number 502-092) was analyzed with each batch of samples to ensure accuracy and recovery rate.

3.6 Determination of Fatty Acid Profile

After thawing, 2 g meat sample was extracted with a chloroform:methanol (1:2; v/v) solution according to a modified method of Folch, Lees and Stanley (1957). All the extraction solvents contained 0.01% butylated hydroxytoluene (BHT) as an antioxidant. A polytron mixer (WiggenHauser, D-500 Homogenizer) was used to homogenise the sample with the extraction solvent. Heptadecanoic acid (C17:0) was used as an internal standard (catalogue number H3500, Sigma–Aldrich Inc., 3050 Spruce Street, St. Louis, MO 63103, USA) to

quantify the individual fatty acids. A sub-sample of the extracted lipids was transmethylated for 2 h at 70 °C using a methanol/sulphuric acid (19:1; v/v) solution as transmethylating agent. After cooling to room temperature, the resulting fatty acid methyl esters (FAMEs) were extracted with water and hexane. The top hexane phase was transferred to a spotting tube and dried under nitrogen.

Analysis was done on a Thermo Focus GC equipped with a flame ionized detector using a BPX70 capillary column (60 m x 0.25 mm internal diameter, 0.25 µm film, SGE, Australia). Gas flow rates were 25 ml/min for hydrogen and 2–4 ml/min for the hydrogen carrier gas. Temperature programming was linear at 3.4 °C/min, with an initial temperature of 140 °C, a final temperature of 240 °C, an injector temperature of 225 °C and a detector temperature of 300 °C. The FAMEs were identified by comparing the retention times to those of a standard FAME mixture (SupelcoTM 37 Component FAME Mix, 10 mg/ml in CH2Cl2, Catalogue Number 47885-U. Supelco, North Harrison Road, Bellefonte, PA 16823-0048, USA).

3.7 Mineral Analysis

Mineral contents was determined on 2 g dried, defatted meat samples which was finely ground in a pestle and mortar. The sample was ashed at 460-480 ºC for 6 h, and after cooling 5 ml 1:1 HCl was added. The sample was then placed in an oven for 30 minutes at 50ºC. Subsequently 35 ml distilled water was added and the solution was filtered into a brown bottle. Element concentrations were measured on an ICP-AES (Inductive Coupled Plasma Atomic Emission Spectrophotometer; Liberty Series AA Varian).

3.8 Statistical Analysis

Data was analysed by one way analysis of variance using PROC ANOVA on SAS. All data was normally distributed and homoscedastic except the data from the proximate analysis; moisture and fat were heteroscedastic. This was overcome by the use of Welch's ANOVA, which delivered the same results as the normal ANOVA. The fat water line was created using Microsoft® Excel.

4. Results

4.1 Proximate Analysis

The results of the proximate analysis of the 17 yellowtail are shown in Table 4.1. Significant differences ($P < 0.05$) can be noted in the moisture and fat concentrations. A correlation can also be noted from the results where a decrease in water is linked to an increase in fat content (Figure 4.1). The $R^2 = 0.314$ of the regression line is relatively low. This is due to variations between individual fish for the same sample region and a few outliers. This phenomenon is referred to as the "fat water line" and is common in many fish species (Love, 1988). The highest level of water was found in the tail (F) section of the fillet and this section also contained the lowest levels of total fat. Fat levels were highest in the belly region of the fish with levels of 10.4% ± 0.86 in section C, and 8.7% ± 0.98 in section E. Protein and ash levels did not differ ($P > 0.05$) along the fillet.

The moisture content of sections B, D and F were similar ($P > 0.05$) to the whole fillet (A). Sections B, D and F were also similar ($P > 0.05$) to the whole fillet (A) in fat content. With all of the sections being statistically similar ($P > 0.05$) in protein and ash content, one could use either section B, D or F as a representative of the proximate composition of the whole fillet (A). Of these, section B would be the most practical.

Table 4.1

A comparison of the proximate composition of *S. lalandi* at five anatomical locations

	A (control)	B	C	D	E	F
Moisture	$70.8^{a} \pm 0.32$	$70.9^{a} \pm 0.43$	$66.9^{b} \pm 0.50$	$70.1^{a} \pm 0.43$	$66.3^{b} \pm 1.00$	$71.5^{a} \pm 0.4$
Protein	$20.6^{a} \pm 0.41$	$21.8^{a} \pm 0.50$	$19.9^{a} \pm 0.82$	$22.4^{a} \pm 0.5$	$20.9^{a} \pm 0.95$	$22.2^{a} \pm 0.44$
Fat	$5.3^{b} \pm 0.12$	$5.4^{b} \pm 0.42$	$10.4^{a} \pm 0.86$	$5.2^{b} \pm 0.34$	$8.7^{a} \pm 0.98$	$4.3^{b} \pm 0.23$
Ash	$1.2^{a} \pm 0.03$	$1.3^{a} \pm 0.04$	$1.2^{a} \pm 0.02$	$1.3^{a} \pm 0.02$	$1.2^{a} \pm 0.02$	$1.3^{a} \pm 0.02$

Values are means (%ww) ± standard error of the mean (n=17)

^{ab}means within a row with the same superscript do not differ ($P > 0.05$)

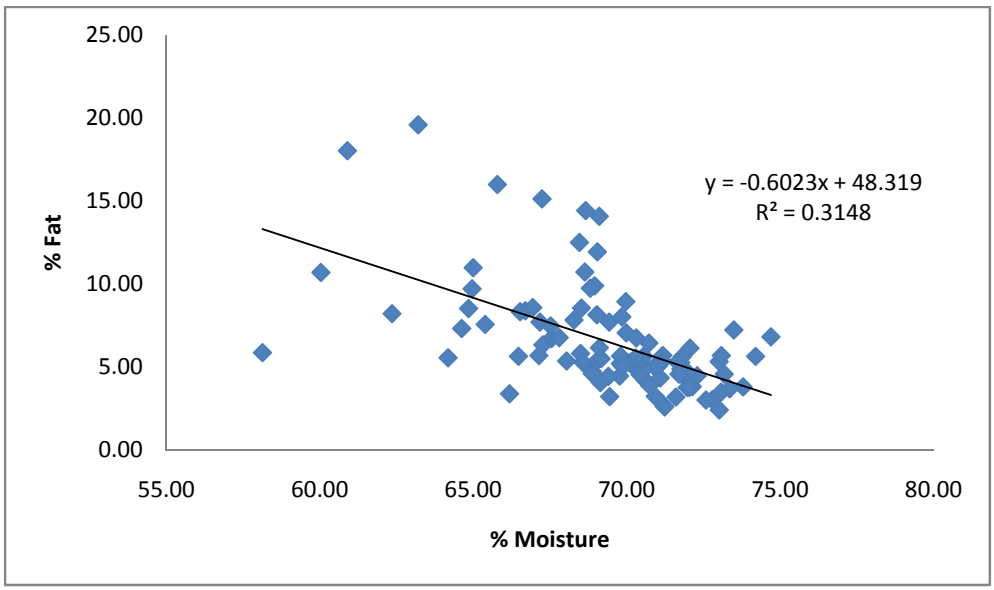

Figure 4.1 The fat-water line of *S. lalandi*.

4.2 Fatty Acid Analysis

The total fat content (g/100 g wet tissue) of the whole fillet (A) was 5.3 ± 0.11 of which saturated fatty acids (SFA) accounted for 35.5% ± 1.13, monounsaturated fatty acids (MUFA) for 25.7% ± 0.51 and polyunsaturated fatty acids (PUFA) for 38.2% ± 0.88. Table 4.2 depicts the fatty acid profile of the different samples. Three long chain n-3 fatty (LC n-3 PUFA) acids of dietary importance are eicosapentonic acid (EPA, 20:5n-3), docosapentaenoic acid (DPA, 22:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) (Abbas *et*

al., 2009). Previous studies indicated that these fatty acids could play a role in reducing cardiovascular disease (He, 2009). In the whole fillet, EPA levels were 0.2% ± 0.03, DPA levels were 11.9% ± 0.31 and DHA levels were 10.9% ± 0.44.

The most predominant saturated fatty acid was palmitic acid (hexadecanoic acid, C16:0) with levels reaching 24.2% ± 1.25 in section E of the fish while the whole fillet (A) contained 22.1% ± 1.25. Oleic acid (octadecenoic acid, C18:1n-9) was the most abundant monounsaturated fatty acid with a level of 16.5% ± 0.33 in the whole fillet, and the highest amount occurring in section C, 16.7% ± 0.33.

No sample could be identified that was statistically similar to the whole fillet. The fatty acids that were similar ($P > 0.05$) in all samples were C16:0, C21:0, C22:0, C14:1, C18:1n-9c, C18:1n-9t, C22:1n-9, C18:2n-6t, C20:4n-6 and C22:5n3.

Table 4.2

The fatty acid profile (% of total fat) of *S. lalandi* at different anatomical locations

Fatty Acid	**A (control)**	**B**	**C**	**D**	**E**	**F**	**Standard Error of the Mean**
C14:0	4.6^{a}	3.3^{ab}	4.5^{a}	3.0^{b}	4.6^{a}	3.5^{ab}	0.33
C15:0	0.5^{a}	0.4^{bc}	0.4^{ab}	0.4^{c}	0.4^{c}	0.4^{ab}	0.02
C16:0	22.1^{a}	21.0^{a}	20.5^{a}	20.8^{a}	24.2^{a}	21.2^{a}	1.25
C18:0	7.6^{a}	7.7^{a}	6.2^{b}	8.1^{a}	6.3^{b}	8.6^{a}	0.26
C20:0	0.3^{bc}	0.3^{bc}	0.4^{a}	0.3^{bc}	0.4^{ab}	0.3^{c}	0.01
C21:0	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}	0.01
C22:0	0.3^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.01
C24:0	-	0.1^{a}	-	0.1^{a}	-	0.1^{a}	0.00
C14:1	0.1^{a}	0.1^{a}	0.1^{a}	0.1 ^{a}	0.1^{a}	0.1^{a}	0.01
C15:1	0.1^{a}	0.1^{b}	0.1^{ab}	0.1^{b}	0.1^{b}	0.1^{ab}	0.00
C16:1	8.1^{ab}	7.4^{ab}	8.8^{a}	7.0^{ab}	7.7^{ab}	6.8^{b}	0.43
C18:1n9c	16.5^{a}	16.0^{a}	16.8^{a}	15.9^{a}	16.3^{a}	15.8^{a}	0.33
C18:1n9t	0.4^{a}	0.4^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.03
C20:1	0.3^{a}	0.3^{a}	0.2^{b}	0.3^{ab}	0.2^{b}	0.2^{ab}	0.01

C22:1n9	-	-	-	-	-	-	0.00
C24:1	0.6^{bc}	0.7^{ab}	0.6^{c}	0.8^{ab}	0.5^{c}	0.8^{a}	0.03
C18:2n6c	10.1^{ab}	10.1^{ab}	10.9^{a}	10.0^{ab}	10.6^{ab}	9.8^{b}	0.22
C18:2n6t	0.2^{a}	0.1^{a}	0.2^{a}	0.1^{a}	0.2^{a}	0.1^{a}	0.01
C18:3n6	0.9^{bc}	0.9^{bc}	1.1^{a}	0.9^{c}	1.0^{ab}	0.9^{c}	0.02
C18:3n3	1.5^{b}	1.6^{b}	2.0^{a}	1.4^{b}	1.7^{ab}	1.3^{b}	0.09
C20:2	0.2^{ab}	0.2^{ab}	0.2^{ab}	0.2^{a}	0.2^{b}	0.2^{ab}	0.01
C20:3n6	0.9^{bc}	1.0^{ab}	0.8^{c}	1.0^{a}	0.8^{c}	1.1^{a}	0.03
C20:3n3	0.4^{a}	0.5^{a}	0.3^{bc}	0.4^{a}	0.3^{c}	0.4^{ab}	0.02
C20:4n6	1.0^{a}	1.1^{a}	1.1^{a}	1.1^{a}	1.1^{a}	1.0^{a}	0.03
Fatty Acid	**A (control)**	**B**	**C**	**D**	**E**	**F**	**Standard Error of the Mean**
C20:5n3	0.2^{a}	0.3^{a}	0.3^{a}	0.3^{a}	0.2^{a}	0.3^{a}	0.03
C22:2	0.2^{ab}	0.2^{a}	0.1^{bc}	0.2^{a}	0.1^{b}	0.2^{a}	0.01
C22:5n3	11.9^{b}	12.9^{ab}	13.4^{a}	12.9^{ab}	12.6^{ab}	11.9^{b}	0.31
C22:6n3	10.9^{b}	13.4^{a}	10.6^{b}	14.2^{a}	9.8^{b}	14.3^{a}	0.44
SFA	35.5^{a}	33.0^{a}	32.3^{a}	33.0^{a}	36.3^{a}	34.5^{a}	1.13
MUFA	25.7^{ab}	24.5^{ab}	26.4^{a}	24.0^{b}	24.9^{ab}	23.9^{b}	0.51
PUFA	38.2^{c}	42.0^{ab}	40.8^{abc}	42.5^{a}	38.4^{bc}	41.2^{abc}	0.88

Values are means

^{ab}means within a row with the same superscript do not differ ($P > 0.05$)

4.3 Mineral profile

Significant differences ($P < 0.05$) were found in phosphorus, potassium and copper concentrations. The other minerals, namely calcium; magnesium; sodium; iron; zinc; manganese; boron and aluminium showed no significant differences ($P > 0.05$) between sections. The mineral profile is displayed in Table 4.3.

Table 4.3

The mineral profile of *S. lalandi* (mg/kg dried defatted sample).

Mineral	A control	B	C	D	E	F
Phosphorus	$0.0178^{ab} \pm 0.0005$	$0.0200^{a} \pm 0.0006$	$0.0151^{b} \pm 0.0015$	$0.0199^{a} \pm 0.0008$	$0.0193^{a} \pm 0.0010$	$0.0188^{ab} \pm 0.0005$
Potassium	$0.0162^{ab} \pm 0.0005$	$0.0189^{a} \pm 0.0008$	$0.0143^{b} \pm 0.0010$	$0.0179^{a} \pm 0.0008$	$0.0161^{ab} \pm 0.0008$	$0.0170^{ab} \pm 0.0006$
Calcium	$0.0020^{a} \pm 0.0003$	$0.0034^{a} \pm 0.0009$	$0.0034^{a} \pm 0.0007$	$0.0028^{a} \pm 0.0005$	$0.0031^{a} \pm 0.0005$	$0.0026^{a} \pm 0.0005$
Magnesium	$0.0032^{a} \pm 0.0001$	$0.0035^{a} \pm 0.0001$	$0.0029^{a} \pm 0.0002$	$0.0035^{a} \pm 0.0002$	$0.0035^{a} \pm 0.0002$	$0.0034^{a} \pm 0.0001$
Sodium	$24.54^{a} \pm 1.179$	$26.12^{a} \pm 1.750$	$27.00^{a} \pm 1.987$	$24.67^{a} \pm 2.116$	$26.27^{a} \pm 2.033$	$31.05^{a} \pm 1.414$
Iron	$1.30^{a} \pm 0.166$	$0.97^{a} \pm 0.095$	$1.10^{a} \pm 0.135$	$1.12^{a} \pm 0.110$	$1.21^{a} \pm 0.109$	$1.38^{a} \pm 0.099$
Copper	$0.0397^{b} \pm 0.0074$	$0.0444^{ab} \pm 0.0097$	$0.0601^{ab} \pm 0.0138$	$0.0677^{ab} \pm 0.0125$	$0.0952^{ab} \pm 0.0136$	$0.1051^{a} \pm 0.0231$
Zinc	$0.4413^{a} \pm 0.0195$	$0.4874^{a} \pm 0.0793$	$0.4782^{a} \pm 0.0759$	$0.5139^{a} \pm 0.0520$	$0.4863^{a} \pm 0.0298$	$0.5195^{a} \pm 0.0215$
Manganese	$0.0283^{a} \pm 0.0036$	$0.0345^{a} \pm 0.0064$	$0.0401^{a} \pm 0.0080$	$0.0294^{a} \pm 0.0032$	$0.0322^{a} \pm 0.0025$	$0.0345^{a} \pm 0.0063$
Boron	$0.0805^{a} \pm 0.0629$	$0.1273^{a} \pm 0.1077$	$0.1095^{a} \pm 0.0629$	$0.1869^{a} \pm 0.1109$	$0.2146^{a} \pm 0.1317$	$0.1465^{a} \pm 0.0832$
Aluminium	$1.68^{a} \pm 0.294$	$1.53^{a} \pm 0.339$	$3.37^{a} \pm 1.332$	$2.09^{a} \pm 0.389$	$3.38^{a} \pm 0.421$	$2.43^{a} \pm 0.261$

Values are means ± standard error; ^{ab}means within a row with the same superscript do not differ ($P > 0.05$)

5. Discussion

The primary aim of this study was to investigate the possibility of finding a section of the fillet that is chemically representative of the whole fillet. This would simplify the process of taking samples for use in proximate analysis. The data shows that one could use either section B (anterior dorsal), section D (mid dorsal) or section F (dorsal and ventral posterior sections combined) as a representative sample when doing proximate analysis. The ventral region of the fish differed significantly ($P > 0.001$) to the dorsal region with regards to the fat content. This is mainly due to the high fat concentration in the belly region that serves to protect and insulate the internal organs. There were also significant differences ($P > 0.001$) in fat concentrations between the ventral and caudal and dorsal and caudal regions. The same differences were also true for the moisture content when dorsal and ventral samples were compared. There was too much variation between all samples with regard to the fatty acid profile to identify a section that is representative of the whole fillet. The mineral analysis showed little variation in mineral concentrations along the fillet, although there were significant differences in phosphorus, potassium and copper concentrations.

In this study, it was shown that the anatomical position of a sample can affect the outcomes of proximate and chemical composition tests. Due to the high fat content, it would be advisable to avoid using samples from the belly (ventral) region of the fish for proximate analysis, but rather the dorsal region or the whole fillet for sampling. The data contained in this study could also be a useful reference to fish processors and food scientists as different regions of the fish are used for different purposes.

The secondary focus of this study was to examine the general nutritional quality of farmed yellowtail. LC n-3 PUFA play an important role in disease prevention and nutrition in humans. LC n-3 PUFA cannot be synthesised by humans and must therefore be obtained through the diet (Alasalvar *et al.*, 2002). The American Heart Association recommends eating at least two servings of fatty fish per week in order to reduce the risk of heart disease (Abbas *et al.*, 2009). Fish lipids are a good source of EPA and DHA (LC n-3 PUFAs) which are considered to reduce the risk of coronary heart disease. The edible portion of the farmed yellowtail examined in this study contained EPA and DHA levels of 0.24% and 10.90%

respectively, which is notably lower than other marine fish species. Nichols *et al.* (1994) found levels of 3.6% EPA and 41.8% DHA in *Latris lineate* (striped trumpeter); 21.6% EPA and 31.1% DHA in *Champsocelphalus gunnari* (mackerel icefish); 20.0% EPA and 23.0% DHA in *Chaenodraco wilsoni* (spiny icefish) and 8.4% EPA and 20.3% DHA in *Dissostrichus eleginoides* (Patagonian toothfish). Nakamura *et al*. (2007) found levels of 6.4% EPA and 21.5% DHA in cultured Pacific bluefin tuna and 6.9% EPA and 23.3% DHA in wild Pacific bluefin tuna. The low levels of LC n-3 PUFA could be linked to the diet that these specific yellowtail were fed, as the lipid profile of the diet has an effect on the lipid profile of the fish (Shirai *et al*. 2002). The diet of the farmed yellowtail could be manipulated in order to meet the fatty acid requirements of humans.

The total fat of the fish in this study was 5.3% ± 0.12. The farmed yellowtail thus proves fairly fatty when compared to other fish such as cod (0.3% ± 0.1), hake (1.2% ± 0.5), sole (1.0% ± 0.2) and even certain tuna (yellowfin; 2.2% ± 0.5) (Wheeler & Hebard, 1981). Again, this could be manipulated to suit consumer needs to a certain degree by altering the diet of the fish. Protein levels of the farmed yellowtail were fairly high in comparison to other species and moisture levels were shown to be relatively low. The combination of high fat, high protein and low moisture would lead to a good eating fish with favourable sensory characteristics such as flavour and texture.

Significant variation was noted between individual fish in this study. This could be due to the fact that fish were caught at random and comprised of both male and female fish. Although the gonads appeared to be immature upon visual examination, there could be variations between the proximate composition of male and female yellowtail. Productions systems could be designed to exploit these differences if present.

6. Further Research

Further studies could include a comparison between the proximate and chemical composition of wild and farmed yellowtail. Also, the sensory properties of farmed yellowtail was not analysed in this study and the results of such a study could be of great significance for the industry; certain studies have shown there to be noticeable differences in the sensory aspects

of farmed fish when compared to their wild counterparts. Studying the effect of diet on the fatty acid profile of farmed yellowtail could also be of great value.

As sex was not a factor in this study, it would be of value to do a similar study on male and female fish separately and examine the effects of sex on the proximate composition of mature and immature fish.

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